# Embedded FM/TV Antenna System

## Final Report

**Prepared for**

NAB TECHNOLOGY ADVOCACY PROGRAM

FASTROAD

Flexible Advanced Services for Television & Radio On All Devices

**By**

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# 1 INTRODUCTION

The purpose of the “Embedded FM/TV Antenna System Project” is to research, specify, prototype, and test a tri-band embedded antenna capable of servicing mobile DTV and FM radio antenna requirements in a mobile, handheld device. This work, being conducted for the National Association of Broadcasters (NAB) under the FASTROAD technology advocacy program, is intended to hasten development of key embedded antenna technology which in turn could help remove roadblocks related to the inclusion of FM radio and mobile DTV in mobile handsets and other portable devices.

This *Final Report* provides measured performance data on the prototype FASTROAD antenna developed during this project. The goal of this report is to provide a specification for an antenna for FM radio and mobile DTV applications, along with a high level design of the antenna. This report was preceded by two reports, a *Milestone 1 Report* (dated May 3, 2010) which included a review of antenna system capabilities and performance, and a *Milestone 2 Report* (dated June 1, 2010) which included a technical specification and proposed antenna design for an embedded FM/TV antenna system for mobile applications.

The measured antenna data in this report shows that the active tunable antenna approach selected for this project is providing the required antenna performance required for mobile DTV and FM applications.

# 2 TECHNICAL SPECIFICATION

Specifications for an antenna for mobile DTV and FM radio applications were presented in the *Milestone 2 Report* and are repeated here.

**Electrical Specification:**

| Band | Frequency (MHz) | 1 dB Bandwidth | VSWR | Output Impedance (Ohms) | Polarization |
|---|---|---|---|---|---|
| VHF1 | 54 – 108 | 6 MHz, 54 – 88 MHz<br>400 kHz, 88 – 108 MHz | 3.5 | 50 – 100 | Linear |
| VHF2 | 174 – 216 | 6 MHz | 2.5 | 50 – 100 | Linear |
| UHF | 470 – 698 | 6 MHz | 2.5 | 50 – 100 | Linear |

**Control Signals:**

| | | |
|---|---|---|
| Supply voltage | 3V | |
| Band select signal | 0 to 3V | 3 band select signals required |
| Tuning voltage | 0 to 3V | 1 tuning voltage required |
| Current consumption | 10 mA max | |

**Antenna Gain Specification:**

| Band | Frequency (MHz) | Average Gain (dBi) Minimum across band |
|---|---|---|
| VHF1 | 54 – 108 | -24 |
| VHF2 | 174 – 216 | -12 |
| UHF | 470 – 698 | -2 |

**Mechanical:**

| | |
|---|---|
| Dimensions (Length x Width x Height) max | 48 mm x 16 mm x 4 mm |
| Weight (gm) | TBD |

## 3 PROTOTYPE ANTENNA

The FASTROAD prototype antenna consists of a two piece design: an active, tunable module along with an antenna element. During development of the prototype active antenna it was determined that a tuning circuit was not required for the UHF band. The tuning circuit was replaced with a passive matching circuit for UHF to simplify the circuit and for future cost reduction. The active tunable module topology is shown in Figure 1.

The active, tunable module contains a pair of 3-port switches with three tuning or matching circuits between the switches to tune the individual frequency bands. A low noise amplifier (LNA) is connected to the output of the second switch and provides a nominal 15dB of gain across the 50 to 700 MHz frequency range.

The VHF1 and VHF2 tuning circuits each consist of a varactor diode and two high Q inductors. The values of the inductors are optimized per band to provide a high Q tunable circuit for impedance matching the common antenna element. When integrated into a production mobile device the tuning circuits can be controlled via a lookup table residing in the firmware of the processor used to control the mobile DTV receiver chipset. Using varactor diodes in the tuning circuits for the variable capacitance, a variable DC voltage can be used to optimize the frequency response of the tuning circuit at a specific channel. Alternately, a pulse width modulated (PWM) signal can be used to simulate the analog tuning voltage required to select the frequency of operation of the antenna. The control schematic for the FASTROAD active tunable module is shown in Figure 2. A more detailed schematic defining the pad layout for the active tunable module is shown in Figure 3.

A single antenna element was designed and optimized for the active, tunable circuit and connects to the input port of the active, tunable module. The antenna element is an inductively loaded monopole structure. This unbalanced structure has two advantages over a balanced antenna such as a loop: 1) the monopole structure presents a high impedance which minimizes coupling of noise and transient responses in the near field of the mobile device and 2) the monopole structure coupled to the tuning circuits provides a wider bandwidth tuned frequency response compared to a loop. Inductive loading of the monopole element improves antenna performance at VHF1 and VHF2 by increasing the electrical length of the radiator.

For test and evaluation of the FASTROAD antenna a demonstration board was developed that simulates the width and length of a typical handset or smart phone. The demonstration board is 50mm by 100mm and contains a battery for powering the active module along with a DIP switch and potentiometer to switch bands and tune the antenna response. The active, tunable module is re-flow soldered to the demonstration board.

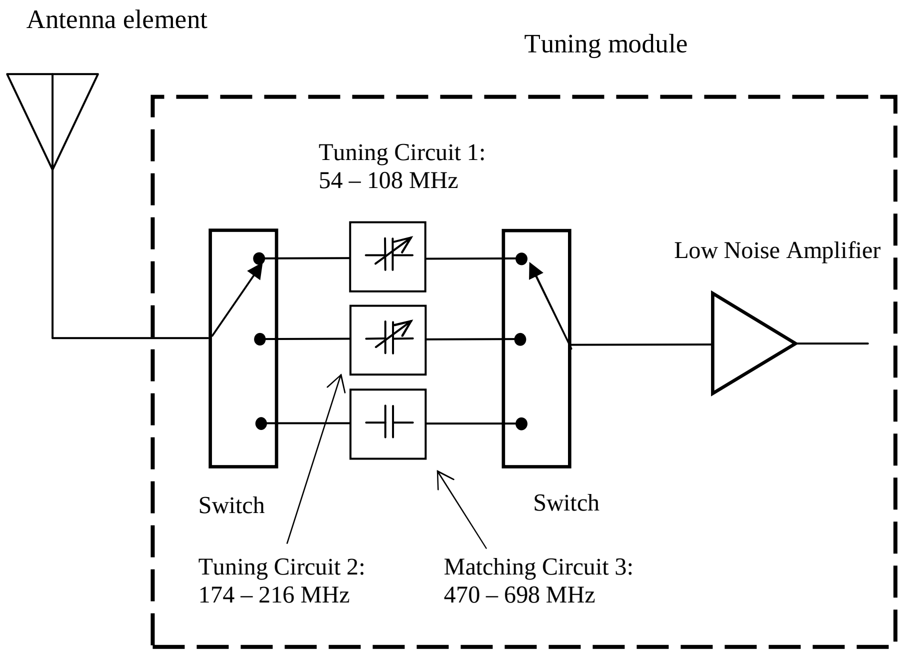



Figure 1. NAB FASTROAD embedded antenna topology

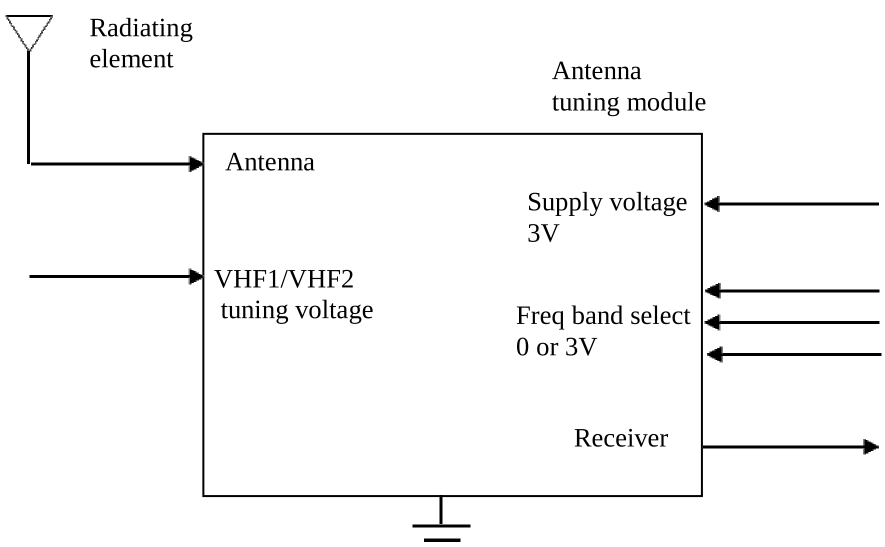



Figure 2. NAB FASTROAD embedded antenna control schematic

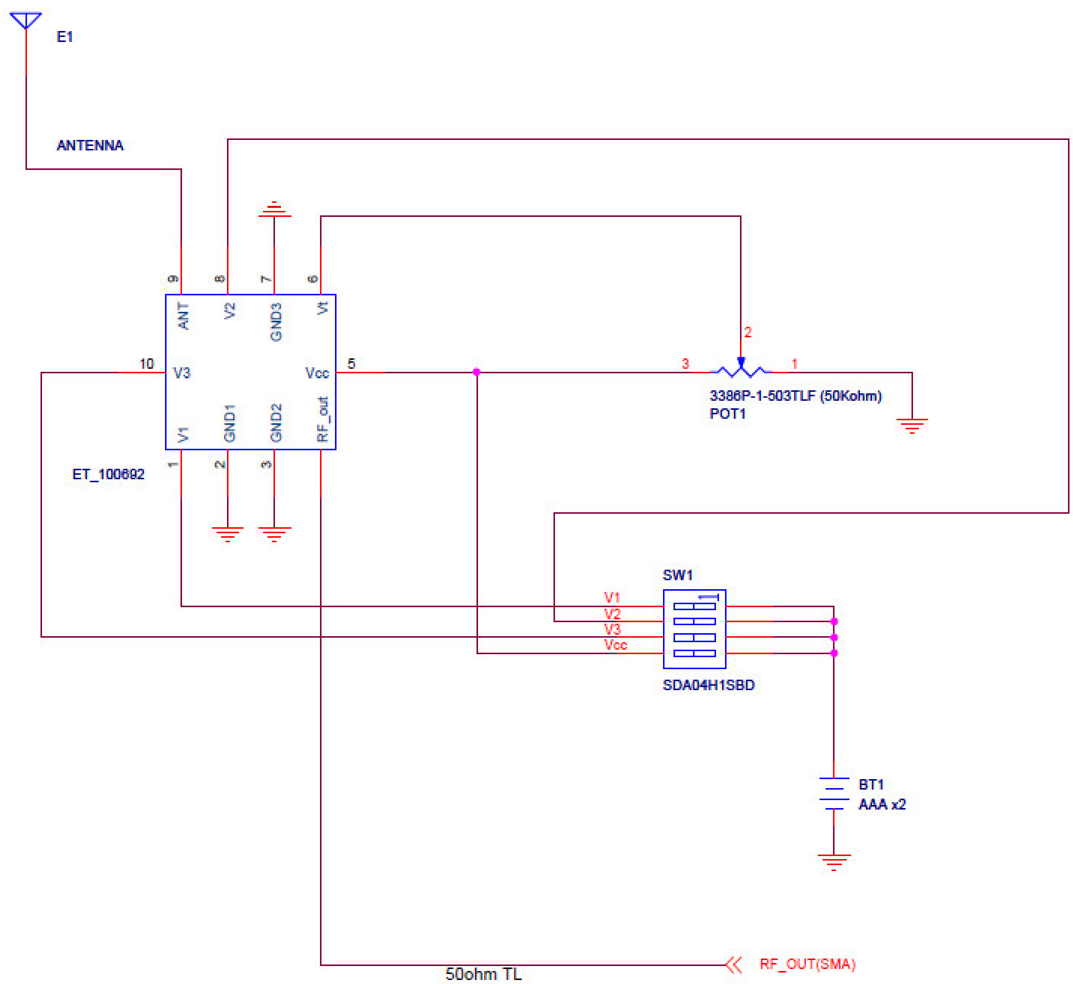



Figure 3. Control schematic for FASTROAD active tunable module

## 4 FASTROAD ACTIVE MODULE FABRICATION

The FASTROAD active, tunable circuit developed for this project is fabricated as a module that can be re-flow soldered to the circuit board of the host device, such as a handset, net book, or other mobile device. The fabrication method chosen was to design and fabricate a two layer printed circuit board (PCB) using standard FR4 substrate. Discrete components comprising the active circuit were mounted on this PCB, using standard manufacturing guidelines in regards to component spacing and circuit board trace dimensions. The components are mounted on the top side of the PCB and ten (10) mounting pads are designed into the bottom side of the PCB to provide connection to the host device PCB; these ten pads provide RF input and output connections, RF and DC ground, and control and supply voltage connections. The PCB contains the attach pads for a shield can, which is attached to the PCB after discrete component placement. The PCB, discrete components, and shield can comprise the FASTROAD active, tunable module. The module, when assembled in this fashion, is ready for SMT (surface mount technology) onto the PCB of the host device in a high volume production setting.

The module is 11mm wide, 15.5mm in length, and a height of 3.5mm with shield can attached. A photograph of the FASTROAD module is shown in Figure 4. In the photograph, both the top and bottom sides of the module are shown. The shield can is not shown in this photograph. On the top side of the module (component side), the ten plated pads are for shield can attachment by soldering. On the bottom side of the module, the ten attach pads are shown for connection of the module to the PCB of the host device. These ten pads correspond to the ten control lines shown in Figure 3.

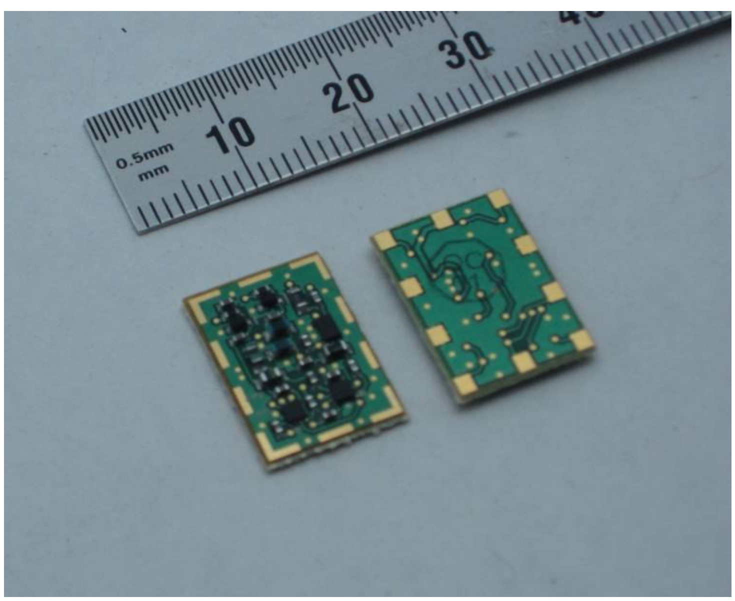



Figure 4. FASTROAD prototype module; top (left) and bottom (right) sides of module are shown

# 5 DEMONSTRATION BOARD DESIGN

To provide for test and evaluation of the FASTROAD active, tunable antenna a demonstration board was designed and fabricated (Figure 5). The purpose of the demonstration board is two-fold:

1) Provide power and control signals to the active, tunable module
2) Provide a ground plane to simulate the circuit board of the host device

A 50mm wide and 100mm length circuit board dimension was chosen to represent a typical handset sized mobile device. A two layer PCB was designed and fabricated for the demonstration board. The demonstration board contains a battery holder and two size “AAA” batteries, a 4 position DIP switch, a potentiometer, a SMA RF connector, and an etched antenna element.

