Calculating the Range of a Radio Direction Finder

A Technical Application Note from Doppler Systems

7 August 2024

1.0 Introduction

One of the most asked questions we receive is “What range can I expect for the Doppler Radio Direction finder.” Our answer is always “it depends.” Although, there are many variables that determine the range, the primary variables are frequency, the transmitted power, and the heights of the transmitting and direction finding antennas. Secondary variables include terrain and environment. This application note will give some guidance to allow the system designer to approximate the range of the direction finder.

2.0 Theory

Defining Path Loss

To estimate the direction finder’s range, the path loss must be calculated. The path loss is simply the attenuation between a transmit and receive (df) antenna having unity gains (isotropic antennas).

The equation for path loss is

$$P_l = P_t - P_r + G_r + G_r$$

where,

P_l is the path loss in dB

P_t is the transmitted power in dB

P_r is the received power in dB

G_r, G_t are the gains of the antenna in dB

If the transmitting and df antennas are dipoles the equation reduces to

$$P_l = P_t - P_r + 4.3$$

Free Space Loss

The free space path loss is the most optimistic loss and can only be used for short distances; however, it provides a starting point for the more realistic loss estimation. The equation for free space path loss is given by

$$P_l = \left(\frac{4\pi d}{\lambda}\right)^2$$

where,

d is the distance in meters between the antennas

λ is the signal wavelength

Converting to dB and using frequency instead of wavelength, the equation becomes

$$P_l = -27.6 + 20\log(f) + 20\log(d)$$

where,

P_l is the path loss in dB

f is the frequency in MHz

d is the distance between the antennas in meters

The Real World

Unfortunately, due to the effects of terrain, the free space model does not give an accurate estimate of loss. So, instead the radio waves traveling in free space we have a space wave as depicted in Figure 1. The power received is a combination of the direct wave and the reflected wave. This is where the variability comes in. The power of the reflected wave varies significantly depending on the terrain. If the Ground in the figure below is sea water the loss is lower than if it is dry dirt or pavement.

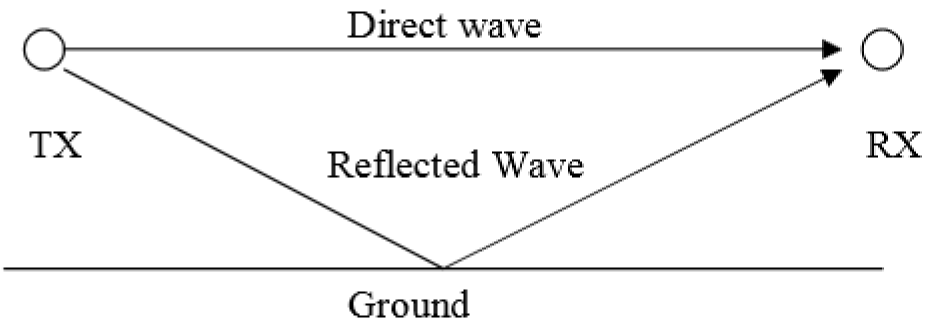

Figure 1:Space Wave

Additionally, effect of reflection diffraction, and scattering effect the path loss.

In the 1980's, Yoshihisa Okumura made a series of measurement for the path loss from a base station to a mobile station. Using this data Hata came up with closed form solutions based on curve fitting of Okumura data. He extended the Okumura models to include the effect due to diffraction, reflection, and scattering of transmitted signal in a variety of environments. Hata's results can be found at [Hata Okumura model for outdoor propagation - GaussianWaves]().

For our purposes the equation

$P_L = 88.1 + 20\,log(\mathrm{f}) - 20\,log(\mathrm{h_t h_r}) + 40log\,(\mathrm{d})$ *Equation 1*

where,

h_t, h_r are the heights in meters of the transmit and receive antennas respectively.

is a good approximation to calculate the path loss.

