PACIFIC CREST

Guide to Wireless Data Links

Notice

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Introduction

This guide is designed to provide a basic nuts-and-bolts awareness of the issues and tradeoffs concerning radio frequency data communication (RFDC). The objective is to provide the surveyor with the skills and knowledge required to successfully estimate the data link requirements, set up the data link, and to diagnose and fix problems that are common to these systems. Those interested in further understanding of the technical or academic aspects of RFDC should refer to the bibliography in Appendix B.

Before beginning, a few simple points. Radio data communication is not difficult or mysterious. Detailed knowledge of data and radio communication theory is not required. With an understanding of a few basic principles, you can design and set up an RFDC link that will provide reliable data communication.

Naturally, the physical laws of nature place bounds on what can be expected of an RFDC system. Recognizing these bounds and knowing some basic rules-of-thumb can be very helpful. You will find throughout this guide, text boxes which highlight things to do or things to avoid. Following these simple rules will allow you to get the most out of your RFDC system.

Maximize the performance of your RFDC system

First things first

How many of us have arrived at a job site, only to find that we have forgotten a cable, or battery, or other necessary component? We waste valuable time trying to track down the equipment, when this problem is best solved by being organized. Invest in a carrying case and system that assures all the necessary equipment is accounted for. This is not a radio issue per se, but we want to save you the frustration of arriving at a remote job site without the proper equipment!

Maintenance

Cables, connectors, and antennas are subject to stresses that ultimately lead to failure. Preventative maintenance is important to reduce down time. Inspect cables frequently and replace those that show wear. It's always a good idea to have a spare set of cables to cover for loss or failure due to normal wear and tear.

Batteries

Batteries are another concern. Especially in areas where high powered radio modems are used, the condition and degree of charge are critical for best operation. Only use batteries that are designed for deep discharge and frequent charging. Keep in mind that batteries degrade over time. Depending on usage patterns, you should replace your battery every one to three years.

Picking a location

Radio link range is directly related to antenna height. The best thing you can do to increase your system's range (a common complaint) is to get your transmitter (fixed base) and receiver (mobile) radio antennas as high as possible. If possible, select a base location that takes advantage of terrain, and make use of telescoping masts to improve range in all circumstances.

Use quality antennas

If you want superior performance, demand a high-quality antenna. Next to antenna height, having a good antenna is the most effective and inexpensive way to improve system performance. So-called rubber duck antennas are okay for short-range site surveys, but if you want the best possible performance, invest in a high-performance antenna. Our technical assistance staff can make recommendations for you depending on your application.

Select the best available channel

Radios often operate over a wide area depending on the application. If you work in a fixed location, a coordinated frequency is best used. For those who move about, the use of itinerant frequencies is called for. When you enter a new location, it's important to select a channel that minimizes interference with other users (and subsequent complaints), as well as one that provides the best operation. Radio frequency scanners can help you select the best channel for operation given conditions when setting up the RFDC system.

The table below summarizes the points made in this chapter. You will improve your level of success and satisfaction by following these simple rules.

1. Keep your equipment organized – a carrying case is helpful.
2. Inspect and replace cables and batteries before they fail.
3. Maintain spares of cables and other equipment prone to failure through normal wear and tear.
4. Select a location that takes advantage of terrain – the higher the better.
5. Elevate all antennas, especially in challenging base station locations.
6. Use high quality antennas. Rubber duck antennas are not for high performance systems.
7. Monitor and select an appropriate channel to minimize interference with other users.

Get a license

You are legally required to license your narrow-band radio modem system. We can recommend a licensing service that will help you with the paper work and the application process. (See section on Licensing and Regulations). If you operate without a license, you are subject to fines and possible equipment confiscation.

Turn off your radio when not in use

Never leave your base station broadcasting when you are not using the signal. Continuous operation, especially on itinerant applications, may lead to co-channel user complaints. Remember, data is secondary to voice in the itinerant bands. This means that if there's a conflict, you (the data user), are obligated to vacate the frequency.

Limit output power

If you're doing a local area survey on a construction site or other short range application, limit your RF output power by selecting the lowest power setting you need to get the job done.

Select a channel with the least activity

This is common sense. Monitor the available channels prior to operation and select the channel with the least activity.

Get along with co-channel users

If there's a complaint from a co-channel user, move to another frequency. If you operate out of a fixed location, then coordinate a frequency specifically for your use. You will not be given an exclusive frequency, but you will be placed on a frequency that is appropriate for your activity.

Basics of Radio Frequency Data Communication Systems

Understanding the basics of Radio Frequency Data Communications (RFDC) provides a foundation for successful implementation of a data communication system.

In this section, the fundamentals are addressed in layman's terms, beginning with the concepts of radio signal propagation.

At the end of this section, you should be familiar with some common radio terms and have a basic understanding of radio transmission theory including data communication.

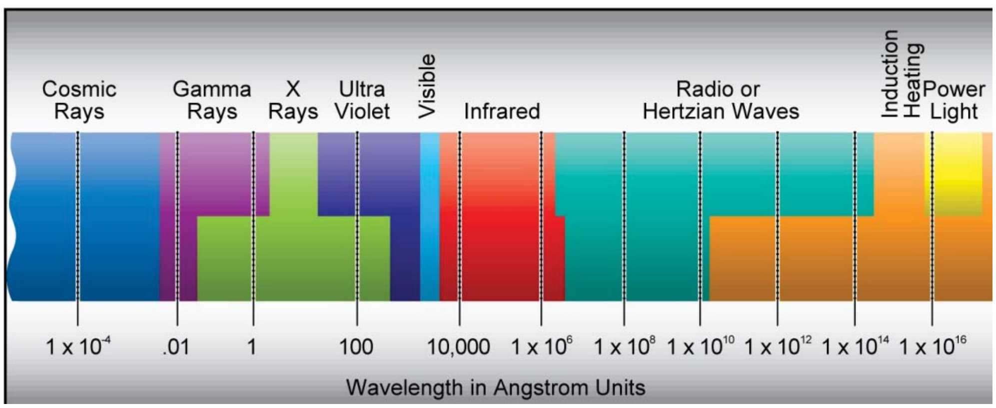

Figure 1 – Electromagnetic spectrum

Radio wave propagation

Radio waves are part of the electromagnetic spectrum which encompasses visible light, x-rays, ultra-violet radiation and microwaves (see Figure 1). Electromagnetic waves travel at roughly the speed of light and have wavelengths which are related to the frequency of the wave. Table 1 below shows the spectrum of frequencies which are considered radio waves and their classifications:

Frequency	Wavelength	Classification
10 - 30 kHz	30km - 10km	Very Low Frequency (VLF)
30 - 300 kHz	10km - 1km	Low Frequency (LF)
300 - 3000 kHz	1km - 100m	Medium Frequency (MF)
3 - 30 MHz	100m - 10m	High Frequency (HF)
30 - 300 MHz	10m - 1m	Very High Frequency (VHF)
300 - 3000 MHz	1m - 10cm	Ultra-High Frequency (UHF)
3 - 30 gHz	10cm - 1cm	Super-High Frequency (SHF)
30 - 300 gHz	1cm - .1cm	Extremely-High Frequency (EHF)

Table 1 – Radio spectrum classifications

We're all familiar with portions of the radio spectrum that many of us use on a daily basis as we communicate, work, or relax. You may have enjoyed music or listened to news on your car radio on the way to work this morning. FM radios operate at VHF frequencies between 88 and 108 MHz (check your radio dial). AM radios operate at a much lower frequency in the MF band from 530 to 1700 kHz. Television stations operate at various frequencies in the VHF and UHF bands. Cellular phones operate in the 800 MHz region of the UHF band. We live in a world bathed in electromagnetic energy from television, radio, cordless phones, microwaves, and visible light.

Most radio frequency bands are divided into channels, each of which may be used to transmit voice, data, or signaling information. RFDC systems make use of discrete radio channels where information is communicated by modulation of the radio carrier. There are other mediums and techniques used to communicate data using the electromagnetic spectrum, including fiber-optics, infra-red, spread-spectrum, and others. These are beyond the scope of this book and will only be mentioned in passing.

Terminology

Before describing the characteristics of the different radio bands, let's review some basic radio terminology (refer to the glossary in Appendix A for an extensive listing of radio terminology). The following terms will be used in the sections which follow and should be understood.

propagation: The path and manner which a radio wave travels from its source (the transmitter) to its destination (the receiver). The path (often called "mode") of propagation differs depending on the frequency of the radio signal. Also dependent on frequency is the reflection or refraction of the radio signal as it passes through layers of the ionosphere or as it reflects off of objects in its path.

range: The distance at which radio communication is adequate for a particular task. Voice communication is acceptable with noise or interference conditions that would make data communication unreliable.

coverage: The ability of the radio signal to be available within the expected range but where the signal is blocked by man-made or natural structures.

