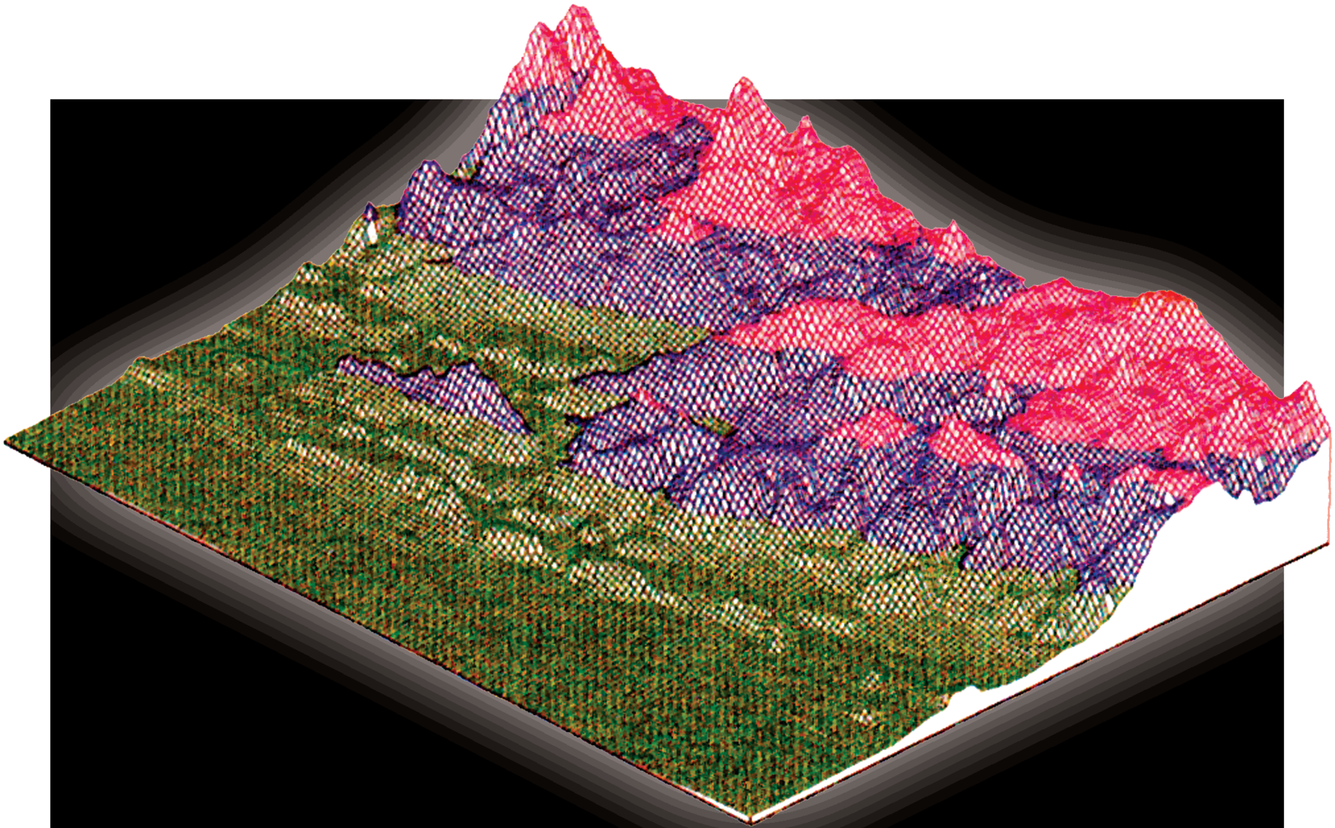


NEW PROPAGATION MODELING TECHNOLOGIES

Digital system design relies on the same fundamental building blocks as good analog systems.

By Larry D. Ellis

A revolution is occurring as users abandon analog (FM modulated) two-way radio and fixed-point links and embrace a wide variety of digital radio systems. Many experienced RF engineers and technicians who are very familiar with conventional analog systems feel like they have been left behind in the wake of new digital technology, which they do not understand.

