

an American National Standard

ANSI/BICSI 006-2015

**Distributed Antenna System (DAS)
Design and Implementation
Best Practices**



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PREFACE

Revision History

May 13, 2015	First publication of this standard, titled ANSI/BICSI 006-2015, <i>Distributed Antenna System (DAS) Design and Implementation Best Practices</i>
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Translation Notice

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1 Introduction

1.1 Overview

A distributed antenna system (DAS) is a group of antennas spatially separated and distributed over a given geographic area to augment existing wireless (e.g., cellular, radio signal) service. Although useful in any circumstance where a single antenna is insufficient to provide the service levels expected, sophisticated commercial deployments typically take place in:

- Medical facilities
- Educational and industrial campuses
- Hotels
- Casinos
- Airports
- Tunnels
- Subways
- Office complexes
- Shopping malls
- Parking garages

A DAS may also be deployed to provide extra network capacity in venues that are infrequently used but are subject to high demand of wireless services such as stadiums, arenas, and auditoriums.

A DAS may be deployed either indoors or outdoors. It is a system of antennas typically deployed within isolated areas of a building or series of buildings, such as a campus, to increase the ubiquity of coverage within the objective. When a DAS is used to provide wireless service as part of an outdoor application, natural or manmade morphological or environmental factors are essential to consider during a full wireless signal distribution design. When a DAS is used to provide wireless service as part of an indoor application, architectural features, morphologies, and macro environmental impacts are essential to consider.

Some commonly retransmitted services of a DAS include:

- 700 MHz
- Cellular service (850 MHz)
- Global System for Mobile Communications (GSM) (900/1800 MHz)
- Personal communications service (PCS) (1900 MHz)
- Enhanced specialized mobile radio (ESMR) (800/900 MHz)
- Advanced Wireless Services (AWS) (1700-2150 MHz)
- Broadband Radio Services (BRS) (2600 MHz)
- Public safety and business band land mobile radio (LMR) (150-170 MHz, 450-512 MHz)

NOTE: 47CFR90.35 assigns 450-470 MHz to LMR; heavily used for businesses and government.

Uncommonly transmitted services of a DAS include:

- Pocket pagers
- Emergency medical service (EMS) radio
- Industrial, scientific, and medical (ISM) band equipment
- Wireless local loop
- Local unlicensed walkie-talkies

These lists are not intended to be comprehensive; they are used only to illustrate the variety of retransmitted services possible.

1.1.1 Trends Affecting DAS

1.1.1.1 Building Design and Construction

Since the 1990s, there has been an increasing focus of integrating sustainable practices into building design and construction. Defined within Leadership in Energy and Environmental Design (LEED), Energy Star[®], and other programs are requirements and recommendations that encourage the reuse of existing buildings, which will often block effective RF transmission penetrations through the outer shell, throughout a floor, or between floors within the interior space of a building. A DAS is one means to enable wireless services for new building tenants.

NOTE: Methods to reduce or eliminate thermal radiation through windows are effective at reducing or blocking most types of wireless transmission since microwave and other RF frequency bands fall under the broader spectrum of thermal radiation.

The macro network is becoming less and less able to deliver ubiquitous service as the number of buildings or the height of buildings in a given area increases. Both obstructions and elevated noise levels demand higher levels of signals than can be generated by conventional macro cellular base stations.

1.1.1.2 Public Safety and Services

Legislative developments have seen the creation of requirements for public safety wireless systems in the form of NFPA 1, *Fire Code*, NFPA 72, *National Fire Alarm and Signaling Code*, and the latest edition of the *International Building Code*. Adoption of these codes and their requirements is ongoing, and this is a trend that is expected to increase in the future.

As technology is increasingly integrated into safety and security services, additional capabilities and new functionalities become possible. With these advances in function, communication with a building's surveillance, fire detection/suppression, and access control systems by police, fire, and other personnel are now possible. Near-term objectives include allowing first responders access to information from the site's information systems, as well as allowing systems of differing responders to share information quickly and efficiently. Some authorities having jurisdiction (AHJs) are now creating requirements to ensure continued and effective wireless communication between responders, their equipment, and staff or equipment reporting about the incident on the site itself.

The public safety component for in-building solutions requires consideration of three capabilities. The first capability is being able to alert people in the building that there is danger (indoors or outdoors), and they should either shelter in place or evacuate as the situation dictates. The second is providing the capability for building occupants to both obtain and give "expected" information when an incident occurs in the facility. The third is providing the capability for responders to communicate clearly and effectively with each other, as well as to their dispatchers.

1.1.1.3 Underground Installations and Transit Corridors

As population densities increase within metropolitan areas, building underground has become a solution for providing additional space and transportation options, while minimizing the impact from construction and eventual use, as compared to its equivalent located above ground. However, the ground and the required infrastructure for underground structures are very effective at blocking wireless signals, making it necessary to implement a complete wireless transmission infrastructure for these spaces.

1.1.1.4 Data Traffic Explosion

In addition to the growth that is projected to continue, radio access (e.g., 4G Long-Term Evolution [4G-LTE]) is reaching the limits of spectrum availability. With this limit in sight, another solution must be found to increase overall mobile network capacity. One way to facilitate this objective is by deploying small cell and DAS technologies.

Now in their fifth generation, the most efficient way to use small cells is to position them in locations where significant amounts of data are being generated but where macro cell coverage is lacking or a DAS deployment is impractical for the size of the coverage hole being filled. In larger work places, university campuses, shopping malls, stadiums, public transportation hubs, and the like, one effective deployment method is to use an array of low power small cells to provide RF source signals to a well-engineered DAS.

1.2 Purpose

The purpose of this standard is to afford designers and installers an opportunity to enhance their knowledge of quality DASs, understand the requirements of superior performing systems, and provide requirements and recommendations for the design and installation of standards-compliant, vendor-neutral systems.

1.3 Categories of Criteria

Two categories of criteria are specified—mandatory and advisory:

- Mandatory criteria generally apply to protection, performance, administration and compatibility; they specify the absolute minimum acceptable requirements.
- Advisory or desirable criteria are presented when their attainment will enhance the general performance of the system in all its contemplated applications.

Mandatory requirements are designated by the word *shall*; advisory recommendations are designated by the words *should*, *may*, or *desirable*, which are used interchangeably in this standard. Where possible, requirements and recommendations are separated to aid in clarity.

Notes, cautions, and warnings found in the text, tables, or figures are used for emphasis or for offering informative suggestions.

2 Scope

This standard provides industry and service provider neutral requirements and acceptable best practices for the design and installation of DAS. For brevity, as used in this document, the terms *distributed antenna system* or *DAS* includes other in-building wireless and similar systems, such as radiating cable and small-cell networks, unless these systems are specifically described.

The document will address, at minimum, the following:

- A description of a typical DAS
- Components used within a DAS
- Types of host systems (2-way voice, cellular, LTE, public safety, business band, analog, digital, other)
- Compliance and integration with existing related codes and standards and other legal concerns
- Coordination with the host system owner(s)
- RF system design methods
- Telecommunication infrastructure design
- Installation and commissioning methods
- Electromagnetic compatibility (EMC) and radio frequency interference (RFI) mitigation
- Designer, installer and service personnel qualifications
- Administration, labeling and documentation
- Inspection, testing and maintenance

There are also sections devoted to trouble spot areas where RF coverage is often difficult, such as stairwells and elevators, and to special locations, such as hospitals, parking garages, schools and industrial plants.

While the specific requirements and recommendations of this standard were written for areas within North America, the general principles and recommendations are applicable throughout the world.

2.1 Limitations

Although the principles of this standard are applicable to all signal source technologies, this standard does not specifically address:

- Wi-Fi
Although some vendors are beginning to include Wi-Fi capability in their DAS product lines, Wi-Fi networks are relatively mature and can often be deployed just as effectively using standard structured cabling methods.
- WiMAX
At the time of publication, WiMAX technology is not highly used within DAS deployments.

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3 Required Standards and Documents

The following standards and documents contain provisions that constitute requirements listed within this standard. Unless otherwise indicated, all standards and documents listed are the latest published version prior to the initial publication of this standard. Parties to an agreement based on this standard are encouraged to investigate the possibility of applying a more recent version as applicable.

Where equivalent local codes and standards exist, requirements from these local specifications shall apply. Where reference is made to a requirement that exceeds minimum code requirements, the specification requirement shall take precedence over any apparent conflict with applicable codes.

BICSI

- ANSI/BICSI 003, *Building Information Modeling (BIM) Practices for Information Technology Systems*

European Committee for Electrotechnical Standardization (CENELEC)

- EN 50173-1, *Information technology – Generic cabling systems – Part 1: General requirements*
- EN 50174-2, *Information technology – Cabling installation – Installation planning and practices inside buildings*

Institute of Electrical and Electronics Engineers (IEEE)

- IEEE C2, *National Electrical Safety Code*
- IEEE 802.3, *Standard for Ethernet*

International Electrotechnical Commission (IEC)

- IEC 60364, *Electrical installations of buildings*
- IEC 62305-3, *Protection against lightning - Part 3: Physical damage to structures and life hazard*
- IEC 62305-4, *Protection against lightning - Part 4: Electrical and electronic systems within structures*

International Organization for Standardization (ISO)

- ISO/IEC 11801, *Information technology – Generic cabling for customer premises*
- ISO/IEC 14763-2, *Information technology – Implementation and operation of customer premises cabling – Part 2: Planning and installation*
- ISO/IEC 30129, *Application of equipotential bonding and earthing in buildings with information technology equipment*

National Electrical Contractors Association (NECA)

- ANSI/NECA/BICSI 607, *Standard for Telecommunications Bonding and Grounding Planning and Installation Methods for Commercial Buildings*

National Fire Protection Association (NFPA)

- NFPA 70[®], *National Electrical Code[®] (NEC[®])*
- NFPA 72, *National Fire Alarm and Signaling Code*

Telecommunications Industry Association (TIA)

- ANSI/TIA-568-C.2, *Balanced Twisted-Pair Telecommunications Cabling and Components Standard*
- ANSI/TIA-568-C.3, *Optical Fiber Cabling Components Standard*
- ANSI/TIA-569-D, *Telecommunications Pathways and Spaces*
- ANSI/TIA-606-B, *Administration Standard for Telecommunications Infrastructure*
- ANSI/TIA-607-B, *Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises*

United States Code of Federal Regulations (CFR)

- *Federal Communications Commission (FCC)*
 - 47 CFR 1.1310, *Radiofrequency Radiation Exposure Limits*
 - 47 CFR 17, *Construction, Marking, And Lighting Of Antenna Structures*
 - 47 CFR 90.219, *Use of Signal Boosters*

4 Definitions, Acronyms, Abbreviations, and Units of Measurement

For the purpose of this standard, the following definitions, acronyms, abbreviations, and units of measurement apply.

4.1 Definitions

antenna	A conductive structure which is specifically designed to couple or radiate electromagnetic energy. In radio frequency systems, the antenna may be used to both transmit and receive electromagnetic energy.
attenuation	The decrease in magnitude or the power loss of a signal that propagates between points, expressed in decibels (dB), as the ratio of received signal to transmitted signal level.
array (antenna)	An antenna made up of a number of elements, including an active or driven element, a reflector, and a director. Array antennas may be narrowband or broadband and are used in all frequency bands.
backend equipment	The equipment components of a distributed antenna system that are located in an area of coverage and receives and transmits signals to the headend.
backhaul (wireless)	The portion of a cellular wireless network that connects a cell tower to an Internet service provider.
bandwidth	A measure of the range of frequencies associated with a given signal or communication channel, typically expressed in hertz. It is used to denote the potential transmission capacity of the medium, device, or system.
base station	The fixed part of a mobile radio frequency network through which mobile and portable terminals (or stations) communicate and may be operated by local or remote means. A base station may also be known as a base transceiver station (BTS).
beamwidth (antenna)	The angular separation in which the gain of the antenna decreases by 3 dB (50% of the power) relative to that at the peak of the main beam. Also known as <i>half power beamwidth</i> .
bidirectional amplifier	See <i>signal booster</i> .
broadband	The transmission of signals through the simultaneous use of multiple communication channels or frequencies, allowing for more information or data to be transmitted in a given period of time. Contrast with <i>narrowband</i> . NOTE: <i>Broadband</i> is commonly used to describe a high speed digital signal associated with backbone or multiplexed transmissions.
cell	The fixed area in which a wireless base station or access point is configured to operate.
combiner	A device that merges two or more input signals into a single output signal.
coaxial cable	A cable consisting of a central metallic inner conductor separated from an enclosing outer conductor by a dielectric material. This material may be solid, foam, a suitable gas, or dry air. The outer conductor comprises a metallic braid, a foil layer, combination of braid and foil, or a solid metallic sleeve. The cable may be protected by an outer jacket of non-conducting material.
diplexer	A passive three-port frequency-dependent device that allows two transmitters operating at different frequencies (e.g., 150 megahertz [MHz] and 450 MHz) to share a single antenna system.

dipole	An antenna formed by splitting two wires of a two-wire transmission line and bending them back to form a single straight line. The antenna feed is in the middle of the dipole antenna where the split occurs. A dipole antenna is a resonant antenna. The optimal length of a dipole antenna is one half of the wavelength of the signal being received or transmitted by the antenna. A dipole antenna is a narrowband antenna, operating efficiently in only a narrow band of frequencies.
directional antenna	An antenna that radiates greater signal power in one or more specified directions, which yields increased transmission and reception performance with reduced interference from unwanted sources in those directions.
directional coupler	A device typically used in transmission line circuits to isolate the transmitter from the receiver while using a common antenna. Transmitted signals pass easily to the antenna while being blocked from reaching the receiver. Received signals pass to the receiver and are blocked from the transmitter. Unlike with a duplexer, transmission and reception cannot occur simultaneously.
distributed antenna system	A network of spatially separated antenna nodes, connected to transmission equipment by one or more types of transmission media, which provides wireless service(s) within a defined area.
donor signal	The signal from the originating source that is amplified and distributed throughout a facility by a distributed antenna system (DAS). The donor signal may be received by the DAS via either a donor antenna or by direct cable connection to the donor site.
downlink	Signals transmitted from the wireless service provider equipment to a wireless mobile device.
duplexer	A device that allows an antenna to be used to transmit and receive simultaneously by isolating the receiver from the transmitter.
effective isotropic radiated power	The power supplied to an antenna multiplied by the antenna gain in dBi in a given direction. Sometimes called equivalent isotropically radiated power.
effective radiated power	The power supplied to an antenna multiplied by the antenna gain in dBd in a given direction.
electromagnetic interference	Radiated or conducted electromagnetic energy that has an undesirable effect on electronic equipment or signal transmissions.
frequency	The number of cycles or sine waves occurring in a given time. If the unit of time is one second, then the frequency is stated in hertz (Hz); one Hz is equal to one cycle per second.
frequency band	A specified range of frequencies in the radio frequency (RF) spectrum for the operation of different radio communication classes.
frequency converter	An integrated component assembly required for converting signals into lower or higher frequency ranges for further processing.
gain	The increase in output current, voltage, or power relative to input current, voltage, or power, respectively. Gain is usually expressed in dB.
gain (antenna)	The ratio of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength at the same distance. Antenna gain is usually expressed in decibels relative to an isotropic radiator (dBi) (isotropic reference) or half wavelength dipole reference (dBd).
headend equipment	The main active equipment within a DAS that provides the interface between provider services (i.e., those to be retransmitted by the DAS) and the equipment and components distributing radio frequency signals to designated coverage areas.

ingress protection	The capability of an enclosure (e.g., outlet box, connector), equipment or other object to resist ingress of foreign objects and water. Ingress protection of an object is expressed in the form of IP xy where x represents the capability to resist penetration of foreign objects, and y represents resistance to water.
leaky coax	A colloquial term for <i>radiating cable</i> .
loss	The attenuation undergone by an electromagnetic wave in transit between a transmitter and a receiver. It may be caused by many effects such as free-space loss, refraction, reflection, aperture-medium coupling loss, and absorption.
morphology	The differences in the path loss decay between free space and the actual venue conditions. An RF signal's propagation is unique to each venue, being impacted by numerous factors, including the type of venue (arena, stadium, offices, cubicles, tunnel, outdoor open space, etc.); the venue structural materials (concrete, steel, wood, etc.); the signal's frequency and the modulation method. Therefore, a simple calculation, such as free space loss, cannot accurately predict actual RF signal coverage, especially indoors.
N type or N connector	A medium-size threaded coaxial connector, having a center pin that is installed over the cable's center conductor, typically used for radio frequencies up to 18 GHz.
narrowband	A limited (narrow) band of frequencies that carries voice information. Contrast with <i>broadband</i> . NOTE: Within the United States, it is a specific frequency range set aside for mobile or radio services, including paging systems, from 50 cycles per second (cps) to 64 kilobits per second (Kbps).
null	Area where signal strength has a non-detectable magnitude.
omnidirectional antenna	An antenna that radiates signal power equally in all directions along one plane with signal power decreasing as the angle between the radiated signal and the plane increases.
passive intermodulation	Undesirable mixing of signals by non-linear passive components.
radiating cable	A coaxial cable with a solid copper helical outer conductor and a solid copper inner conductor with a foam dielectric in between. The helical outer conductor has slots that allow ingress and egress of RF signals within a limited range, allowing the cable to function as an omnidirectional antenna. Radiating cable may also be called <i>leaky coax</i> .
radio frequency	An electromagnetic frequency typically between 3 kHz to 300 GHz used in wireless communication.
radio frequency interference	Electromagnetic interference that occurs at frequencies within the radio spectrum.
receiver	An electronic device that detects, demodulates, and amplifies transmitted signals.
repeater	A device (e.g., station, transceiver) that incorporates transmission and reception functions and is used to extend geographical range or coverage ability of wireless systems.
remote unit	Within a DAS, the term given to the distribution cable signal to RF signal converter that is connected to one or more antenna(s).
signal booster	A device at a fixed location that automatically receives, amplifies, and retransmits on a one-way or two-way basis, the signals received from base, fixed, mobile, and portable stations, with no change in frequency or authorized bandwidth. A signal booster may also be termed a <i>bidirectional amplifier</i> or <i>BDA</i> .
simulcast	An identical transmission in time, frequency, and phase between or among a set of emitters in a network.

site survey	A process used to identify the characteristics (e.g., physical, electromagnetic) within a defined area that will impact the installation and operation of a network within that area.
splitter	A device that divides an input signal into two or more output signals.
transceiver	A radio transmitter and receiver combined into a single unit.
wavelength	The length of a wave measured from any point on one wave to the corresponding point on the next wave (e.g., from crest to crest). Wavelength is inversely proportional to frequency.
wireless local area network	A local area network that functions wirelessly between the client and a wireless access point.
wireless service provider	A company or other entity that offers transmission services to users of wireless devices (handheld computers and telephones) through radio frequency (RF) signals. Signals from a wireless service provider are sometimes termed a <i>donor signal</i> .
Yagi antenna	A tree-shaped antenna that uses a reflector element and one of or more director elements to focus the radiated signal in one direction or plane.

4.2 Acronyms and Abbreviations

Abbreviations and acronyms, other than in common usage, are defined below.

AC	alternating current	MIMO	multiple input/multiple output (antenna)
AHJ	authority having jurisdiction	PoE	power over Ethernet
BIM	building information modeling	PIM	passive intermodulation
BDA	bidirectional amplifier	PTP	point-to-point
BTS	base transceiver station	RF	radio frequency
CW	continuous wave	RFI	radio frequency interference
DAS	distributed antenna system	TR	telecommunications room
DC	direct current	UMTS	universal mobile telecommunications system
EIRP	effective isotropic radiated power	UTP	unshielded twisted-pair
EMI	electromagnetic interference	UHF	ultra high frequency
ER	equipment room	VHF	very high frequency
ERP	effective radiated power	VSWR	voltage standing wave ratio
ICT	information and communication technology	WAN	wide area network
LMR	land mobile radio	WLAN	wireless local area network
LTE	long term evolution	WSP	wireless service provider
MCU	master control unit		

4.3 Units of Measurement

The units of measurement used in this standard are metric. Approximate conversions from metric to U.S. customary units are provided in parentheses; e.g., 100 millimeters (4 inches).

Units of measurement used in this standard are defined below:

Ω	ohm
BTU	British thermal unit
dB	decibel
dBd	dB (dipole)
dB _i	dB (isotropic)
ft	foot
ft ²	square foot
GHz	gigahertz
hr	hour
Hz	hertz
in	inch
kJ	kilojoule
kHz	kilohertz
m	meter
m ²	square meter
mm	millimeter
MHz	megahertz
V	volt
V _{AC}	volt alternating current
V _{DC}	volt direct current
W	watt

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5 Regulatory and Safety

5.1 Local Code Requirements

Local code requirements shall be followed. Always review the local code requirements with the local AHJ before proceeding with the installation. This includes reviewing what code and edition is adopted and what, if any, exceptions to the code are adopted by the governing authority. Most of the code requirements for the job should be included in the scope of work documents. The installer should never take this information for granted since the telecommunications contractor is fully responsible for all work done on the project.

If no code has been adopted locally, consult with the fire marshal's office to determine what agency is responsible for that geographic area and what codes are in effect. Do not depend on other installers, contractors, or even site owner personnel in making these determinations.

5.2 Local DAS Requirements

Within NFPA 72, there is inclusion of an annex recommending specific DAS or other in-building wireless system requirements for certain commercial buildings to provide coverage for public safety radio systems. The International Code Council (ICC) has developed a similar initiative.

A growing number of cities and states are adopting this or a similar code, making such coverage mandatory at least for new construction of a certain size. The specifics of these ordinances and codes vary, but most include:

- A minimum signal strength limit
- Application of the limit over a specified percentage of each floor
- A specific level of reliability or confidence in the signal level
- A specified frequency band or bands for public safety coverage
- Testing requirements and procedures
- Provisions for penalties
- Provisions for waivers of the requirements
- Pathway survivability

5.3 Personnel Safety Requirements

A number of jurisdictions have established personnel RF exposure standards for wireless transmission facilities, based on input from the public, academia, scientists, the telecommunications industry and government health and safety agencies. Follow local RF safety requirements. In the United States, the FCC has published OET Bulletin 65, to provide assistance in determining whether proposed or existing transmitting facilities, operations or devices comply with limits for human exposure to radiofrequency (RF) fields.

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6 Distributed Antenna Systems and Components

6.1 Types of DAS

6.1.1 Overview

There are three primary types of distributed antenna systems as explained in the following sections. While these types are shown in the context of a single building, all three may be deployed across multiple buildings, in an outdoor environment, or a combination thereof.

6.1.2 Passive DAS

Passive solutions distribute RF energy over coaxial cables and through signal combiners and filters to coverage antennas. Between the RF sources and the coverage antennas, there are only losses. There are no link budget gains. Although typically used to distribute small amounts of energy from RF sources less than 1 watt in power through distribution trunks and branches of less than 200 feet, high power systems of 20 or 40 watts can drive thousand-foot runs of radiating coaxial cables through train or pedestrian tunnels. Passive solutions are often desirable in small to medium buildings with less than 11,150 m² (120,000 ft²) of floor space when there is a good signal on the outside but assistance is needed to penetrate the building.

NOTE: A repeater or bidirectional amplifier, small cells, or macrocells can all be used as a source for a passive DAS.

A network of 50 ohm coaxial cabling, couplers, and splitters is used to carry the RF signal to and from the distributed antennas. Figure 6-1 shows a passive DAS with the three main stages indicated.

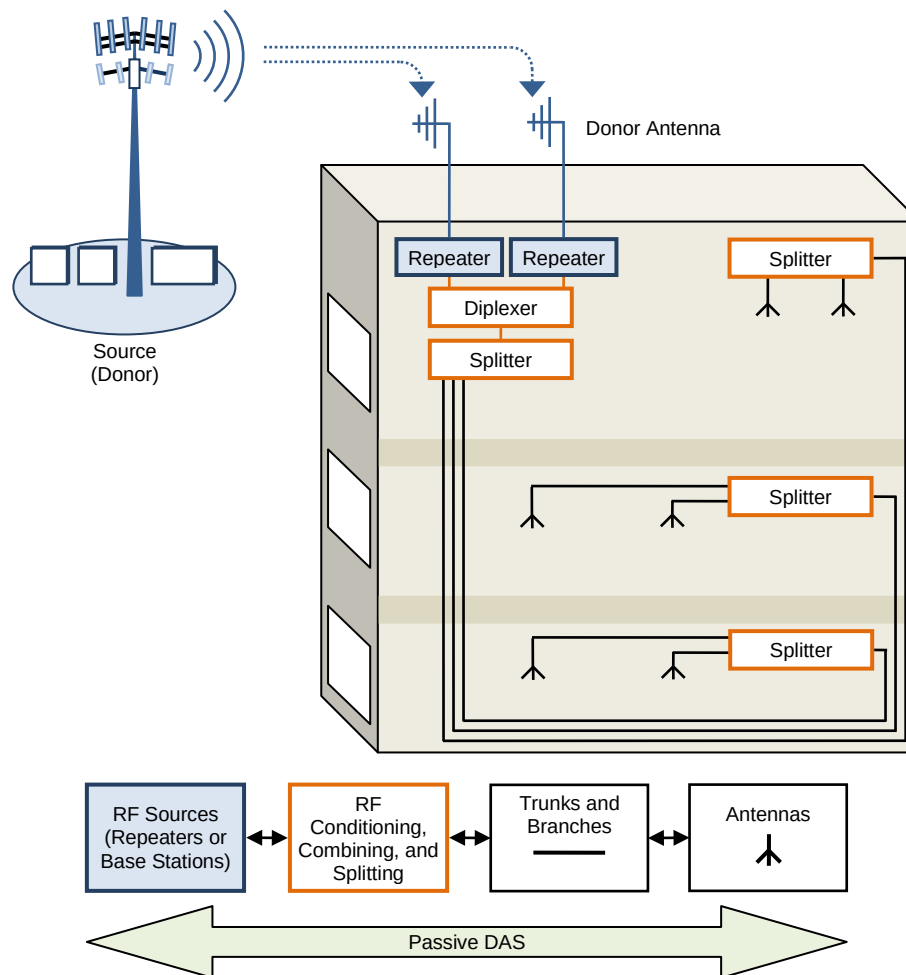


Figure 6-1
Example of a Passive DAS

While Figure 6-1 shows just one coaxial cable run per floor from the wideband splitter, further splitters can be used to distribute the RF signal via coaxial cable to multiple splitters.

In practice, a purely passive approach to distributing signals to each floor is limited. Each time a cable is split, the signal level is reduced, with potential additional losses from reflections and connections. Additionally, while attenuation of the cable can be lowered by the use of larger diameter coaxial cables, larger cabling typically has a higher cost per foot and an increased difficulty in installation as a result of its inherent stiffness. Thus, purely passive systems tend to be used only for small venues.

6.1.3 Active DAS

An active DAS is characterized by a main hub (located in a headend) that bidirectionally downlinks RF signals into media signals and uplinks media signals into RF signals. Remote media downlink to RF downlink and RF uplink to media uplink converter units tactically placed across the venue provides coverage to an array of zones or areas of interest. An active DAS is mostly deployed with dedicated base transceiver stations (BTS's) because of traffic demand.

Optical fiber cabling is the most common medium used by far in active DASs for the distribution of signals to the service zones even though other media, mainly unshielded twisted-pair (UTP), are recognized. This section discusses Active DASs in the context of optical fiber distribution, recognizing that other non-coaxial physical media are occasionally used as well. Figure 6-2 illustrates an active DAS, including an optical fiber distribution between floors.

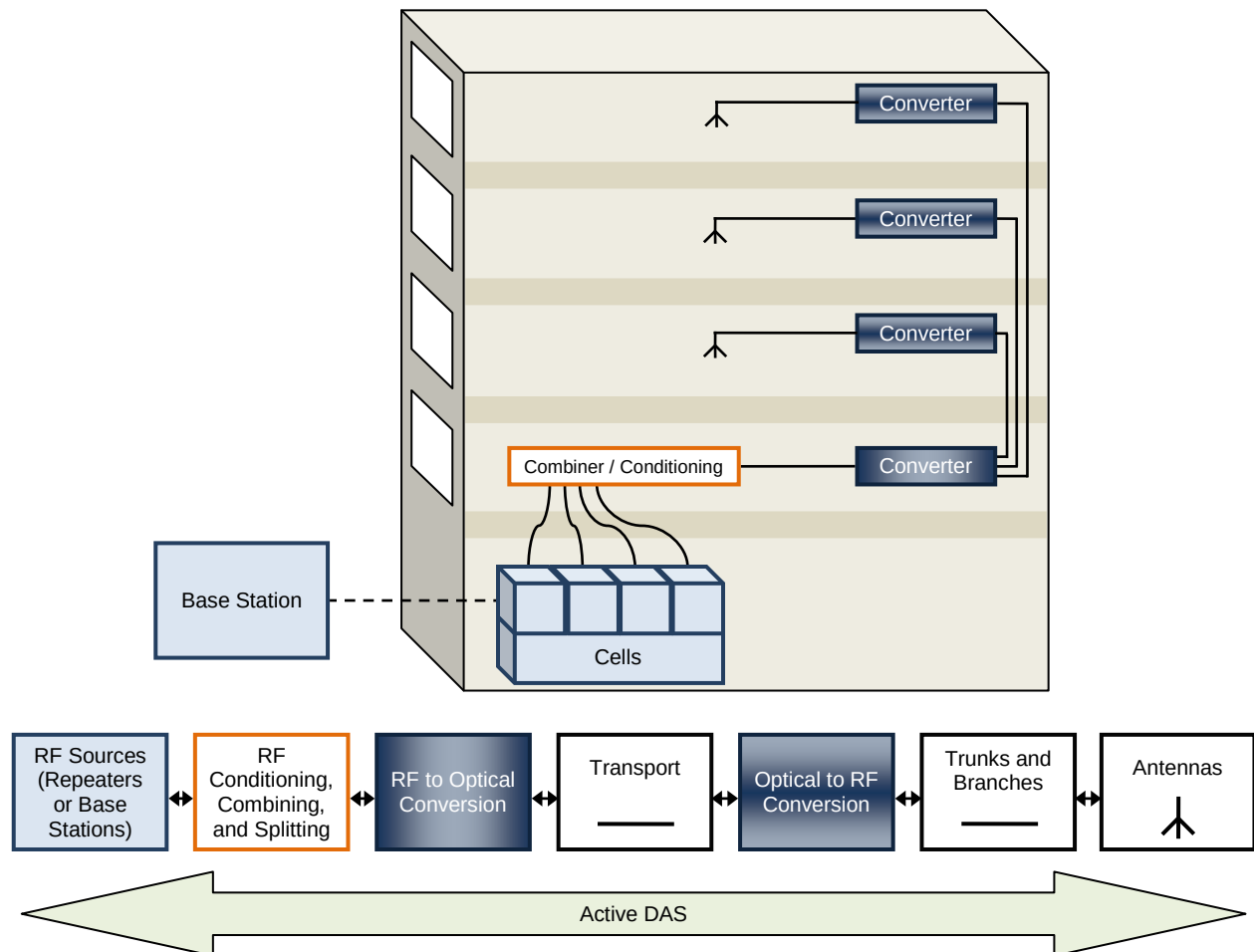


Figure 6-2
Example of an Active DAS

While Figure 6-2 shows a base station in place of the donor antennas shown in the passive system (Figure 6-1), both passive and active DASs use the same type of operator feeds and operator specific conditioning units. Multiple signals may be combined in both, however in an active DAS, the combined RF signal is fed to an RF-to-optical signal converter and then split off into multiple fiber ports supporting the combined signals. An optical fiber cable is then connected from each port to a remote active unit that serves to convert the optical fiber signals back into RF signals. After going through the remote unit's filtering and amplification stages, the RF signals are subsequently coupled to the antennas.