General Rules

A few generalities can be made about radio communication. Lower frequencies provide better range than higher frequencies. Lower frequencies are more susceptible to interference than higher frequencies. Coverage and signal penetration is better at higher frequencies than at lower frequencies. Most reliable data communication depends on line-of-sight conditions where the range is limited by the radio horizon. Figure 2 below illustrates a line-of-sight transmission.

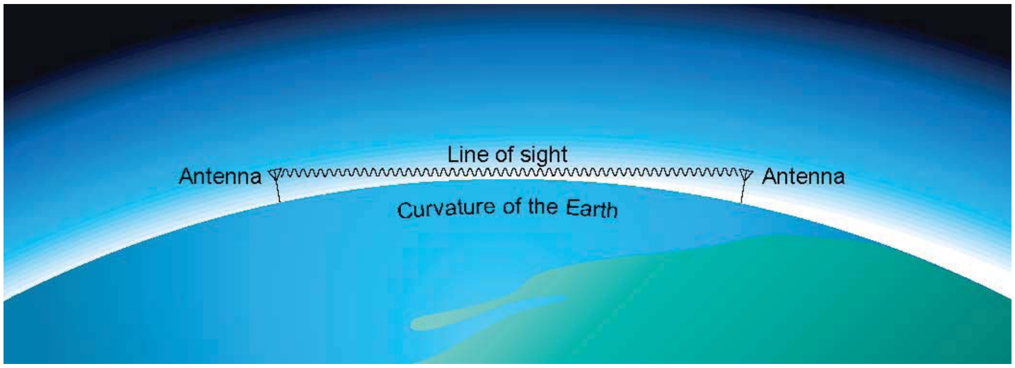

Figure 2 – Direct wave propagation "line-of-sight"

VLF, LF, and MF radio signal propagation

This portion of the spectrum does not offer channels available for data communication except in a few special cases. Signals in these bands have exceptional range but suffer from man-made and environmental noise which would limit data transmission in most circumstances to very low rates (<300 bits per second). Some radio navigation beacons operating in the 285 to 325 kHz range provide 200 baud data DGPS corrections for marine based navigation. These beacon transmitters provide ranges in the hundreds of miles.

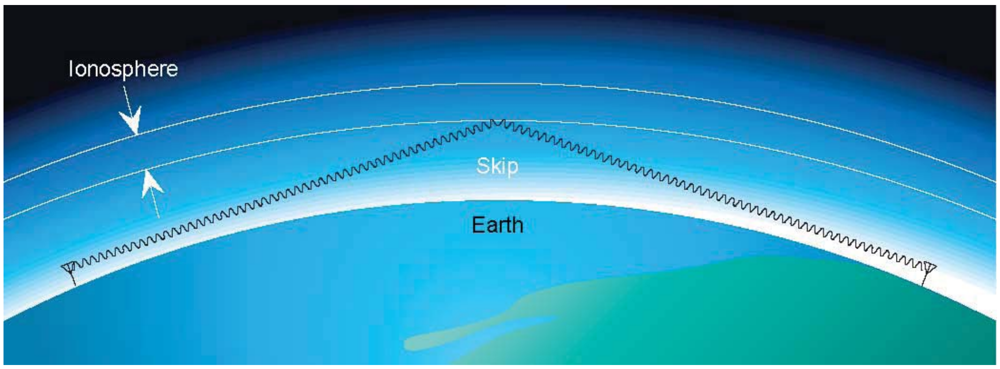

Figure 3 – HF signal propagation via "skip"

HF radio signal propagation

HF radio signals provide excellent range, but suffer low reliability for data communication because of co-channel interference from distant radio stations and susceptibility to man-made noise. The FCC has allocated channels in the upper portion of the HF band starting at 25 MHz. Another mode of propagation for HF signals is via ionosphere reflection. At these frequencies, the radio signal will reflect off of the ionosphere and travel back to the earth. See Figure 3 above. This "sky-wave" propagation from distant radio stations is difficult to predict, and is often influenced by the time of day and year, and the activity of sun-spots. Because of these various phenomena, HF data communication is limited to low baud rates and questionable reliability.

The higher the frequency the lower the influence of man-made noise and the co-channel interference caused by sky wave interference (also called "skip").

VHF radio signal propagation

While not entirely eliminated, problems of signal skip and susceptibility to interference from man-made and environmental noise are minimized in the VHF spectrum. Good signal coverage is provided but at a some¬what shorter range than can be achieved in lower bands. VHF frequencies above 100 MHz (high band) provide characteristics which make them adequate for moderate or high speed data communication. The availability of channels in the VHF high band (150to 174 MHz) for non-voice radio communication provides capabilities for transmitting data in excess of 19,200 bits per second.

VHF high band and higher frequency radio signals are considered to travel in a line-of-sight (also called direct wave) mode with minimal problems from skip and noise. Line-of-sight propagation means that the range of the radio link is limited by the radio horizon, being the point at which the curvature of the earth blocks the signal between the transmitting and receiving antennas.

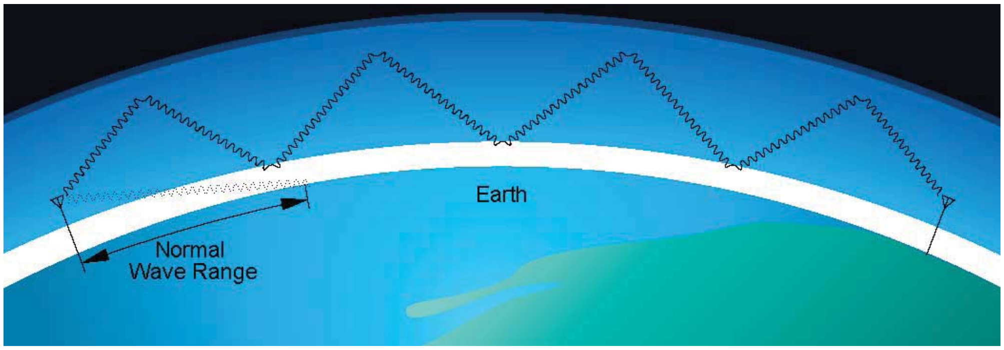

Figure 4 – VHF signal propagation via "ducting"

On rare occasions, VHF signals may propagate in a mode called "ducting." See Figure 4 above. This occurs when a temperature inversion provides atmospheric conditions such that the radio signal becomes trapped between layers in the atmosphere. The radio waves travel in the "duct" and may propagate for long distances. Naturally, this is not a reliable mode of propagation and may be a source of interference with distant radio transmissions interfering beyond their normal range of influence.

UHF radio signal propagation

The UHF frequency band provides a good compromise for radio data communications where range and data throughput are required. Signal skip and ducting are minimal, and the susceptibility to noise, including co-channel interference is much easier to control. Radio coverage is excellent with penetration into buildings and over terrain better than at lower frequencies. Propagation is direct wave limited by the radio horizon. Problems associated with man-made noise are minimal.

At UHF and higher frequencies, care must be taken to minimize system losses which increase as the frequency increases. Also, at higher UHF frequencies and microwave frequencies, attenuation through foliage and caused by meteorological conditions must be considered.

Modulation

The modulation of the radio signal provides the ability to communicate information. Modulation adds information to a radio wave by modifying one of its fundamental characteristics. The fundamental characteristics of radio waves are frequency, phase, and amplitude.

Different modulation schemes have been devised which make use of varying the frequency (frequency modulation), amplitude (amplitude modulation), and phase (phase modulation). These terms should be familiar to radio listeners who tune in frequency modulated (FM) or amplitude modulated (AM) radio stations.

Figure 5 here shows the different modulating waveforms of a baseband signal. The baseband signal is the actual data which is represented by a serial stream of 0's and 1's.

The type of modulation and suitability of a modulation for a particular application is beyond the scope of this course material. Most modern high-speed data links use one of the forms of frequency modulation which is spectrally efficient and provides immunity from variations in signal strength known as fade (more on this later).

