Replacing Analog Links with Digital Links for STL or Intercity Relay

Things you need to know before you make a change!

By the time we have reached the Sprint Nextel relocation deadline in 2007, hundreds of existing 2 GHz STLs and ICRs will be replaced to meet the new 12 MHz bandwidth requirements in the revised 2 GHz FCC band plan   In the 7 and 13 GHz bands, ICR systems will be converted from analog to digital to support newly upgraded digital ENG central receive sites. When planning a change from analog to digital, it is important to understand the differences between the existing equipment and the replacements, and how the operating parameters may be affected.

System Transport Requirements

Over the years, analog baseband loading has been consistent on STL and intercity relay (ICR) systems: NTSC video at 1.0 V P/P, with up to four audio subcarriers, and one or two auxiliary data channels. The only real changes have been with regard to squeezing more subcarriers above the video to support the full BTSC payload and the growing need for additional data channels. Other changes include digital audio and T1 subcarriers, both of which have been available for many years. In the aftermath of the ATSC DTV build-out, STL systems still follow predictable patterns, typically transporting analog video and a 19.39 Mbps SMPTE 310M or ASI stream, or alternately, a 19.39 Mbps stream by itself with ancillary data for transmitter control.

With the conversion to digital video, the loading of an ICR system is not as predictable due to the variability in MPEG compression rates for a given application, and the need to support multiple ASI streams. Depending on the individual situation, intercity relays (which include TSLs) may be required to support one or more ASI streams with aggregate data rates up to, and beyond 50 Mbps.

The higher the data rate, the more complex modulation format is for a fixed bandwidth. More complex modulation formats have a negative impact on system gain, resulting in lower fade margins and reduced path reliability. ***It is important to analyze system loading requirements before making a change from analog to digital.***   Failure to understand the trade-offs between system throughput and reliability may result in less than satisfactory link performance.

Path Basics

Analog fade margin is measured as the difference from the unfaded RF input level at the microwave receiver, to the input level that produces a 37 dB video SNR. This method was established in the EIA/ANSI RS-250C standard, and has been in use for many years. Designing to a fade margin of 40 dB was based on maintaining the video signal to noise ratio (SNR) above the FM limiting threshold of the video demodulator for a high percentage of the time. Once the signal drops below the hard limiting level, the video SNR degrades on a dB for dB basis, until the receiver threshold is reached.   The video noise build-up may be objectionable to viewers, leading to high fade margins as the standard practice.

The fade margin in a digital system is measured from the unfaded RF input level, to the point that produces the maximum acceptable error rate, which is 10^{-6} (one error per megabit) for video, and occurs very close to the carrier to noise threshold. In digital microwave systems, the video SNR remains about the same until the receiver threshold is reached. With no need to be concerned about FM limiting, a lower fade margin can provide completely acceptable performance in a digital system, and the most useful path determinant becomes the calculated reliability. In making path reliability calculations, the fade margin is one of several variables that enter into the equation.

The most commonly accepted method of determining path reliability was developed by Bell System engineers decades ago, and in modified form, remains the standard of the industry today. Arvids Vigants and W. T. Barnett, studied active microwave paths to determine the effects of numerous variables, and found that system unavailability could be characterized as follows:

$U = a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{(-F/10)}$

where: U = Unavailability (actual fade probability as a fraction)

a = {4 for very smooth terrain; 1 for average terrain with some roughness;
0.25 for mountainous, very rough or very dry areas}

b = {0.5 for Gulf coast or similar low-lying, humid areas;
0.25 for normal interior, temperate or northern areas
0.125 for mountainous or very dry areas.}

f = frequency in GHz

D = path length in miles

F = fade margin in dB

The answer can be easily converted to express availability as a percentage of time on an annual, or worst month basis. The only drawback to this method is that it does not account for rain attenuation, which is a significant factor above 10 GHz, and must be added to the fade margin to provide a more accurate estimate.

Figure 1 represents a graph of system reliability at 7 GHz, based on the Vigants & Barnett formula for fade margins between 30 and 50 dB. The terrain and climate factors have been set for inland temperate, or northern paths with average hills, valleys, and watersheds.

