INTRODUCTION

360° RF has been retained to test, analyze, and optimize the matching of supplied single band 2.4 GHz WiFi water sensor antennas and associated circuitry (figures 1 and 2). The prescribed solution will preferentially involve component changes on existing circuitry and may include antenna structural changes and placements.

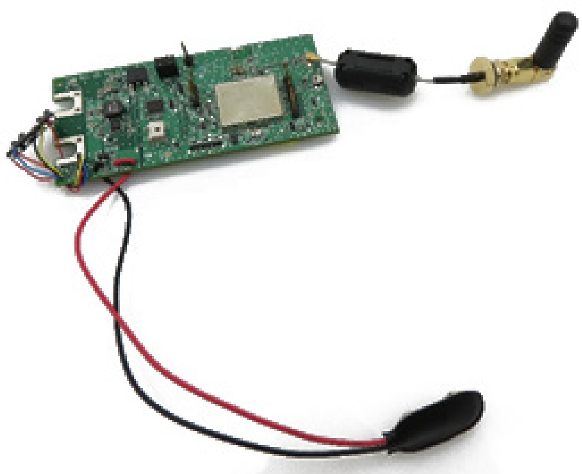

Figure 1: Water Sensor Circuit Board and Antenna

Figure 2: Tested BRAND-provided Antennas (short antennas were numbered 1-5 left to right)

Equipment

A Rohde & Schwarz model FSH6.26 spectrum analyzer combined with a high-gain log-periodic antenna (figure 3) were employed in order to measure the 2.4 GHz band WiFi RF signal field strength from the supplied water sensor. The water sensor was powered by a bench power supply set at 9 VDC, and TI RadioToolGUI was the transmitter control software (figure 4.)

[It was noted by 360°RF engineers that varying the software "power" level setting does not change the transmitter power level, however, the "tone" (frequency offset) setting appears to toggle the power on and off; any tone setting other than 0 and a signal is transmitted.]

Eight of the provided WiFi antennas were swept by a calibrated Agilent 8720ES Vector Network Analyzer (VNA) over the 2.4 GHz WiFi frequency band (figure 5.)

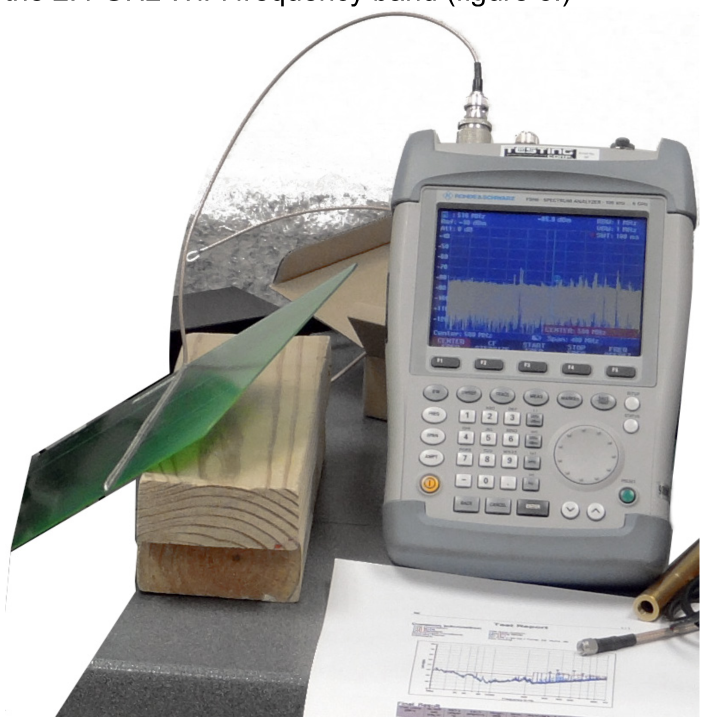

Figure 3: Calibrated Rohde & Schwarz FSH6.26 Spectrum Analyzer with Calibrated 6 dB Gain Log-Periodic Antenna

