SPECIFICATIONS AND APPLICATION NOTES

September 24, 2004

BlackChip™ Antenna

CENTURION™

WIRELESS TECHNOLOGIES, INC.

Contents

Description

The BlackChip™ is a versatile and easy to use antenna for 802.11b, 802.11a, Hyperlan, Bluetoooth, and all other applications from 2.4 to 2.5 GHz and 3 to 6 GHz. Designed for high volume surface mount attachment in pick-and-place manufacturing processes, the BlackChip is in use today in many different applications. More than 1 million pieces have been used and the applications span virtually every wireless data scenario in the market.

Physically, the BlackChip is an approximately 12 x 6 x 2.5 mm SMT package with two solder pad locations. The part is comprised of a metal radiating element encapsulated in high temperature injection molded resin. There is one RF feed leg and a second leg for mechanical attachment. No ground connection is made to the antenna. A notch in one end of the part indicates the un-terminated leg used for mechanical attachment, and serves as a feature for vision-based pick and place systems to orient the part. The antennas are packaged in standard tape and reel packaging.

The metal radiator of the BlackChip is a partially self-resonant meander line structure which behaves similarly to a ¼ wavelength monopole antenna when it is adjacent to a counterpoise or ground plane. The self resonance of the meander line, combined with the dielectric loading of the low-loss plastic encapsulation, allows the part to be shorter than a traditional monopole. When designed with a proper transmission line feed structure and ground plane, the resulting antenna system achieves performance similar to a ½ wavelength dipole.

Because most wireless devices have a PC board as part of the radio system, the ground layer of the PC board may be used as the counterpoise for the BlackChip. When properly designed, the result is an efficiently matched BlackChip/ground plane system which radiates at the desired frequency bands without adding an extended antenna. In this sense, the BlackChip is a compact RF coupling device which converts some of the PC board to which it is attached into a radiator. Thus, the designer can use the already present PC board in a second way and achieve excellent RF performance.

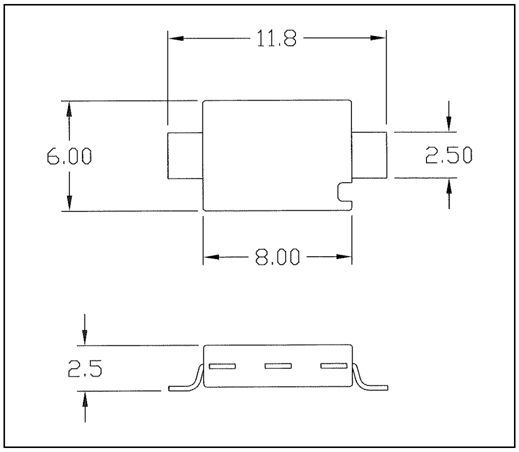
The BlackChip can be configured on a PCB to be matched and radiate in the 2.4 GHz band and a broad 3 - 6 GHz band simultaneously, without increasing the footprint over the 2.4 GHz only application design. By designing your application to take advantage of the unique multi-band properties of this antenna, you can reduce future design time when new chipsets become available and you expand your product line into other frequencies and protocols.

Since the BlackChip is integrated directly onto the PC board, it should be considered a key element of system integration during all phases of the design. Design factors which affect the impedance, frequency response, and radiation efficiency should be considered and optimized where possible for best antenna performance. Examples of such factors are feed line impedance, matching network design, feed line losses, ground plane geometry near the antenna, orientation of the antenna, the presence of plastic or other dielectric housings or covers near the antenna, other local ground planes, etc.

It is recommended, as with any internal antenna, that successful integration of the BlackChip antenna be obtained at the onset of the design, using a mockup of the device PCB (e.g., FR4) with the appropriate shape. Centurion has successfully integrated the BlackChip antenna many times using this mockup approach. Early mockups and integration will be conducive to the standard iterations and refinements typical of RF design, before the design for the PC board becomes fixed.

Physical

- Overall Dimensions with Solder Tabs: 11.8 mm x 6 mm x 2.5 mm

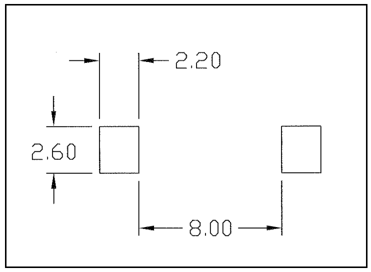


note: dimensions in mm

- Mass: 0.21 grams

Solder Pad Dimensions

- Two solder pads are required for attachment to a PC board
- Solder pads on the PCB should be 2.6mm x 2.2mm and spaced 8 mm apart
- The antenna may be attached by reflow or hand soldering operations

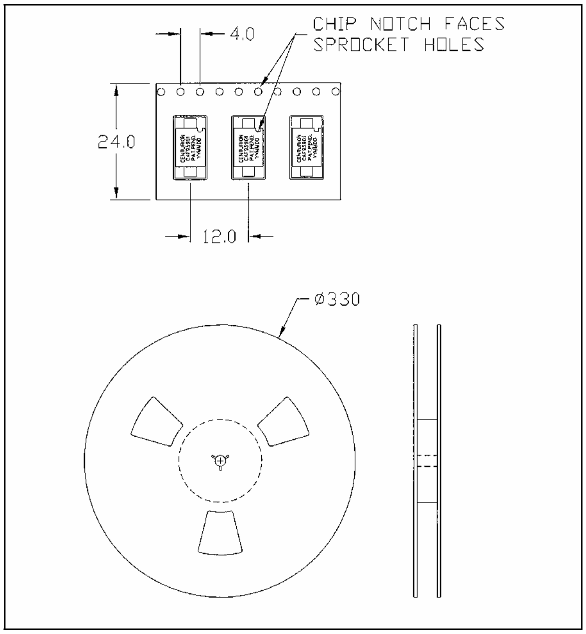


note: dimensions in mm

Tape and Reel Information

The BlackChip comes standard in Tape and Reel Packaging. All packaging meets EIA-481 standards.