The new equipment is often smaller, programmable, and more reliable and durable than earlier analog radios. Yet any significant servicing of the new digital equipment requires far more than the old bench set of equipment — RF oscillator, audio oscillator, SINAD meter, frequency counter, and wattmeter. The vast array of new manufacturer-coined terms can cause engineers to question whether their education and experience are adequate for system design and maintenance.

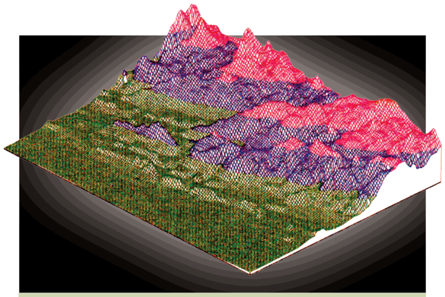
But while the technology associated with transmitting and receiving equipment has radically changed, the concepts of antenna placement, transmission line losses, building and body signal losses, and radio propagation prediction methodology remain fundamentally unchanged. Without a practical knowledge of radio propagation, you cannot fully understand all of the critical factors that must be considered to ensure that a predicted performance level is realistic and attainable. This article is applicable to all forms of RF wireless systems, including cellular, PCS, air-to-ground, and spread-spectrum technology.

Predicting Radio System Performance

Radio propagation modeling software is widely used to calculate and plot radio coverage maps and predict radio-link performance. The accuracy of the maps is highly dependent on how these tools are employed by engineers. Prediction coverage maps are very accurate if proper conditions are applied to the predictive tool.

In digital radio systems, RF energy is generated, amplified, modulated, encoded, and decoded in a different manner than analog systems. Once an RF signal enters the output connector of the radio, however, it operates the same as an analog system until it arrives at the antenna terminals at the receiving end. This is true for all RF-based technologies. The fundamental premise that a specified level of received voltage or power on the front end of a receiver is required to provide a full performance of the radio link has remained unchanged since the inception of radio. This concept — long understood by microwave system designers — is now equally important to those responsible for the design of a repeater site for a digital two-way radio system.

The most important requirement for good radio-link performance is the received signal level (RSL) at the receiver input. Every receiver carries a manufacturer's specification of sensitivity or required voltage into the receiver that ensures it performs according to factory specifications. This, of course, assumes that a radio is properly aligned, within frequency tolerance, and operating in an interference-free environment. For a digital radio, a required RSL will provide a bit error rate (BER) of a specified level.



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BER and Performance

The BER measures the integrity of data transmission. The concept is quite simple. The BER is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as 10 to a negative power. For example, a transmission might have a BER of 10^{-6}, meaning that out of 1 million bits transmitted, one bit was in error. The BER is an indication of how often a packet or other data unit has to be retransmitted due to an error. A BER that is too high may indicate that a slower data rate could actually improve overall transmission time for a given amount of transmitted data, since the BER might be reduced.

A certain required RSL specification (in either dBm or microvolts) will provide a statistically reliable performance of the specified BER. At times there might be two different specified BERs, both having a required received signal level. The higher the received signal level, the better the BER (lower BER). In real-life operation, the BER will vary within your radio coverage area, partly because of the typically wide variation in RSL. Other factors also can adversely affect BER, however, even with a sufficient received signal level. Successful operation not only requires sufficient RSL, but also a high-quality signal.

In a digital system, noise impacts system performance just as it does in an analog system — the noise increases the BER. When the BER is degraded to a level below the specification of the equipment being used, the voice and data transmissions can become unintelligible. Factors other than a low RSL can cause degradation as well, including interference, which comes in many forms.

The most common cause of interference is destructive levels of undesired received signal at a receiver location. The signal may originate from another user that shares the same frequency at a different location. It might be a transmitted carrier that is close to your desired frequency or one that is in the immediate physical proximity of your receiver, which overloads the front end. It might be intermodulation, a combination of transmitted frequencies and their harmonics, which combine and form destructive noise for your particular frequency at certain locations.

