6100-C Frost Place • Laurel, MD 20707 • (240) 456-4100 • Fax: (240) 456-0655

Antenna Solutions for 2.4 GHz Bluetooth™ and 802.11b/g Wireless Applications: ClearLink 2400

Who Should Read This Application Note?

This application note is for designers, developers and manufacturers of mobile and wireless products. More specifically, it is intended for Bluetooth™ and Wi-Fi module manufacturers and designers who are in need of antenna solutions for end products such as cellular phones, PDAs and laptops. Whether your focus is on 802.11 or Bluetooth protocols, the enclosed data will provide a 2.4 GHz antenna solution that addresses size, performance and cost targets of wireless devices (see Appendices for additional data).

Features & Benefits

- Small form factor (10 x 14 x 2.4 mm)
- Ability to be mounted directly over board components thus saving board space; components can sit beneath the antenna
- High-volume production design using light-weight molded plastics
- Assembled using standard surface mount technology (SMT) processes (no cables or connectors required)
- Insensitive to groundplane size, adjacent components, proximity of users, loading effects of plastic housings, and temperature and humidity changes
- Very competitive price point
- Mounts directly to groundplanes
- No external matching components required

Product Overview

This application note describes Etenna's ClearLink 2400 miniature single band (2.4 – 2.5 GHz) antenna product that utilizes Etenna's DC-Inductive (DCL) Frequency Selective Surface (FSS) antenna technology (patent pending). This design stemmed from customer desires to easily surface mount the antenna directly onto a printed circuit board above the conducting layer (groundplane), with high efficiency and low profile. This antenna design is relatively insensitive to its local environment. In other words, the frequency of operation varies little with close proximity to other nearby components such as integrated circuits (IC), passive chips and plastic housing. The antenna design does not use dielectric loading or traditional meander lines to reduce size, thus efficiency is maximized for minimum Q-factor. Further, Etenna's product is specifically designed for repeatable high volume manufacturing (Fig. 1).

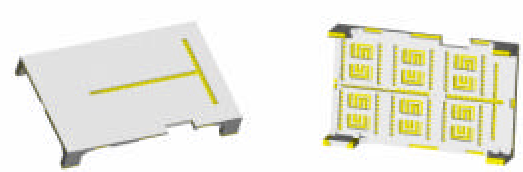


Figure 1. Table-top antenna (TTA) design for high volume production.

In addition to being surface mountable directly on the board, we have found that components such as front-end modules or filters can be directly placed inside the antenna volume. Subsequently, the antenna can be seamlessly integrated into the radio frequency (RF) front end without adversely affecting performance[1]. Our strategy for rapidly developing products in a final form factor that can accommodate all of our customers' requirements is to first provide rapid prototype samples using flex-on-foam (FOF) manufacturing processes (Fig. 2). Here, a patterned flexible circuit is folded over a foam core and held in place by a pressure sensitive adhesive (PSA). The process for making the FOF samples is not suitable for high volume production, but does allow rapid prototyping and accurate in-situ electrical performance evaluation. Once the customer has quantified performance with the FOF samples the appropriate table-top antenna (TTA) model number can be ordered. The evolution of this form factor is shown in Figure 2.

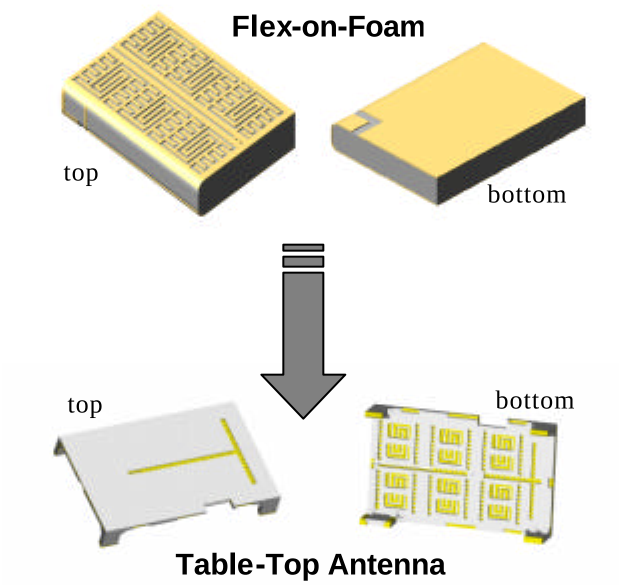


Figure 2. Evolution of FOF to TTA form factor.

The TTA form factor has no foam but uses four plastic legs to support the structure. The legs have metalized contacts, which are positioned on the customer's board for solder reflow connection. This form factor permits the antenna to straddle components on the board as shown in Figure 3.

[1]W. McKinzie, G. Mendolia and J. Dutton, "Novel Packaging Approaches with Miniature Antennas," presented at the 2002 IMAPS/SMTA conference on telecom hardware solutions in Plano, TX.

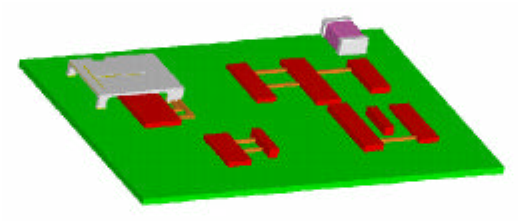


Figure 3. Possible layout illustrating TTA covering components on printed circuit board (PCB).

The TTA units are supplied in tape and reel and do not require any cables, connectors, tuning, matching components or hand assembly. When mounting the antenna on a printed circuit board (PCB), edge or corner locations are best for optimal performance. Detailed drawings and typical performance data are described in the following sections.

The process for selecting the appropriate model number for your unique application is as follows:

1. Mount TTA samples (10 x 14 x 2.4 mm) to location on PCB as required by your design. Be sure to mount all surrounding or underlying components. Use standard SMT assembly with 5 mils thick solder paste on all mounting pads.
2. Measure antenna performance including resonant frequency and bandwidth. It is recommended that components used are no greater than 1.0 mm in height from the PCB ground layer.
3. Etenna will specify TTA model number for production based on measured return loss.

