The University of British Columbia
Department of Electrical and Computer Engineering

EECE 496 Final Report:

Measurement-based Modeling of Propagation in Vehicular Environments

Part II. Measurement Methodology and Tool Development

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ABSTRACT

For any measurement-based project or research, it is imperative that time is spent collecting as much data as possible while making sure the data is valid and useful. This project's measurement plan, as well as a description of all the equipment and tools used is reported. Also, many of the problems that came to pass during the project as well as the resulting modifications are looked at.

The information described in this report can be a good building block for similar measurement-based research or projects. Future work on this or other related projects should avoid the problems and issues discussed or possibly use and build upon the measurement procedure presented. In turn, future measurement sessions should be more efficient and productive.

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GLOSSARY

Scattering Parameters – reflection and transmission coefficients between the incident and reflected waves

Vector Network Analyzer – a "stimulus-response" test set that is used to determine the characteristics of an unknown device or system

Pathloss – Attenuation in signal power through propagation

Noise floor – The signal strength of all the noise. A signal must be above the noise floor (have a higher signal strength) in order to be distinguishable

LIST OF ABBREVIATIONS

dB – decibel

GHz – Gigahertz

VNA – Vector network analyzer

S/N – Signal to noise

S parameters – Scattering parameters

1.0 INTRODUCTION

In the first part of this project report, the background, motivations and anticipated outcomes of the project have been discussed. As stated earlier, the approach chosen here for propagation modeling in vehicular environments is measurement based. To this end, proper tools should be developed in order to enable project contributors to obtain accurate data in a reasonable time frame.

An essential part of the project is finding an approach that optimizes the efforts in terms of time spent, validity and usefulness of the results. Also, investigating the validity of the specific hypotheses that have been presented in the previous sections requires an appropriate procedure and plan for conducting the measurements.

This part of the report consists of these plans, procedures, and specifications of the tools used throughout this project and are another useful outcome in addition to the main research results. This document helps the future investigators in avoiding the mistakes made in this project and to improve their efficiency.

This report is divided into the following sections: Scattering parameters, The Vector network analyzer, Antenna positioner, Bluetooth antenna, Measurement plan, Vehicles, Mechanical problems and Improvements made for the production runs.

2.0 SCATTERING PARAMETERS

Scattering Parameters, or s-parameters, are the reflection and transmission coefficients between the incident and reflected waves. S-parameters are use to describe the behaviour of a system. There are 4 different s-parameter coefficients for a two-port network:

Coefficient	Input port	Output port	Description
S_{11}	Port 1	Port 1	Input reflection
S_{21}	Port 1	Port 2	Forward transmission
S_{12}	Port 2	Port 1	Reverse transmission
S_{22}	Port 2	Port 2	Output reflection

The subscripts describe which is the input and output port. The first subscript describes the output while the second subscript describes the input. So for S_{21}, the input is through port 1 and the output is through port 2, thus, it is called the forward transmission coefficient. When an incident wave travels through the device, the output can be determined by multiplying the incident wave value with the appropriate s-parameter, in this case, the S_{21} coefficient. Thus, the s-parameters are able to completely describe the transmission and reflection characteristics of a device.

In this project, the S parameter of interest was the S_{21} coefficient, the forward transmission coefficient. This coefficient describes how much power is transferred from the transmitting antenna to the receiving antenna. Basically, the higher this coefficient is, the less pathloss between the two antennas.

3.0 THE VECTOR NETWORK ANALYZER

The Vector Network Analyzer (VNA) was the main piece of equipment used in this project. The VNA is used to measure the characteristics of an unknown system; with this project, the unknown system was the two Bluetooth chip antennas. The VNA is known as a "stimulus-response" test set since it operates by sending a reference signal through the input of the system and then comparing it with the response received at the output of the system. By connecting the transmitting antenna to the reference signal port and the receiving antenna to the response port, the VNA can determine exactly what the pathloss between the two antennas is.

The VNA is capable of determining many different characteristics of a system and displaying them in a number of ways. The VNA can determine the frequency response of the system and display it on a Smith Chart or find the magnitude and phase of any of the four S-parameters and plot it on a rectangular plot, and these are just a few of the many features of the VNA.