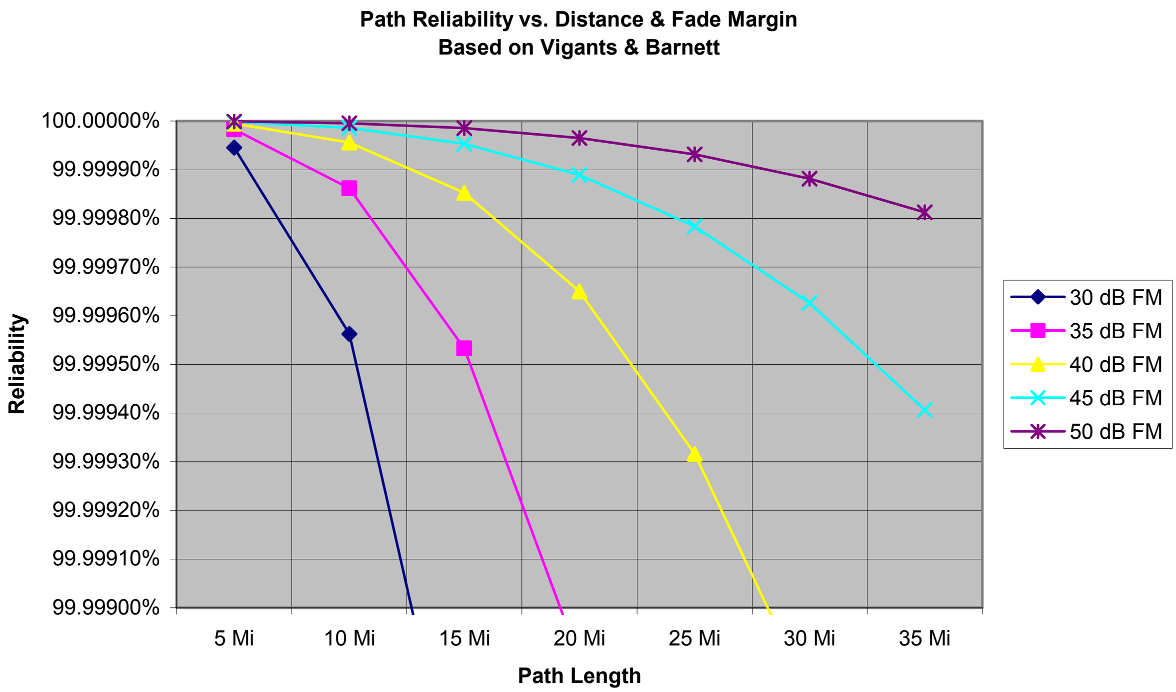
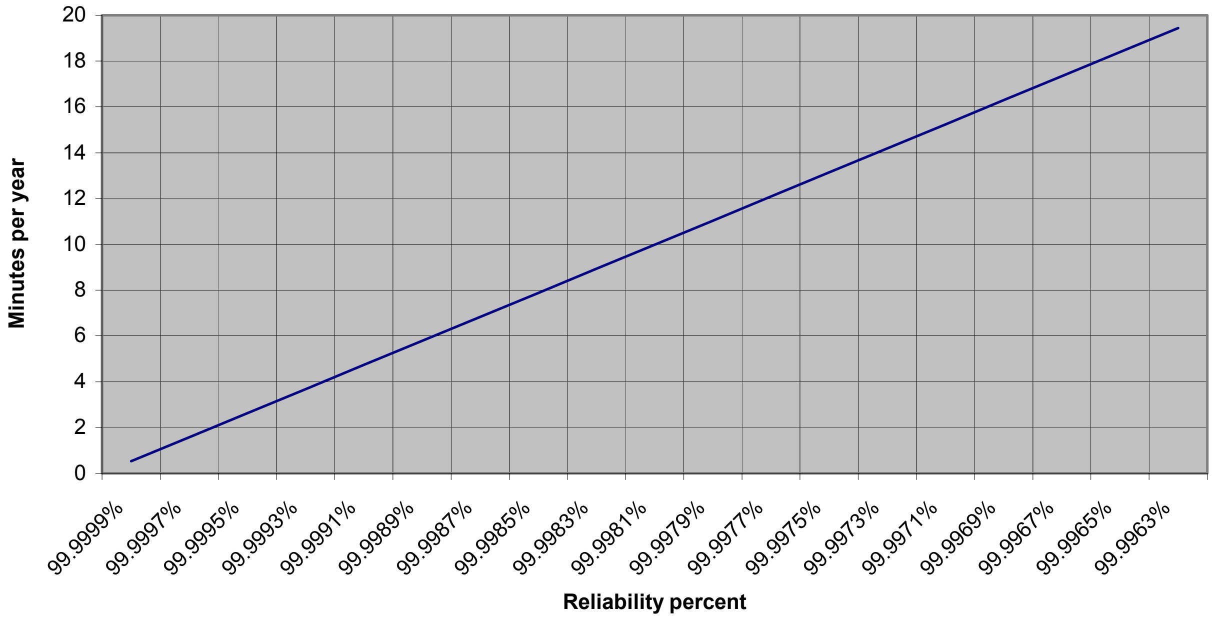


Figure 1

If the same parameters were graphed for coastal paths in humid areas with flat terrain, the reliability would drop dramatically, to the point of increasing the outage time by a factor of seven. See figure 6 for details.

The correlation between reliability percentage and outage time is shown in figure 2.

Figure 2 - Annual Outage vs. Reliability



Putting these charts to use, if we were to analyze an 18 mile path at 7 GHz with a 40 dB analog fade margin, the same path would exhibit a 35 dB fade margin if converted to QPSK digital, due to the normal difference in system gain between the two modes. Assuming that the path is inland, the calculated reliability decreases from about 1 minute per year in analog mode, to about four minutes per year in digital mode; or from 99.9997% to 99.9991%, which is not a worrisome increase. No change would be required with respect to power level or to the antenna system to maintain an acceptable fade margin.

If the same exact 40 dB analog path were located in a coastal area, it would exhibit a lower starting reliability of 99.9974%, or 10 minutes per year in analog mode, and would drop to 34 minutes per year (99.99354%), if converted to QPSK digital. In this case, one or more of the following options should be considered:

a) Increased antenna gain
b) Higher-powered digital transmitter
c) Space diversity antennas.