The choice of an active DAS versus a passive DAS is based on many site specific factors. In the past, purely active solutions were less likely to be seen in the building coverage application as there were several downsides to this purely optical approach. Although the installation of optical fiber cabling is typically more convenient than the installation of coaxial cable, optical fiber cabling requires the presence of active equipment at each antenna location. Today's systems are increasingly required to support more frequencies and technologies over larger areas. As a result, several manufacturers have developed solutions that deploy active antennas that greatly reduce the amount of loss between the headend and the antenna.

For large installations, the number of converters required can increase the complexity of designs as space and power needs to be allocated for each converter. This can be mitigated by using a hybrid cable that contains an optical fiber cable and an electrical conductor pair, for direct powering of the converter.

6.1.4 Hybrid DAS

A hybrid DAS combines the use of both active and passive components and system architectures. Various amounts of passive connectivity are required to couple the remote active units to its set of associated antennas. In order to overcome the limitations of the splitter and coaxial cable approach to distributing the wireless signals to multiple locations on each floor, alternative approaches to the fully active and fully passive DAS can be used.

While a hybrid DAS is configured primarily as an active DAS, passive DAS components are used between the optical-to-RF signal converter and the antennas.

An example of a hybrid DAS and its elements is shown in Figure 6-3.

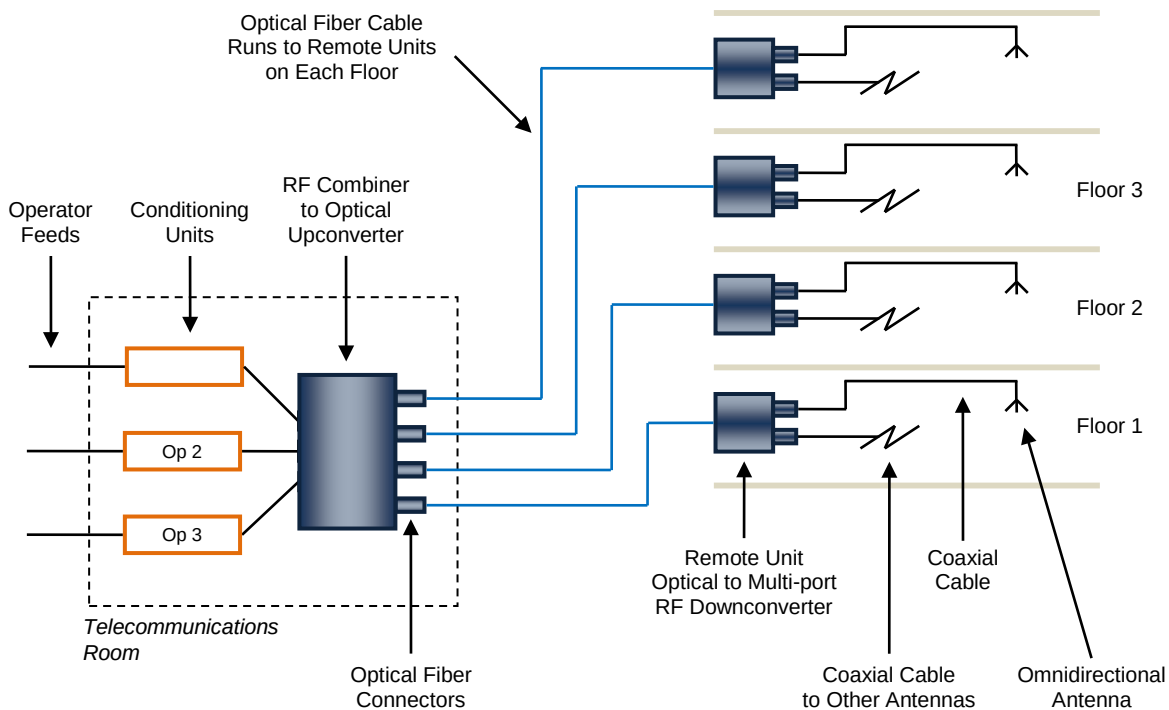


Figure 6-3
Example of an Hybrid DAS

The optical-to-RF converter in a hybrid DAS is connected to the DAS headend by optical fiber cable, but includes multiple coaxial cable ports to connect to the antennas being served. In addition to reducing issues because of coaxial cable length, other advantages include:

- Decreased numbers of active optical-to-RF converters
- Telecommunication spaces (e.g., TR) can be used to support active converters
- The use of telecommunications spaces for active equipment provides safe and secure accommodation of active equipment. (contrast with mounting active equipment near an antenna within a plenum space)

6.2 Signal Source Technology

6.2.1 Introduction

There are two methods for linking a DAS to a signal source. One is with a donor antenna installed on the roof of the building, directed toward the nearest wireless service provider's (WSP) tower. Since the tower's radio resources are used with this method, the DAS is not adding capacity; it is only improving coverage.

The second method is to install a dedicated cable (usually optical fiber) between the DAS and the donor network. This method allows for both coverage and capacity improvement, but it is more expensive.

The DAS designer's selection will depend on a number of factors, including, for example, the system's mission (improve coverage, improve capacity, or both), the WSP's preferences, obstructions to an antenna link between the DAS site and the signal source site, potential cable routes, and budget. Often, a combination will be used. For example, optical fiber cables may link to the cellular networks of the various WSPs while a roof-top antenna links to the local public safety LMR systems.

6.2.2 Common Signal Types

6.2.2.1 Global System for Mobile Communications (GSM)

GSM is a time-division multiple-access (TDMA) standard developed in the 1980s by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks. It became the de facto global standard for mobile communications with over 80% market share. Since its original development, several upgrades and enhancements have added frequency bands, data capability, and higher throughput speeds.

GSM phones have a Subscriber Identity Module (SIM) that holds the user's telephone number, personal information, and an authentication and encryption key to deter theft of service and illegal call monitoring. The SIM can be easily moved from phone to phone.

GSM is evolving into, and gradually being replaced by, third generation technologies, such as Universal Mobile Telecommunications System (UMTS) and High-Speed Packet Access (HSPA), and by fourth generation technologies such as Long Term Evolution (LTE). But, to date, GSM continues to have the majority of cellular phone users.

GSM, UMTS, and HSPA networks operate in over two dozen frequency bands, ranging from 380 MHz to over 3500 MHz. The DAS designer will need to consult with the local WSPs to determine which band(s) they use.

6.2.2.2 Code Division Multiple Access (CDMA)

CDMA is a channel access method protocol used in wireless communication. CDMA is a form of multiplexing, which allows several transmitters to send information simultaneously over a single communication channel, optimizing the use of the available bandwidth. By doing so, a band of frequencies can be shared by several users. CDMA uses spread-spectrum technology and a special coding scheme to prevent interference between the users. CDMA is used in cellular telephone systems in the 800 and 1900 MHz bands.

6.2.2.3 Wideband Code Division Multiple Access (W-CDMA)

W-CDMA is a third generation cellular standard developed in the late 1990s, and it was eventually accepted by the International Telecommunications Union as part of its IMT-2000 family of standards. W-CDMA uses direct sequence spread spectrum techniques, transmitting on a pair of 5 MHz-wide radio channels. Major advantages of this standard are its performance in the face of interference and its resistance to interception. As with the other protocols described here, W-CDMA networks operate over numerous frequency bands. The DAS designer will need to consult with the local WSPs to determine which band(s) they use.

6.2.2.4 Long Term Evolution (LTE)

LTE is a fourth generation standard for wireless communication of high-speed data for mobile phones and data terminals. Recent developments are adding voice and land mobile radio (LMR) to the standard's capabilities. The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s. It supports scalable carrier bandwidths from 1.4 MHz to 20 MHz and both frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based network architecture supports seamless handovers for both voice and data to cell towers with older network technology such as GSM, UMTS, and CDMA2000. However, typical service has downlink speeds of 12 Mbits/s and uplink speeds of 5 Mbits/s or 5 times faster than 3G technology peak speeds.

LTE has become the primary upgrade path for both GSM-based and CDMA-based WSPs. As with the GSM and CDMA families of protocols, LTE can be used in a multitude of frequency bands, ranging within the current spectrum allocations between 700 MHz and 3800 MHz. The DAS designer will need to consult with the local WSPs to determine which band(s) they use.

6.2.2.5 Land Mobile Radio (LMR)

LMR systems use a fleet of vehicle-installed and handheld two-way radios to allow users to communicate among themselves and often with one or more base stations. LMR systems are used by emergency first responder organizations, public works organizations, companies with large vehicle fleets, campus or regional security staff, maintenance and operation crews, construction workers, and the military, among others.

The primary frequency bands used are the 150-172 MHz, 450-512 MHz, 800 MHz, and 900 MHz bands. The use of the 700 MHz band is growing as the result of congestion in the 800 MHz band. There are some LMR systems in the 30-50 MHz band, but the large equipment and long (up to 10 m [33 ft]) antennas required limits mobile and portable use.

Analog frequency modulation (FM) has been the primary modulation method for several decades. Although analog amplitude modulation (AM) exists, it is primarily in the broadcast and aeronautical bands and is generally not used for professional LMR systems. Although AM supports greater ranges, it is susceptible to interference from mechanical (e.g., vehicle engines) and natural (e.g., lightning) sources. Advances in technology in the last several years have allowed a migration to digital modulation methods to where analog LMR are now considered legacy systems for many applications.

LMR systems have a long life span, typically more than ten years, so it will be some time before analog LMR is no longer in service. This means that the DAS designer must be prepared to develop a system that can handle analog, digital or both modulation types.

There are numerous digital protocols that have been developed for use in the LMR bands. Some of these protocols also have applications that permit the use of analog radios, primarily to allow system owners to gracefully migrate their legacy analog system to digital in a cost effective manner. Further, whether analog or digital, LMR systems can also be categorized as either "conventional" or "trunked," depending on the overall system topology.

One version of conventional systems have mobile, portable, and base stations that link directly to each other, usually using a single frequency, referred to as simplex operation. This limits the range of the system because of power constraints of the portable and mobile units and to obstructions that block the signal. To overcome these limitations, the other version has one or more repeaters installed at elevated locations (on mountaintops or using tall towers), called half-duplex operation. The mobile, portable, and base stations transmit on one frequency to the repeater, which simultaneously re-transmits the signal on a second frequency. The higher power of the repeater and its higher elevation provides a much greater coverage area.

Trunked systems were developed when the available spectrum for conventional systems became heavily congested. Trunked systems use two or more repeaters along with a specially designed computer, called a controller, to allow a substantial increase in traffic capacity for a given set of channels. When a portable, mobile, or base station first transmits, it sends a "request to transmit" signal to the controller, which assigns an available repeater. The requesting unit and all other units in its group change to that repeater's channel and begin the conversation. When the communication is complete, the repeater is released and becomes available for other groups.

Amongst the protocols used for LMR are:

- Project 25 (P25)—The trunked protocol used by most public safety organizations in North America. Also used in several other nations.
- Terrestrial Trunked Radio (TETRA) —Used throughout Europe and most parts of the world. Some use is beginning in North America.
- Digital Mobile Radio (DMR) —A lower cost protocol used world-wide in both conventional and trunked topologies.
- Digital Private Mobile Radio (dPMR) —A digital protocol used mainly in Europe in both conventional and trunked topologies.

Detailed descriptions of these protocols and topologies are beyond the scope of this document, but the DAS designer should become at least somewhat familiar with them.

6.2.3 Common Services and Systems

6.2.3.1 Cellular 800 Mhz

The first commercial standard for mobile connection in the United States was the Advanced Mobile Phone System (AMPS), which was in the 800 MHz frequency band. The cellular frequencies are the sets of frequency ranges within the UHF band that have been allocated for cellular phone use by the FCC. The 800 MHz band includes the frequency bands of 824-849 MHz and 869-894 MHz. Because of the longer wavelength at 800 MHz, the 800 MHz cellular signals can travel farther and can penetrate common building materials better than higher frequencies used within the wireless industry.

The FCC has split the cellular band into two sets of frequencies, which means there can only be up to two carriers operating in the 800 MHz cellular band in the same region. The A channel frequency set includes 824-835 MHz, 845-846.5 MHz, 869-880 MHz and 890-891.5 MHz. The B channel frequency set includes 835-845 MHz, 846.5-849 MHz, 880-890 MHz and 891.5-894 MHz. Similarly the carriers operating these sets of frequencies are referred to as the "A" and "B" carriers for a specified area.

6.2.3.2 Personal Communications Service (PCS)

The personal communications system (PCS) evolved from mobile satellite technology. In February 1976, Communications Satellite (COMSAT) Corporation launched the Maritime Communications Satellite (MARISAT) System to provide mobile services to the U.S. Navy and other maritime customers. In the early 1980s, the Europeans launched the Maritime European Communications Satellite (MARECS) series to provide the same services.

PCS was introduced in 1998. In the fully developed PCS, a person can carry a wireless telephone anywhere to be used for voice or data. Several companies have committed themselves to providing a version of this system using satellites in low Earth orbit (LEO). Modern PCS is the result of the FCC's auctioning of frequencies in 1995. This provided a new generation of wireless telephone technology that introduced a range of features and services surpassing those available in analog and digital systems. Operating at 1.8 GHz for mobile telephony, PCS provides users with an all-in-one wireless telephone complete with paging, messaging, and data services with a greatly improved battery standby time. When the 900 MHz GSM cellular network was developed, provisions were made for a second network in the 1.8 GHz range. The higher frequency was expected to be used for low-cost, highly portable PCS.

The original cellular networks were developed for car telephones, and the progression to portables made a worldwide frequency standard desirable. The original cellular licenses were awarded in a lottery by using metropolitan statistical areas (MSA) and rural service areas (RSA), which were developed by Rand McNally for map census areas. For PCS, the FCC auctioned the frequencies in six blocks designated A to F. The PCS licenses were awarded using slightly different census areas (also from Rand McNally) called metropolitan trading areas (MTA) and basic trading areas (BTA). A major difference in the two schemes is that MTAs overlap BTAs like cities are to states or provinces (the New York BTA is part of the New York MTA).

6.2.3.3 Advanced Wireless Services (AWS)

AWS is a wireless telecommunication spectrum band used for mobile voice and data services, video, and messaging. AWS is used in the United States, Canada, Mexico, Chile and Peru. It replaces some of the spectrum formerly allocated to Multipoint Multichannel Distribution Service, sometimes referred to as Wireless Cable that existed from 2150 to 2162 MHz.

The AWS band uses microwave frequencies in two segments: from 1710 to 1755 MHz for uplink, and from 2110 to 2155 MHz for downlink. The service is intended to be used by mobile devices such as wireless phones for mobile data, video, and messaging services. Since for downlink AWS uses a subset of UMTS frequency band I (2100 MHz) some UMTS2100 capable handsets do detect AWS networks but cannot register on them because of the difference in uplink frequencies (1710–1755 MHz for AWS vs. 1920–1980 MHz for UMTS2100).

In the USA, the service is administered by the Federal Communications Commission. The licenses were broken up into 6 blocks (A–F). Block A consisted of 734 Cellular Market Areas (CMA). Blocks B and C were each divided into 176 Economic Areas (EA), sometimes referred to as BEA by the FCC. Blocks D, E, and F were each broken up into 12 Regional Economic Area Groupings (REAG), sometimes referred to as REA by the FCC.

6.2.3.4 Public Safety Services

In a growing number of jurisdictions, public safety radio systems (such as those used by police, firefighters and emergency medical technicians) operate in several portions of both the 700 Mhz and 800 MHz bands. Commonly used frequency bands include 763-769 MHz, 793-799 MHz, 806-824 MHz and 851-869 MHz.

In some countries, such as the United States, additional wireless spectrum within the 700 MHz band has been added to existing public safety frequency bands as part of the transition to digital television transmission.

Specifically within the United States, the additional ranges for public safety are 758-763 MHz and 788-793 MHz, with the frequency bands of 769-775 Mhz and 799-805 MHz being specifically reserved for public safety narrowband.

6.3 Headend and Backend Equipment

6.3.1 Overview

Headend equipment provides interfaces between signal sources (those to be retransmitted by the DAS) and the backend equipment that facilitates the distribution of RF signals to areas needing coverage, such as on different floors inside a building or to other buildings in a campus environment. Headend equipment is the core of the DAS. It is the point of interface where all RF sources and all distributed nodes meet and where resource couplings determine the geometry of simulcast zones.

Headend equipment conditions signals from WSPs and other sources to the DAS. Pre-conditioning often occurs between the base transceiver station (BTS) and the DAS headend components by using a DAS interface tray. The DAS tray typically reduces the BTS power to the DAS and aggregates several bands as required by the system design. The configuration of a DAS interface tray is unique to the coverage required at a particular venue.

DAS backend equipment typically consists of active components that transmit and receive signals from the headend equipment or other backend elements and radiate RF signals into antennas. Backend equipment can include signal repeaters, expansion modules, and remote units.

6.3.2 Master Control Unit (MCU)

The primary headend device is the master control unit (MCU). The MCU consists of several subsystems that have specialized functions within the DAS architecture.

Subsystems typically include inputs for signals that will be retransmitted through the DAS, amplifiers for signal balancing, output links to the backend devices, and power supplies for delivering power to the transmission equipment.

6.3.3 Signal Booster (Bidirectional Amplifier)

There are two basic types of signal boosters: narrowband and broadband. A narrowband booster amplifies only those discrete channels intended to be retransmitted while a broadband booster amplifies all signals within the passband of the signal booster filter, usually many kilohertz or megahertz wide. The U.S. FCC refers to these types as “Class A” and “Class B,” respectively.

Under U.S. FCC regulations, a Class A signal booster with output power that results in over 5 watts ERP per channel is NOT authorized under the signal booster rules. If the signal booster ERP exceeds 5 watts (+37 dBm), then the installation must be licensed as an individual base station site. Further, signal boosters must also comply with human RF exposure limits (e.g., FCC 47CFR1.1310). Accepted practice is to limit ERP of any single in-building antenna to 600 milliwatts (+28 dBm) maximum composite power. Example: For a 10 channel system, this is approximately +18 dBm maximum per channel.

High performance broadband signal boosters now have the capability to store and report excessive output excursions. These reports may also be used as alarms of oscillations. This data, combined with the option of remote controlled fixed gain adjustments, allow a system to easily be optimized for long term operation.

6.3.4 RF Source Equipment

A BTS (macro cell), small cell, fiber repeater, or an over-the-air repeater are all possible RF sources to a DAS headend. Base stations and small cells are connected to the radio access network (RAN) through a WSP’s backhaul. Femto cells can also drive a DAS; however, their backhaul goes through a local Internet service provider’s connectivity links to the RAN. Over-the-air repeaters use the WSP’s licensed spectrum to bridge the gap between the venue being covered and the signal source.

Distributed base station architectures, where baseband processing can be separated from remote radio heads containing modulation, amplification, and filtering modules, are occasionally used to drive an active DAS. The link that carries the baseband data to the remote radio heads, which in turn may drive the DAS, is termed *fronthaul*.

6.3.5 Backend Equipment

Typical backend equipment consists of the following components:

- Slave processor(s)—signal processing for headend synchronization
- Power supplies—voltage supply and conditioning
- Host port(s) —communication interface between backend and host unit equipment
 - Backend equipment ports—communication interface between backend unit and other backend units farther down the system
 - Power ports—connectors for cables feeding power from backend unit to other backend units farther down the system
 - Signal converters and combiners—frequency conversion and consolidation
- Amplifiers and transceivers—signal regeneration and transmission
- Antenna port(s) —connector for coaxial cable to antennas
- Antennas—internal or external to discrete components

Backend equipment typically has a set number of devices or antennas it will serve. The number of devices is usually limited by the additive uplink noise contribution to the system by these devices.

6.3.6 Remote Monitoring and Network Management

Headend equipment may have provisions for Ethernet network management via a transmission control protocol/Internet protocol (TCP/IP) connection to remotely access the DAS, repeaters, or any other devices that are otherwise isolated from physical connectivity. Remote monitoring and maintenance systems can provide notification of equipment alarms while providing technicians the ability to problem-isolate, troubleshoot, and bring the appropriate replacement parts if a site visit becomes necessary. If the manufacturers’ equipment does not provide direct network management, it is possible to include a modem to achieve remote monitoring of or access to some DASs.

6.4 Passive Distribution Equipment

6.4.1 Introduction

Passive distribution equipment in a DAS is defined as equipment not requiring external power input. Signals from an external source are coupled into a passive medium transporting RF signals. These components can be used in conjunction with active equipment in a hybrid DAS or as a completely passive system. Characterized by frequency response, power, and PIM ratings, the components selected need to be matched to the mission they are assigned. Further, performance of coupled passive devices is significantly dependent on proper installation.

6.4.2 Passive Intermodulation

6.4.2.1 Introduction

Passive intermodulation (PIM) distortion is created by either poor quality components or installation practices that cause non-linearities in the downlink RF path. These non-linearities leak (couple) modulated signal into the uplink band, affecting system performance.

6.4.2.2 Requirements

All passive materials in the RF signal path(s) of a DAS (e.g., cable, connectors, lightning protection devices) shall be designed and manufactured to have a passive intermodulation (PIM) rating of -150 dBc (decibels relative to the carrier) or better as given by the manufacturer. PIM requires that power level be specified as well as dBc rating. Commonly, two 20 watt modulated signals are specified with the -150 dBc specification.

6.4.3 Components

6.4.3.1 Directional Couplers

Directional couplers are linear devices that use induction, capacitive coupling, or another method to differentially split downlink power from an input connector to two or more output connectors. Unlike splitters, more downlink power is supplied to one output than the other. Uplink power is likewise combined with a bias toward one or the other connector. Cable taps can be used to achieve a similar effect without cutting the cable. These devices come in various coupling losses, starting with 6 dB and stepping up to 10 dB, 15 dB, and 20 dB.

6.4.3.2 Voltage Injectors (Bias Tees)

Voltage injectors combine direct current (DC) power with the alternating current (AC) RF signal on a coaxial cable and tap it off at the other end, thereby allowing remote powered devices to operate without a separate power source.

6.4.3.3 Hybrid Couplers

Often referred to as crossband couplers, hybrid couplers are designed to meet the special needs of the wireless market. They most commonly are used to combine two wireless bands to a single antenna feed or distribution cable. They are also called diplexers.

6.4.3.4 Signal Splitters

Signal splitters are used to connect more than one antenna to a single radio. It is sometimes necessary to attach multiple antennas to one radio interface to increase the area of coverage for that one transmitter/receiver. This does not provide antenna diversity or alleviate multi-path issues. Splitters only allow for multiple antennas to be connected to one interface for a larger coverage pattern around that one radio.

Signal splitters are also used to connect multiple radio receivers to a single antenna, which commonly are called receiver multicouplers. The multicoupler normally will be frequency selective and have an RF amplifier in front of it as a result of the loss incurred when the signal passes through the unit. The unit also is designed to keep the impedances at 50 ohms per port and limit the amount of signal allowed from the receiver to be radiated back to the other ports or the antenna.

6.4.3.5 Power Splitters

A power splitter is a passive device that accepts an input signal and delivers multiple output signals with specific phase and amplitude characteristics. Output signals theoretically possess the following characteristics:

- Equal amplitude
- Zero degree phase relationship between any two output signals
- High isolation between each output signal

6.4.3.6 Unequal Splitters

Unlike capacitive couplers, unequal splitters maintain DC continuity to both the main and coupled ports.

6.4.3.7 Power Combiners

Considered a reverse of a power splitter, a power combiner is used to combine two or more inputs into one output. A transmitter combiner allows several radios to use a single antenna. This could be used for different types of radios to combine transmit signals in the same frequency range but share the same antenna and provide separate functionality to separate applications using circulators and isolators.

NOTE: The power handling capability is not necessarily equal in both the splitter and combiner directions.

6.4.3.8 Duplexers

Duplexers are used to enable a repeater's receiver and transmitter to use a single antenna or to separate already combined transmit and receive signals. They may also minimize nearby RF interfering signals. Duplexers are three port combiners: transmit, receive, and antenna ports. The duplexers have filters that isolate the transmitter and receiver, ensuring each rejects the undesired frequencies while allowing the desired frequencies to be passed. A duplexer must be designed for operation in the frequency band used by the receiver and transmitter and must be capable of handling the output power of the transmitter. A duplexer must provide adequate rejection of transmitter noise occurring at the receive frequency and must be designed to operate at or less than the frequency separation between the transmitter and receiver. A duplexer must provide sufficient isolation to prevent receiver desensitization.

6.4.3.9 Filters

Filters are available as:

- Pass band filters
- Full band filters
- Notched filters (able to limit downlink out-of-band signal impedance)
- PCS cavity reject filters (when used with a repeater, these can provide out-of-band signal rejection)

6.4.3.10 Attenuator

Attenuators are designed to reduce the transmitter power, allowing RF signals to be reduced to the appropriate level. This can be useful when RF coverage is required inside a small office or business but is not to extend to the adjacent building or office. Even the lowest gain antenna (typically 2 dBi) and the lowest power setting on some transmitters will radiate farther than necessary or acceptable. In-line attenuators are also used to protect test equipment and to manage signal power levels interfacing to the DASs.

6.4.3.11 DAS Interface Unit/Tray

A DAS interface unit is an integrated passive or active component that simplifies the interconnection of repeaters and base stations to the DAS. These points of interface (POIs) are customizable to meet the headend technology, frequencies to be supported, test port requirements, connector type, and fixed or variable attenuation needs.

Active DAS interface units may also provide local and remote access via a LAN connection to make conditioning adjustments, use integrated test tools and for SNMP alarm monitoring to help diagnose potential issues.

6.5 Cabling

6.5.1 Coaxial

6.5.1.1 Coaxial Cable

Coaxial cable is the most common RF distribution cable used for both indoor and outdoor applications. It is most commonly used for interconnecting antennas to remote transceivers or repeaters in smaller applications and interconnections involving the headend and BTS. Coaxial cable may be standard (non-radiating) or radiating coaxial (sometimes called *leaky coax*).

Table 6-1 provides information on the three main construction types of coaxial cables.

Air dielectric cables are mainly used on systems in the range of 1–2.5 GHz or with high-power broadcasting transmitters (above 1 kW) in the VHF/UHF frequency range (30–550 MHz).

Foam dielectric cables are used extensively for equipment interconnections and are usable to about 2 GHz for antenna feeds and to about 10 GHz for inter-equipment connections. They may also be used where pressurization equipment is not available or cannot be justified.

Table 6-1 Coaxial Construction Advantages and Disadvantages

<i>Coaxial Cable Construction¹</i>	<i>Advantages</i>	<i>Disadvantages</i>
Solid Dielectric A solid, stranded or woven inner conductor; a solid polyethylene dielectric covered by one or more braided outer conductor(s) and shielding foil(s) and a polyethylene outer jacket.	Flexible Easy to install No pressurization needed Inexpensive	High signal loss RF signal leakage Deteriorates over time
Foam Dielectric A solid wire core conductor; a smooth or corrugated outer conductor of copper or aluminum with a polymer foam dielectric in between.	Low power loss No pressurization needed Good crush resistance Long functional life	Lossier than air dielectric
Air Dielectric A solid stranded or woven inner conductor; an open air space created by spacers (which separate the inner and outer conductors) covered by one or more braided outer conductor(s) and shielding foil(s) and a polyethylene outer jacket.	Low signal loss Long life High power and frequency capacity	Requires pressurization with nitrogen or dry air Requires gas pass or barrier connectors Vulnerable to moisture

Note 1: Cables with braided outer conductors may exhibit increased levels of PIM that can adversely affect signal quality.

Radiating coaxial cable may also be used as an antenna. Common antenna applications include:

- Long horizontal or vertical linear (straight) pathways (e.g., tunnels, subways, mines)
- Areas where lower power transmission is required (e.g., hospitals, prisons)
- Large open areas above or below ground (e.g., parking garages, malls, convention centers) where it is desirable to limit transmission to neighboring areas out of the structure
- Environments consisting of harsh or corrosive chemicals

See Section 7.7.2 for requirements and recommendations for coaxial cable and Section 6.5.2 for further information on radiating coaxial cable.

6.5.1.2 Coaxial Connectors

Selecting the wrong coaxial cable connector may cause failures in the radio system, such as having too high a power level on a connector, leading to deformation from heat caused by arcing.

Types of coaxial cable connectors commonly associated with DASs are listed below:

- **N type**
The N connector is useful up to 11 GHz. It is used commonly in the two-way radio industry at 300 MHz and above because of its low loss and impedance matching characteristics. The N connector is available in 50 and 75 ohm impedance in both normal and reverse polarity configurations, straight and right angled versions. While right angle connectors are beneficial in tight spaces and to dress cables neatly, they have marginally higher loss than straight connectors.
- **7-16 DIN type**
Standardized by the Deutsches Institut für Normung, the 7-16 connector is a 50 Ω threaded RF connector that produces lower inter-modulation distortion as compared to other connectors. The 7-16 in the name refers to the 7 mm inside diameter of the inner contact and the corresponding 16 mm inner diameter of the outer contact. These connectors are used by systems using medium power levels and antennas rated for low passive inter-modulation (PIM) performance.

NOTE: Smaller form factor coaxial connectors which have similar RL and PIM performance as the 7-16 DIN connectors are increasingly used on base stations, remote radio heads, points of interface, jumpers and antennas due to tight space constraints. 4.1-9.5 and 4.3-10 are two common sizes. These are often referred to as “Mini-DIN” connectors.
- **SubMiniature version A (SMA) Type**
SMA is a threaded sub-miniature connector used on DAS conditioners, antennas and headend equipment.
- **QMA type**
The QMA is a quick disconnect version of a SMA connector. The connector has a 50 Ω impedance, designed to be used up to 18 GHz.

6.5.2 Radiating Coaxial

6.5.2.1 Overview

Radiating cable is composed of a solid copper helical outer coaxial cable with a solid copper inner conductor and a foam dielectric. The helical outer conductor has slots that allow ingress and egress of signals within a limited range of the cable. Radiating cable used in this manner is often termed *leaky coaxial cable* or *leaky coax*.

Leaky coaxial cable is useful in combined systems because of its wide bandwidth, allowing operation from 70 MHz to more than 2.4 GHz. It is frequently used in areas where other antennas would not provide the required coverage such as in tunnels, mines, and similar types of environments.

6.5.2.2 Radiating Cable as an Antenna

Radiating cable produces even coverage with moderate transmission power levels near the antenna and, therefore, allows direct control over signal power levels. Radiating cable is particularly useful in areas where signal power is highly regulated (e.g., hospitals, especially neonatal and radiography units) or where radio broadcast propagation is poor (e.g., prisons, tunnels).

A traditional DAS uses regular low-loss coaxial cable and signal splitters or couplers to split the transmit signal to each antenna. Radiating cable of similar dimensions has slightly worse longitudinal loss because the signal is continually leaking out along its entire length, which is required for its role to be an antenna. One advantage of coaxial cable solutions is that they are wideband, provided that wideband splitters and couplers are used. Entirely passive coaxial cable networks are reliable and virtually maintenance free.

It is relatively rare to use radiating cable along with an optical fiber-based DAS as most optical fiber-based DAS designs provide a large number of distributed antennas, which lessen the benefit of a radiating cable.

6.5.2.3 Applications

Radiating cable is typically the best choice for linear coverage areas such as in a high rise or tunnel.

DAS designs may use radiating cable to provide RF coverage for long horizontal or vertical pathways for both the building interior and exterior, above ground and below ground. Radiating cable may serve these larger areas, such as tall structures, tunnels, or similar environments, better than discrete antennas. When higher frequencies (above 1 GHz) are required, a 22 mm (0.875 in) radiating cable may be required, at least for the main feeder. For long cable lengths, such as metro tunnels (e.g., subways) or mineshaft subways, 22 mm (0.875 in), 32 mm (1.25 in), and 41 mm (1.625 in) cables may be required.

