White Paper

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The Impact of Return Loss on Base Station Coverage in Mobile Networks

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When designing and building cellular infrastructure, one objective is to maximize the RF signal level seen throughout the coverage area. Assuming the noise level remains constant, higher signal levels mean faster data rates and fewer dropped calls, ultimately resulting in happier customers.

In many cases, the personnel building a cell site do not control every variable necessary to ensure strong signals. Some of the variables outside the installer's control include transmit power levels from the radio, cable type, antenna gain and antenna height. Important variables that installers do control are losses in the cable feed system due to reflections and absorption. As we all know, minimizing these losses will improve the quality of the system. But, as we will see in this paper, there are points of diminishing return. Sometimes "better" may provide very little practical benefit to customers. In times where operators are seeking sensible ways to reduce installation costs, knowing when to stop chasing that last decibel is important to understand.

In this paper we will focus on losses due to reflections. These reflections are measured using a cable and antenna analyzer such as the Anritsu Site Master. Operators often specify that the worst case reflections (return loss) over the operating frequency range of the system must be 18 dB. But, what exactly does that mean? It means the reflected signal must be 18 dB lower than the signal that is transmitted into the system. Or, another way of looking of this is that the reflected signal must be less than 1/64th the magnitude of the signal transmitted into the system. Where did this limit come from? In many cases, it has been based on what an operator knows is possible when high quality components are installed according to the manufacturer's specifications using good workmanship. As feed systems become shorter and antenna systems are required to operate over broader frequency ranges, achieving an 18 dB return loss may not be practical.

To understand the impact return loss has on the power arriving at the user, we will start by reviewing the equations. Return loss is a logarithmic ratio of the power reflected from a system to the power entering that system, as defined in Equation 1. Return loss is expressed in decibels. The higher the number, the lower the amount of reflected energy.

$$\text{Return Loss (dB)} = -10 * \log_{10} (P_R/P_I) \qquad \text{[Equation 1]}$$

Where:

P_R = Power reflected (W)

P_I = Power incident (W)

Another important value to understand is insertion loss. Insertion loss is a logarithmic ratio of the power passing through a system (power out) to power entering that system, as defined in Equation 2. Insertion loss is also expressed in decibels. The lower the number, the lower the amount of energy that is "lost".

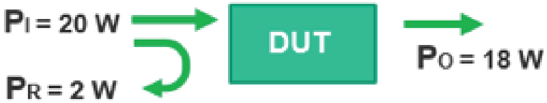
Insertion loss (dB) = $-10*\log_{10}(P_O/P_I)$ [Equation 2]

Where:

P_O = Power out (W)

P_I = Power incident (W)

As an example, we can use Equations 1 and 2 to calculate the insertion loss and return loss of a system where P_I, P_O and P_R have been measured:



Return loss = $-10*\log_{10}(2/20)$ = 10 dB

Insertion loss = $-10*\log10(18/20)$ = 0.46 dB

In a real system, some energy would be absorbed and converted to heat. As a result, the power out would be lower by the amount of energy "lost" to heat. For determining the impact of return loss on system performance, we are only going to consider reflected energy and assume the following is true:

$P_O = P_I - P_R$ [Equation 3]

As we stated in the beginning, our objective is to maximize the power out (P_O) for any given power in (P_I). We ultimately need to derive an equation that allows us to input return loss values and see the impact on P_O. We will begin by re-arranging Equation 1 to solve for P_R:

$P_R = P_I * 10\wedge^{(-RL/10)}$ [Equation 4]

Next, we substitute Equation 4 into Equation 3 to get:

$P_O = P_I - P_I*10\wedge^{(-RL/10)} = P_I*(1 - 10\wedge^{(-RL/10)})$ [Equation 5]

Substituting Equation 5 into Equation 2 we get:

Insertion Loss = $-10*\log_{10}(P_I* (1 - 10\wedge^{(-RL/10)})/ P^I) = -10*\log_{10}(1 - 10\wedge^{(-RL/10)})$ [Equation 6]

This equation gives us a way to evaluate the ratio of power out to power in (insertion loss) for a range of return loss values. As a reminder, we are assuming that all "lost" energy is due to reflections for this analysis. To verify our equation is correct, we can substitute the 10 dB return loss value from our previous example to see if the result is 0.46 dB. Per the following, it appears that our equation is correct.

Insertion Loss = $-10*\log_{10}(1 - 10\wedge^{(-10/10)}) = -10*\log_{10}(1 - 10\wedge^{(-1)}) = -10*\log_{10}(0.9) = -10* -0.0457$ = 0.46 dB

Using Equation 6, we can calculate how much power is lost (insertion loss) in decibels for a range of return loss values, as shown in Table 1. Substituting the calculated insertion loss back into Equation 2, we can solve for the ratio P_O/P_I and express the power lost ($1 - P_O/P_I$) as a percentage.