The TTA form factor makes our antennas particularly well suited for applications with densely populated PCBs. The TTA electrical characteristics are ideal for Bluetooth and 802.11b/g products particularly since they are often used in different environments ranging from groundplanes the size of a thumbnail (for products such as wireless hands-free kits) to large groundplanes (for applications such as printers or laptops). Also, the TTA form factor maintains a very low profile for demanding portable Bluetooth devices with severe restriction on total height.

Traditionally, an antenna has always been a separate component, whether it was an internal or external antenna, but Etenna's new class of antennas can ultimately be fabricated as an integral part of the RF module. These antennas provide a new opportunity for an even greater level of RF integration, and antennas of this type can be fabricated with a complete Bluetooth RF multi-chip module (MCM) system embedded inside the antenna. Using new, low-cost engineered materials (patent pending), antennas can be designed to accommodate both passive and active RF components within their form factor without any significant degradation of performance.

Electrical Specifications for FOF & TTA

Electrical Data Summary

Frequency Range	2400–2480 MHz
Peak Gain	+1.0 dBi nominal
3 dB Bandwidth	200 MHz minimum
Voltage Standing Wave Radio	<2.0:1 nominal
Efficiency	50% minimum
Polarization	Linear
Power Handling	2 watt cw
Feed Point Impedance	50 ohms unbalanced
Temperature	-35^{o} C ~ 85^{o} C

Note: Specs are subject to change without notice.

The following data summarizes the 2.4 GHz antenna performance fabricated either using Etenna's FOF rapid prototyping process or the TTA process. A number of environmental and pre-production tests have been completed to characterize any detuning effects. The objective was to predict the variation in resonant frequency due to manufacturing and/or environmental factors.

Worst Case Unit-to-Unit Variation. A sample of 10 FOF antennas were assembled by hand, and measured for return loss and efficiency. These displayed an average resonant frequency of 2.444 MHz with a standard deviation of 14 MHz. Unit-to-unit variation for the TTA is less than 1.0 MHz.

Variation in Antenna Thickness. At a nominal height of 2.5 mm, a slope of 65 MHz per 0.1 mm was observed. A realistic standard deviation of .025 mm in the FOF antenna height implies a standard deviation of 16 MHz in resonant frequency. Less than a 4 MHz deviation is expected for volume production of the TTA.

Variation in Substrate Permittivity. Replacing polyimide (ε_r~3.4) with liquid crystal polymer (LCP) (ε_r~2.9) created a shift of ~16 MHz in the average resonant frequency for the FOF antennas. This variation does not exist for the TTA.

Cover Loading. When a molded plastic cover or housing was placed close to and parallel to the antenna's upper surface, resonant frequency decreased. A total shift of 45 MHz was seen between the cases of no cover versus a cover placed only 0.5 mm above the antenna. Plotting the resonant frequency versus cover height yields a slope of approximately 8 MHz per 0.1 mm variation at a cover height of 0.5 mm above the antenna. Assuming a standard deviation of .25 mm in cover height, this implies a standard deviation of 20 MHz in resonant frequency. Much of this cover loading effect can be compensated for if the distance between antenna and housing is known.

Groundplane Size. Return loss experiments yielded a 3 MHz variation in resonant frequency from the baseline case of 250 mm square groundplane down to as small as 30 mm square.

Installation Location Effects. The actual location on the PCB impacts performance more than groundplane size. Data shown in Appendix A-1 illustrates typical performance for preferred placement of the antenna on our standard 45 mm x 45 mm evaluation board. For each configuration, the data shows return loss and efficiency plotted on the same graph versus frequency. Total gain (dBi) is plotted in color contours versus θ and ϕ (standard spherical coordinates relative to the coordinate system shown in the plot). Principal plane cuts are also shown for total gain as well as θ-polarized and ϕ-polarized patterns. **In general, the corners are the best mounting location, and the feed pad can be either outbound or inbound from the board edge.** Movement of the antenna to the sides of the board, away from the corner, results in a 2 to 3 dB loss in efficiency. Movement to the center of large boards is not recommended.

The effects of placing a surrogate 5 x 5 x 1.3 mm front end module within the antenna volume are illustrated for FOF antennas in Appendix A-2, showing negligible change from the baseline FOF results in Appendix A-1. Similar TTA results are shown in Appendices A-3 and A-4, which also demonstrate the ability of the TTA form factor to straddle components with very little degradation to the electrical performance.

Combined High Temperature and Humidity. The total increase in resonant frequency between the cases of a dry 25° C antenna and a humidity soaked 85° C antenna is at most 12 MHz.

Temperature Cycling. The antenna was subjected to 15 temperature cycles from -34° C to 85° C. The antenna sustained the cycling test and showed only a deviation of 2 MHz in resonant frequency before and after testing.

Mechanical Features. The construction and mechanical features of the FOF antennas are as follows: rectangular FOF frame is constructed with dimensions of 12.6 x 8.9 x 2.25 mm. Syntactic foam is used in order to meet all SMT assembly process requirements. The circuit is fabricated using 1-ounce copper printed on a polyimide substrate material. The flexible substrate is then attached to a PSA and wrapped around the syntactic foam core.

Mechanical Specifications

TTA	
Size	10 x 14 x 2.4 mm
Weight	0.18 g maximum
Mounting Area Required on PCB	140 mm^2
Total Contact Area on PCB	2.0 mm^2
Maximum Height of Components Under Antenna	1.7 mm
Recommended Height of Solder Paste	5 mils
FOF	
Size	9 x 13 x 2.5 mm
Weight	0.100 g
Mounting Area	117 mm^2

Note: Specs are subject to change without notice.

