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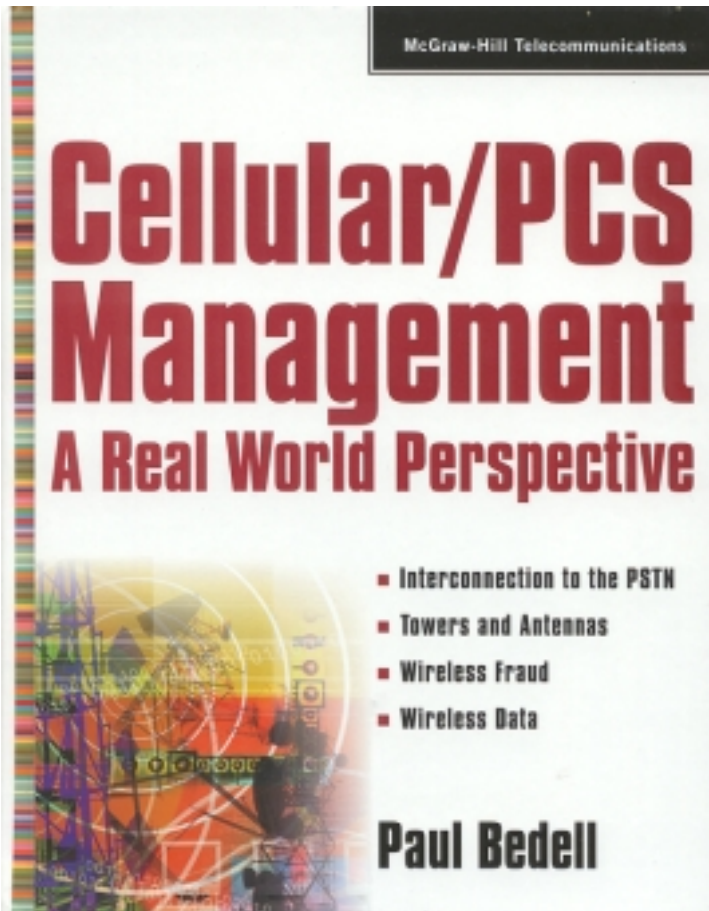
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CHAPTER

# 5

## Radio-Frequency Propagation and Power

## 5.1 Overview

Radio is an electromagnetic phenomenon in which energy travels in waves through a given medium. In the air, radio signals propagate at the speed of light: 186,282 miles per second. This equates to nearly a *billion feet per second!* The only significant functional difference between cellular telephone systems and the conventional landline telephone system is the *radio link* that connects the subscriber unit to the cellular network via the cell base station.

Radio frequencies differ in energy and ability to propagate media. Cellular frequencies are primarily reliant on direct waves; that is, they do not bounce off the earth's ionosphere as does short-wave radio, for example. However, direct wave does not mean that cellular radio signals are limited to line of sight. Radio signals can bend through the atmosphere (*refraction*), bend around obstructions (*diffraction*), and bounce off obstructions and solid objects (*reflection*). Radio-frequency (RF) propagation refers to how well a radio signal radiates, or travels, into free space. In the cellular industry, it refers to how well RF radiates into the area where cellular coverage must be provided, which is determined by RF engineers working for wireless carriers.

Omnidirectional (“all directions”) radio-frequency propagation can be compared to the waves created by throwing a pebble into a pond. The waves made by the pebble emanate in all directions equally. The waves are proportional to the *size and weight* of the pebble and the *force* with which it was thrown into the pond. This pebble-in-a-pond analogy applies to the design of RF coverage for a cell. Actual RF coverage is mainly determined by three key factors: the height of the cellular antenna (tower) at the base station, the type of antenna used at the cell base station, and the RF power level emitted. These three factors, together, equate to the size and weight of the pebble thrown in the pond, and the force with which the pebble was thrown

## 5.2 Ducting

Ducting is defined as the atmospheric trapping of a cell base station's RF signal in the boundary area between two air masses, hot air over cold air or vice versa. Ducting of a cellular RF signal is caused by an atmospheric anomaly known as *temperature inversion*. Ducting is an anomaly of nature that can affect how well RF propagates through a given area.

**EXAMPLE**

If the ground temperature is 30°F up to 2000 feet, and then there is a layer of ice cold or very hot air, the RF signal could be trapped between these two air masses and propagate for as long as the duct exists. The duct could go on for hundreds or even thousands of miles! This creates a problem because instead of being absorbed by ground clutter (which is usually desirable to a degree), once trapped the ducted signal could cause interference in distant cellular systems.