A minimal high-rise building installation may include several runs of vertical radiating cable that may be required to be run up the building core. This could be because of multiple transmit and receive frequencies that may not be compatible (e.g., very high frequency [VHF] repeaters that have close-spaced transmit and receive frequencies that need a separate transmit and receive cable to enable the systems to operate properly). The coverage of this type of system will be less than what would be provided by conventional antennas as the coupling losses are typically 30 dB greater than other antennas.

For more complete coverage in deeper plan buildings, branches can be coupled to extend the radiating cable horizontally around floors and parking lots.

Care must be taken to ensure that radiating cable is properly polarized for the application for which it is intended. Changing the polarization of the cable run can cause distortion and loss of the signal. In applications below 400 MHz, separate cable runs should be used for transmit and receive signals to avoid undesired signal coupling.

The downside of leaky coax is the loss per distance which eventually needs to be made up for by adding an amplifier. Amplifiers add noise to the system and need power to operate. Amplifier selection needs to match the bandwidth requirements for the system.

The DAS designer should ensure that the addition of amplifiers does not cause adverse effects on the design in terms of increasing cascaded system noise that degrades the signal.

6.5.3 Balanced Twisted-Pair

Balanced twisted pair cabling is typically used for power over Ethernet (PoE) applications within DAS, but it may also be used to distribute radio signals. See Section 7.7.3 for requirements and recommendations for balanced twisted-pair cable.

6.5.4 Optical Fiber

Single-mode optical fiber cable is the predominant optical fiber used for both indoor and outdoor applications for interconnecting remote transceivers and expansion units back to the headend. Multimode optical fiber cable is typically only used for indoor applications for interconnecting remote transceivers.

DAS equipment requiring optical fiber cable will determine the type of fiber connector and the end face finish necessary to meet the loss and return loss thresholds. Digital optical fiber systems can tolerate better loss and return loss than analog RF optical fiber networks. Angle polish connectors (APC) are frequently used to reduce reflections in an optical network. Ultra polish connectors (UPC) provide low insertion loss however, they do not provide as good return loss as APC connectors. SC/APC and SC/UPC are common connector types/finishes used in DAS as are LC/APC and LC/UPC.

See Section 7.7.4 for requirements and recommendations for optical fiber cable

6.6 Antennas

6.6.1 Overview

An antenna transmits and receives free space electromagnetic waves (radio waves) and transforms them to RF signals for transmission on a conductor such as coaxial cable. Accurate radio transmission for frequencies above 100 MHz is dependent on line of sight or a clear path between the antenna and radio. Obstructions, such as buildings, walls, trees, terrain, shelving for inventory or books, will interfere with the radio transmission and increase signal attenuation.

Depending on the antenna's construction, it will have either a broadband (BB) or narrowband (NB) capability. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band (NB). An antenna must be tuned (matched) to the same frequency band(s) as the radio system to which it is connected; otherwise, the reception and transmission will be impaired. Broadband antennas typically have the capability of covering from 700 MHz to 2.6 GHz. Narrowband antennas generally cover a single band such as 700–800 MHz, 800–900 MHz, etc.

6.6.2 Antenna Parameters

Some parameters to consider when selecting the type of antenna are:

- Physical parameters
 - Interior or exterior physical placement of the antenna (e.g., wall, ceiling, mast, interior, exterior, aesthetics)
 - Location of the antenna in relation to the intended users (consider radiation pattern and range and capacity)
 - Operating distance from the antennas and the frequencies to be transmitted and received
 - Desired qualities such as small size, good gain characteristics, and omnidirectional or directional radiation pattern
 - Desired radiation pattern (directivity, front-to-back ratio) to ensure coverage to the intended areas, but limiting the transmission to undesired locations such as out of the building (e.g., using a flashlight instead of a lantern), which could cause interference
- Performance parameters
 - Isolation, which is the minimum distance (or signal blocking material such as metal or concrete) between donor and inside antennas. This is important to prevent interference
 - Antenna gain (dBi) is related to the type of antenna, its radiating pattern, and coverage range. An antenna does not amplify the signal; a high-gain antenna directs the signal farther in a particular direction than a low-gain antenna
 - Power and PIM ratings
 - Ensure each antenna has a power rating in excess of the maximum transmitter power.

6.6.3 Antenna Characteristics

Antennas have characteristics that determine their effective coverage range and radiation pattern. Voltage standing wave ratio (VSWR) is a measure of the reflected power on a transmission line between the transmitter and the antenna. A smaller VSWR means the antenna is better matched to the transmission line and more power is delivered to the antenna. A VSWR of 1.0 would mean no power is reflected from the antenna.

Generally, DAS designers desire an antenna with a 1.5:1 or less VSWR, which equates to a return loss of approximately 14 dB. While they focus on this antenna characteristic, the difference between a 1.5:1 and a 2.0:1 VSWR is only about 0.2 dB of signal loss. A 1.5:1 VSWR is more easily achieved with a narrowband antenna than a broadband antenna.

To ensure effective RF communication, the key is to select the proper antennas and place them in the correct location.

6.6.4 Antenna Types

6.6.4.1 Overview

Antennas can be classified into the type of coverage they provide such as:

- Omnidirectional
- Directional
- Sector

A combination of all three can be used, taking advantage of the radiation patterns of each type of antenna to best meet the venue characteristics and design objectives.

6.6.4.2 Omnidirectional Antennas

Omnidirectional antennas broadcast equally in all directions (360 degrees) in a single plane (typically horizontal), creating a toroidal (doughnut-shaped) three-dimensional radiation pattern. All omni antennas are not equal. The characteristics of an omni antenna are that it has an intentional null area directly above and below the antenna and that the peak signal is not directly on the horizon. This allows the omni antenna to cover a greater horizontal area; however, the antenna will be more sensitive to changes in elevation between the antenna and the user's device.

An antenna that truly broadcasts with equal power in all directions (i.e., isotropic antenna) is not technically feasible although it can be approximated with arrays of antennas in phased cooperation. As an analogy, an omnidirectional antenna is similar to a camping lantern where the bulk of the light radiates horizontally.

6.6.4.3 Directional Antennas

6.6.4.3.1 Overview

Directional antennas are useful indoors to control signal leakage out of the building and to provide floodlight coverage in areas that are difficult to cover. As an analogy, a directional antenna is similar to a flashlight. Directional antennas are used outdoors to direct signals to the WSP's site and prevent signals from affecting other sites. The higher the gain, the more directionally focused the antenna is. High gain directional antennas are often used in stadiums to create smaller coverage areas for each antenna to reduce co-channel interference and increase capacity.

Table 6-2 provides a summary of directional antennas typically used within a DAS.

6.6.4.3.2 Yagi Antennas

The Yagi antenna is an array antenna composed of one driven element, one reflector behind it, and multiple directors in front. The reflector and directors are collectively called parasitic elements. The spacing and length of the elements are chosen such that the parasitic elements have currents induced in them by the driven element field that, in turn, create their own field to reinforce the radiation from the driven element.

There is a limit to the maximum gain that can be achieved with a Yagi because the directors have less current induced in them the farther they are from the driven element. The bandwidth of a Yagi antenna can be increased by increasing the element diameter using bow tie flat elements or V-shaped elements.

Gain over a single dipole ranges from 6 dB for a three-element Yagi to 13 dB for a 15-element unit. Yagi antennas are frequently used as a donor antenna and in other point-to-point applications. The Yagi focuses the majority of the radio signal in one direction. Because of the narrow directivity of a high gain Yagi antenna, it is important to properly aim the antenna during setup. A Yagi antenna with more elements has more gain and can, therefore, receive a lower signal than one with fewer elements.

Table 6-2 Types of Directional Antenna and Associated Applications

Type	Variation	Application
<i>Yagi</i>	Standard four- to nine-element Yagi (bandwidth typically five percent of center frequency)	RF controls (fixed two-way radio mobiles, short-range (campus) WLAN outdoor links); used where rejection of interfering signals or multipath fading is not an important consideration—not suited for heavy ice-loading zones
	Stainless steel Yagi	Used in corrosive or high-wind environments and cyclone areas for additional strength
<i>Parabolic Dish</i>	Small diameter 300–600 mm (12–24 in), standard horn fed	Short-range point-to-point (PTP) links (up to several kilometers/miles) usually above 10 GHz, often integrated with the transceiver unit as a single assembly
<i>Grid</i>	Small parabolic reflector grid (under 1.2 m [4 ft])	Short-range IEEE 802.11b (wireless WAN, short-range low-capacity digital pulse code modulation) links (<8 Mb/s); subscriber radio concentrator systems (used as a Yagi array substitute); microwave distribution system (subscription) television home receiver antenna—used with lightweight towers and masts or roof mount pipes
	Corner reflector grid	High gain VHF and UHF link terminals in severe wind environments; mechanically stronger, better interference rejection than Yagis; less susceptible than Yagis to wind or ice damage; vertical array variant used as a cellular or wireless WAN sector antenna

6.6.4.3.3 Parabolic Dish Antennas

A parabolic reflector can be used to capture a large area of wave front and focus it onto a slot or horn antenna, which is called an illuminator. Conversely, the reflector has the ability to focus or concentrate a wave front transmitted by the illuminator. The effective aperture (A_{EFF}) is comparable to the area of the reflector (dish), generally over 50 percent of physical area and up to 65 percent for spun aluminum dishes (spun on a mandrel from a flat plate to close dimensional tolerances). The aperture achieved depends on the surface material, number of joints, and machining tolerances of the dish.

For all types of parabolic reflector antennas, the radiation is concentrated near the boresight by the reflector with a number of side lobes and sharp nulls in the directive gain characteristic within about 10–30 degrees of the boresight, depending on the dish size. The amplitudes of side lobes well away from the boresight can be significantly reduced by adding a shroud (tube of matted absorbent material) around the edge of the dish.

Since the exact position of the nulls depends on dish machining, the dish manufacturer usually guarantees only that the side lobes will be below a guaranteed radiation pattern envelope (RPE), which graphically describes the guaranteed maximum directive gain (relative to boresight gain) that should be encountered because of side lobes. In general, directivity is proportional to the reflector area; a 6 dB increase in gain may be expected for a doubling in reflector diameter.

The directivity also is inversely proportional to wavelength, so the gain theoretically increases by 6 dB for every doubling of frequency without changing the dish size. However, the illuminator still must be changed to suit the drive frequency.

The typical gain from directivity of a 2 m (6.5 ft) dish:

- At 2 GHz equals 28 dB.
- At 6 GHz equals 40 dB.

WARNING: The very high gain of dish antennas can lead to an EIRP at a boresight of 10 kilowatts (kW) or more with a typical 1 watt (W) transmitter power. It is extremely hazardous to stand or work in front of a live transmitting dish antenna or in the boresight beam at ranges under 100 m (328 ft). Check with local safety regulations (e.g., FCC OET 65) for calculations of safe exposure levels.

6.6.4.3.4 Parabolic Grid Reflector Antenna

Grid reflectors are generally only practical at frequencies below 2.5 GHz. Parabolic grid reflector antennas can provide good front-to-back ratio and extremely high gains, enabling them to be great donor antennas. Like corner reflectors and Yagi antennas, the grid antenna is also highly directional. This type of antenna is often used in 1900 MHz systems where higher gain is needed to obtain an acceptable donor signal level.

Grid reflectors can be assembled on site and experience reduced wind loading. However, grid reflectors typically have reduced side lobe suppression and inferior front-to-back ratio as compared to a parabolic antenna and are more susceptible to ice loading.

6.6.4.4 Sector Antennas

6.6.4.4.1 Overview

Sector antennas are used to provide radio coverage over a portion of the azimuth range (as opposed to omnidirectional coverage). The sector antenna radiates well within a range of azimuth angles usually ranging between a 90 and 180 degree beamwidth while strongly attenuating signals in other directions, especially backward (in the opposite direction to boresight).

Their pattern usually requires them to be located at the corner of the target coverage area. For in-building coverage, they are typically located at outside building corners facing inward, preventing interference to or from indoor systems in adjacent buildings and minimizing radiation outside the desired coverage area. See Table 6-3 for various types of sector antennas.

Reasons for providing sector coverage include the following:

- Confine or maximize coverage to a geographic corridor or within a building
- Prevent interference to co-channel systems within radio range but outside the sector beam
- Increase traffic carrying capacity without building new sites by subdividing the coverage area of a site

Sector antennas are commonly deployed at cellular and wireless WAN base station sites and on indoor cellular and WLAN systems.

Table 6-3 Sector Antenna Types and Their Application

<i>Type</i>	<i>Application</i>
Corner reflector (one driven element, narrow aperture)	VHF and UHF fixed PTP links where superior side lobe rejection is required; situations where Yagis are unsuitable
Indoor sector antenna about 90 degree beamwidth	Indoor coverage from placement on outside corner facing inward; indoor cellular coverage, WLAN; stops interference to and from outdoor network coverage and improves security from eavesdropping
Outdoor sector antenna about 120 degree beamwidth	Cellular telephone and broadband wireless WAN cell sector coverage, usually 800 MHz–5.8 GHz; highway or rail corridor coverage; point-to-multipoint systems where the base is at the edge of the coverage area; television translator fill in coverage systems where the translator is at the edge of the coverage area

6.6.4.4.2 Corner Reflector Antennas

Corner reflector antennas are almost exclusively based on a vertically mounted design. They are made up of two plane reflector panels and a dipole element. This type of antenna restricts radiation to the angle between the planes (frequently ninety degrees) and prohibits side lobes and radiation to the back by reflecting the signal in the forward direction. Corner reflectors minimize interference from/to adjacent cells when used as a donor antenna. These types of antennas can provide gains of 14 dBi.

The signal reflected by the reflector is added in phase to the driven element signal, increasing gain. The gain advantage of a corner reflector of a given front face area is not as great as a parabolic reflector dish of the same area, but the side lobe performance and front-to-back ratio are very good and typically better than an un-shrouded dish.

Reduced vertical beamwidth and increased gain are achieved by extending the height of the reflector and replacing the single dipole with a collinear dipole array.

Most corner antennas provide the option of down-tilt. This ensures that:

- The edge of the coverage area is in a pattern null, reducing spillover into adjacent cells.
- The locations right under the antenna are not in a pattern null, which is important where the antenna is roof mounted and covering the area below a tall building.

There are two means of achieving down-tilt:

- **Mechanical**—The top of the antenna is bolted to an extension bracket that allows the whole antenna to be physically tilted several degrees downward. Geometry restricts the down-tilt to the center of the beam; the edges still radiate horizontally.
- **Electric**—The antenna is mounted vertically, but phasing of the dipole elements is used to achieve a down-tilted pattern that faces down across the entire beam. The phase control can be switched by remote control to allow remote fine-tuning of sector coverage and traffic levels.

6.6.4.4.3 Panel Antennas

A panel antenna is, in principle, a special case of a sector antenna with the aperture angle set to 180 degrees, resulting in a flat reflective surface and low profile. This antenna typically has a 120 degree beamwidth.

The main distinction of the flat panel array when compared with other sector antennas is that dipole elements may be grouped both horizontally and vertically and oriented in any polarization.

Different bands and polarizations can be mixed on the same antenna assembly with each band and polarization having its own feeder connection. A panel antenna with multiple vertical rows of dipoles or a vertical stack of horizontal dipoles exhibits the properties of both broadside dipole arrays and sector antennas.

6.7 Active Distribution Equipment

Active distribution equipment consists of the electronics associated with a DAS that require separate input power. Electrical power requirements for DAS active equipment vary for each manufacturer and should be identified and considered before conducting a site survey.

6.7.1 Transceivers

Transceivers transmit and receive RF signals. This dual function allows one device to function as two and thereby reduces the number of overall components within the DAS architecture. In duplex systems, the transmission and receiving frequencies must be different. In simplex systems, both links share a common frequency.

6.7.2 Amplifiers

Amplifiers can be used to boost the signal and increase the operational range of the RF transmitter. Amplifiers also can alleviate trouble areas where the signal strength is low, especially outdoors. It is important to calculate the antenna gain and transmitter power when designing any RF system to comply with the applicable regulatory agency rules.

NOTE: Use of RF amplifiers typically is subject to government regulations. The user is responsible for compliance with applicable laws and regulations. For example, at 2.4 GHz, the maximum transmitter power is 1 W or 30 dBm. In point-to-multipoint systems, the FCC limits the maximum effective isotropic radiated power (EIRP) to 36 dBm.

6.7.3 Bidirectional Amplifiers (BDA)

Bidirectional amplifiers (also called signal boosters) in RF communications systems operate in much the same way as transceiver elements. Bidirectional amplifiers receive RF in one port and transmit RF on another port. They contain two amplifiers oriented in opposite directions with inputs and outputs combined and steered by directional elements, generally either circulators or diplexer filters.

In the DAS environment, amplifiers are used to couple input signals of donor systems and amplify them in the host system for rebroadcast to antennas within the DAS. A WSP-grade amplifier is capable of providing 60–85 dB of gain and contains a filter and a digital signal processor (DSP) to determine a pass band for the specific system.

The amplifier will amplify noise as well as the desired signal. The downlink signal goes from the BDA to the DAS. The uplink signal goes from the user's device to the DAS back to the BDA. BDAs may have the ability to adjust the gain on the uplink and downlink and select specific channels or frequencies to support the DAS. BDAs can be remotely monitored for performance and may be remotely configurable and shut off if found to be causing problems with the macro environment.

The use of bidirectional amplifiers may also require compliance with the local AHJ. For examples of requirements, see regulations such as FCC Regulation 47 CFR 90.219.

6.7.4 Unidirectional Amplifiers

Unidirectional amplifiers receive RF in one port and transmit RF on another port but only amplify a single path of RF signal (either forward path or reverse path). They contain one amplifier and may use directional elements, such as circulators or diplexer filters, to separate and combine the different RF paths. An example of a unidirectional amplifier is a tower mount amplifier used to amplify the receive path prior to coaxial and line losses down to a base station receiver.

6.7.5 Repeaters

These devices are often referred to as bidirectional amplifiers although some repeaters may receive signals on one frequency and retransmit the signals on another frequency. Repeaters typically offer higher gain performance than bidirectional or unidirectional amplifiers. The filter band-pass characteristics are also more selective. Additional processing of the radio signals, such as down conversion, signal monitoring, and automatic gain control, and feedback control may occur within the unit.

6.7.6 Media Converters

Media converters typically receive power or data from one standard interface and output that power or data to a different standard interface. Most wireless equipment vendors provide power over Ethernet (PoE) capabilities to simplify installation.

Some vendors have implemented power injector media converters that receive data over the optical fiber cable through optical fiber connectors and then convert the optical fiber signals to Ethernet data signals, providing this data to the wireless bridge/access point through a balanced twisted-pair 8-position, 8-contact (8p8c) modular jack. Media converters can enhance the wireless design in instances where radios are to be installed beyond the 100 m (328 ft) horizontal cabling distance limit of a structured cabling distribution system.

6.7.7 Frequency Converters

These devices are designed to shift RF signals from one range to another. One example would be to migrate IEEE 802.11b wireless networks operating in the overloaded 2.4 GHz (2400–2483 MHz) unlicensed band into the 5.8 GHz (5725–5850 MHz) range.

6.7.8 Relays

Relay platforms have two bidirectional RF links. Those links may provide mesh connectivity between a serving node and gateway node or use separate RF protocols for serving the subscribers in its coverage objective and backhauling that service.

6.8 Electrical Components

6.8.1 Overview

While purely passive systems will have little, if any, need for electrical equipment or power supplies, passive systems will still have some electrical systems considerations such as bonding and grounding.

6.8.2 Suppression Units

6.8.2.1 Lightning arresters or suppressors

Lightning arresters or suppressors limit the amplitude and duration of disturbing interference voltages. Voltage transients can be created through lightning static discharges, power lines, or earth currents. Therefore, it is important to install some form of lightning protection to any outdoor antenna. Lightning arresters are typically installed between the antenna cabling from the radio and the outdoor antenna and connected to a proper ground.

6.8.2.2 Surge Suppressors

There are two main types of coaxial surge suppressors:

- DC blocking—This prevents DC from passing through the center conductor of the protector.
- DC passing—Used in systems that need to power remotely mounted equipment located near the antenna; this type of protector will pass a DC voltage through, but it will divert a surge to ground.

6.8.3 Power Supply

6.8.3.1 Overview

The following is a listing of commonly found voltages on a site:

- 48 V_{DC} positive ground
- 28 V_{DC}
- 24 V_{DC}
- 12 V_{DC} negative ground
- 120 V_{AC}
- 240 V_{AC}

6.8.3.2 Power Supply Units

These devices typically convert the commercial AC power supply to DC operating voltages. The V_{DC} ranges from 12 to 48 V_{DC} for carrier modulation and 5 to 12 V_{DC} for circuit board logic voltage. Specific function and architecture vary based on the DAS manufacturer.

A designer should take into account the power requirements of all the equipment involved. This may entail uninterruptible power supply (UPS) systems that will generate 120/240 V_{AC} at 50/60 hertz, battery rectifiers that will operate the equipment as well as recharge the battery banks after a power failure, and wind and solar power generation systems for remote areas. Consider the requirement for powering remote amplifiers as well as equipment located away from the equipment room.

If the equipment is operating from the power supply directly without using batteries, fuse both the positive and negative leads to the supply with the proper fuse size. This will prevent the equipment from becoming the return path for the system ground should the main ground fail.

If using a rectifier system to charge the batteries as well as operate equipment, size it so that if there is a fully discharged battery system, then it will be able to bring the batteries back to a full charge in 12–24 hours as well as operate equipment during the charge process. The charging system also should be able to equalize the battery system to extend the battery system life. The charge current is normally 1/10 of the capacity of the battery.

If using a battery and rectifier system, install a DC distribution system with a low-voltage disconnect as part of the designed system. A low-voltage disconnect will prevent damage to the equipment or battery system by disconnecting the load either fully or in stages from the batteries to prevent the batteries from being fully discharged or damaged.

6.8.3.3 Uninterruptible Power Supplies

For the UPS requirements of the equipment needed, determine the full load power required in both watts and volt/amps. Determine how long the UPS should support the required load as well as any future growth. An important item to remember is that when the power goes out, unless the entire facility is on a backup generator, the air-conditioning system will no longer operate. In most facilities, the room air temperature will quickly rise to unsafe levels for both the equipment and personnel. In some limited cases, exhaust fans can bring cooler air into the enclosure to limit heat rise. However, the power to run the fans will be coming from the UPS system. If it is a critical system, plan for both standby power as well as short-term battery backup. This allows equipment to be minimally affected by power fluctuations during short outages. If it is a longer duration outage, the generator will power the system for a limited time until facilities can be restored.

6.8.3.4 Voltage Injectors

Voltage injectors are used to power electronic equipment located away from convenient sources of power. There are two major types of voltage injectors used within a DAS, a coaxial type used to power remote-mounted preamplifiers, amplifiers, and bidirectional amplifiers and injectors used within PoE systems.

For large installations, the number of converters required can increase the complexity of designs as space and power needs to be allocated for each converter. This can be mitigated by using a hybrid cable that contains an optical fiber cable and an electrical conductor for direct powering of the converter.

6.8.3.4.1 Requirements

Implementation and installation of voltage injectors shall meet applicable codes and requirements of the AHJ. PoE injectors shall be implemented as per IEEE 802.3.

6.8.3.4.2 Recommendations

Coaxial power injectors should be installed as close as possible to the equipment that will be receiving the resulting signal.

If placing the remotely powered radio equipment outside the enclosure, pay close attention to the lightning surge protection used on the incoming balanced twisted-pair cable connected to the equipment. The suppressor used should not attenuate the DC voltage powering the remote mounted unit or the network signals passing through it. The best solution for this type of installation is to place the power supply in the remote-mounted enclosure and send the signals via optical fiber cable.

6.9 Software and Management Systems

6.9.1 Overview

A DAS must be configured properly in order to ensure that it is operating in accordance with the WSP's frequency and power specifications. The DAS must also be configured so that it is providing coverage for the areas specified in the design. In a passive DAS, this configuration is accomplished by physically installing various signal and power conditioning devices. In an active DAS, the configuration is accomplished using system management software.

The system management software is used to view and adjust settings on various DAS components via a direct connection, local network connection, or remotely. In most cases, the system management software resides on a particular piece of DAS equipment, usually a headend component. In some cases, the system management software will reside on an external computer such as a laptop.

Connections to the DAS for system and component configuration can be made several ways. The most common is a physical connection using a jumper (serial cable or patch cord). In this method, the technician will use a jumper to connect an external computer's communications port to the designated communications port on the DAS. Once connected to the DAS, a technician can then configure the DAS settings per the design requirements and then download and save the settings for the DAS.

Another possibility is to remotely access the DAS. In order to do so, the DAS must be simple network management protocol (SNMP) capable. If the DAS is SNMP capable, connections to the DAS can be made through a local area network or via the Internet. Security measures should be taken whenever a DAS has remote network access capabilities. Anyone accessing the system should be prompted for an identification credential. When the credential is validated, the person accessing then has the ability to make changes to the DAS components.

SNMP capability provides several benefits when managing and maintaining a DAS. When dealing with a large DAS, SNMP allows for a central point for configuration, thus eliminating the need to travel back and forth between multiple buildings or long distances to configure each component. Also, if the DAS goes into an alarm state, the SNMP feature can allow for remote access for diagnosing potential issues. This could reduce the number of costly site visits associated with issues that could be handled remotely.

7 DAS Design

7.1 Overview

Designing a DAS may require planning and managing additional details and interested parties as compared to a communication network infrastructure. Depending on the client or the property manager, DAS infrastructure may be considered as part of the ICT infrastructure. In other circumstances, it is standalone infrastructure.

7.2 DAS Personnel

7.2.1 Overview

Proper design coordination of the DAS installation requires extensive amounts of multi-disciplined engineering efforts because of the numerous site-based physical structural, surrounding environment, electrical, and owner/vendor entity considerations that are impacted by the implementation.

7.2.2 Division of Design and Installation Task Responsibilities

The DAS designer is responsible for the design of the system. This requires identifying which services will be supported by the DAS and the areas to be covered. The designer should create construction documents the installer will use to build the system. The designer's construction documents typically identify the location of the headend equipment, signal sources, and donor antennas. It should also include a layout of the DAS cabling infrastructure, which shows the interconnection requirements between the headend equipment and remotes as well as the locations and types of antennas required to provide coverage throughout the areas requiring coverage. The DAS designer may also provide coordination, guidance, and assistance between host and owner for contractual requirements between the host and owner entities.

The DAS installer may install the structured cabling system, which typically includes an optical fiber or balanced twisted-pair backbone and the antennas with their respective cabling (coaxial, balanced twisted-pair, or optical fiber). In addition, the DAS installer may provide the active DAS components such as the headend equipment and remotes. However, the primary responsibility of the DAS installer is to install the system components, both passive and active, according to the design and then configure, optimize, and commission the system. Once the system has been commissioned, the installer will complete the installation by performing walk testing to verify the system is providing coverage at the proper signal levels as specified by the designer.

7.2.3 Designer Qualifications

DAS designers require some key skill sets, some in common with designers of other ICT systems and others unique to this design specialty. A DAS designer may also have project management responsibilities to make adjustments to the design during the construction and implementation phases. Therefore, a wide variety of experience and skills are required.

The basis for these skills is an understanding of radio frequency propagation and the related physics behind it as well as a knowledge of the active and passive parts from which a designer draws to craft solutions to a customer's need. In general, there is the ability and experience to use the tools of the trade, (e.g., spectrum analyzer, cable tester, testing and modeling software) as well as the ability to read, understand, and address the information that these tools make available to the designer.

7.2.3.1 Required Skills

- Strong knowledge of wireless theories and principles
- Strong knowledge of cabling infrastructure design
- 5+ years of experience in RF design or system performance, specifically with DAS experience
- Familiar with the different host system types (e.g., LTE, GSM, CDMA, land mobile radio) and their requirements
- Excellent oral and written communication skills
- Ability to use basic office applications, such as word processing, spreadsheets, and email
- Capable of reading planimetric and elevation architectural drawings from simple space plans to complete building mechanicals
- Good interpersonal skills

List continues on next page

- Willingness to embrace cross-functional team leadership responsibilities
- Strong knowledge of general structure construction materials and methods
- Project management skills to ensure deliverables are met on time
- Proficiency in using and understanding the MasterFormat system of specification organization
- Ability to help conduct integration testing and acceptance testing on new systems
- Familiar with environment simulation tools (e.g., ibWave Design, Atoll, etc.), their limitations, and how to validate and verify their utility

7.2.3.2 Preferred Skills

- 4-year electrical or electronics engineering degree from an accredited university program
- Five or more years participating on multi-disciplined cross-functional teams with overlapping responsibilities
- RCDD certification
- Ability to use software CAD and BIM tools

7.2.4 Installer and Service Personnel Qualifications

Installer and service personnel, being the hands-on people actually assembling the solution and calibrating the system under the guidance of a qualified integrator, have a somewhat easier path to proficiency than the designer. The difficulty and complexity in the selection and location of the appropriate components has, in theory, already been determined prior to their involvement. Their skills are consistent with that of other mechanics in other fields—a basic capability to work with their hands and tools. Their specific role does have the unique characteristics consistent with that of some other trades in that there can be direct performance impact on their systems based on the quality and consistency with which they exercise their trade.

7.2.4.1 Required

- Proficient with wireless theories and principles
- Strong knowledge of basic electrical and electronic principles
- Trained and certified by the DAS equipment manufacturer or working under the close supervision of a more senior technician with a valid manufacturer certification
- Ability to install, terminate, and test all types of cable (e.g., optical fiber, balanced twisted-pair, coaxial) used by a DAS
- Ability to install DAS antenna components, donor antennas, coverage antennas, couplers, splitters
- Thorough understanding of all safety requirements, including RF exposure, use of personal protective equipment, and above ground risk mitigation (e.g., climbing ladders, working on roof-tops)
- Able to safely use power tools
- Ability to read and understand all documentation, including CAD and BIM-produced drawings
- Good oral communication skills
- Good interpersonal skills
- Strong analytic and troubleshooting skills

7.2.4.2 Preferred

- High school diploma or equivalent
- 2-year college degree or a minimum of 4 years relevant experience
- BICSI® certified installer or technician
- Working knowledge of various types of RF test equipment, including an RF power meter and a spectrum analyzer
- Safe driving record with a valid driver's license

7.3 Design and Implementation Coordination

7.3.1 Overview

DAS designers, project managers and installers will interface with the customers and A/E firms regarding the overall distributed antenna system (DAS) project plan. The initial meetings with the customer will involve coordinating the scope of work (SOW), organizational breakdown structure (OBS), work breakdown structure (WBS), safety plan, quality plan, scheduling plan, budget plan, and communication plan. The designer will work with the owner and the A/E firms from the beginning and make recommendations on design improvements, construction technology, schedules, and budget as the project moves forward.

It is to be stressed that the best time to install a DAS is during the construction of a building. Installing a DAS after construction has been completed is typically more expensive, labor intensive, and disruptive to business operations than if the installation is performed while the walls and ceilings are unfinished.

7.3.2 Plan Documentation

7.3.2.1 Scope of Work

A scope of work (SOW) is based on the project requirements and design documentation such as a request for quote (RFQ), design drawings, customer specifications, or needs analysis. A good SOW provides a detailed summary of the requirements for the project and is a useful tool for tracking changes to the project scope. The SOW can also be used as a checklist to confirm completion of the project with the client and will assist in getting final acceptance for the system.

A good SOW contains the following elements:

- Customer needs
- Project objective
- Project size
- Project budget
- Project schedule
- Assumptions
- Deliverables
- Reference to design documentation

7.3.2.2 Organizational Breakdown Structure (OBS)

The organizational breakdown structure identifies the people and organizations needed to complete the SOW and describes their roles in the project's work breakdown structure (WBS).