The DIP switch controls the pair of 3-port switches which are used to switch in one of three tuning or matching circuits. Table 1 shows the settings for the four DIP switch positions to select one of the three frequency bands. The potentiometer is used to provide a DC voltage to the two varactor diodes, one located in the VHF1 and VHF2 tuning circuits. Rotating the potentiometer knob will vary the DC voltage to the varactor diodes, which will cause a change in capacitance of the varactor diode which will in turn change the impedance of the tuning circuit. The tuning circuits are optimized to impedance match each of the three frequency bands.

| Band | DIP Switch | | | |
|---|---|---|---|---|
| | 1 - Vcc | 2 – UHF | 3 – VHF2 | 4 – VHF1 |
| VHF1 | ON | OFF | OFF | ON |
| VHF2 | ON | OFF | ON | OFF |
| UHF | ON | ON | OFF | OFF |

Table 1. DIP switch settings to select a specific frequency band

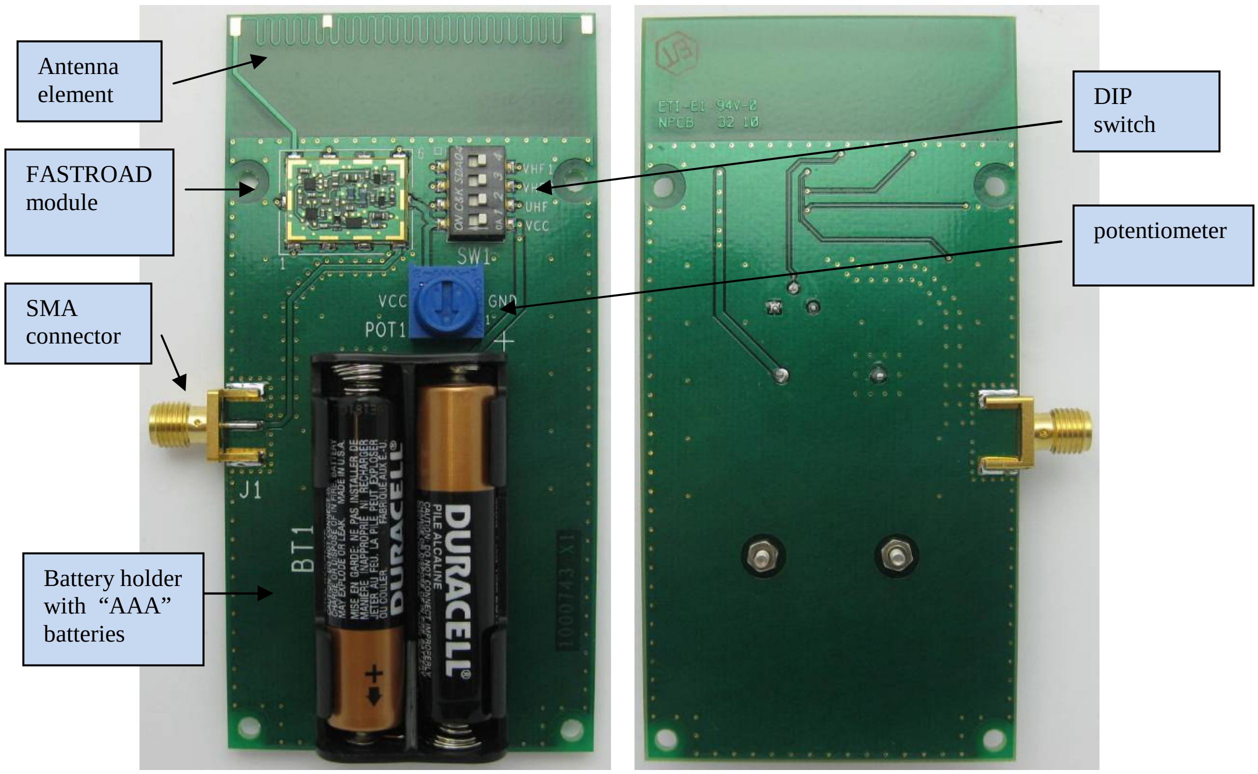



Figure 5. Demonstration board containing FASTROAD prototype active, tunable module; top (left) and bottom (right) sides of the demonstration board are shown

# 6 MEASURED DATA

## 6.1 VHF1/VHF2 Tuning Data

The FASTROAD active tunable antenna, comprised of a module and antenna element, is an active receive-only antenna. As such, a direct measure of input antenna impedance is not feasible. A method for characterizing the tuning circuits is to conduct an S12 transmission measurement, where a signal is radiated by an antenna and the FASTROAD active tunable antenna is used to receive the signal. A two port network analyzer is applicable for this measurement.

A two port network analyzer allows for the measure of four S-parameters: S11, S12, S21, and S22. The first number in the S-parameter denotes the port that the signal is received from while the second number denotes the port that the signal is transmitted from. Since we are concerned with measuring the performance of a received signal through the receive-only active antenna, an S12 measurement can be conducted where a transmit antenna is connected to port 2 and the active receive-only antenna is connected to port 1. This will provide a radiated signal from port 2 and will allow for a signal to be received and measured at port 1. During this test the bandpass characteristics and tuning range of the tunable matching circuits can be measured. This measurement was conducted on the demonstration board containing the FASTROAD active module and antenna element. The test procedure is as follows:

1. Connect a transmit antenna to port 2 of a two port network analyzer.
2. Connect the LNA output of the demonstration board to be tested to port 1 of the network analyzer.
3. Set the network analyzer to the S12 measurement mode.
4. Set the start and stop frequencies to cover the frequency range of interest. To test VHF1 set the start frequency to 50 MHz and the stop frequency to 120 MHz.
5. To test VHF1 set the DIP switch on the demonstration board to the VHF1 setting (DIP switch settings shown in Table 1). The trace on the network analyzer will show the receive response of the FASTROAD active tunable antenna. The potentiometer can be adjusted and the change in frequency response can be viewed.
6. To test VHF2 set the start frequency to 160 MHz and the stop frequency to 240 MHz. and repeat step 5, changing the DIP switch settings to the VHF2 state.

Figure 6 shows a photograph of the demonstration board containing the FASTROAD module and antenna element connected to port 1 of the network analyzer and a wire antenna connected to port 2. Figures 7 and 8 show measured S12 transmission measurements of the demonstration board. The different color traces represent several potentiometer settings, each potentiometer setting providing a specific DC voltage to the varactor diode in the tuning circuit to adjust the capacitance, which in turn adjusts the impedance of the matching circuit to optimize the antenna impedance. As can be seen from the plots the tunable circuits provide the required minimum 6 MHz bandwidth for each of the tuning states. Only four states are shown for VHF1 and three states for VHF2. The potentiometer provides for continuous adjustment so the antenna impedance can be optimized for all channels in each frequency band. The UHF frequency band did not require a tunable circuit due to the antenna element being more appropriately sized at this higher frequency range.

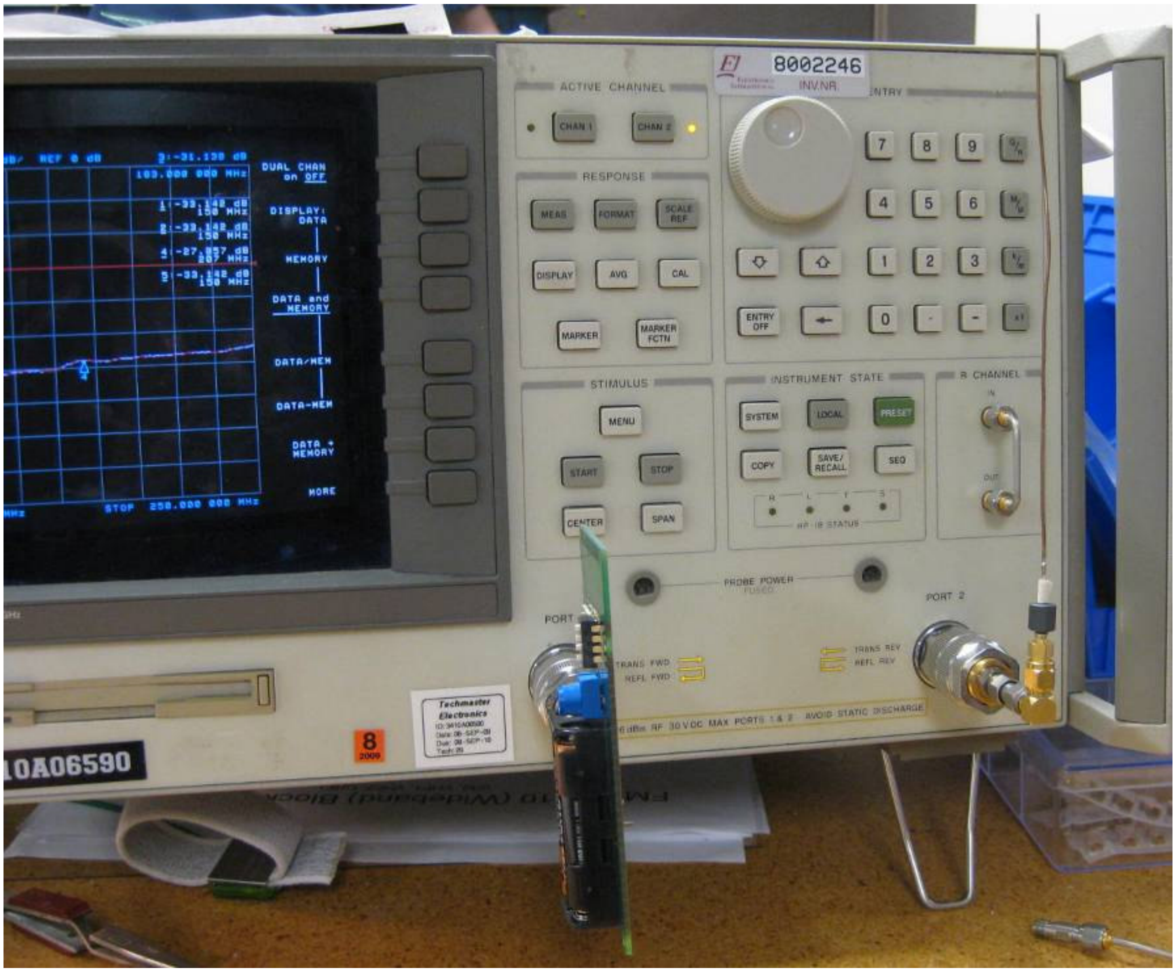



Figure 6. Demonstration board containing the FASTROAD module and antenna element connected to a network analyzer

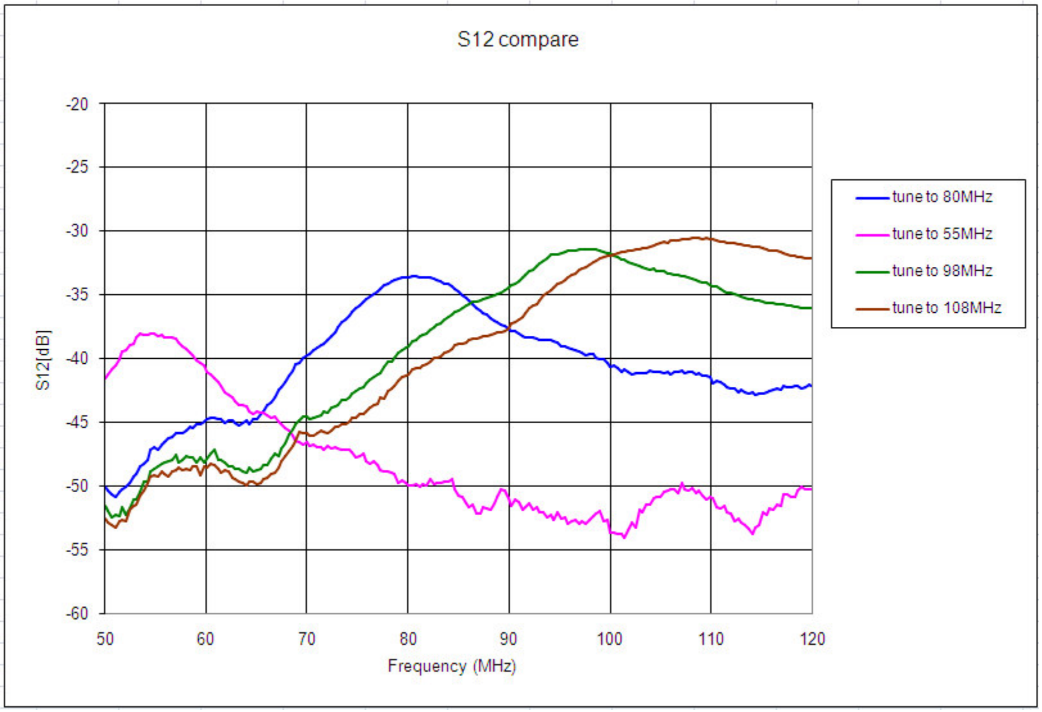



Figure 7. Tuning data for the VHF1 tuning circuit in the FASTROAD module

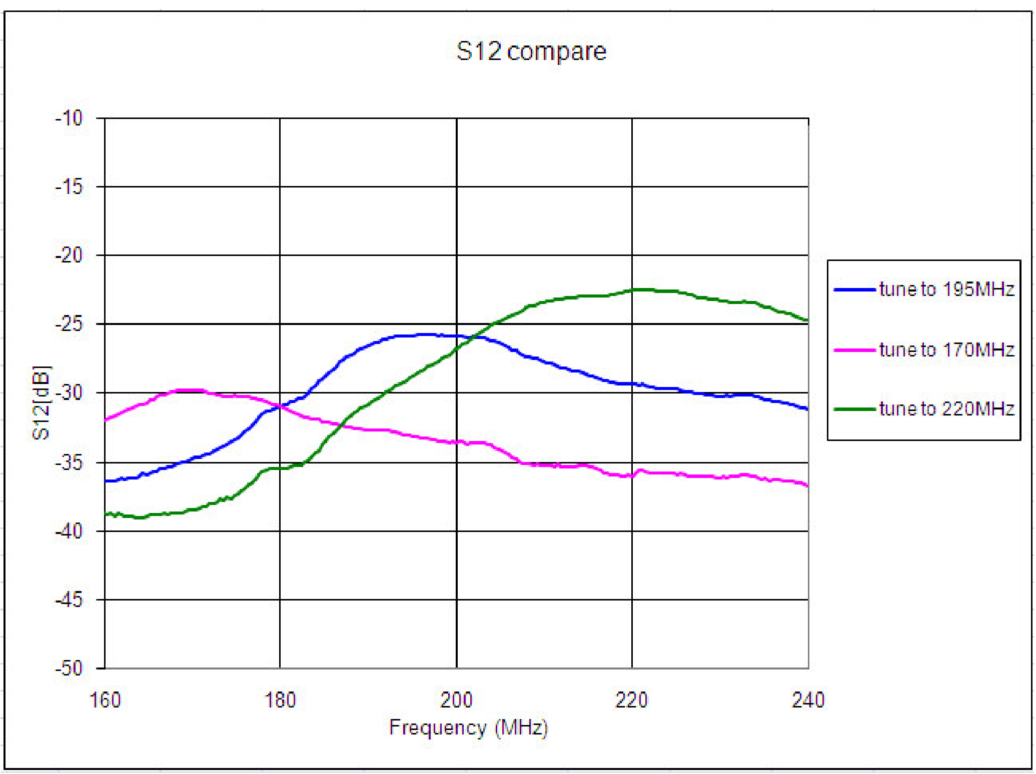



Figure 8. Tuning data for the VHF2 tuning circuit in the FASTROAD module

## 6.2 VHF1/VHF2 Radiation Pattern Measurement

Measuring radiation patterns and peak gain at commercial VHF frequencies poses a challenge because of the low frequencies involved. Traditionally, low frequency antenna pattern measurements have been conducted on outdoor ranges to accommodate the long wavelengths involved. Indoor anechoic far field chambers are sized according to the wavelength that the test is to be conducted at. Typically an anechoic chamber designed for far field measurements needs to have physical dimensions on the order of 10 wavelengths for length, width, and height, or greater if possible. The absorbing material used to suppress reflections from the walls of the chamber need to be on the order of one wavelength or greater to provide the necessary attenuation and scattering of the incident wave. These dimensional constraints make anechoic chambers unrealistic for use in the 50 to 150 MHz. frequency range.