Ducting is undesirable in RF propagation design, but also unavoidable. *Downtilting* of cellular antennas may compensate for ducting. Downtilting is the act of electrically (and sometimes mechanically) directing the RF emitted by the cellular base station antenna toward the ground at a predetermined angle. (See Chapter 7, “Antenna Types and Uses.”) The most common place for ducting to occur is across large bodies of water like the Great Lakes. Michigan cell base stations are picked up routinely along the Illinois and Wisconsin shore lines and Illinois stations are routinely picked up in Michigan.

There are other physical anomalies that may affect propagation. What may happen to the signal must be examined and hopefully compensated for by cellular RF engineers when designing cell sites. “Hopefully” is the word because the anomalies mentioned above can have unpredictable consequences on RF propagation.

## 5.3 Signal Fading

There are three basic types of fading of cellular (UHF) signals: absorption, free-space loss, and multipath fading (also known as *Rayleigh fading*).

### 5.3.1 Absorption

Absorption describes how a signal is *absorbed* by objects. When a radio wave strikes materials it can be absorbed. Cellular RF can be absorbed by buildings, trees, or hills.

*Key:* Organic materials tend to absorb more RF signal than inorganic materials. Pine needles are noted for absorbing a great deal of cellular RF because their needle length is close to  $\frac{1}{4}$  wavelength of cellular signals.

Absorption can be compensated for by using higher-gain antennas and higher power levels, in order to cover the same geographic area.

Absorption can also be compensated for by using shorter spacing between cells. The greater the amount of absorption of an RF signal, the less geographic area covered.

### 5.3.2 Free-Space Loss

Free-space loss describes the attenuation of a radio signal over a given distance, or the path length of the signal.

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*Key:* The higher the frequency of a radio signal, the greater the free-space loss.

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Cellular radio power levels determine at what point a signal will completely fade away to nothing.

### 5.3.3 Multipath Fading (Rayleigh Fading)

When RF signals arrive at an antenna out of phase, they will either cancel each other out or supplement each other. One signal path arrives at an antenna (either mobile or base station) as a *direct* signal, while other signals are multipath, or *indirect*, signals. This phenomenon is known as *Rayleigh fading*. The indirect signals reflect off any and all objects in the path to the receiving antenna. These indirect signals arrive at receiving antennas via reflection paths.

RF signals can bounce off many objects, and some of the multipath reflected signals will arrive at antennas at different times, in or out of phase with the direct signal. This is known as multipath, or Rayleigh, fading. These indirect signals can add to or subtract from the direct signal arriving at the antenna. Multipath signals can reflect off bodies of water, vehicles, and even buildings on their way to a receiving antenna. See Figure 5-1.

## 5.4 Why the 800-MHz Band Was Assigned to the Cellular Industry

The radio-frequency spectrum that was assigned to the cellular industry was mostly unused UHF television spectrum. The “800 Meg” spectrum had been unused for years, and the TV broadcasters (networks) fought

  
**Figure 5-1**

Multipath (Rayleigh)  
fading.

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the FCC vehemently against reallocating their spectrum, even though it was grossly underutilized. The TV industry didn't use the spectrum, but also didn't want to give it up.

The following list describes the nature of radio propagation at 800 MHz, and explains why the assigned frequency range for cellular is mostly beneficial:

- Very short signal wavelength (about 12 in).
- Tends to be line of sight, similar to light itself. It is not really subject to skipping or bouncing off the ionosphere, as with short-wave radio for example.
- Signal is easily reflected off buildings, cars, and trucks.
- Signal is easily absorbed by foliage (i.e., trees, forest, etc.). This aspect of the 800-MHz spectrum can be both good and bad for cellular coverage. It is good because it allows for efficient frequency reuse. It is bad because it can cause problems when major coverage points of the cell (e.g., highways, towns) are in heavily wooded areas.

*Example:* A cell site in a California town covered by a redwood forest does not cover more than 1.5 mi at maximum power.

These factors combined make the 800-MHz spectrum ideal for cellular radio transmission.

## 5.5 Frequency Coordination

Frequency coordination is the effort to assign frequencies to cellular channels in such a way as to minimize interference within your *own* cellular system and *neighboring* systems of different wireless carriers. There are two kinds of frequency coordination: intramarket and intermarket.

### 5.5.1 Intramarket Frequency Coordination

This type of frequency coordination is internal to a cellular system (market). It is the effort to keep adjacent cell and cochannel cell channel assignments as far apart as practical and feasible. It is based on a frequency-reuse growth plan using the hex grid. Internal frequency coordination is done to minimize interference and optimize cellular system operations.

### 5.5.2 Intermarket Frequency Coordination

This type of frequency coordination is external to a wireless carrier's cellular system, and involves coordinating frequency assignments with neighboring cellular systems' border cells within 70 mi, according to FCC rule. The FCC dictates that all reasonable actions must be taken to limit and/or reduce interference between two cellular systems. This usually relates to border cells between two cellular markets. There are at least two ways to approach intermarket frequency coordination: (1) A cellular engineer could simply call the engineering department of a neighboring cellular company. Engineers from both companies would exchange information regarding frequency assignments at border cells for their respective markets, and work together to resolve possible interference problems. (2) An outside vendor could be hired to handle the situation. This is not advisable, because it costs extra money, and the results may not be as accurate and reliable as approaching the other cellular carrier directly.