For the TTA antennas, the radiating component is fabricated out of patterned metal, which is then insert-molded into a high temperature plastic carrier. Tight height and coplanarity tolerance can be achieved by the injection molding process. The TTA antenna is a four-leg structure with an overall size of 10 x 14 x 2.4 mm. The maximum height of a component that the TTA can straddle is 1.7 mm. The interface drawings for board mounting of the FOF and TTA form factors are shown in the Appendix. Preferred location on the board for the TTA is shown in Appendix A-5.3. The TTA units are packaged in surface mount tape and reel format according to Electronic Industry Association (EIA) standard 481-2. The width and pitch of the carrier tape is 24 mm x 16 mm. Typical quantity is 1,400 units per 13” reel.

Conclusion

This application note has introduced a robust and mature antenna product of low cost, single-band performance for Bluetooth and 802.11 applications. This 2.4 GHz antenna is electrically small given that its largest dimension is $\lambda/10$. Size reduction is achieved without any dielectric loading, but instead by designing the antenna with built-in inductive and capacitive features to act as a slow wave structure. Such internal loading allows the resonant frequency to be insensitive to proximity effects and to changes in groundplane size and component layout. But most unique is the ability of this class of low profile antennas to be surface mounted directly onto a groundplane. Thus, the board area on the opposite side of the PCB can be used for additional components.

The integration of all RF functionality into a single multi-chip module, including the antenna, is the ultimate reduction in size and cost of an RF subsystem. This also simplifies packaging and assembly, resulting in improved reliability. A single solution that is tolerant to changes in its environment will also reduce design cycles and accelerate time to market—a must for companies competing in wireless consumer electronics markets.

For board mounting and packing specifications for the 2.4 GHz antenna product please email us at info@etenna.com; reference Etenna Application Note APP003-B.

Corporate Profile

Headquartered in Laurel, Md., Etenna Corporation designs and produces antennas for applications ranging from wireless phones to 802.11 and Bluetooth devices. Employing Etenna's proprietary antenna technologies, the company significantly improves the size, performance and cost of wireless devices and equipment. In addition, Etenna makes use of patented Artificial Magnetic Conductor (AMC) technology to enable high antenna performance and isolation in an attractive form factor for wireless products. Backed by a dedicated team of researchers and design engineers, Etenna's intellectual property (IP) portfolio includes more than 25 issued or pending patents. San Diego-based The Titan Corporation (NYSE: TTN) and New York-based Archery Capital are primary investors in the company.

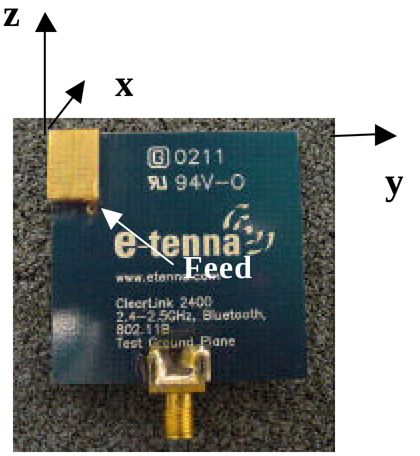
For Further Information

Etenna Corporation
6100-C Frost Place
Laurel, MD 20707
Tel: (240) 456-4100
Fax: (240) 456-0655
www.etenna.com

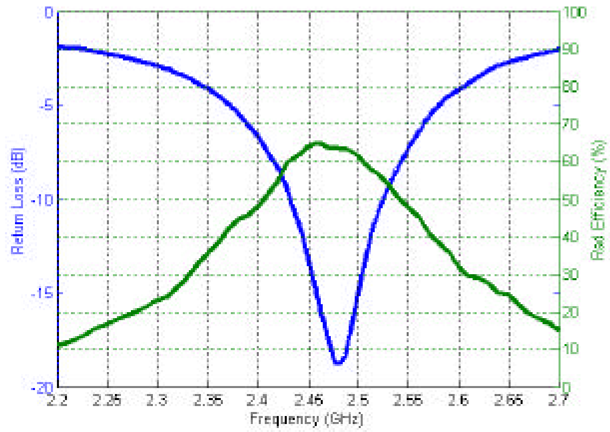
Appendix A-1

FOF, top left corner, 2450 MHz

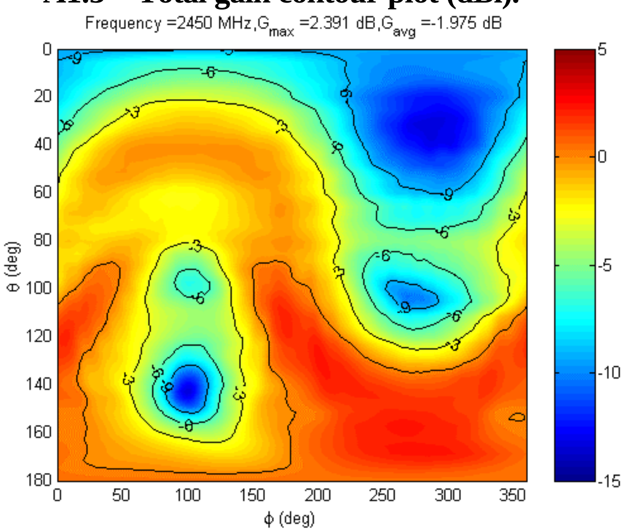
A1.1 - Test board.



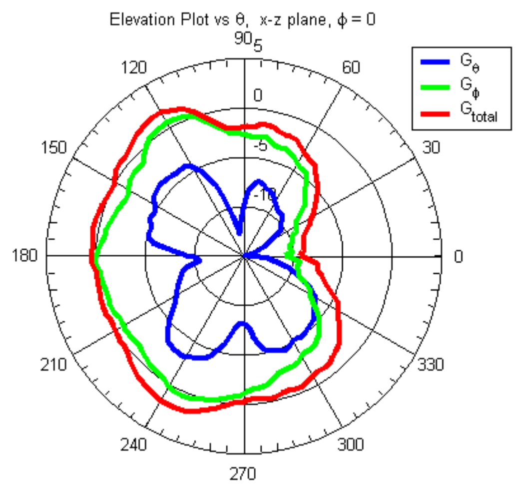
A1.2 – Efficiency and return loss.