7.3.2.3 Work Breakdown Structure (WBS)

A WBS is a categorized depiction of the work that must be accomplished to complete the project. The WBS must cover the elements of the project's end product or deliverables; they can be diagrammed as a tree structure or an outline and must list all required tasks in sufficient detail to ensure satisfactory project completion. The WBS should include:

- Initiating
- Planning
- Executing
- Monitoring and controlling
- Closing

7.3.2.4 Safety Plan

The project manager (PM) is the chief safety officer. Having a safety plan and an active safety program sends a good message to the customer and all team members. Safety is the area of greatest personal liability to the PM. Appoint a safety coordinator for the project; the safety coordinator will review the current safety plan and apply the plan to the project. All subcontractors should be required to have a safety plan. The safety coordinator should hold a safety meeting prior to the start of the project. The safety coordinator is typically a part-time position. It is a good idea to rotate the assignment among the team members.

Some areas that should be addressed by the safety plan are:

- RF exposure; proximity to functioning antennas
- First aid training
- First aid kits
- Emergency numbers
- Motor vehicle safety
- Work area protection
- Ladder safety
- Rooftop safety
- Working with optical fiber cable
 - Lasers
 - Glass shards
- Safety glasses
- Hard hats
- Hazardous materials
- Towers and masts
- Confined spaces
- Inclement weather
- Other specific hazards, procedures, and requirements of the work site (e.g., the site owner's safety plan)

7.3.2.5 Quality Plan

There are several stages a quality plan should address. The primary stages include the following:

- Conformance—focuses on physical quality (e.g., neatness, test results)
- Customer satisfaction—involves asking customers whether they are satisfied with the service they received
- Customer value—evaluates the relationship between cost and quality
- Customer/supplier model—benchmarks quality performance, relative to competition. (e.g., Six Sigma—this is a continuous effort to reduce the variations in output to achieve a zero defect level.) The steps in customer/supplier model processes are:
 - Define what the results need to be.
 - Measure the performance.
 - Analyze the results.
 - Implement changes to improve the product.
 - Control the performance.

A good quality plan must identify, in detail, the steps and procedures that will be followed to address each of the identified quality stages. By doing so, the customer will have confidence that the product and services being delivered are of the best possible quality.

7.3.2.6 Scheduling Plan

Project schedules are a critical piece of project documentation. A project schedule identifies all the steps and phases associated with a project, and it is used to help identify items on the critical path. It is also used to identify dependencies to other phases, work, and materials. The project schedule must be constantly maintained. This helps to identify and document reasons for delays and can help to avoid cost overruns or fines especially when liquidated damages are included in a project contract.

Project schedules can take several forms. Some of the most popular are:

- PERT diagrams—used to calculate the start and finish date for each task
- Gantt chart—shows the duration of the activity by using a bar chart from start date to finish date
- Milestone chart—shows the start and finish date on a calendar graph
- Calendar chart—shows the schedule using a simple calendar layout

7.3.2.7 Estimates and Budget Plans

Developing the schedule and budget requires estimates of duration and cost.

There are several methods of developing an estimate:

- Analogy—Analogy estimates are based on the time/costs it took to perform similar work in the past. The better the current costs are tracked, the more accurate the future estimates will be. Analogy estimates must be adjusted for current job conditions (e.g., building size, type of construction).
- Parametric—Parametric estimates are based on dollar/foot, dollar/drop, time, and costs. A parametric estimate is handy for developing a rough-order of magnitude (ROM) estimate and is used to check an analogy estimate.
- Engineering—An engineering estimate, developed by the customer, will be put out to bid later.
- Subcontractor bids—Subcontractor bids are used to develop cost and time estimates for work that requires special tools or skills. The subcontractor will provide the customer a price not to exceed a specified amount. This provides an option to use the subcontractor to perform the work.
- PERT—The same program that developed the PERT chart develops PERT estimates. The program looks at the potential for overruns and underruns of time and cost and then develops a weighted average estimate. PERT uses three estimates for each activity:
 - Optimistic estimate—Lowest projected cost or fastest time
 - Most likely estimate—Average projected cost or time
 - Pessimistic estimate—Highest projected cost or slowest time

Budget plans are used to identify funding allocated for the various stages of a project. Budgets are developed based on estimates provided by designers or integrators and take into account the design requirements, equipment needs, and expected conditions for the project. The budget needs to be maintained throughout the duration of the project. This is very important because it shows whether the project cost is within expectations or is about to exceed budget where any overruns need to be justified and documented.

7.3.2.8 Communication Plan

Communication plans are used to identify the procedures that should be followed regarding general day-to-day communications as well as an escalation process for critical items and incidents. At a minimum, the communication plan should identify key points of contact and their respective contact information. The plan should also address the various ways the team will communicate status, change orders, and completion reports. The methods may include e-mail, shared drives/folders, whiteboards, meetings, conference calls, and Web-based portals.

7.3.2.9 Project Management

All projects require project management. A wireless PM will sequence the work and ensure that the job stays under control. As projects become larger and more complex, there is more risk. As projects become larger or new team members become involved in the work, project management tools provide great benefits. All projects benefit from the development of a complete project plan. Communication between team members while building the plan is often more important than the actual document. Effective project management makes use of these various planning and documentation tools and provides for thorough project coordination and clean system implementation. These techniques help ICT projects meet the following objectives:

- On time completion
- Staying within the budget
- Compliance with the specifications
- Meeting or exceeding customer expectation

7.3.3 Coordination of Specific Parties

7.3.3.1 Host/Donor

The architecture selected for distributing the services within the facility must be matched to the performance specifications of the system participants. The DAS design process may include “co-engineering” efforts between the equipment manufacturer and the venue’s solution designer to ensure optimal performance and guarantee host compatibility. In a host-neutral installation, multiple coordination efforts may be necessary, including a detailed review of each performance specification the DAS will support.

7.3.3.2 Cellular Service Providers

Because licensed spectrum cellular service providers are regulated by national and international agencies, systems that radiate into bands of licensed spectrum must do so only after receiving permission from the service providers who are gatekeepers for the spectrum they control. These entities have coordination departments that act as liaisons for the connection of private DAS equipment to the public cellular network.

The wireless designer should consider this requirement and identify those responsible for ensuring that the appropriate approvals have been secured. Approval from the service providers normally is based on a value proposition that evaluates their investment, the subscribers in need of service, and the impact on network statistical performance. Even when service provider investment is not required, the quality of the system deployed must still meet the performance objectives to be accepted as part of the network.

Under favorable circumstances, WSPs will often provide the installation of the infrastructure from the remote units to the headend and from the headend to the cell site or RF source locations. However, coordination between the wireless designer or DAS installer and the participating service providers will be required in all cases. If providing service from multiple service providers, each service provider will likely require separate RF source feeds to the DAS. Once service is provided to the headend equipment, traffic from all service providers will run concurrently over the DAS.

7.3.3.3 Antenna Coordination

Donor antenna placements on the roof level are considered structural and may impact numerous factors relating to roof stability. Typical areas affected are as follows:

- Wind loading and seismic structural performance
- FCC required painting or lighting because of elevated structures
- Penetrations required for coaxial transmission cables and antenna structure installation
- Grounding and surge arrest/protection system requirements
- Roof membrane warranties as a result of riser penetration
- Structural mounting attachment method used
- Antenna and RF coupling device placement, including physical mounting method
- Collocation impacts with other RF-based transceiver equipment (e.g., land mobile radio, RF repeaters, WAPs, other RF devices)

It is important that the DAS designer knows which of the items above is applicable to the design and each must be coordinated with the appropriate authority prior to installation.

7.3.3.4 Coordination with Site Owner(s)

Coordination with the site owner is a fundamental requirement for all DASs. The site owner coordination will be specific to the real estate involved in the DAS design. The primary items to be discussed with, and agreed to by, the owner are:

- Identification of a secure space for the DAS backend equipment installation
- Whether and where a rooftop donor antenna is installed; whether and where the membrane will be penetrated for cables and antenna supports
- Existing and surrounding RF sources and their location
- Owner requirements for the DAS (e.g., radio systems for supporting site security and maintenance personnel)
- Existing cable pathways
- Potential new pathways

List continues on the next page

- Requirements and sources for power, grounding, air conditioning, fire protection
- Owner policies and procedures concerning personal safety, access to secure areas, contractor work permits, contractor work hours, noise mitigation requirements
- Staging area location and secure storage of contractor tools, equipment, and materials
- Aesthetic requirements (e.g., low visibility antennas, color coordination)
- Exclusion zone
- Intrusion plan

7.4 Site Survey and Needs Analysis

7.4.1 Site Survey

7.4.1.1 Overview

A site survey should be conducted before designing and implementing a DAS to identify issues that need to be mitigated.

7.4.1.2 Survey Topics

The following items should be noted and recorded to aid in planning and designing the DAS:

- Building configurations
 - Propagation morphologies present
 - Single or multistory
 - Single or multiple building campuses
 - Single tenant or multi-tenant
- System orientation
 - Above ground
 - Below ground
 - Vertical or horizontal orientation (tunnel or high-rise)
- Composition of construction materials
 - Concrete, masonry, brick, or stone outer walls
 - Wood floors, studs, or roof
 - Drywall, plaster, metal, or masonry inner walls
 - Metal studs, floors, or roof
- Windows
 - Number and size of windows per floor
 - Architectural tinted or metallic-coated windows
 - Ultraviolet film
 - Low-E windows
 - Other coatings
- Mapping of existing coverage
 - Current number of RF-emitting devices and frequency range of each
 - Location of existing RF antennas
 - Location of radiating cable
- Mapping of existing nulls, holes, and exclusion zones:
 - No coverage required
 - No coverage exists
 - Interfering frequencies block intended ones from reaching receiver
 - Building materials are impossible to penetrate with RF (e.g., lead-lined walls, thick concrete, bank vaults)
- Determining the propagation characteristics of all identified morphologies and penetration losses through common wall types

7.4.1.3 Completing the RF Survey

The RF performance characteristics of the owner's facility must be determined prior to initiation of the detailed facility DAS design process. Retrofit facilities can be surveyed immediately for site specific requirements and RF propagation performance in all frequency bands of interest.

Interference sources should be identified, localized to source, and a mitigation plan established.

Highly shielded portions of the existing facility (e.g., MRI, X-ray, Faraday cage protected rooms) must be identified, and a strategy for increasing RF performance in and around these locations must be addressed. Alternatively, these or other areas may be owner-designated as "RF free zones" within which RF signals must be reduced to undetectable levels. In this case, a plan for eliminating signal propagation from the DAS into these areas is required.

Thematic maps showing energy gradients throughout the venue must be created so as to indicate relative RF field strength for each frequency band of interest.

Space planning surveys must be completed that identify where all active and passive components will be installed.

New construction facilities may have a preliminary design completed for the purpose of budgetary projections. However, all final radiating device locations should not be determined until the infrastructure is in place and an RF survey is completed, that is, until after:

- Structural elements impacting RF absorption, shielding, and reflectivity, such as walls and ceiling, are in place
- Window tint treatments (as a result of their shielding characteristics) have been completed.

7.4.1.4 Tools Used for RF Survey Completion

The RF spectrum analyzer is the most accurate survey tool available and will provide detailed and discrete RF signal levels in each frequency band of interest.

Software-based survey tools are becoming more useful for projecting propagation analysis and creating graphical analysis, such as heat maps based on actual RF spectrum field measurement data input by survey personnel.

RF communication service monitors and RF field strength meters may also be used to determine signal coverage within an area.

Handheld RF transceivers and cell phones may be used to determine signal level in their specific channel; however, this would be considered a basic survey and should not be used as the survey basis for design.

RF signal sources and carrier generators may be used to simulate the presence of an RF signal in order to model a facility propagation study and survey.

The objective of the data collection is to determine path loss, diffraction, and material penetration coefficients. In addition, sufficient data shall be collected for all morphologies to determine margins for fading and confidence.

See also Appendix B, *Tools Used for Testing Coaxial Transmission Lines and Antennas*.

7.4.2 Needs Analysis

7.4.2.1 Overview

In conjunction with a site survey, a needs analysis provides additional information that may impact the design of a DAS.

7.4.2.2 Types of Service

Determine the types of services that are required in the structure. This can include cellular services, voice private branch exchange (PBX), paging services, unlicensed or licensed radios, and data and video services. Emergency response (e.g., E911) location requirements within the building or structure may be influenced by a DAS solution. The initial approach is to identify the requirements for each service type, how they will be used, and who will use them.

Basic steps for a needs analysis are described below:

- 1) In existing or new construction, determine the different wireless services in use and the new services to be deployed. Determine what RF signals will be transmitted over the DAS and their source frequencies. Determine whether the system will be fed directly from a cellular base station or other radio signal generator or fed from an off-air amplifier.
- 2) Identify any non-participants whose radio resources may impact or be impacted by the deployment.
- 3) Obtain existing maps of the area and detailed drawings of the building, tunnel, or structure to be surveyed and conduct a walk-through. In cases of preconstruction of a facility, a desktop survey can be performed using the drawings to identify intended coverage areas and the structure's design and layout. Locate ERs, TRs, and cabling pathways within the facility.
- 4) Perform a site inspection and perform an RF audit of the facility to determine existing RF signals. Identify their frequency and relative strength using a spectrum analyzer or other suitable measuring device. Record these for use as a function of their location in the design process.
- 5) Work with the WSP to determine frequency bands to be supported, how many radio channels will be supported, the type of radio signal modulation, and minimum coverage requirements. Some WSPs may have certain band-pass requirements and require different degrees of isolation from adjacent WSP signals.
- 6) Document the key findings of the needs analysis for use in the DAS design.

7.4.2.3 System Reliability

Determine the reliability level required for the system or how much downtime can be tolerated when a component fails. System redundancy and other features may need to be designed into the system to ensure that the reliability stays above the tolerable level.

The reliability level often is determined by the services on the system or by the AHJ. For example, local regulations may require that a DAS serving public safety systems has a certain high reliability level. Another example is a site with no backup communication lines in the event of a PBX failure. Such a site would depend on using cell phones to contact emergency responders during a PBX outage, thereby requiring a higher level DAS for reliability.

Reliability is often given as an availability percentage and is sometimes quoted as a certain number of "nines." For example, a DAS provider may state that its system has "five nines" availability. Table 7-1 provides different availability rates as expression of time.

Table 7-1 Availability as an Expression of Time

<i>Availability %</i>	<i>Downtime per year</i>	<i>Downtime per 30 days</i>	<i>Downtime per week</i>
90% ("one nine")	36.5 days	72 hours	16.8 hours
95%	18.25 days	36 hours	8.4 hours
98%	7.30 days	14.4 hours	3.36 hours
99% ("two nines")	3.65 days	7.20 hours	1.68 hours
99.5%	1.83 days	3.60 hours	50.4 minutes
99.9% ("three nines")	8.76 hours	43.8 minutes	10.1 minutes
99.99% ("four nines")	52.56 minutes	4.32 minutes	1.01 minutes
99.999% ("five nines")	5.26 minutes	25.9 seconds	6.05 seconds

NOTE: Assumes a 365-day year.

Note that the downtimes expressed in Table 7-1 are averages over the expected lifetime of the system. For example, a system designed and installed to an availability of 99.999% may work perfectly for several years before failing for 15-20 minutes or more, depending on the response time of the maintenance personnel.

7.4.3 Building/Structure Construction

7.4.3.1 Overview

How buildings and structures are constructed, of what they are constructed, and the materials used to partition shared and dedicated facilities are among the issues that DAS designers and installers should be prepared to consider.

7.4.3.2 Building and Structural Elements

The following is a listing of what might be found in existing structures and those currently being designed that could have an adverse effect on RF signal propagation:

- Skeleton and decking:
 - Steel columns and beams with corrugated steel decking topped with concrete
 - Poured concrete columns, beams, and decking; all containing steel rebar
 - Precast concrete columns, beams, and decking; all containing rebar and/or post tension reinforcing cables
 - Poured concrete shear walls
- Skin:
 - Metal (e.g., aluminum, steel, etc.)
 - Concrete and/or masonry, containing rebar
 - Precast concrete wall sections and decking; all containing rebar and/or post tension reinforcing cables
 - Glass. Some glass and their treatments can adversely affect RF signal propagation. (e.g., low-E glass or low-E glass coatings)
 - Plastic
- Mechanical, Electrical, Plumbing Systems (MEP Systems):
 - HVAC ducts, air treatment and air handling equipment, plus control cabling and their conduits
 - Electrical, communication, fire alarm, access control, plus security cabling and their conduits
 - Plumbing piping for fire suppression systems, potable water, sanitary sewer, rain water drainage, and HVAC chilled water/steam
- Elevators:
 - Structural components and cabs
 - Electrical, fire alarm, and communication pathways, wiring/cabling, and components
 - Cab and shaft ventilation equipment
- Interior walls/partitions:
 - Metal wall studs
 - Fire-rated walls (may have fire-rated doors in them)
 - Lead-lined walls (e.g., in a healthcare facility)
 - Special wall linings in secure communication facilities
- Interior environments:
 - Open environment—An area where no physical obstructions exist between DAS antennas and wireless devices (e.g., conference room, atrium)
 - Partially open environment—An area containing low-severity obstructions (e.g., cubicle partitions) separating DAS antennas from wireless devices in an open office environment
 - Closed environment—An area containing moderate-severity obstructions (e.g., plaster or brick walls) separating DAS antennas from wireless devices
 - Obstructed environment—An area containing high-severity obstructions (e.g., metal reinforced concrete walls, elevator shafts, or large metal surfaces) separating DAS antennas from wireless devices

7.5 Cabling Topology

Active DASs and the active equipment (e.g., MCU, BDA) in passive DASs supported by the structured cabling infrastructure should use a star or hierarchical star topology, as shown in Figure 7-1, for required backbone and horizontal cabling. Non-star based topologies may be used to support a DAS in addition to a star topology. For example, a passive DAS may be configured in a tree topology. Examples of non-star topologies that are commonly used within a DAS are shown in Figure 7-2.

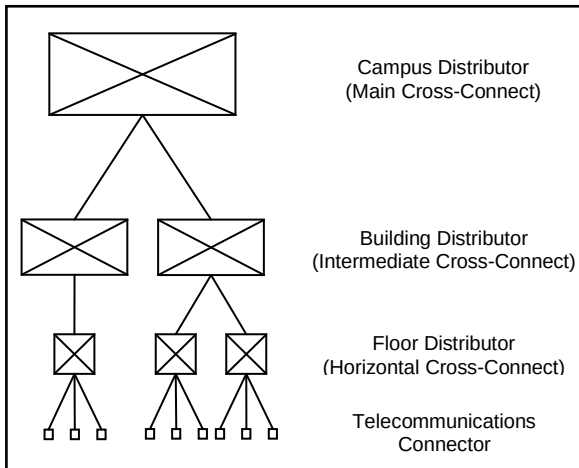


Figure 7-1
Hierarchical Star Topology

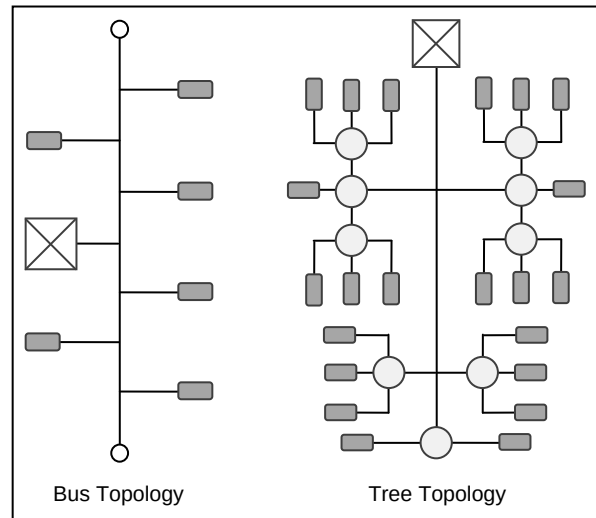


Figure 7-2
Examples of Non-star Topologies

7.6 Pathways and Spaces

7.6.1 Overview

Depending on the type of DAS to be deployed and site requirements, a DAS may be deployed wholly or partially outside of traditionally defined telecommunication pathways and spaces.

7.6.2 Spaces

7.6.2.1 General Requirements

Telecommunications spaces (e.g., equipment room, telecommunications room) containing DAS equipment shall meet the requirements of applicable standards (e.g., TIA-569-C, ISO/IEC 14763-2, EN 50174-2).

7.6.2.2 Space for Wireless Service Provider Equipment

7.6.2.2.1 Overview

WSPs provide RF sources for delivering wireless services, such as cellular and PCS, to the DAS. WSP equipment is the actual radio base station, micro-cells, and off-air or fiber-optic based donor systems that are used to provide such WSP services.

7.6.2.2.2 Requirements

The site owner shall provide sufficient space, cooling, and electrical power within their facility for the planned WSP equipment and all components of the DAS.

7.6.2.2.3 Examples

For buildings where the ground floor footprint is less than 28,000 m² (300,000 ft²) and the total of all floors is less than 93,000 m² (1,000,000 ft²), the WSP equipment is likely to be configured as a single “sector”. Space and other requirements for a WSP vary as illustrated by four examples in Table 7-2. Table 7-2 also provides information on other systems that may use a DAS and need to be accommodated in space planning.

Table 7-2 Example Wireless Service Provider Equipment Information

<i>WSP</i>	<i>Element</i>	<i>Physical Space (H) × (W) × (D)</i>	<i>Heat Dissipation</i>	<i>110 V_{AC} Dedicated Circuits (Qty × Amps)</i>
Internal Wireless	1 Rack	2134 × 482 × 610 mm 84 × 19 × 24 in	1583 kJ/hr 1,500 BTU/hr	1 × 4
Service Provider 1	1 Cabinet	2134 × 914 × 914 mm 84 × 36 × 36 in	39,565 kJ/hr 37,500 BTU/hr	2 × 20 1 × 40 1 × 20
	Battery Backup	2134 × 914 × 914 mm 84 × 36 × 36 in		
	2 Racks	2134 × 482 × 610 mm 84 × 19 × 24 in		
Service Provider 2	2 Cabinets	2134 × 914 × 914 mm 84 × 36 × 36 in	47,478 kJ/hr 45,000 BTU/hr	3 × 20 1 × 60
	Battery Backup	2134 × 914 × 914 mm 84 × 36 × 36 in		
Service Provider 3	1 Cabinet	2134 × 914 × 914 mm 84 × 36 × 36 in	31,652 kJ/hr 30,000 BTU/hr	2 × 20 1 × 40
	Battery Backup	2134 × 914 × 914 mm 84 × 36 × 36 in		
	1 Rack	2134 × 482 × 610 mm 84 × 19 × 24 in		
Service Provider 4	2 Cabinets	2134 × 914 × 914 mm 84 × 36 × 36 in	15,826 kJ/hr 15,000 BTU/hr	2 × 20
	Battery Backup	1524 × 1524 × 914 mm 60 × 60 × 36 in		
Paging	1 Half Rack	1067 × 482 × 610 mm 42 × 19 × 24 in	791 kJ/hr 750 BTU/hr	1 × 2
Public Safety	1 Half Rack	1067 × 482 × 610 mm 42 × 19 × 24 in	396 kJ/hr 375 BTU/hr	1 × 1
UHF Two-way	1 Rack	2134 × 482 × 610 mm 84 × 19 × 24 in	396 kJ/hr 375 BTU/hr	1 × 1
	Totals		137,687 kJ/hr 130,500 BTU/hr	348 Amps

Figure 7-3 illustrates a typical ER floor plan to accommodate the scenario using all the information found in Table 7-2.

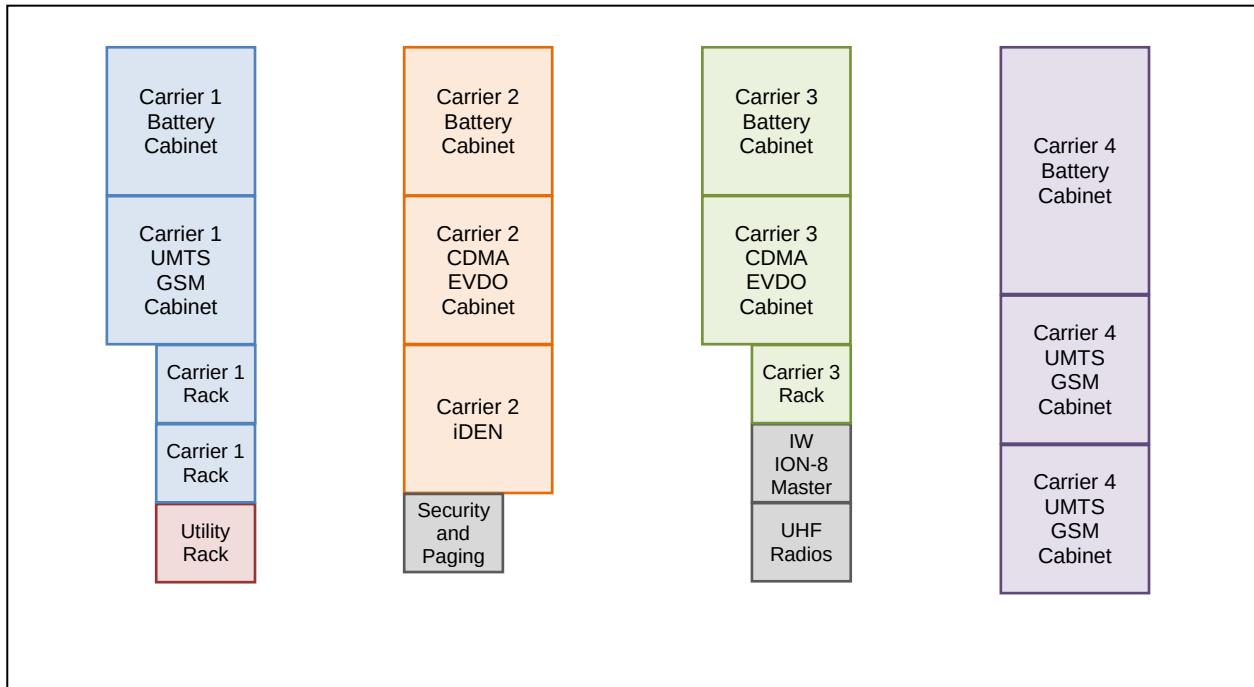


Figure 7-3
Example Floor Plan for MIMO Antenna Operations

If the site owner chooses or if the WSPs require, the DAS headend can be configured for a MIMO antenna operation. The impact would be the addition of a second rack for the DAS headend. No additional impact is expected with regards to the WSP equipment.

If the facility is large enough or if the WSPs estimate their capacity needs to be higher than typical, the WSP equipment is likely to use a "3 sector" configuration. Assuming that all 4 WSPs make the decision to increase to a "3 sector" configuration, the impact to space, cooling, and electrical power will be approximately 150%.

Figure 7-4 illustrates a typical ER floor plan to accommodate the 3 "sector" scenario.

7.6.2.3 Additional Information

Sizing requirements vary by manufacturer and are unique to each system.

The MCU can be located in the main equipment room (ER), telecommunications room (TR), or penthouse near the roof. This is best determined during the site survey phase of a DAS implementation. The wireless designer should consult the manufacturer's installation guide to determine the space, electrical, and environmental requirements for the installation. Installation methods may include wall-, rack-, or cabinet-mounted configurations.

The backend equipment is commonly located in a TR. The wireless designer should consult the manufacturer's installation guide to determine the required space for installation. Installation spaces may include wall- or rack-mounted configurations.

Designs need to allocate enough space for BDAs, fiber panel and coax distribution fields and dedicated power sources.

When designing a DAS for a WSP, the designer should check applicable WSP standards for racks, cabling and approved products; as well as installation and testing practices.

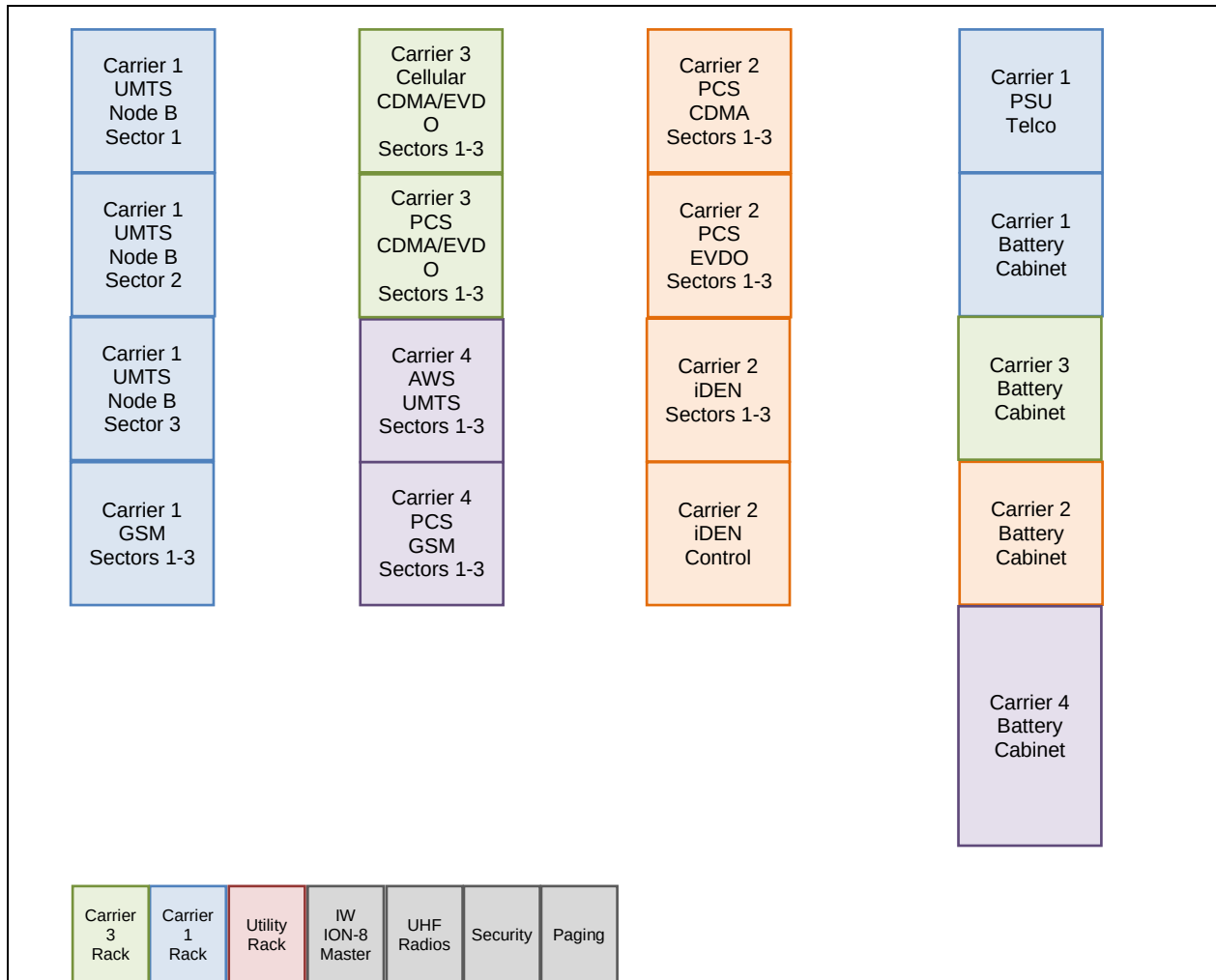


Figure 7-4
Example Floor Plan for a Three Sector DAS

7.6.3 Pathways

7.6.3.1 Overview

Typical DAS cabling pathways include the following if the client and their property manager allow that cabling to share the IT cabling pathways:

- Cable trays
- Conduits
- Rated innerducts
- Non-continuous supports (e.g., J-hooks, cable slings)

If the client or the property manager will not allow DAS cabling to share the IT cabling pathways, the installation of separate pathways may be required.

7.6.3.2 Requirements

Appropriately rated sleeves and firestop systems through fire walls and smoke walls will be required by the AHJ.

Radiating coaxial cables shall not be over 3 m (10 ft) in length within metallic conduit.