There are many sources of error that can affect the data produced by the VNA, such as imperfect cables and connectors. Therefore, the VNA must be calibrated with all the cables and connectors attached before inspecting the unknown system (the pathloss between the antennas). There are three types of calibration methods: the frequency response method, the reflection method and the full twelve-term error method. The method used for this project was the full twelve-term error method, as this is the best calibration method that removes all the systematic errors on both ports of the VNA.

4.0 ANTENNA POSITIONER

The antenna positioner was initially designed to be able to suspend an antenna inside an automobile. It is composed of two tripods each attached to a vertical aluminium pole. On each vertical pole is a wooden slider; the sliders are used to support a clear plastic horizontal pole. There is a wooden horizontal slider that is fitted around this horizontal pole. The horizontal slider is connected with a small vertical plastic tube. On the vertical plastic tube sits a small wooden base that is used to hold an antenna.

The antenna positioner operates by having the tripods and vertical aluminium poles stand on opposite sides of a vehicle while the horizontal piece in between is held inside the vehicle. The antenna on the wooden base is therefore suspended inside the vehicle. Adjusting the vertical and horizontal sliders can easily move the position of the antenna.

Since this project is concerned with measuring radiowave propagation, it was vital that the component of the antenna positioner that is placed inside the car be not made of metal. This is the reason for using wooden sliders and clear plastic tubing for the central vertical and horizontal poles.

The structure can be taken apart and be used to hold the antenna when it needs to be suspended outside the car.