- Tape Material: Static Dissipative Styrene
- Tape Width: 24mm
- Part Pitch in Tape: 12mm
- Reel: 330mm (13inches)
- Qty: 2000 pcs. per Reel



note: dimensions in mm

Thermal/Environmental Qualification

The BlackChip antenna has been designed to meet the requirements of both high volume assembly and end-use conditions. The following specification was used to qualify the part for use in customer applications.

- Material compatibility
    - Reflow temperature compatibility
        - Heat 3 parts in 260 C solder bath for 10 seconds
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz
    - Temperature stability
        - Heat 3 parts at 185 C in oven for 5 minutes
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz
        - Printing to remain legible on all treated parts in this section
    - Solvents
        - Immerse 3 parts in boiling water for 5 minutes
        - Remove parts and air dry
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz
        - Immerse 3 parts in iso-propyl alcohol for 5 minutes
        - Remove parts and air dry
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz
        - Printing to remain legible on all treated parts in this section
- Solder reliability
    - Temperature Humidity ALT
        - Solder 3 parts to test PCBs
        - Temperature cycle at 95% RH: -40 C to +95 C 1 hour, 100 cycles
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz
    - Thermal shock
        - Solder 3 parts to test PCBs
        - Room temperature to –40 C 1 hour, -40 C to + 95 C 5 minutes, 95 C to room temperature 1 hour
        - Compare mean resonant frequency of 3 parts to 3 untreated parts
        - Change in mean resonant frequency < 25 MHz

- No solder failures allowed on treated parts in this section

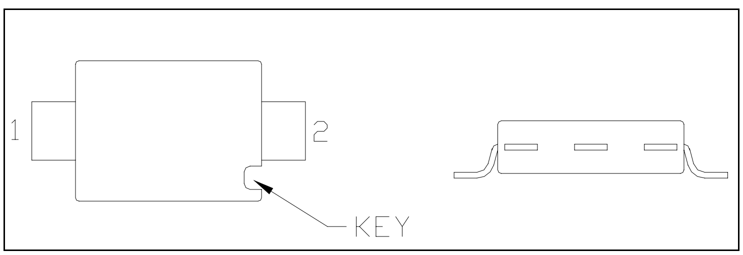
- Mechanical force
  - Solder 3 parts to test PCBs
  - Apply force parallel to PCB, to side of chip, to failure
  - Mean failure force > 1 lbf
- Mechanical shock/vibration
  - Solder 3 parts to test PCBs
  - Subject for 1 hour on the axis perpendicular to the PCB to the following profile:

Freq (Hz)	PSD (G2/ Hz)	Slope	Area	**Vibration Survivability Vibe Profile**
10	0.4	-8.17	1.02	
14	0.16	0.00	0.96	
20	0.16	-2.27	3.29	
50	0.08	-7.78	1.14	
73	0.03	-3.87	0.66	
100	0.02	-11.41	0.29	
120	0.01	0.00	8.80	
1000	0.01		**16.15**	**sum**
			4.02	**Grms**

  - Verify operation with no solder joint failures.
  - Solder 3 parts to test PCBs
  - Protect RF connector with vinyl cap. Drop 3x from 18" onto concrete surface, random drops.
  - Verify operation with no solder joint failures.

Feed Configuration

The BlackChip has two tabs for solder attachment to PCB solder pads. Tab #1 is for the RF feed line. The line impedance is usually 50 ohms and the ground plane configuration and matching network are chosen to achieve a good match. However, it is possible to use non-50 ohm line sections as distributed matching and eliminate the lumped element matching network. In general, this takes more PCB turns and development time.



Top View Side View

Note that the feed transmission line can be coaxial, microstrip, coplanar waveguide, stripline, or any controlled impedance line. In most applications, the board onto which the antenna is mounted is a multi-layer structure; e.g. 6 layers totaling 30 mils. In that case, it is necessary to know the layer thickness and laminate dielectric properties to properly design a 50 ohm line feeding the antenna. The most common method is to place the feed line on the top layer with the RF ground on the next layer. One consequence of this construction is that the small layer thickness leads to very narrow lines (less than 10 mil) which can result is large impedance errors and variations from board to board in production.

As noted above, the antenna drives currents on the local ground layers which effectively are part of the antenna. Because of this, it is beneficial to ensure that all ground layers are properly interconnected with vias near the edges and near feed lines. Common design practices for multiplayer microwave boards intended to reduce noise, crosstalk, and unwanted modes are all equally applicable to ensuring a stable structure at the high frequencies in the antenna part of the board.

Many applications include an outer conductive shell, such as the metal can on a PCMCIA card or a shielded housing on a USB dongle. In these designs, it is extremely important to ground the outer shell to the ground layers of the PCB. This is most often done with spring contacts from the PCB to the metal shell, or using tabs from the metal shell to pads on the PCB. Failure to account for this feature can lead to new modes existing with the outer shell on than without the shell, and a resulting shift in frequency response and impedance.

Tab #2 is for mechanical support, and is identified by the notch or "key" adjacent to it. Tab #2 should not be connected to the PCB ground plane. Because of the close proximity of the second pad to the radiating element of the antenna, the pad is coupled to the antenna and may therefore be used for tuning the BlackChip by adding capacitance to the structure. Additional methods to optimize the BlackChip are described below.

In general, the PCB ground plane must not extend under the BlackChip antenna. As explained above, the BlackChip is similar to a quarter wave monopole with the polarization axis along a line between tabs 1 and 2. Therefore, locating ground plane beneath the antenna is the same as laying a monopole against a ground plane, a condition know to short the electric fields of the antenna, causing large shifts in impedance, and resulting in mismatch. In addition, the patterns will be affected and may exhibit high directivity in some areas and very low directivity in other areas.