System Gain

The easiest way to visualize the overall performance of a microwave system, exclusive of path variables, is to look at the system gain. System gain is the difference in dB between the transmitter RF output power and the practical threshold of the receiver. In the chart below, the system gain of an MRC DAR-6 Plus microwave system is compared in analog FM and QPSK modes to provide the reader with an easy way to visualize these parameters.

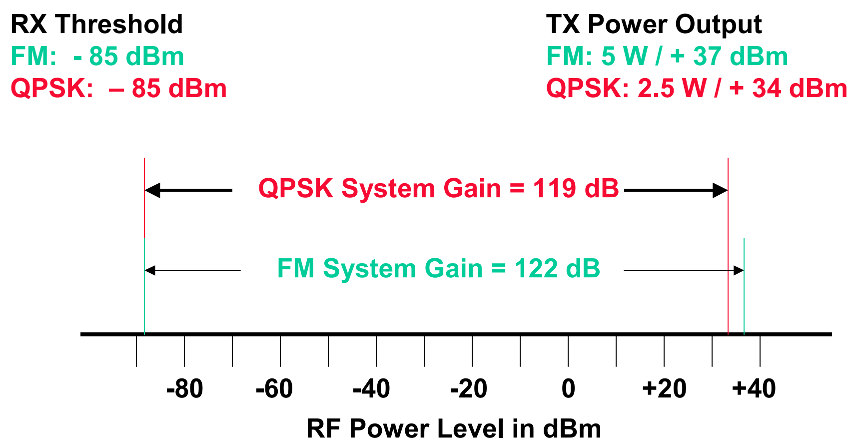


Figure 3 – DAR-6 Plus System Gain
Analog versus QPSK - High Power Options

The reduction in system gain between analog and digital modes is a function of the increased linearity requirement in the transmitter, and the minimum threshold requirement in the receiver.

The linearity requirement of an FM analog transmitter is not demanding, and most amplifier stages are operated in saturation. In a digital transmitter, amplifier stages must be operated in their linear regions to minimize distortion products that could hamper the demodulation process, and could cause adjacent channel interference.

The practical threshold of an FM receiver is determined by observing the point at which the video SNR reaches 37 dB, even though the demodulator may continue to function adequately at lower SNRs. In a digital receiver, the practical threshold occurs at an error rate of 10^{-6}, and within a dB or two of the carrier to noise (C/N) threshold, below which, the demodulator ceases to function.

When converting a path to digital, every effort should be made to match the required data rate to the available system gain, as determined by the modulation format.

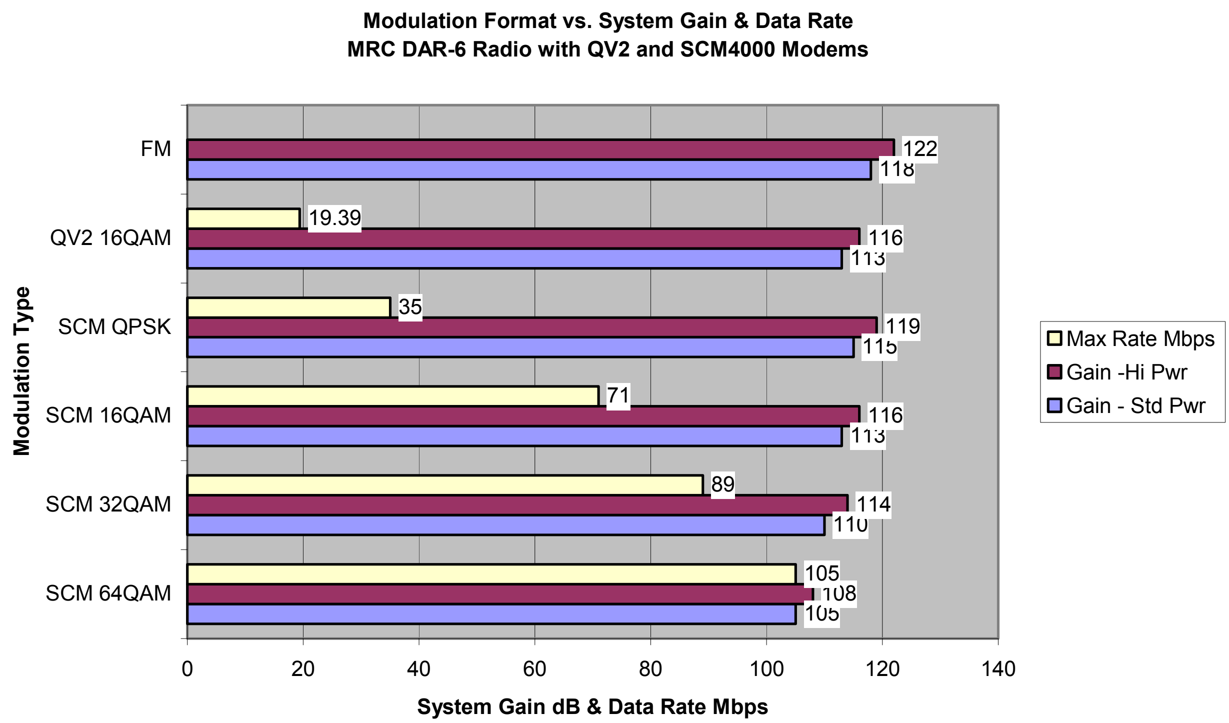


Figure 4

System gain comparisons at 7 GHz for various modulation formats

Determining your own needs

In order to determine what your present system reliability is, and what your existing antenna and transmission lines will support in digital modes, only a few simple steps are required.