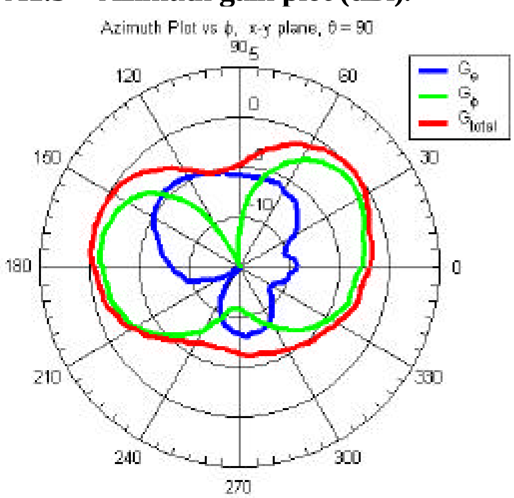
A1.3 – Total gain contour plot (dBi).



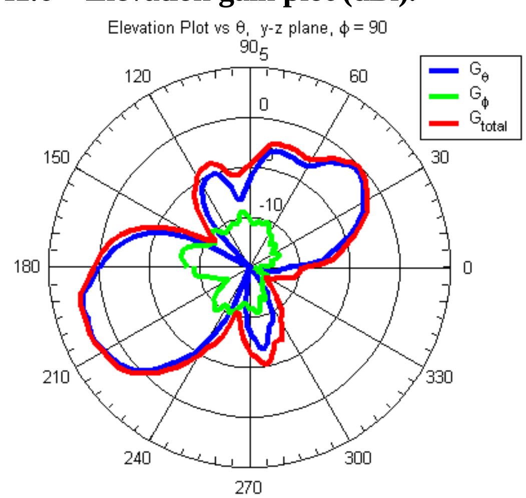
A1.4 – Elevation gain plot (dBi).



A1.5 – Azimuth gain plot (dBi).



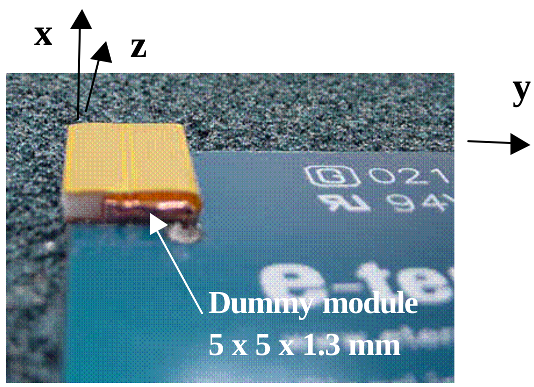
A1.6 – Elevation gain plot (dBi).



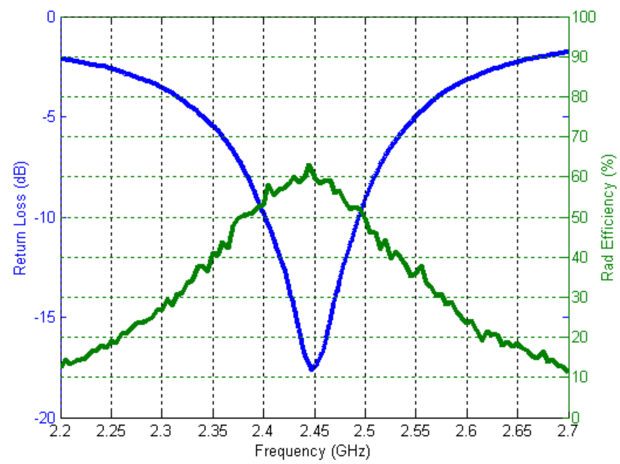
Appendix A-2

FOF, top left corner with internal dummy module, 2445 MHz

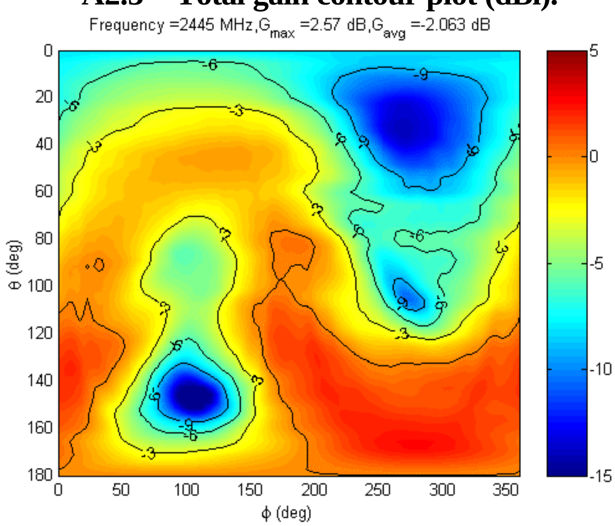
A2.1 - Test board.



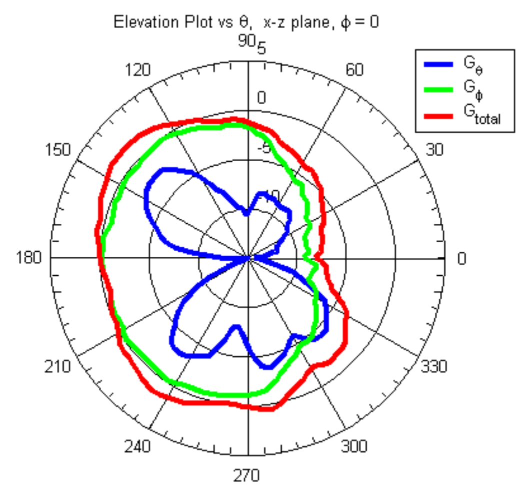
A2.2 – Efficiency and return loss.