For optimum antenna efficiency and bandwidth, It is recommended that the PCB ground plane be kept at least 3 mm away from the BlackChip antenna, in the "keep out" region of no ground plane under the antenna. However, this should be understood as a guideline only, as it is the combination of feed line geometry, ground plane geometry, dielectric loading from the device, and matching network that determine antenna performance. Therefore, it is often possible to adjust another variable to achieve good results. However, it is true that you cannot reduce the size of the keep out region of no ground plane arbitrarily, without significantly affecting antenna performance.

Often there are other conductive structures which are part of the device to which the BlackChip is integrated as the antenna. Examples include the aforementioned PCMCIA metal can, internal metal shields attached to plastic housings, other circuit boards, etc. In the ideal case, these other ground planes, if they are in a plane parallel to the long axis of the antenna (line through tabs 1 and 2), would be no closer than one quarter wavelength to the antenna. (For 2.4 GHz, this is about 1.2 inches). Rarely can this be achieved, and many successful applications have been designed with local ground planes. Note that ground planes which parallel the PCB ground plane will have minimal effects if they do not encroach on the "keep out" designed into the PCB containing the antennas.

Applications Background

Bluetooth

The BlackChip has been used successfully in many bluetooth applications. Applications range from USB bluetooth devices attached to laptops to embedded bluetooth radios in wireless headsets for mobile phones. Typical PCBA sizes are 25 x 50 mm and as small as 20 x 40 mm with good results. Bluetooth applications typically use one antenna and are designed without a matching network where possible for cost reasons.

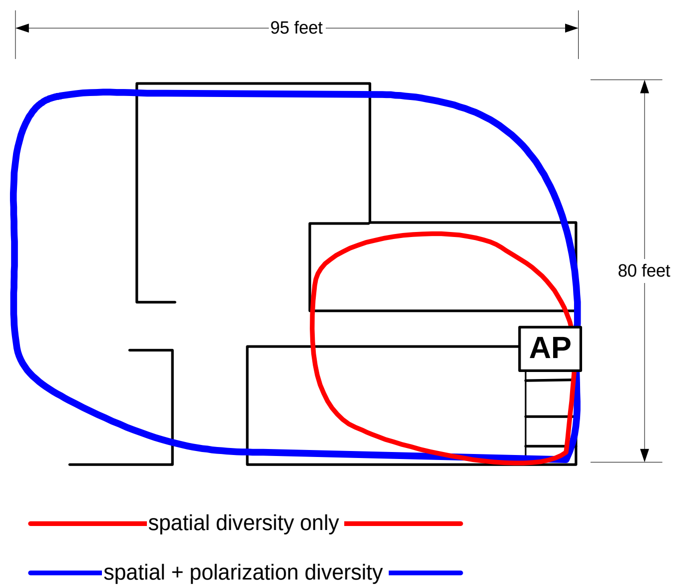
802.11b/g

The BlackChip is widely used in 802.11b/g PCMCIA card radios. There are many designs on the market today and many more in development. All these designs use two antennas near the end of the card. Most use a layout with "mirror" symmetry to achieve pattern diversity, but there are designs using asymmetric layouts, such as one antenna aligned to the long axis of the card and the second antenna aligned to the short axis of the card.

In addition to PCMCIA cards, the BlackChip has been integrated directly onto the PCB of access points, gateways, 802.11b dongles, and other devices. In some cases, the BlackChip has been used as an internal diversity antenna combined with an external antenna, such as a traditional dipole.

In these applications, where the boards are much larger than the PCMCIA cards or BT modules, it can be useful to orient the BlackChip at an angle, such as 90 degrees, relative to the other antenna. This can achieve polarization diversity in addition to the pattern and spatial diversity inherent in the design. Centurion has found in field trials of throughput that the combination of spatial and polarization diversity increases coverage at high data rates of 802.11b WLANs compared spatial diversity alone.

An example is given here of a commercial 802.11b access point configured with two spatially diverse antennas and the same two antennas with polarization diversity added. This case study was done in a building which had been found to have very limited coverage, and included stairwells and other features where it was initially impossible to maintain 11 Mb/sec coverage. Adding polarization diversity significantly increased the coverage at 11 Mb/sec and increased the stability of the data rate when connected to moving clients.



Floor Plan Diagram of 802.11 Access Point Coverage Test Area

802.11a, Dual-band, and Multi-band

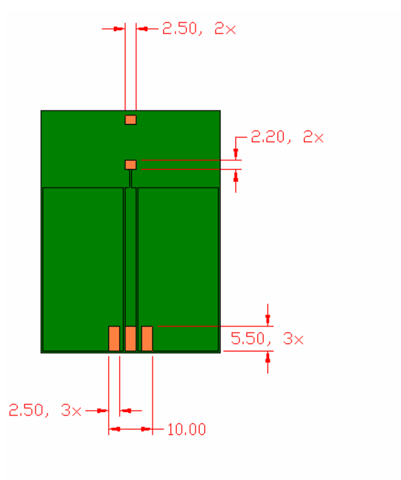
The BlackChip is ideally suited to migrate a design from 802.11b to 802.11a/b or Multi-band (for example, including 4.9 GHz, or Hyperlan at 5.47 to 5.725 GHz, along with 802.11a (5.15 to 5.35 GHz) and 802.11b). Included in this application note is information to allow designers to use the BlackChip and add performance from as low as 4.5 GHz to over 6 GHz. Current designs are underway for multi-band PCMCIA card applications. In the PCMCIA design, the same footprint is used as the single band design, allowing the same basic card layout to be refreshed for multi-band from an original single band design.