Outdoor ranges are available for low frequency test but can not operate at the FM and VHF TV frequency bands due to interference concerns. Even if temporary waivers are obtained to transmit in these frequency ranges, the low power level constraints will result in the commercial transmit channels in the FM and TV bands interfering with the intended test frequency.

For radiation pattern testing at the VHF1 and VHF2 bands we used a simple technique to solve this dilemma. A spectrum analyzer and receive antenna were set up outdoors and used to survey the existing commercial signals in the FM and VHF frequency bands. These channels were measured for signal strength and stability to determine the usefulness as test signals to measure radiation patterns. Multiple FM and VHF TV channels were determined to be strong enough and stable for use as test signals. Six frequencies were chosen: 89.5, 96.5, 105.3, 175, 183, and 196 MHz.

Radiation patterns were measured on the FASTROAD active tunable antenna at the VHF1 and VHF2 frequency bands at the six test frequencies using a spectrum analyzer, shown in Figure 9 connected to the antenna under test to receive the commercial signals. The antenna under test was positioned on a turntable that provided continuous rotation and is shown in Figure 10. A ferrite loaded choke, shown in Figure 11 was used to de-couple the antenna under test from the coaxial cable used to connect the antenna to the spectrum analyzer. The antenna under test was positioned and measured in three orientations:

1. Demonstration board positioned vertically
2. Demonstration board positioned horizontally, with the PCB normal to the incident signal
3. Demonstration board positioned horizontally, with the PCB in the plane of the incident signal

The three orientations are shown in Figures 13, 14, and 15.

An adjustable dipole was used as a reference antenna and is shown in Figure 12. A gain calibration table for the reference dipole provided the peak gain which was used to provide a measure of absolute gain for the antenna under test.

Radiation patterns at the six VHF1 and VHF2 test frequencies are shown in Appendix A.

Figure 9. Spectrum analyzer

Figure 10. Antenna under test on turntable

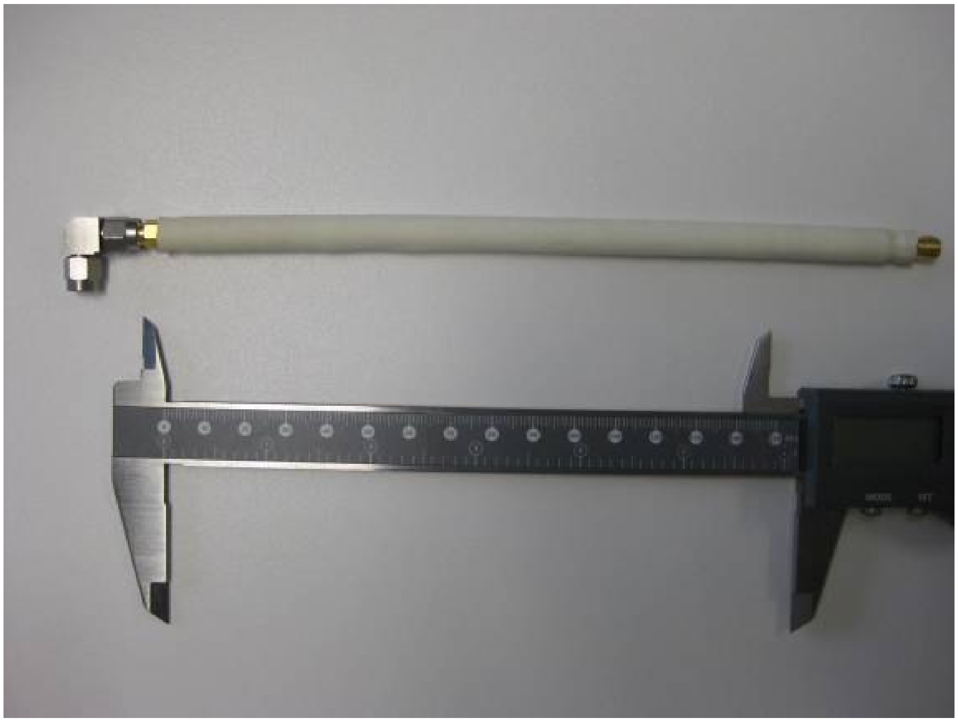


Figure 11. Ferrite loaded choke

Figure 12. Reference dipole

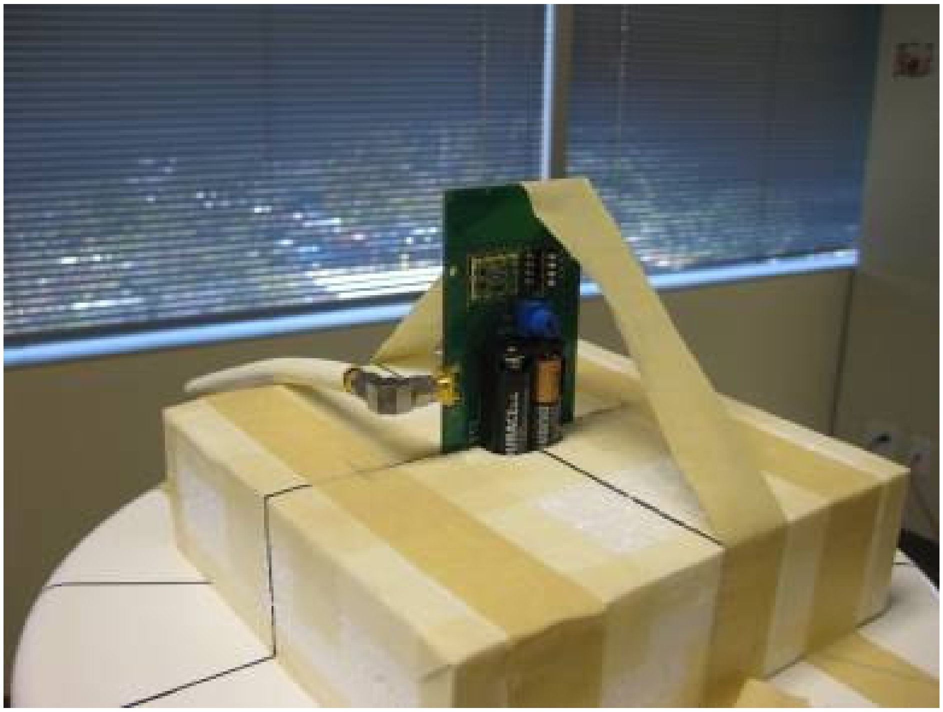


Figure 13. Orientation 1

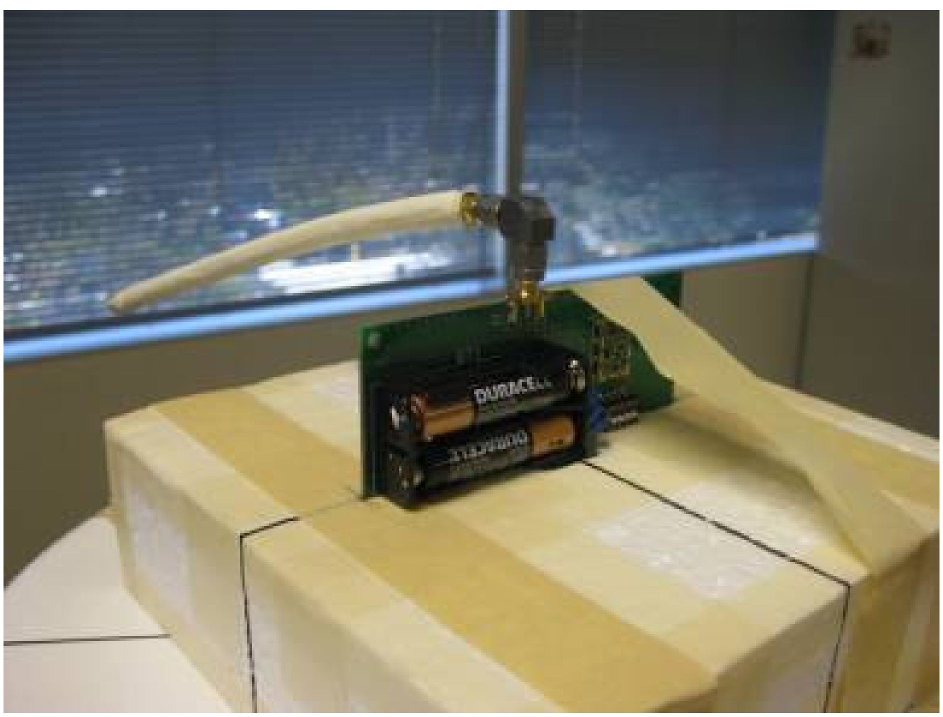



Figure 14. Orientation 2

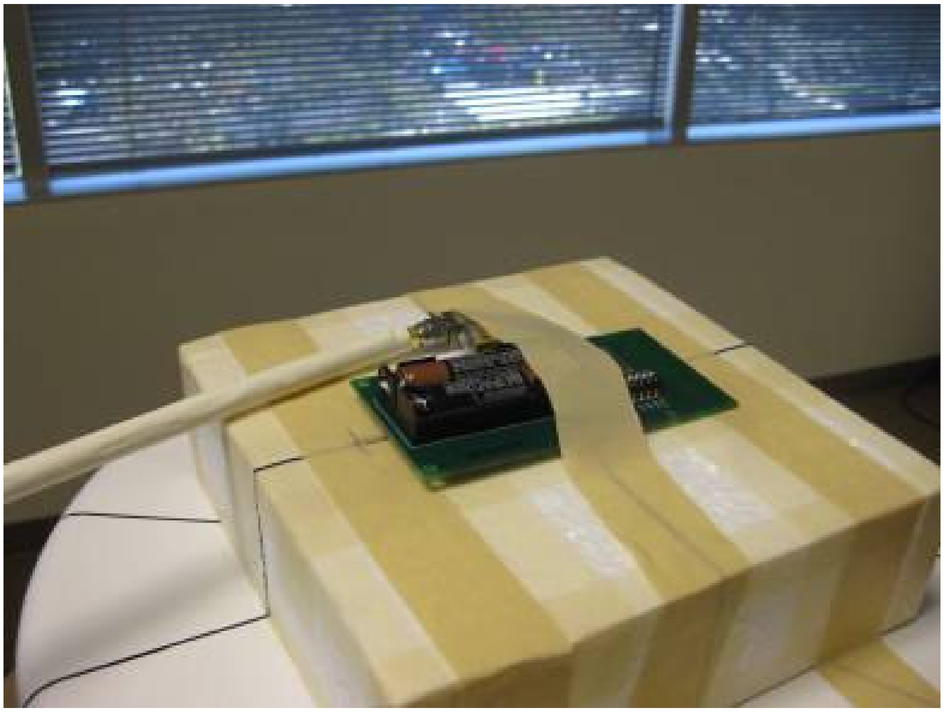


Figure 15. Orientation 3

## 6.3 UHF Radiation Pattern Measurement

Radiation patterns and peak gain measurements at the UHF band which covers 470 to 698 MHz. were conducted in an anechoic chamber (Figure 16). Ethertronics operates two anechoic chambers capable of antenna pattern measurements down to 400 MHz. These far field chambers provide the ability to rotate the antenna under test in both azimuth and elevation (Figure 17), allowing for a full 3D radiation pattern set. Radiation patterns were measured between 470 and 785 MHz at 5 MHz intervals, for a total of 64 frequencies. 2D and 3D radiation patterns are shown for three frequencies, 470, 585, and 695 MHz, in Appendix B.

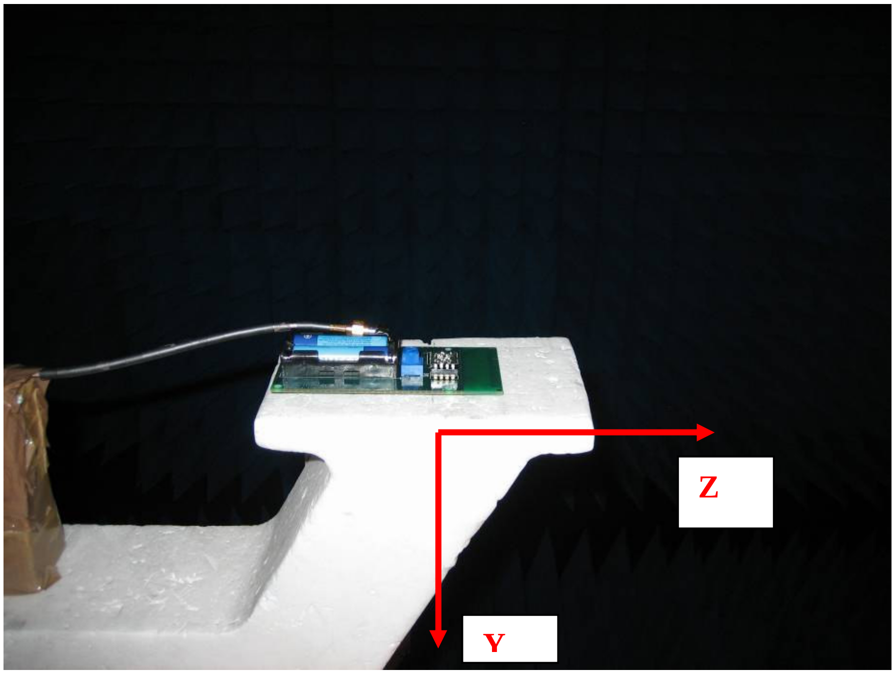



Figure 16. FASTROAD demonstration board mounted in anechoic chamber

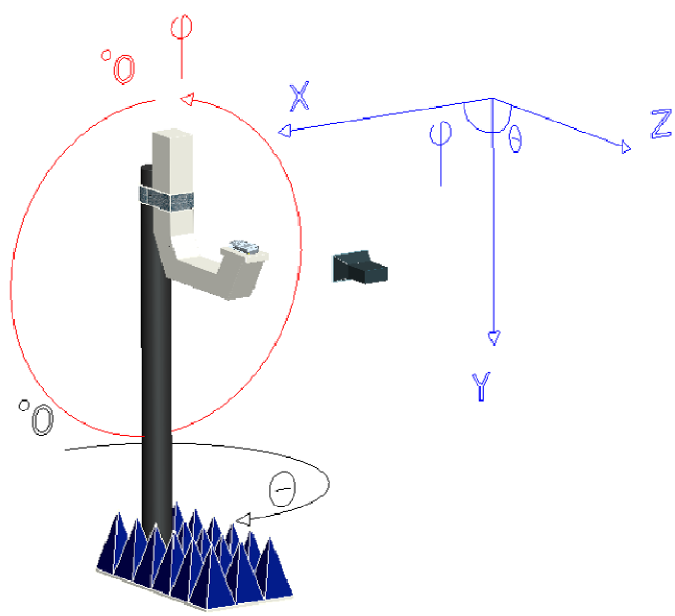



Figure 17. Coordinate system for all radiation pattern measurements, VHF1, VHF2, and UHF

# 7 PEAK GAIN DATA

Peak gain data was derived from the radiation pattern measurements conducted at the various test frequencies. The peak gain at three VHF1 frequencies, three VHF2 frequencies, and eleven UHF frequencies are shown in Figures 18, 19, and 20 respectively. The peak gain of the FASTROAD active tunable antenna is compared to the simulated gain of a 6 inch external whip antenna, which was previously shown in the FASTROAD *Milestone 2 Report*. The peak gain measured on the FASTROAD active tunable antenna shows that the active tunable approach chosen for this application is working quite well. The peak gain at the FM frequency band as well as the UHF frequency band is equal to or greater than the gain achieved from a 6 inch whip at a majority of the frequency range, with the performance at VHF2 (170 to 240 MHz) is within 5 dB of the performance of the whip. It is important to note that the simulated gain for the external whip does not includes conductor or mismatch losses; the actual measured peak gain for the external whip will be lower.