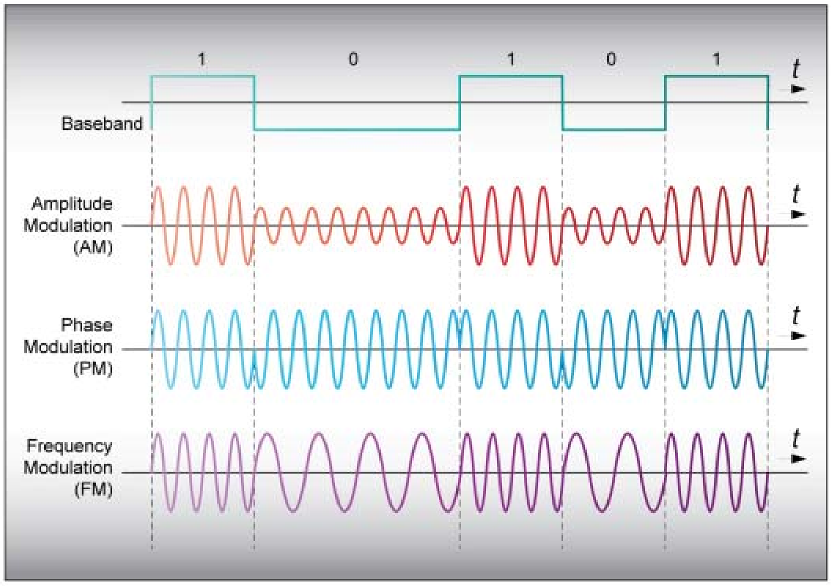

Figure 5 – Modulation waveforms

Data communication

Data communication over radio waves provides an efficient and reliable transfer of information. Because of the limited spectrum available for communication, more and more digital systems are being utilized. In comparison to voice radios, the amount of information transferred over a radio link via modulated data is astounding. Because of this, traditional users of voice radios in the public safety sector (police, fire, search-and-rescue, etc.) are turning to radio data communications to provide dispatch and other information.

Data communication is fundamentally similar to voice communication in the manner in which the radio signal is modulated. Most modern voice and data communication systems in the UHF and VHF commercial bands make use of frequency modulation, although amplitude modulation is common in some marine and aviation applications. For voice communication, the audio signal is picked up by the microphone and changed into a varying voltage level. The voltage level is applied to the radio transmitter to modulate the carrier frequency. The radio receiver in a voice system takes the modulated frequency and produces a signal which replicates the signal from the transmitter, which is then applied to a speaker producing audio output.

Data communication is performed by encoding the digital signal on an analog waveform which is capable of being passed via radio modulation (see Figure 5 above). Digital signals are composed of groups of binary data consisting of 0's and 1's which represent numbers, or characters (called bytes). The stream of 0's and 1's from a digital device such as a GNSS receiver or environmental sensor are processed by a radio's modulator to produce an analog waveform representing the data. This signal, called the baseband modulation, is designed to provide a signal that can be transmitted and received by the radio hardware. High speed data requires special filtering to assure that the data modulated signal fits within the channel spacing mandated by governing agencies such as the FCC and ETSI.

A measure of how good a communication system can transmit data is the Bit Error Rate (BER). A bit error occurs due to interference or low signal levels where a bit as sensed by the receiver is not correct. The BER is the ratio of bit errors to the total number of bits transmitted. For valid comparisons of radio data systems, the BER must be measured within the context of a total system that includes low signal levels and fade conditions.

Sophisticated RFDC systems use Forward Error Correction (FEC) protocols which allow errors in the received data to be corrected. Because of the nature of RFDC, an FEC algorithm should be chosen which works well in the correction of burst bit errors as opposed to single bit errors.

Antennas

Selection and proper installation of the antenna system often makes the difference between a reliable and robust or an unreliable data communication system. The antenna is the radiating element which takes the RF energy generated by the radio and begins its propagation through the air. Antennas come in a variety of sizes and shapes designed for specific uses.

The ability to focus the RF energy in a specific pattern provides a method for optimizing the coverage and range of the communication network. Some antennas are highly directional and allow the use of relatively low power radio transmitters to send data over long distances. Other antennas are designed for omni-directional use where the relationship between the transmitter and receiver is constantly changing. The nature of the communication activity normally dictates what sort of antenna to use (directional or omni-directional).

The most important activity in setting up a radio transmitter is determining the placement and type of the antenna. Where flexibility permits, always place the antenna on the highest point available and always select an antenna with a gain pattern (more on this later) which optimizes the coverage. In general, use a directional gained antenna such as a Yagi for a point-to-point fixed location application and a gained omni-directional antenna for mobile point-to-point or point-to-multipoint communication systems. See Figures 6 and 7.

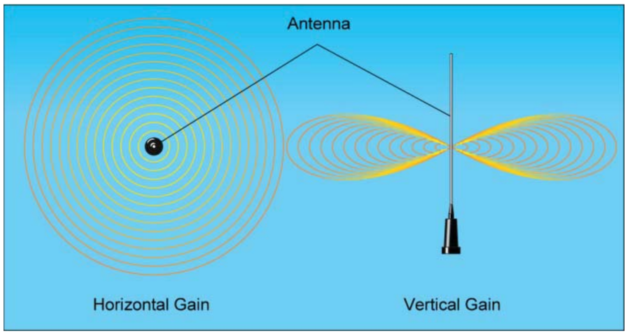

Figure 6 – Omni-directional antenna gain pattern

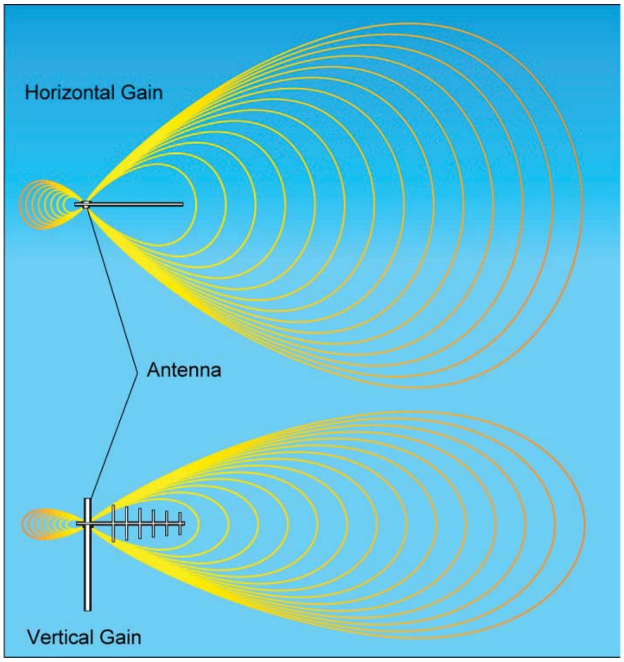

Figure 7 – Directional antenna gain pattern

Things to do

- Be aware of power lines or other obstacles that can inadvertently come in contact with the antenna and cause potentially lethal conditions.

- Use guy-wires on antenna masts higher than 10 feet.

- Use lightening arrestors for equipment and personal protection if erecting an antenna in areas prone to lightening.

- Installation of antennas on buildings or other structures (towers, etc.) must be done in accordance with local building regulations. Contact a local antenna installer who is familiar with building codes and proper antenna installation for any permanent installation.

In some applications the antenna system must be moved from location to location. Mobile RFDC users often move an entire radio system from location to location depending on the requirements of the job. In these circumstances, it is difficult to optimize the radio antenna setup. Use an antenna mast to get the antenna at least 10 feet above the terrain. Make sure that the RF power coming from the transmitter is attenuated as little as possible by making use of the highest quality coaxial cables with the minimum length required between the radio and the antenna.

Antennas provide the most economical method for improving the performance of the radio communication system.

Things to do

- Never transmit data from a radio without first attaching the antenna.

- Maintain the antenna and interconnecting cables in excellent condition.

- Tune the antenna as per the instructions included to the proper length for the frequency of the transmission.

- Use a professional antenna installer for permanent installations and make sure that the antenna is tuned for minimum reflected power.

- Take advantage of any landform or structure for higher placement of the antennas.
  Getting the best possible performance from a radio communication system requires attention to the fundamentals as addressed in the previous chapter.

Performance issues

In this chapter we discuss in greater detail the component parts of a radio system and “rules-of-thumb” as well as specific recommendations which will lead to good radio system performance.

The order of topics in this chapter follows the path of a transmitted signal, beginning with the transmitter, followed by the antenna feed-line system and transmitting antenna.

Next, the attenuation (reduction) of the signal as it propa¬gates between the transmitting and receiving antenna is addressed.

Lastly, the signal is received and processed by the radio receiver. (See Figure 8.)

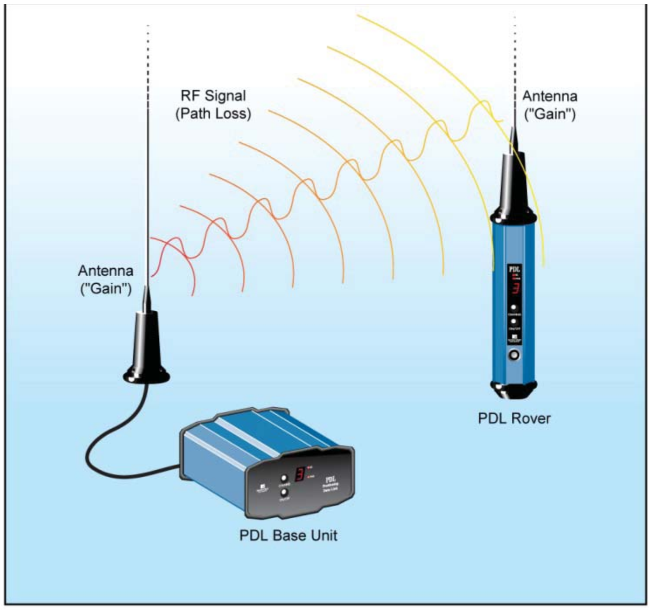

Figure 8 – Radio data link

At each stage of the RF signal, performance should be optimized for the requirements of the application.