Evaluation Boards

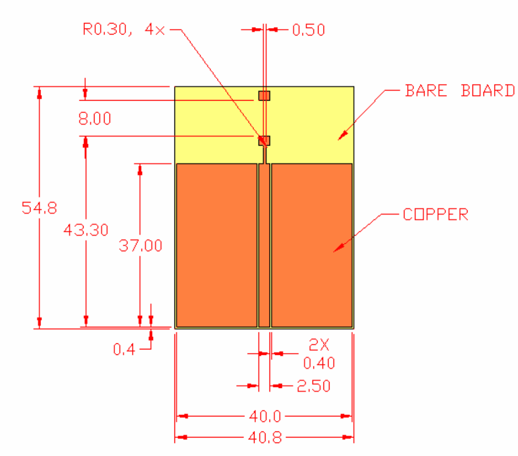
The BlackChip is available on evaluation boards in both the single band 2.4 GHz 802.11b version (CAF95943) and the multi-band 2.4/UWB version (CAF94408).

The evaluation boards are intended to allow the user to gain a general understanding of the behavior of the antenna. In most individual applications, however, the user design will have a PCB of significantly different size, geometry, and layer construction than the evaluation boards. Therefore, although the information regarding the design and performance of the evaluation boards may be a starting point, it is not intended to mimic any particular application. Typically, the matching and the local ground plane layout of the evaluation board cannot be directly implemented in the users design.

The 2.4 GHz evaluation board is constructed of 0.06” FR4 with 1 oz copper. The feed line is 50 ohm coplanar waveguide and is fed from an SMA edge launch connector soldered to the pads provided. Note that the first pad is located 4.1 mm from the edge of the ground plane. In this configuration, with no housing or other dielectric loading, the BlackChip resonance was about 100 MHz above the target center frequency of 2450 MHz. The tuning was corrected in this case simply by extending the line away from the ground plane edge thereby increasing the electrical length of the antenna slightly.



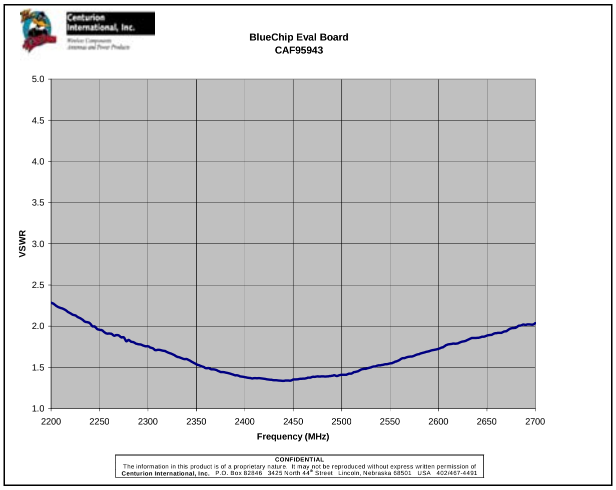
Finished Board



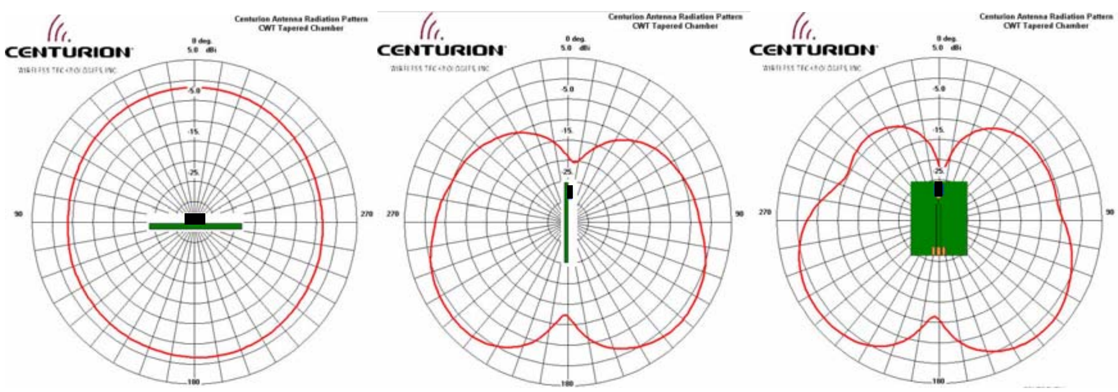
Board before Solder Mask

note: dimensions in mm

The 2.4 GHz evaluation board demonstrates the wide bandwidth potential of the BlackChip in the single band implementation, combined with omindirectional patterns and high gain. Here, the VSWR plot shows a 2:1 bandwidth of > 400 MHz:

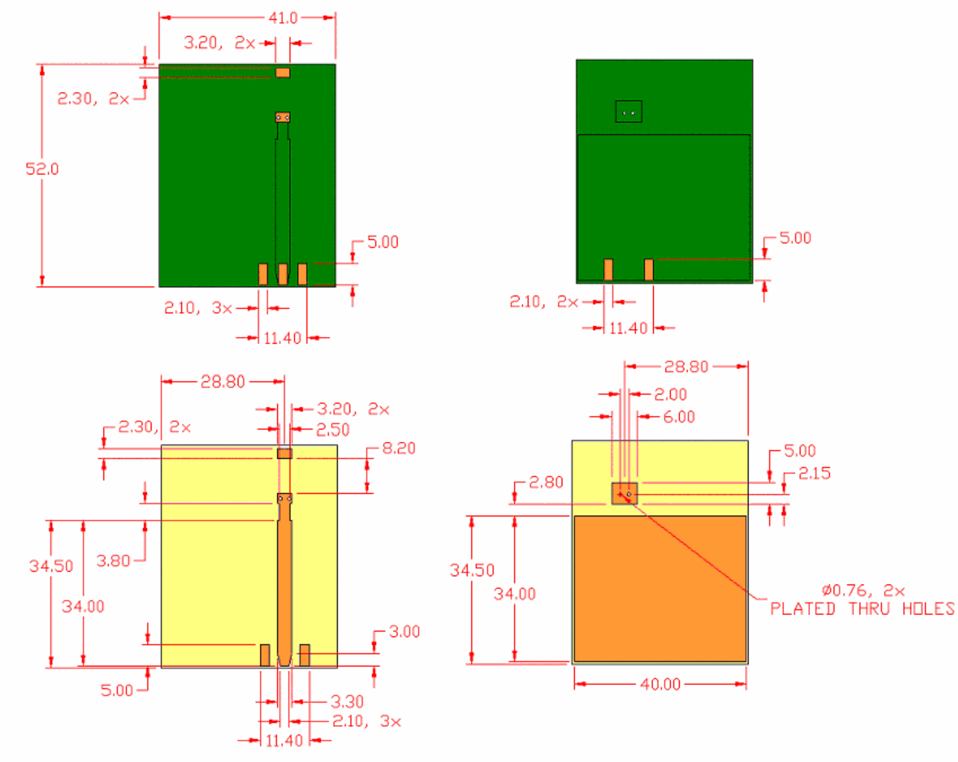


The radiation patterns at 2450 MHz are shown here for reference. These patterns were measured in Centurion's anechoic chamber using a ferrite loaded feed cable connected to the SMA edge launch connector on the evaluation board.



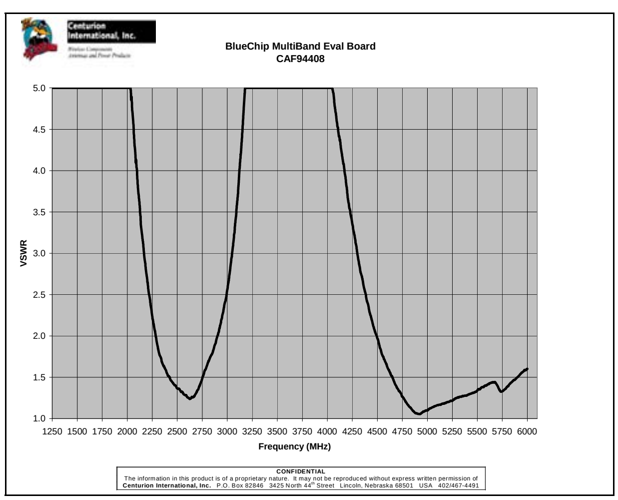
Peak gain is over 2 dBi in this configuration, and the patterns are typical of a monopole over a small ground plane, as expected.

The multiband evaluation board is also constructed of 0.06 FR4 with 1 oz copper and is the same overall dimension as the 2.4 GHz board. Microstrip transmission line is used to feed the BlackChip, and an additional pad is located on the back of the board and connected to the feed pad with three vias. This technique will be described later.

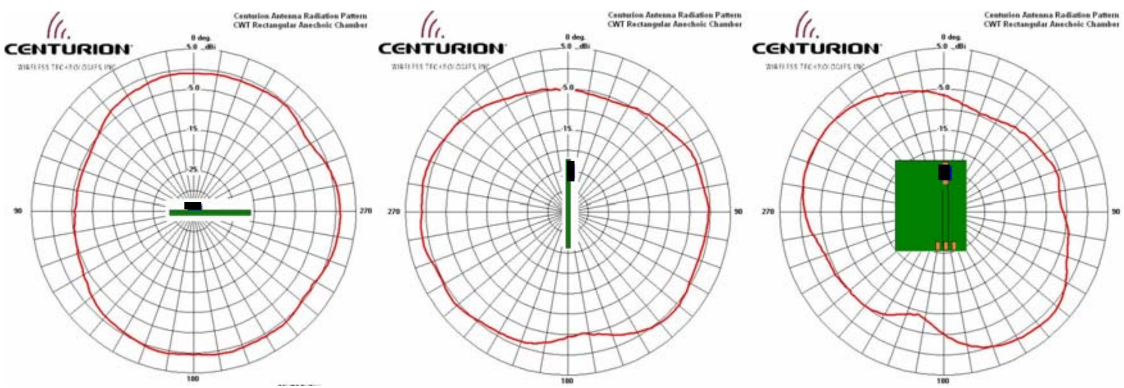


note: dimensions in mm

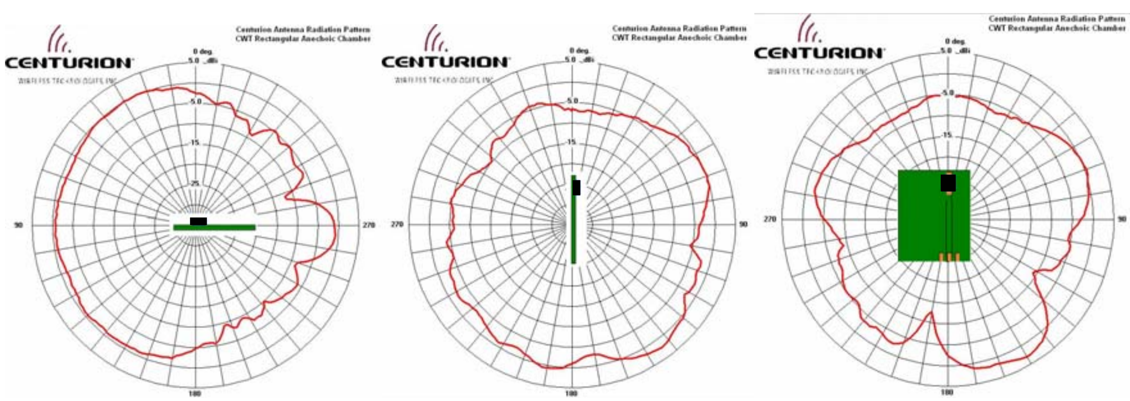
In this configuration, bandwidth in the 2.4 GHz band is greater than the single band board, with more than 500 MHz bandwidth from 2.3 to 2.8 GHz. In addition, the upper resonance is broadened to cover from 4.5 GHz to above 6 GHz:



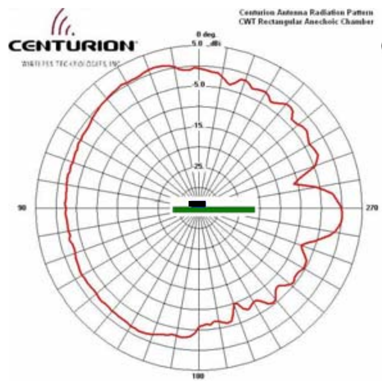
As expected from the asymmetric layout, the patterns for the multiband configuration are somewhat more complex than the single band evaluation board. This behavior illustrates what is typical of actual customer applications in that the location available for the antennas is usually not symmetric with respect to the ground plane and therefore the patterns show asymmetry. This fact is used to good advantage on PCMCIA card layouts where the spacing between the two antennas is less than the ideal 0.75 wavelength for spatial diversity. The asymmetry in the patterns of the antennas caused by the ground plane geometry shows a mirror image symmetry when the antennas are placed in a mirror configuration on opposite sides of the PCB. In that case, a high degree of so-called pattern diversity is achieved and diversity performance is significantly enhanced.

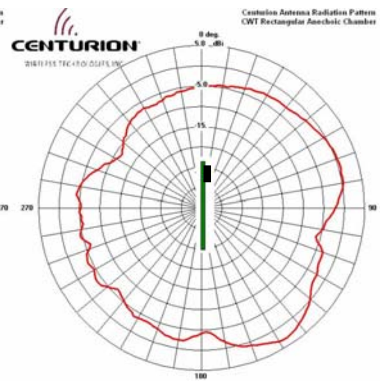


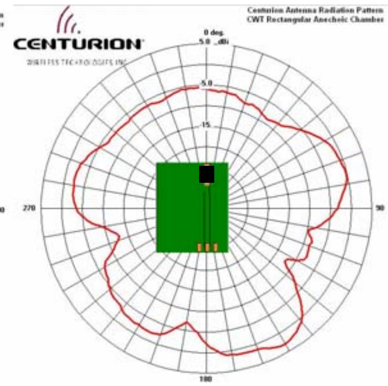
Peak gain for this configuration is 1.7 dBi in the 2.4 GHz band.



In the 5.15 to 5.35 MHz band, peak gain increases to over 3 dBi.







The gain in the Hyperlan region is very similar to the 802.11a band with slightly higher peak gain.

Single Band Tuning Techniques (2.4 GHz)

Electrical performance of the BlackChip antenna is influenced by the physical characteristics of the surrounding ground plane, feed line, other devices, and materials. This can be used as an advantage by manipulating certain parameters to affect resonant frequency and match:

- Ground plane configuration
  - Distance from antenna
  - Topology around antenna
- Feed point transmission line impedance
  - Trace width
  - Trace length
  - Matching network
- Capacitive loading
  - Enlarge or extend the solder pad for Tab #2
  - Adjust length and width of the extended Tab
- PCB substrate thickness
- PCB substrate dielectric constant

Although in many cases it is easy to achieve excellent results only by adjusting the ground plane and feed line geometry, Centurion recommends designing the feed with a matching network as close as possible to the actual feed point. Keep in mind that the feed point is that point where the feed line leaves the ground plane and therefore is no longer a controlled impedance transmission line. Any trace not over a ground plane extending from the feed line to the antenna becomes part of the antenna. Therefore, the start of such a trace is the actual feed point.

A 3-component matching network is adequate in most cases. The matching network should be as closely spaced as possible and designed with the smallest components possible. Package size 0402 is desired at 2.4 GHz and above. Component manufacturer and tolerances should be chosen carefully to ensure the components behave as expected; in particular the self resonant frequency must be above the desired frequency of operation. Therefore, components must have a self resonant frequency above 3 GHz for single band use and above 6 GHz for multiband use. In general, good tolerance components such as 1 percent tolerance will be necessary for a solution to be reliable in volume production.

A significant factor in the design of the board for the use of the BlackChip is to account for the dielectric loading of the plastic housing, if any, that will surround the antenna. Several factors should be taken into account in the design. The most general factor is the trend that the housing will lower the resonant frequency of the antenna. Therefore, a design which is matched at 2450 MHz for the bare board in free space may exhibit a low characteristic frequency when assembled into the actual device. This can be compensated for by shortening the distance between the ground plane edge where the line crosses to feed the antenna and the feed pad. In some cases, this will not be adequate and the matching network values will be chosen to do the remainder of the frequency offset compensation.

General rules to follow for the housing in the vicinity of the antenna are to make it as thin as possible and to place it as far away as possible from the antennas. In many designs, metallization of the housings is used for shielding purposes. Avoid metallization of the housing, especially near the antenna.