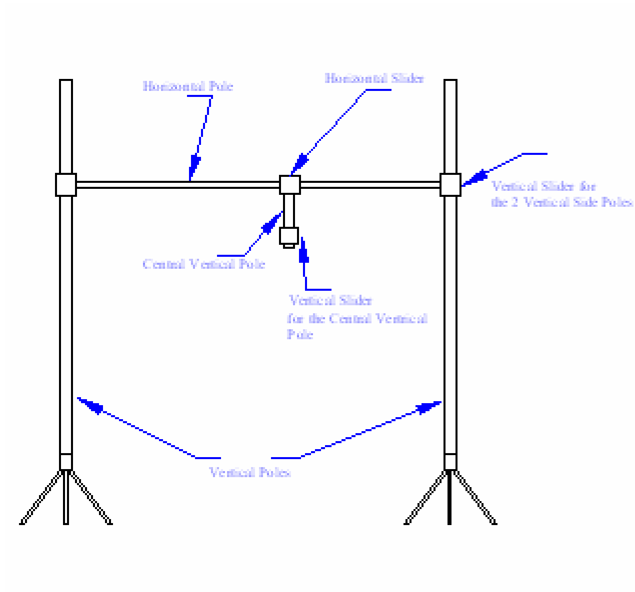


Figure 1: Antenna positioner schematic

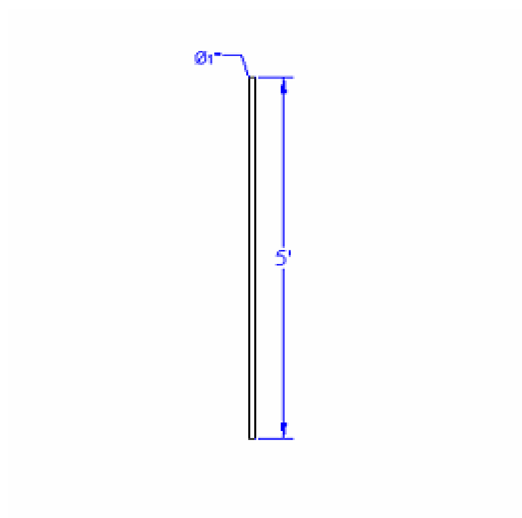


Figure 2: Vertical pole schematic

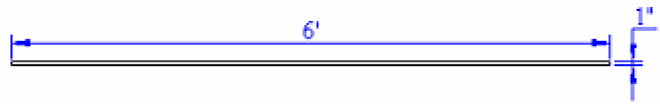


Figure 3: Horizontal pole schematic

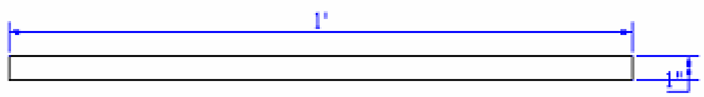


Figure 4: Central vertical pole schematic

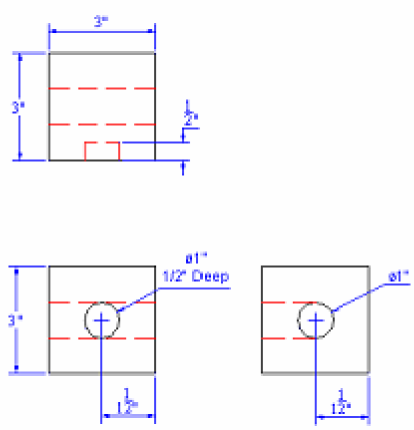


Figure 5: Horizontal slider schematic

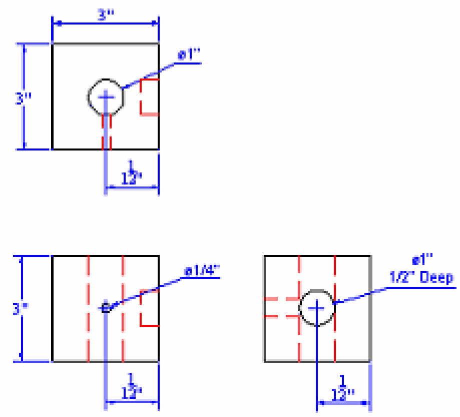


Figure 6: Vertical slider for vertical pole schematic

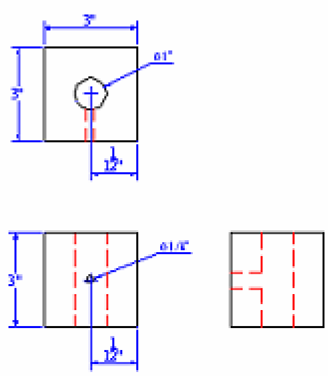


Figure 7: Vertical slider for central vertical pole schematic

Figure 8: Antenna positioner

Note that in the picture above, the central vertical component was removed, leaving only the horizontal pole and slider in place. The antenna is mounted onto the horizontal slider.

5.0 BLUETOOTH ANTENNA

For this project, two Bluetooth chip antennas were used. One antenna acted as the transmitting antenna and the other as the receiving antenna. The two chip antennas are mounted on evaluation boards and are soldered to a SMA-female edge-mount used for connecting to an external cable. The model number of the antennas is BlueChip™ WIC2450 and Centurion Wireless Technologies Inc. produced both of these antennas.

Figure 9: Bluetooth chip antenna

The only difference between the two antennas is that one is a single-band antenna and the other is a multiple-band antenna. The single-band antenna's frequency range is between 2.4GHz to 2.5GHz while the multiple-band antenna had a frequency range between 2.4GHz to 2.5GHz, 5.15GHz to 5.35GHz and 5.75GHz. The frequency range that was of interest with regards to this project is the 2.4GHz to 2.5GHz band. The single-band antenna was designated as the transmitting antenna and the multiple-band antenna acted as the receiver.

The extra frequency ranges on the receiving antenna were irrelevant since the only common frequencies between the two antennas were 2.4GHz to 2.5GHz. Each of the chip antennas is about 8mm in length, 6mm in width and 2.5mm in height. Including the solder tips on the sides, the total length of one antenna is approximately 12mm with a mass of 0.21 grams.