Coverage Prediction

Several well-accepted propagation models are used throughout the industry for coverage prediction. Each model represents an attempt to predict radio propagation as it is affected by real-world conditions. Bullington, Okumura, and Longley-Rice are the most common. These analytical models consider a number of factors including individual obstructions (terrain or manmade) and terrain roughness.

Okumura is often used in urban environments since it includes correction factors for various area types, such as urban and suburban. Bullington considers individual obstructions and computes losses for terrain obstructions, ridges, etc. Longley-Rice is a general model that considers radio horizons and various environmental conditions. A prudent engineer will learn the weaknesses and strengths of the models as well as their limitations. An engineer must also fine-tune each model and independently select values for various parameters based on good engineering judgment and the particular circumstances of the study at hand.

An additional problem that may arise when predicting repeater coverage is the distortion of an omnidirectional radiation pattern when an antenna is mounted on a metal tower. In this situation, the antenna acts like a directional antenna and the shape of the distorted pattern is dramatically controlled by its location on the tower, the tower face size, distance from the tower, and gain of the antenna.

New technologies are allowing engineers to assess the quality of received signal level. Using flexible software tools, they are able to prepare a coverage map of predicted RSL and model interfering signals. An aggregate coverage map shows only locations where the incident signal is at the desired level and where no interfering signal would prove destructive to the signal level. Particularly troublesome are shared frequencies where one or both sites are located at very high elevations. Interference in these situations cannot be predicted without sophisticated software tools.

How Much Field Strength is Enough?

The FCC expresses electric field intensity in units of dBu when referring to field strength. Electric field strength is always expressed in some relative value of volts/meter — never in volts or milliwatts. Electric field intensity is independent of frequency, receiving antenna gain, receiving antenna impedance, and receiving transmission line loss. Therefore, this measure can be used as an absolute measure to describe service areas and compare different transmitting facilities independent of the many variables introduced by different receiver configurations.

Figure 1: Calculating Field Strength

Field strength as a function of received voltage, receiving antenna gain, and frequency when applied to an antenna whose impedance is 50 ohms can be expressed as:

$$E(\mathrm{dB\mu V/meter}) = E(\mathrm{dB\mu V}) - Gr(\mathrm{dBi}) + 20\log F(\mathrm{MHz}) - 29.8$$

E(dBµV/meter) is received field strength; E(dBµV) is received votage on the antenna terminal; Gr is the gain of the receiving antenna in dBi; F is the frequency in MHz

Solved for received voltage this equation becomes:

$$E(\mathrm{dB\mu V}) = E(\mathrm{dB\mu V/meter}) + Gr(\mathrm{dBi}) - 20\log F(\mathrm{MHz}) + 29.8$$

For power and voltage calculations into a 50-ohm load:

$$P(\mathrm{dBm}) = E\ (\mathrm{dB\mu V}) - 107$$
$$P(\mathrm{dBm}) = E\ (\mathrm{dB\mu V/m}) + Gr(\mathrm{dBi}) - 20\log F(\mathrm{MHz}) - 77.2$$

P is received power in dBm

Note: *These predictions are strictly for the voltage at the antenna terminals. This is the actual voltage (and power) delivered to the receiver. It must exceed the specified sensitivity (or threshold) of the receiver. Voltage and power levels at the receiver input must take into account additional loss in the receiving transmission line.*

The line-of-sight is essentially the direct path between the center of radiation of the transmitting antenna to the center of radiation of the receiving antenna. Fresnel zone is a mathematical, calculated, 3-D envelope around the line-of-site path. The simplest prediction of field strength occurs with an unobstructed line-of-sight path and no obstructions that fall within 0.5 of the first Fresnel zone, which would introduce additional attenuation in the RSL. In this case, the received electric field strength, E(dBµV/m) or dBu, will approximate that of free space and may be calculated from the following equation:

$$E(\mathrm{dB\mu V/m}) = 106.92 + ERP(\mathrm{dBk}) - 20\log d(\mathrm{km})$$

- *E* is received electric field strength
- *ERP* (effective radiated power) is expressed in dB above 1 kW
- *d* is distance expressed in kilometers

Received Voltage and Power

Although calculations of electric field strength are independent of the receiver characteristics mentioned above, predictions of voltage and received power supplied to the receiver input must carefully take each of these factors into account.