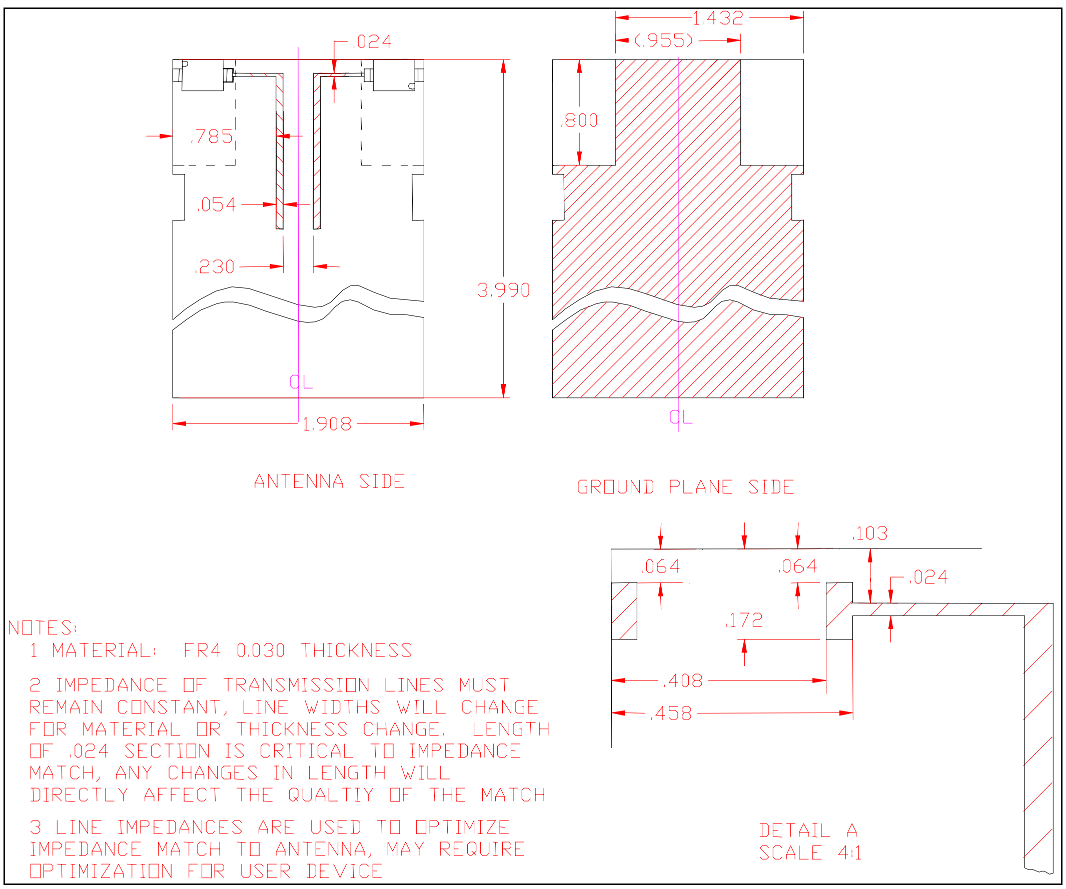
Housing materials can affect the frequency response further if they are of higher dielectric constant. Most injection molded plastic resins in use are ABS/PC alloys or pure polycarbonate, which have very similar dielectric properties, with relatively low loss and dielectric constants around 2.5 to 3. However, some flexible plastics such as polyurethanes have higher loss tangents and higher dielectric constants and can cause difficulties if introduced late in the design. A final consideration are the pigments used in the housing resin during molding. Many pigments are either metallic based or carbon based, both of which can lead to a highly lossy structure degrading RF radiation performance.

The best approach to take with any design is to construct a mock up as early as possible. Once the general board layout is defined and locations for the antennas are chosen, a simple 2 side board can be manufactured which has the ground layer and the feed layer to mimic the final board. Major components like shield cans, outer metal cans, and plastics can be added or mocked up with sheet metal and copper tape to produce a device which looks electrically similar to the final product. If a matching network topology is included, then initial tuning and verification can be done very early in the design stage. Problems such as inability to achieve a low or high enough resonance or inability to achieve a good match can be identified while there is time in the design cycle to make changes to the board layout in the antenna area.

Some or all of the techniques listed at the beginning of this section can be applied to the mockup depending on what fits with the overall design and the approach of the designer. It should be possible to optimize the solution at this stage. This optimization of the mockup can be used to fix the ground plane and feed line geometry, so that final tuning is merely a matter of selection of final matching network values.

Single Band Application Examples

PCMCIA diversity layout for 802.11b card.

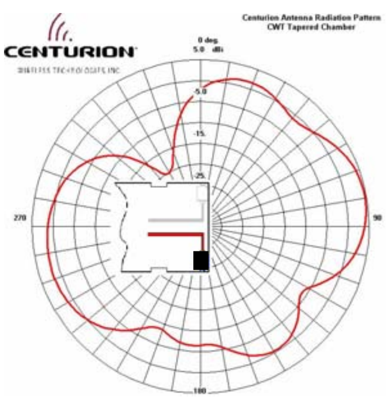


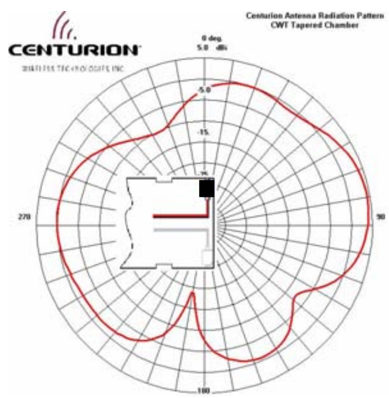
note: dimensions in inches

This layout was designed to utilize some non-50 ohm transmission line sections as distributed matching and eliminate the lumped element matching network. The narrower line section serves this purpose. Because of the non-50 ohm section, the length of that section is critical to the match. Changing either the length or the width of the line will degrade the match, as well as changing the dielectric properties of the PCB substrate. For these reasons and to reduce total design time, Centurion recommends that a layout like this one be approached by changing the line to constant 50 ohms, and adding a matching network at the edge of the ground plane where the feed line crosses going to the antennas.

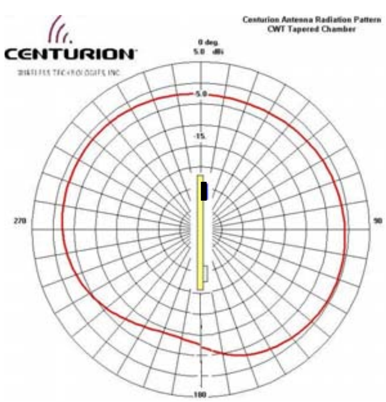
This particular geometry has been shown to minimize generation of currents on the PCMCIA card frame and case, which results in a very stable solution regardless of the device the card is installed to. Other designs have been used successfully for PCMCIA cards using the BlackChip, including both chips parallel to the long axis of the card, each chip at 45 degrees outwards and some asymmetric designs.