Return Loss (dB)	Power Lost due to reflection (dB)	% Power Lost
0	∞	100.0%
1	6.868	79.4%
2	4.329	63.1%
3	3.021	50.1%
4	2.205	39.8%
5	1.651	31.6%
6	1.256	25.1%
7	0.967	20.0%
8	0.749	15.8%
9	0.584	12.6%
10	0.458	10.0%
11	0.359	7.9%
12	0.283	6.3%
13	0.223	5.0%
14	0.176	4.0%
15	0.140	3.2%
16	0.110	2.5%
17	0.088	2.0%
18	0.069	1.6%
19	0.055	1.3%
20	0.044	1.0%
21	0.035	0.8%
22	0.027	0.6%
23	0.022	0.5%
24	0.017	0.4%
25	0.014	0.3%
26	0.011	0.3%
27	0.009	0.2%
28	0.007	0.2%
29	0.005	0.1%
30	0.004	0.1%

Table 1

An interesting observation is that as the return loss improves, additional dBs of improvement in return loss have less and less impact on power lost. This is often confusing to people applying the rule that "a change of 3dB means that the power is doubled or cut in half." It is a common mistake to misapply this rule and falsely believe that improving return loss from 15 dB to 18 dB, for example, will double the coverage area of a site. What actually occurs is that the power lost is reduced by half (relative to its starting value) when the return loss changes by 3 dB. Looking at Table 1, the power lost due to a 15 dB return loss is 0.14 dB. By improving the return loss to 18 dB, the power lost is indeed reduced by half to 0.07 dB. However, rather than 50% improvement in transmitted power one might expect, the improvement is only 1.6% (3.2% – 1.6% = 1.6% improvement).

But these are still not very intuitive numbers to help an engineer make a decision when a particular feed line at a site is failing its return loss specification by a few dBs. To help understand the coverage impact associated with changes in return loss, we will assume a typical site configuration and use the propagation loss equation (Equation 7) to solve for the distance "d" associated with a desired signal level.

Propagation loss (LP)= $-27.56 + 20*\mathrm{Log}_{10}(f) + n*10*\mathrm{Log}_{10}(d)$ [Equation 7]

Where:

f = Frequency (MHz)

d = Distance (m)

n = 3.0 for urban morphology

In this example, we will assume the following site configuration:

Power transmitted by the radio (PT) = 20W = 43 dBm

Frequencies of interest = 700 MHz, 850 MHz, 1900 MHz, 2100 MHz

Feed system loss due to absorption (L_A) = 2.5 dB

Feed system loss due to reflections (L_R) = Equation 6

Antenna gain (G) = 17 dBi

Desired power level arriving at the mobile (P_R) = –75 dBm

A simplified link equation for calculating the signal level arriving at the mobile can be expressed as:

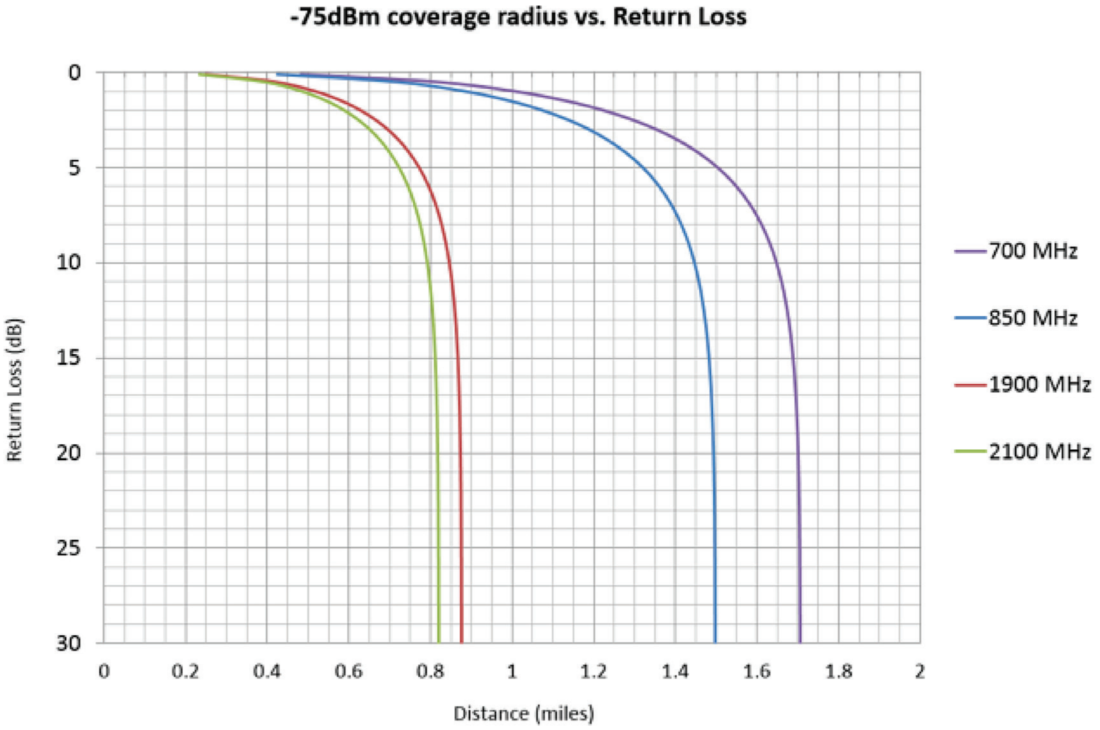
$P_R = P_T - L_A - L_R + G - L_P$ [Equation 8