Table 2 provides measured peak gain as well as standard deviation data for the frequencies tested. The peak gain in Table 2 are the data points shown in Figures 18, 19, and 20 and represent the maximum gain for the three principal planes measured: XY, XZ, and YZ. The standard deviation is calculated for the XY plane only, since this is the one plane that the antenna can have an omni-directional radiation pattern due to symmetry of the antenna configuration tested. The XZ and YZ planes will contain nulls or pattern minima in the radiation pattern. As can be seen, the standard deviation is quite small at the UHF frequencies and increases as the frequency of operation is decreased. This is due to two factors: 1) the difficulty of de-coupling the antenna and ground plane from the test cable and 2) the reflections due to the outdoor environment at the VHF1 and VHF2 frequency bands. The UHF patterns were measured in an anechoic chamber, which provides a more stable and near reflection-free environment.

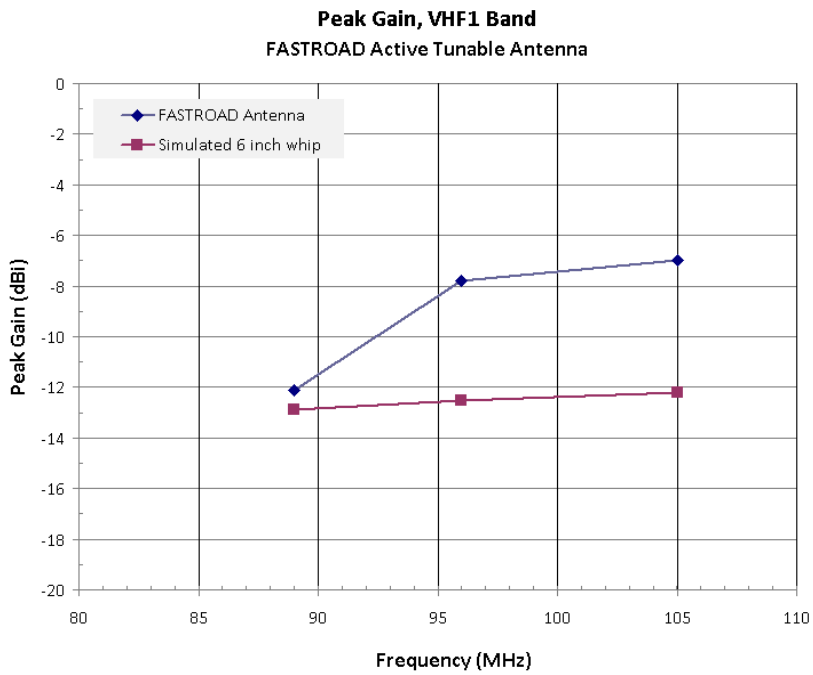



Figure 18. Measured peak gain of FASTROAD active tunable antenna at VHF1 band compared to simulated peak gain of 6 inch external whip antenna

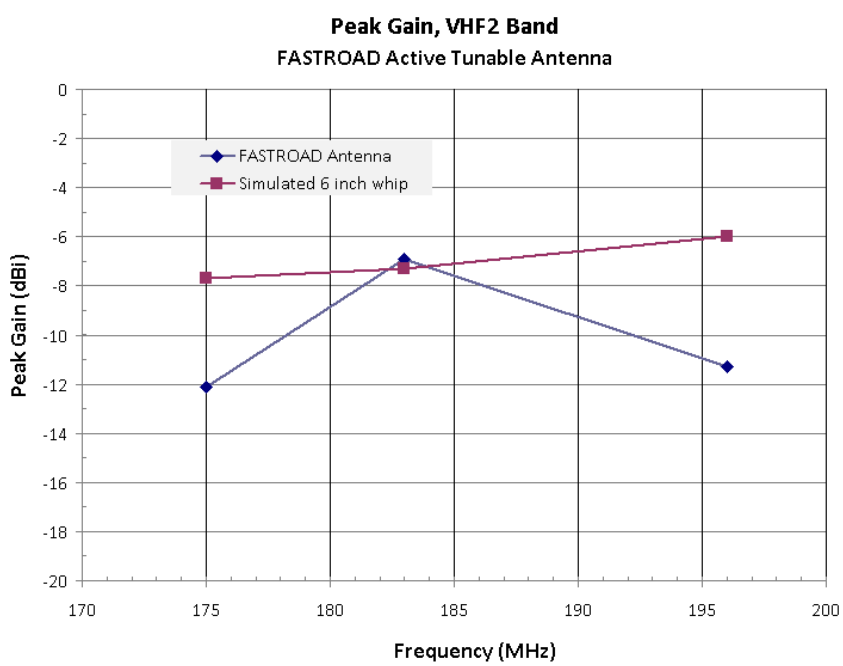



Figure 19. Measured peak gain of FASTROAD active tunable antenna at VHF2 band compared to simulated peak gain of 6 inch external whip antenna

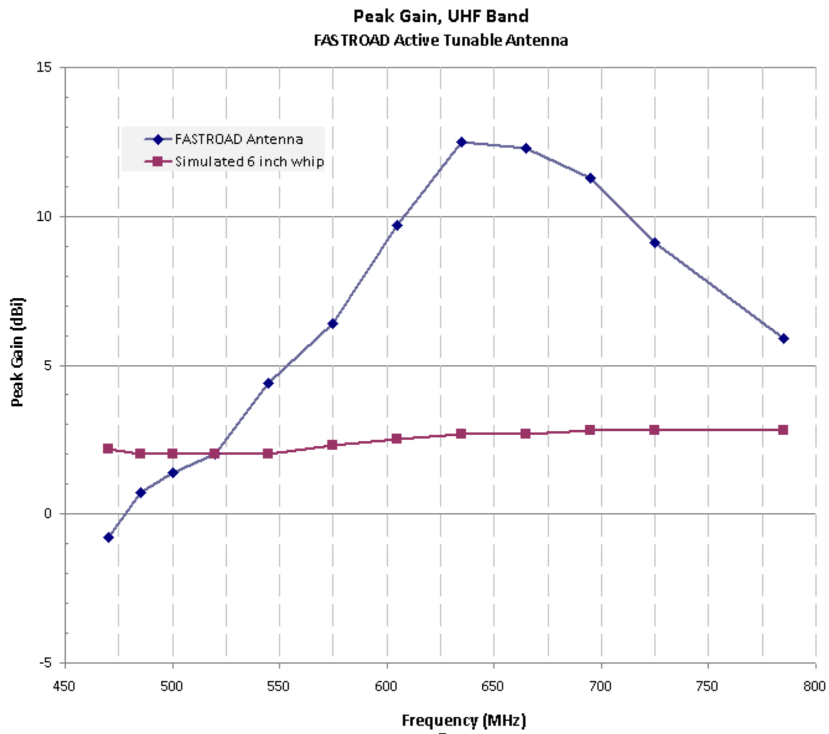



Figure 20. Measured peak gain of FASTROAD active tunable antenna at UHF band compared to simulated peak gain of 6 inch external whip antenna

| Frequency, MHz | Peak gain, dBi | Std. Dev., XY Plane |
|---|---|---|
| 89.5 | -12.1 | 2.74 |
| 96.5 | -7.8 | 4.23 |
| 105.3 | -7.0 | 4.49 |
| 175 | -12.4 | 2.22 |
| 183 | -6.9 | 3.01 |
| 196 | -11.3 | 1.65 |
| 470 | -0.8 | 0.39 |
| 485 | 0.7 | 0.21 |
| 500 | 1.4 | 0.14 |
| 520 | 2.0 | 0.32 |
| 545 | 4.4 | 0.30 |
| 575 | 6.4 | 0.41 |
| 605 | 9.7 | 0.15 |
| 635 | 12.5 | 0.13 |
| 665 | 12.3 | 0.38 |
| 695 | 11.3 | 0.62 |
| 725 | 9.1 | 0.28 |
| 785 | 5.9 | 0.18 |

Table 2. Measured peak gain and standard deviation of prototype FASTROAD antenna

# 8 ANTENNA INTEGRATION DESIGN GUIDELINES

When integrated into a production mobile device, control voltages will need to be provided to switch frequency bands and tune to a specific channel. The tuning circuits can be controlled via a lookup table residing in the firmware of the processor used to control the mobile DTV receiver chipset. A variable DC voltage is used to optimize the frequency response of the tuning circuit at a specific channel. Alternately, a pulse width modulated (PWM) signal can be used to simulate the analog tuning voltage required to select the frequency of operation of the antenna.

The FASTROAD antenna has been designed for ease of integration into a wide variety of mobile wireless devices. The FASTROAD prototype active tuning module (ATM, shown in Figure 21) is designed to be capable of "pick and place" attachment to a PCB and re-flow soldered. This SMT (Surface Mount Technology) design makes it cost effective in a high volume production environment. A specific pad layout is required on the PCB of the host device. The required pad layout is shown in Figure 23.

The single antenna element developed for the FASTROAD demonstration board (shown in Figure 22) can be directly designed onto the host circuit board as long as some simple design guidelines are followed. Alternately, a custom antenna can be designed for a specific mobile device form factor. A custom antenna design will typically more efficiently utilize the internal volume of the mobile wireless device.

To design in the antenna element developed for the FASTROAD demonstration board, the following design guidelines should be observed for optimal antenna performance:

1. A 50 mm by 17 mm area allocated for antenna placement
2. The antenna area is located at one end of the circuit board, with the antenna element parallel to the edge of the circuit board
3. Complete ground plane removal for all layers of the circuit board in the antenna area
4. No components placed within the antenna area

For some antenna applications for mobile devices the area requirements for the antenna element from the FASTROAD will be too restrictive. In these cases a custom antenna element can be designed. The only requirement for use of a custom antenna with the FASTROAD ATM is that the antenna element be designed to have a 500 nH reactance. This will provide the reactance required for the tuning circuits within the ATM to impedance match the antenna across the frequency bands.

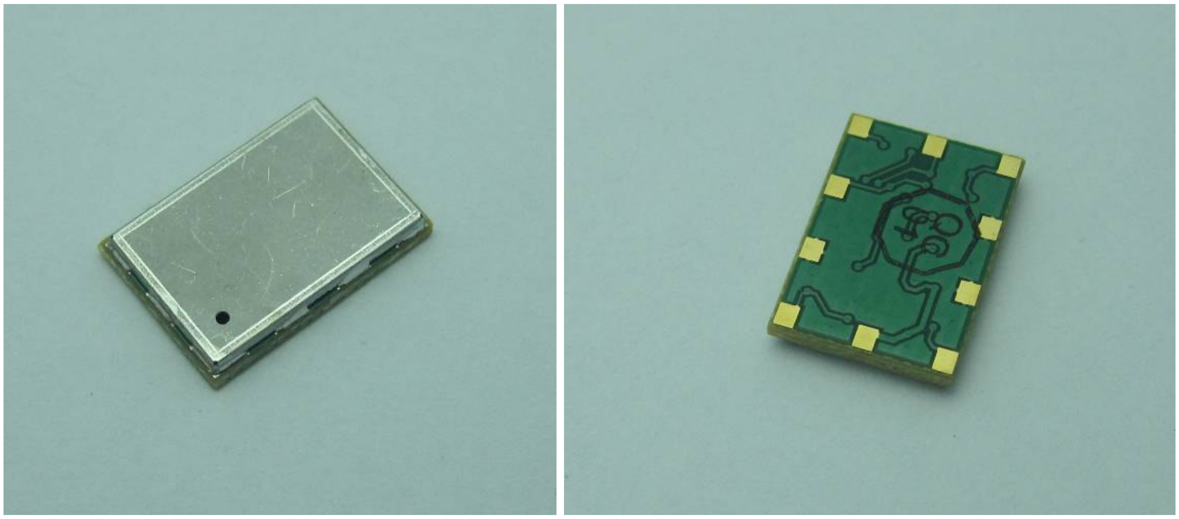


Figure 21. Photograph of FASTROAD ATM

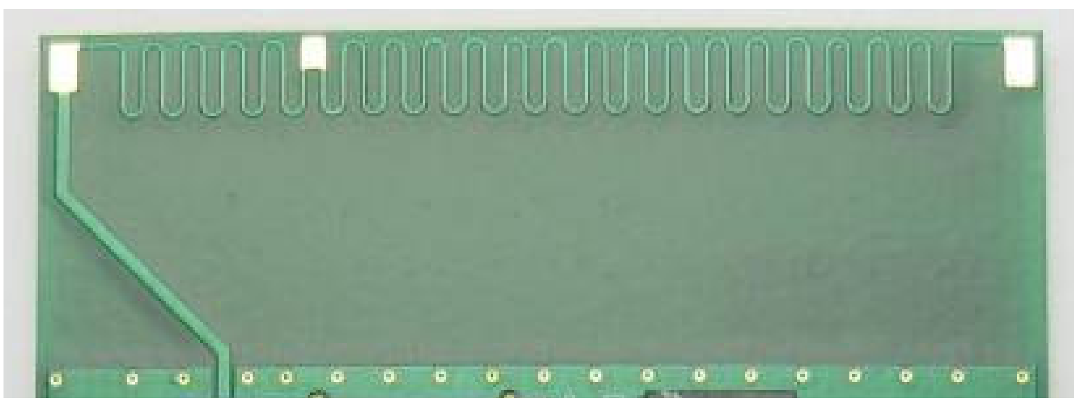
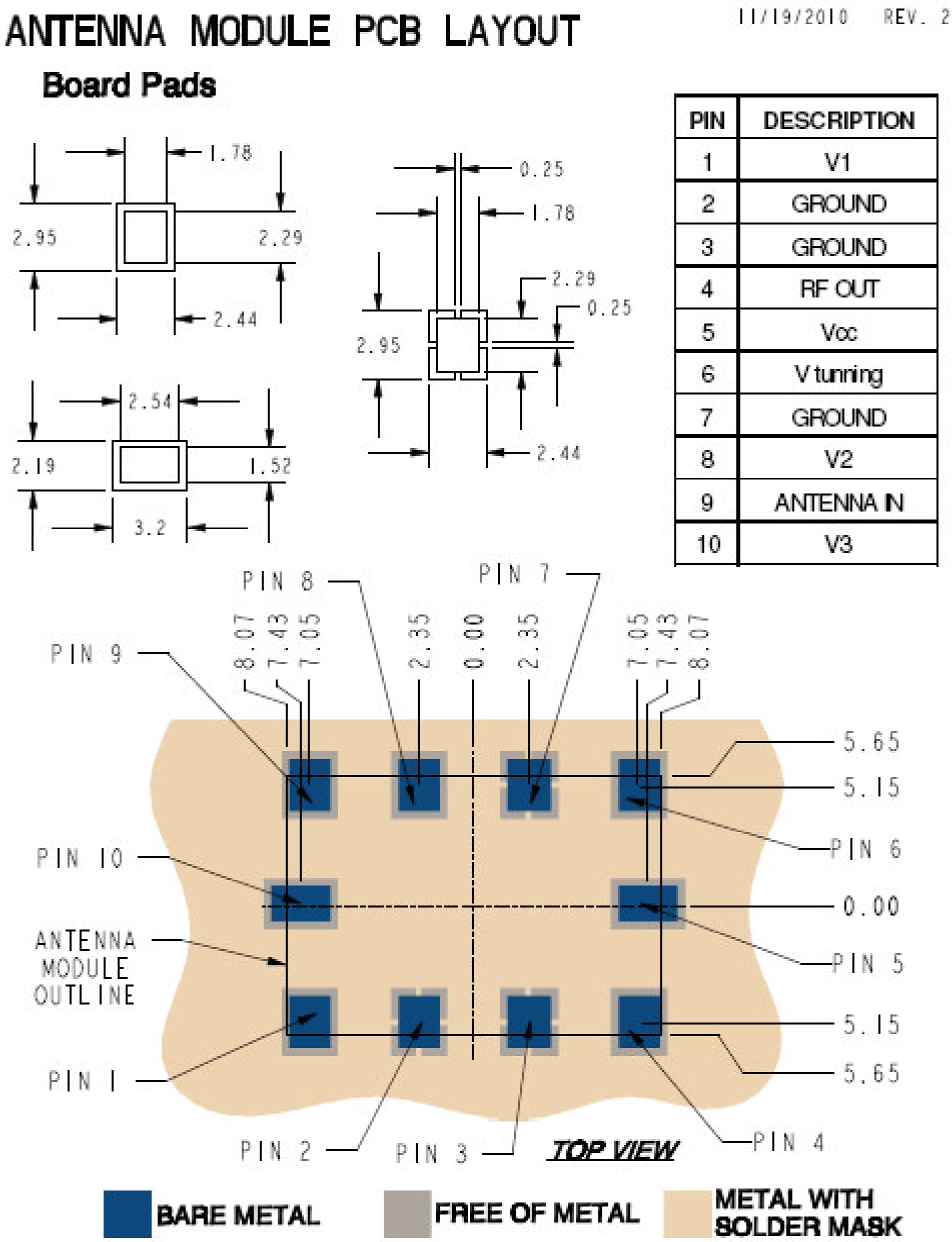


Figure 22. Photograph of FASTROAD antenna element




| PIN | DESCRIPTION |
|---|---|
| 1 | V1 |
| 2 | GROUND |
| 3 | GROUND |
| 4 | RF OUT |
| 5 | Vcc |
| 6 | V tunning |
| 7 | GROUND |
| 8 | V2 |
| 9 | ANTENNA IN |
| 10 | V3 |

Figure 23. PCB pad layout for FASTROAD ATM

# 9 CONTROL SIGNALS FOR FASTROAD ANTENNA OPERATION

Ten (10) pads etched onto the bottom side of the FASTROAD ATM provides a method of connecting the ATM to the circuit board of the host device and provide connections for supply and control voltages, as well as antenna connection and RF connection to the receiver chipset. The function of the ten (10) pads is listed in Figure 23.