7.6.3.3 Recommendations

Conduit criteria should be as given in the BICSI *Telecommunications Distribution Methods Manual* (TDMM) and as specified by the cable manufacturer. Normally, risers to the roof are 100 mm (4 in) unless the local code specifies otherwise. Coaxial cable risers do not have to be in conduit if they are adequately protected by the pathway.

Designer should verify riser conduit size and coax minimum bend radius when specifying riser pathway. If manufacturer bend radius specifications are not available, as a general rule, conduit should be sized at four times the outside diameter on the coax, due to the cable's limited bend radius.

RF system cabling should be installed in dedicated conduit, innerduct, or other raceway for the following reasons:

- To isolate the cabling from other systems, reducing the risk on cross-connecting DAS cabling into other ICT systems and to ease identification and administration
- To protect the cabling from physical damage through impact, fire and other hazards
- To provide proper support and minimize bending. Optical fiber cable is much more flexible than coaxial and easier to install. Even so, it is best to install the cable with a minimum number bends.

7.6.3.4 Special Pathways and Spaces Considerations

7.6.3.4.1 Requirements

The AHJ shall be consulted before designing systems within areas which have additional requirements because of codes, environmental factors, intended use, or other factors not listed here. Typical areas with additional requirements include:

- *Seismic requirements*—Codes, regulations and the AHJ may have specific operational parameters that designs must address and may require or prohibit the use of specific installation methods.
- *Hazardous (Classified) environments*—Depending on the classification of the environment, additional measures, such as conduit seal or explosion proof apparatus may be required. Review of codes, regulations and AHJ requirements shall be accomplished to satisfy local requirements. See Appendix C and Appendix D for additional information.
- *Space*—New construction pathways shall be coordinated with other trades. Building information modeling (BIM) should be used for this purpose.
- *Pathway Survivability* – Public safety radio and code required NEMA-4 enclosures, 2 hour rated pathways, redundant backup power for headend and BDA remote DAS units. Remote monitoring of DAS system alarms. (e.g., NFPA 72)
- *Healthcare facilities*—Compliance with codes, standards and regulations (e.g., NFPA 99, Americans with Disabilities Act) pertaining to healthcare facilities, patient and information privacy, and public access is required.
- *Corrosion/corrosive environments*—All metallic cabling pathways (e.g., conduits, hangers and supports) shall contain corrosion protection or be resistant to corrosion when used as pathways installed in corrosive atmospheres.
- *Wet and damp locations*—When metallic cabling pathways are installed in outdoor and indoor locations that may be considered to be wet or damp, appropriate cabling and metallic cabling pathway types shall be selected for use in these environments.

7.6.3.4.2 Recommendations

Additional special pathway and space considerations include:

- Environmental
 - *EM*—Electromagnetic interference can disrupt signaling. Shielded cabling or metallic pathways may reduce the effects of EMI.
- Architectural
 - *Existing conditions*—Surface mounted raceway, other compliant cabling pathways or other accommodations that are used when installing cabling in existing structures with limited or no existing cabling pathways.
- Building Function
 - *Security / sensitive information*—Physical protection of pathways and spaces should be considered to deter or prevent the systems from being accessed or compromised by unauthorized personnel.
 - *Places of assembly*—In theaters, stadiums, and conventions centers, because of the presence of large groups of people, the AHJ may have design or installation method restrictions so that systems do not jeopardize the safety of occupants.

7.6.3.4.3 Secure Areas

Governments and military organizations handle sensitive and classified material over secure networks, which are located in areas most commonly referred to as secure areas. At times, these organizations may need to route telecommunications cabling outside of these secure areas. When cabling containing sensitive or classified information is routed outside of a secure area, the cabling is required to be protected from unauthorized access. Although these systems of distribution are known by many names, they are most commonly referred to as protected distribution systems (PDSs).

PDSs protect sensitive cabling from unauthorized access outside of secure areas by enclosing the cabling in a sealed raceway or conduit system. Generally, these raceways or conduit are located in common areas where they can be inspected on a regular basis for unauthorized access. Routing a PDS through a locked area or a little used area is not recommended.

Government and military organizations will have their own set of guidelines for how they construct PDSs. The designer should check with the organization requiring the system for their particular guidelines.

7.7 Cabling

7.7.1 General Requirements

Determine if the space above ceilings in which DAS cabling needs to be placed is a plenum or non-plenum environment. Then specify the appropriate rated cabling for the project.

Armored or metallic reinforced cable shall be bonded (earthed) per applicable standards (e.g., NFPA 70, TIA-607-B, IEC 60364).

When the use of metallic conduit or raceway is impractical, the cable itself must be rated (e.g., Listed by an NRTL) for the environment.

Rated cables may be required per applicable codes and standards for specific applications (e.g., public emergency alarms).

7.7.2 Coaxial Cable

7.7.2.1 Requirements

All coaxial cable used for DASs shall be 50-ohm type, not 75-ohm. The connectors shall match the antenna on one end and the equipment on the other. For the donor antenna, this is typically N-male type connectors. For indoor distribution antennas, it is either an N-male or SMA-male type.

Coaxial cable shall be installed in conformance with applicable standards, (e.g., NFPA 70, IEC 60364).

7.7.2.2 Recommendations

Cables used should meet the following criteria for the specific site:

- Power rating
- Guaranteed return loss or VSWR
- Physical diameter
- Bending radius
- Attenuation (dB/100 m [328 ft])
- Differential attenuation (slope) across frequency range
- Shielding performance
- Connector types

For indoor installations, NEC type CATVP (plenum rated), 13 mm (0.50 in) diameter is recommended in North America. Outside of North America, low smoke, zero halogen (LSZH) cable should be used. 50 ohm, 13 mm (0.5 in) diameter coaxial cable is typically very stiff. For short runs (e.g., 3 m [10 ft] or less), 6.3 mm (0.25 in) diameter coaxial cable may be used between the remote unit and the antenna. Consult the cable manufacturer's specifications for appropriate minimum bend radius.

For outdoor installations, a minimum 22 mm (0.875 in) low loss cable rated for outdoor installations should be used. If the distance to the antenna is short (less than 9 m [30 ft]), 13 mm (0.50 in) diameter cable may be used. These cables are typically difficult to access for replacement or expansion, o cables suitable for outside application, with a corrugated solid copper outer shield should be used for all cables going to donor antennas. Solid copper shielded coax should transition to a short (about 1 m [3 ft]) high quality flexible jumper when connecting to DAS components and antennas. This will maximize flexibility for future expansion of the system.

When selecting connectors, the following characteristics should be used in the determination:

- Frequency range
- Power
- Return loss (RL)
- Passive intermodulation (PIM)
- Environment
- Cable to be used
- Equipment connections and specifications

7.7.3 Balanced Twisted-Pair Cable

7.7.3.1 Requirements

Balanced twisted-pair cabling shall meet the requirements of applicable standards (e.g., TIA 568-C.2, ISO 11801, EN 50173-1).

Modular connectors used shall comply with applicable standards (e.g., TIA-568-C.2, ISO 11801, EN 50173-1), be compatible with the cable used, and be suitable for the termination of the conductor (i.e., solid or stranded wire).

Cables run between buildings, in tunnels, or other exposed areas shall be rated for the environment.

7.7.3.2 Recommendations

Category 6A/Class E_A or higher performance cabling should be used when transmitting radio signals.

Shielded cabling should be used in areas where there is an increased risk of radio frequency or electromagnetic interference.

7.7.4 Optical Fiber Cable

7.7.4.1 Requirements

Optical fiber cables used shall meet the requirements of applicable standards (e.g., TIA-568-C.3, ISO 11801, EN 50173-1).

Angle-polished connectors (APC) shall not be mated with flat polish connectors (PC), super polish connectors (SPC), or ultra-polish connectors (UPC) as it this may damage the fibers and connectors.

Optical fiber jumpers shall be used between the end of the permanent optical fiber cable and the RF equipment. This reduces the possibility of damaging the ends of the permanent cable.

Cables run between buildings, in tunnels, or other exposed areas shall be rated for the environment.

7.7.4.2 Recommendations

Armored or metallic reinforced optical fiber cables may require a larger bend radius than conventional tight buffer indoor optical fiber cable. Consult the cable manufacturer's specifications for appropriate minimum bend radius.

Multimode optical fiber cables should be OM3 or OM4, which typically have aqua jackets. Single-mode optical fiber cables are OS1 or OS2, which typically have yellow jackets.

When choosing fiber types, consideration should be given to distance, bandwidth, and complexity. Single mode fiber can support longer distances, and higher power laser transmitters. Multimode cable often meets the needs of data systems over standard indoor distances [≤ 100 m (328 ft)] and may be adequate for RF systems of short runs, though the distance restriction can limit the usefulness and future expansion of a system.

For indoor installations in North America, NEC type ONFP (plenum rated) cable is recommended. Outside of North America, low smoke, zero halogen (LSZH) cable should be used.

Typically, a fiber cable of at least four, and often six, strands are run to each remote hub. Two strands are used immediately, and the rest are spare.

Digital systems typically use ultra-polish connectors (UPCs) while analog RF systems use angled polish connectors (APCs) to reduce the reflections back to the laser transmitter. Reflections can reduce efficiency and even cause damage in extreme cases. Special training and tools may be required to properly attach and test APC connectors.

Some DAS equipment manufacturers have specific requirements for connector type and splicing methodology that must be met to comply with system warranty requirements.

7.8 Wireless Configuration

7.8.1 Signal Source and Site Orientation

In planning the deployment of a DAS, the wireless designer should consider the technical aspects of the installation. These include the RF signal source and various site orientation considerations. The RF signal source should be placed where it will best reach the intended coverage area without interference from other RF signals present. Conducting RF measurements will identify existing signals and their frequency and strength.

7.8.1.1 Radio Frequency (RF) Measurements

7.8.1.1.1 Introduction

An on-site survey of the radio environment (site survey or RF audit) is necessary to the wireless designer and is especially important if the goal is augmentation of existing coverage. During a site survey, benchmarking is done to document the existing RF environment within the coverage objective, concurrently continuous wave (CW) testing is performed to characterize the propagation models used throughout the objective.

7.8.1.1.2 Benchmarking

The following items should be benchmarked:

- Macro network cellular signals
- Public safety frequency
- WLAN APs
- Television (TV) towers
- Radio towers/repeaters/paging systems
- Medical equipment (e.g., X ray, magnetic resonance imaging [MRI], computed tomography [CT], radio frequency identification [RFID])

7.8.1.1.3 Continuous Wave (CW) Testing

The propagation and path loss of radio signals in the target environment can be sampled using portable transmitters to provide continuous test signals. Signals can be measured using simple radio power meters or examined with more sophisticated receivers that demodulate and decode actual broadcasts and reveal more detailed characteristics specific to an air interface standard. The use of broadband spectrum analyzers makes it easier to detect and characterize spurious signals, intermodulation products, and noise sources.

If a site survey is feasible prior to design, the resulting information can help the wireless designer set expectations of RF propagation and path loss. If the goal of the design is to fill in where existing coverage is weak, a site survey is essential to define the boundaries of the problem. The site survey also allows the wireless designer to assess and quantify interference and noise sources.

Radio propagation simulation software often is used to design wireless networks in buildings, tunnels, and other structures. CW surveys can be used to tune the behavior of indoor RF propagation models, calibrate wall losses, and assess fading and other margins. Model calibration is the process by which a set of data is synthesized into a propagation model of the environment with the lowest possible standard deviation and zero mean. When the model built from a set of data collected in one location generates a zero mean and low standard deviation when examined against a data set collected in a different location but of the same morphology, the model is said to be validated. Nominal data collections confirming acceptability of the model under other circumstances is verification. However, pre-design site surveys often are not feasible because of financial or time constraints. Wireless designers can NOT rely on modern software tools to provide high-quality simulation results without site survey input.

7.8.1.2 Existing Structures

Once the RF measurements have been conducted, the wireless designer needs to identify how the DAS signals will behave when they are propagated in the existing structure. Testing is one method to determine how and where the antennas should be deployed.

If the models created cannot keep up with frequently changing morphological conditions as indicated by the standard deviations between measurements and predictions being greater than 8 dB, then it may be beneficial to test the antenna location for its ability to deliver the coverage intended. This type of testing can be performed only in existing structures. This testing consists of placing DAS transmitters in various sample locations that will be expected to serve intended coverage areas. Measurements then should be taken to determine the specific antenna or radiating cable location in the final design.

The primary means of planning a DAS is to employ indoor RF coverage modeling tools to estimate signal propagation. These tools are commercially available and aid in validating hypothetical designs. Modeling tools typically create three-dimensional simulations of planned structures and calculate various scenarios based on design consideration inputs in which simulated results can be achieved. The accuracy of the results varies depending on the inputs into the model, but results can precisely predict the expected coverage of a DAS.

7.8.1.3 Planned Structures

While testing RF propagation is feasible in an existing structure, it is not feasible in an incomplete structure. When only architectural drawings exist, different testing methods can and should be used. Similar to an existing structure, the wireless designer may employ indoor RF coverage modeling tools.

7.8.1.4 Post-Installation Verification

After a DAS has been installed, a final site survey for verification and validation is an important step for quality control. During the final site survey, the signal quality provided by the installed system is assessed and later compared with the anticipated signal quality of the design. A record drawing survey also provides a point of reference for future troubleshooting efforts.

7.8.2 Antenna

7.8.2.1 Antenna Selection

Antenna selection should be based on the type of radiation pattern, frequency, and signal strength needed to meet the coverage area requirements. The type of antenna may also be affected by the location where the antenna will be installed (e.g., roof-top, ceiling, along a wall, in a corner).

7.8.2.2 Environmental Conditions

As environmental factors, such as chandeliers can generate passive intermodulation effects, antenna locations need to be free of such conditions. Radiation power, found in hospitals and some manufacturing facilities, will also impact the decision for discrete antennas or radiating cable. Chemicals or other substances in the DAS environment should be identified with any potential issues addressed.

7.8.2.3 Location

The location of the antenna should be based on the area needing coverage, elevation, and away from structures that would block the RF signal. Perform a physical site inspection for line of sight (LoS) and possible rooftop space management issues. This includes optimizing space and lease revenue potential while minimizing conflicts because of zoning, installation and construction, and interference. Other location considerations include the aesthetics of the environment where the antennas will be installed and the location of the users they are intended to serve. Identifying traffic patterns of personnel who will use the DAS is vital to proper antenna location.

7.8.2.4 Safety

The safety of personnel needs to be considered, especially for rooftop antennas. The antennas must be located so as to minimize RF hazard risk to workers. One method is to paint a line on the roof around the antenna at a safe distance to create a buffer zone and place signage warning workers not to enter the zone without authorization.

Applicable regulations (e.g., FCC 47 CFR 1.1310) and requirements of the AHJ shall be met.

7.8.2.5 Security

Security, theft, and vandalism concerns should be considered. Antenna, equipment, and cabling infrastructure should be installed at a secured height and location.

7.8.3 Power (Link) Budgets

The term *link budget* also is called *operating margin*. It refers to the sum of gains and losses in a DAS, beginning with the transmitter and continuing to the receiver, including transmission line loss and antenna gains. When performing a link budget calculation (See Equation 7-1), add the losses and gains to determine whether there is excess signal (operating margin).

$$\text{Link budget (operating margin)} = P_R = P_T - L_T + G_T - L_P + M_f + G_R - L_R \quad (7-1)$$

Where:

P_R = Received power

P_T = Transmitter power output (same units as P_R)

L_T = Transmission line loss between transmitter and transmit antenna (dB)

G_T = Transmit antenna gain (dB)

L_P = Free space path loss between antennas (dB)

G_R = Receive antenna gain (dB)

L_R = Transmission line loss between receive antenna and receiver input (dB)

M_f = Morphology factor, which includes differences in the path loss decay between free space and the actual venue conditions

When considering the DAS operating margin for things like cellular transmissions, the path loss is an important concern and normally will be affected by the path the RF takes to reach the intended coverage area. This may include open areas that are unobstructed or areas that are densely populated with objects that may reflect, refract, or absorb the DAS signals.

To make a link budget calculation, the wireless designer must:

- Identify all of the equipment specifications and additional applicable losses (e.g., path loss, building losses).
- For downlink link budgets, determine what the power per carrier will be. This may depend on the equipment manufacturer's rated composite output power, 1 dB compression point of the amplifiers, optical path loss reduction to RF power, and coaxial cable losses.
- For uplink link budget calculations, calculate the noise figure depending on the system noise, which is based on the number of active elements in the system, cascaded noise figure, and antenna gain.
- Add the specifications and applicable losses together to determine whether the total value exceeds the minimum signal level required by the system.

7.8.4 RF Signal Conversion and Combining

Modern DAS equipment often distributes signals from multiple donor systems, including cellular/PCS signals from multiple WSPs, as well as WLAN and land mobile radio transmissions on the same physical network. Combiners, filters, and other devices are used to combine and separate the signals in a DAS and to minimize intermodulation effects and other negative consequences of mixing RF signals.

The DAS must use components designed to properly handle all of the signals being transmitted. Because component performance is often frequency specific, the design performance must be analyzed for each frequency. The antennas must be suitable for multiple frequency bands unless remote units separate the signals in the system. The radio path loss also is frequency specific, so the propagation portion of the design must consider each broadcast frequency to provide proper coverage for each wireless network using the DAS.

Some typical considerations for frequency conversion and combining are:

- **Diplexing**
Combine the output of two transmitters into a single antenna system while achieving the desired signal strength and system performance. The objectives of diplexing are to:
 - Maintain proper transmission limits set by the manufacturer or regulatory body
 - Provide adequate bandwidth at each frequency that is diplexed
 - Control and minimize signal loss
- **Duplexing**
Combine the forward and reverse signal paths onto a single cable
- **Amplifier/repeater selection:**
 - Frequency ranges
 - Power requirements
 - Band-pass filter performance

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8 DAS Infrastructure Implementation

8.1 Overview

The implementation of the DAS infrastructure is critical to its long-term reliability. Once designed by a qualified DAS designer, it is important that an experienced contractor team install the system and that only qualified radio technicians connect, tune, and commission the RF portions of the equipment. Poorly adjusted equipment can cause interference, both within this system and to other systems. Such interference is illegal and can result in the client being fined and the DAS equipment being shut down.

8.2 Administration and Documentation

8.2.1 Requirements

DAS administration shall comply with applicable administration standards (e.g., TIA-606-B, ISO/IEC 14763-2).

ICT infrastructure shall be clearly labeled to identify all system components, including racks, cables, panels, and telecommunications outlet/connectors. Labels shall be machine printed and uniquely identify the cable origin and destination.

All applicable documentation, including accurate drawings, applicable to the work performed shall be provided by the installer upon work completion.

BIM documents created for the telecommunications systems shall comply with the requirements of BICSI 003.

8.2.2 Recommendations

The use of automated infrastructure management systems should be considered for the applicable portions of the DAS.

8.3 Grounding, Bonding, and Lightning Protection Requirements

A telecommunications grounding and bonding system shall be provided for the telecommunications infrastructure. Grounding and bonding shall conform to codes (e.g., NFPA 70), applicable standards (e.g., TIA-607-B, ISO/IEC 30129), and the local AHJ. Indoor cables and pathways shall be bonded to the telecommunications grounding and bonding system per NECA/BICSI 607.

All outside cables and pathways shall be grounded per applicable codes and standards (e.g., IEEE C2). Cables installed on rooftops, such as coaxial cables to donor antennas, shall be bonded to the structure's lightning protection system using bonding kits listed for the purpose and the cable being used.

For some locations, lightning protection is required by the AHJ for basic building safety and protection. If a lightning protection system is present, the DAS shall be bonded to it in the same manner as the other ICT systems in the venue.

Where lightning protection from voltage fluctuations and transients is to be provided for protection of facilities or systems, installation shall be in accordance with industry recognized standards such as NFPA 780, IEC 62305-3, and IEC 62305-4.

Adherence to manufacturers' bonding and grounding requirements (e.g., Motorola R56) shall be followed when installing cabling systems with metallic elements.

8.4 Cabling Installation Requirements

8.4.1 Overview

This section applies to the installation of all forms of recognized cable and connecting hardware, including:

- Optical fiber cabling
- Balanced twisted-pair cabling
- Coaxial cabling

In practice, there is little difference in the installation of cabling for DAS (or other RF systems) and the installation of the same type of cabling for wire-line networking.

8.4.2 Requirements

Cabling installation shall conform to applicable standards (e.g., TIA-568-C Series, ISO/IEC 11801, EN 50173 series) as given in Section 3.

All outside connectors shall be weatherproofed using kits listed for the purpose and the cable and connector being used.

Installation procedures shall carefully follow the manufacturer's instructions to ensure a high-quality installation with minimum PIM. Installed systems shall be tested with a PIM tester. Any defects found shall be corrected and the system re-tested.

8.4.3 Recommendations

Cabling installation should conform to global best practices (e.g., BICSI *Information Technology Systems Installation Methods Manual*).

8.5 Antennas

8.5.1 Donor Antenna

The donor antenna is typically a directional antenna, pointed at a nearby macro cell site or land mobile radio repeater site. It is usually mounted on the roof or a side of the structure and must have a clear line-of-sight path to the distant radio tower.

On a building's roof, the antenna is mounted to a tower structure or a pipe mast of sufficient size and strength to withstand the wind load imposed. The mounting hardware is sometimes bolted into the roof. Often, however, the building owner will not allow penetrating roof mounts. In that case, the installer must use a non-penetrating mount. A non-penetrating mount consists of a rectangular metal frame to which the mast is bolted and supported by three legs. Most frames are approximately 1 m (3.3 ft) on a side, depending on the total wind load to be supported. Concrete masonry units (CMUs) or similar heavy material is stacked onto the frame to keep it in place.

For installation on the side of a structure, a two- or three-point mounting bracket is bolted to the building's wall. The antenna manufacturer can typically provide a wide variety of brackets and structures for antenna installation.

Typical equipment:

- 10 dB gain directional antenna
- Roof antenna mast, 38–50 mm (1.5–2 in) with mounting brackets
- Non-penetrating roof mount frame if needed

8.5.1.1 Requirements

The donor antenna, its support structure, and its transmission line shall be bonded to the building's lightning protection system per Section 8.3 above.

8.5.2 Indoor Antennas

Indoor antennas can be placed at the end of a coaxial cable or “tapped” into a coaxial cable to allow multiple antennas along the coaxial cable route. Ideally, the indoor antennas will be located where they are optically visible from every location being served by the antenna. RF signals can travel through building elements (e.g., walls, floors, ceilings), however signal attenuation will occur and varies based on the composition of the elements.

There are a variety of indoor antenna styles and types. The size and configuration will depend to some degree on the frequencies being covered by that antenna. The particular antennas and their locations for the project will be specified by the system designer. For example, in parking garages, low profile (50 mm [2 in] thick, 150 mm [6 in] diameter) antennas are sometimes glued to the lower side of overhead structural beams with construction adhesive. Locations of antennas sometimes follow the layout for video surveillance cameras with both often serving the same area.

Typical indoor antennas are surface mount, unity gain with an N-male or SMA-male connector.

8.6 DAS Specific Equipment

8.6.1 Bidirectional Amplifier (BDA)

A common problem with DAS installations is inadequate isolation (path loss) between the rooftop donor antenna and the indoor coverage antennas, which allows the indoor antennas to repeat the signal heard by the donor antenna. When isolation is insufficient, the system “oscillates” and causes severe in-band and adjacent band interference. Harmful interference is illegal. Both the AHJ and the WSPs will require the system to be shut down until the interference is corrected.

The industry standard for minimum antenna-to-antenna isolation, or stability margin, is: BDA gain + 15 dB. For example, a BDA with 70 dB of gain + 15 dB = 85 dB minimum isolation between the donor and indoor antennas.

Channelized systems often have higher gain than broadband signal boosters, making the antenna-to-antenna isolation more difficult to maintain and, because of their higher output power per channel, the oscillation interference level can be much greater than from a lower power broadband signal booster. Most signal boosters use some form of automatic gain control to maintain operation within the AHJ’s limitation on out-of-band emissions. This is usually near the 1 dB compression point of the amplifiers.

One solution is to reduce the gain of the signal booster. Excessive gain does not improve performance and may create noise in nearby receivers. Always use the minimum gain setting that provides the required coverage. If necessary, install additional indoor antennas.

Headend electronics must only be installed and tuned by qualified radio technicians, preferably factory-certified technicians.

Follow standard practices for installing optical fiber cable between the BDA and the remote hubs. Each cable from a remote hub is home run to the BDA.

A combination splice tray and fiber patch panel is recommended at the BDA to manage the various fiber cable runs.

8.6.2 Remote Amplifier Modules

Remote amplifier modules are installed near the indoor antennas in systems that use optical fiber cable for distribution. The amplifier module converts the uplink RF signal to light and light from optical fiber cable to RF as the downlink source. Trunks and branches connect the antenna array to the last active DAS element.

Fiber cable terminations and short fiber jumpers are required at each remote hub as well as a power source. In exposed areas, such as parking garages, this is often mounted inside a small IP52 (NEMA 12) utility box.

Rated enclosures may be required by AHJ or per applicable standards (e.g., NFPA 72).

Headend hardware may include:

- Coaxial cable jumpers with necessary connectors (e.g., N-male, SMA-male) to connect the BDA to the hub
- An output power supply
- Headend unit(s)
- Patch panels and cable jumpers
- Cabinet or rack to house equipment (e.g., BDA, headend, patch panel, power supply)

Remote amplifier hardware may include:

- Electrical-to-optical converters
- Optical-to-electrical converters
- Amplifier and signal conditioning hardware
- A DC power supply

If amplifier modules are installed in an open area and required to be protected from weather, additional items that may be needed include:

- An enclosure suitable for the environment (e.g., IP52 [NEMA 12] type case)
NOTE: The typical size of an enclosure used is $400 \times 400 \times 200$ mm [$16 \times 16 \times 10$ in]. For lower bands and multiband systems, the case will be larger.
- A small fiber patch box, typically with 2 fibers in-service and others serving as spares
- Single mode fiber cables, typically 0.9 m (36 in) in length, with connectors matching the fiber hub
- RF jumpers, typically used when the assembly is fabricated in the field

Various antenna and coaxial cable hardware (e.g., taps, splitters), as specified by system designer, will also be required.

NOTE: Different components are usually required for each radio frequency band. Some combinations of frequency bands, such as public safety and cellular bands, may not be compatible with each other or require special and additional hardware. Consult the system designer for additional information.

8.6.3 Receivers

In more advanced designs, the gain of the receiver may be adjustable to prevent overdrive. Overdrive can distort the recovered RF signals. Receivers also include linear compensation circuits and are commonly available.

9 Management: Operations, Maintenance, and Administration

9.1 Introduction

Much of the management of a DAS is the same as managing other ICT systems, since it consists largely of cable and devices terminated on the cable. As such, system managers should follow the guidance in the latest edition of BICSI's *Telecommunications Distribution Methods Manual* (TDMM).

This section describes considerations specific to RF system installations, DAS and small cells in particular.

9.2 Managing and Operating DAS and Small Cell Systems

In-building and campus wireless systems provide not only the convenience of being able to make a phone call, but they are also often critical business operation and life safety systems. They enhance the ability of site security and maintenance personnel to use their radios systems, allow workers to call for help in an emergency from any location, and allow emergency responders to communicate with their command posts during a response. For these reasons, ensuring the system functions legally, reliably, and with high quality over the long term is as important as its initial installation.

9.2.1 System Manager

The site owner of a DAS or small cell system should designate an individual member of its staff to assume responsibility for the system. The manager must have, not only the responsibility, but also the authority to make decisions and act to keep the system functioning properly.

Among the duties of the system manager are:

- Oversee the system to ensure that its long term security, reliability, and coverage levels are maintained.
- Oversee upgrading of the system as needed for any changes or additions required by the signal providers (e.g., frequency band changes).
- Oversee all maintenance. Ensure that all periodic inspections and upgrades are timely and properly done. Maintain the manufacturer-recommended stock of on-site spares. Replace spares that become outdated or are used.
- Ensure that the system remains in compliance with all laws, ordinances, codes, and regulations.
- Periodically review all agreements with signal providers and public service agencies. Revise and renew them on a timely basis.
- Participate, as needed, in all project planning sessions involving building construction, remodeling, or expansion, to ensure the DAS is included in the planning and required coverage is installed or maintained in the new or remodeled areas.
- Participate, as needed, in all project planning sessions involving telecommunications infrastructure changes to ensure that the DAS is not negatively impacted.
- Oversee owner staff and contractors involved with the system.
- Oversee all projects involving the planning, design, and construction of DASs or components.
- Maintain all construction project, provider agreement, and test and maintenance records. This includes a complete inventory of all DAS equipment, including such data as:
 - Brand
 - Model number
 - Serial number
 - Software version
 - Installation date
 - Maintenance data
- Maintain all warranty records on the equipment.

9.2.2 Other Personnel Needed

In addition to the system manager, other personnel are needed. They may be employees of the owner, but are often contracted, because of the special nature of their qualifications. These positions include:

- Regulatory Specialist
- Alarm Monitoring Organization
- Qualified RF and Cabling Maintenance Staff

9.2.2.1 Regulatory Specialist

The regulatory specialist must be knowledgeable in all of the applicable laws, ordinances, codes, and regulations that affect DAS and small cell system operation for the site. The specialist advises the system manager and assists in maintaining compliance with all requirements, which includes:

- Monitor the state and local laws, ordinances and codes concerning DAS and small cell system requirements.
- Understand the impact the DAS may have on the public safety E911 system.
- Monitor government regulations for changes that may impact the system.
- Maintain a liaison with all service providers, and monitor reports concerning service provider systems to ensure that the system manager is aware of planned service provider system upgrades, expansions, and other changes (e.g., frequency changes or additions) that could impact the DAS.
- Ensure that all agreements with service providers and public service agencies are properly executed, valid, and current. Advise the system manager when renewals or revisions are needed.
- Timely renew all wireless licenses (if any).
- Ensure that any required local government system-related permits and certificates of occupancy are kept up to date and that compliance with their requirements is maintained.

Typically, a DAS or small cell system does not require licensing for itself. The licenses are held by the service provider and used by the DAS or small cell system according to the agreements negotiated between the system owner and signal providers. However, there may be occasions when owner-held licenses are required. Some jurisdictions may require a separate license for the system, or the owner may have onsite radio systems for security or maintenance personnel.

9.2.2.2 Alarm Monitoring Organization

A well-designed and installed system will have numerous monitoring and alarm features maintaining a constant watch on its operation. Local codes concerning DAS and small systems for public safety typically require such monitoring. It is critical that these alarms and events be reported to a designated location that is manned 24 hours a day with personnel trained in how to respond to each alarm and event. Most often, this is the security control center for the site, although it could also be the building management system monitoring center or a contracted off-site agency.

Depending on local ordinances, the alarm monitoring organization may also need to notify the local public safety agency(ies) of any system failure.

9.2.2.3 System Maintenance Staff

A DAS or small cell system, especially ones serving public safety systems, must function reliably and with a high level of quality. Only experienced and qualified personnel should be allowed to maintain these systems. The personnel may be either employees or contracted. Local codes concerning these systems typically require:

- 24-hour, 7-day emergency response. (See Section 9.5.2)
- For the RF systems, a current FCC general radiotelephone operator license, acceptable manufacturer or industry certification, electrical engineering license, or as required by the AHJ.