1) Determine your present analog fade margin.
Most receivers made in the last decade include a calibrated received signal level (RSL) readout. The difference between the normal RSL and the radio threshold sensitivity is the fade margin.

For example: an RSL of – 40 dBm versus a receiver threshold of –86 dBm:

Fade Margin = RSL – threshold, or (-40 dBm) – (-86 dBm)
= 46 dB

If your receiver does not include an RSL readout, we can help you determine how to make an accurate measurement.

2) What is your system gain?
As stated previously, system gain is the difference in dB between the transmitter RF output power and the practical threshold of the receiver.

For example: a 5 watt (+37 dBm) transmitter and a receiver with a threshold of –86 dBm:

System Gain = Tx Power – Rx threshold
= (+37 dBm) – (-85 dBm)
= 122 dB

	Analog	QPSK	16QAM	32QAM	64QAM
Std Pwr	33	30	28	26	23
Hi Pwr	37	34	31	30	26
Threshold	-85	-85	-85	-84	-82
Gain - Std	118	115	113	110	105
Gain-HiPwr	122	119	116	114	108

Table 1 – DAR-6 System Gain Summary

3) Determine your present reliability
The charts on the following pages were developed to assess path reliability from three known factors: path length, fade margin, and climate and terrain condition. Suppose you have a 20-mile inland path with a 46 dB fade margin on 7 GHz, located in an area of the country with normal terrain features and excursions in temperature. The graph in figure 5, corresponding to these parameters, shows the reliability to be about 99.9999% per year. With reference to figure 2, the annual outage time less than one minute per year.

4) How will your new system perform?
You want to convert your 7 GHz ICR/TSL to digital, with a 50 Mbps payload capacity to support multiple ASIs totaling 50 Mbps, or one 50 Mbps HD feed.

In figure 4, the closest combination to provide that capability is a DAR-6 with an SCM4000 variable rate modem set for 16QAM, which will support data rates up to 71 Mbps. The system gain options are 113 dB with a standard power transmitter, and 116 dB with a high power transmitter. The present system uses a high power transmitter with a fade margin of 46 dB. From number 3 above, we saw that the reliability is 99.9999% per year, or under one minute per year of outage.

Based on the system gain summary in table 1, the difference in gain, and therefore fade margin is 9 dB for a standard power transmitter, and 6 dB with a high power version. With a 9 dB change in fade margin, the chart in figure 5 shows that the reliability drops from 99.9999% to about 99.9993 %. Figure 2 shows the revised path downtime to be less than four minutes per year. The key significance is that a -9 dB change in fade margin will still provide acceptable reliability.

Some things to consider….

Antennas
In the previous example, we analyzed a 20 mile ICR path at 7 GHz, and found that a fade margin decrease of 9 dB was acceptable. This conclusion may lead you to think that the path was over-engineered in the first place, however this is not necessarily true.

Many antenna systems have been in place for a long time; possibly decades. Over the years, technology improvements have allowed manufacturers to build microwave transmitters with higher output power, and receivers with better sensitivity. If an antenna system has been in place for a long while, it may have been designed at a time when system gains were considerably lower. The simple act of replacing an older microwave system with a new can provide better path reliability as a bonus, due the increase in system gain.

Remember; any changes in transmit power, EIRP, antenna gain, modulation type, and antenna height requires a modification to your existing license. Also, changes must be analyzed by a frequency coordinator, and prior coordination notification must be completed before filing. Refer to FCC Part 74.638 for additional details.

If your antenna system does require upgrades, now is good time to think about future requirements. Dual polarization and high performance antenna options should be considered as a defense against potential interference and an aid to adding more links.

Reliability

There is no question that an STL requires high reliability as determined by a low calculated outage time. Most engineers want to see three to four “9’s” after the decimal point and with good reason. The good news is that most STLs support a maximum of 19.39 Mbps, which does not significantly change the system gain when compared to analog. If your analog STL was reliable, your digital STL should be as well. In extreme cases, with long paths, tall towers, and high waveguide losses, space diversity may be the only answer. The diversity improvement factor can be 50 to 1, or better, with two antennas separated by 40 feet.

On an ICR system, reliability requirements are not as stringent, a fact that must be considered when planning a digital conversion. Path reliability between 99.99% and 99.999% may be totally adequate, especially if the link is used for only a few minutes per day. Previous experience with analog ICRs is generally a good reference. If they were marginal to begin with, it’s time to upgrade the antennas or increase the system gain.

Lets’ Review

The time has come to switch to a digital microwave system, what do I do?

Establish a baseline:

1) Determine present fade margin (difference between RSL and Rx threshold)
2) Determine present reliability (from figures 5 through 10)
3) Determine present system gain (difference between Tx RF o/p and Rx threshold)
4) Determine Present outage time (from figure 2)

New system parameters:

1) Establish maximum system data rate (what through-put do you need?)
2) Determine available system gain options (from figures 11 & 12)
3) New fade margin can be found from the difference between present system gain & new system gain. (add or subtract the difference from the old fade margin)
4) Determine new reliability based on new fade margin (from figures 5 through 10)
5) Determine new annual outage prediction (from figure 2)

If the new reliability is acceptable, it’s time to place the order. If it is not, consider the options:

- Higher transmit power
- Larger antennas
- Better transmission line
- Space diversity
- Lower data rates
- Reduced reliability

The final answer may be a compromise, but it will be one that you understand.
Need more help or more information? Contact your nearest MRC sales office.