When integrated into a production mobile device the FASTROAD antenna can be controlled via a look-up table residing in the firmware of the processor used to control the mobile DTV receiver chipset. A sample look-up table is shown in Table 3. $V_{cc}$, V1, V2, and V3 control signals remain as shown in this look-up table for all mobile devices. Tuning voltage $V_t$ is optimized for a specific mobile device and antenna element design.

| Band | Channel | Frequency (MHz) | DC Voltage Levels (volts) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Vcc | V1 | V2 | V3 | Vt |
| VHF1 | 2 | 57 | 3 | 3 | 0 | 0 | 0.10 |
| | 3 | 63 | 3 | 3 | 0 | 0 | 0.41 |
| | 4 | 69 | 3 | 3 | 0 | 0 | 0.72 |
| | 5 | 79 | 3 | 3 | 0 | 0 | 1.03 |
| | 6 | 85 | 3 | 3 | 0 | 0 | 1.34 |
| | | | | | | | |
| FM Radio | | 88 | 3 | 3 | 0 | 0 | 1.50 |
| | | 90 | 3 | 3 | 0 | 0 | 1.61 |
| | | 93 | 3 | 3 | 0 | 0 | 1.76 |
| | | 96 | 3 | 3 | 0 | 0 | 1.92 |
| | | 100 | 3 | 3 | 0 | 0 | 2.13 |
| | | 104 | 3 | 3 | 0 | 0 | 2.34 |
| | | 108 | 3 | 3 | 0 | 0 | 2.55 |
| | | | | | | | |
| VHF2 | 7 | 177 | 3 | 0 | 3 | 0 | 0.10 |
| | 8 | 183 | 3 | 0 | 3 | 0 | 0.53 |
| | 9 | 189 | 3 | 0 | 3 | 0 | 0.96 |
| | 10 | 195 | 3 | 0 | 3 | 0 | 1.40 |
| | 11 | 201 | 3 | 0 | 3 | 0 | 1.83 |
| | 12 | 207 | 3 | 0 | 3 | 0 | 2.26 |
| | 13 | 213 | 3 | 0 | 3 | 0 | 2.70 |
| | | | | | | | |
| UHF | 15 | 479 | 3 | 0 | 0 | 3 | 0.00 |
| | 16 | 485 | 3 | 0 | 0 | 3 | 0.00 |
| | 17 | 491 | 3 | 0 | 0 | 3 | 0.00 |
| | etc | | 3 | 0 | 0 | 3 | 0.00 |

Table 3. Sample look-up table for control of the FASTROAD ATM

## 10 RECEIVER SENSITIVITY MEASUREMENTS

The FASTROAD "Embedded FM/TV Antenna System Project" has resulted in the design of a tunable, active antenna that utilizes a single antenna element. The antenna gain performance across the frequency bands of interest has been measured and reported in Sections 6 and 7 of this Report. The most important parameter for an active receive antenna is sensitivity. The sensitivity of the active antenna solution can only be measured when the antenna is integrated into the mobile wireless device along with the receiver. This main parameter will vary from one mobile wireless device to the next and will be dependent on parameters such as internal noise characteristics of the mobile device. The FASTROAD antenna has been designed to reduce the effects of internal system noise by providing a bandwidth limited antenna response and by designing an antenna element that is more immune to near field signals.

To complete the characterization of the FASTROAD antenna, two commercially available ATSC mobile TVs were procured, with one TV modified by installing the FASTROAD ATM and the other TV un-modified and used as a baseline TV. The ATSC mobile TVs used for sensitivity testing have a 7 inch color display and use an external 10.5 inch whip antenna to receive the TV signals. The external whip retracts into a 2.5 inch long plastic paddle which folds into the body of the mobile TV when placed in the stowed position. A simple coil antenna was fabricated that fit within the plastic paddle for use with the FASTROAD ATM installed in the mobile TV. The coil antenna is shown in Figure 28along with the rotating mechanism that is used to attach to the circuit board of the mobile TV. The paddle was placed in the stowed position to approximate an internal antenna. Figure 24 shows the mobile TV circuit board prior to installing the FASTROAD ATM. Figure 25 shows the FASTROAD ATM installed on the mobile TV circuit board. The ATM is placed upside down to allow for access to the control and ground pads. The black coaxial cable shown in Figure 25 was installed to connect the output of the ATM to the ATSC receiver.

Figure 26 shows the transmit antenna used to transmit the ATSC channel during test. A DTA-115 transmitter manufactured by Dektec was used to generate the ATSC test signal and is shown in Figure 27. The DTA-115 is a circuit card that is installed in a computer. The DTA-115 generates test signals at all ATSC channels, covering the VHF1, VHF2, and UHF frequency bands. Figure 29 is a screen shot of the program used to control ATSC transmitter. Figure 30 is a photograph of the baseline mobile TV installed in the anechoic chamber, while Figure 31 shows the mobile TV modified to include the FASTROAD ATM and antenna element.

The sensitivity test consisted of placing the baseline TV in a shielded anechoic chamber to isolate the TV from external signals. The transmit antenna was positioned at one end of the chamber and the Dektec ATSC transmitter was connected to the transmit antenna. With the TV under test and the Dektec transmitter both set to the first test channel, the transmit power of the Dektec transmitter was reduced in 0.5 dB steps until the picture quality of the received test signal started to degrade. A camera system installed in the anechoic chamber allowed for the viewing of the test video on the TV under test. The transmit power level was documented and the test then repeated using the mobile TV modified with the FASTROAD ATM and antenna element. The transmit power levels for the baseline and modified TVs were compared and the difference in dBs were calculated. This difference in transmit power level is the difference in receiver sensitivity for the two mobile TVs. The baseline TV was tested with the external whip extended as shown in Figure 32. The TV modified with the FASTROAD ATM was tested with the plastic paddle containing the antenna element stowed as shown in Figure 33.

Figure 34, Figure 35, and Figure 36 show plots comparing receiver sensitivity between FASTROAD antenna and external whip. The plots show the difference in receiver sensitivity in dB between the FASTROAD ATM and coil antenna installed in the paddle of the TV in the stowed position, simulating an internal antenna, and the external 10.5 inch whip. As can be seen in the plots the receiver sensitivity with the FASTROAD antenna is within 4.5 dB of the receiver sensitivity of the 10.5 inch external whip. The FASTROAD antenna provides improvement in receiver sensitivity of 1.5 dB at the upper channels of all three frequency bands. This initial integration and test of an internal ATSC antenna is not optimized, since an internal antenna was not considered during product design. This initial integration and test does show the potential for quality TV reception at the low frequencies associated with ATSC applications. It is also important to keep in mind that smaller mobile devices envision for use with ATSC will include smart-phones, which may be limited to a shorter external whip, which will reduce receiver sensitivity.

