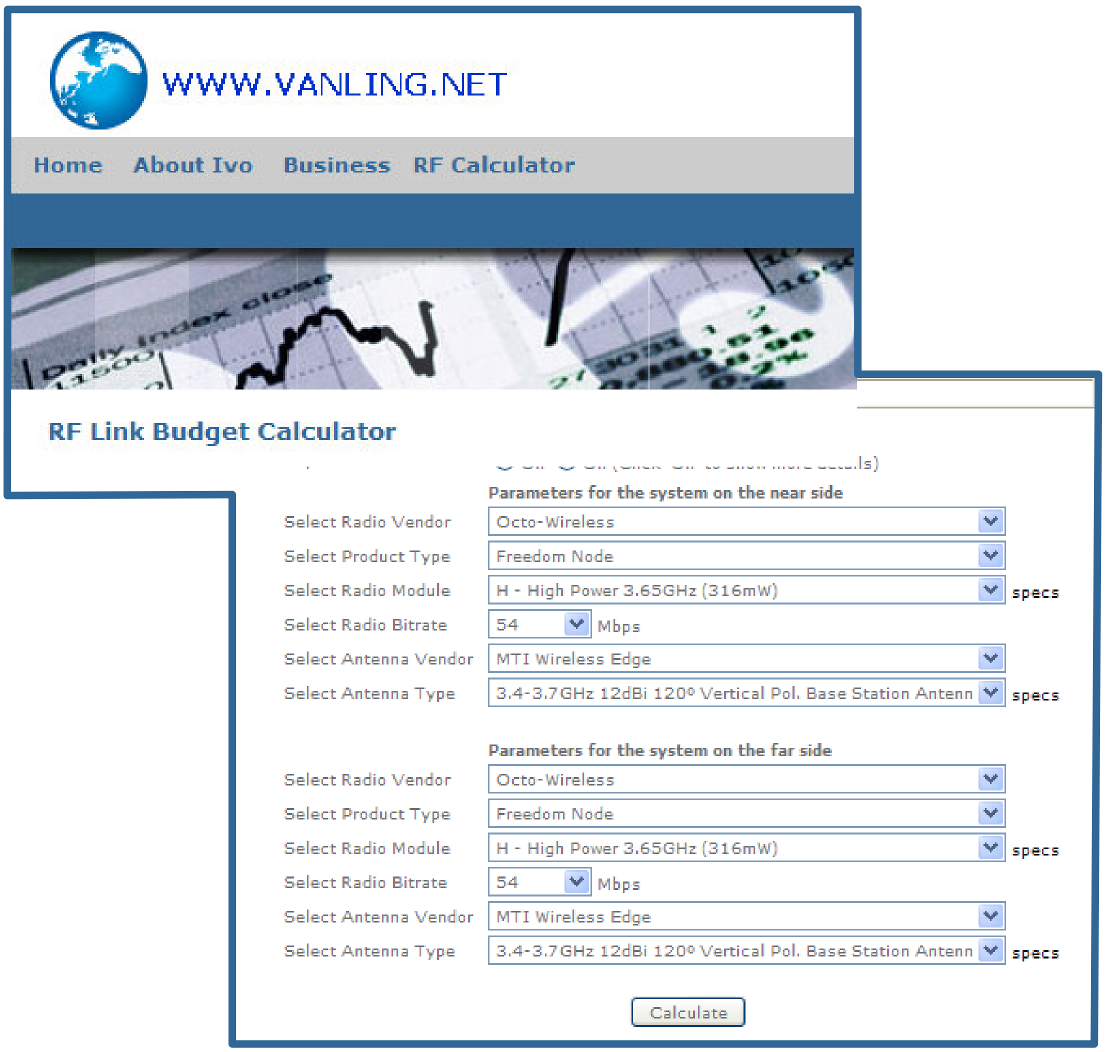
RF Link Budget Calculator
Manual



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Manual Version	**1.00**
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Contents

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RF Link Budget Calculator Manual

1 Introduction

This document describes the use of the RF Link Distance Calculator, Version 1.00, and Dated 4 January 2010. This is an online tool and can be used to calculate the Line-Of-Sight (LOS) distance between two radio systems dependent on radio type, antenna type and frequency. Furthermore, it also calculates the required antenna height on each side of the link to allow for the Fresnel zone and the curvature of the earth over the calculated link distance.