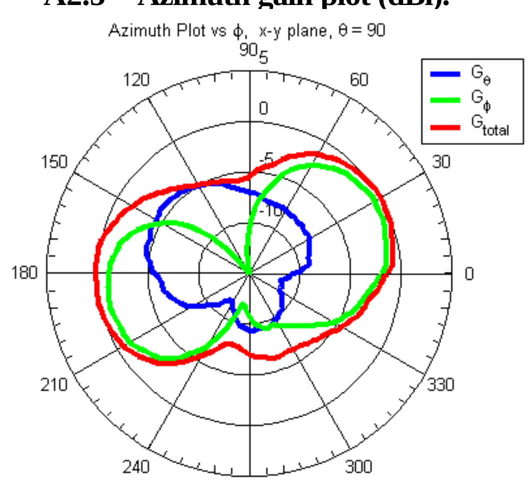
A2.3 – Total gain contour plot (dBi).



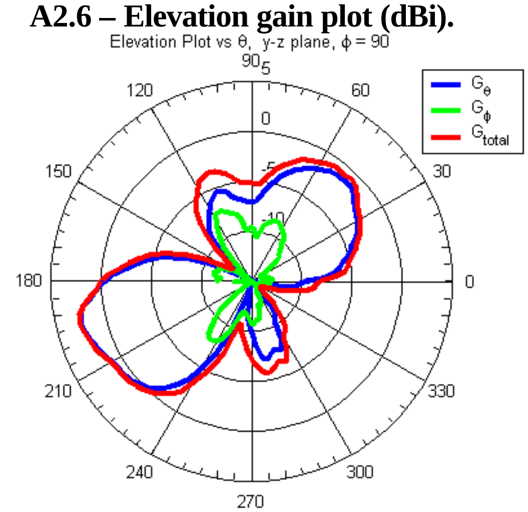
A2.4 – Elevation gain plot (dBi).



A2.5 – Azimuth gain plot (dBi).

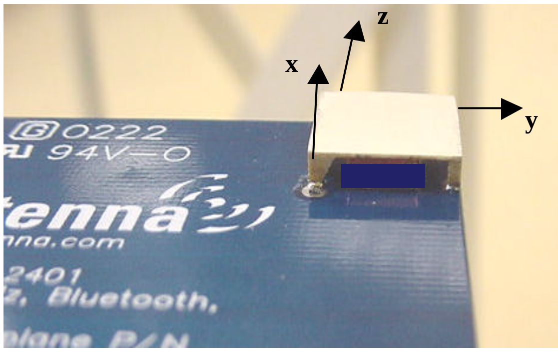


A2.6 – Elevation gain plot (dBi).

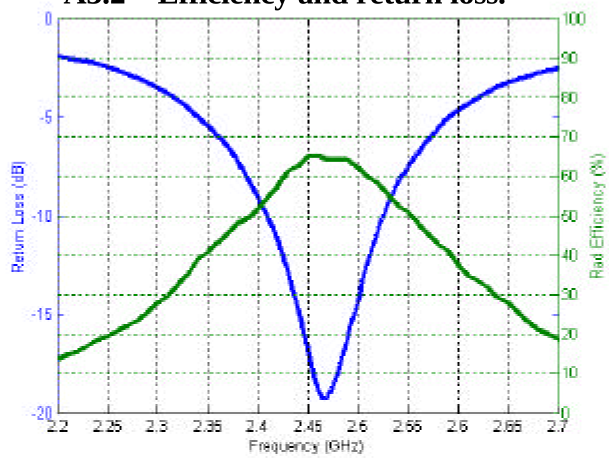


Appendix A-3
TTA, top right corner mount, 2450 MHz

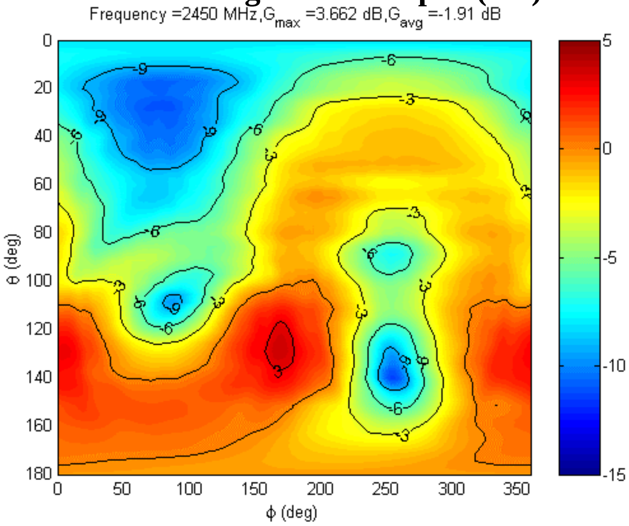
A3.1 - Test board.



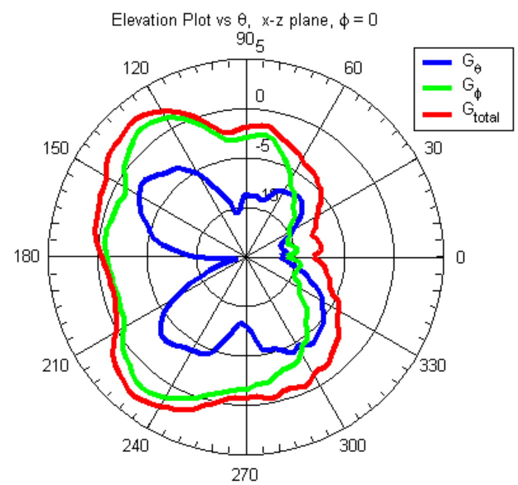
A3.2 – Efficiency and return loss.