An understanding of these topics provides a basis for determining the trade-offs in setting up an RFDC system.

RF power

A radio modem transmitter provides RF power at the antenna port which consists of a fundamental carrier of a specific frequency which is modulated with data. The power of the signal is generally specified in watts, but may also be specified dBm (dB with respect to a 1 milliwatt transmitter). Many calculations are simplified by working in units of “dB” so the conversion of watts to dBm is given in Equation 1.

Equation 1

$X = 10 \log^{10} \left(\frac{P}{.001} \right)$

To convert from dBm to watts, use Equation 2.

Equation 2

$P = .001 * 10^{\left(\frac{X}{10}\right)}$

X = power as expressed in dBm
P = power as expressed in watts

The output power at the radio antenna port is the starting point as the signal moves from transmitter to receiver. The power as seen by the radio receiver is determined by all of the losses and gains in the system. RF output power minus the system losses must exceed the sensitivity of the receiver for successful communication to occur.

The RF output power of a RFDC link is fixed by the radio system. The selection of the RF output power appropriate for a system depends on the range requirements in the context of the frequency band, antenna type and placement, terrain, and the radio performance parameters. Governing agencies such as the FCC and ETSI place limits on the output power that can be used on a particular frequency or for a particular application.

Some systems make use of external RF power amplifiers to boost the signal level of the transmitter. RF power amplifiers work by using high-speed RF power transistors which amplify the voltage swing of the RF signal. RF power transistors are designed for stable operation at the frequency of the radio signal.

Power is calculated as the voltage squared divided by the impedance of the output as seen in Equation 3.

Equation 3

$$P = \frac{V^2}{R}$$

Where:

P = power in watts
V = voltage across an impedance
R = impedance

Solving the above equation for voltage gives you Equation 4 next.

Equation 4

$V = \sqrt{PR}$

Assuming an impedance of 50ohms which is standard in most commercial RFDC equipment, a 2-watt transmitter voltage swing is 10 volts. ($\sqrt{2 \text{x} 50}$)

The voltage swing of a 35-watt RF signal is 42 volts. The increased voltage with power levels with high power output radio equipment should be respected.

Line and system losses

After the signal leaves the transmitter, the process of signal attenuation begins. Most RFDC systems have the radio equipment connected to the antenna through a length of coaxial cable of matched impedance to the antenna and radio ports. This cable can be a major source of power attenuation and should therefore be optimized for best system performance.

Two types of system losses predominate when the transmitter is connected to the antenna through a feed-line. First is VSWR (frequently pronounced as “vis-wahr”) which is the Voltage Standing Wave Ratio. The VSWR is measure of the reflection of the voltage (or power) as the signal passes across an impedance boundary. The connection of a coaxial cable to the antenna port of the radio presents such a boundary. It’s important to use coaxial cable and connectors which will minimize the impedance mismatch which would otherwise cause part of the RF energy to be reflected back into the transmitter.

The second type of system loss is the attenuation of the signal as it propagates along the cable length. The attenuation of the signal is a function of the frequency and the properties of the cable. The higher the frequency, the higher the attenuation of the cable. Attenuation is caused by the leakage of RF through imperfect shielding of the cable as well as resistance in the cable conductors. Table 2 shows some popular cables and their attenuation across the frequencies commonly used in RFDC.

Nominal attenuation (dB/100 feet)

Cable	Impedance	150 MHz	450 MHz	900 MHz
RG-58	50	5.7	10.5	16
RG-8	50	2.3	4.3	7.6
RG-213	52	2.3	4.3	7.6
Heliax® ½-inch	50	.9	1.4	2.2

Table 2 – Common RF Cable Characteristics

As a rule of thumb, 3 dB of attenuation is equivalent to approximately halving the output power of the transmitter. As an illustration of the losses which commonly occur with a coaxial feed-line, consider a 35-watt power output at 460 MHz going through 33 feet of RG-58 cable. The effective power delivered to the antenna is only 15.7 watts! Using RG-8 cable, the power delivered to the antenna is 25 watts.

Things to do

- Use coaxial cable and connectors which are impedance matched with the radio equipment (generally 50 ohms).
- Use the shortest length of cable required to move the signal from the transmitter to the antenna.

Path loss

Path loss is the loss in signal strength as the signal passes through free space between the transmitter and receiver. The loss of power is inversely proportional to the square of the distance between the antennas. The attenuation or weakening of the signal is dependent on factors including antenna height, natural obstructions to the radio signal such as foliage or terrain, and man-made obstructions such as buildings, bridges, etc.

Path loss is also affected by a phenomenon known as multi-path where reflections or refractions of the direct-path signal combine with the original signal producing destructive interference. The multi-path effect is often noticed on television reception where ghost images appear as an airplane (RF reflective source) flies overhead. In a mobile data communication system, multi-path may cause a signal variation as the vehicle moves through roadways where bridges, buildings, terrain and other objects cause signal reflections.

Things to do

- Select antenna location to minimize obstacles between the transmitting and receiving antennas.
- Elevate the antenna above the terrain to keep path loss at a minimum.

Antenna gain

All antennas focus RF energy in a non-isotropic manner. The focusing of the RF energy is called the antenna gain, and is generally represented in terms dB with respect to either a theoretical isotropic antenna (dBi), or a dipole antenna (dBd). Antenna manufacturers often omit this relationship when placing a gain value on their antennas. This is an important point. A dipole antenna has a gain of 2.1dBi. An antenna reported to provide a gain of 5dB may be equivalent to 5dBi or 7.1dBi. Always compare antennas using either dBi (commonly used for portable or mobile whip antennas) or dBd (commonly used for higher quality fixed base antennas).

Antenna design is the art of shaping the radiation pattern of an antenna to provide a signal density pattern appropriate for the application. For many applications, an omni-directional gain pattern is desirable. Mobile data communication, where the position of the receiver with respect to the transmitter may vary, calls for an omni-directional antenna. Depending on the terrain, it is generally advisable to use a high-gain antenna for best performance. High-gain omni-directional antennas have an increased horizontal radiation pattern with a decrease in the vertical radiation pattern.

For applications where the transmitting and receiving antennas are fixed in location with respect to each other, directional antennas provide best performance. Both transmitter and receiver should use the gained antennas in fixed location applications. With careful design, most systems of this type will be able to operate on relatively low power outputs.

Most antennas require grounding in order to provide the focused energy pattern for which they are designed. At lower frequencies where fractional wavelength antennas are used, it is critical to have a good ground connection. It is not uncommon for HF frequency antenna installations to make use of hundreds of feet of copper wire buried beneath the antenna to provide the grounding required for best operation. As the frequency is increased and antennas can be constructed of 1/4wave lengths or longer economically, the requirement of a ground plane connection becomes less critical, however, it is still recommended to ground the antenna for best performance.

Things to do

- Use a gained omni-directional antenna (>3.5 dBd) over flat or hilly terrain.
- Use a gained directional antenna (>6 dBd) in fixed location applications.
- Ground the antenna for both performance and safety reasons.

- Mobile and portable antennas are also available with excellent gain patterns. In some applications where ground planes are not available, antennas designed for no-ground plane operation are available. 1/2 wavelength antennas operate well in a no ground plane application and should be used if antennas designed specifically for no-ground plane operation are not available.

Receiver sensitivity

Receiver sensitivity is a characteristic of the radio equipment which determines its ability to receive low level signals. Traditionally, receiver sensitivity is measured in terms of the signal input level at the antenna port is required to provide a signal to noise and distortion level of 12dB. The RF signal is modulated with a 1kHz tone producing a +/-3kHz deviation of the carrier. The measurement, called the 12dB SINAD (signal to noise and distortion, commonly pronounced "sign-ad") is often reported in the specifications of the radio equipment.

The more sensitive the radio receiver, the better the range. There is a limit to receiver sensitivity which is set by the ambient RF noise in the signal band. This background noise level determines the minimum level where the RF signal can be recognized.

Most radio data communication equipment relies on a carrier detect signal which is generated by circuitry that measures the power of the received signal. The carrier detect lets the radio modem know that a signal is available which may contain data. The setting of the carrier detect should be chosen to take full advantage of the receiver sensitivity, but not so sensitive that ambient RF energy causes false triggers.