This calculator tool can be used in two modes: ‘Normal’ and ‘Expert’ mode.

The ‘Normal’ mode is meant to calculate the maximum wireless link distance between two wireless nodes in combination with a certain set of antennas. In this mode, the tool can be used to quickly verify the validity of a proposed technical solution.

The ‘Expert’ mode can be used manually change all parameters effecting the link distance. You can for example select a radio and antenna type that closes matches the required setup and then manually ‘tweak’ the parameters that differ from the values that are stored in the database of the tool.

The actual calculator can be found at the following URL: http://www.vanling.net/LinkCalculator.htm

Please note that the distances calculated by this tool are best case values under ideal conditions assuming clear line of sight and should be treated as such. In real life the conditions are far from ideal, so the radio waves transmitted from our wireless nodes tend to bump into things (buildings, leaves, and people) and either get absorbed or bounce off again in some random direction. Therefore, no rights can be obtained from the information displayed. This tool and the information contained therein are provided as is and may be changed without notice.

1.1 Calculate Maximum Distance

The RF Link Distance calculator can be used to calculate the maximum link distance between two wireless network nodes. The distance covered between the nodes is dependent on the type of radio, antenna equipment and frequencies used on each side of the link. One side of the link is called the “**near side**” and the other side is called the “**far side**”.

In order to calculate the maximum distance between two nodes you have to select the type of radio and type of antenna at each side (Near and Far side) of the link. Consider the following example network setup with two Freedom nodes (Near Side and Far Side) each equipped with a 3.5GHz 12dBi base station antenna.

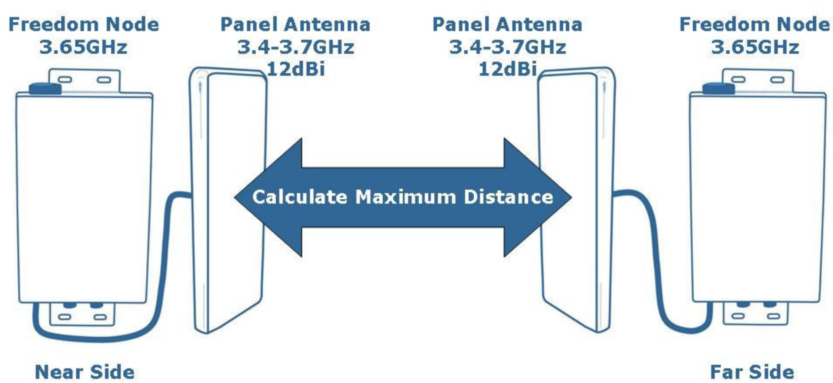


Figure 1: Example Network setup for maximum distance calculation

In the start-up screen of the RF Link Distance Calculator you find a number of list boxes to select the Near Side and Far Side equipment. In order to calculate the maximum distance between the two nodes in the example above make the following selections for the near side radio equipment and antenna:

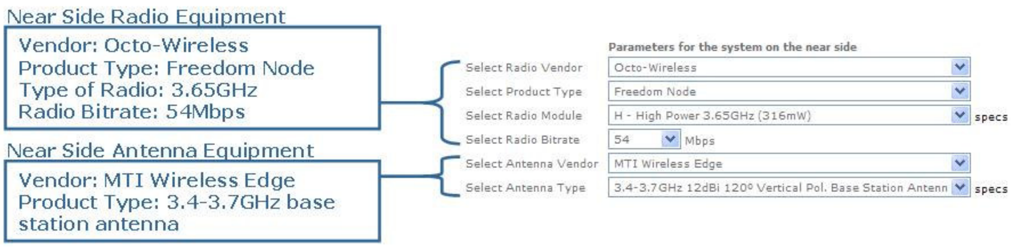


Figure 2: Select Equipment on the near side for maximum distance calculation

Then select the radio equipment and antenna for the far side:

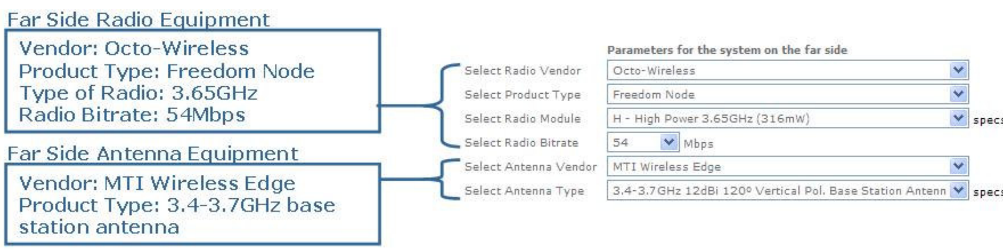
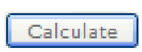


Figure 3: Select Equipment on the far side for maximum distance calculation

Upon pressing the 

button the RF Link Distance Calculator calculates the maximum distance between the two nodes dependent on the types of radio, antenna and usable frequencies to establish a working radio link.

In this example the maximum distance between the Near Side and Far side is given as 2.88 kilometers.

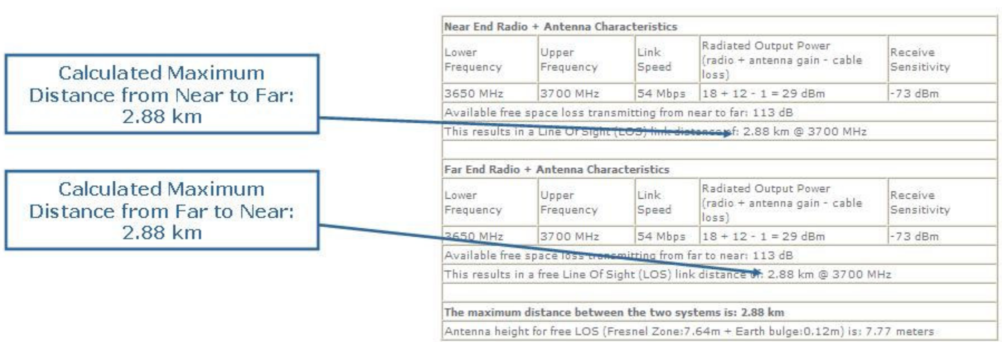


Figure 4: Calculated Maximum Distance between two nodes

At the same time the maximum distance going from the Far to Near node is also calculated. In this example the distance is exactly the same, however if you use two different types of radios on each side of the link these distances might be different.

1.2 The Mathematics behind Maximum Distance Calculation

If you only want to use the tool to determine the distance given a set of antennas and radio equipment then read no further. Otherwise this chapter describes in more depth how the RF Link Distance Calculator calculates the maximum distance between two nodes.

The maximum distance that you can cover between those two wireless nodes is determined by a number of factors:

1. The radio output power of the near node.
2. The antenna cable and connector loss at the near node.
3. The antenna gain of the near node.
4. The Free Space Loss, or the attenuation of the radio signal, as it travels from the near node to the far node.
5. The antenna gain of the far node.
6. The antenna cable and connector loss at the near node.
7. The receive sensitivity of the far node.

Of course the same holds true for the maximum distance going from the far node to the near node. For sake of simplicity we only consider one way traffic, i.e. going from the near node to the far node. However, the maximum distance going from "near" to "far" might be different than going the other way. In the tool we calculate both paths simultaneously.

In order to determine the maximum distance between the two nodes the Link Distance Calculator tool needs to calculate the seven factors above and then present you with the maximum distance in meters. To give you an example how the tool calculates the maximum distance we will use the same network example as shown in the previous chapter.