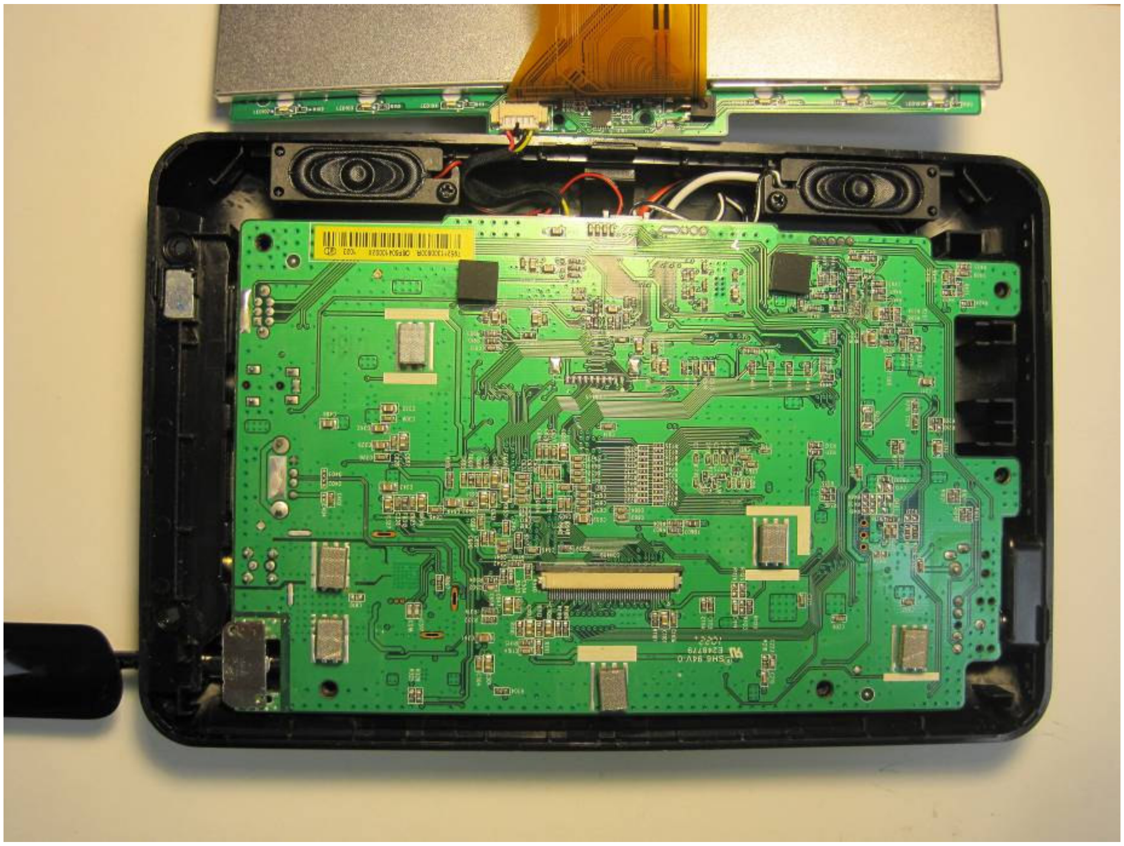


Figure 24. Mobile TV circuit board prior to modification

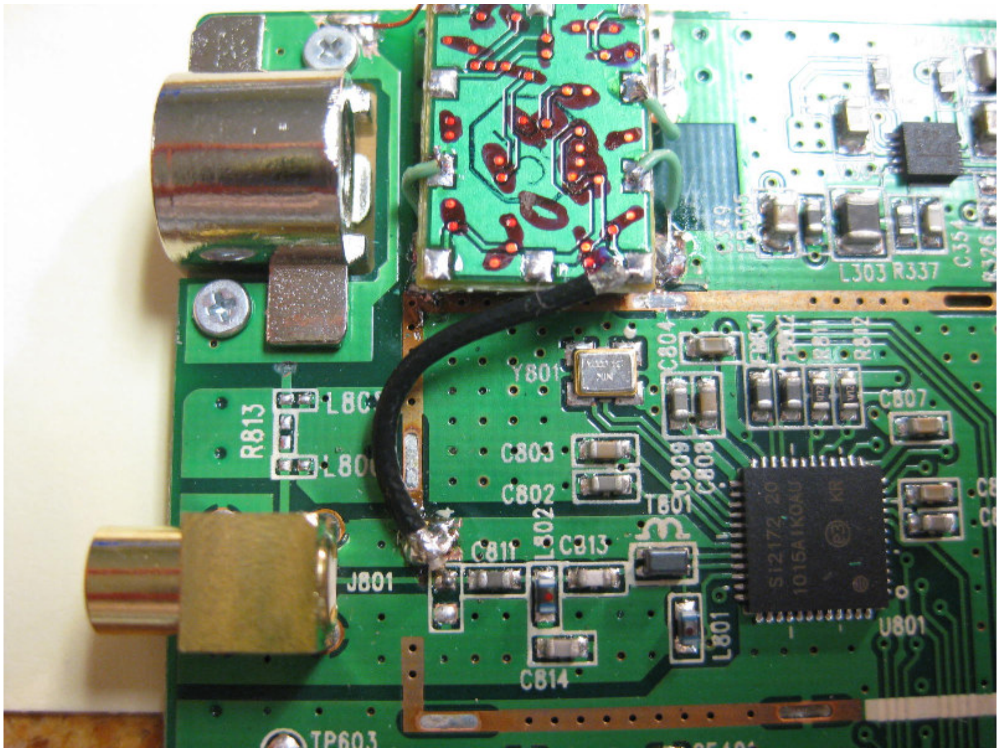



Figure 25. FASTROAD ATM installed in TV

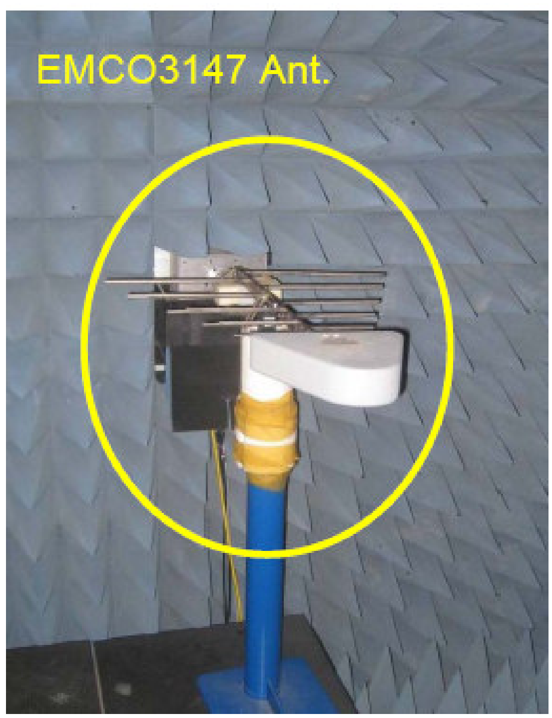



Figure 26.  Transmit antenna

Figure 27.  ATSC transmitter installed in computer

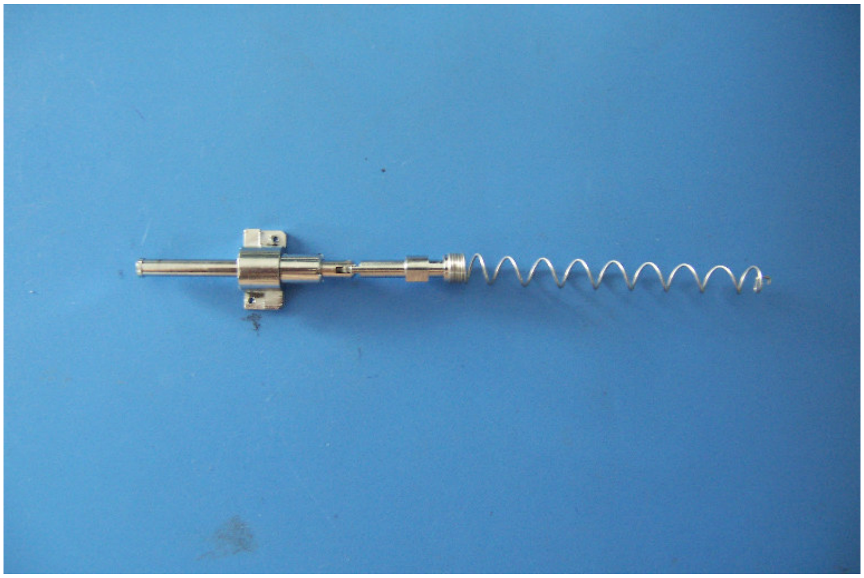


Figure 28.  Data sheet for Dektec DTA-115 ATSC transmitter

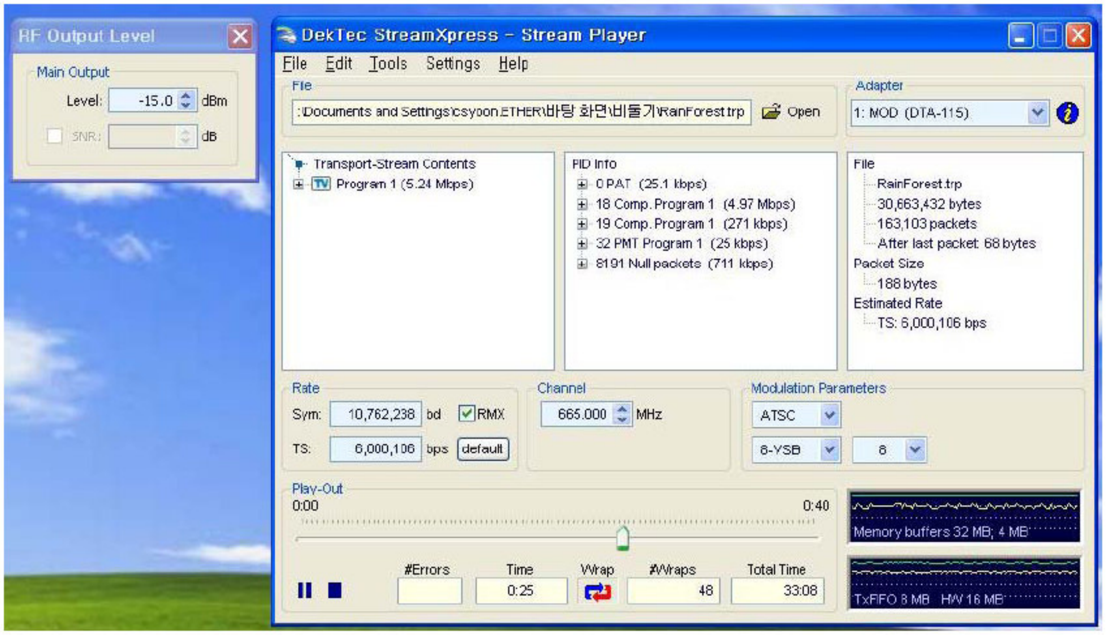



Figure 29. Screen shot of program used to control ATSC transmitter

Figure 30. Baseline mobile TV in anechoic Chamber during test

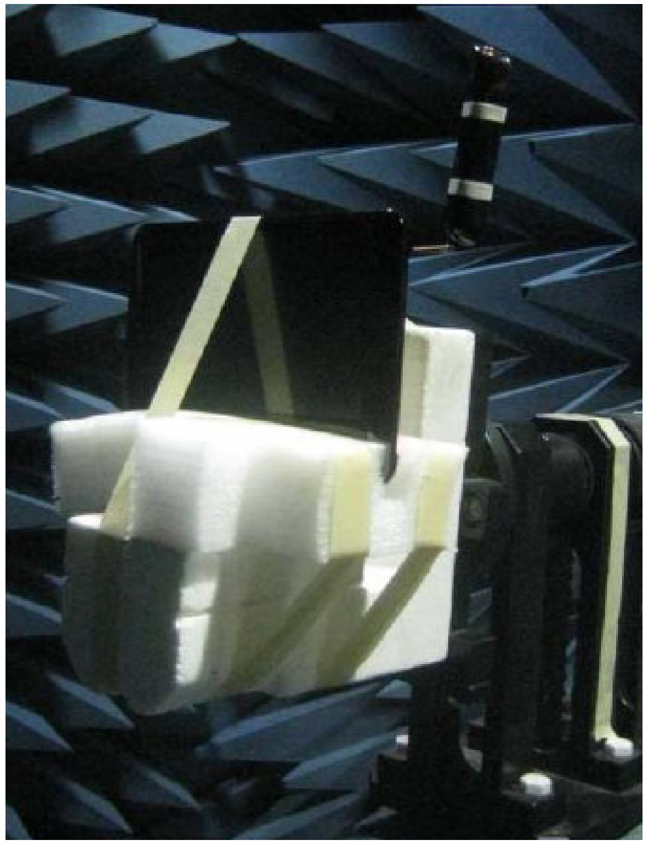


Figure 31. Modified mobile TV in anechoic chamber during test

Figure 32.  Baseline whip position

Figure 33.  Modified TV with paddle stowed

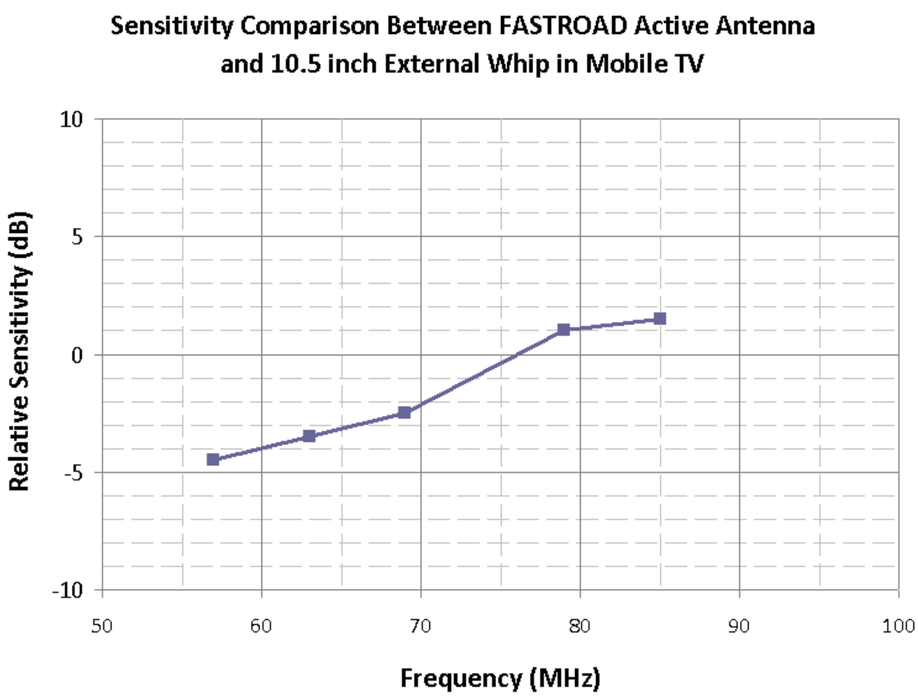



Figure 34. Measured comparison receiver sensitivity at VHF1

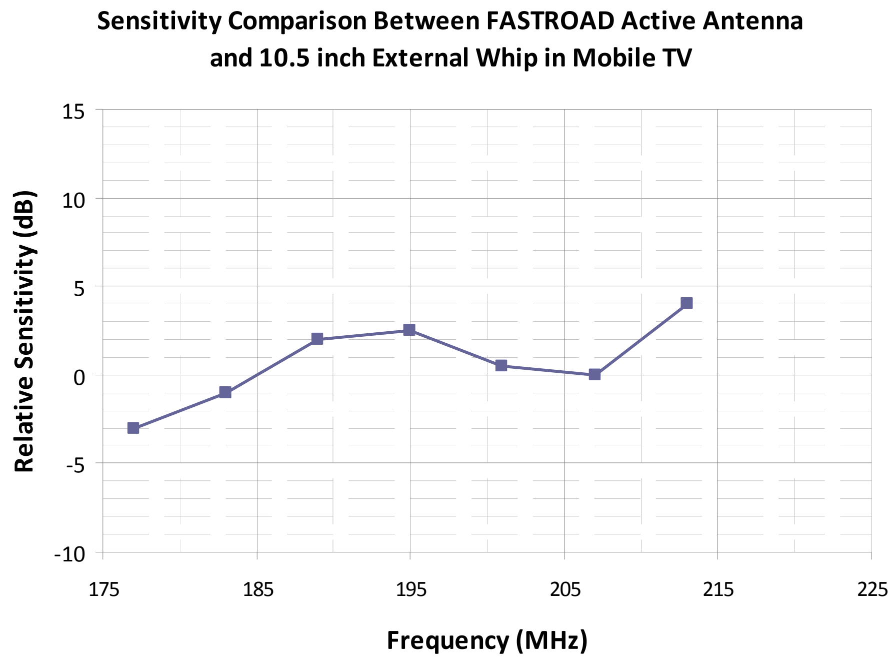



Figure 35. Measured comparison receiver sensitivity at VHF2

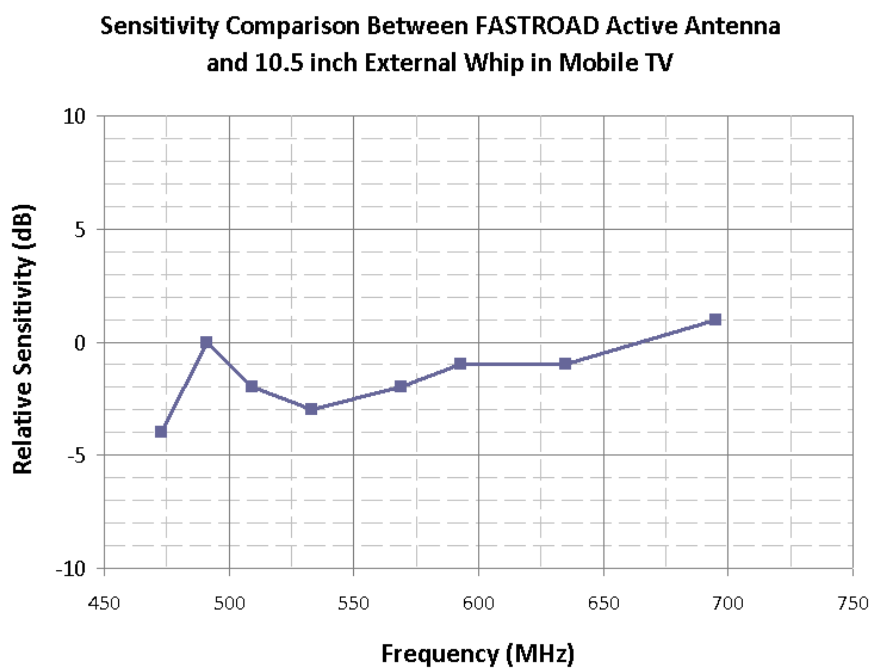



Figure 36. Measured comparison receiver sensitivity at UHF

# 11 TYPICAL PROJECT PLAN AND TARGET COST

Due to the wide frequency bandwidth required for this low frequency requirement, a customized antenna element will typically needed when integrating the FASTROAD antenna solution into a mobile device. A sample project plan for designing in the FASTROAD antenna into a production device is as follows:

**FASTROAD Antenna Design In and Test**

1. Review mobile device 3D CAD drawing package to determine optimal antenna location. Work with project engineering to determine acceptable locations for FASTROAD ATM and antenna element.
2. Select best antenna location available. This location will have volume available for the antenna element, PCB area close to antenna element feed point for ATM placement, and PCB routing area for control, supply, and RF transmission lines.
3. Wireless device PCB is designed with the layout required to accept the FASTROAD ATM. The antenna element is designed into the PCB or volume for a 3-dimensional coil element is allocated and features are designed into the mobile device to captivate and support the antenna element.
4. Prototype mobile device is fabricated and the FASTROAD ATM is soldered to the PCB.
5. Testing is conducted to verify proper supply voltage and control signals are available at ATM pads.
6. Receiver sensitivity measurements are conducted in a shielded enclosure to determine that the FASTROAD antenna has adequate sensitivity. The sensitivity criteria will typically be a comparison with an external whip antenna.

**FASTROAD Antenna Target Cost**

The FASTROAD antenna was developed to be a cost effective, internal antenna solution for ATSC and FM radio applications in mobile devices. The ATM (Antenna Tuning Module) is a standard active module that can be mass produced and used in a wide variety of mobile wireless devices. Component type, along with module construction was chosen with cost in mind.

A cost estimate for volume manufacturing of the FASTROAD ATM in quantities of 200K or higher is $1.85. A breakdown is shown below.

| **Line Item** | **Notes** | **Cost ($)** |
|---|---|---|
| Components | LNA, switches, varactors, passives | 1.20 |
| PCB and shield can | Part cost | 0.35 |
| Assembly | SMT mounting of components and shield can | 0.20 |
| Test | Electrical test | 0.10 |
| **Total cost** | | **1.85** |

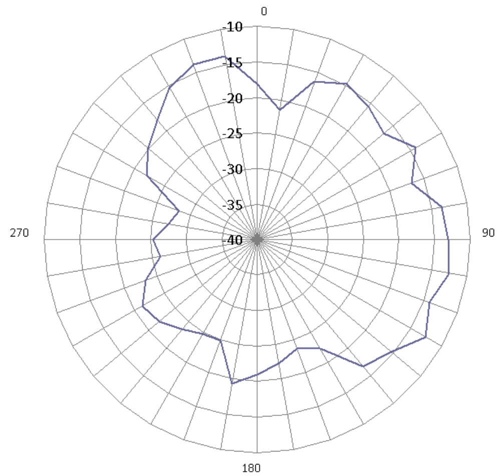
Table 2. Cost estimate for FASTROAD ATM

The antenna element used in conjunction with the FASTROAD ATM can vary in cost from $0.00 (simple trace etched on PCB of host device) to approximately $0.40 for a 3 dimensional coil fabricated out of wire.

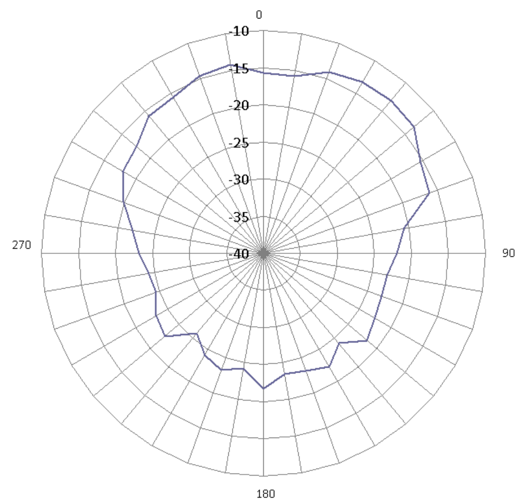
## 12 SUMMARY

The FASTROAD active tunable antenna has been prototyped and tested and the results show that the antenna is capable of providing good antenna gain performance across the three designated frequency bands. The technique of using a single common antenna element and driving it with multiple tuning circuits and a common LNA has proven to be a viable solution for an internal antenna for mobile FM and DTV applications. The antenna form factor is small enough to be integrated into a wide variety of mobile devices.