Things to do

- Select radio data communication equipment with receiver sensitivity better than -116 dBm.

- If available, select radio data communication equipment with an adjustable carrier-detect level (some times called squelch).

Fade margin and multi-path

Variation in signal level as a result of multi-path or obstacles in the RF signal path results in a condition known as fade. High speed data communication is especially susceptible to failure caused by fade conditions. Radio equipment designed for high speed data communication must make use of fade resistant modulation schemes and be readily adaptable to varying signal levels. For this reason, most radio data communication makes use of frequency modulation instead of amplitude modulation where varying signal levels (amplitudes) due to fade conditions can corrupt the data.

Estimating System Performance

PCC Range Estimator is a software program distributed by Pacific Crest Corporation that provides useful tools for estimating system performance.

It also provides a means for optimizing the RFDC network by antenna systems, cable types and lengths, power outputs and radio parameters.

PCC Range Estimator is best used as a reference tool to see how adjusting different parameters affects range. Actual system performance over greatly varying terrain cannot be addressed with PCC Range Estimator.

RF range calculations

Estimating the range over which an RF data communication system will work reliably is not a trivial matter. Indeed, the most often asked (and dodged) question of designers and manufacturers or radio data communication equipment is "What's the range?" To make a rough estimate, the following factors must be considered:

Transmitter power
Transmitter frequency
Antenna feed-line length and type
Antenna type and placement
Terrain relief
RF obstructions (buildings, foliage, etc.)
Receiver antenna type and placement
Receiver antenna gain
Receiver carrier detect
Receiver sensitivity

Sometimes minor adjustments in an installation can make major improvements in the range and coverage of the radio system. Radio system designers and installers are well aware of these parameters and are able to optimize the range of a system in a given circumstance.

This section details the concepts which can be used to determine roughly the range which you may expect to achieve in a link over flat ground, or water, or in a ground-to-air situation. Range over varying terrain is beyond the scope of this course and generally requires sophisticated software with digitized terrain data access.

The approach to range calculation is simple. First, start with the output power of the transmitter. From this, subtract all of the system losses and gains as the signal passes through the various feed-lines, antennas, and through free space. The resulting power of the signal at the receiver must be above the level required for reliable data communication. Now let's get into the details. (Don't worry, you can use PCC Range Estimator to do the actual math.)

Figure 9 below shows the calculations which are used to determine the range of VHF and UHF radio propagation. Note that these calculations provide line-of-sight values, and do not consider the effects of ducting or skip which may occur at lower VHF frequencies.

RF range calculations

Step 1: Calculate system gain

Transmitter System Gain (TSG) Tx Pwr - Feedline Loss + Ant Gain **+** Treceiver System Sensitivity (RSS) - Rec Sens - Feedline Loss + Ant Gain **=** System Gain (SG)

Step 2: Select path model

Free Space Gain (FSG) 37 + 20log(f) + 20log(d) **+** Atm Fade margin (AFM) Estimate/Calculate *or* Antenna Gain Factor (AGF) 149 - 40log(d) - 20log (HtHr) **+** Terrain Fade Margin (TFM) Estimate/Calculate

Step 3: Equate system gain to selected path model and solve for d (miles)

Free Space Range	Over Ground Range
((SG - 37 - AFM - 20log(f) / 20) d = 10	((SG - 149 - TFM - 20log(HtHr) / 40) d = 10

Use the value which translates into the shortest range

Tx Pwr - dBm, Feedline Loss - dB, Ant Gain - dBi, Rec Sens - dBm @12dB SINAD Frequency (f) - MHz, Distance (d) - Miles, Height of Antennas (Ht, Hr) – Feet

Figure 9 – RF radio range calculations

The first step is to calculate the various gain factors which are characteristic of the transmitter, receiver, and the RF path which is dependent on antenna height or alternatively free space. In general, air-to-air or air-to-ground communication systems use the free space gain while over-ground communication is dependent on the antenna gain factor.

Next, the subjective influences must be evaluated, either through measurement or estimation. These include the noise floor limits which affect the ultimate sensitivity of the radio receiver in the context of the ambient RF levels at the frequency being used. Also, estimation of multi-path fading which is dependent on relative antenna considered at this stage in light of the movement, frequency, and terrain (not an issue in air-to-air data communication). PCC Range Estimator doesn’t consider these issues which are environment dependent in its calculations.

Fade margin factors are also considered at this stage in light of the reliability of the radio data communication (See Table 3 for commonly used fade margin factors.) More sophisticated radio coverage software would estimate multi-path and fade effects looking at the true terrain profile.

The final step is to calculate the system gain and equate it with the path loss. For reliable data communication to occur, the system gain must be greater than the path loss gain. Equating the system gain to the path loss gain and solving for distance gives the maximum range at which the radio communication network will operate.

RF over-ground range estimate equation

The following equation provides a range estimate for RF over-ground radio link (antenna gain factor calculation):

((SG – 149+ 20log10(Ht x Hr)) / 40))Dagf = 10

Where:

SG = system gain

Ht = height in feet of the transmitter

Hr = height in feet of the receiver

RF air-to-air/ line-of-sight ground-to-air range estimate equation

For air-to-air and line-of-sight ground-to-air, the following equation provides a range estimate for a VHF and UHF radio link (free space calculation):

((SG – 37– 20log10(f)) / 20))Dfs = 10

Where:

SG = system gain

Ht = height in feet of the transmitter

Hr = height in feet of the receiver

FEC and data scrambling

When data is transmitted by any medium, as the rate increases, the energy per bit of information decreases. This decrease in energy per bit leads to increased difficulty in discerning the bit information in a system where noise is present. Noise is present in all communication systems. Because of this, high-speed data communication is limited by noise in the system.

To compensate for the higher bit error rate with increasing data transmission speed, communication system designers often include forward error correcting algorithms which allow the receiving modem to recognize and correct errors in the received data. All forward error correcting algorithms require additional overhead bits to be sent with the actual data bits. The objective in forward error correcting systems is to send an optimal number of bits so that the effective data throughput is increased.

Radio data communication errors typically occur in bursts and are caused by fade conditions or interference. Because of this, forward error correcting schemes for radio data communication should be designed to detect and correct burst errors.

One popular method for forward error correction in mobile data environments is a block coded shortened Hamming Code (12,8). The (12,8) designation means that 12bits are sent for each 8 bits or raw data resulting in a 50% overhead. This code is interleaved to provide burst error protection, with the interleave factor determining the minimum block size and the maximum burst error correction size. Popular mobile data networks use a block size of 20words, giving burst error protection for 1 to 20 bits.

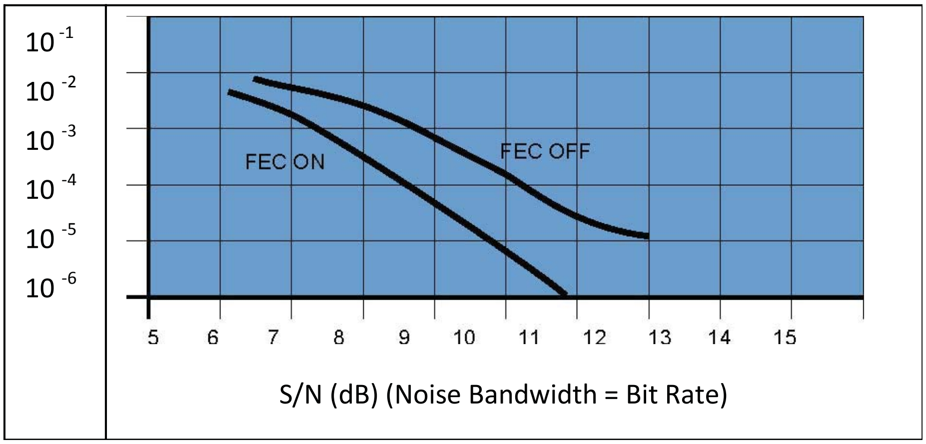

Figure 10 – Theoretical gain with FEC

Forward error correction is mandatory in high speed, high reliability data links where fade conditions are present. The inclusion of forward error correction allows much lower signal levels to provide equivalent or lower bit error rate (after correction). Figure 10 above demonstrates the theoretical gain for low signal levels in the context of a system with forward error correction turned on and turned off.

Modulation schemes for high-speed data most often allow coherent signal detection. In order for the demodulator circuit to know when to sample the signal to get the proper bit value, the zero-crossings must be identified. Transmitting and receiving radio modem clocks are never perfectly synchronized and therefore the receiving circuit must derive the transmitting circuit clock from the data. The circuit which does this function, called a phase-locked loop, requires that the signal have a sufficient number of transitions to maintain bit alignment. Because of this, high speed radio data modems normally provide scrambling of the data to assure that sufficient signal transi¬tions are present.