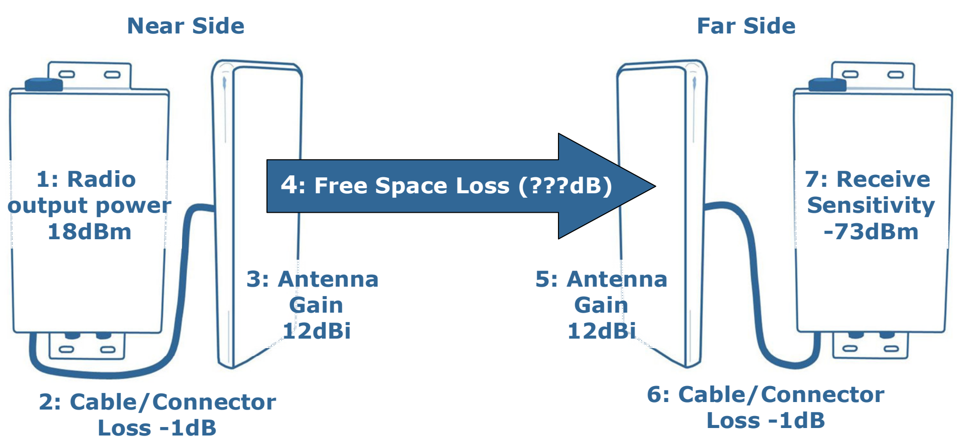


Figure 5: Radio output power, cable losses and receive sensitivity are known values

Here we have two nodes placed at an unknown (???) distance apart. The "Near Side" node is transmitting radio signals with a certain radio output power (+18dBm) that are being amplified (+12dBi) by the "Near Side" antenna. The radio signal travels a distance until they hit the antenna of the "far node". There they amplified by the antenna (+12dBi) and then presented to the receiver of the "Far Side" radio. The losses of the connectors, pigtails and antenna connectors at each end of the link are set at a fixed value of -1dB.

All values for connector and cable losses can be altered and further specified when switching to expert mode.

The equation for calculation of the received signal strength on the far node is as follows:

$$FAR_{Rec\ Sig} = NEAR_{Pout} - NEAR_{cable\ loss} + NEAR_{ant\ gain} - FSPL - FAR_{cable\ loss} + FAR_{ant\ gain}$$

Where:

$FAR_{Rec\ Sig}$ = The Received Signal on the far node.
$NEAR_{Pout}$ = The radio output power of the near node.
$NEAR_{cable\ loss}$ = The cable and connector losses at the near node.
$NEAR_{ant\ gain}$ = The antenna gain of the near node
$FSPL$ = Free Space Loss.
$FAR_{cable\ loss}$ = The cable and connector losses at the far node.
$FAR_{ant\ gain}$ = The antenna gain of the far node.

In our equation we know everything but the value of the **Free Space Loss**. This is because the Free Space Loss is dependent on the distance between the nodes and the frequency on which the link between the nodes is established.

As we are trying to work out what the maximum distance between the nodes can be we need to calculate the maximum Free Space Loss allowed to establish a working link between the two nodes.

We need to make one assumption, namely: "As long as the radio signal that is being presented to the receiver has higher signal strength than the receive sensitivity of the receiver (-73dBm) your are able to establish a working radio link". Thus the minimum signal level that need to be present at the receiver is the same as the receive sensitivity of the far node.

We can rewrite the equation to read:

$$FSPL = NEAR_{Pout} + NEAR_{ant\ gain} + FAR_{ant\ gain} - FAR_{Rec\ Sens} - NEAR_{cable\ loss} - FAR_{cable\ loss}$$

Where:

$FSPL$ = Free Space Power Loss.
$NEAR_{Pout}$ = The radio output power of the near node.
$NEAR_{ant\ gain}$ = The antenna gain of the near node.
$FAR_{ant\ gain}$ = The antenna gain of the far node.
$FAR_{Rec\ Sens}$ = The Received Signal on the far node.
$NEAR_{cable\ loss}$ = The cable and connector losses at the near node
$FAR_{cable\ loss}$ = The cable and connector losses at the far node

When we fill in all the know variables from our example we get:

$$FSPL = NEAR_{Pout} + NEAR_{ant\ gain} + FAR_{ant\ gain} - FAR_{Rec\ Sens} - NEAR_{cable\ loss} - FAR_{cable\ loss}$$

$$FSPL = 18dBm + 12dBi + 12dBi - (-73dBm) - 1dB - 1dB$$

$$FSPL = 18dBm + 12dBi + 12dBi + 73dBm - 1dB - 1dB$$

$$FSPL = \mathbf{113dB}$$

The Free Space Loss in this example can thus be **113dB** before the Far Side node is unable to receive the broadcast coming from the near node.

The further the distance between the two nodes the more the signal traveling from the near node to the far node will be losing power (attenuated). Free-space power loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal.