Figure 2 - Annual Outage vs. Reliability

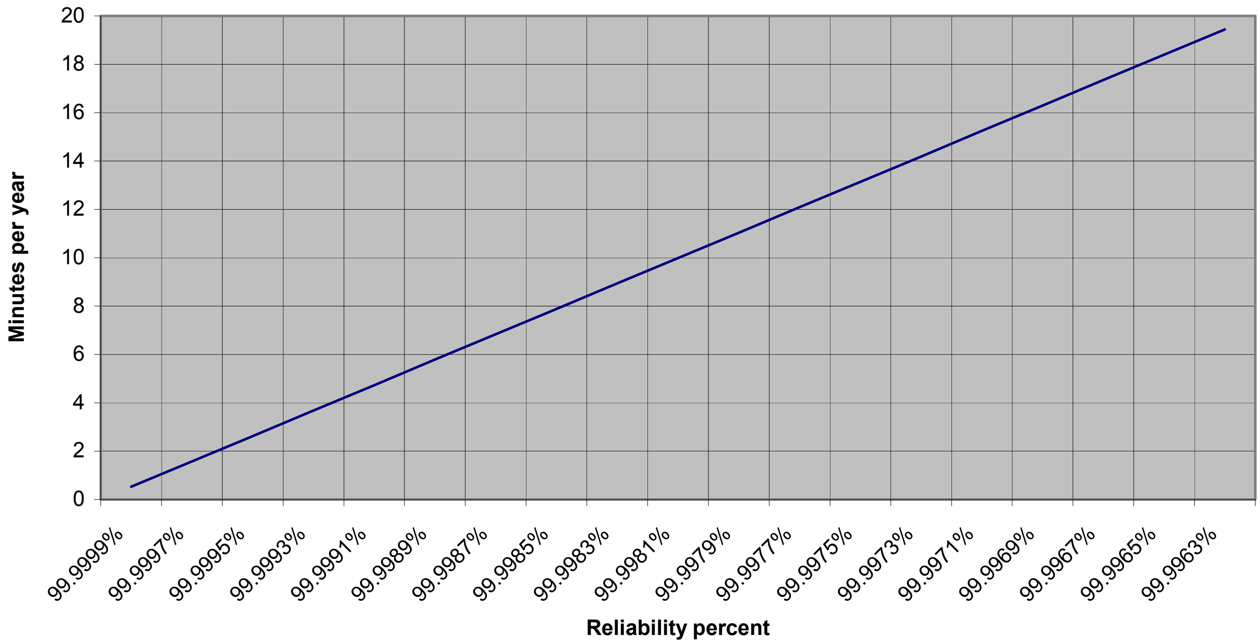


Figure 5 - Path Reliability vs. Distance & Fade Margin at 7 GHz
Based on Vigants & Barnett for normal inland/ northern terrain and climate

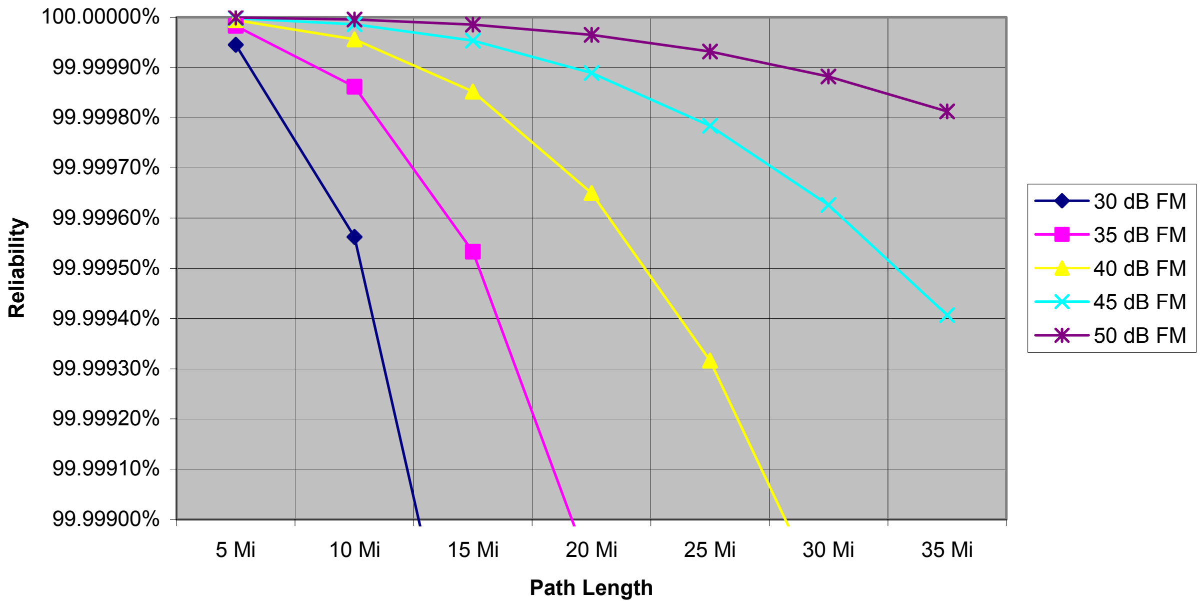


Figure 6 - Reliability vs. Fade Margin & Path Length at 7 GHz
Based on Vigants & Barnett for moist, Southern coastal areas