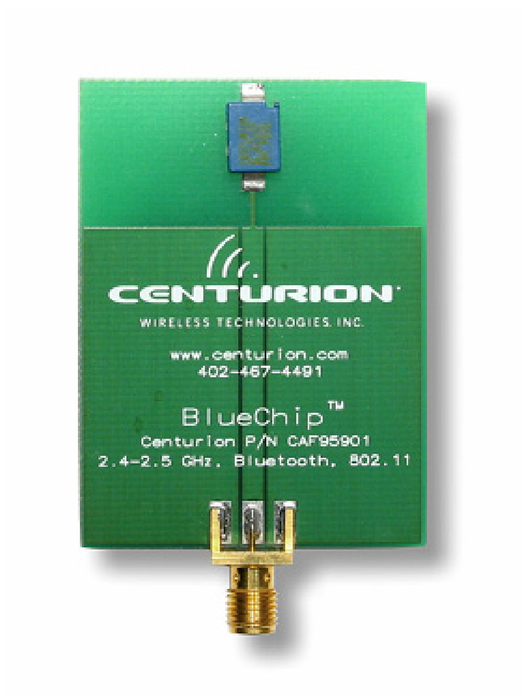


Figure 10: Single-band antenna on evaluation board with connector

Figure 11: Multiple-band antenna on evaluation board with connector

6.0 MEASUREMENT PLAN

For this project, one week was spent on “development measurement runs”, while about three weeks were spent on “production measurement runs”. The development runs were used to test the antenna positioner, get an understanding of how to calibrate the VNA and basically get an idea of how the measurement process would work. The data collected during the development runs were kept for record but not used as part of the final results. The production runs were used for collecting the data that would be used in the results and be used to prove or disprove the original hypotheses. The measurement procedures described below were used during the production runs.

The equipment and supplies that were used in the measurement process are as follows:

- a Vector network analyzer (VNA)
- an antenna positioner
- two Bluetooth chip antennas
- three cables (two short and one long)
- a laptop
- duct tape
- a measuring tape
- chalk
- floppy disks

For the VNA calibration process, one short cable (12 ft.) was used on port 1, and was connected to the transmitting antenna for inside the vehicle. The other short cable, connected with the long cable (24 ft.), goes onto port 2, and was connected to the receiving antenna. The receiving antenna was mounted onto the positioner.

Figure 12: Antenna positioner (at bumper height)

Figure 13: Antenna positioner (at roof height)

The Vector network analyzer is calibrated using the full twelve-term error model. The VNA was set at a frequency range of 2.4GHz to 2.55GHz. While the Bluetooth antennas are specified to be at the range of 2.4GHz to 2.5GHz, the specification sheet that came with the antennas showed that there is response at frequencies slightly above 2.5GHz, therefore 2.55GHz was chosen instead of 2.5GHz. The maximum number of data points was taken at this range, which is 1601. So for each measurement, 1601 data points were collected at regular intervals of frequencies starting at 2.4GHz up to 2.55GHz.

The power coming from the VNA through port 1 to the transmitting antenna was set at 7dBm. This value was used because it was thought that any value higher would have damaged the antenna. The reason for using the highest possible power is to attain the best signal power to noise ratio (S/N ratio). When the S/N ratio is low, even if the two antennas are not that far apart, the pathloss may be great enough to bring the signal to the noise floor at the receiving antenna. When a signal hits the noise floor, it is no longer distinguishable and the data captured by the VNA will be useless. For this project, the transmitting and receiving antennas were placed as far as 12 meters apart; therefore, it was essential to have the highest S/N ratio possible.

All measurement runs were conducted in the B4 parking lot at University of British Columbia. Before the measurements were taken, the points at which the antenna positioner was placed for each measurement point was marked by chalk. The measurement points formed 6 quarter-circles with a common origin.

The measurement points are shown in the two figures below, one for the receiving antenna placed at bumper height (0.5m off the ground) and one for roof height (1.5m off the ground).