Figure 4: Water sensor transmitter test set-up

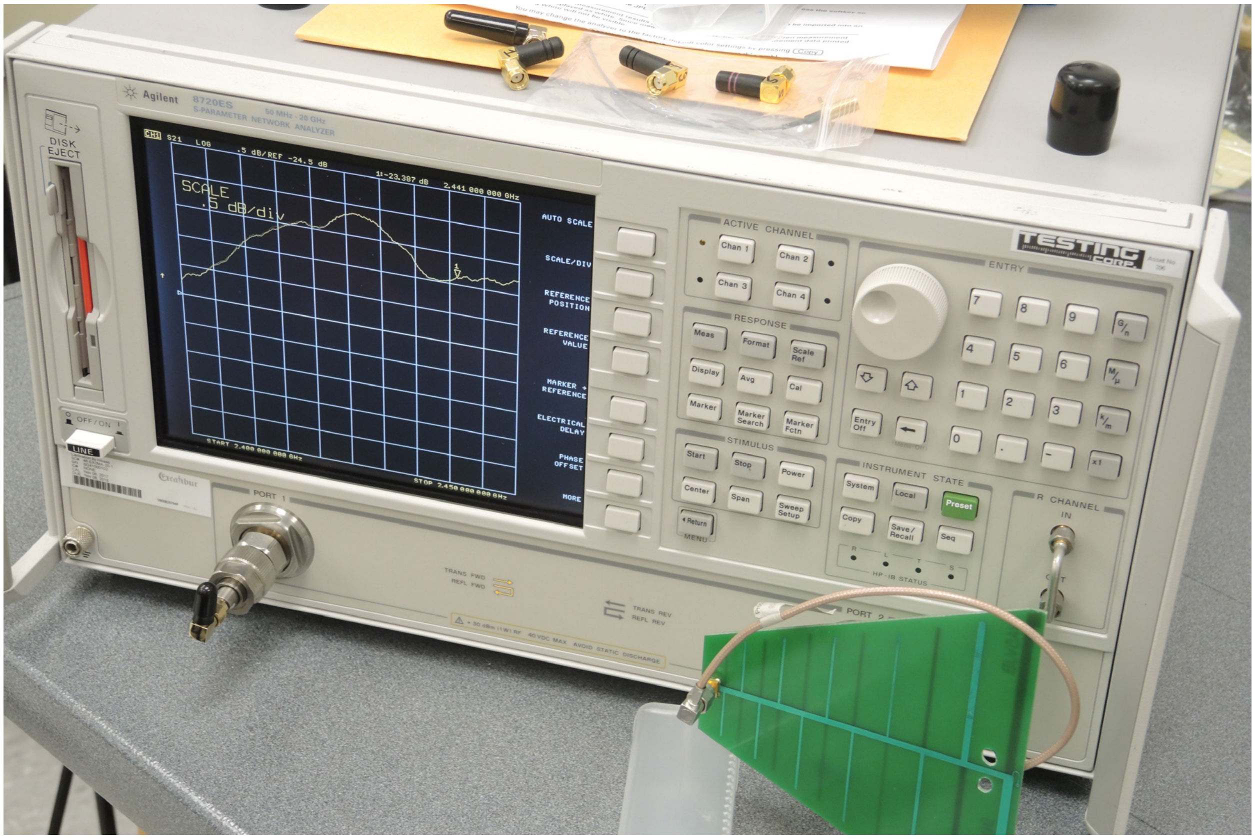

Figure 5: Calibrated Agilent 8720ES Vector Network Analyzer

The following presents the testing procedure and results of 360°RF's optimization of the provided BRAND water sensor's antenna related functions.

Procedure

The provided water sensor board was connected to a bench power supply providing a constant 9VDC, and to a laptop via a USB connection, running the TI "RadioToolGUI" version 1.0.2.0 software for transmitter control. The CC3220 UART was selected, and its data was successfully read and a connection was made from the laptop to the board. A calibrated Rohde & Schwarz FSH6.26 spectrum analyzer was situated in the far-field, several feet away from the transmitting antenna, using a calibrated high gain log-periodic array antenna for reception.

The jumpers on the water sensor circuit board were pre-configured as received for internal (chip) antenna operation. The jumpers were then set by 360°RF personnel to use the external antenna with the on-board mini RF connector, J5.

In order to isolate the antenna from the coaxial cable used to attach the antenna to the circuit board mini RF connector, a ferrite choke of the appropriate material was installed on the cable assembly. This provides more accurate antenna and/or component optimization measurements.

Moreover, a "CW" type of transmitted signal was selected in order to more accurately observe received signal amplitude.