After descrambling and forward error correction, the data integrity must be checked. Most high speed radio modems calculate and transmit error detection information which is checked by the receiver to assure data validity. The checking information can be a simple checksum or a more robust cyclic redundancy check (CRC). The popular 16-bit cyclic redundancy check provides exceptional performance in detecting errors in the received data. Table 3 illustrates the error checking available with a 16-bit CRC.

Type of error	Detection Capabilities
Single-bit errors	100%
Double-bit errors	100%
Odd-number errors	100%
Burst errors shorter than 16 bits	100%
Burst errors of exactly 17 bits	99.9969%
All other burst errors	99.9984%

Table 3 – 16-bit CRC error detection capabilities

For robust and reliable operation, all high-speed data communication systems should provide forward error detection, data scrambling and 16-bit CRC error detection mechanisms.

Fade considerations

It's traditional for designers of radio data communication systems to use a fudge factor called the fade margin that provides a margin for naturally occurring fade considerations. Most fading problems are caused by multi-path which increases with frequency and path distance. Multi-path fading follows a Rayleigh probability distribution. The "fudge factor" is subtracted from the receiver sensitivity in the range calculations. Table 4 provides a rule-of-thumb value for fade margin as it relates to the reliability of the data link.

Reliability	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

Table 4 – Fade margin for reliable data communication

Note: fade conditions are more severe in mobile environments. Expect degraded performance if you are in a mobile environment. If you are in a fixed location and you are experiencing multi-path, try adjusting the antenna position. Often, minor adjustments of the radio antenna can improve performance substantially.

FCC Licensing and Regulations

The FCC regulates the portions of the electromagnetic spectrum used for radio communication.

The entire set of regulations is contained in Title 47 of the Code of Federal Regulations (CFR).

The sections of Title 47 which are applicable to radio frequency data communication are contained in Parts 90, 17 and 15 which contain the rules and regulations for the operation of land mobile radios for voice and non-voice applications. Licensees of narrow-band radio communication equipment for use in commercial or non-profit activities are required by law to have a copy of these regulations. Other parts of Title 47 con¬cern amateur (Part 47), Marine (Part 80), Aviation (Part 87), and other uses of radio in voice and non-voice communication.

An excellent publication is available from the Personal Communications Industry Association (PCIA). This publication contains a detailed explanation of the licensing process, as well as current copies of Parts 90 and 17. PCIA can be reached by calling (703) 739-0300. All titles of the CFR are available at government bookstores. This section is not intended to be a description of how the various FCC forms need to be filled out for a particular circumstance. The FCC is continuously amending the forms and the regulations are subject to change at any time. Frequency coordinators and businesses offering services for FCC licensing issues should be consulted if required for help in filling out the forms.

Licensing requirements

Part 90 of Title 47 describes the rules, regulations and licensing requirements for private land mobile use of the radio spec¬trum. In general, radio transmitters licensed under the Part are for use in public safety, special emergency, industrial, or land transportation activities.

As part of the application process, licensees will be asked to describe the activity for which the radio system will be used, and also to cite the regulation under which eligibility is required. (See CFR Title 47, Part 90.75(a)(1) as an example of an eligibility citation.)

> **Caution**
> Never operate a radio transmitter without proper licensing (the FCC has authority to impose fines for several thousands of dollars per day of illegal operation).

Application forms

Section 90.119 outlines the application forms which are required for licensing a radio transmitter. Note that through April 1995, application was made using FCC Form 574. As of April 1995, the FCC requires application be made with FCC form 600. Copies of FCC form 600 can be obtained by fax by calling 1-202-418-0177.

Several manufacturers place application forms and applicable information in boxes of radio equipment for sale. These forms may be outdated or may reflect erroneous information causing delay in the processing of your application. Please note the current acceptable edition date(s) by referring to the Private Radio Bureau Fee Filing Guide. The filing guide also presents the licensing fees and where to submit the license applications.

Contact your local FCC field office for information on current application forms or call the Private Radio Bureau's Consumer Assistance staff in Gettysburg, Pennsylvania at 1 888 CALL FCC. You may also contact the appropriate FCC appointed frequency coordinator and request forms and filing information.

Frequencies

Frequency assignment for operation of a radio transmitter under Part 90 is done in cooperation with a frequency coordinator. The FCC has appointed groups, normally trade organizations, as frequency coordinators to act as intermediaries between the license applicant and the FCC. Frequency coordinators assign and control blocks of frequencies set aside for particular uses. For example, the frequency coordinator for police licensing is the Associated Public Safety Communications Officers (APCO). Business radio licensing is coordinated through the Personal Communications Industry Association (PCIA). (A complete listing of frequency coordinators as of the printing of this manual is available in Appendix C.)

Frequency coordination is required for all applications except for those where application is being made for operation on itinerant frequencies. Itinerant frequencies are set aside by the FCC for operation of radio stations at unspecified locations for varying periods of time. Radio systems are generally licensed for operation in a specific geographic area. For applications where the geographic location of the radio transmitter cannot be fixed in advance, and where the radio transmitter will only be operating for a short or varying period of time, then itinerant frequencies are available.

Some restrictions apply to operation on itinerant frequencies. Currently, the maximum allowed output power is 35watts. The FCC does not provide protection from interference from other itinerant frequency users. Non-voice (data) communications are permitted only on a secondary basis to voice communication on these frequencies. This means the voice use takes precedence such that data users may be forced to vacate a frequency should interference with voice operations be reported.

Before licensing any frequency it is a good idea to ascertain the appropriateness of the frequency for a particular application. You are generally allowed to monitor the frequency and request another should the frequency prove inappropriate for the application. Keep in mind that local frequency coordinators know how many people may be licensed on a given frequency in a given area, however they do not know the usage pattern or incidences of illegal use of that frequency.

Things to do

- Monitor frequencies in your area prior to licensing.
- Get licensed prior to beginning transmissions.
- License and use itinerant frequencies if your area of operation changes routinely.

Technical issues

To submit an application, a number of radio specific technical issues need to be included. The FCC uses the technical parameters to determine the area of influence of your radio transmitter. This information allows for even loading of the radio channels in a given area.

The FCC needs to know what frequency you will be operating on, how much power will be being delivered to the antenna, and the effective radiated power which is a function of radio transmitter power minus the line losses plus the antenna gain. You should be familiar with these terms as these are the fundamentals used in determining range calculations explained in an earlier chapter.

Another parameter of interest to the FCC and also required for the application is the radio emissions designator. The emissions designator is a technical descriptor of the bandwidth requirements and type of modulation used by the radio transmitter. This information allows the FCC to judge the channel requirements in terms of channel width. Primary channels are generally spaced at 25 kHz intervals across the band. In the UHF commercial band (450 - 470 MHz), the FCC allows operation on offset channels which are spaced at 12.5 kHz offsets from primary channels. The emissions designator is normally supplied with the radio equipment, but may also be obtained by calling the radio manufacturer directly.

For fixed location stations, the coordinates of the fixed base transmitter must be supplied. These coordinates are referenced to a particular datum (NAD27 or NAD83 or other) and are given in latitude (degrees, minutes, seconds), longitude (degrees, minutes, seconds) and ground elevation (meters). This information can be determined using a topographic quadrangle map of the area, or you may consult the city or county surveyor in your area. Topographic maps of the United States can be purchased from the www.usgs.gov.

How to get help

We recommend that you use licensing service to help you apply for a license. These services are very knowledgeable regarding all the proper forms and submission requirements for expediting the licensing process. Many of our customers arrange licensing through consultants such as Enterprise Wireless Alliance/Licensing Assistance Office. For more information go to www.dci-lao.com.

There are a number of private businesses who have access to the FCC database and provide help in filling out the FCC forms. These businesses often add addi¬tional support in the form of site surveys and coverage analysis. Look in the Yellow Pages for Communication Consultants in your area.

Another resource for licensing help is the manufacturer or reseller of the radio equipment. Technical characteristics and emissions designator information which are required for the license application are best obtained directly from the manufacturer. Some manufacturers provide licensing assistance of which you can take advantage.

The FCC can be contacted directly for access to forms and some technical infor¬mation. The local FCC field office can answer regulatory questions, but is not equipped to help with the license application process.

As mentioned earlier, the PCIA Resource book is an invaluable aid to help with the license application process and also meets the regulatory requirement that the licensee maintain a set of the rules and regu¬lations.

The licensee is ultimately responsi¬ble for compliance to the regulations. Informed use of the radio spectrum will pro¬tect you from being subject to fines, and will also provide you with knowledge of your rights as a radio station operator.

Users outside the U.S. may also be required to license their radio system prior to transmission. Please contact your in-country dealer for information concerning the requirements in your country.