## 5.6 System Interference

Interference is defined as any interaction of radio signals that causes noise or effectively cancels out *both* signals. Interference usually occurs between two radio signals whose frequencies are too close together, or even identical.

Base transmit and mobile transmit cellular frequencies were assigned with a 45-MHz separation between them to avoid interference. However, most interference experienced in cellular systems is still *internally* generated.

Higher frequencies may require less of a separation between transmit and receive than lower frequencies to reduce or eliminate interference.

### 5.6.1 Cochannel Interference

Cochannel interference occurs when there are two or more transmitters within a cellular system, or even a neighboring cellular system, that are transmitting on the *same* frequency (channel). This type of interference is usually generated because channel sets have been assigned to two cells that are *not far enough apart*; their signals are strong enough to cause interference to each other.

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*Key:* Cochannel interference, when it occurs, is a by-product of the basic tenet of cellular system design: frequency reuse.

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Though the basic principle of cellular system design is to reuse assigned frequencies over and over again throughout a system, it is also very important to ensure that the frequencies are reused far enough apart, geographically, to ensure that no interference occurs between identical frequencies (i.e., channel sets). Therefore, there must be enough base stations between cochannel cells to provide a level of protection to ensure that interference is thwarted and/or eliminated. In conjunction with ensuring that the cell sites are placed far enough apart geographically, the appropriate power levels must be maintained at cell base stations throughout a system to avoid cochannel interference.

The following factors must be carefully determined to reduce the possibility of interference to a minimum:

- RF power levels (most important factor)
- Geographic distances between cochannel cells (cells using the same sets of frequencies)
- Types of antennas used

As more cells are added to a system operating on cochannel frequencies, it becomes more difficult to keep cochannel interference at a level that is not noticeable to subscribers of cellular service. Cochannel interference could manifest itself in the form of cross talk, static, or simply dropped calls.

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*Key:* Cells that are cochannels must never be direct neighbors of each other. Other cells must be placed in between cochannel cells to provide a level of protection against signal interference.

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An “infant” cellular system can start out in its early developmental stages with no cells that are cochannel. But as the subscriber base grows, additional capacity is needed in the system. New cells and radio channels are added until a point is reached where cochannel frequencies must be introduced.

The following options are available to wireless carriers to reduce or eliminate cochannel interference:

1. Use downtilt antennas when and where appropriate (see Chapter 7)
2. Use reduced-gain antennas (see Chapter 7)
3. Decrease power output at base stations
4. Reduce the height of towers

## 5.6.2 Carrier-to-Interference Ratio

The carrier-to-interference ratio ( $C/I$ ) is a measure of the desired signal the cell or mobile phone “sees” relative to interfering signals.

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*Key:* Ideally, the goal in RF design is to have a  $C/I$  ratio of 18 dB or better throughout a cellular system to avoid cochannel interference. The 18-dB level was chosen by the cellular industry to obtain a “clean, noise-free, landline-quality signal.”

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There should be an 18-dB difference between *any given cell* and all other cells (and mobile phones) throughout a cellular system. The carrier-to-interference ratio is also known as the *signal-to-interference* ratio. The frequency-reuse plan is a tool used to keep the *C/I* ratio at the ideal level of 18 dB or better.

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*Key:* As more cells are added to a cellular system, a migration occurs from a noise-limited system to an interference-limited system. The system has more potential to produce cochannel interference and/or adjacent channel interference (described below).

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### 5.6.3 Adjacent Channel Interference

Adjacent channel interference is caused by the *inability* of a mobile phone to filter out the signals (frequencies) of adjacent channels assigned to side-by-side cell sites (e.g., channel 361 in cell A, channel 362 in cell B, where cells A and B are next to each other). Adjacent channel interference occurs more frequently in *small* cell clusters and *heavily used* cells.

Good system design can minimize adjacent channel interference temporarily by preventing adjacent channel assignments in cells that are next to each other.

There are differing views as to why specifications for mobile phones are so poor concerning their inability to filter out adjacent frequencies. However, this situation will not be changed soon, so cellular carriers must live with the problem and try to engineer their systems better to avoid this type of interference.

### 5.6.4 Intermodulation Interference

There are other types of interference that occasionally plague cellular systems. The most common form of interference, other than cochannel and adjacent channel interference, is *intermodulation* interference (IM). If a cell site is colocated with other radio-based services, *intermodulation interference* may result; competent engineering practices should overcome this interference.