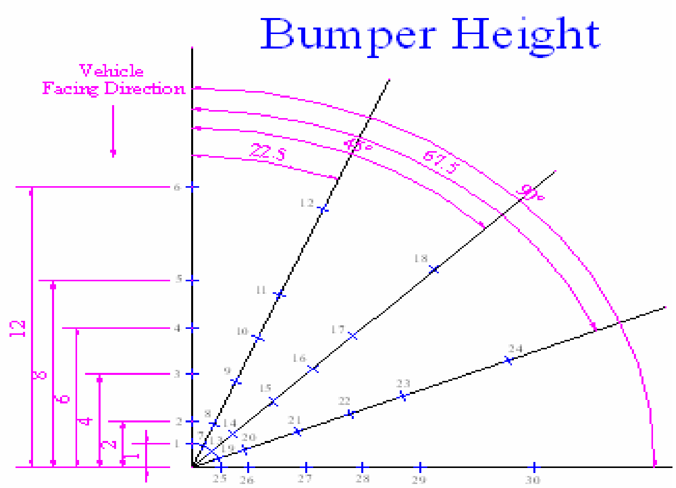


Figure 14: Measurement points at bumper height

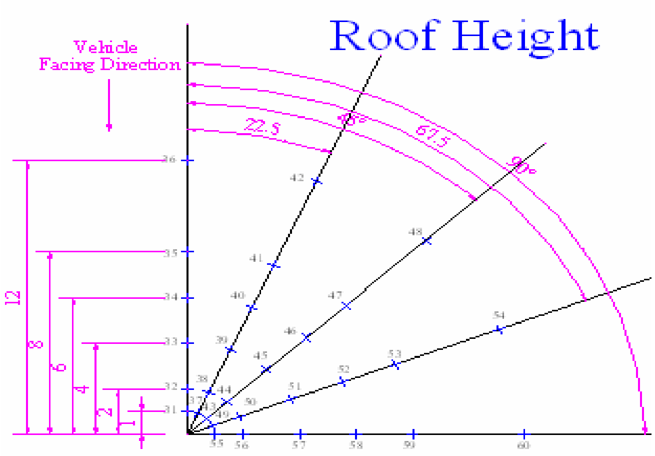


Figure 15: Measurement points at roof height

The pink numbers along the side indicate the distances (in meters) from the car, while the black numbers on the radial lines indicate measurement points used for recording on the data sheets.

Once all the measurement points have been marked off, the testing vehicle was moved so that the transmitting antenna inside the vehicle was directly above the origin of the quarter circle. While there are 60 measurement points shown in the figure, for each different transmitting antenna position, there were only approximately 55 measurements taken due to the vehicle obstructing some of the points that were very close to the origin.

After about 55 measurements, the transmitting antenna was shifted to another position inside the vehicle. In order to reuse the points marked on the ground, the vehicle was positioned so that the new antenna position was over the origin.

The transmitting antenna was placed at 4 different positions for each vehicle: on top of the dashboard, on the gearbox, under the dashboard (or under the steering wheel, depending on the car), and under the dome light.

Figure 16: Receiving antenna on top of the dashboard

Figure 17: Receiving antenna on the gearbox

Figure 18: Receiving antenna under the steering wheel

Figure 19: Receiving antenna under the dome light

During the measuring process, a laptop was occasionally used to reduce and plot the captured data. This was to ensure that valid data are being capture from the VNA. This also showed whether the measurements were being done correctly, by checking to see if the data made sense or if they were just random numbers.

Approximately 240 measurements in total were taken for each vehicle. In this project, there were 3 test vehicles, 2 sedans and a jeep. Including measurements from the development measurement runs, around 1000 measurements were taken.

7.0 VEHICLES

In total, three vehicles were used for this project. For the initial development run, the red Plymouth Sundance was used. For the production runs, the 1996 Chrysler Neon sedan, and 1998 Toyota RAV4 jeep and the red Plymouth Sundance sedan were used.

The Neon sedan and the RAV4 jeep were chosen because their external shapes were drastically different. The RAV4 is a smaller car and the passenger component is higher from the ground than the Neon sedan. Also, the two vehicle's interior was diverse in size and shape. It was ideal to test two vehicles that were not similar because comparing the results of the two vehicles from the same measurement procedure would provide some insight as to how antenna propagation would be affected by the shape and size of a vehicle.

The Plymouth Sundance sedan was used as the third testing vehicle for the production measurement runs. The Sundance sedan was chosen because it was very close to Neon sedan in shape and size. Therefore, by comparing the results of the measurements of these two vehicles, it was possible to check the validity of the data. The measurement runs for the Sundance and the Neon sedans were on different days, thus, the equipment was set up differently for each run. If the results of the measurement runs from these sedans were similar and show the same patterns, it would at least show that the measurement procedures were being carried out properly.