The chart in Figure 2 shows the results for the various models

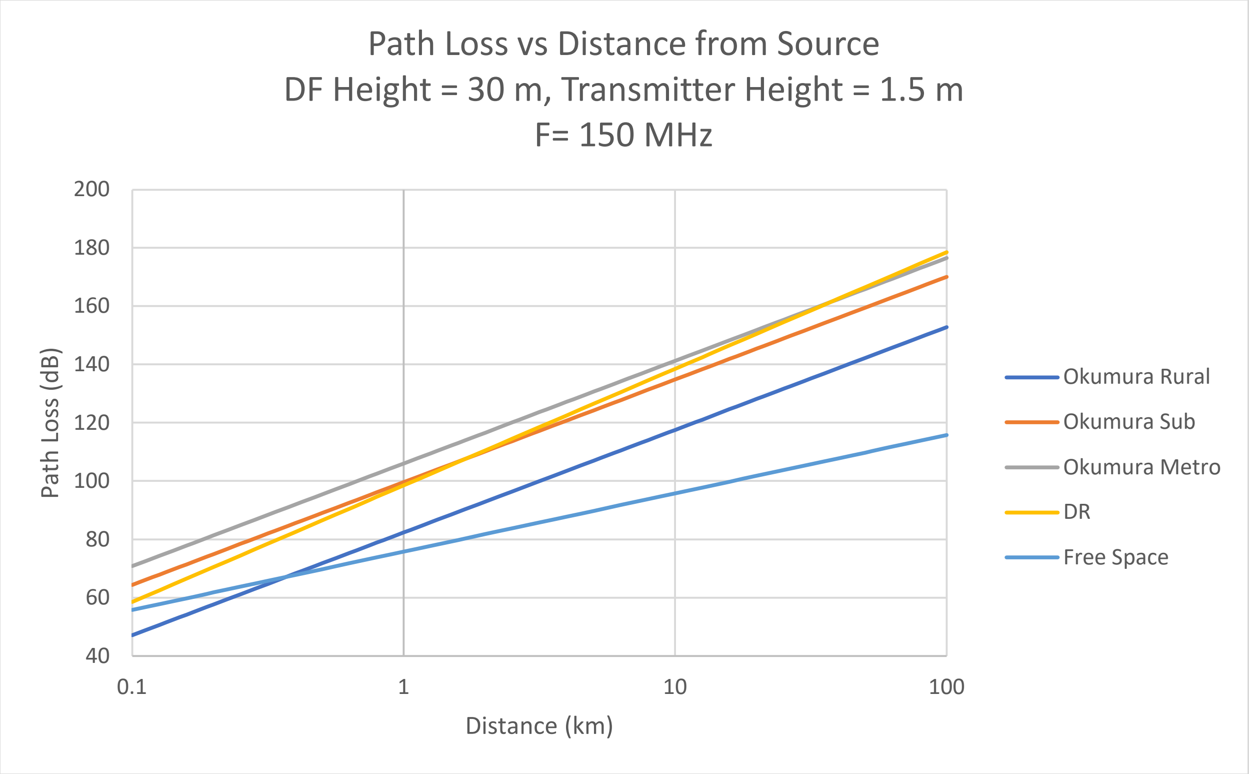

Figure 2: Path Loss Results for Various Models

Notice the DR model gives a fairly pessimistic path loss.

3.0 Range

From the path loss equations, we can now calculate the expected range. To calculate the range we calculate the fade margin. The fade margin is defined as the amount which a received signal level may be reduced without causing system performance to fall below a specified threshold value. For our purposes it is the amount the signal level can be reduced and still have a 90% probability of detection.

We solve the equation below to calculate the fade margin

$$P_t + G_t + G_r - C_t - C_r - P_l = S_d$$

where,

P_t is the transmitted power in dBm
G_t is the gain of the transmitter antenna in dB
G_r is the gain of the DF antenna (~ 4 dB)
C_t is the coax loss of the transmit coax in dB
C_r is the coax loss of the receive coax in dB

P_l is the path loss as calculated by Equation 1 above
S_d is the sensitivity at which we obtain a 90% reliable bearing reading

This equation is easily solved graphically. Using the same frequency and antenna heights as above we obtain the following graph.