RDFC Applications

Applications for radio frequency data communication are increasing in number as the requirements for real-time data grows.

Getting data from one location to another using traditional wire-line or telephone communication can be overly expensive or impossible. Radio data communication is growing fast in areas such as computer-automated dispatch, remote monitoring and control, automatic vehicle monitoring, RTK, and others.

This section shows a small sampling of applications and common radio data communication topologies.

Point-to-point

Simple point-to-point RFDC links are often used to replace wired communication links where the cost or difficulty of wiring makes it appropriate. An example of this type of system is a remotely monitored weather station making use of low-powered radio modems and directional antennas to meet the link range requirement. See Figure 11.

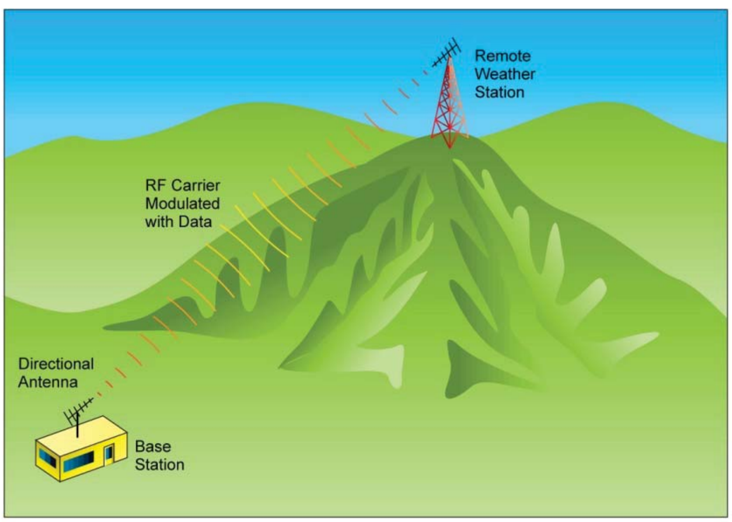

Figure 11 – Point-to-point application

This system illustrates a very common topology, with a computer connected to the radio modem to broadcast commands and receive information from the remote site which consists of various sensors connected to a data logger or remote terminal unit (RTU). The computer control location is often called the base station, while the instrumentation and equipment at the weather station sight is called the remote station. Note the use of low power transmitters with highly gained antennas pointing at each other. Many applications such as this must rely on battery power at the remote station, and therefore require efficient use of the power resource. Antenna selection and placement is critical in this type of application where it is desirous to minimize power consumption.

Another point-to-point application where the receiver station is mobile and the transmitting station is stationary is a DGPS or RTK correction link. In a DGPS or RTK correction link application, a GNSS base station is placed in a fixed known location and monitors errors in the system. Correction factors are then broadcast to the mobile DGPS receivers being used in a survey or navigation activity. The common terminology for the mobile DGPS or RTK receiver is the rover.

Repeater

Figure 12 below illustrates the use of a repeater, which typically is a standalone radio that receives a data broadcast and then retransmits it on the same or a different frequency. The rebroadcast allows for long distance radio communication and also provides a means for getting coverage in areas which may be shadowed from the direct radio broadcast.

Note that in this application, it's common to use omni-directional antennas for the base and rover stations. This allows for operation in a 360-degree pattern about the fixed base. If the use of the rovers is limited to one direction from the fixed base, output power can be reduced and a unidirectional antenna such as a Yagi can be used. DGPS operations are often itinerant and may make use of itinerant frequencies as required and in accordance with the FCC Low Power regulations. Because of the varying conditions encountered in different DGPS sites, it is difficult to provide a single configuration which can be used in all situations. DGPS users must have a basic understanding of radio data communication in order to make choices in setting up the communication link for best performance.

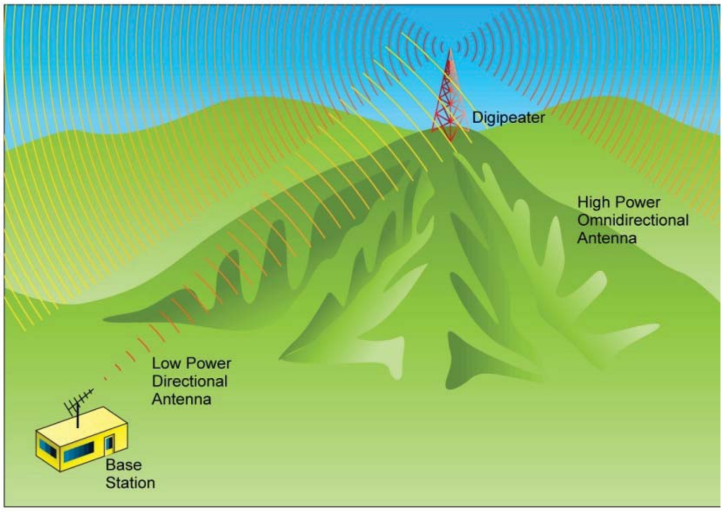

Figure 12 – Repeater application

In amateur packet radio, repeater networks can be taken advantage of to allow data communication across the country. In commercial activities, there is no repeater infrastructure in place, so repeaters are installed in a system for a particular application. Note that repeating functions are often designed into high quality radio data communication products.

Packet operation

Sophisticated radio data communication makes use of packet operation to allow for addressed, point-to-multipoint operation. In packet operation, each node in a network is assigned a unique address. Packets of information are broadcast to specific notes in the network and acknowledgments are returned to the transmitting node. This allows for a reliable data network with multiple nodes sharing a specific frequency.

Figure 13 shows a typical packet operation network used in a taxi dispatch system. The dispatcher needs to send specific information to one of the fleet of taxis, and may also require a broadcast capability to send information to all taxis in the fleet.

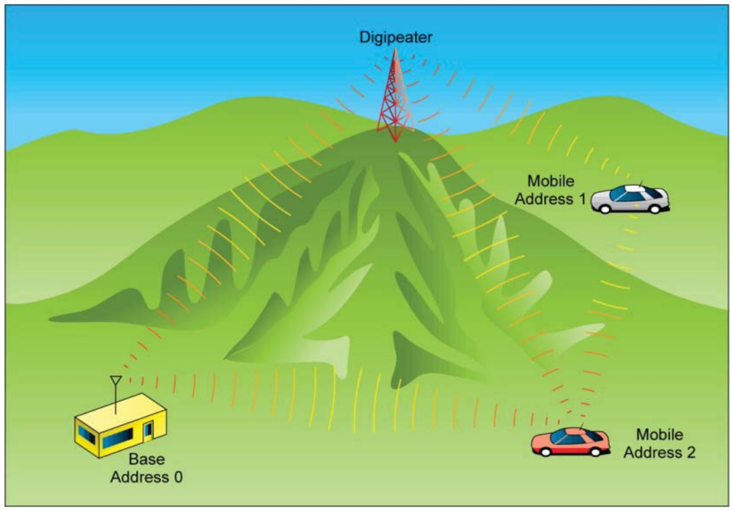

Figure 13 – Packet switched application

Virtually all packet network applications require application specific software. The management of information is generally administered at a fixed base site which controls the flow of information via a polled or Time Division Multiple Access (TDMA) algorithm. High quality radio data communication equipment often provides much of the packet protocol operation which facilitates the design and implementation of these systems. At a minimum, the RFDC equipment should provide unique addressing capabilities and automatic acknowledgment capabilities as part of the modem protocol.

Appendix A
Glossary

antenna: The radiating/receiving element in a radio system. Antennas are designed for the efficient transmission and reception of a radio signals and vary in length and electrical configuration to match the frequency and impedance of the radio system.

antenna gain: A shaping of the pattern of an antenna to concentrate radiated energy, or received signal pickup, in some direction at the expense of others. All antennas exhibit gain over an isotropic radiator.

amplitude modulation (AM): A modulation of a carrier making use changes in signal voltage levels to encode the signal.

attenuation: Reduction of energy or signal level.

baseband: A digital signal which contains the binary information which is used to modulate a carrier.

baud: A measure of the symbol rate with the symbol being the shortest element in the data encoding scheme. Each symbol may encode one or more bits.

bit error rate (BER): A ratio of the number of bits found to be in error to the total number of bits transmitted. Commonly used to compare the quality of a data link.

bits per second (BPS): A measure of the number of bits (binary digits) transferred per second.

burst error: A sequence of consecutive bits which are received in error.

byte: A grouping of bits which constitute a discrete item of information, normally 8bits in length.

carrier: A signal of fixed frequency or amplitude which is modulated with an information-bearing signal.

carrier detect: A signal passed from the radio to an external device that indicates that a carrier of predetermined strength is present.

channel: A data communication path which may consist of a discrete frequency (FDMA), time-slot (TDMA) or spreading code (CDMA).