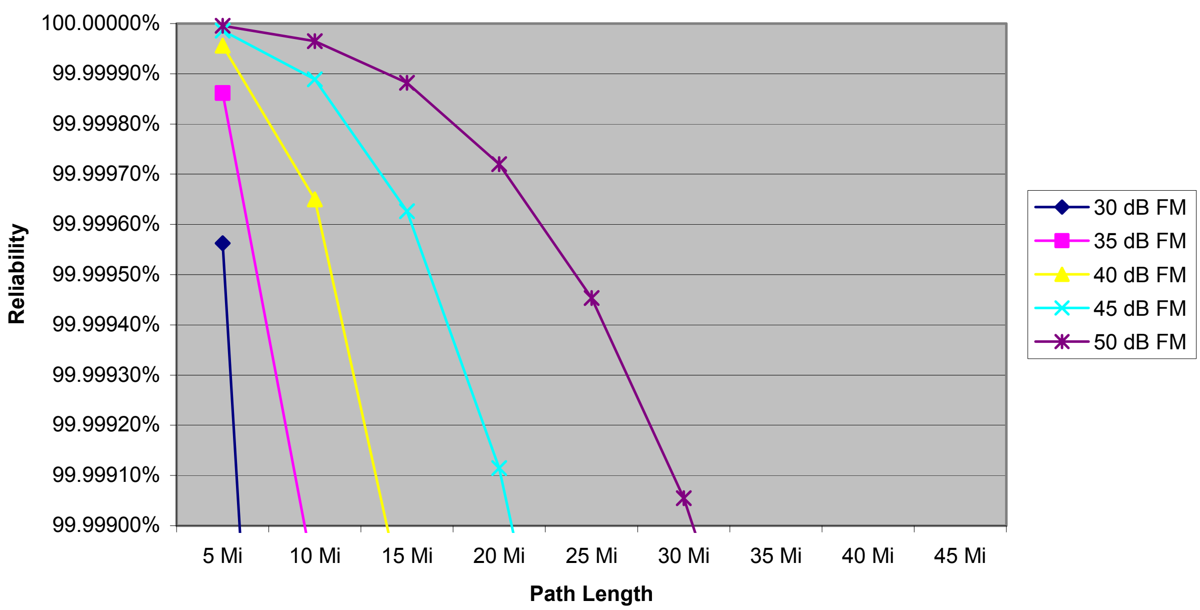


Figure 7 - Reliability vs. Distance & Fade Margin at 7 GHz
Based on Vigants & Barnett for dry, very rough/ mountainous terrain

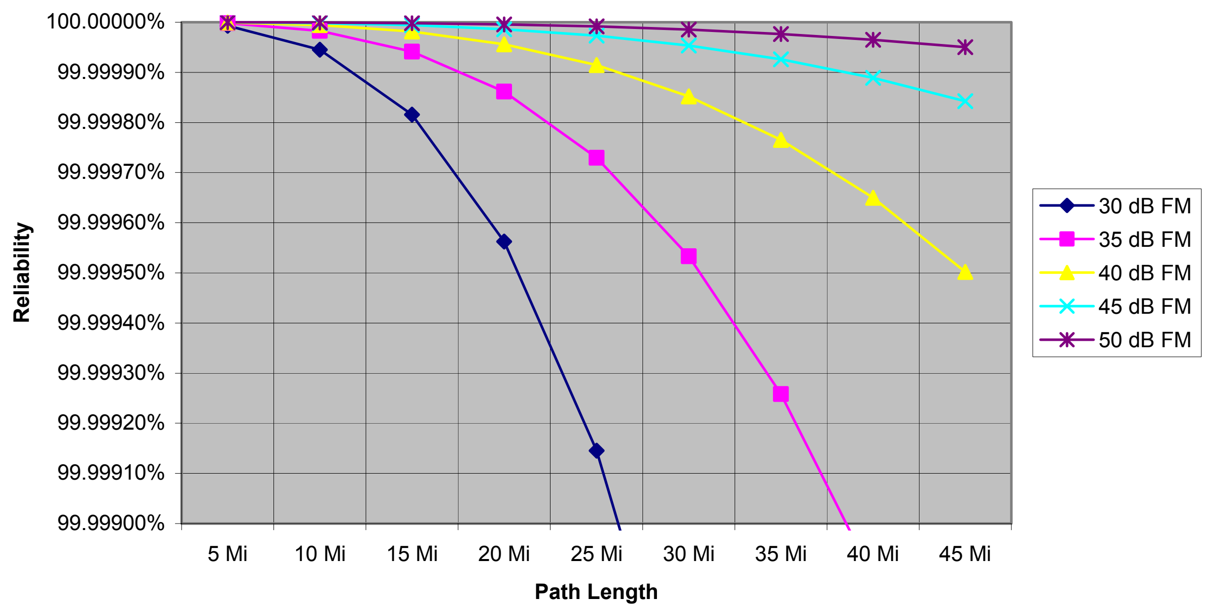


Figure 8 - Path Reliability vs. Distance & Fade Margin at 2 GHz
Based on Vigants & Barnett for normal inland/ northern terrain and climate