When using the equation for field strength found in Figure 1, one must remember that these predictions are strictly for the voltage at the antenna terminals. This is the actual voltage (and power) delivered to the receiver, assuming no signal loss in the receiving transmission line. The RSL must exceed the specified sensitivity (or threshold) of the receiver. Actual voltage and power levels at the receiver input must take into account additional loss in the receiving transmission line. This loss in signal is particularly critical at high frequencies when cables are long. The electric field induces a voltage into the antenna, transferring power into the antenna. The voltage (dBµV) at the terminals of the antenna is a function of the gain of the antenna for the particular frequency under consideration.

The power (dBm) available at the antenna terminals is also a function of the antenna impedance (usually 50 ohms). The transmission line (usually coaxial cable or wave guide) connects the antenna terminals to the receiver input terminals. The voltage and power at the receiver input terminals are reduced by loss in a transmission line. Transmission line losses are a function of the size and type of the

Figure 2: General Guidelines for External Losses

In addition to the impact of terrain, engineers must also consider external losses such as body absorption, building losses, and values introduced in various circumstances. The following table provides some general guidelines for external losses.

Measured Losses by General Electric
150-170 MHz
Handheld, vertical: -6 dB
Handheld, angled: -10 dB
Hip-mount: -17 dB

450-470 MHz
Handheld, vertical: -17 dB
Handheld, angled: -18 dB
Hip-mount: -17 dB

In-Vehicle Measurements by General Electric
150-174 MHz
Radio on driver's left hip, antenna clear: -25 dB
Radio laying on seat, speaker up with antenna toward front: -36 dB
Radio connected to vehicular charger and unity gain antenna on rooftop: -2 dB

450-470 MHz
Radio on driver's left hip, antenna clear: -24 dB
Radio handheld, vertical: -16 dB
Radio connected to vehicular charger and unity gain antenna on rooftop: -4 dB (15-foot RG-58/U coax)

Note: *These loss values can be used when determining the amount of signal available at a receiver's input terminals for a given field strength.*

transmission line and the operating frequency. In addition, other losses affect the power transferred to the receiver input terminals.

In addition to the impact of terrain, engineers must also consider external losses such as body absorption, building losses, and values introduced in various circumstances. (See Figure 2.) For in-vehicle applications, additional losses may be caused by the vehicle's emergency light bar if an antenna is mounted on the center of the roof. Figure 2 estimates this loss to be -2 to -7 dB at 840 MHz.

In another example, a 150 to 170 MHz handheld receiver worn on the hip will experience approximately 17 dB of loss (due primarily to the body proximity), according to the measurements in Figure 2. Therefore, if the computed field strength for a given location is 40 dBu, the actual field strength available to the antenna on the hip-mounted receiver may be as low as 23 dBu.

The loss values shown in Figure 3 can be used along with the manufacturer's specification for required receiver input (voltage or power) to determine the field strength (in dBu) necessary to produce that voltage or power at the receiver input terminals in the presence of losses due to a number of variables, including body or vehicle proximity.

Based on the actual equipment proposed and the equations presented in this article, an engineer can calculate the actual field strength necessary for any particular receiving system. Operating the receivers in interference-free areas where field strength meets or exceeds the equipment design level should produce satisfactory system performance. If you carefully consider all these factors during system design, you can be confident in the reliability of your radio system under study.

Figure 3: In-Building Losses

Additional measured losses inside buildings should be included when designing a system for operation of mobile units inside buildings:

Building floor	VHF	UHF
Basement	-34 dB	-27 dB
1st	-29.5 dB	-23.5 dB
3rd	-26 dB	-20 dB
5th	-23 dB	-15 dB
10th	-12 dB	-3.5 dB
14th	-7.8 dB	+2.0 dB

Source: *"Two-Way Personal Radio System Design," General Electric Co.*

Digital system design relies on the same fundamental building blocks as good analog systems of the past. Solutions to the issues presented in this article can be isolated using experience, common sense, available predictive software tools, and suitable diagnostic and field strength measuring equipment. ■

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