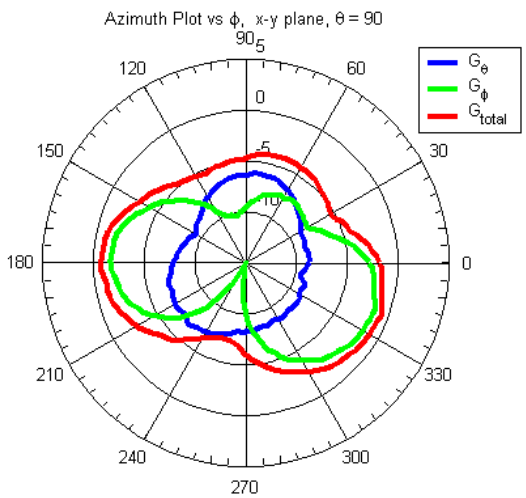
A3.3 – Total gain contour plot (dBi).



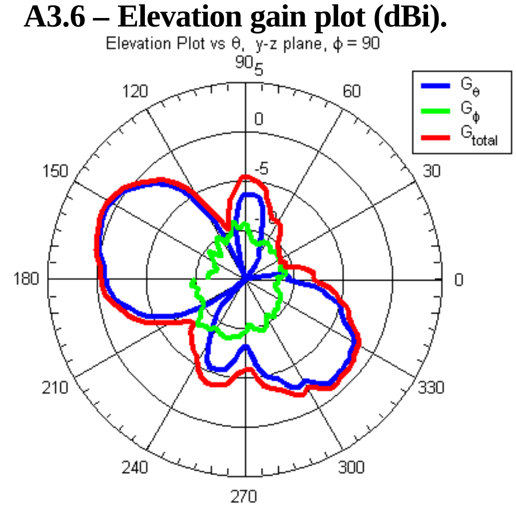
A3.4 – Elevation gain plot (dBi).



A3.5 – Azimuth gain plot (dBi).

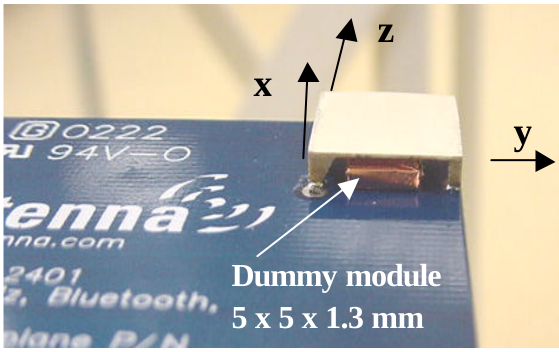


A3.6 – Elevation gain plot (dBi).

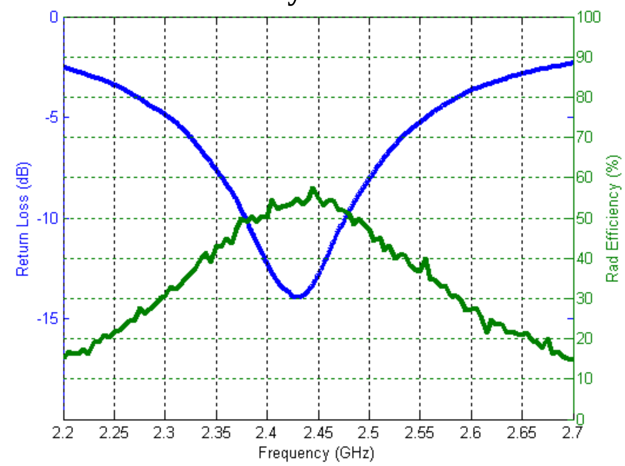


Appendix A-4
TTA, top right corner mount, 2445 MHz

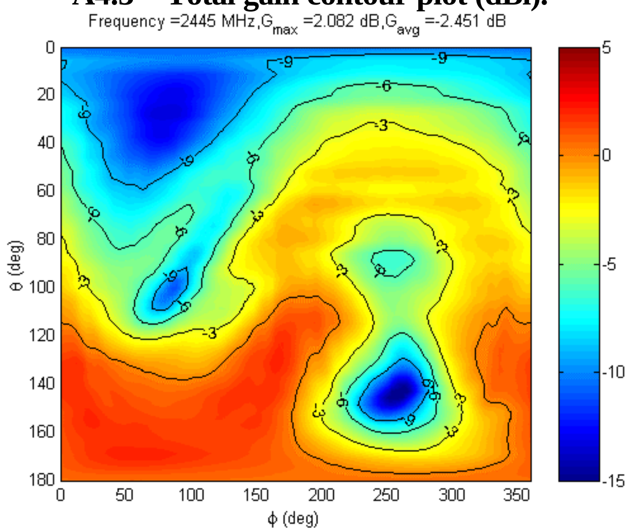
A4.1 - Test board.



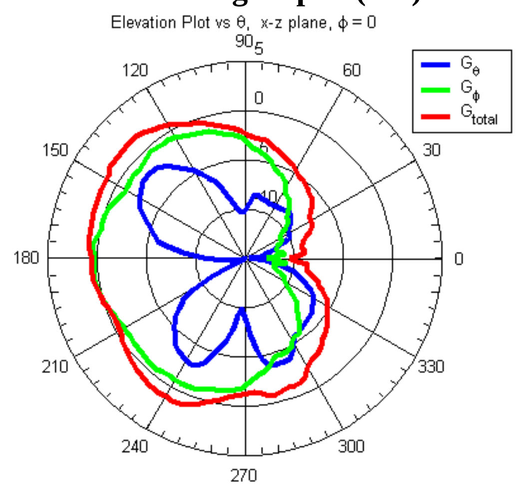
A4.2 – Efficiency and return loss.