Carrier Sense Multiple Access (CSMA): A protocol in which a radio must “listen” for signal on the selected channel before it is allowed to transmit.

Code Domain Multiple Access (CDMA): A communication channel making use of spread-spectrum technology which uses a spreading code to modulate the wideband carrier.

coverage: A measure of the proportion of a given error which meets the communication channel requirements.

decibel (dB): A relative unit of measure often used to describe power or voltage.

demodulator: A circuit which takes a modulated signal and converts it to the baseband information.

differential GPS (DGPS): A technique using standard GPS information along with correction information broadcast from a base station which monitors the pseudo-range errors in the GNSS signals. Allows for accuracy measures in meters and centimeters.

filter: An electronic circuit which changes the properties of a signal passing through it.

firmware: A program which controls the operating characteristics of a microcontroller based device. Normally stored in non-volatile memory such as a PROM (Programmable Read-Only Memory).

forward error correction (FEC): A technique used to improve the effective data throughput in a communication link where errors due to noise are present. A transmission of extra data which is encoded with information which allows the receiving device to correct information which is corrupted.

four-level minimum shift keying (4LFSK): A very efficient variant on minimum shift keying modulation that encodes additional bits per symbol by looking for zero crossings at different levels.

frequency division multiple access (FDMA): A division of the radio spectrum into different frequency channels to allow concurrent simultaneous transmissions to occur.

frequency modulation (FM): A modulation of the carrier by varying its frequency with time.

frequency shift keying: A modulation technique with the digital signal states (generally 1's and 0's) being translated into different frequencies which are capable of being transmitted through the communication medium.

full duplex: A communication system capable of simultaneous transmission and reception of data.

gain: An increase of power or voltage on the output of a circuit which is proportional to the input.

Gaussian minimum shift keying: A variant on minimum shift keying modulation which uses a baseband Gaussian filter to shape the modulation output. GMSK is commonly used in high speed data applications because of its bandwidth conservative nature and good immunity to fade conditions.

Global Positioning System (GPS): A system of satellites which provide timing and other information via spread spectrum radio transmissions allowing the precise determination of position using relatively inexpensive receivers. GPS satellites are managed by the US Department of Defense.

Global Navigation Satellite System (GNSS): Any system of orbiting satellites and ground stations offering positioning and timing services. The Global Positioning System (GPS) is the GNSS operated by the US Department of Defense.

half duplex: A communication system capable of transmission and reception of data in a mutually exclusive manner. (Cannot transmit and receive at the same time.)

handshaking: A hardware or software mechanism which allows for the control of data flow.

isotropic radiator: A theoretical point source of radiation which radiates equally in all directions.

modem: A circuit or device which is designed to modulate and demodulate a signal from its digital representation to a waveform which is appropriate for the transmission medium.

noise: Unwanted signals caused by sources external and internal to any circuit. The limiting factor in most communication systems.

parity: An additional bit sent in a serial data stream which is dependent on the byte being sent and is used to check for errors in the data. Even parity means that the parity bit will be set such that there is an even number of 1's in the data stream. Odd parity bit will be set such that there is an odd number of 1's in the data stream. Parity is a poor error detection because it does not catch errors where an even number of bits are affected.

phase modulation (PM): A modulation method where the phase of the signal is varied to provide information content.

point-to-multipoint: A communication system where a single point is capable of addressing multiple points using a packet switched mechanism of addressed data delivery.

point-to-point: A fixed data path communication system where information flows between two points.

propagation: The path or method which a radio wave travels from its source to its destination. The mode of propagation differs depending on the frequency of the signal.

range: The distance at which radio communication is adequate for a particular task.

signal-to-noise (S/N): A measure of the ratio of signal to noise in a received signal. Signal-to-noise is often expressed in terms of dB

signal-to-noise and distortion (SINAD): A measure of the ratio of signal to noise and distortion. SINAD is a common test for radio receiver sensitivity where an RF signal which is modulated with a 1kHz audio tone at +/-3kHz deviation is applied to the radio receiver. A notch filter circuit is used to analyze the audio output signal to noise and distortion. The RF signal is lowered until the audio signal is measured to be 12dB. The power of the RF is the 12dB SINAD figure used to indicate radio receiver sensitivity

synchronous modem: A modem which makes use of synchronous clock extraction which relies on a continuous stream of data.

time division multiple access (TDMA): A division of a single channel into a number of time slots where devices are assigned specific time slots when they can transmit data. This multiplexing of a frequency allows multiple users to share a single frequency.

telemetry: The transmission of non-voice signals for the purpose of automatically indicating or recording measurements at a distance from the measuring instrument.

t**urnaround time:** The time required to switch from a transmit to a receive function in a half duplex data link.

watt: A unit of measure of power being equivalent to 1joule/second.

Appendix B
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Appendix C
Frequency Coordinators

Public safety radio services

Fire
International Association of Fire Chiefs (IAFC)
4025 Fair Ridge Drive,
Suite 300
Fairfax, VA 22033-2868

Phone: 703.273.0911
Fax: 703.273.9363
http://www.iafc.org/

International Municipal Signal Association (IMSA)
P.O. Box 539 - 165 East Union Street
Newark, NY 14513-0539
Phone - 315.331.2182
Toll Free - 800.723.IMSA (4672)
Fax - 315.331.8205
http://www.imsasafety.org/

Highway Maintenance
American Association of State Highway and Transportation Officials (AASHTO)
444 North Capitol Street Northwest Suite 249
Washington, DC 20001
Tel 202 624 5800
Fax 202 624 5806
http://www.transportation.org/

Forestry conservation
Forestry Conservation Communications Association (FCCA)
PO Box 3217
Gettysburg, PA 17325
Phone: (717) 338-1505
FAX: (717)334-5656
http://www.fcca-usa.org/

Industrial Radio Services

Power
Utilities Telecom Council (UTC)
Utilities Telecom Council
5th Floor
1901 Pennsylvania Avenue, NW
Washington, DC 20006
Phone: 202.872.0030
Fax: 202.872.1331
http://www.utc.org/

Petroleum
Petroleum Frequency Coordinating Committee (PFCC)
c/o Enterprise Wireless Alliance (EWA)
8484 Westpark Drive, Suite 630
McLean, VA 22102
703.528.5115 (ph)
703.524.1074 (fx)
Toll-free: 800.886.4222
www.ita-relay.com

Special industrial
Enterprise Wireless Alliance (EWA)
8484 Westpark Drive, Suite 630
McLean, VA 22102
703.528.5115 (ph)
703.524.1074 (fx)
Toll-free: 800.886.4222
www.ita-relay.com

Personal Communications Industry Association (PCIA)
1501 Duke Street
Alexandria, Virginia 22314
Tel 703.739.0300
Fax 703.836.1608
http://www.pcia.com/

Telephone maintenance

Telephone Maintenance Frequency Advisory Committee (TELFAC)
c/o Enterprise Wireless Alliance (EWA)
8484 Westpark Drive, Suite 630
McLean, VA 22102
703.528.5115 (ph)
703.524.1074 (fx)
Toll-free: 800.886.4222
www.ita-relay.com

Industrial radio groups

Airport terminal use frequencies

Personal Communications Industry Association (PCIA)
1501 Duke Street
Alexandria, Virginia 22314
Tel 703 739 0300
Fax 703 836 1608
http://www.pcia.com/

Alarm frequencies

Central Station Alarm Association (CSAA)
8150 Leesburg Pike, Suite 700
Vienna, VA 22182
Tel: 703/242-4670
Fax: 703/242-4675
http://www.csaaul.org/

Offshore zone frequencies

Petroleum Frequency Coordinating Committee (PFCC)
c/o Enterprise Wireless Alliance (EWA)
8484 Westpark Drive, Suite 630
McLean, VA 22102
703.528.5115 (ph)
703.524.1074 (fx)
Toll-free: 800.886.4222
www.ita-relay.com

Other land transportation radio services

Trucking

American Trucking Associations (ATA)
Attention: Frequency Coordination
950 North Glebe Road, Suite 210
Arlington, VA 22203-4181
Tel 703 838 1730
Fax 703 683 1934
http://www.truckline.com

Taxicabs

Taxicab. Limousine and Paratransit Association (TLPA)
3200 Tower Oaks Boulevard
Suite 220
Rockville, MD 20852
Phone: (301) 984-5700
Fax: (301) 984-5703
http://www.tlpa.org/

Automobile emergency

American Automobile Association (AAA)
Frequency Coordination Department
1000 AAA Drive
Heathrow, Florida 32746-5063
Tel 407 444 7786
Fax 407 444 7749

Subject to change

For the most current address of any certified frequency coordinating committee, call the FCC's Consumer Assistance Branch at 1 888 CALL FCC.

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