UHF/VHF RANGE CALCULATIONS
#127 Rev 1.1

INTRODUCTION

This application note provides an overview of the considerations in determining the range that can be expected in a radio data link. Because of the number of variables which can, and do, influence the actual range of an RF communication link, it is beyond the scope of this application note to provide a more than precursory overview of the range calculations.

Range determination involves five parameters, which must be must be calculated or determined with testing. These parameters are:

1. Radio line-of-sight.
2. Transmitter and receiver line losses.
3. Power output and receiver sensitivity.
4. Transmitter and receiver antenna gain.
5. Path loss.

Once these parameters have been determined, then the radio range can be estimated.

RADIO LINE-OF-SIGHT CALCULATION

The radio line-of-sight provides a limit on the range of an hypothetical RF link. Because of the nature of UHF and VHF radio wave propagation, range is limited by the radio horizon caused by the curvature of the earth. The line-of sight can be calculated using the following equation:

D = 1.33(SQRT(2Hr) + SQRT(2Ht))

Where
D = distance to radio horizon (miles)
Hr = height of RX antenna (feet)
Ht = height of TX antenna (feet)

This calculation determines the theoretical maximum range. The actual range is usually less than this, because of the variables in transmitter power, receiver sensitivity, line losses, and antenna efficiency. Also, operating frequency is another factor which influences the ultimate range.

LINE LOSSES

The path followed by the RF energy, as it is sent to and from the antenna, is associated with a loss of power. This loss occurs because of the escape of energy through less than perfect shielding, resistance, and because of the reflection of energy as it passes through less than perfect line couplers. Line losses which occur in commonly used coaxial cables are quantified, and are published by the manufacturer. The best way to determine actual line loss is with an RF power meter inserted before and after the transmission line.

Typical values for line loss of the most commonly used coaxial cable, RG-58A/U, is approximately 9.5 dB per 100 feet.

POWER OUTPUT AND RECEIVER SENSITIVITY

Transmitter output power, usually specified in watts, is the power which is available at the transmitter. Using the units of decibels relative to 1 mW (dBm), a 2 watt transmitter produces +33 dBm of power (10*log10(2/.001)).

Receiver sensitivity is typically specified in units of microvolts for a 12 dB SINAD (signal to noise and distortion). The amount of RF power required by the receiver to faithfully represent the actual signal transmitted is arbitrarily set at the 12 dB SINAD, which translates into -114 dBm for a typical receiver.

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ANTENNA GAIN

Antennas are passive elements in an RF circuit, and do not actually produce a gain (amplification) of the RF power. However, antennas can be designed to focus the energy in a specific plane or pattern, thereby producing an effective gain in a particular direction. The gain pattern can be omni-directional (360 about the antenna), or uni-directional depending on the construction of the antenna.

Antenna manufacturers generally specify the radiation pattern and effective signal gain for their directional antennas. For example, a 6 element yagi antenna may have a 10 dB gain in the direction specified by the radiation pattern.

PATH LOSS

Path loss is the loss of power that occurs to the signal as it propagates through free space from the transmitter to the receiver. The calculation of the path loss takes into account the distance the radio wave travels, the frequency of operation, and the antenna height factors. The following equation is used to calculate path loss in dBm.

$$PL = 117 + 20\log_{10}(F) - 20\log_{10}(Ht*Hr) + 40\log_{10}(D)$$

Where

PL = path loss in dBm
F = operating frequency in MHz
Ht, Hr = height of transmit and receive antennas (feet)
D = distance between antennas (miles)

FADE MARGIN

Maximum range calculations must also consider the reliability of the radio link. At the theoretical maximum range, you can only expect a useful circuit 50% of the time due to the fluctuations in the different parameters which contribute to the range.

In the design of a communication system, it is customary to take into account a fade margin, such that the receiver threshold is exceeded by the arriving carrier level by a margin. The fade margin relates to the reliability of the link. Accounting for a fade margin is particularly critical for data applications, where corruption of a single bit may invalidate the entire data interaction. For a 99% reliability, a fade margin of 18 dB should be used.

PUTTING IT ALL TOGETHER

As an example of how a range estimation is calculated, we will consider a system using two RDDR-96 RF modems. We wish a 99% reliable data link (retransmission of packets will be required), so we will use a fade margin of 18dBm.

Both RDDR-96s have 5/8 wave, omni-directional antennas with a 3 dB effective gain. The antennas are placed 20' above the average terrain, using an RG-58A/U coaxial cable of the same length.

From the RDDR-96 data sheet, we know that the RF output power is nominally 2 watts, or 33 dBm. Because of the directional antenna, the effective power output is 36 dBm (33 dBm + 3 dBm due to antenna gain). The 20' length of coaxial cable contributes to a line loss of 1.8 dBm, making the final effective radiated power of 34.2 dBm (ignoring VSWR mismatch). We assume that the RDDR-96 is transmitting at 450 MHz.

The receiver sensitivity is .45 uV or better at 12dB SINAD. This is equivalent to approximately -114 dBm. The receiving antenna has a 3 dBm gain, making the sensitivity factor -117 dBm. The line loss from the 20' length of coaxial cable is 1.8 dBm, resulting in -115.2 dBm. Taking into account the fade margin, we need a signal -97.2 dBm (-115.2 dBm + 18 dBm fade margin).

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Using the equation for path loss calculation, and solving for the distance between transmitter and receiver, we have the following.

$$D = 10^{((PL-117-20\log_{10}(F)+20\log_{10}(Hr*Ht))/40)}$$

Where

$PL = 34.2 - (-97.2)$ dBm = 131.4 dBm
$F = 450$ MHz
$Hr = Ht = 20'$

Giving a distance of 2.16 miles.

INCREASING RANGE
The easiest and cheapest ways of increasing the range in an RF data application come from careful selection and placement of the antennas. Select an antenna which provides maximum gain, taking into account the nature of the application. For fixed point-to-point applications, use a Yagi antenna for maximum gain. For omni-directional use, perhaps a 5/8 wave antenna is a better choice than the standard 1/4 wave.

Select an antenna location which is as high above the surrounding terrain as possible. Also, keep the length of the coaxial cables between the radio transceiver and antenna as short as possible. (NOTE: FCC regulations may restrict antenna placement height and the use of directional antennas in some situations. Consult the CFR-47, Part 90 for complete regulations.)

The next step to increase the range of the system is to increase the power output of the transmitter by using an RF amplifier. The RDDR-96 will work with a high quality RF amplifier, to produce a power output up to the maximum which the FCC allows.

The most expensive means of increasing the range of a system is with the use of repeaters, which receive information on one frequency, and transmit it on another. With repeater stations, the data can be relayed over long distances.

SUMMARY
This application note gives a brief overview of the factors which go into the range calculations for a radio link. Because of the multitude of factors which may influence a particular system, it is important to realize that the actual range may differ substantially from the theoretical.

Understanding the different variables, and how they contribute to increasing or decreasing range, will allow the system designer to optimize the radio link in a given application.

MORE INFORMATION
For more information about radio range calculations, consult the following:
International Telephone and Telegraph Corp., "Reference Data for Radio Engineers", 6th Edition, Howard Sams, New York, NY 1981

Lee, William, "Mobile Communications Engineering", McGraw-Hill, New York, NY 1982

ARRL, "The ARRL Handbook", 69th Edition, The American Radio Relay League,

QUESTIONS OR COMMENTS
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