Figure 20: Chrysler Neon sedan

Figure 21: Plymouth Sundance sedan

Figure 22: Toyota RAV4 jeep

8.0 MECHANICAL PROBLEMS

Throughout all the measurement runs, there were several mechanical problems that either slowed down the measurement process or possibly introduced errors into the actual measurements. These problems occurred as a result of carelessness with the equipment and being unprepared.

On the Vector network analyzer, there are two thick cables that are connected to the two ports. At the end of each cable is a connector that is used with external cables or devices. Usually, these 2 cables are secured to the side of the base that the VNA sits on so that the weight of the connector at the end doesn't pull down on the cable. However, when transporting the VNA from the laboratory to the B4 parking, the cables must be taken off the base. With the cables dangling, they are vulnerable to being bent and possibly destroying the inside. This is exactly what happened during one measurement run. Fortunately, it was just the barrier on the cable that was cracked open and the data from the VNA didn't seem different before it happened.

Another problem transpired during the initial development runs. At the time, the transmitting antenna inside the vehicle was held down with regular clear tape. However, the clear tape did not stick to the plastic surfaces inside the car very well. As a result, the antenna inside the vehicle was loosely held and a slight pull to the cable connecting it would move its position. During the development run, the VNA was moved and yanked on the cable and the antenna. The antenna fell and the connector broke off the evaluation board, rendering the antenna useless. New antennas had to be ordered for the production measurement runs.

During the measurement runs, the VNA would sit on a table that had wheels at the end of each leg. At times, when the receiving antenna had to be place far away from the vehicle, the table was moved around to compensate for the short cables that were used. During one production run, the table was accidentally pushed and rolled over a segment of the cable. The cable ended up with a lot of scratches on it but the insides did not seem to be damaged. The measurements taken afterwards did not seem to differ from the ones taken before the accident.

9.0 IMPROVEMENTS MADE FOR THE PRODUCTION RUNS

During the development runs, many mistakes were made and unforeseen problems delayed the data collection process. They were recorded, discussed and changes were made to the measurement procedure, thus improving the efficiency of the time spent on the following production runs.

In the development runs, there were only 18 measurement points, form by three distances, on three different angles, and two heights (bumper and roof). The three distances were 160 inch (approximately 4 meters), 260 inch (approximately 6.6 meters) and 460 inch (approximately 11.6 meters). When analyzing the data received during the development runs, it was found that all the measurements at 460 inch were useless since the signal was so low that it was at the noise floor. Therefore, for the production run, much more points closer to the origin were added, thus producing the figure shown in the measurement plan (figures 14 and 15).

Also, for the two different heights of the receiving antenna, bumper and roof, they were chosen randomly for convenience. For the production runs, the bumper height was set to 0.5 meters off the ground and the roof height was set to 1.5 meters of the ground, the standardized values for these heights.

One problem that greatly delayed the development runs was that the receiving antenna was very hard to secure properly with clear tape. The tape could not hold the antenna down very well and the antenna moved around quite a bit, affecting the measurements. For the production run, duct tape was used instead of clear tape, as duct tape stuck to the plastic inside the vehicles much better than regular tape.

Another unanticipated problem was the floppy disks used to save the data from the Vector network analyzer. The VNA could only save data onto disks that were formatted by the VNA itself. A lot of time was wasted in the first development run trying to figure out why all the floppy disks were not working. For the production run, the entire packet of disks was formatted by the VNA before starting the measurement run.

During the development runs, a laptop was not used to periodically check the captured data. Had there been a mistake in the preparations such as the VNA being not calibrated properly, the entire measurement run's data would have been useless. For the production runs, a laptop was used to check if good data was being taken.