Intermodulation interference describes the effect of several signals mixing together to produce an unwanted signal, or even no signal at all. Another type of IM is created by mobile phones themselves. If a

customer is on a call in close proximity to a cell site operating on the opposite band (A band/B band), the power from all of the radio channels in the cell can cause the receiver in the mobile phone to overload. When this happens the result will be a dropped call. This problem is a direct result of mobile phone manufacturers' reducing the cost of producing the phones. To resolve this situation, both cellular carriers operating in the market may have to place cell sites near each other so that a stronger signal is maintained in the mobile phone. Then, the mobile phone will not overload and drop the call.

## 5.7 Radio-Frequency Power

RF power is defined as the amount of radio-frequency energy, in watts, delivered by the cellular base station radio to the base station's transmit antenna. Power is determined by RF amplifiers used at the cell site and the amount of RF energy that is delivered to the base station antenna by the cellular radio (transceiver). There will also be loss of the signal as it propagates through the coaxial cable due to *impedance*. This is factored into cellular RF design by engineers.

### 5.7.1 ERP and How It Is Determined

*Effective radiated power* (ERP) is determined by multiplying the gain of the antenna (mobile or base station) times the power delivered to the base of the antenna. ERP is measured in watts.

*Example:* 10 W of radio energy directed into a 10-dB-gain cellular antenna equals 100 W of ERP.

*Author's note:* Formulas used to determine ERP can be very granular, as they represent logarithmic relationships. That is beyond the scope of this text.

### 5.7.2 Allowable Power Levels

**Cell Base Stations** In the cellular industry, carriers are allowed to use up to a maximum of 500 W ERP at cell base stations. The range of 100 to 500 W is primarily used in RSA base stations. BTS power levels used depend on the frequency-reuse pattern. Ideally, the maximum power level needed to provide coverage is used, but no more than that.

The average power level for MSA base stations (macrocells) is 20 to 100 W to cover an area from 8 to 30 mi. Again, this level will depend on terrain in the coverage area and antenna gain.

The actual range of ERP in a cellular system can be anywhere from 0.1 to 500 W.

**Mobile Telephones** Mobile telephones have allowable power classes assigned to them by the FCC. These power levels are known as *station class marks*, and have a range from 0.006 W (six thousandths of a watt) to 4 W. Mobile telephones (car installations) have higher power levels; they emit more power because they run off car batteries. Table 5-1 gives allowable power levels for different types of mobile phones in an AMPS system.

**TABLE 5-1**

Allowable Power Levels of Mobile Phones, Watts

Mobile Station Power Level	Station class marks		
	Class 1	Class 2	Class 3
0	4.000	1.600	0.600
1	1.600	1.600	0.600
2	0.600	0.600	0.600
3	0.250	0.250	0.250
4	0.100	0.100	0.100
5	0.040	0.040	0.040
6	0.016	0.016	0.016
7	0.006	0.006	0.006

## 5.8 Test Questions

### True or False?

1. \_\_\_\_\_ Downtilting of cellular base station antennas may compensate for the ducting phenomenon.
2. \_\_\_\_\_ There are three main types of signal fading: absorption, free-space loss, and cross-channel equalization.
3. \_\_\_\_\_ Inorganic materials tend to absorb more RF signals than organic materials.

4. \_\_\_\_\_ Ducting of a cellular RF signal is caused by an atmospheric anomaly known as *temperature inversion*.

## Multiple Choice

5. The three key parameters that determine actual RF coverage from any given cell base station are:
- (a) RF power levels at the cell base station
  - (b) The height of the cellular base station antenna
  - (c) The type of tower used
  - (d) The type of antenna used
  - (e) How many buildings are in the area
  - (f) None of the above
  - (g) a, b, and d
6. The higher the frequency of a radio signal, the greater the:
- (a) Absorption rate
  - (b) Free-space loss
  - (c) Antenna reverberation
  - (d) Cochannel interference
  - (e) None of the above
7. Cochannel interference describes which of the following?
- (a) Interference between mobile phones
  - (b) The inability of the mobile phone to filter out signals of contiguous cellular channels (e.g., channel 331, channel 332)
  - (c) Interference between two base stations transmitting on the same frequency
  - (d) All of the above
  - (e) a and b only
8. The *multipath* effect of cellular RF signals bouncing off of many objects, resulting in signals arriving at a mobile antenna at different times, in or out of phase with the direct signal, is known as:
- (a) Fessenden fading
  - (b) Uplink fading

- (c) Rayleigh fading
  - (d) Free-space loss
  - (e) Ducting
  - (f) None of the above
9. Radio signals in free space travel at:
- (a) The speed of sound
  - (b) Twice the speed of sound
  - (c) Half the speed of light
  - (d) The speed of light
  - (e) None of the above