9.3 Administration

9.3.1 Documentation

9.3.1.1 Requirements

The system manager shall maintain a number of documents. Among them are:

- Technical specifications of the system
- All records and drawings concerning the construction and commissioning of the system
- Records and drawings for all upgrades, revisions, and expansion to the system
- Current and previous agreements with the signal providers, including public safety agencies, allowing the use of their signals and licenses
- Any licenses required for the system or owner-owned radio systems connected to the system
- Local permits for the system and system-related certificates of occupancy
- Current and previous contracts with non-employee organizations involved in monitoring, testing, or maintaining the system
- Records of the qualifications of the companies and personnel that installed and maintain the system, including for RF equipment, copies of federal licenses, manufacturer certifications, and other documents acceptable to the AHJ
- All records of system and component tests
- All records of maintenance and repairs

The technical system specifications shall contain, as a minimum, the frequencies required, the location and EIRP of radio sites used by the system, the maximum propagation delay (in nanoseconds), and other supporting technical information.

Local codes concerning these systems often require that the designated public safety contact be provided with:

- The name and phone number(s) of owner personnel responsible for the system
- The name and phone number(s) of the contractor or personnel responsible for system maintenance
- The nature and status of system malfunctions, including estimated time to repair
- A copy of the most recent system test results

9.3.1.2 Recommendations

The following information should be maintained at the headend equipment site:

- An up-to-date system drawing(s), showing the floor plan, cable routing, and all antenna locations
- A list of all signal providers, including the frequencies used, along with labeling showing which components serve which provider
- The name and phone number(s) of owner personnel responsible for the system
- The name and phone number(s) of the contractor or personnel responsible for system maintenance
- A copy of any licenses required for the system

9.4 System Testing and Inspection

9.4.1 General Requirements

All testing should repeat the applicable portions of the initial acceptance tests and must conform to the requirements of the AHJ, if any. Local ordinances concerning DAS and small systems for public safety typically require that the systems be tested at least:

- Prior to occupancy of any newly constructed building.
- Whenever structural changes occur, including additions to buildings that would materially change the original field performance tests.
- Annually.
- When repairs or alterations are made to amplification systems.

These ordinances also typically require additional testing at least every five years and that the local AHJ be notified in advance and permitted to observe the testing. The AHJ may require additional testing as well.

Such annual and five-year testing may also be required by other signal providers as part of their agreement with the system owner. Even if not required, the testing is best practice.

9.4.2 Annual Testing

As a minimum, all active components of the system, such as signal boosters, power supplies, and backup batteries, must be tested at least every 12 months.

NOTE: Depending on the system availability requirements, quarterly testing may be needed.

The annual tests must include:

- Signal boosters
 - Ensure that spurious oscillations are not being generated by the signal booster as a result of coupling (lack of sufficient isolation) between the input and output antenna systems
 - Ensure that the gain is the same as it was upon initial installation and acceptance
- Backup batteries and power supplies
 - Shall be tested under load for a period of 1 hour to verify that they will properly operate during an actual power outage. If within the 1 hour test period the battery exhibits symptoms of failure, the test shall be extended for additional 1 hour periods until the integrity of the battery can be determined.
- All other active components shall be checked to determine that they are operating within the manufacturer's specifications for the intended purpose
- Passive components shall be inspected for damage as well as wear and tear; especially outdoor components. Such inspections include, among other items:
 - The donor antenna and transmission line, if any
 - The radome, if utilized
 - Areas where cabling is exposed and can be subject to damage
 - The indoor antennas
 - All connectors throughout the system
 - All grounding and bonding connections, especially those made in an outdoor environment
- Signal strength
 - Minimum inbound signal strength required by the service provider
 - Minimum outbound signal strength required by the service provider
 - If a donor antenna exists, isolation shall be maintained between the donor antenna and all inside antennas and shall be a minimum of 15 dB above the signal booster gain under all operating conditions
- Authorizations
 - All testing shall be done on frequencies required by the AHJ or additional frequencies are made available
 - Testing of each signal provider's sub-system, including public safety agencies, shall be done on frequencies, and at time periods, required by the provider or AHJ

9.4.3 Five-Year Testing

The performance test performed during the original system acceptance testing should be repeated at least every five years to demonstrate that adequate radio coverage is available in all required areas of the site.

9.4.3.1 Signal Coverage

- **Critical Areas**
Critical areas, such as the following, shall have the required floor area radio coverage, typically 99 percent:
 - Emergency command center(s)
 - Fire pump room(s)
 - Exit stairs
 - Exit passageways
 - Elevator lobbies
 - Standpipe cabinets
 - Sprinkler sectional valve locations
 - Other areas deemed critical by the AHJ
- **General Building Areas**
General building areas shall have the specified floor area radio coverage, typically 90 percent.
- **Test procedure**
In the absence of guidance from initial acceptance testing or the AHJ, the following summarizes a typical coverage test process.
Testing is typically done on a grid system with 20 grid cells. For most buildings, a minimum grid dimension of 6 m (20 ft) and a maximum grid dimension of 24 m (80 ft) will suffice to encompass the entire floor area. Where a floor exceeds 11,900 m² (128,000 ft²), which is the floor area that can be covered by the maximum grid dimension of 24.4 m (80 ft), the floor should be subdivided into sectors, each having an area of less than or equal to 11,900 m² (128,000 ft²), and each sector should be tested individually with 20 grid cells in each sector. Signal strength measurements should be taken at the center of each grid and should be performed using standardized parameters.
- **Signal quality**
The quality of voice signals is typically measured using the delivered audio quality (DAQ) scale, which has the following levels:
 - DAQ 1: Unusable; speech present but not understandable
 - DAQ 2: Understandable with considerable effort. Frequent repetition because of noise/distortion
 - DAQ 3: Speech understandable with slight effort. Occasional repetition required because of noise/distortion
 - DAQ 3.5: Speech understandable with repetition only rarely required. Some noise/distortion
 - DAQ 4: Speech easily understood. Occasional noise/distortion
 - DAQ 4.5: Speech easily understood. Infrequent noise/distortion
 - DAQ 5: Speech easily understoodTypically, the minimum allowable DAQ for each grid cell is 3. No two adjacent grids should be allowed to fail the test. Not more than two non-adjacent grid cells should be allowed to fail. Failures should not be allowed in critical areas. Measurements should be made with the antenna held in a vertical position at 0.9 to 1.2 m (3 to 4 ft) above the floor. The DAQ readings should be recorded on small-scale drawings showing the grid layout.
- **Parameters**
Downlink measurements should be made with the following standardized parameters:
 - A calibrated spectrum analyzer or a calibrated automatic signal level measurement recording system
 - Receive antennas of equal gain to the system user's standard portable radio antenna, oriented vertically, with a centerline between 0.9 m and 1.2 m (3 ft and 4 ft) above the floor
 - A resolution bandwidth nearest the bandwidth of the channel under testLevels recorded while walking an "X" pattern with the center of the pattern located approximately in the center of each grid area

List continues on the next page

- The linear distance of each side of the “X” equal to at least 10 percent of the length of the grid’s side and a minimum length of 3 m (10 ft)
- Measurements sampled in averaging mode to include a minimum of one sample per each 1.5 m (5 ft) traveled, recorded with not less than five samples per measurement per side of the “X”
- Authorizations:
 - All testing shall be done on frequencies required by the AHJ or additional frequencies made available.
 - Testing of each signal provider’s sub-system, including public safety agencies, shall be done on frequencies and at time periods authorized by that provider.

9.4.4 Field Testing

Local codes concerning these systems often require that designated public safety personnel shall have the right to come onsite and conduct their own field-testing to be certain that the required level of radio coverage is present.

9.5 System Revisions and Maintenance

9.5.1 System Upgrades, Revisions and Expansions

System owners will be required to modify or expand the system at their expense in the event frequency changes are required by the government or additional frequencies are made available by the government. A modification or expansion will also be required should any signal provider, including public safety agencies, change or expand the frequencies they use. Failure to modify the system to accommodate frequency additions or changes could invalidate signal provider agreements, violate local or national law, and require that the system be shut down until it is brought into compliance. For this reason, it is important that the system be designed and installed to allow for easy upgrades, revisions and expansions.

9.5.2 System Maintenance

Because of the special skills required by personnel working on DAS and small cell systems, maintenance is typically performed by contracted personnel, rather than system owner employees. Often, the contractor that installed the system is hired to maintain it.

All maintenance must be done only by technicians with a current FCC general radiotelephone operator license, acceptable manufacturer/industry certification, an electrical engineering license, or as required by the AHJ.

The system owner should ensure that the service contract for emergency repair provides for a response to the site based on the severity of the issue. Critical issues (no service) should have a response time of 1 hour. Major issues (partial service outage) should have a response time of 2-4 hours. Minor issues should have a response time of 24 hours.

Often, ordinances require that a copy of the maintenance contract be submitted to the AHJ at the time of acceptance testing. If the system owner drops the maintenance contract, the contractor must notify the AHJ within 24 hours.

A preventative maintenance schedule should be established and closely followed. The schedule should include monthly and annual tasks as well as the above described annual and five year tests.

9.6 DAS Security

NOTE: This section discusses only the physical and logical security of the distributed antenna system itself. The traffic that rides on the DAS usually has a wide variety of logical security requirements, ranging from essentially none to life-safety critical. Each application using the DAS should include the appropriate security functions within its operation. Such discussions are beyond the scope of this document. Further, statements to this effect should be considered for all agreements between any parties involved, including the owner, designer, contractor and WSPs.

9.6.1 Overview

Security is a broad subject that needs to be considered and included in all phases of a DAS project including:

- Planning
- Design
- Installation
- Operation

The overarching goal of a security system is to avoid loss of assets, loss of data integrity, and loss of uptime of a DAS. The planning, design, installation, and operation of a DAS should be developed in accordance with the overall security plan of the building.

NOTE: When BICSI 006 was published, TIA-5017 was in development for the physical security of networks.

9.6.2 DAS Cabling

DAS cable should be routed through secure areas of the building. Cables installed in public areas should be in metallic conduit or secure pathways. All access points to DAS cabling should be locked and additionally monitored by video surveillance.

Since DAS cabling is a critical utility, consideration should be given to using automated systems that can detect unauthorized changes to the DAS and trigger alarms that are sent to network management personnel.

The DAS security management system should be able to communicate or exchange data with and consolidate information from other systems and databases. The use of standard protocols and database formats (e.g., XML, SNMP, SQL) is encouraged. The DAS security system should work in conjunction with the other security systems in place in the facility to offer a concerted security umbrella for the entire facility.

9.6.3 DAS Pathways

Pathways and pathway elements should be located to prevent tampering or vandalism. Monitoring and additional security measures may be required by the client or AHJ.

Pathways in public areas should be metal conduit or secure pathways.

9.6.4 DAS Spaces

DAS spaces are used to house equipment, cabling, and protective devices. Access to these spaces shall be monitored or controlled using locks, security cameras, and alarm systems.

DAS equipment should be protected from tampering or vandalism using suitable cages, enclosures, or other protective devices.

DAS distributor enclosures should be accessible and shall incorporate a means of security that discourages unauthorized entry.

All DAS spaces should be developed in accordance with the security plan of the building.

9.6.5 DAS Connections

All changes to the DAS should be implemented in accordance with an authorized work order. Changes should be documented in an administration system. Automated systems that record and detect connected patch cords and equipment are recommended since the databases they use are updated automatically.

DAS antennas should be placed to optimize both coverage and security. The locations of antennas should be monitored using security cameras, alarms, or both.

Labels for DAS facilities should be developed in conjunction with the security plan of the building. The labels should not allow unauthorized persons to gain an understanding of the DAS layout easily.

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10 Location Technologies

10.1 Introduction

Many users are replacing landlines with wireless phones, and calling patterns are changing. Numerous studies and surveys indicate that the majority of emergency calls to public safety access points (PSAPs) are made from wireless phones, and approximately 80 percent of all smartphone use occurs indoors. However, current FCC rules require location information from wireless callers to be reported to PSAPs based solely on the performance of outdoor wireless emergency calls.

Indoor emergency calls often cannot be located accurately because GPS satellite signals may be blocked in urban canyons; and GPS satellite signals do not penetrate many building structures. Additionally, indoor distributed antenna systems and repeaters may degrade position accuracy.

To address this issue, the FCC began work in the first quarter of 2014 (as this document was being prepared) on a proceeding for establishing rules mandating that commercial WSPs meet indoor location-accuracy requirements when customers call 911, including information regarding the vertical location of a caller, so they can be found more quickly in a multi-story facility. Specifically, if enacted without change:

- Commercial mobile radio system (CMRS) providers would be required to provide horizontal location (x- and y-axis) information within 50 m (150 ft) of the caller for 67 percent of 911 calls placed from indoor environments within two years of the effective date of adoption of rules and for 80 percent of indoor calls within five years.
- CMRS providers would be required to provide vertical location (z-axis) information within 3 m (10 ft) of the caller for 67 percent of indoor 911 calls within three years of the adoption of rules and for 80 percent of calls within five years.
- As is the case with existing emergency response (e.g., E911) location rules, CMRS providers would be required to meet these indoor requirements at either the county or PSAP geographic level.
- The maximum time period allowed for a CMRS provider to generate a location fix would be 30-seconds.

This data would help first responders determine the floor and room where the emergency caller can be found to improve response times.

The above proceeding followed a set of indoor location technology tests conducted in the winter of 2012–2013 by Working Group 3 of the Communications Security, Reliability, and Interoperability Council (CSRIC) at the FCC's request. The tests were conducted in the San Francisco Bay Area because it included a variety of different environments within a fairly limited geographic area, allowing testing by just one team. Three technologies from three companies were tested. The report, issued in March 2013, found that the technologies tested showed significant promise, but they needed additional development as accuracy results varied by technology and the particular environment. However, all vendors were continuously improving their technologies. Also, other technologies are also being tested by other organizations, also with promising results. According to the FCC, "Vendors argue that indoor location technology has since evolved considerably, suggesting the provision of indoor location information may be within reach."

The problem with obtaining better accuracy of a cell caller's location while using an in-building DAS is the added time delays inherent within DAS-deployed solutions. Unfortunately, this leaves venues vulnerable to large position errors in the places likely to be in need of assistance.

Among the compounding issues that influence the location accuracy in a DAS are repeaters and the DAS environment.

10.2 Repeaters

Repeated signals are delayed by several microseconds, distorting measurements by thousands of feet.

Base transceiver station (BTS) signals used for positioning require much lower signal-to-noise ratio than those needed for communication; therefore, some non-repeated signals are heard, which can result in a pathologic condition—some signals are delayed; others are not.

10.3 DAS Environments

Standard practice forbids the use of measurements from BTS signals that go through fiber (not line of sight and the velocity is only 0.6 times the speed of light).

Operational paradigm forbids measurements from BTS signals that are ambiguous because of simulcasting.

Geometric techniques, such as signal strength measurements, are compromised because of the inability of tools to model small or oddly shaped DAS coverage footprints.

Currently, there are only two communication protocols that have been used with techniques for enhanced location accuracy. Several possible approaches are under consideration with LTE, but no one approach has emerged a winner and evaluations continue.

GSM service providers use uplink measurements of cell phone transmissions to determine caller position solutions. Uplink Time Difference of Arrival (U-TDOA) is the standard technique; cell phone signals are measured at the BTS. Location measurement units (LMUs) measure the relative uplink signal delays.

CDMA service providers use downlink measurements of base stations and GPS satellite transmissions to determine caller solutions. Assisted GPS (A-GPS) is part of the emergency caller solution.

Advanced Forward Link Trilateration (AFLT) is the terrestrial technique; BTS signal delays are measured at the cell phone and compared with pilot signals in CDMA carriers.

10.4 Summary Comments

Position determination for emergency caller/public safety is more problematic indoors than outdoors. Coverage and capacity enhancements adversely impact location accuracy. Smart phone applications do not currently help the public safety system. Exceptions to the E911 FCC mandate are sufficient today to account for in-building positioning errors. When indoor subscribers have sufficient reference points, location accuracies are much improved.

One approach to address the above issues in DAS environments is to program the system to provide specific location information, including building address and floor level information, for the origination of the indoor call. As cell sizes shrink, the location of the serving cell (or antenna) itself may suffice for a position estimate for both E911 call routing and first responder dispatch.

11 Site and Functional Support Issues

11.1 Overview

Depending on the specific site and the functions the DAS is supporting, there may be additional issues or elements that need to be addressed. The following section provides information for different site issues and applications.

11.2 Interior Trouble Spots

In today's modern building environment, there are always locations in buildings that are problematic to cover with wireless signals. Wireless signal propagation depends on a number of things, including the type of signal (spectrum) being transmitted, building materials, and the quality of the wireless network.

Building materials that tend to attenuate wireless propagation include certain types of glass, metal, concrete, some ceramic tiles, and increased thickness of some materials that may not commonly cause attenuation problems. The combination of a thick concrete slab with embedded rebar, for example, will magnify the problem. A vault with double layers of thick dry wall with security mesh between the layers may likewise cause problems.

The most common and cost efficient way to overcome poor wireless propagation is to extend the network infrastructure and antenna system into the area where the signal is blocked or weakened by the building environment. Common examples of these areas are building cores, stairwells, subterranean basements, elevator shafts, operating rooms, lead lined treatment rooms, and vaults.

In many of these cases, infrastructure expense will increase. Elevators are particularly costly when extending the network into the shaft, and these expenses should be planned for in advance. However, depending on the jurisdiction of the structure, it may be against code to provide anything other than elevator hardware and cables in the shaft. In any event, early planning is essential for overcoming the issues described above. The designer should engage the AHJ regarding projected trouble spots early in the design process.

In a medical setting, an owner may influence the AHJ by asserting that it is a life safety issue (for patients during transition of care, proper connectivity for clinicians and security staff), and they would be correct. However, if it is not possible to enter the elevator shaft or other areas where propagation is poor, an alternative is to design the infrastructure to saturate the area with the desired RF.

11.3 Office Buildings

11.3.1 Introduction

When planning an in-building DAS for an office building, there are several factors that must be considered. In addition to the size and physical makeup of the building structure, the designer must also know and understand the purpose and function the office building is supporting.

11.3.2 Building Ownership and Tenants

Two important factors the designer must consider when designing an in-building DAS are building ownership and number of tenants. These two things will have a big impact on how the designer will proceed with the design. In most cases, the designer will be faced with one of the three following scenarios when it comes to building owners and tenants:

- Building owner is the only tenant.
- Building owner leases to a single tenant.
- Building owner leases to multiple tenants.

In the scenario where the building owner is the only building tenant, the owner of the building occupies and uses all the spaces within the building. When designing the in-building DAS, the designer will work with the building owner to perform the needs analysis and identify the required areas for coverage. The designer will also work with the owner when coordinating service requirements with the WSPs. In this scenario, the needs of the owner may only require the DAS to support a single WSP. Funding and ownership of the DAS will most likely be provided by the owner. In the case of a large profile owner/tenant, the WSPs may place a high value on making sure their signal is accessible from within the building and, therefore, opt to provide funding for the DAS.

In the scenario where the building owner leases the building space to a single tenant, the tenant will occupy the majority of the building spaces. However, it is not uncommon for the building owner to occupy a few support spaces such as areas for their on-site building support personnel as well as the spaces used to house and maintain building control systems such as mechanical, electrical and plumbing systems. In this scenario, the tenant will provide the owner with its requirements, and the owner will use this information when constructing the building. Even though the tenant dictates the function of the building, the owner will have final approval over the design of the building.

This scenario can complicate the coordination and design requirements for the in-building DAS. When designing the DAS, the designer must first obtain the service and coverage requirements from the tenant. Then, during the coordination process with the WSPs, the designer will need to work with all three entities (WSPs, tenant, and building owner). Designers will not only need to coordinate the needs of the tenant with the WSPs, but they will also have to coordinate the WSP needs with the building owner as well as get approval from the building owner for any construction required to implement the in-building DAS. This would include items such as the build-out of the WSP's headend, installation of riser and horizontal support pathways and power and cooling systems to support the WSP's signal source equipment and the DAS equipment.

In this scenario, the needs of the tenant may only require the DAS to support a single WSP; however, the building owner may stipulate that the DAS must be designed to support multiple WSPs and be configured as such at time of installation. Funding and ownership of the DAS may be provided by the building owner, tenant, or by the WSP.

In the scenario where the building owner leases space to multiple tenants, the design of an in-building DAS for the wireless designer is much more complicated. Now instead of obtaining the requirements for a single tenant, the wireless designer needs to take into consideration the potential needs of multiple tenants. In this case, the possibility now exists to have multiple in-building DAS networks and various WSP signal source equipment. This can limit the amount of coverage available for each tenant and can potentially result in denial of service for future tenants.

When an office building has multiple tenants, it is highly recommended that the building owner take the lead on ownership of the DAS. In addition, the in-building DAS should be designed to support the primary WSPs that offer service for that area. Designing a DAS that supports multiple WSPs will allow for an easier transition when tenant needs and occupancy change.

11.3.3 Office Building Core and Shell

The construction process for an office building can present multiple challenges to the design and installation of an in-building DAS. This becomes more of a factor when the office building will support multiple tenants. There are two main construction phases when dealing with an office building. They are referred to as the core and shell phase and the tenant fit-out phase.

The construction of the core and shell areas covers the requirements associated with the maintenance support spaces and the building envelope. The architect will design these spaces first and issue the construction plans to the general contractor. This allows the construction of the building to start while architects work out the finer details with the owner and tenant of what will go inside the building. Core and shell spaces include the following:

- Floor slabs
- Stairwells
- Electrical rooms
- Mechanical rooms
- Plumbing risers
- Elevator cores
- Public restrooms
- Entrance facilities
- Telecommunications/Data rooms
- Building exterior surfaces
- Windows

The tenant fit-out phase covers the construction requirements associated with each tenant's office space. During this process, the tenant spaces will start to take shape. Once the architect specifies the materials and completes the design for the tenant space, the wireless designer can then incorporate this information into the in-building DAS design. Until this process takes place, it will be difficult for the wireless designer to lay out antennas and perform propagation studies. Tenant fit-out incorporates the design of the following:

- Interior walls and partitions
- Interior doors
- Lighting
- Electrical
- HVAC
- Plumbing
- Telecommunications/Data
- Security

If the office building being designed will support multiple tenants, it will complicate the in-building DAS design for the wireless designer. This occurs because the tenant fit-out of each tenant's space may be completed at different times. It is common for a building to open with only a few tenants and a portion of the building left untouched until the building owner can find a tenant to fill the empty space. Therefore, it is important that the wireless designer specify a DAS that can be easily modified and expanded and capable of supporting multiple WSPs.

11.3.4 Physical Construction

Another important factor the wireless designer must take into consideration is the physical construction of the office building. Office buildings come in all shapes and sizes. Whether the office building consists of a single story structure or is a structure in excess of 50 stories, today's construction materials are playing a much larger role in the need for an in-building DAS.

As the American Institute of Architects (AIA) moves to be more environmentally conscious (green), they are promoting the development and use of standards and regulations that encourage the use of materials that reduce carbon footprints and increase the efficiency of building management systems. Organizations such as the US Green Building Council (USGBC) have developed programs and certifications such as LEED (Leadership in Energy & Environmental Design) that qualify the building owners for money-saving incentives like tax rebates and zoning allowances.

As a result, new materials are being developed that help to shield and insulate building structures. One of the most widely used materials that is great for conserving energy but wreaks havoc on RF signals is low emissivity (low-E) glass. The use of low-E glass is pretty standard on all new construction. Low-E glass not only reduces the amount of thermal heat that penetrates the glass, but unfortunately, it also reduces the amount of RF energy/signal that will propagate into the building. This ultimately reduces the use and coverage of wireless systems that rely primarily on services that are broadcast from outside the building, such as cell phones and public safety radios. Wireless designers must make sure they take this into account when designing an in-building DAS. The wireless designer must plan for quality coverage to ensure there is a proper handoff between the macro and in-building DAS. Typically, the designer should ensure that there is a 10 dB difference between the macro and in-building DAS signal levels.

Another item to consider, especially when it comes to government office buildings, is the age of the facility. If the office building is preexisting and has been in use for an extended period of time, there are some other issues the wireless designer may encounter. These potential issues could include the presence of asbestos containing materials (ACM) and historically significant structures.

It is common to find ACM in buildings that were constructed prior to the mid-70s. ACM could be found in the materials used to insulate high temperature pipes and ceilings. It could also have been used in the makeup of the floor tiles. It is extremely important for the designer to find out if the existing building contains any ACM. This will potentially affect antenna placement as well as the routing and installation of cable. Working in areas that contain ACM will potentially require the development of an ACM mitigation plan. Developing an ACM mitigation plan often requires the need to hire a certified industrial hygienist. If abatement is required, further expenses will be incurred by the need to have a certified abatement contractor complete the work. All of these potential needs can add significant cost and expense to the project.

With regard to historically significant structures, extra care must be taken as not to affect or alter the appearance of the building. This may also be the case with the aesthetic structures inside the building. The wireless designer must consider these structures when specifying mounting locations and requirements for things, such as donor antennas, that need to be mounted on the exterior of the building. This also goes for antennas and cabling that need to be routed and installed in decorative areas inside the building. In such cases, the building owner or architect may require the wireless designer to submit the design for review and approval. They will often have on staff a consultant that specializes in historic preservation. This consultant could potentially have the final say on where the designer may or may not place in-building DAS components and infrastructure. It is recommended that the wireless designer coordinate the design with the preservation consultant prior to finalizing their design.

11.3.5 Coverage Areas

Coverage requirements are another key factor that the wireless designer must consider when designing an in-building DAS for an office building. During the design phase, the wireless designer needs to identify the areas requiring coverage. In an office building, these areas typically include spaces such as hallways, offices, conference rooms, gathering spaces, common areas, stairwells, elevators, and depending on the tenant, possibly bathrooms.

While identifying areas that require coverage, it is important to identify areas that do not require coverage, or more importantly, areas where coverage must be restricted. Restricted coverage areas may include a government agency or a defense contractor occupying space within an office building. Often, these types of tenants have the need to handle classified information and will have dedicated space, such as a SCIF (Sensitive Compartmented Information Facility), for discussing and reviewing classified information. When designing an in-building DAS in an office building that contains these types of spaces, the designer should take extra care in laying out antennas to make sure they are not placed in areas that will violate the security standards for the restricted areas. This can usually be accomplished by strategically placing a mixture of low power or highly directional antennas around these areas. Coordination of the antenna placement should be done with input from the agency that certifies the restricted areas.

11.4 Multi-Tenant Residential Buildings

Multi-tenant residential buildings should be handled in a similar manner as a multi-tenant office building. They are similar in many ways and require detailed coordination between the building owner and service providers. The building owner will most likely be required to cover the cost of the DAS, and the DAS should be designed to support multiple service providers, which will minimize required changes to the DAS as the building loses or gains new tenants.

There are, however, two main differences between office and residential buildings. First, the tenants of a residential building are less likely to have a strong voice in the design of the DAS or which service providers will be supported. The DAS designer is unlikely to consult with the tenants. Second, when laying out the infrastructure for the DAS in residential buildings, the wireless designer should avoid placing any antennas, cabling, or DAS equipment in private residential spaces. This will help to avoid access issues when performing routine maintenance or repair work.

11.5 Industrial Facilities

11.5.1 Overview

Industrial facilities are located in a county, city, or town zoned for the purpose of industrial development. There are two types of industrial facilities. One type is referred to as light industry, such as a business park, which consists of offices, warehouses, data centers, research and development laboratories, technology centers, etc. The other type is heavy industry such as an oil refinery, chemical manufacturing and processing, steel plants, coal processing plants, factories and assembly plants, etc.

The construction materials used to support both industry types and their environmental surroundings present problems for DAS designers and installation technicians. They affect radio frequency (RF) signal transmission and reception for cellular phones, two-way radios, broadcast radio, Long Term Evolution (LTE), and wireless LAN (Wi-Fi).

Heavy industrial facilities are usually located close to transport infrastructures, especially where more than one coincides, such as highways, railroads, water-ports, and airports. They also demand high-power electric supplies (usually three-phase power), high-speed network communications, large volume water supplies, and high-volume fuel lines.

11.5.2 Light vs. Heavy Industry

The following features can distinguish light vs. heavy industry facilities.

11.5.2.1 Light Industry Facilities

- Wood columns and beams with wood flooring and wood or plaster walls
- Poured concrete columns, beams, walls and flooring-all containing rebar reinforcements
- Precast concrete columns, beams, walls, and flooring-all containing rebar and/or post tension reinforced cables
- Steel I-beams and columns with precast exterior and interior concrete walls and having corrugated steel decking with concrete poured
- Steel I-beams and columns with metal exterior and interior walls (e.g., corrugated aluminum, tin, steel) and poured concrete floor with rebar reinforcement
- Window frames made out of metal or aluminum with two or more panes and glass coated with low-emissivity (low-E) material
- Some buildings are single level, and some are multi-story higher than 10-floors
- Some buildings have subterranean floors that could be 1-3 levels below ground level

11.5.2.2 Heavy Industry Facilities

- Surrounding structure environment
 - Pipeways supported by steel I-beams or poured concrete columns containing rebar reinforcements
 - Steam, furnace, and reactor tower stacks made out of steel and composite concrete materials
 - Water cooling towers and steel storage containers
 - Aerial pathways made out of wood, steel, or composite concrete used for poles or towers to distribute high voltage and communications transport systems. Underground pathways made of rigid metal conduits entering buildings also used for high electrical voltage and communications transport systems.
 - Motors, electrical switches, and power transformers
 - Tunnels
- Building main structure
 - Poured concrete columns, beams, walls, and flooring-all containing rebar reinforcements
 - Precast concrete columns, beams, walls, and flooring-all containing rebar and/or post-tension reinforced cables
 - Steel I-beams and columns with precast exterior and interior concrete walls and floors having corrugated steel decking with poured concrete
 - Steel I-beams and columns with metal exterior and interior walls (e.g., corrugated aluminum, tin, steel) and poured concrete floor with rebar reinforcement
 - No windows, or if windows are present, window frames are made out of metal or aluminum with two or more panes and glass coated with low-emissivity (low-E) material
 - Some buildings have subterranean floors that could be 1-2 levels below ground level

11.5.3 Chemical and Petrochemical Plants

Before designers begin designing or installers begin installing a DAS in a heavy industrial facility, it is recommended that they have a current site plan. In addition, they must be familiar with the customer's facility process safety management (FPSM) policy. In a heavy industrial facility, there are hazardous locations where fire or explosion hazards may exist because of flammable gases, vapors, and liquids; combustible dust; or other ignitable materials. These locations must be identified at the start of system design so that all safety and control protocols are included within the design from start to finish.

It is recommended that the designer and installer be familiar with the following:

- NFPA 704, *Standard System For The Identification of the Hazards of Materials For Emergency Response Rating*
- NFPA 497M, *Classification of Gases, Vapors, and Dust for Electrical Equipment in Hazardous (Classified) Locations*
- NFPA 70, *National Electrical Code*
 - Article 500 – Hazardous (Classified) Locations, Class I, II, and III, Divisions 1 and 2
 - Article 501, 502 and 503 – Addresses Class I, Class II, and Class III Locations respectively
 - Article 504 – Intrinsically Safe Systems.
 - Article 505 – Zone 0, 1, and 2 Locations
 - Articles 510 through 517 – Covers Occupancies
- NESC C2, *IEEE National Electrical Safety Code 2012*
- OSHA 1926.407 – *Hazardous (Classified) Locations*
- OSHA 29CFR1910.146 – *Permit-Required Confined Spaces*
- ASME A13.1 2007 – *Pipe Color Marking Standard*

This standard provides information on identifying hazardous materials transported in above-ground piping systems, as well as potential hazards if the contents were released into the environment.

NOTE: Appendix C provides additional information related to hazardous environment and locations.

Although the above listed codes and standards should be applied when designing and installing in a heavy industrial environment, the AHJ has the final approval.

In fossil fuel refineries and chemical manufacturing and processing plants in the United States, contractors are required to be certified with a minimum of 8-hours of HAZMAT (Hazardous Material) and PPE (Personal Protective Equipment) training before they are allowed to work in the facility. Once contractors show proof of HAZMAT and PPE certification, an additional of 4-8 hours of training could be required of the contractors by the operating company so that they are familiar with the local heavy industrial facility's FPSM.