10.0 CONCLUSIONS

This report presented the methods, procedures, and tools used for this project. This report contains the final production measurement process, an accumulation of improvements and modifications made from analyzing the mistakes and mechanical problems from the development measurement runs. Also, the design and schematics of a simple but efficient antenna positioner were given. The topics discussed in this report and its results are as important as the actual research results to anyone planning future work for this or a similar project

Scattering parameters were introduced and how they were used to determine the pathloss between two antennas was discussed. The operation and calibration of the Vector network analyzer were investigated, as well as its role in this project. The complete measurement process was documented along with how the antenna positioner and antennas were used in the procedure. Finally, the three test vehicles were presented as well as the motivation of using those particular vehicles.

This report is a good source of information for similar measurement-based projects and is a good foundation for any follow up work. All the methodology of the measurement process as well as the aforementioned modifications in the measurement approach examined in this report should help others improve the efficiency of their work and avoid the problems experienced in this project.

11.0 REFERENCES

[1] D. Michelson, “Introduction to Vector Network Analyzers,” class notes for EECE 483 – Antennas and Propagation, Department of Electrical Engineering, University of British Columbia, Fall 2004.

[2] Spread Spectrum Scene, “An Archive of GREAT S-Parameter Stuff,” January 2005, http://www.sss-mag.com/spara.html.

[3] Centurion Wireless Technologies, “Centurion Bluetooth Antennas – Bluechip,” April 2005, http://www.centurion.com/home/antennaProd/bluechip.asp.

12.0 APPENDIX

Specification sheet of the Bluetooth antennas:

CENTURION — Specifications

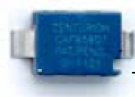
BlueChip™

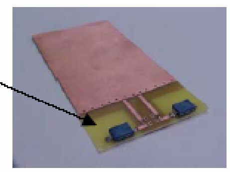
Internal Antenna – Surface Mount

Model Number:
WIC2450-U

Specifications:

- Small and lightweight
- Wide bandwidth, ultra-wide band capable
- Available in tape and reel packaging
- SMT compatible

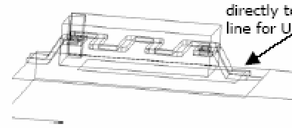




PCMCIA Design

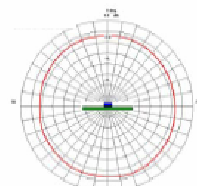
Frequency Range	2.4 – 2.5 GHz	5.15-5.875 GHz
Peak Gain	> 2 dBi	> 3 dBi
Polarization	Linear	
Nominal Impedance	50 ohms	
VSWR (Min. Performance)	<2.0:1	
Temperature Range	-40° to +85°C	
Vibration	6G RMS (9.04g2/Hz) for 15 minutes each in vertical and horizontal. No appearance or functional axis.	
Thermal Shock	Change after 4 repeated cycles of 1 hr. at +85°C and 1 hr. at -40°C. Transfer time is 5 min.	
Radiating Element Size	8 x 6 x 2.5 mm (L x W x H)	
Physical Mass	0.21 grams	
Length w/ Solder Tabs	12mm	

Parallel Patch on PCB connected directly to feed line for UWB

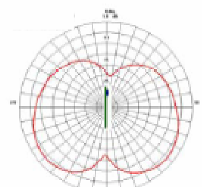


Connectors:

Model #	Part #	Description	Connector
WIC2450-U	CAF95901	Tape and Reel	N/A
WIC2450-U-SM	CAF95943	Single-band on eval board	SMA-female Edge-mount
WIC2452-U-SM	CAF94408	Ultrawide-band on eval board	SMA-female Edge-mount

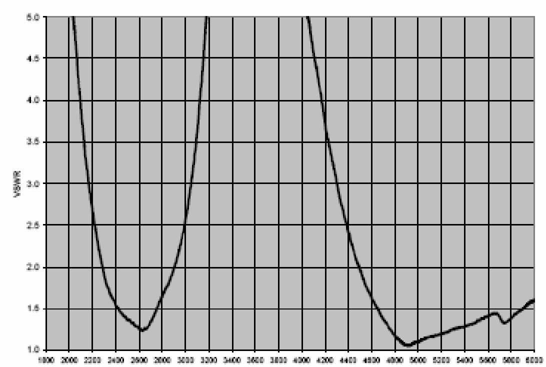


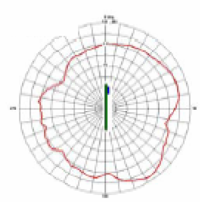
Azimuth
2.45 GHz
Free Space



Elevation
phi=0
2.45 GHz
Free Space

Typical VSWR performance on evaluation PCB





Elevation
phi=0
5.8 GHz
Free Space

Specifications subject to change without notice.