Analysis, Observations, and Results

The absolute signal level of the WiFi transmitter was measured to ensure that it was producing a signal within the manufacturer's specifications. At the WiFi band center channel 7 of 2.442 GHz, the signal was measured to be **within specs** at an absolute level of +15 dBm.

The initial group of provided small antennas were evaluated for relative performance on a calibrated Agilent 8720ES Network Analyzer measuring insertion loss (S21) and VSWR. It was found that of these, antenna "#3" was the best performer AND its resonant frequency was closest to the center of the 2.4 GHz WiFi band. An estimated 2 dB correction factor was taken into account for the connector and cable losses for antennas 1, 2, 3 and 5. Antenna 4 has a non-RP SMA connector and was directly connected to the VNA without a similar provided cable and adapter.

Comparative VNA plots of a relatively high-performing, poorly-performing, and large antennas are displayed in the following VSWR graphs, figures 6-8. They show antennas #3, #5, and a large antenna, respectively. The marker frequency is set to 2.442 GHz, center channel 7.

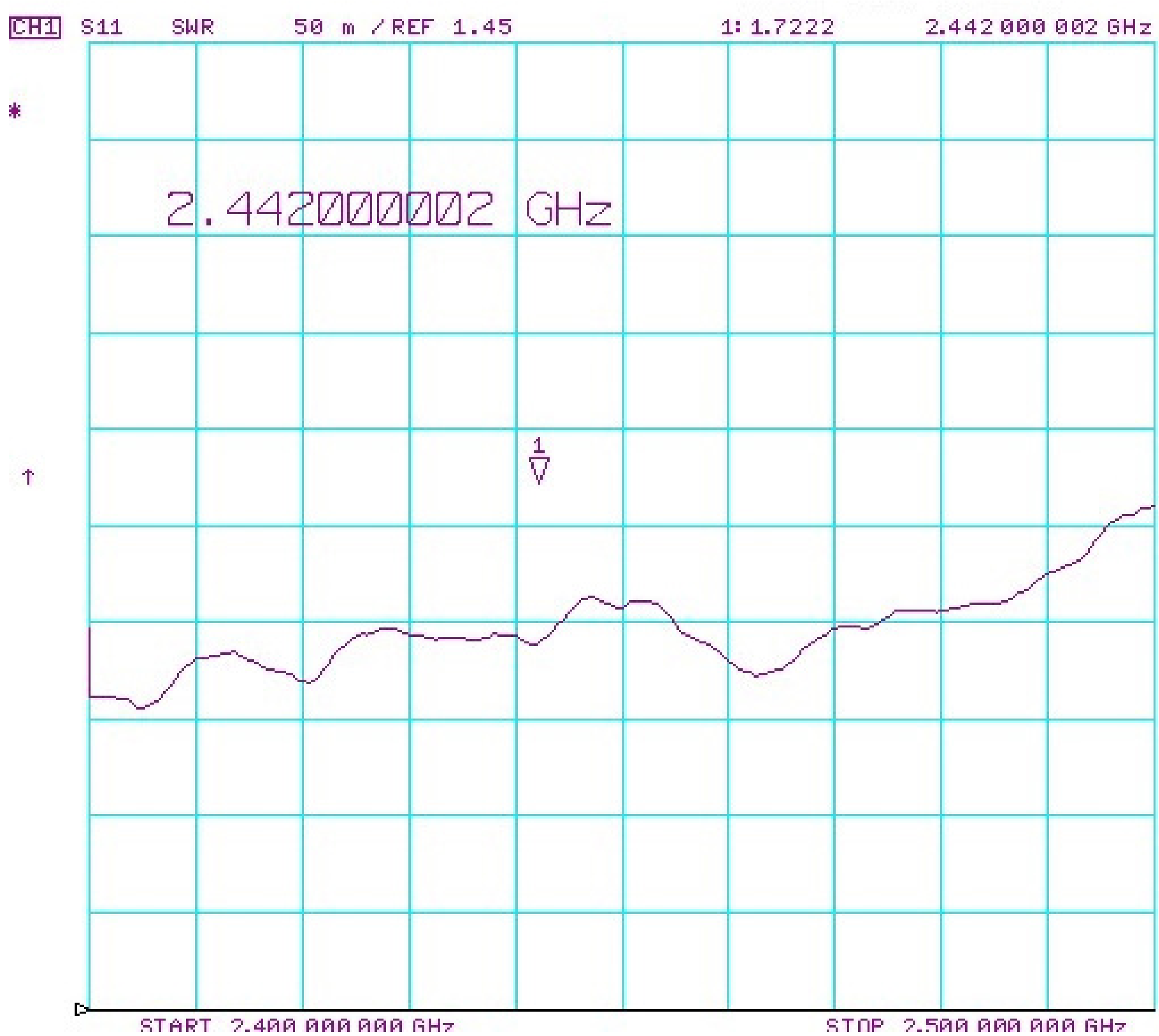

Figure 6: Antenna #3 VSWR Sweep

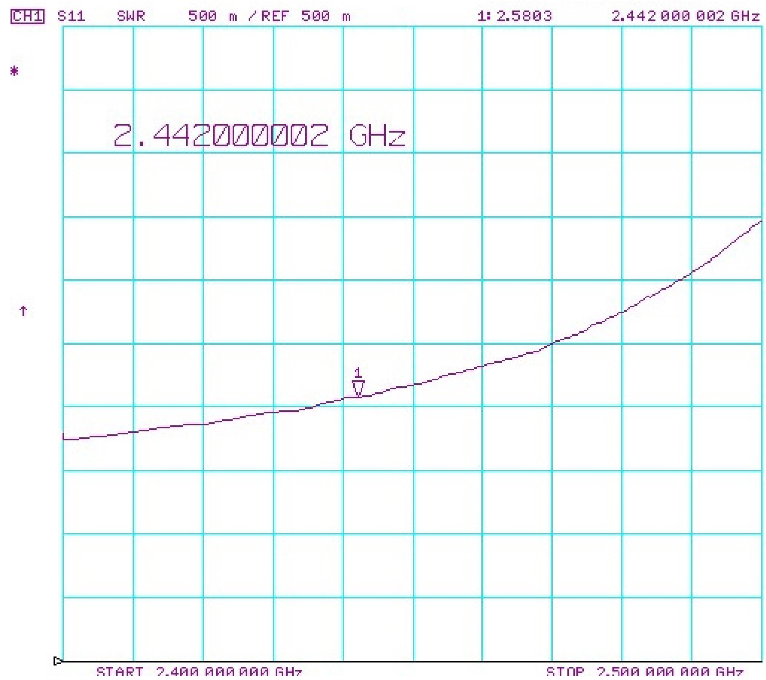

Figure 7: Antenna #5 VSWR Sweep

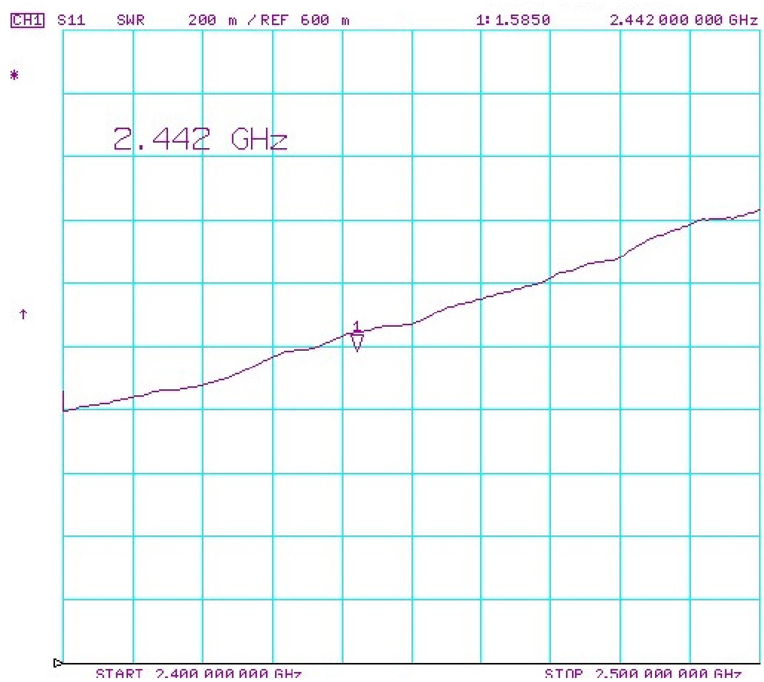

Figure 8: Large Antenna VSWR Sweep

- Figure 6 shows a VSWR of 1.7:1 at 2.442 GHz for antenna #3, the best stubby performer.
- Figure 7 shows a VSWR of 2.6:1 at 2.442 GHz for antenna #5, the worst stubby performer of the 5 supplied.
- Figure 8 shows a VSWR of 1.6:1 at 2.442 GHz for a sample full-size antenna from the 3 supplied.