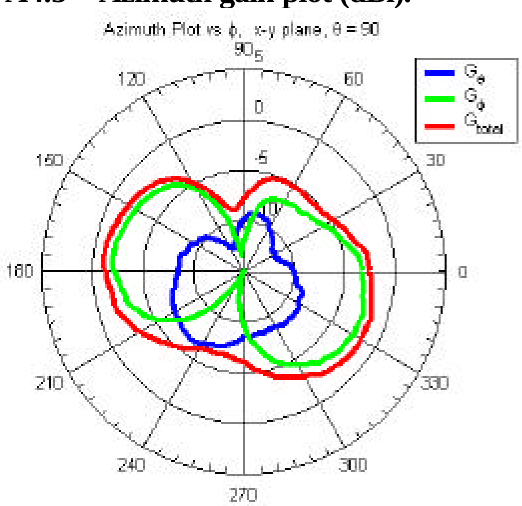
A4.3 – Total gain contour plot (dBi).



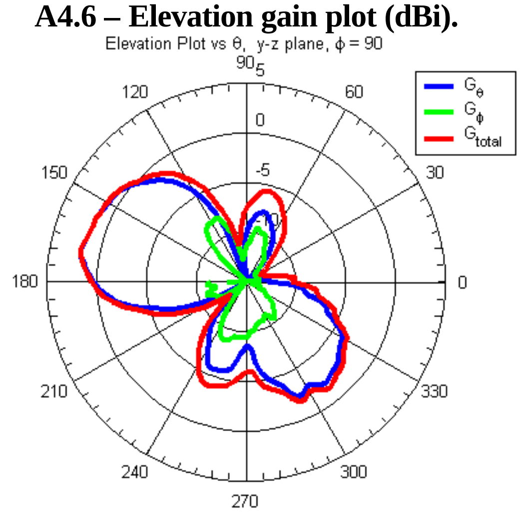
A4.4 – Elevation gain plot (dBi).



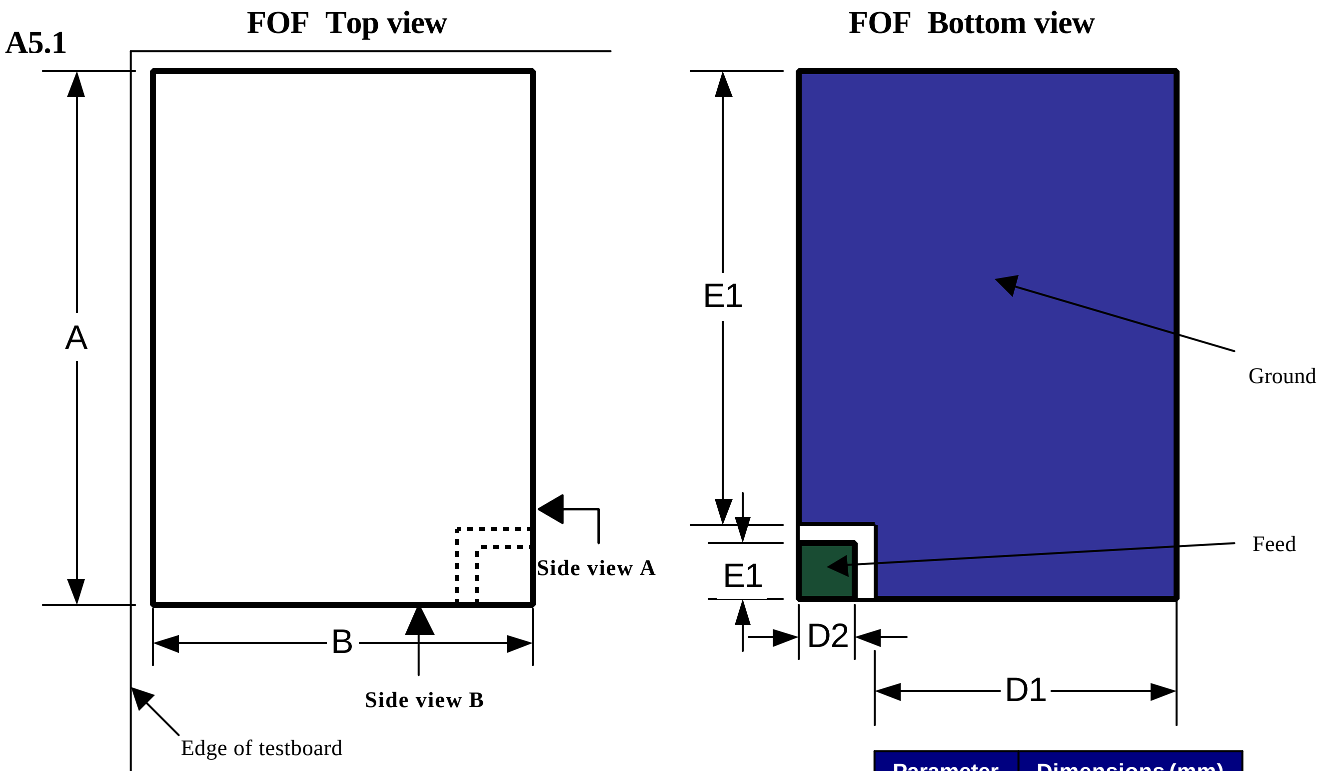
A4.5 – Azimuth gain plot (dBi).