WIC2450U a – 5/18/04

3425 N.44th Street, LINCOLN, NE 68504 USA
SALES PHONE: 800.228.4563
PHONE: 402.467.4491 • FAX: 402.467.4528
www.centurion.com • sales@centurion.com

QS-9000 REGISTERED ISO 9001

A portion of the raw data file from one measurement on the vector network analyzer:

```
##3┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌


##2┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌
37225A
##1┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌┌

MODEL:                DATE:               Page    1
DEVICE ID:             OPERATOR:

START:    2.400000000 GHz  GATE START:     -      ERROR CORR: 12-TERM
STOP:     2.550000000 GHz  GATE STOP:      -      AVERAGING:   1 PT
STEP:     0.000093750 GHz  GATE:           -      IF BNDWDTH: 1 KHz
                   WINDOW:         -

              ---CH1---
PARAMETER:           -S21-
NORMALIZATION:         OFF
REFERENCE PLANE:     11.3386cm
SMOOTHING:         0.0 PERCENT
DELAY APERTURE:         -

MARKERS:

MKR    FREQ        MAGNITUDE
#      GHz         dB


FREQUENCY POINTS:

PNT    FREQ        MAGNITUDE
#      GHz         dB

1     2.400000000   -73.707
2     2.400093750   -71.528
3     2.400187500   -73.443
4     2.400281250   -73.950
5     2.400375000   -75.132
6     2.400468750   -76.255
7     2.400562500   -70.792
8     2.400656250   -73.809
9     2.400750000   -76.028
10    2.400843750   -72.080
11    2.400937500   -69.361
12    2.401031250   -71.795
13    2.401125000   -69.232
14    2.401218750   -71.816
15    2.401312500   -78.502
16    2.401406250   -70.954
17    2.401500000   -72.791
18    2.401593750   -72.604
19    2.401687500   -74.277
20    2.401781250   -73.458
21    2.401875000   -75.949
```

22	2.401968750	-71.919
23	2.402062500	-71.273
24	2.402156250	-71.874
25	2.402250000	-71.353
26	2.402343750	-75.022

MODEL: DATE: Page 2
DEVICE ID: OPERATOR:

---CH1---

FREQUENCY POINTS:

PNT #	FREQ GHz	MAGNITUDE dB
27	2.402437500	-72.127
28	2.402531250	-70.220
29	2.402625000	-76.211
30	2.402718750	-77.148
31	2.402812500	-74.851
32	2.402906250	-74.569
33	2.403000000	-74.044
34	2.403093750	-73.235
35	2.403187500	-73.034
36	2.403281250	-68.980
37	2.403375000	-72.025
38	2.403468750	-71.527
39	2.403562500	-72.392
40	2.403656250	-70.898
41	2.403750000	-71.332
42	2.403843750	-73.790
43	2.403937500	-72.946
44	2.404031250	-76.107
45	2.404125000	-68.346
46	2.404218750	-73.528
47	2.404312500	-73.879
48	2.404406250	-83.163
49	2.404500000	-70.640
50	2.404593750	-74.270
51	2.404687500	-70.150
52	2.404781250	-70.806
53	2.404875000	-71.314
54	2.404968750	-69.893
55	2.405062500	-71.780
56	2.405156250	-73.499
57	2.405250000	-76.617
58	2.405343750	-69.333
59	2.405437500	-73.266
60	2.405531250	-76.226
61	2.405625000	-75.715
62	2.405718750	-76.166
63	2.405812500	-70.711
64	2.405906250	-72.980
65	2.406000000	-71.129
66	2.406093750	-73.471
67	2.406187500	-74.064
68	2.406281250	-69.064