The gain of an antenna is not necessarily directly related to VSWR; however, the above sweeps do show that the worst gain performer tested also showed the worst VSWR (Antenna #5). This is consistent with its tested performance in the application. The graph for the antennas were auto-scaled by the VNA, indicating that the actual VSWR for antenna #5 increases very rapidly as the frequency increases compared to the others.

It was observed that a long thermal relief "via" (connection from one area of the board to another) is employed on the provided circuit board to the external antenna connector, which at 2.4 GHz behaves as an inductor (see figure 9.) It is recommended that this behavior at microwave frequencies be taken into account for future circuit board revisions.

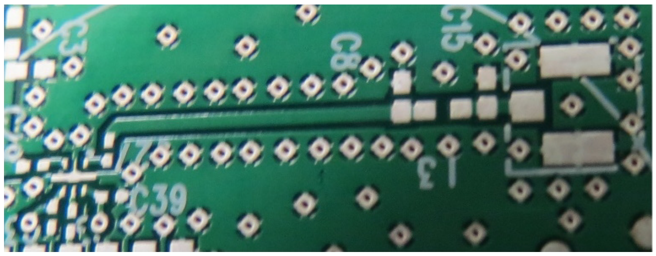

Figure 9: Circuit Board Long Via in RF Section

360°RF also noted that component T1, which appears on the provided schematic circuit diagram, as well as being marked on the provided circuit board, is not installed.

Part of the antenna and therefore signal strength optimization procedure was to determine if the addition of a ground plane, i.e., a circular metallic sheet attached to the ground of the antenna and placed below it, would improve the transmitted signal strength. It was found that created an improvement of only about 1 dB. This falls within the margin of error of measurement, and therefore nothing conclusive can be deduced. In any case, adding a ground plane did not significantly improve antenna performance.

Another task which was performed as a part of the optimization effort was to (temporarily) attach a small quantity of conductive material, in this case copper foil, to each of the provided antennas. This modification did not improve the received signal strength, in fact, it made it worse.

Several additional antennas, some high-gain, were also provided to 360°RF. The relative performance of the original group of stubby antennas, the on-board internal chip antenna, and the newly provided full-size antennas are show in table 1. Additionally, a polypropylene sheet was placed between, underneath, and on the opposite side of the transmitting antenna, with respect to the receiving antenna, to simulate the water sensor case material.

Received Signal Level, dBm	Antenna Evaluated
-48	Antenna #1
-48	Antenna #2
-46	Antenna #3
-46	Antenna #3, polypropylene sheet
-47	Antenna #4
-48	Antenna #5
-54	Chip antenna on circuit board
-40	All "large" external antennas

Table 1: Far-field Relative Signal Strength of Tested Antennas

Received signal results displayed in table 1 are summarized as follows:

- The performance of each individual antenna from initial group of five provided “small” antennas was approximately the same, within 2 dB. Antenna #3 consistently performed slightly better.

- The on-board chip antenna had the worst performance of any antenna; it was 6-8 dB worse than any of the small external antennas.

- The large external antennas provided the best performance; they were 6-8 dB better than any of the small external antennas.

It should be noted that a signal level difference of 3 dB represents a signal strength factor of two, and a signal level difference of 6 dB represents a factor of four. At extremes, the measured gain difference between the chip and large antennas was 14 dB. This is the equivalent of multiplying the signal strength by a factor of 25 !

Using the on-board chip antenna would significantly reduce the range of the water sensor transmitter compared with other classes of antennas. Using any of the large antennas provides the longest-range signal coverage compared with the other classes of antennas.

Matching

In order to maximize coverage of the transmitted signal, optimization of the antenna matching circuit was performed. It was observed that as provided, the received signal was several dB stronger at a lower frequency than the 2.442 GHz WiFi center channel frequency. Therefore increasing the resonant frequency of the antenna matching circuit was the logical place to begin optimization.