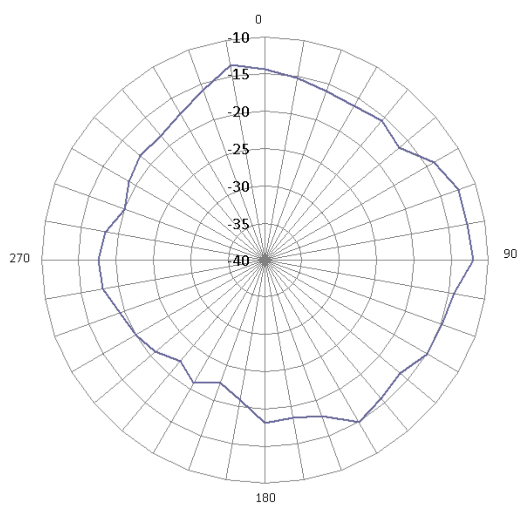
## 13 APPENDIX A




**XY**

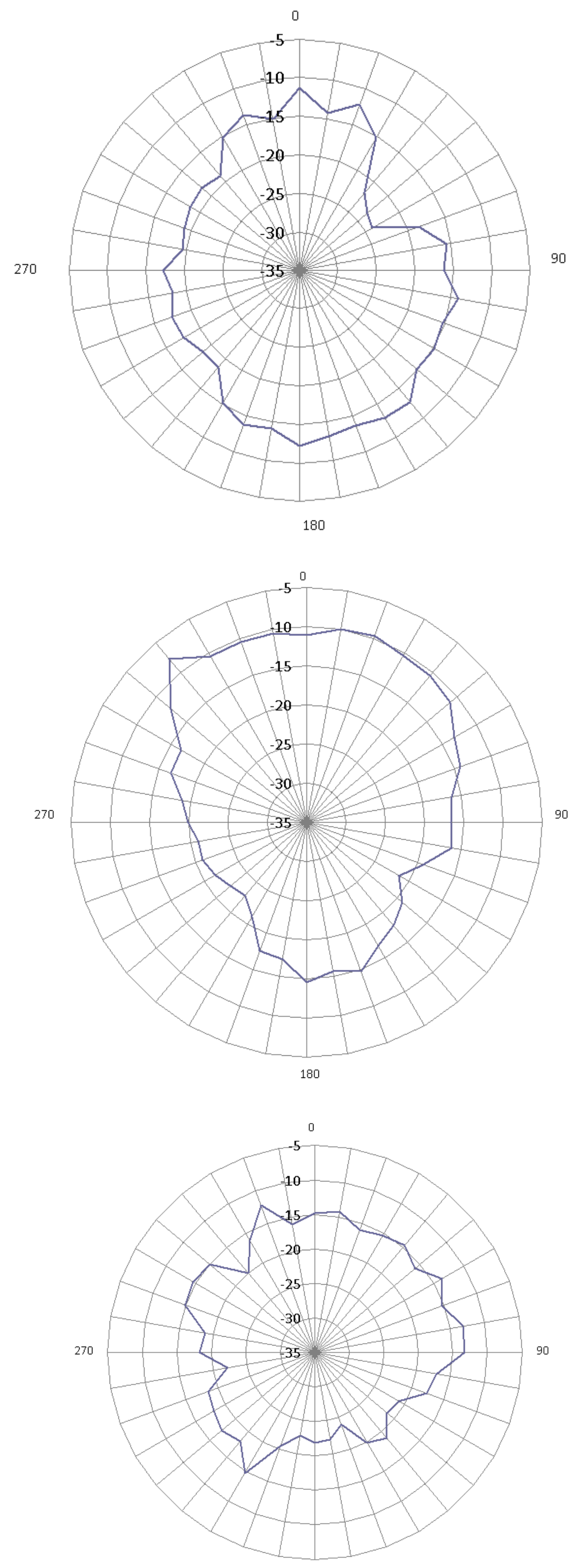



**XZ**




**YZ**

Figure 37. 2D radiation patterns at 89 MHz; scale is in dBi




XY

XZ

YZ

Figure 38. 2D radiation patterns at 96 MHz; scale is in dBi

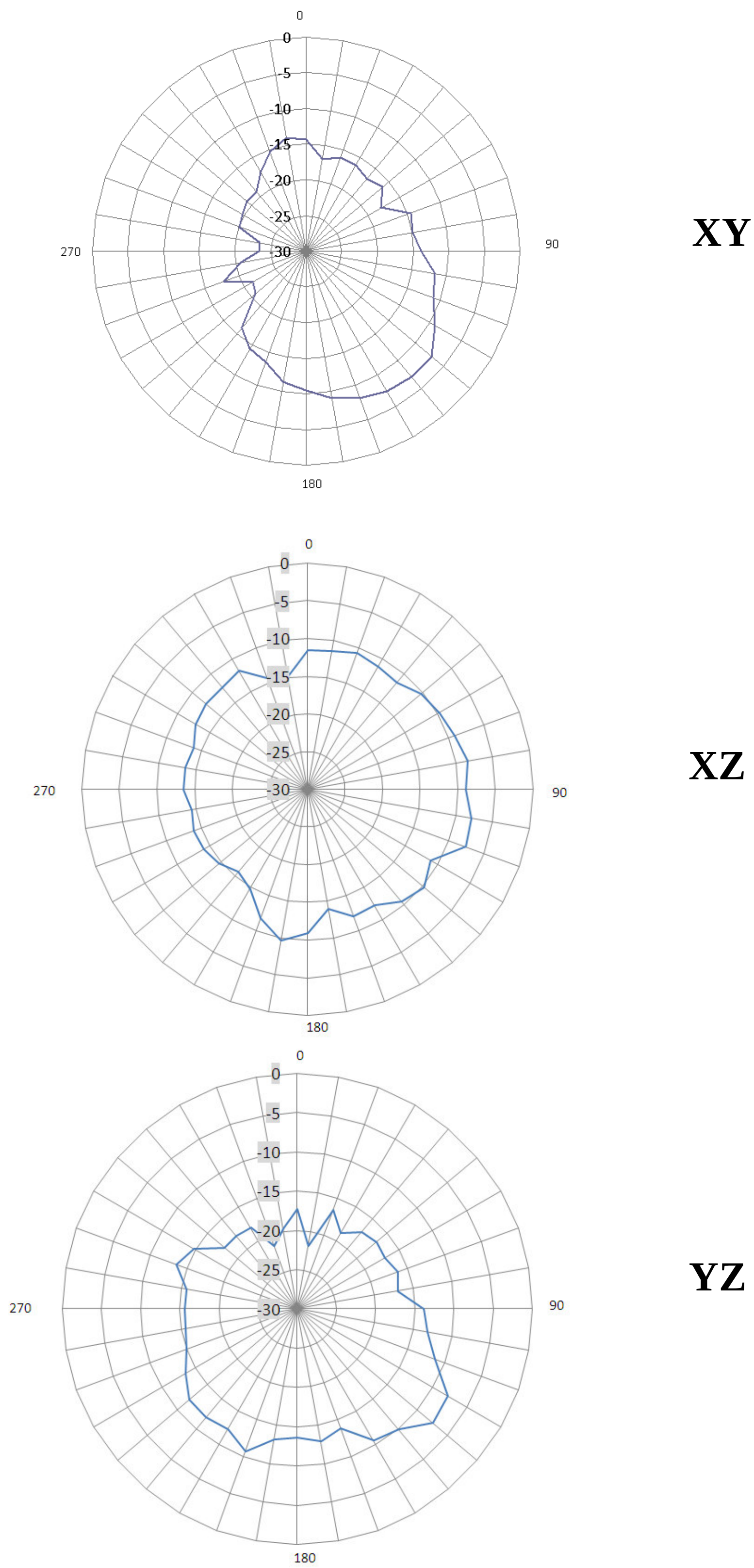



Figure 39. 2D radiation patterns at 105 MHz; scale is in dBi

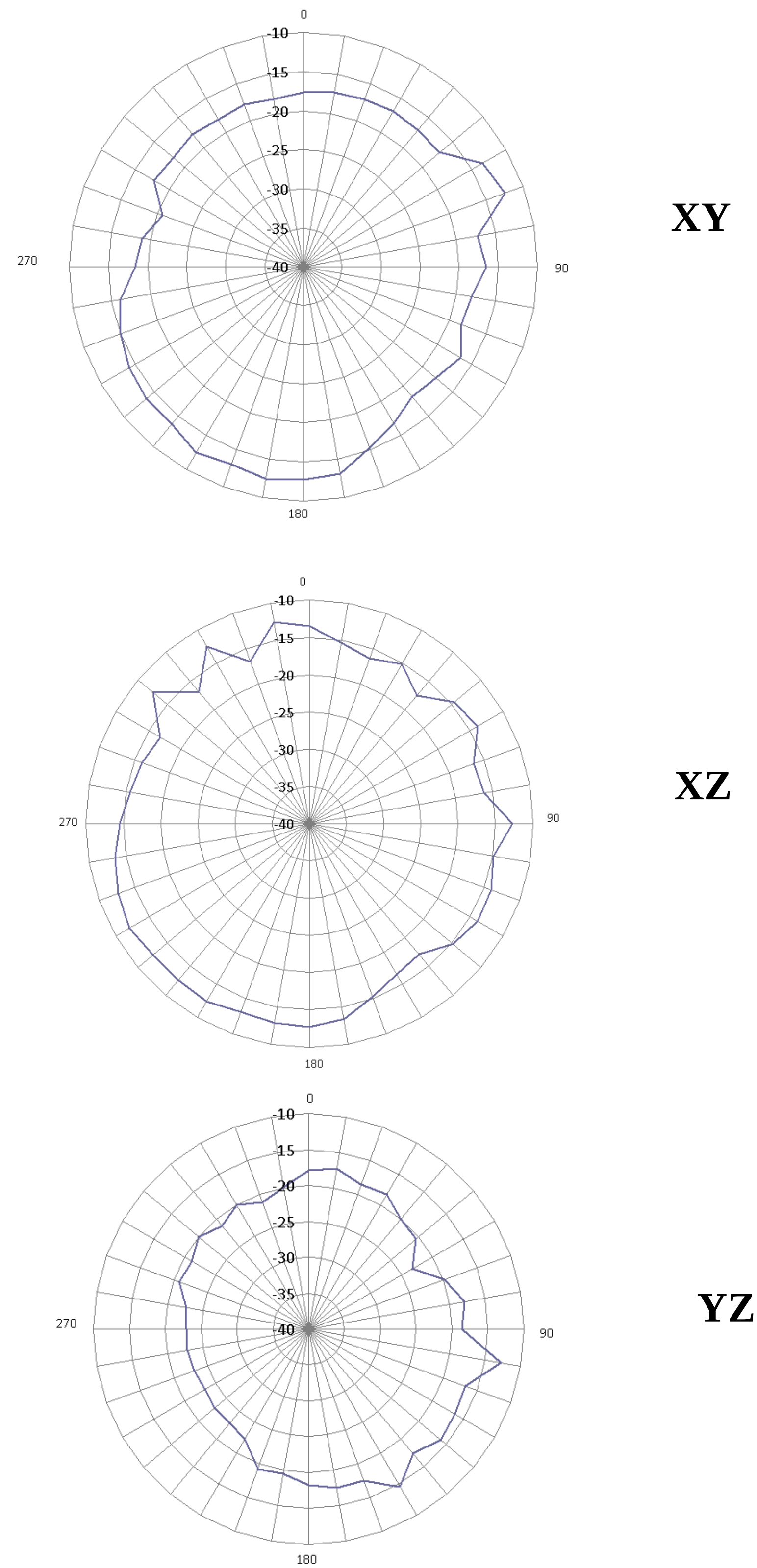
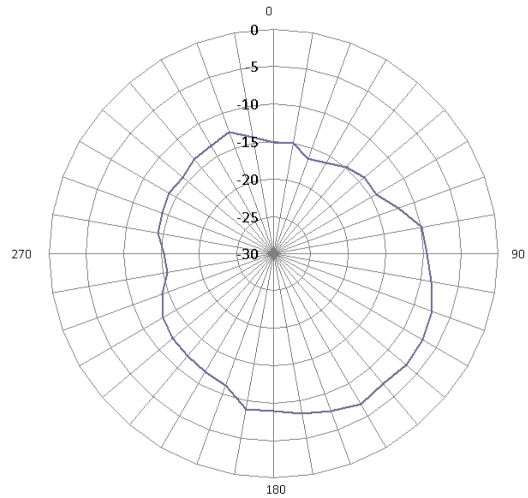
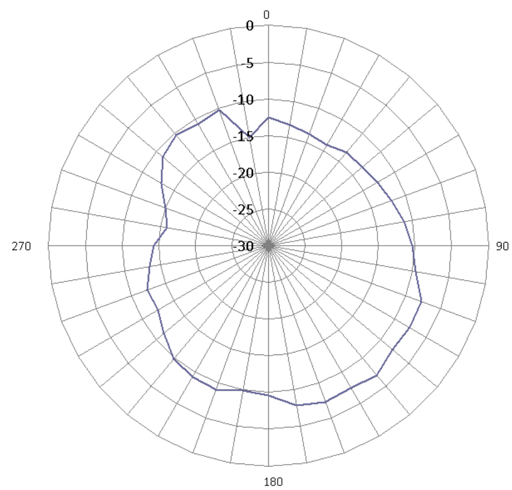


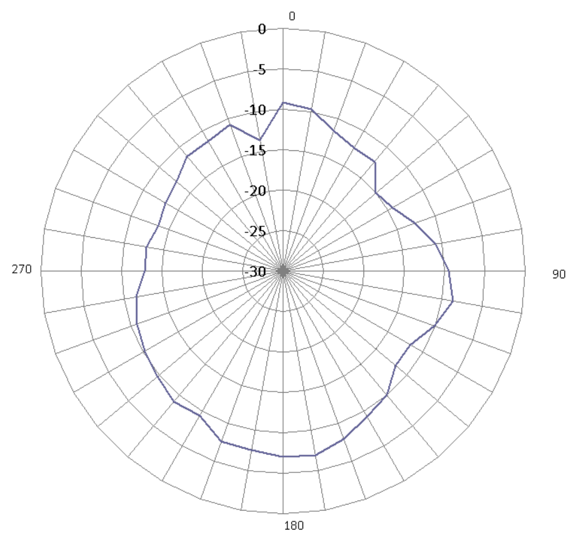

Figure 40. 2D radiation patterns at 175 MHz; scale is in dBi




**XY**

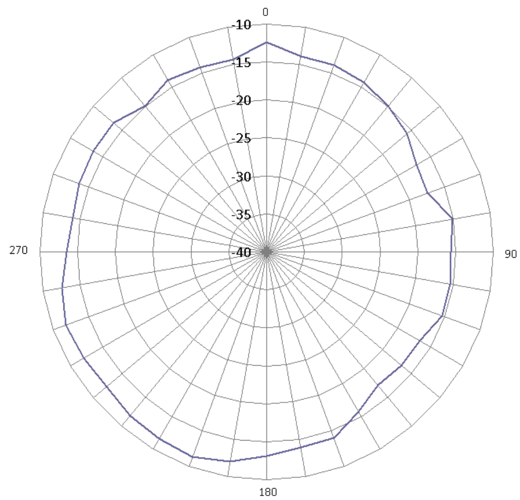



**XZ**

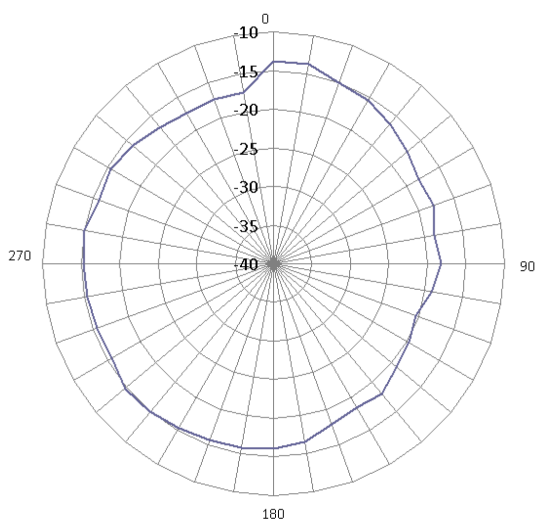



**YZ**

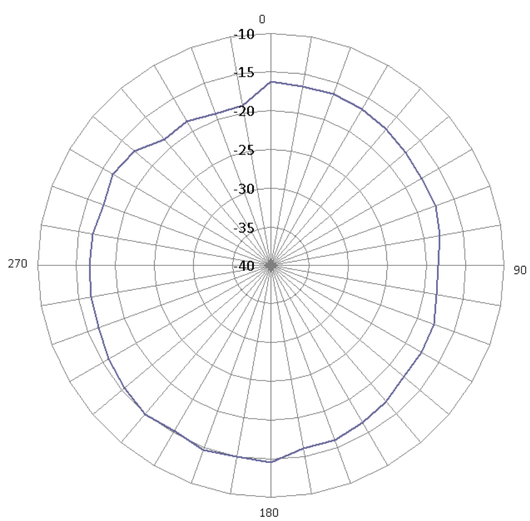
Figure 41. 2D radiation patterns at 183 MHz; scale is in dBi