The equation for free-space power loss (FSPL) is:

$$FSPL = \frac{(4*\pi*d*f)^{2}}{c}$$

Where:

FSPL = Free Space Power Loss.
f = the signal frequency (in Hertz).
d = the distance from the transmitter (in meters).
c = the speed of light in a vacuum, 2.99792458×10^{8} meters per second.
π = taken as 3.14159

A convenient way to express free-space loss is in terms of dB (since we have calculated it as 113dB in the example above) is:

$$FSPL(dB) = 20*\log_{10}\frac{(4*\pi*d*f)}{c}$$

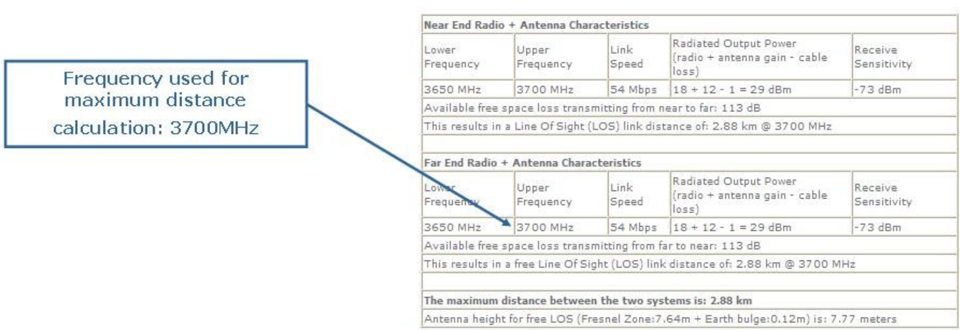
$$FSPL(dB) = 20*\log_{10}(d) + 20*\log_{10}(f) + 20*\log_{10}\frac{(4*\pi)}{c}$$

In order to calculate the distance (**d**) from the transmitter we can rewrite the equation to read:

$$20*\log_{10}(d) = FSPL(dB) - 20*\log_{10}(f) - 20*\log_{10}\frac{(4*\pi)}{c}$$

The RF Link Distance Calculator uses the formula above to calculate the maximum distance between the two nodes. The frequency used for this calculation is the highest frequency that can be used to make a working link between the two nodes. Since the highest frequency gives the highest attenuation of the radio signal the maximum distance is calculated based on worst case conditions. The RF Link Distance Calculator determines the highest usable frequency of a radio link based on the used radios and antennas at each side of the link.

For the example above the RF Link Distance Calculator uses the frequency of **3700MHz**, as this is the maximum frequency of the antenna used.



Near End Radio + Antenna Characteristics				
Lower Frequency	Upper Frequency	Link Speed	Radiated Output Power (radio + antenna gain - cable loss)	Receive Sensitivity
3650 MHz	3700 MHz	54 Mbps	18 + 12 - 1 = 29 dBm	-73 dBm
Available free space loss transmitting from near to far: 113 dB				
This results in a Line Of Sight (LOS) link distance of: 2.88 km @ 3700 MHz				
Far End Radio + Antenna Characteristics				
Lower Frequency	Upper Frequency	Link Speed	Radiated Output Power (radio + antenna gain - cable loss)	Receive Sensitivity
3650 MHz	3700 MHz	54 Mbps	18 + 12 - 1 = 29 dBm	-73 dBm
Available free space loss transmitting from far to near: 113 dB				
This results in a free Line Of Sight (LOS) link distance of: 2.88 km @ 3700 MHz				
The maximum distance between the two systems is: 2.88 km				
Antenna height for free LOS (Fresnel Zone:7.64m + Earth bulge:0.12m) is: 7.77 meters				

Figure 6: Automatic selection of highest usable frequency based on radios and antennas

Filling in all the know values we get:

$$20*\log_{10}(d) = 113 - 20*\log_{10}(3700*10^{6}) - 20*\log_{10}\left(\frac{4*\pi}{c}\right)$$

$$20*\log_{10}(d) = 113 - 191.36 + 147.56$$

$$20*\log_{10}(d) = 69.2$$

$$\log_{10}(d) = 3.46$$

d = 2884 meter

The RF Link Distance Calculator uses the method above to calculate both the maximum distance from the “near” node to the “far” node as vice versa. Because in this example we use exactly the same radio and antenna at each side of the link both distances are exactly the same.