11.5.3.1 Installation Considerations:

Cable Type

- See the BICSI *Outside Plant Design Reference Manual*, or check with the cable manufacturer for the type of cable construction needed to meet the corrosion, steam, and high temperature requirements in the harsh environment of the facility.

Enclosures and Connectors

- In heavy industrial facilities, enclosures with NEMA 1 thru 13 ratings are used depending on the type of environment or classified location where the DAS equipment is going to be installed. It is recommended that the designer and installer understand the customer's facility site plan before specifying the type of enclosure and connectors to be installed.

Example: A NEMA 6 type enclosure and an IP67 type connector is used in a tunnel where the equipment could be sprayed or submerged in water or oil or experience severe weather conditions.
- In hazardous (classified) locations, this operating area of the heavy industry is specialized, and the selection of available enclosures and connectors is limited. Some of the enclosures and connectors are not readily available off the shelf, and delivery of the product could hinder a project.
 - A DAS designer should check with the manufacturer during the design phase for availability and delivery of the product.
 - If the product needed is no longer manufactured, the designer should check with the AHJ for other approved design alternatives that could be installed.

11.5.3.2 RFI/EMI

In a heavy industrial facility, the demand for high voltage power to run each operating plant is high. It is needed to run three-phase and single-phase electrical motors and other heavy operating equipment. In each plant facility, high voltage transformers, electrical switches, high voltage power lines, and cogeneration operations are normally present. The DAS designer and installer will need to note their locations and provide as much space as possible between these RFI/EMI generators and the cables and equipment being installed.

In areas of industrial plants where metals are fabricated, RFI and or EMI are generated around this type of location from welding and cutting tools. Routing cables or installing DAS equipment in this location should be avoided. If installing cable in these areas cannot be avoided, strong consideration should be given to using non-conductive optical fiber cable only. If active DAS equipment must be installed, it should be placed in a grounded, sealed, solid metal enclosure with only the antenna exposed. Media converters can be used inside the enclosure to change from optical fiber to copper cable with the copper cable being kept as short as possible.

11.5.3.3 DAS Antenna Locations and RF Radiation

It has long been understood that the high level of electromagnetic energy produced by radio frequency radiation under the right circumstances could cause an arc sufficient to ignite flammable materials in the air in locations deemed hazardous. Radio waves and microwaves induce currents in metallic structures (e.g., pipes, metallic I-beam structures, machinery, cranes, etc.) that can cause an arc if there is a gap in the structure.

A designer, when planning for a location to mount a DAS antenna, or an installer installing an antenna should be aware of the following:

- The geographical and structural surroundings where the antenna is going to be located
- Hazardous classification of the immediate location and adjacent surrounding locations
- Electronic equipment classification rating

There are industrial radios that are manufactured to operate in Class I Division 2 environments. This equipment carries the label “Intrinsically Safe” for operation in the classification specified. The designer should ensure during the design phase that the equipment and the hardware components are approved to operate in the various levels of classified locations.

11.5.3.4 Pathways

The three most common pathways used in a heavy industrial facility are aerial, underground, and pipe racks.

11.5.3.4.1 Aerial

Telephone poles are used in chemical and petrochemical plants because of their:

- Flexibility—whenever a temporary shutdown plant needs to be build, the route for the poles could be quickly determined and installed in place
- Reduced cost, as compared to an underground or a pipe rack pathway
- Much lower amount of potentially hazardous materials that must be legally and expensively disposed of as compared to trenching for an underground installation

In instances where the antenna is mounted on a telephone pole to meet the calculated height for transmit/receive parameters, the DAS designer should consider and include the following:

- The location of the pole and whether the pole can be accessed using a vehicle (e.g., bucket truck) or by climbing
- Loading effect of the antenna and attachments to the type of pole
- Slack span of the cable(s) from the pole to the building and hardware attachments
- The height clearance of the cables from the pole to the building if crossing a road, sidewalk, etc.
- Bonding, grounding (earthing), and electrical protection

11.5.3.4.2 Underground

Rigid conduits are used in industrial plants in underground pathways because they are robust in protecting the cables in them and can be easily sealed when installed in hazardous environments having vapors and gases.

11.5.3.4.3 Pipe Racks

Pipe racks are used in many industrial plants. I-beams or composite cement columns support them. Many plant products, water, and steam are distributed throughout the plant using the pipe racks. Many of the plant's products are under high temperature and pressure and are highly caustic.

Rigid conduits may be installed on these pipe racks to distribute electrical and communication cables to various processing and control devices.

As in underground, both ends of the conduit can be easily sealed when installed in hazardous environments having vapors and gases.

When designing and installing DAS cables or equipment on top or underneath pipe racks, the designer and installer shall check with the *NEC* and *NESC* or applicable electrical codes for space and distances of communication cable and equipment from the infrastructure on the rack carrying the plant's product (e.g., high temperatures and pressures, hydrogen sulfide, steam, acids, caustics, LPG).

NOTE: Direct-buried cables are seldom used because they are not as flexible as aerial pathways or as robust as underground conduit, so they do not provide the needed protection to the cable from digging and contaminants in the soil.

11.5.4 Factories and Assembly Plants

Designing and installing a DAS in factories and assembly plants is just as challenging as in chemical and petrochemical plants. In factories and assembly plants, sophisticated machinery and robotics are used to reduce operational cost while increasing production. Factories and assembly plants are also taking advantage of wireless communication where a hardwired network connection is not practical as a networking alternative. Wireless offers installation cost savings and quicker deployment to remotely control and monitor the operations of mechanical motors and robotics from their plant's central command center.

Factories and assembly plants are constantly rearranging their production locations to make them quickly available for the next product to be manufactured or assembled. Some of these spaces could be a block or several miles away from the plant's central command center.

Factories and assembly plant owners are continuously planning, designing, and constructing new plants as well as tearing them down to make ready for the next product to be put into production. A designer and installer should be familiar with the customer's business and the type of operating environment the new plant will have. Operation environmental considerations include:

- Expected levels and size of dust and particulates
- Presence of steam or extended periods of high humidity
- Current levels of RF "noise" from equipment, electrical systems, and other RF systems
- Planned or projected addition or expansion of equipment, electrical systems, and other RF systems

NOTE: The most common approach to wireless is RF transmission in the 2.4 GHz and 5.8 GHz frequency bands using spread spectrum—a modulation technique which permits high speed communications while being designed to operate in noisy environments where multiple RF systems are present.

11.5.5 DAS and Wireless LAN Antennas

Machine locations and building structures will determine antenna placement for both DAS and wireless LAN antennas. The designer and installer would need:

- A floor plan design drawing of the machines locations.
- An architectural drawing of the building structure.
- Locations of existing antennas in use for business or operational functions (e.g., machine monitoring).

When extending a DAS in factories or assembly plants, a designer and installer should observe the locations of the existing or new wireless antennas to ensure that they do not interfere with each other.

11.5.6 Warehouses

The warehouses today are taking advantage of wireless technology by using radio frequency identification (RFID) to track inventory to its location. Warehouses today are also equipped with electromechanical machines that can be controlled and operated remotely using wireless, eliminating the traditional forklift driven by a human operator.

DAS and wireless system designers and installers should familiarize themselves with the warehouse operation and check for the following:

- The various types of RF systems used in the warehouse's operation
- The type of materials used to construct the warehouse walls (wood, cinder-block concrete, poured concrete with rebar, corrugated metal with I-beam framing, etc.)
- Footprint of the usable storage space and the type of storage racks used
- The height and width of the storage racks
- RF obstructions in the open ceiling space

Since a warehouse's primary characteristic is that of open space, keeping the RF signal contained inside the building needs close analysis, planning, and design concerning the antenna system and transmitter output power to prevent interference with the WSPs, PSAP, and other frequencies distributed throughout the warehouse.

11.6 Healthcare Facilities

11.6.1 Introduction

Safely managing wireless infrastructure within hospital walls is a serious challenge as a result of the explosive growth in consumer and medical wireless devices, the construction density of the hospital, and the wide variety of spectrum consumed in the hospital. This makes it almost impossible for a doctor's tablet, a patient's smartphone, and a wireless infusion pump to work simultaneously at the level of assurance required in the medical setting.

The wireless healthcare environment is characterized by inconsistent and widely varying practices as well as a dearth of standards. The hospital setting, in particular, faces the perfect storm of high growth in user demand for wireless services versus availability of spectrum with assurance, and the healthcare community is ill prepared to manage this challenge. Exacerbating growing demand issues are the potential for co-channel interference, device makers' calls for proprietary networks, and a lack of vendor-neutral best practices or standards against which network infrastructure can be installed and measured. These factors contribute to high cost and low network reliability.

The hospital environment is increasingly reliant on numerous wireless services that span the spectrum bands. There has been tremendous growth in healthcare apps, wireless sensors for health monitoring, handheld mobile devices for clinicians, and inpatient wireless medical devices. The increase in wireless medical devices, coupled with consumer and enterprise use of wireless networks in health care, require a reliable and well-engineered wireless network infrastructure with the assurance necessary to support these needs.

The Medical Grade Wireless Utility is a wireless infrastructure that encourages hospital facilities, IT, and Biomed executives to think of wireless as a utility like other base building utilities of electrical, mechanical, and plumbing and embed and protect it in the building. It includes three grades of service for consumer, enterprise, and medical grade applications. The grades of service span four networks including the:

- Wireless local area network (WLAN) —consisting primarily of 802.11 Wi-Fi
- Wireless wide area network (WWAN) —consisting of PCS/cellular, paging public safety radio, and two way radio
- Wireless clinical data network (WCDN) —includes telemetry and patient monitoring devices, infusion pumps, and other devices that transport life critical data
- Location local area network (LLAN) —includes all manner of location technologies (e.g., infrared, ultrasound, RFID, UWB, Zigbee, 802.11)

Each network is engineered with the assurance appropriate for each grade of service.

11.7 Schools and Colleges

11.7.1 Overview

Schools, colleges, and universities contain large and specialized spaces compared to typical commercial buildings. Special attention must be paid to those spaces during DAS design and installation.

11.7.2 Elementary and Secondary Schools

Elementary and secondary schools typically contain the following spaces requiring special attention:

- Classrooms
- Libraries
- Lunchrooms
- Laboratories
- Gymnasiums
- Cafeterias
- Stadiums
- Playgrounds; sports fields
- Long corridors
- Detached buildings (e.g., portable buildings used as single classrooms)

11.7.3 School Administration Entities

Many school administration entities (e.g., school board—governing public schools; board of trustees—governing private schools) have specific rules pertaining to cellular telephone usage on school properties by students. Those administration entities may have DAS usage prioritized as follows:

- Public safety two-way radio
- Campus operations two-way radio
- Cellular service for faculty and staff
- Cell service for student calls only to a public safety answering point (PSAP) (e.g., 911 center, 999 center) in time of an on-campus emergency

11.7.4 Colleges and Universities

Colleges and universities can contain spaces listed in other sections of this standard and may contain the following specialized spaces requiring special attention:

- Lecture halls
- Teaching laboratories
- Research laboratories
- Clean rooms
- Theater/music performance halls
- Arenas
- Dormitories/student apartments
- Stores, shops
- Restaurants, cafes
- Student health facility
- Receiving/storage warehouses
- Maintenance facilities
- Parking structures
- Hazardous waste storage facilities
- Large open grass fields or wooded areas

In addition to specialized functional spaces, a typical college or university is comprised of multiple buildings on parcels of land ranging from 20–200 hectares (50–500 acres).

DAS usage priorities are typically the same as the priorities listed for school administration, except student cell phone usage may be discouraged or limited while in class, but allowed elsewhere on campus.

NOTE: In-class phone usage may be limited to cellular calls by students only to a PSAP (e.g., 911 center, 999 center) in time of a campus emergency, or if a college or university has a student health facility, the DAS may be required to handle medical telemetry for patient vital signs monitoring equipment.

11.8 Retail Locations

11.8.1 Description

A retail location, for the purposes of this section, is any physical location where goods or services are sold, which includes a range of sizes and operational hours from temporary (e.g., “street vendor”) to single building owned by single vendor to the “mega mall”, which contain hundreds of individual vendors and are in excess of 93,000 m² (1,000,000 ft²) of building space. In addition to building space, retail locations often have an infrastructure for vehicles (e.g., parking lot(s), loading dock(s), public transit station).

While any retail location may have a DAS, large or multi-tenant retail locations typically consider and implement a DAS.

Multi-tenant retail locations are often termed “malls”. Malls are typically operated by a management group, and provide leasable space to vendors. These leasable spaces are served by common pedestrian areas (e.g., sidewalk, walkways). In addition to smaller leasable areas, a mall may also have one or more “anchor” stores, which are large stores often placed in prominent locations(s) to serve as a focal point.

11.8.2 DAS Challenges

The designers of DASs for shopping malls face a number of challenges. Larger malls are often configured to have individual stores of different sizes located in a centralized and covered housing. The housing, in turn, may assume different shapes ranging from single axis rectangular, through L-shaped or cross-shaped to more complex configurations. The mall may be open or closed, but typically the larger malls are of closed design. In the US, the majority of shopping malls occupy one, two, or, at most, three levels. Newer malls appear to be surpassing this, and many of the larger malls have many more than three levels, frequently going to 6 or 7 floors and occasionally going to up to nearly twenty (20) levels.

In addition to the challenges of providing adequate radio coverage in the mall, the designer is often faced with the requirement to provide satisfactory service in the car parking areas. Very often, parking for cars and buses is configured to surround the housing of the mall. The size of a car park is usually in relation to the person traffic expected at a certain time. (See Section 11.10 for more information concerning parking.)

The designer will require recourse to effective software planning tools and, in turn, possess a good understanding of the walls and ceiling types to understand the attenuation environment to ensure adequate coverage and capacity.

A variety of coverage patterns obtained from different antenna types will be expected. Many of the stores that open out to pedestrian areas tend to be long and narrow, confined to one floor. The pedestrian area itself is frequently long, occupying hundreds of feet in a straight line, or with bends and corners. In addition, malls may also contain open spaces, typically at walkway intersections or atriums that can be viewed from multiple levels and provide space for temporary events such as special displays, performances, exhibits.

In order to achieve good coverage, the designer will need to make recourse to the use of both omnidirectional and directional antennas. Directional antennas with different gains, and hence different 3 dB beamwidths, will sometimes be required. Distances encountered in some of the larger malls are significant, and the designer will need to understand the attenuation incurred by a run of coaxial cable from the media converter located in a TR to the antenna.

Occasionally, use will be made of two directional antennas placed back to back facing in opposite directions; see Figure 11-1.

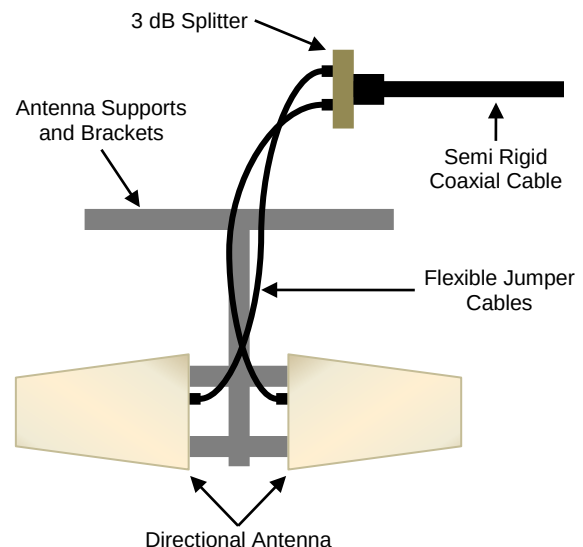


Figure 11-1
Outline for Coverage Model Provided by Two
Directional Antennas Back to Back

This antenna configuration would be used along a long corridor, such as a straight pedestrian walkway, to give effective coverage along the length of the walkway. A single coaxial cable would feed the antenna combination, but the main arm of a 3 dB splitter is attached to the coaxial cable, and short flexible jumper leads used to connect the arms after they split to each of the antennas. Care must be taken in the design of components and field installation of connectors onto coaxial cable to avoid generation of excess levels of third and higher order intermodulation products. Use must be made of low PIM products and installation techniques. It is recommended that in DASs involving high powers and larger numbers of carriers that field measurements of PIM are made to avoid encountering problems at a critical deployment stage. In particular, attention needs to be focused on flexible jumpers since metals in contact that move (e.g., braided jumper being flexed by vibration) can give rise to excess levels of intermodulation products.

11.9 Hospitality and Entertainment

11.9.1 Overview

Hospitality and entertainment venues include hotels, casinos, stadiums, convention centers, and arenas. The successful venue is made to support many people in relatively small geographical areas. This creates a particularly complicated design for DAS designers. The construction materials used to support many of these facility types and their environmental surroundings presents problems for DAS designers and installation technicians. They affect RF signal transmission and reception for cellular phones, two-way radios, broadcast radio, and Long Term Evolution (LTE).

11.9.2 Hotels

These structures are generally constructed with multiple floors and many small rooms with sound resistant walls and floors. Issues that affect a DAS design include:

- Account for 3 to 4 devices every 28–37 m² (300–400 ft²)
- Elevator and mechanical equipment ducting in the middle of the building
- Underground garage parking and utility areas
- Large conference areas with varying seating capacities

11.9.3 Casinos

The majority of these structures have large open areas and a high density of patrons. Issues that affect a DAS design include:

- Underground garage parking and utility areas
- Large conference areas with varying seating capacities
- Lots of electronics, and the newer ones generally have very high ceilings and numerous obstructions

11.9.4 Stadiums

Stadiums and arenas present unique issues because of the large amount of clients in one space. Old and new structures with capacities from 5,000 to over 100,000 people are common. Large crowds also create issues surrounding the venues during “game day” or events. Issues that affect a DAS design include:

- Larger coverage issues when the venue is used for special events (e.g., commencement ceremonies, concerts) as the “floor” of the stadium may also be used to seat additional people in excess of the permanent seating capacity.
- Old structures are constructed of large cement blocks for stability, which creates pathway issues as well as degraded coverage.
- Large open spans with limited opportunities for hanging antennas.
- Limited “closet space” for repeaters, amplifiers, and headend equipment.
- Underground parking and utility areas create huge emergency radio issues.
- New stadiums and arenas have less block and more steel structure.
- More office space and “hospitality” luxury boxes.

11.9.5 Convention Centers

Convention centers typically have large open spaces with multiple floors, underground facilities including garages, as well as a high people density within areas of the building or high volumes of people surrounding the venue during events.

11.10 Facilities for Vehicle Parking

11.10.1 Overview

Facilities for vehicle parking are unique structures. They can be stand-alone structures. They can also be structures attached to, or be integrated into, structures such as educational, entertainment, lodging, manufacturing, office, and retail buildings. Their construction and the construction materials used can present problems for DAS design and installation, plus adversely affect cellular, broadcast radio, two-way radio, and Wi-Fi RF signal propagation.

11.10.2 Stand-Alone or Attached Parking Structure Construction

The following is a listing of what might be found in parking structures:

- Main structure
 - Steel columns and beams with corrugated steel decking topped with concrete
 - Poured concrete columns, beams, and decking; all containing steel rebar
 - Precast concrete columns, beams, and decking; all containing rebar and/or post tension reinforcing cables
 - Precast concrete wall sections and decking; all containing rebar and/or post tension reinforcing cables
- Main structure's skin
 - Metal (e.g., aluminum, steel, etc.)
 - Concrete and/or masonry, containing rebar
 - Glass (Some glass treatments can adversely affect RF signal propagation)
 - Plastic
- Mechanical, Electrical, Plumbing Systems (MEP Systems)
 - Ventilation ducts and fans for the removal of vehicle exhaust fumes and providing fresh air; HVAC for office space and pay attendant booths
 - Electrical, fire alarm, and vehicle counting wiring plus communication cabling conduits, typically metallic. Portions of vertically installed conduits may have steel protection shields over them for protection from vehicle crash impact. Emergency telephones, daily parking pass vending machines, IP cameras, and vehicle counting equipment may also be present.
 - Plumbing for rain water drainage, hose bibs for cleaning and maintenance tasks, fire protection piping for serving fire sprinklers and firefighting attack hose pack connections, and potable/drain lines for offices and pay attendant restrooms
- Elevators
 - Structural components and cabs
 - Electrical, fire alarm, and communication pathways, wiring/cabling, and components
 - Cab and shaft ventilation equipment
- Signage
 - Typically metal signage

There can be large quantities of certain construction materials, components, and equipment present in parking structures, which could adversely affect RF signal propagation. Depending on the design, construction, and equipping of the parking structure, a DAS may not be needed or a partial to full DAS build-out may be required.

11.10.3 Parking Facilities Integrated Into Structures

These parking facilities can be below, at or above ground level and the building itself. Sometimes it might not be apparent that a parking facility is integrated into a structure. Ground level parking may be behind retail spaces, office spaces, and back-of-house facilities (e.g., service areas, shipping and receiving facilities, etc.).

The same items (e.g., MEP systems, elevators) listed within Section 11.10.2, can be found in these parking facilities as well.

11.10.4 Parking Structure and Parking Facilities Construction Specifics

Many times electrical, fire alarm, and vehicle counting wiring, plus communication cabling conduits are installed in exposed, surface mounted fashion.

Low clearances can exist between a parking level and the one above it. Vans, pickup trucks and utility body equipped work trucks with tall roof-top mounted ladder or pipe racks might not fit in a parking structure or parking facility.

Careful design and placement of DAS antennas to be mounted to the underside of parking level decks is required, so vehicles will not damage the antennas.

Panel-type DAS antennas should be placed at a height sufficient enough to:

- Not be blocked tall parked vehicles
- Facilitate angular elevation changes of the antenna's coverage to cover ramps between parking levels
- Minimize risk of vandalism

Multi-level parking facilities are typically constructed with open sides, making it more difficult to design a DAS that will keep its signal contained within the facility.

DAS electronic equipment such as WSPs' equipment, BTSs and amplifiers should be placed in a secure and conditioned space such as a telecommunication room.

11.10.5 External Concerns

Nearby buildings and objects of similar size or mass in proximity to the parking structure should be considered as these buildings and objects may adversely affect RF signal propagation.

Appendix A Legal Aspects of Wireless Design (Informative)

This appendix is not part of the requirements of this standard, but it is included to provide additional information related to this standard.

A.1 Introduction

Design the DAS based on building or site inspections, customer preference, system performance, and potential growth. In addition, minimize safety and liability concerns through compliance with the rules and regulations established by organizations such as the Occupational Safety and Health Administration (OSHA) and Federal Communications Commission (FCC).

A.2 Setting the Legal Context

A.2.1 Design Professional's Environment

Architects, engineers, and designers of any structure or system face the threat of legal action or claims on every project they undertake.

Designers of wireless systems are professionals in their own right once they have the required skills and certification.

NOTE: The installer's liability stems from the performance of installations in the field.

The wireless designer's responsibility is to provide the client with specifications for a wireless communication system that will meet the client's performance requirements and budget constraints. The design typically is a schematic or diagrammatic representation of the intended system or network and contains:

- A list of materials.
- An installation plan.
- A cost analysis.

Wireless designers typically perform some type of preliminary onsite survey or inspection. This is necessary because a designed or recommended system must address the environmental constraints in which the communication system will be installed and operated. In addition, consideration of appropriate countermeasures for threats unique to that particular area, environment, or building or its occupants also may be required.

The wireless designer's environment is governed by the regulations, standards, codes, and norms within the industry. Norms can be the most problematic. Norms are dynamic and usually arise in trade usage or trade custom as opposed to the standards and codes, which may have the same purpose as norms but are more specific and readily available.

The following definitions convey the general meaning of regulations, standards, codes, and norms:

- Regulations are similar to statutes and are made by a governmental commission, department or bureau as authorized by statutes created by the legislature (e.g., Parliament, Congress). They usually are referred to as subsidiary laws or legislation or as bylaws.
- Standards are a set of minimum requirements established by a standards development organization.
- Codes are rules specified by governmental entities. Consequently, codes are usually enforceable by governmental entities. Codes are also known as bylaws.
- Norms may transcend state and professional regulations and may represent the informal practices adopted by a particular discipline that are so prevalent that wireless designers may be expected to have knowledge of and adhere to them.

Failure to adhere to regulations, standards, codes, and norms usually gives rise to legal liability. The wireless designer should recognize that each case will vary according to its facts and environment. A court has the authority to decide whether a particular regulation, standard, code, or norm that is applicable in one context is relevant in another. Therefore, design professionals should use all of the available legal means to protect themselves from liability as early in the project as possible by setting a suitable context and environment in which the work will be performed. The social environment also may impact the liability or exposure of wireless design professionals.

Against this background, there has been a proliferation of claims against design professionals with courts willing to ignore privity requirements and find design professionals liable to third parties for their actions or omissions.

NOTE: The principle of privity in the common law's "law of contract" dictates that an individual cannot sue on a contract to which he or she was not a party. A common example of the principle in operation is that if A (a consumer) buys goods from B (a retailer) which B had originally bought from C (the manufacturer) which turn out to be faulty; A cannot sue C in contract law because A has no contract with C.

The opportunity to secure a good outcome in any wireless design project rests with the design professional. When projects fail, judges most often will determine what the parties intended. This appendix attempts to inform wireless designers about the benefits of writing contracts themselves.

A bad outcome on a project usually means that there is some form of legal liability for the wireless design professional. Legal liability is based on either statutes or judge-made (case) law. Case law is inclusive of regulations, norms, standards, and codes.

The legal liability of a wireless designer under statutes or codes is separate from the liability in the court to third parties. In the first case, the wireless designer is liable for fines or penalties that may be prescribed by the code or regulation. In the latter case, the wireless designer is liable to pay damages that a court or judge may order.

A.2.2 Regulatory Process

The liability of the wireless designer under the statute is typically strict. Strict liability means that the law does not provide a legal defense to the claim other than what is set out in the statute itself. It does not depend on the intention of the wireless designer. It is, therefore, clear from the outset what the wireless designer is required to do and what the consequences of failure will be. In some cases, it could lead to the loss of a license or certification. In others, the client will have to pay fines to the local or national authority, or the licensing process must be reinitiated.

Some rules are based on how the electromagnetic radiation spectrum (radio frequency [RF]) is regulated.

RF is regulated globally by the International Telecommunication Union (ITU). The ITU divides the world into three regions (see Figure A-1). RF is typically allocated and coordinated in these regions to prevent interference. The regulation of RF bands has been delegated by treaty to regions and national agencies throughout the world. The agencies have issued regulations that generally comply with ITU rules. The United States agency is the Federal Communications Commission (FCC), which will be referenced in this chapter for example purposes.

NOTE: There are both licensed and unlicensed RF bands. Wireless designers should be familiar with the relevant licensed and unlicensed RF bands for their jurisdiction.

During the site survey, the designer should ascertain whether a system license is needed, and if so, whether the client has commenced the licensing process. Ideally, this should be prior to commencing construction. In the United States, this requires that the potential licensee or his legal representative obtain a copy of the relevant section of the FCC's *Code of Federal Regulations*, Title 47, *Telecommunication*.

Once the basic layout of the network is determined and the decision has been made to use licensed frequencies, the system designer must determine which frequencies are available in the geographic area of interest. The FCC's regulations stipulate that the licensee work with a frequency coordinator to verify the availability of frequencies and that the proposed system meets the FCC's technical requirements. This reference to the FCC rules is not intended to be exhaustive but to sound a precautionary note to the wireless designer.

At all costs, the wireless designer must avoid the unknown. There is a duty to advise the client of the requirement, but there is no duty to accomplish it personally, especially if it is not the wireless designer's area of expertise. In this context, the legal liability can arise not only from mistakes made in carrying out the wireless designer's technical expertise but also from forays into uncharted waters.

Wireless designers who are unfamiliar with the regulations should work closely with a frequency coordinator or seek legal counsel that specializes in radio licensing issues. This will ensure that all pertinent regulations are followed. Radio licensing is an area in which wireless designers can be sued in contract by the client for not delivering what they were contracted to do.

NOTE: DAS installers need to coordinate and register signal boosters as required by the local AHJ.

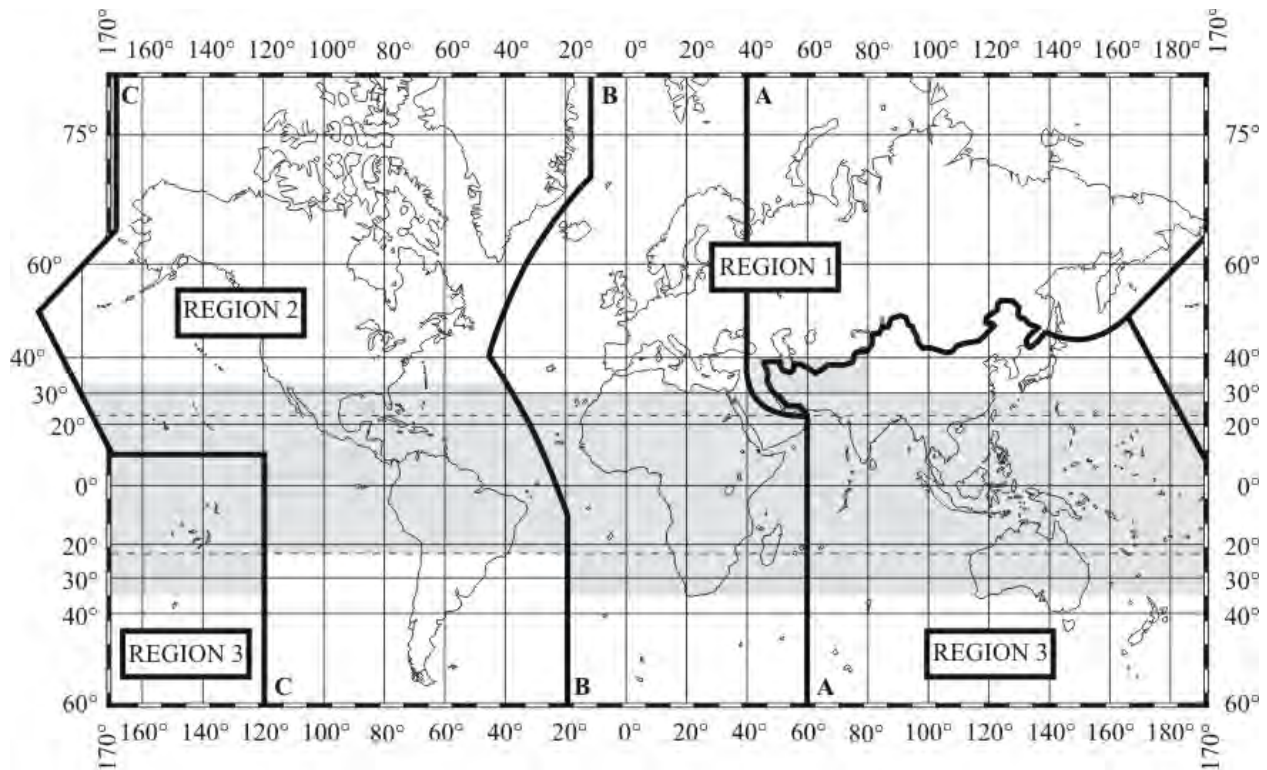


Figure A-1
International Telecommunication Union Regions

Wireless designers also could be sued by third parties for causing interference because of the failure to employ or recommend the employment of the necessary third-party professionals to make the relevant checks and clearances that would have enabled interference-free transmissions.

NOTE: It is important to determine the scope of work (SOW) from the outset as a means of limiting liability.

A.2.3 Approach of the Courts

The regulatory process is self-contained. This means that the statute and codes contain all the rules and procedures that govern the particular procedure, not necessarily in one place and not necessarily in terms that are easily understood by the layperson. The court's process is not overly self-contained and takes into account many factors.