**XY**




**XZ**




**YZ**

Figure 42. 2D radiation patterns at 196 MHz; scale is in dBi

# 14 APPENDIX B

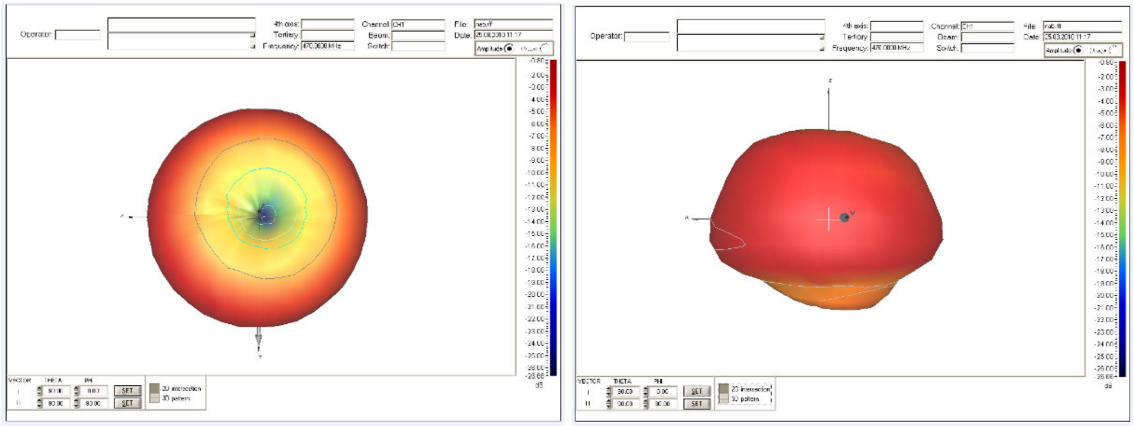


Figure 43. 3D radiation pattern at 470 MHz

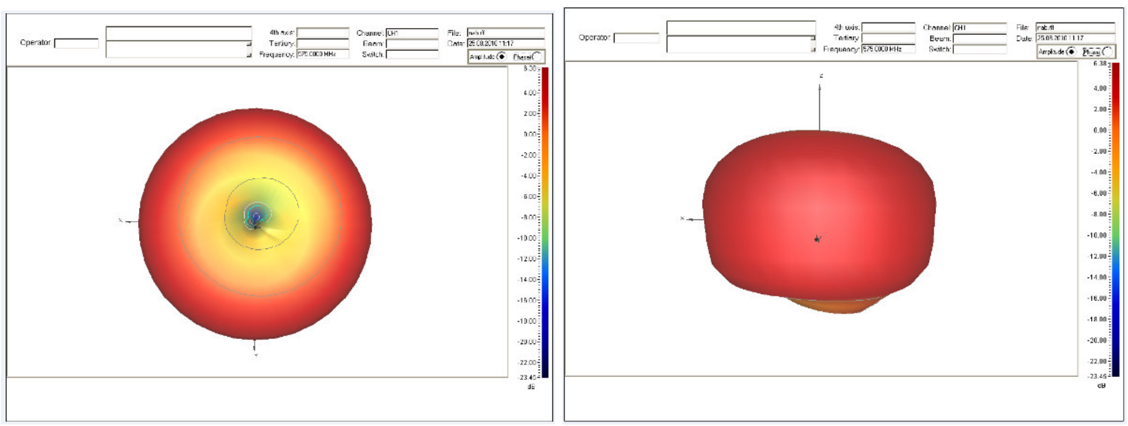


Figure 44. 3D radiation pattern at 585 MHz

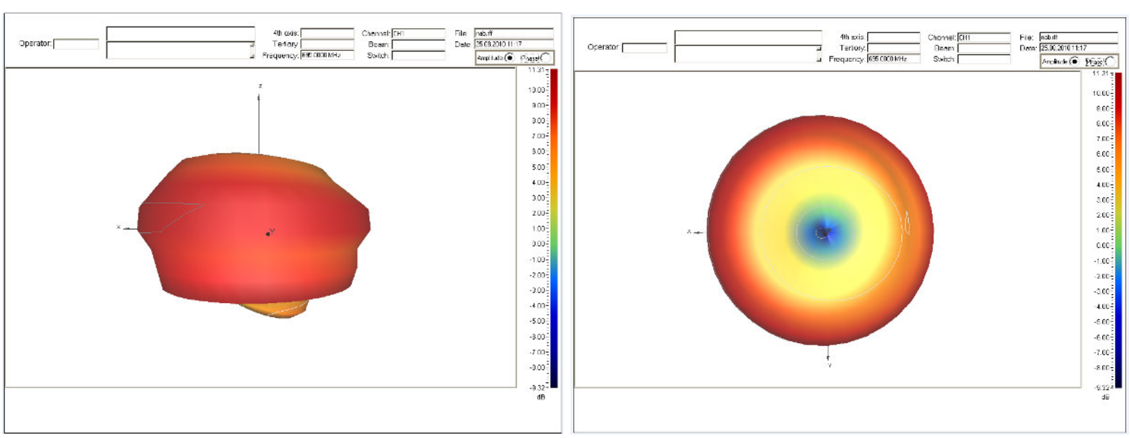


Figure 45. 3D radiation pattern at 695 MHz

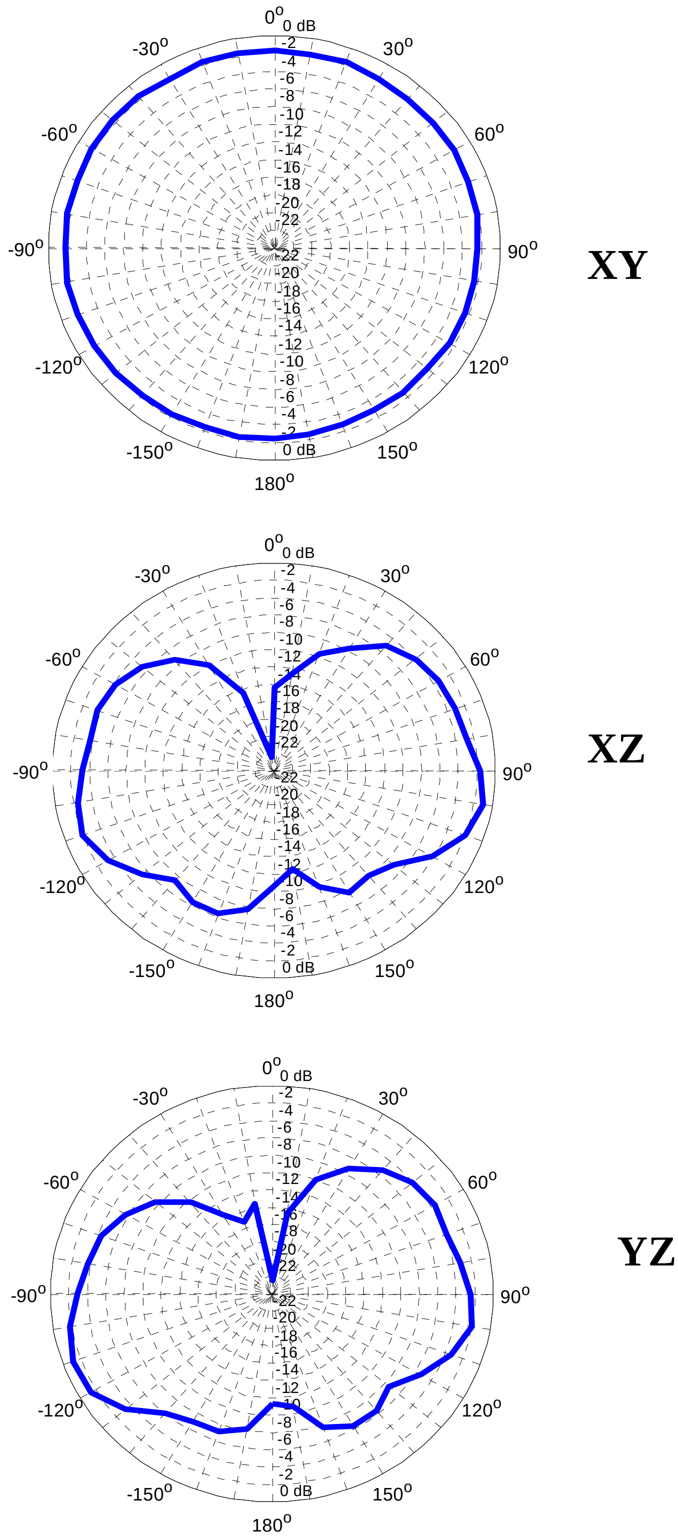



Figure 46. 2D radiation patterns at 470 MHz; scale is in dBi

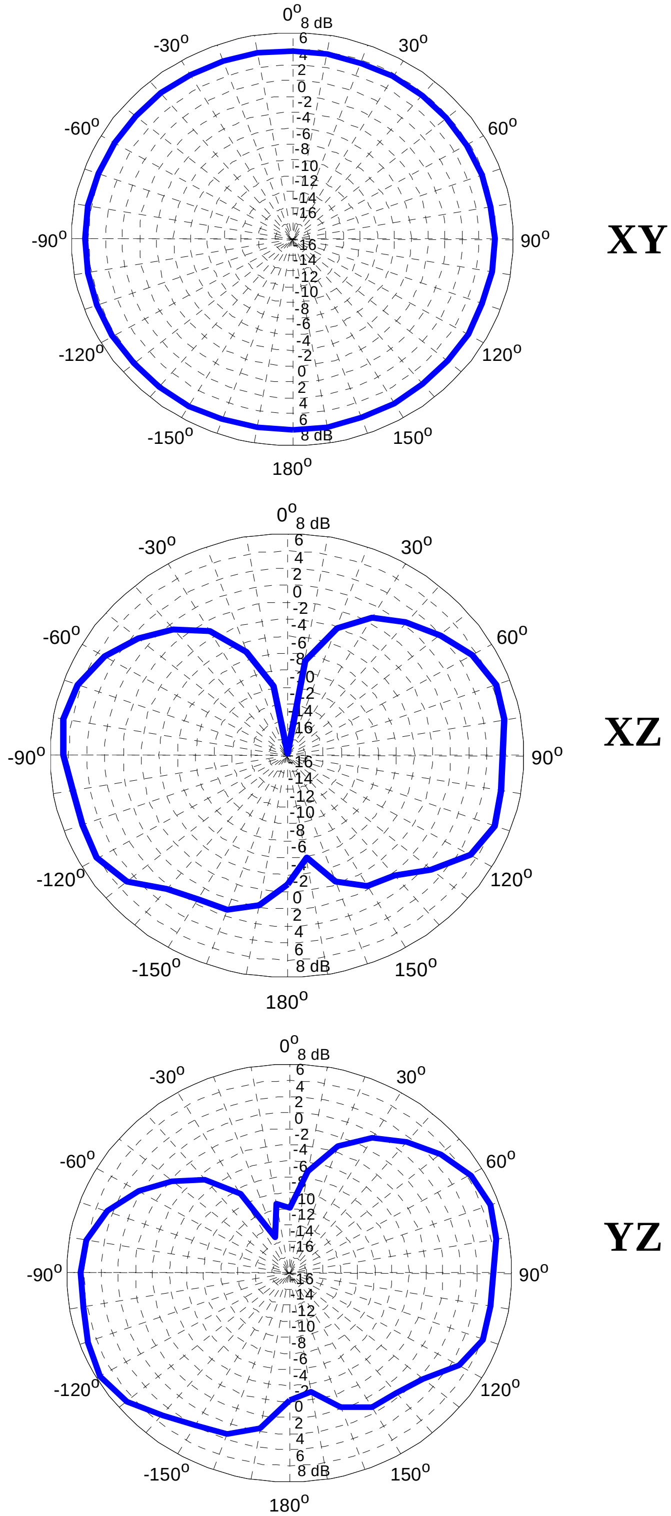



Figure 47. 2D radiation patterns at 585 MHz; scale is in dBi

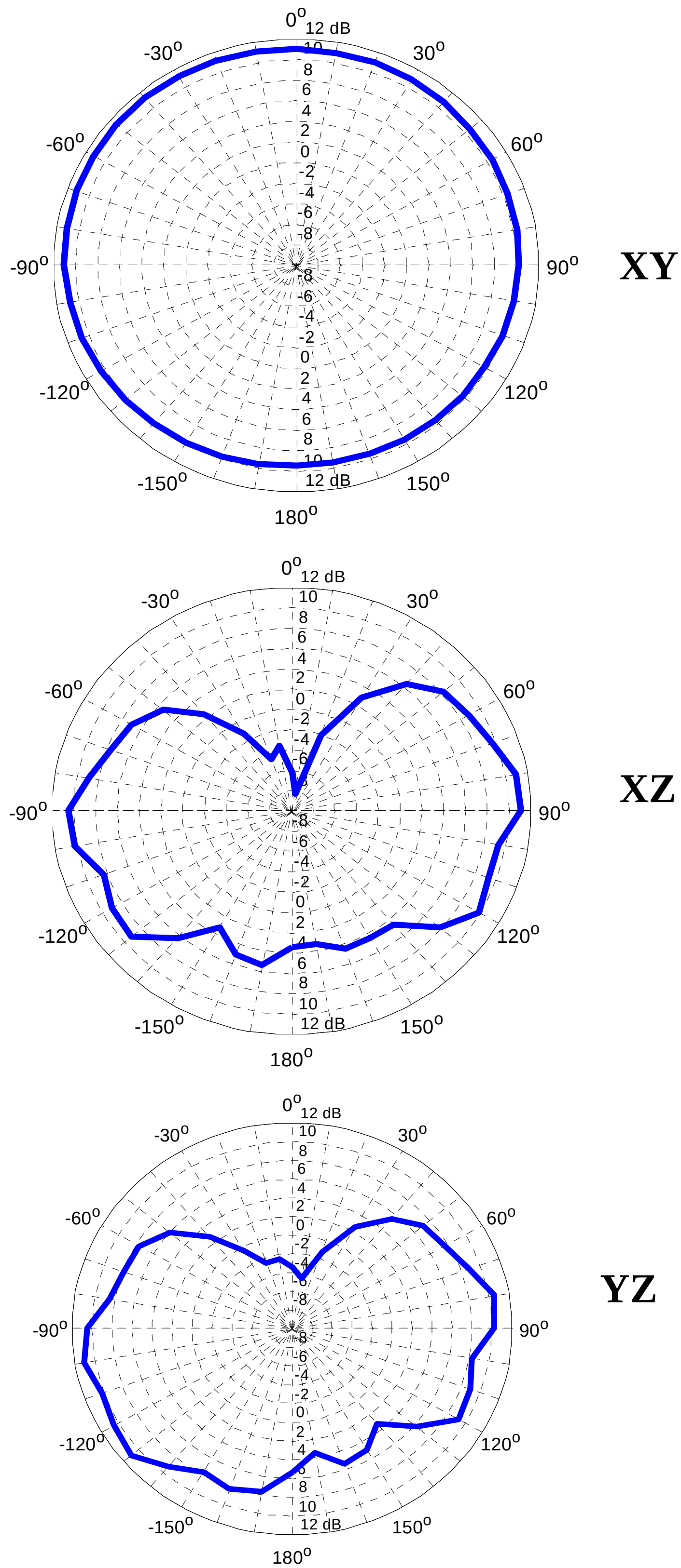



Figure 48. 2D radiation patterns at 695 MHz; scale is in dBi