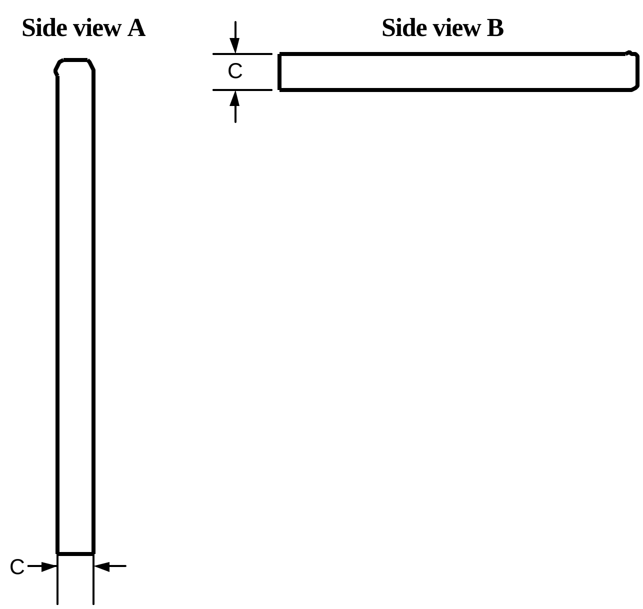
A4.6 – Elevation gain plot (dBi).



FOF (A5.1) part diagram



Parameter	Dimensions (mm)
A	12.60 ± 0.1
B	8.96 ± 0.1
C	2.15 ± 0.1
D1	6.70 ± 0.08
D2	1.66 ± 0.03
E1	10.50 ± 0.08
E2	1.50 ± 0.03

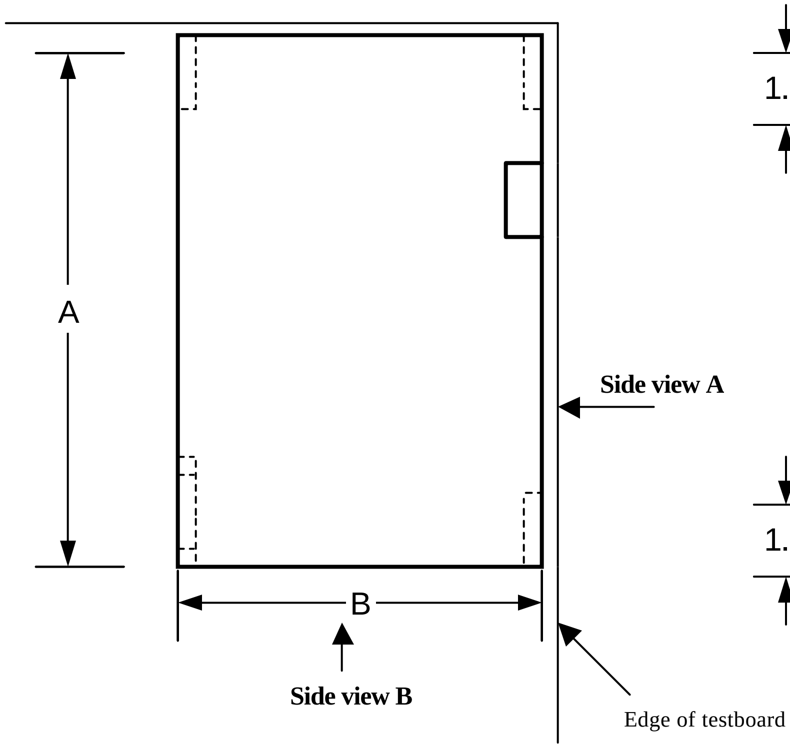


Appendix A-5. TTA part diagram.

Preferred location (A5.3)

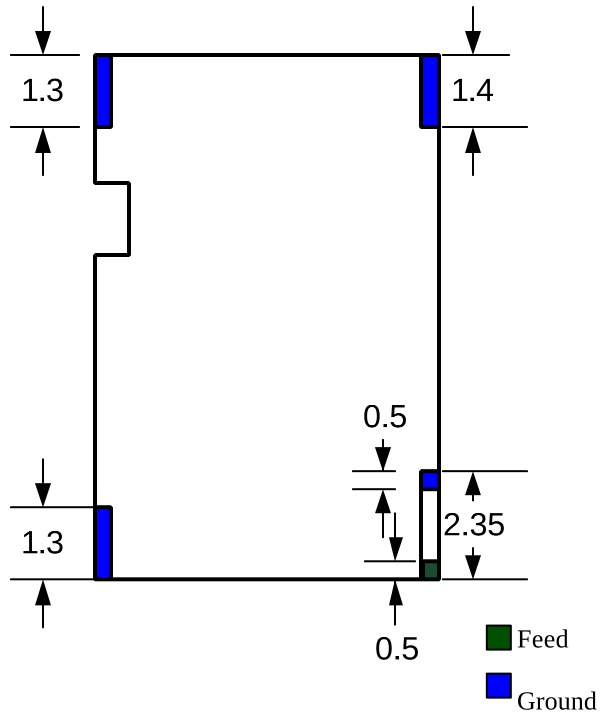
A5.2

TTA Top view



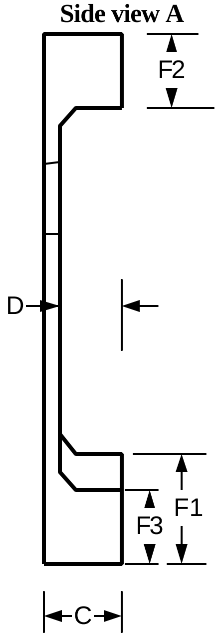
A5.3

TTA Bottom view



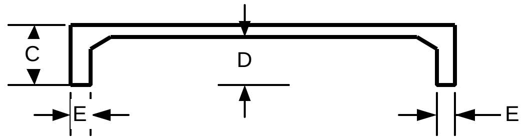
A5.4

Side view A



A5.5

Side view B



Parameter	Dimensions (mm)
A	14.00 ± 0.1
B	10.00 ± 0.1
C	2.4 ± 0.1
D	1.88 ± 0.03
E	0.50 ± 0.03
F1	2.35 ± 0.03
F2	1.40 ± 0.03
F3	1.30 ± 0.03
G	0.50 ± 0.03

Note: Use standard SMT assembly processes with 5 mils of solder paste thickness.