As a general principle, liability is determined on the basis of an objective standard. This is often guided by an industry or professional standard. The legal standard in relation to the wireless design professional, for example, would be based on whether the wireless designer knew that there was licensed and unlicensed RF or whether the wireless designer recommended the right kind of equipment for the right kind of frequency. It is in context that the court may place a duty on the wireless designer to hire a frequency coordinator who is more likely to have made a recommendation that impacts the type and placement of equipment.

When interpreting contracts or determining liability in negligence, the court will take into account the acceptable standard within the industry or profession as well as examine the regulations, standards, and codes.

A.3 Legal Issues

A.3.1 General Duty of Wireless Designer

The most important duty of a wireless design professional is to engage in risk assessment and management. The methods of risk assessment and management figure prominently in any determination of legal liability. The assessor must determine the public's expectation of a design professional and against what standards those expectations will be measured. In such a context, contracts can best assist the design professional in avoiding, or at least minimizing, primary liability.

An equally important issue is how the design professional may avoid secondary liability. The design professional may be found primarily or secondarily liable in the tort of negligence for any loss or damage resulting from a faulty design. The negligence liability is based on the imposition of a duty on the design professional to be skillful, knowledgeable, and careful.

The design professional must have acquired the basic technical competency through formal education, internships, and certifications as well as the knowledge of current developments in the discipline. Yielding to the professional skills of other persons (e.g., scientific, financial, business, and legal professionals) as required is also important.

Many professional liability claims stem from nontechnical aspects of design practice, including:

- The acceptance of onerous contract terms and conditions
- Poor communication
- Careless selection of projects
- Failure to engage in risk assessment and management
- Failure to record all significant decisions and changes

The design professional has a duty to know, observe, and maintain the rules of professional conduct. In the case of a licensed professional, these rules are generally regulated or enforced by a licensing agency. The licensing agency typically has the power to admonish, censure, suspend, or terminate license or membership.

Regulations and codes are extremely important in the context of liability because they can form the basis of disciplinary action with remedies ranging from fines or suspensions to license revocations. Courts are entitled to consider regulations and codes in determining whether particular contractual stipulations are fair and reasonable and whether a particular faulty design was caused by the wireless designer's negligence.

Negligence also is determined by referring to the design professional's general duty to ensure public safety and welfare, whether on public or private property. This is an area in which codes, standards, and regulations interact with the general law insofar as these rules form part of the body of law that courts may consider in making a decision on liability.

A.3.2 Liability in Contract

Liability in contract may be purely contractual or for negligence. The liability in either case is restricted to the duties as defined in the contract between or among the parties to the contract. This is primary liability. Contracts may be oral or written. The rules of evidence relating to contractual liability are strict.

The general rule is that written contracts cannot be varied by oral or other, external, evidence. This usually is referred to as the four corners rule, the entire contract doctrine, or an integrated contract. This means that discussions, negotiations, and understandings prior to the execution of the contract are not admissible to vary the terms of the written document.

There are circumstances in which the court may admit evidence to show that an ambiguity exists or that other terms are incorporated by reference to other documents or discussions. With this in mind, wireless designers should incorporate all of their contract terms in writing, incorporating an entire agreement or integration agreement clause. This will ensure that no duties other than those agreed upon between the wireless designer and the client are imposed. This creates certainty that a court will review to confirm the intention of the parties at the time of contracting.

However, the wireless designer should consider that contracts often are also premised on implied terms. These implied terms are known as warranties. A warranty will not exist in all cases. Courts do not necessarily acknowledge an implied warranty that the design would be suitable for the intended purpose when appropriate assurances are missing. In such a case, the claimant has to show that the wireless designer has been aware of the circumstances and still gave an assurance or undertaking in the specific terms of the lawsuit.

NOTE: This kind of contractual liability exposes the design professional to third-party liability because warranty liability is not limited to negligent performance.

This is an area in which the doctrine of privity of contract has been eroded. The result is an increased exposure of the design professional to third-party claims.

Warranty liability is premised on representations that the work would not be defective and would conform to the contract documents. The warranty theory establishes a standard of performance rather than a standard of care exercised by the wireless designer and installer as the basis for liability. This liability is best understood by recognizing the changing role of the wireless designer and is more applicable where the wireless designer is a hybrid of consultant/installer or designer/installer or an installer.

The distinction between the expectations of the traditional wireless designer in the context of the separation of the three roles and the hybrid designer is that the traditional designer's work does not express or imply a warranty. The wireless designer does not warrant that the work would be carried out in a professional manner or in accordance with the specifications. However, the design/install or consult/install approach requires that the finished project comply with the owner's expectations. Therefore, the risk of the unknown contractually shifts from the owner to the wireless designer/installer. Consequently, the wireless designer/installer is required to perform exactly in accordance with the contractual specifications.

The loss of protection from liability to third parties by the erosion of the economic loss doctrine is closely linked to the issues arising from the warranty liability. According to the economic loss doctrine, the design professional has no liability to the entities to which the design professional does not guarantee contractual privity for purely economic losses or damages.

The economic loss doctrine does not apply throughout the United States. Therefore, design professionals need to seek appropriate legal advice to determine whether the doctrine is applicable in their area. For example, the Florida Supreme Court has ruled that the economic loss doctrine originated in the context of product liability cases and as such "should not be invoked to bar well-established causes of action in tort, such as professional malpractice." The court thus decided that action can be brought against a professional for negligence even for purely economic damages.

In summary, the argument that there is no contractual relationship between the claimant and the design professional may not succeed in some courts. Design professionals may find that they cannot hide behind contractual terms to escape liability. Thus, the importance of very clear contractual terms for work and respective risks cannot be overstated. As little as possible should be left to implication or imagination. Furthermore, wireless designers should only accept the work for which they are qualified.

A.3.3 Liability in Tort—Secondary Liability

Although liability for negligence can arise in a contract, it is a separate and distinct head of liability. The distinction between contractual negligence and tortious negligence is that where negligence is claimed under the contract, it will be restricted to, and hence determined in accordance with, the terms of the contract and between or among the parties to the contract.

Liability in tort is usually wider than the liability arising under a contract because it is premised on a general duty to exercise due care and skill. Notwithstanding the contract terms, the wireless designer may become liable to third parties for negligence. This is what is commonly referred to as secondary liability. It is based largely on expectation.

The expectation from design professionals varies based on whether at the material time they are consulting, designing, or installing; in fact, they may be performing all three tasks:

- The consultant is in the business of giving professional advice.
- The wireless designer creates a plan according to the consultant's recommendations.
- The installer implements the system according to the specifications of the plan prepared by the wireless designer.

The separation of the various areas of the design professional's practice is for ease of analysis, bearing in mind that one person may perform all three functions.

When acting as consultants, wireless designers may be liable for negligent misstatements because they are primarily in the business of giving advice. This liability may be in contract or in tort.

Wireless designers and installers may be liable for faulty designs or installations but generally not for negligent misstatements since they would be installing according to another wireless designer's specifications. Liability may be found in a situation where the wireless designer acting as a wireless designer or installer fails to design or install according to the owner's specifications or fails to exercise their professional judgment to ensure that the design is suitable for the particular environment.

Negligence has five elements:

- Duty
- Foreseeability
- Breach of duty
- Causation
- Damage

The analysis usually begins by determining who the neighbors are. This does not have a literal meaning and, therefore, does not have to be the person next door. This inquiry sets the framework for dealing with the first element of negligence—duty. The neighbors are the people the wireless designer should take into account to the extent that they may be impacted or harmed by the work. They include parties to the contract and third parties who in these circumstances are able to circumvent the contract and sue design professionals for damages. Therefore, the wireless design professional owes a duty of care to this category of people.

In several U.S. jurisdictions, it is common for third parties to sue professionals with whom they have no contractual relationship. Examples include:

- The likely users of a particular wireless local area network (WLAN) for a research data network for library services.
- The issue of how secure it should be and the consequences that flow from inadequate security where there are third-party end users.
- Whether the library administrators who also use this network to transmit and store financial information that was hacked into and stolen can sue the wireless designers of this network.

The wireless designers cannot be sued because they were not asked to design a network with sufficient security to carry or store financial information.

The duty imposes a standard of care and skill on the design professional. This is measured against what is required in the profession by referring to the standards, norms, and codes that govern that profession in the public interest. This duty varies according to the context in which the wireless designer is working.

The term context refers to the place, time, or particular circumstances of the task that the design professional is required to perform. It varies based on whether they are consulting, designing, installing, or engaged in a task for which they have no particular expertise. This explains why judges decide each case according to its particular facts though each case is considered according to the principles of the law that governs the area of liability.

Design professionals must perform within their areas of competence as the risk of liability for negligence increases with each deviation from their particular expertise and knowledge. The scope of duty is limited or restricted by the concept of foreseeability. In general, a third party's opportunity to sue is restricted to whether the injury can reasonably and objectively be predicted to result from the design professional's act or omission.

In concrete terms, liability is determined based on whether the wireless designer knew or should have known of the risk associated with choosing, for example, one type of security over another. The design professional is expected to investigate and determine if a certain type of product, system, or application is inadequate for the types of risks associated with the project or the requirement of the client or the environment.

Only when the injury was reasonably foreseeable is the design professional found liable for breach of the duty of care to a third party. The standard of reasonable conduct for the design professional may be determined by juries.

The assessment of whether the duty has been breached includes, but is not limited to, the following factors:

- Reasonable efforts to ascertain the physical and operational environment of the communication system(s) so that it can be determined whether the design would be appropriate
- Contact with architects, engineers, general contractors, other trades, information technology (IT) department, facilities department, or other entities relating to a particular location or design
- Internal procedures for determining designs
- Response to negative information regarding the feasibility of the design

With appropriate risk management techniques, a design professional may successfully avoid liability to third parties by minimizing the foreseeable risks and the class of persons to whom the duty is owed.

Assuming that a likelihood or possibility of breach exists, the injury suffered by the third party must have been caused or most likely have been caused by the design professional's breach. Therefore, the injured third party is required to show that it is more probable than not that the design professional's act or omission caused the alleged injury.

Having established liability, the third party must go further to demonstrate damage. The third party also must show that loss was suffered as a result of the breach.

The recoverable damages can include:

- Loss of earnings and loss of future earning capacity.
- Past medical expenses and future medical expenses.
- Pain and suffering.
- Disfigurement.
- Permanent or temporary physical impairment.

These are classic remedies in tort theory. In the context of wireless design, it appears that the courts will be struggling more with quantifying the costs of the loss of information.

A.4 Limiting Legal Costs

A.4.1 Alternative Dispute Resolution (ADR)

Litigation is very expensive both in terms of legal costs and the time spent away from business to attend court, meet with lawyers, or collate evidence. In drafting contracts, it is necessary to include alternative and less expensive methods of dealing with disputes, such as alternative dispute resolution (ADR).

The two most common forms of ADR are:

- Mediation.
- Arbitration.

A.4.2 Mediation

Mediation is a nonbinding, facilitated, negotiation process. Its aim is to produce voluntary and acceptable settlement agreements between or among the parties that are involved in a dispute. Although the process starts out as nonbinding, once an agreement is reached and duly signed by the parties, it becomes binding.

A mediator is a person who is trained in dispute resolution, including negotiation techniques, and is familiar with the art of “making a deal.” The mediator is neutral and does not offer legal advice but is actively engaged in the discussion process, including narrowing down the issues, offering alternatives, and directing the parties toward a settlement of the dispute.

Mediation is less expensive in part because the preparations, including the mediator’s fees, are lower than the regular court process fees (e.g., filing of pleadings, disclosure of documents, and attendance for depositions). Mediation offers more flexibility because it is not restricted or bound by the rules of law or legal precedents, making agreements broader and less laden by the rules.

A.4.3 Arbitration

Arbitration is more rule-laden than mediation. An arbitrator is required to apply the law relating to the particular subject matter. Although having one arbitrator is not unusual, it is more common to have a panel of three or more arbitrators. At least one arbitrator is a lawyer, whereas the others may be people familiar with the dispute’s subject matter.

Arbitrators hear evidence in the same way as in a court of law. However, the rules of evidence are more relaxed. In addition, discovery is not as rigorous as pretrial discovery, and the more formal requirements of a trial (e.g., preparation of briefs or closing arguments) are not necessary.

To take full advantage of ADR, it is recommended that it be included in the contract. The initial agreement makes arbitration mandatory between the parties.

In the construction industry, a standard American Arbitration Association (AAA) clause is used. Generating standard AAA clauses for use by wireless designers would be useful. Merely stipulating arbitration without specific details is inadequate for giving a full effect to the intentions. The intentions may be subject to differing rules of interpretation, and thus, the process must be specified.

Some of the important details the clauses must stipulate include:

- The number of arbitrators.
- How they would be chosen.
- Whether the decision would be unanimous or by majority.

A.5 Limiting the Design Professional's Liability

Wireless designers could benefit from the experience of the construction industry, which appears advanced in dealing with professional liability issues. Some of the liability avoidance techniques used in that industry are summarized in this section.

The erosion of the doctrine of privity suggests that design professionals have to be perceptive about the contractual arrangements or their relationship with the owners and the contractors. The construction industry has minimized this exposure by changing the manner of interaction with the builders/owners.

Such interaction was achieved by first changing the relationship from a supervisory role to an inspection role. Second, the inspection role was reduced to the role of observing the work for limited purposes of:

- Ascertaining whether the work was professional.
- Assessing whether the work generally conformed to the contract requirements.
- Advising the owner whether to pay for the work.

The single most important precautionary measure is to avoid oral agreements. Given the nature of the wireless designer's job, all contracts and amendments should be in writing.

In addition, risks can be more carefully allocated when they are fully recognized at the outset. Independent legal advice is recommended to ensure that design professionals do not sign one-sided contracts prepared by the contractors or the owners' attorneys or contracts laden with terms with very serious implications, particularly as related to risk allocation.

Fairness is a requirement on both sides so that inasmuch as unfair contractual terms should not be signed by one contract party, unfair contractual terms should not be imposed on the other contract party. Courts look with disfavor upon unfair contractual terms.

An unfair contract can be as serious as having no contract at all. It also is advisable to insert provisions for early termination of the contract and for a reasonable limitation of damages consequent on early termination.

The scope of services to be provided should be clearly defined and closely regarded. Any variation from the original terms must be put in written form after a careful analysis of the risks and costs involved or associated with the change. Warranties, indemnities, and guarantees should be avoided.

Limitations of liability are another method that can be used to allocate the risks associated with a particular project. One of the most common expressions of limitation of liability clauses is when the client and the wireless designer agree to limit the design professional's risk to the sum of the professional fees.

With the evolution of high availability IT sites like data centers, the value of lost uptime because of manufacturing, installation, or design has increased. If a critical error is traced back to the wireless designer, the amount of the claim can be substantial. This is yet another reason to continue being educated on the legal issues arising from wireless projects.

A.6 Liability on Projects

The previous paragraphs examined the liability of wireless professionals in relation to their contractual duties and any secondary liability flowing from those contracts. This section will provide an overview of the wireless designer's liability when undertaking the management of an entire project from its initiation to completion. In this context, the obligations of project managers arise in a different context that may relate to their responsibility and, hence, liability for the safety of their employees, workers, and third parties who enter or are expected to enter the site.

The project manager can be found liable in this respect for the various types of torts such as negligence in failing to provide a safe system of work. An otherwise safe environment in which to work could result in the wireless designer being held liable as an occupier of the premises, for an environmental or occupational safety type of tort, or for safety breaches.

These liabilities can be prevented or minimized by developing an appropriate safety plan. Project managers need to be aware that their responsibility for these systems and persons should be excluded from the contract unless it is a task that cannot be delegated to someone else.

After ensuring that there is adequate insurance on the project, it should be determined at the outset whether the owner or the project management team is responsible to pay for this insurance.

Appendix B Tools Used for Testing Coaxial Transmission Lines and Antennas (Informative)

This appendix is not part of the requirements of this standard, but it is included to provide additional information related to this standard.

B.1 Introduction

The list presented within this appendix is a guide, in that other items of equipment, cables, adaptors, etc. may be required to fully carry out the test types listed.

The following tools are typically used for testing coaxial cable used for transmission:

- Time domain reflectometer
- Spectrum analyzer
- RF Signal generator/monitor
- 50-ohm thru-line wattmeter
- 50-ohm termination load
- Swept frequency analyzer

B.2 Time Domain Reflectometer (TDR)

A TDR is used to verify:

- Length of the transmission line
- Continuity of the transmission line (i.e., open or shorted)
- Connectors on the transmission line

A TDR can also determine the existence and location of faults on, or damage to, a transmission line, sufficient to impact the signal-carrying ability of the line.

B.3 Spectrum Analyzer

A spectrum analyzer is used to:

- Verify the coaxial transmission line and the antenna response at the operational RF
- Troubleshoot co-channel and adjacent channel interference, harmonics, radiation propagation pattern, and signal levels

B.4 RF Signal Generator/Monitor

A RF signal generator is used as:

- A RF signal source for testing a transmission line or antenna
- A RF receiver to look at the operating received signal level on the installed transmission line coming in from the antenna

A RF signal generator with a range of 1 milliwatt to 1 watt signal transmit output capability is preferable.

B.5 50-Ohm Wattmeter

A 50-ohm wattmeter is used to:

- Verify the forward RF energy and reflected power on the transmission line and antenna at the operational transmitter frequency
- Determine the voltage standing wave ratio (VSWR) on the transmission line

A 50-ohm wattmeter with plug-in frequency power rated elements or an auto sensing frequency power meter is preferable.

B.6 50-Ohm Termination Load

A 50-ohm termination load is used as:

- A termination point at the end of the coaxial transmission line during testing
- A 50-ohm test reference for a spectrum analyzer

The 50-ohm termination load should have a minimum RF power rating of 1 Watt.

B.7 Swept Frequency Analyzer

A swept frequency analyzer is used for measuring:

- The return loss of cables assemblies and antennas
- Passive intermodulation levels of equipment (subject to end user requirements and demands)

Appendix C Hazardous Environments and Locations (Informative)

This appendix is not part of the requirements of this standard, but it is included to provide additional information related to this standard.

C.1 Definitions

C.1.1 Common Terms

The following terms are commonly used when discussing hazardous (classified) locations:

explosion proof: A container that is capable of withstanding and containing an explosion of a gas or vapor that may occur within it. The container must prevent any surrounding gas or vapor from being ignited by sparks, flashes or explosions within it or by the external temperature of the container itself.

hazardous atmospheres: Locations where fire or explosion hazards may exist because of flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings. Such environments are also referred to as "classified" atmospheres.

intrinsically safe: A device in which any spark or thermal effect is incapable of causing ignition of the flammable or combustible material in air. A device (such as a two-way radio) that is rated intrinsically safe is so rated only for the particular locations specified on its case (e.g., Class I, Division 1). The rating includes the battery and all accessories that may be connected to it. The rating for the entire system is invalid if any non-rated accessory or battery is used.

nonincendive: A device that is incapable of igniting flammable or combustible material in air because of arcing or thermal means under normal operating conditions.

ruggedized: Primarily a marketing term used by manufacturers and vendors to refer to a device that has been constructed to withstand certain harsh environments, such as heavy vibration, rain, wind, and/or blowing dust or sand. Also called "hardened," these units often conform to military or government standards for such environments or have been tested and assigned an ingress protection rating per IEC 60529. There is no connection between "ruggedized" devices and devices rated for classified atmospheres. Such units are *not approved* for hazardous locations.

C.1.2 Definitions for Hazardous Locations from 29 CFR 1926.449

NOTE: This is an excerpt from the United States *Code of Federal Regulations* (CFR) Part 29, Section 1926.449 (2011), which provides definitions for electrical issues in labor safety. The definitions here are essentially equivalent to those given in the *National Electric Code* (NEC), Chapter 5.

C.1.2.1 Class I Locations

Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. Class I locations include the following:

- Class I, Division 1

A Class I, Division 1 location is a location:

- (1) In which ignitable concentrations of flammable gases or vapors may exist under normal operating conditions; or
- (2) In which ignitable concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or
- (3) In which breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases or vapors, and might also cause simultaneous failure of electric equipment.

NOTE: This classification usually includes locations where volatile flammable liquids or liquefied flammable gases are transferred from one container to another; interiors of spray booths and areas in the vicinity of spraying and painting operations where volatile flammable solvents are used; locations containing open tanks or vats of volatile flammable liquids; drying rooms or compartments for the evaporation of flammable solvents; inadequately ventilated pump rooms for flammable gas or for volatile flammable liquids; and all other locations where ignitable concentrations of flammable vapors or gases are likely to occur in the course of normal operations.

- Class I, Division 2

A Class I, Division 2 location is a location:

- (1) In which volatile flammable liquids or flammable gases are handled, processed, or used, but in which the hazardous liquids, vapors, or gases will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment; or
- (2) In which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operations of the ventilating equipment; or
- (3) That is adjacent to a Class I, Division 1 location, and to which ignitable concentrations of gases or vapors might occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

NOTE: This classification usually includes locations where volatile flammable liquids or flammable gases or vapors are used, but which would become hazardous only in case of an accident or of some unusual operating condition. The quantity of flammable material that might escape in case of accident, the adequacy of ventilating equipment, the total area involved, and the record of the industry or business with respect to explosions or fires are all factors that merit consideration in determining the classification and extent of each location.

Piping without valves, checks, meters, and similar devices would not ordinarily introduce a hazardous condition even though used for flammable liquids or gases. Locations used for the storage of flammable liquids or of liquefied or compressed gases in sealed containers would not normally be considered hazardous unless also subject to other hazardous conditions.

Electrical conduits and their associated enclosures separated from process fluids by a single seal or barrier are classed as a Division 2 location if the outside of the conduit and enclosures is a nonhazardous location.

C.1.2.2 Class II Locations

Class II locations are those that are hazardous because of the presence of combustible dust. Class II locations include the following:

- Class II, Division 1

A Class II, Division 1 location is a location:

- (1) In which combustible dust is or may be in suspension in the air under normal operating conditions, in quantities sufficient to produce explosive or ignitable mixtures; or
- (2) Where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through simultaneous failure of electric equipment, operation of protection devices, or from other causes, or
- (3) In which combustible dusts of an electrically conductive nature may be present.

NOTE: Combustible dusts which are electrically nonconductive include dusts produced in the handling and processing of grain and grain products, pulverized sugar and cocoa, dried egg and milk powders, pulverized spices, starch and pastes, potato and wood flour, oil meal from beans and seed, dried hay, and other organic materials which may produce combustible dusts when processed or handled. Dusts containing magnesium or aluminum are particularly hazardous and the use of extreme caution is necessary to avoid ignition and explosion.

- Class II, Division 2.

A Class II, Division 2 location is a location in which:

- (1) Combustible dust will not normally be in suspension in the air in quantities sufficient to produce explosive or ignitable mixtures, and dust accumulations are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus; or
- (2) Dust may be in suspension in the air as a result of infrequent malfunctioning of handling or processing equipment, and dust accumulations resulting therefore may be ignitable by abnormal operation or failure of electrical equipment or other apparatus.

NOTE: This classification includes locations where dangerous concentrations of suspended dust would not be likely but where dust accumulations might form on or in the vicinity of electric equipment. These areas may contain equipment from which appreciable quantities of dust would escape under abnormal operating conditions or be adjacent to a Class II Division 1 location into which an explosive or ignitable concentration of dust may be put into suspension under abnormal operating conditions.

C.1.2.3 Class III Locations

Class III locations are those that are hazardous because of the presence of easily ignitable fibers or flyings but in which such fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures. Class III locations include the following:

- Class III, Division 1
A Class III, Division 1 location is a location in which easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.
NOTE: Easily ignitable fibers and flyings include rayon, cotton (including cotton linters and cotton waste), sisal or henequen, istle, jute, hemp, tow, cocoa fiber, oakum, baled waste kapok, Spanish moss, excelsior, sawdust, woodchips, and other material of similar nature.
- Class III, Division 2
A Class III, Division 2 location is a location in which easily ignitable fibers are stored or handled, except in process of manufacture.

C.2 Hazardous Atmosphere Classifications

C.2.1 Introduction

In the U.S., hazardous locations are defined by Part 29, section 1926.449 of the U.S. *Code of Federal Regulations* and by Article 500 of NFPA 70. Hazardous locations are divided therein by *Division*, *Class* and *Group*. While these categories are summarized below, numerous requirements are not listed here such as temperature limits.

In an effort to facilitate compatibility among the many national codes throughout the world, IEC 60079-10 defines a classification system using *Zones*. They are similar to the Divisions used mainly in North America; however, they are only used in conjunction with Class I locations. (See Table C-1 for a comparison of terms).

NOTE: NFPA 70 provides for the Zone system in Article 505.

Anyone intending to use equipment in a hazardous location is advised to become familiar with hazardous location requirements applicable to the specific site.

C.2.2 The Division System

C.2.2.1 Division 1 (Intrinsically Safe)

Locations where the particular hazardous materials are present in the air in potentially flammable concentrations continuously, frequently or intermittently. The energy level available in the equipment is sufficiently low so as not to cause ignition of the explosive atmospheres when the equipment is properly used.

C.2.2.2 Division 2 (Non-Incendive)

Locations where the hazardous conditions are only present in the case of a mechanical breakdown, accidental failure or abnormal operation of equipment (e.g., a room containing normally sealed containers or positive mechanical ventilation), or locations adjacent to Division 1 locations where ignitable concentrations might occasionally be communicated.

NOTE: Equipment listed for use in Division 1 is acceptable in Division 2 locations, but not the reverse.

Table C-1 Comparison of Terminology

29 CFR 1926.449 / NFPA 70		IEC 60079-10
Division 1		Zone 0
		Zone 1
Division 2		Zone 2
Class I		Class I
	Group A	Group IIC
	Group B	
	Group C	Group IIB
	Group D	Group IIA
Class II		N/A ¹
	Group E	
	Group F	
	Group G	
Class III		

¹ Equivalents not defined

C.2.2.3 Class I

Locations in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.

- Group A—Atmospheres containing acetylene
- Group B—Atmospheres containing hydrogen or gases or vapors of equivalent hazards such as manufactured gases
- Group C—Atmospheres containing ethylether vapors, ethylene, or cyclopropane
- Group D—Atmospheres containing gasoline, hexane, naphtha, benzene, solvent vapors, natural gas and similar compounds

C.2.2.4 Class II

Locations which are hazardous because of the presence of combustible dusts.

- GROUP E—Atmospheres containing metal dust
- GROUP F—Atmospheres containing coal or coke dust
- GROUP G—Atmospheres containing combustible dusts not included in Groups E or F, including flour, grain, wood, plastic, and chemicals

C.2.2.5 Class III

Locations which are hazardous because of the presence of easily ignitable fibers or flyings, but in which such fibers or flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.

C.2.3 The Zone System**C.2.3.1 Zone 0**

Includes most of Division 1. Locations where ignitable concentrations of flammable gases, vapors, or liquids can exist continuously or for long periods of time under normal operating conditions.

C.2.3.2 Zone 1

Includes the rest of Division 1. Locations where ignitable concentrations of flammable gases, vapors, or liquids can exist some of the time under normal operating conditions.

C.2.3.3 Zone 2

Essentially the same as Division 2. Locations where ignitable concentrations of flammable gases, vapors, or liquids are not likely to exist under normal operating conditions.

C.2.3.4 Class I

Locations in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. Same as the Division system.

C.2.3.5 Group IIC

Atmospheres containing acetylene, hydrogen, or gases or vapors of equivalent hazards. Equivalent to a combination of Groups A and B.

C.2.3.6 Group IIB

Atmospheres containing acetaldehyde ethylene or flammable gas, flammable liquid-produced vapor, or combustible liquid-produced vapor. Equivalent to Group C.

C.2.3.7 Group IIA

Atmospheres containing gasoline, hexane, naphtha, benzene, solvent vapors, and similar compounds. Equivalent to Group D.

Appendix D Related Documents (Informative)

This appendix is not part of the requirements of this standard, but it is included to provide additional information related to this standard.

The following standards and documents are related to, or have been referenced within recommendations of this standard, and provide additional information which may be of use to the reader.

BICSI

- ANSI/BICSI 001, *Information Transport Systems Design Standard for K-12 Educational Institutions*
- ANSI/BICSI 004, *Information Technology Systems Design and Implementation Best Practices for Healthcare Institutions and Facilities*
- ANSI/BICSI 005, *Electronic Safety and Security (ESS) System Design and Implementation Best Practices*
- *Telecommunications Distribution Methods Manual*
- *Information Technology Systems Installation Methods Manual*
- *Outside Plant Design Reference Manual*
- *Electronic Safety and Security Design Reference Manual*

Institute of Electrical and Electronics Engineers (IEEE)

- IEEE 142 (The IEEE Green Book), *Recommended Practice for Grounding for Industrial and Commercial Buildings*
- IEEE 1100 (The IEEE Emerald Book), *Recommended Practice for Powering and Grounding Electronic Equipment*
- IEEE 802.11, *IEEE Standard for Information technology – Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*

International Code Council (ICC)

- *International Building Code (IBC)*

International Electrotechnical Commission (IEC)

- IEC 60079-10-1, *Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres*
- IEC 60079-10-2, *Explosive atmospheres - Part 10-2: Classification of areas - Combustible dust atmospheres*
- IEC 60364-4-43, *Electrical installations of buildings. Part 4: Protection for safety. Chapter 43: Protection against overcurrent*
- IEC 60529, *Degrees of protection provided by enclosures (IP Code)*
- IEC 62305-3, *Protection against lightning - Part 3: Physical damage to structures and life hazard*
- IEC 62305-4, *Protection against lightning - Part 4: Electrical and electronic systems within structures*

International Organization for Standardization (ISO)

- ISO/IEC 11801, *Information technology – Generic cabling for customer premises*
- ISO/IEC 14763-2, *Information technology – Implementation and operation of customer premises cabling – Part 2: Planning and installation*

International Telecommunications Union (ITU)

- *Radio Regulations*

Motorola Solutions

- *R56, Standards and Guidelines For Communication Sites*

National Electrical Contractors Association (NECA)

- *ANSI/NECA/BICSI 568, Standard for Installing Commercial Building Telecommunications Cabling*

National Electrical Manufacturers Association (NEMA)

- *NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum)*

National Fire Protection Association (NFPA)

- *NFPA 1, Fire Code*
- *NFPA 70E, Standard for Electrical Safety in the Workplace*
- *NFPA 75, Standard for the Fire Protection of Information Technology Equipment*
- *NFPA 76, Recommended Practice for the Fire Protection of Telecommunications Facilities*
- *NFPA 1221, Installation, Maintenance, and Use of Emergency Services Communications Systems*

Telecommunication Industry Association (TIA)

- *ANSI/TIA-222-G, Structural Standards for Antennae Supporting Structures and Antennas*
- *ANSI/TIA-568-C.0, Generic Telecommunications Cabling for Customer Premises*
- *ANSI/TIA-568-C.1, Commercial Building Telecommunications Cabling Standard*
- *ANSI/TIA-758-B, Customer Owned Outside Plant Telecommunications Infrastructure Standard*
- *ANSI/TIA-1005-A, Telecommunications Infrastructure Standard for Industrial Premises*
- *ANSI/TIA-1019-A, Installation, Alteration, and Maintenance of Antenna Supporting Structures and Antennas*
- *ANSI/TIA-1179, Healthcare Facility Telecommunications Infrastructure Standard*
- *ANSI/TIA-4966, Telecommunications Infrastructure for Educational Buildings and Spaces*
- *TIA TSB-162-A, Telecommunications Cabling Guidelines for Wireless Access Points*

United States Code of Federal Regulations (CFR)

- *Department of Labor; Occupational Safety and Health Administration (OSHA)*
 - *29 CFR 1910.132 through 1910.138 (Subpart I) Personal Protective Equipment*
 - *29 CFR 1910.146, Permit-required confined spaces*
 - *29 CFR 1910.268, Telecommunications*
 - *29 CFR 1910.303, Electrical, General Requirements*
 - *29 CFR 1926, Construction Standard*