During the iterative matching process, capacitor C8, a 2 pF SMD size 0402 component, was removed and replaced with a 1 pF capacitor. This alone has the effect of increasing the resonant frequency of the circuit consisting of C8, C15, and L3. Replacement of this capacitor yielded a 5 dB increase in received signal strength. The net result is more than a three-fold increase in power at the receiver than was present compared with the original components. Figure 10 displays the resultant spectrum of the 2.442 GHz WiFi band center frequency transmitted signal at the center of the display (other signals which appear are ambient WiFi transmissions present in 360°RF's labs.)

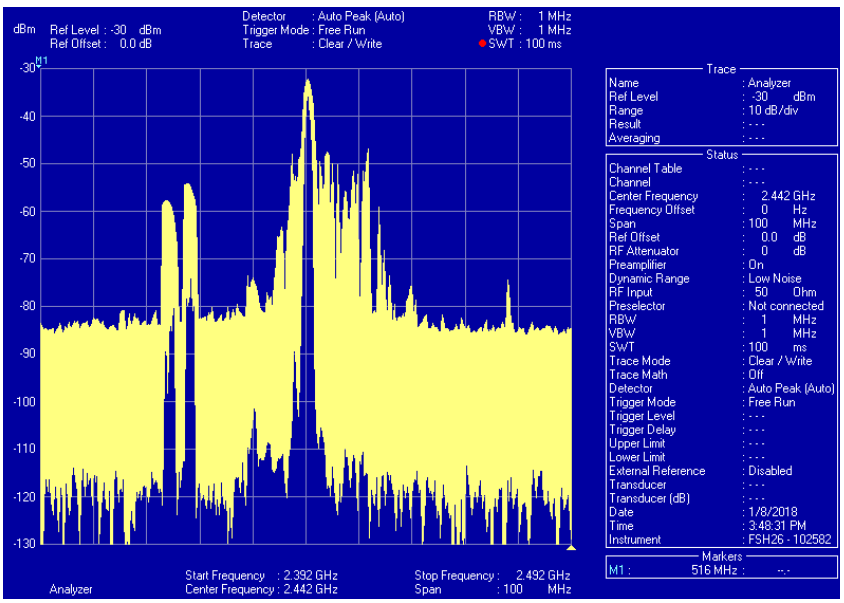

Figure 10: Spectral Display – 2.442 GHz WiFi Center Frequency

In order to verify optimal matching, two methods were employed. The first was to take received signal strength measurements at the upper and lower limits of the 2.4 GHz WiFi band, at channels 1 and13, respectively.

At channel 1, the received signal was 4 dB below the level at the channel 7 band center, and at channel 13, 2 dB below. This indicates balanced roll-off/loss at frequencies away from the center of the band, which implies a proper match.

The second method was the so-called "snow-flaking" technique[1], whereby a very small piece of metallic conductor (the snow flake), equivalent electrically at microwave frequencies to a small capacitor, is touched against various sections of the matching circuitry to see if that action changes the amplitude of the received signal.

[1] http://docplayer.net/46267162-10-ghz-qualcomm-modifications-notes.html , re: paragraph #12.

At all but one “touch point”, the signal level remained the same. At one touch point, it dropped by about 2 dB. Again, this is indicative of a proper match, i.e., additional capacitance anywhere in the matching circuit did not *increase* in the received signal.

Recommendations

Since the strength of the transmitted signal from the water sensor determines the coverage area, i.e., how far it can be placed from the receiver of that signal, it is advantageous to maximize it. Additionally, there was a significant difference in the measured gain of the antennas provided by BRAND.

Based upon these facts, it is 360°RF’s recommendation, therefore, to employ an antenna with the most gain if physical/space limitations will permit. The larger “high-gain” antennas tested provide the best transmitted signal coverage and reception distance.

The next choice would be to use one of the “small” antennas, numbers 3 and 4 specifically, which provided the best gain of that class. The last, and least optimal choice, is to use the on-board chip antenna, since it emanates a significantly weaker signal than the other antennas. This should be done only if the scenario renders the other options to be impractical.

There are many factors besides the transmitting system that can affect whether the received signal is of sufficient strength for proper operation, and a detailed analysis is beyond the scope of this effort. To name a few of these factors…distance from transmitter to receiver, receiver antenna gain, receiver sensitivity, receiver coaxial cable loss, various types of signal loss through obstacles, multipath reflection, and even the relatively humidity of the air.

Reviewed by: DRB ATH