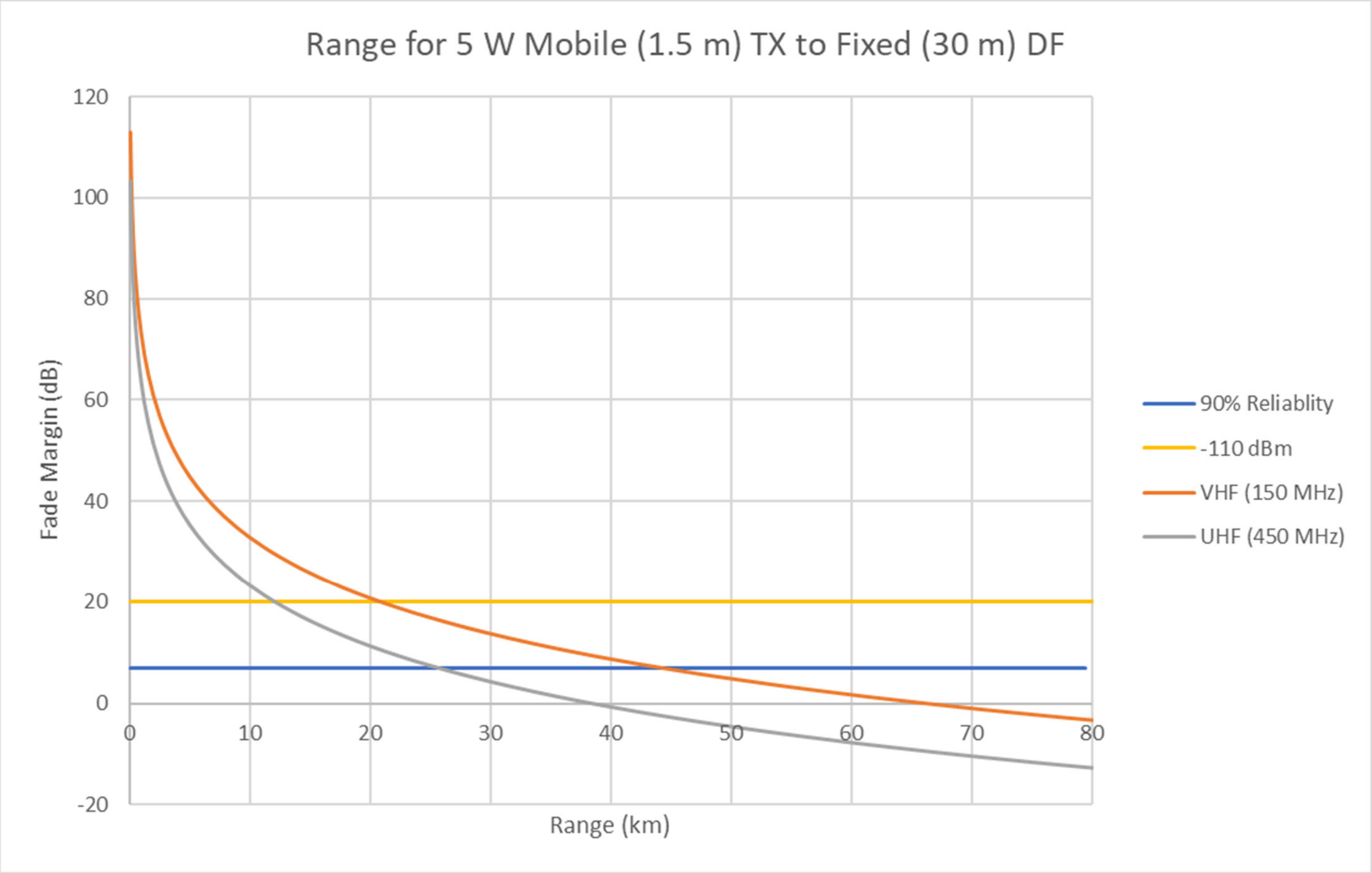

Figure 3: Fade Margin for a Fixed to Mobile Direction Finder Application

As you can see the expected range at VHF is about 40 km for a 90% (-123 dBm) bearing detection reliability and about 25 km at UHF.

4.0 Caveat

The equations above will give reasonable estimates of the detection range; however, the curvature of the earth can sometimes limit the range as shown in Figure 4.

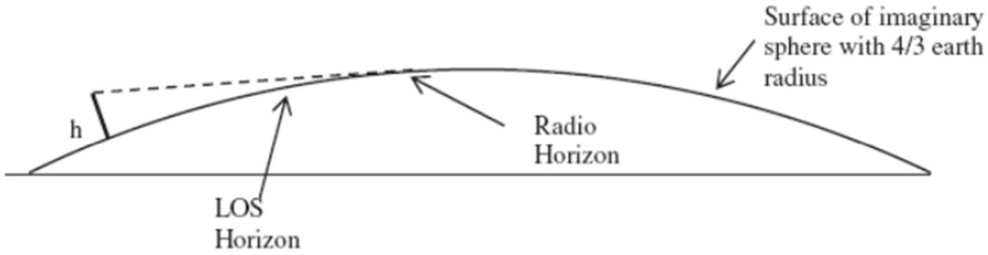

Figure 4: Curvature of the earth can limit the range

The equation for calculating the curvature effect is

$$LOS = 4.11(\sqrt{h_t} + \sqrt{h_r})$$

where,

h_t, h_r are the heights of the antenna in meters
LOS is the line-of-site in km

So, in section 3 the predicted range of detection for the VHF case is about 40 km, the curvature of the earth would limit it to about 27.5 km for a 30 meter high df antenna and a 1.5 meter high mobile antenna.

5.0 Conclusion

The range of detection for a radio direction finder depends on the frequency of transmission, the height of the transmit and receive antennas, and the transmitted power. This application note provides a basis for making estimates of the range.