Putting Equation 8 into words, it says that the power arriving at the mobile is equal to the power transmitted by the radio, minus the losses in the feed system due to absorption and reflection, plus the gain of the antenna, minus the line of sight propagation loss. An actual link budget will contain other variables and margins to improve the accuracy of the prediction. For our purposes, this simplified link budget will suffice to show the relative impact feed system losses.

Substituting Equation 6 for LR and Equation 7 for LP into Equation 8 and solving for the distance (d), we get the following equation for calculating the cell radius as a function of frequency and return loss:

$d = 10\text{^} ((P_T - P_R - L_A + 10*\mathrm{Log}_{10}(1 - 10\text{^}^{(-RL/10)}) + G + 27.56 - 20*\mathrm{Log}_{10}(f)) / (n * 10))$ [Equation 9]

For the frequencies of interest at our site, we can use Equation 9 to plot the distance for which a –75 dBm signal level is achieved based on our site assumptions and based on a range of return loss values. As can be seen in this example, very little improvement in cell site coverage is achieved with return loss values greater than 15 dB.



Looking at specific examples, the change in coverage distance can be evaluated for a return loss improvement from 15 dB to 18 dB (3 dB improvement) and from 17 dB to 18 dB (1 dB improvement) as shown in Table 2 and Table 3. As can be seen, the coverage distance is improved, but only slightly.

	–75 dBm coverage distance (m)			
15 dB return loss	2716	2386	1396	1306
18 dB return loss	2731	2399	1403	1313
Change in coverage (m)	15	13	7	7
Change in coverage (FT)	49.2	42.7	23.0	23.0

Table 2

	–75 dBm coverage distance (m)			
17 dB return loss	2727	2396	1401	1311
18 dB return loss	2731	2399	1403	1313
Change in coverage (m)	4	3	2	2
Change in coverage (FT)	13.1	9.8	6.6	6.6

Table 3

If the operator determines that the non-compliant return loss specification is unacceptable and instructs the crew to perform repairs to achieve the desired value, it is very important to understand the method that the crew uses to improve return loss performance. “Good” ways to improve the performance might be to disconnect and reverse an existing jumper cable to change the phase relationship of reflections in the system. Sometimes, this type of change can cause a “failing” system to now pass. Another “good” method to improve return loss performance might be to perform a Distance-to-Fault (DTF) measurement to determine the RF connection with the highest individual return loss contribution. Opening this connection and improving workmanship may cause a “failing” system to now pass. These are considered “good” changes because they improve return loss without negatively impacting another variable that might degrade overall site performance.

Loosening a RF connector to adjust the phase relationship of reflections in the system and then taping over the connection is a “bad” way to improve return loss. Loose connectors degrade the mechanical reliability of the feed system as well as generate passive intermodulation (PIM).

Another “bad” way of improving return loss is increasing jumper cable lengths. If the antenna is the highest source of reflection in a system (which is often the case), adding 0.5 dB of cable loss will result in 1.0 dB improvement in return loss measured at the system input. While this might seem like a good idea, the added insertion loss has a negative impact on site coverage. Using Equation 9 and changing LA and the return loss, we can evaluate the coverage impact of these changes. As can be seen in Table 4, improving the system return loss from 17 dB to 18 dB by adding 0.5 dB of cable loss results in a significant reduction in site coverage. Adding loss is never a good way to improve site performance!

	–75 dBm coverage distance (m)			
17 dB RL, 2.5 dB cable loss	2727	2396	1401	1311
18 dB RL, 3.0 dB cable loss	2628	2309	1351	1263
Change in coverage (m)	–99	–87	–50	–48
Change in coverage (FT)	–324.8	–285.4	–164.0	–157.5

Table 4

Summary

Each operator has its own specifications for feed system performance and ultimately the crew doing the installation must meet the operator’s specifications. When site performance does not meet the specified requirements, it is up to the operator to determine whether an exception can be made or whether the specification is essential. The information contained in this paper is intended to help operators make this decision based on a stronger understanding of the coverage impact.

Anritsu offers a complete line of Cable and Antenna Analysis solutions with the Site Master™ product family from 1 MHz up to 40 GHz. In addition Anritsu also offers automations tools for measurement intensive sites like a DAS systems with easyTest Tools™.

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