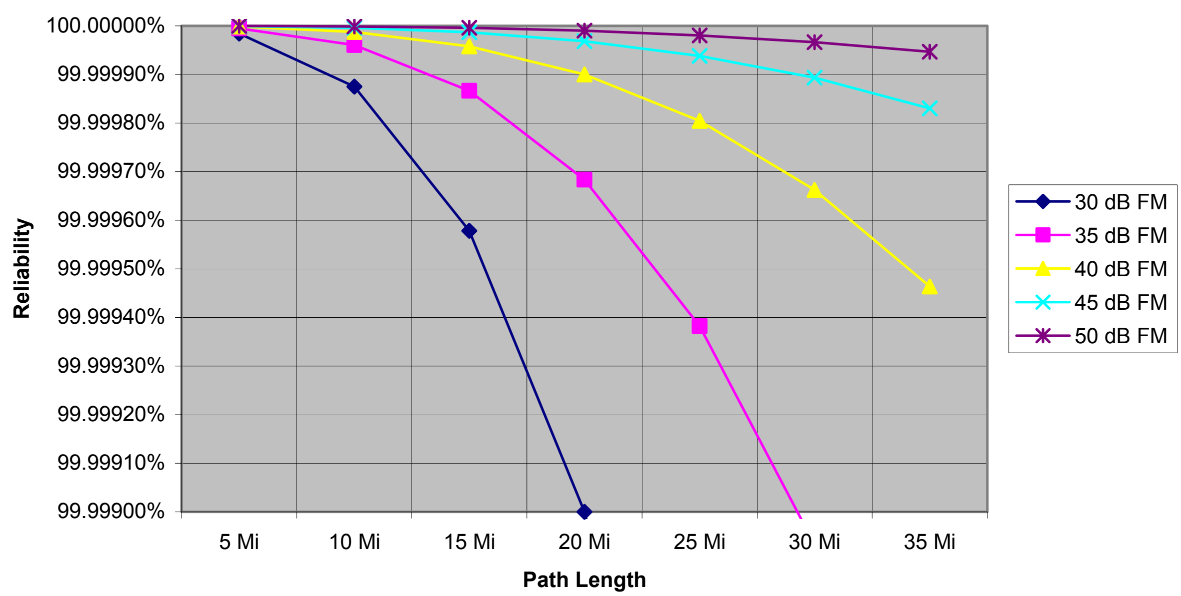


Figure 9 - Reliability vs. Fade Margin & Path Length at 2 GHz
Based on Vigants & Barnett for moist, Southern coastal areas

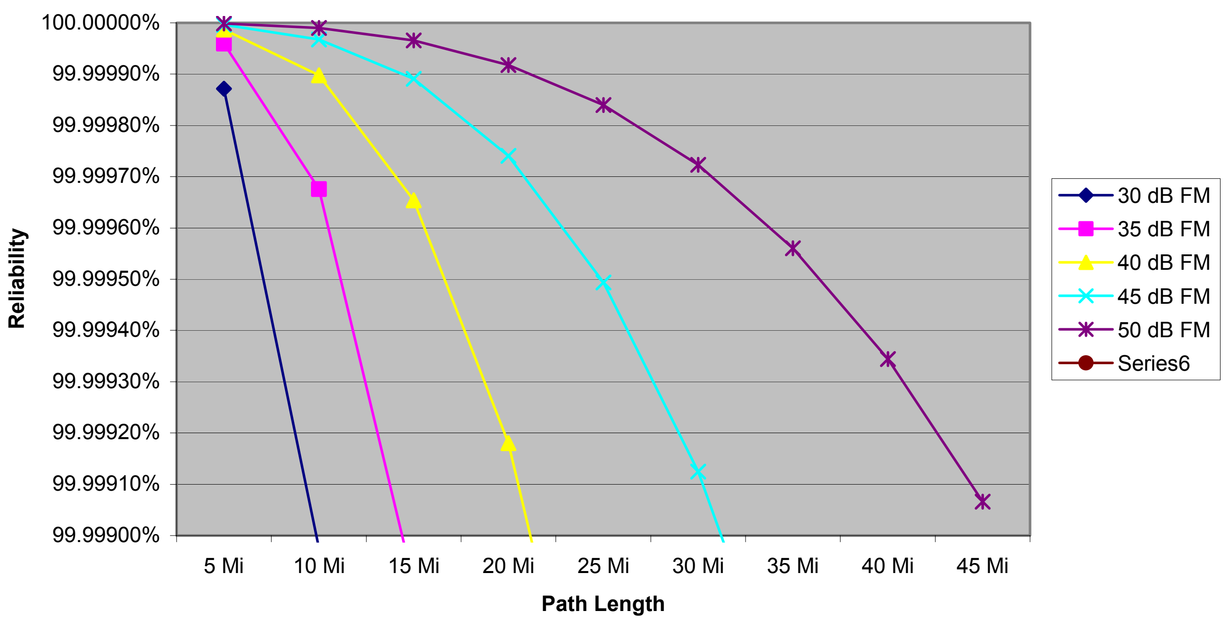


Figure 10 - Reliability vs. Distance & Fade Margin at 2 GHz
Based on Vigants & Barnett for dry, very rough/ mountainous terrain

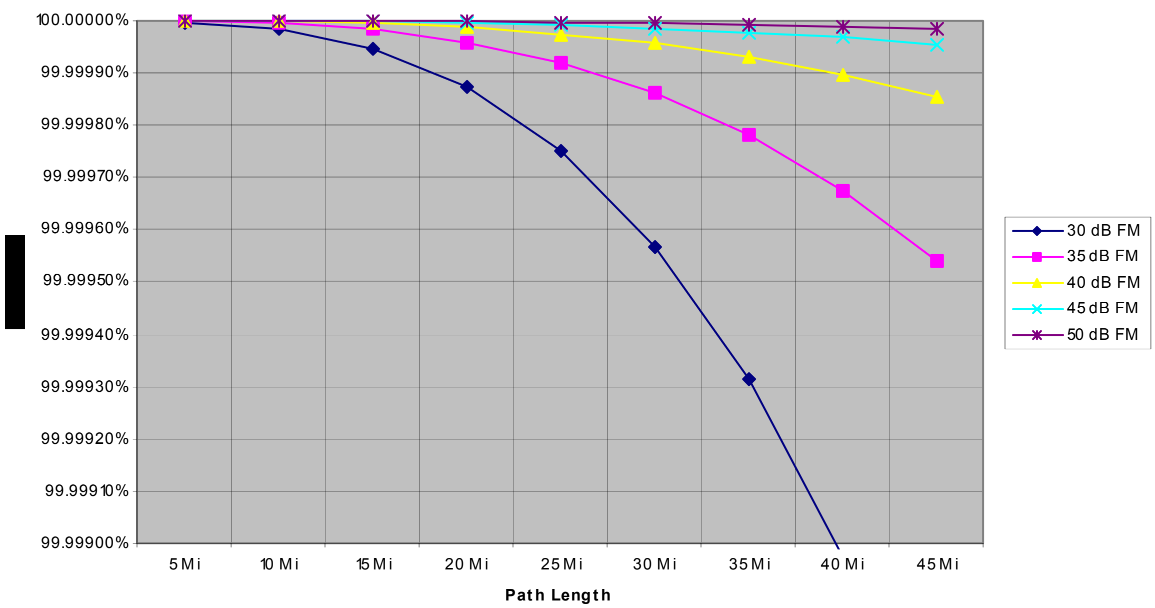


Figure 11- System Gain versus Data Rate & Modulation Type
MRC DAR-2 radio with QV2 or SCM4000 Modems

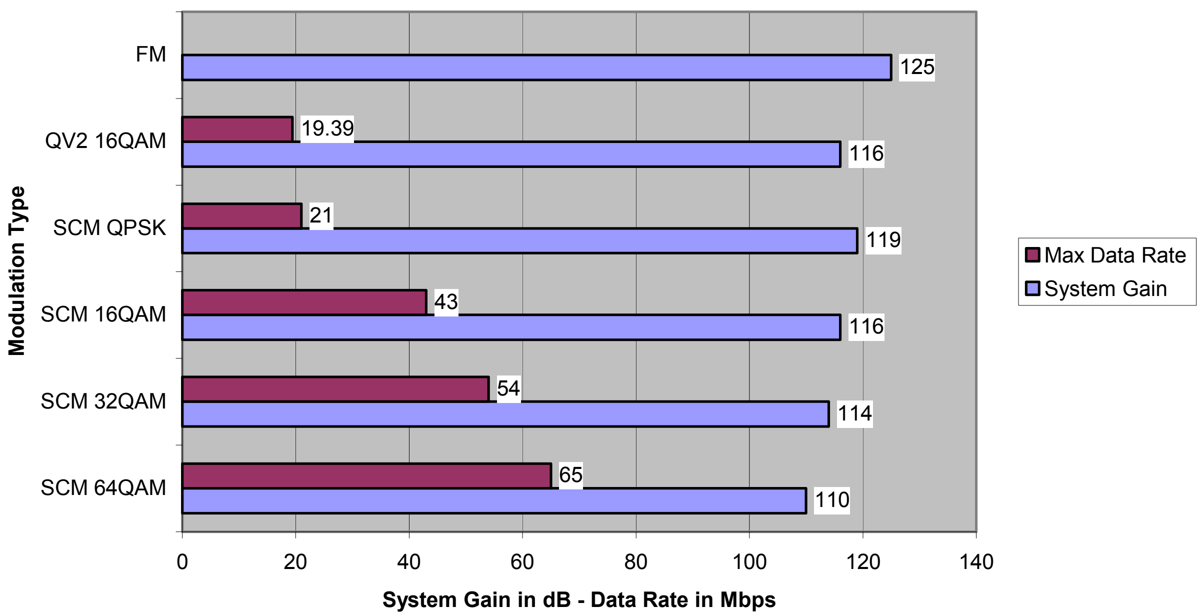


Figure 12 - System Gain vs. Data Rate & Modulation Type
MRC DAR-6 Radio with QV2 and SCM4000 Modems