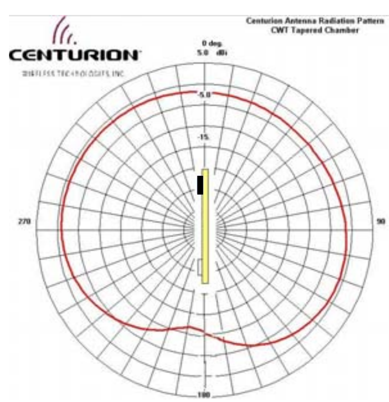
Performance of this design in the prototype stage was extremely good as shown by the following patterns.



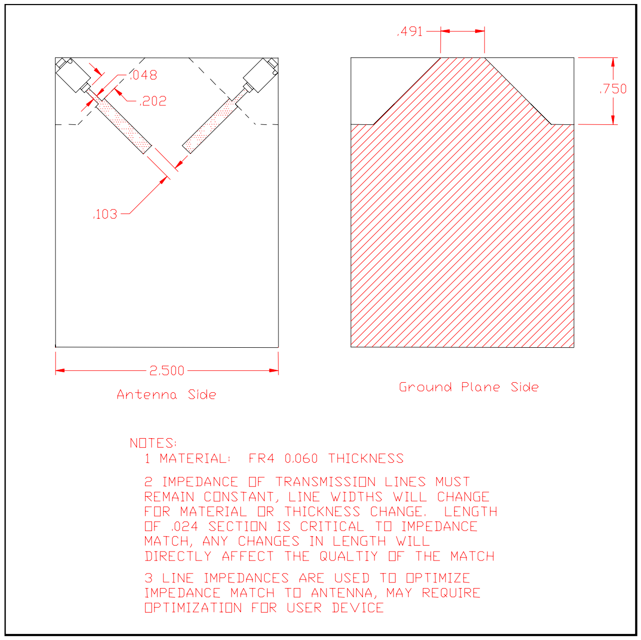


Peak gain in the plane of the PCMCIA card was 4.7 dBi.



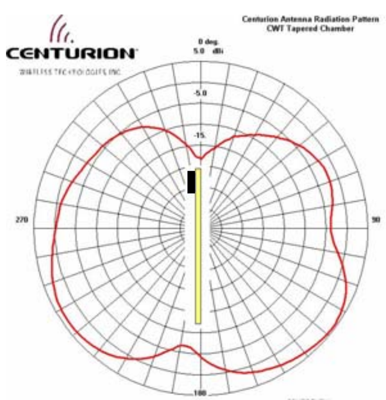


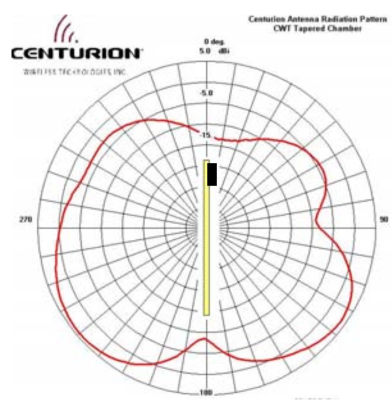
Diversity board for 802.11b radio



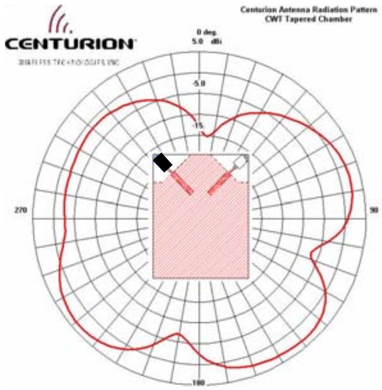
note: dimensions in inches

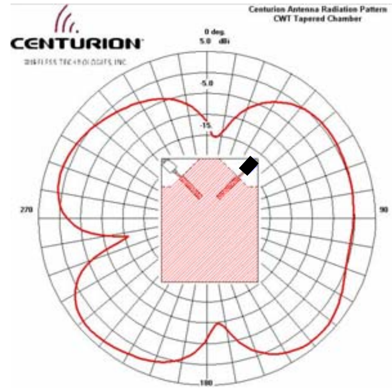
This layout used the corners of the board to provide polarization diversity in the least amount of footprint. In this case, a feed line of 50 ohms was used and no matching required. The frequency response was optimized by adjusting the length of the line between the ground plane and the feed pad (.202 in the drawing). The frequency of the antenna was affected by a plastic housing but the change was minimal enough to allow a solution with no matching network.





Peak Gain was greater than 4 dBi for both ports.



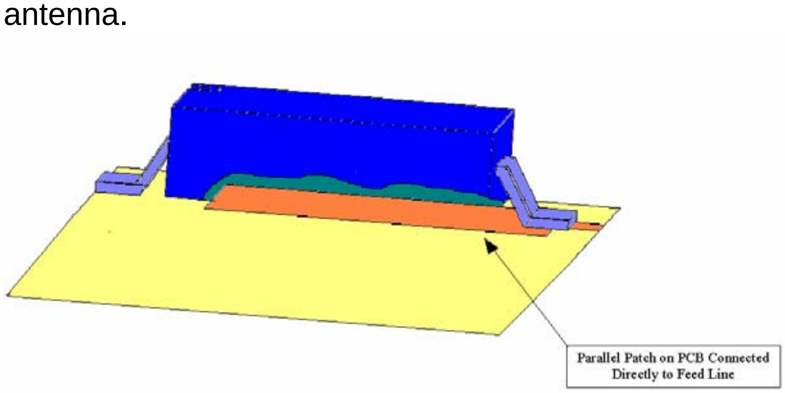


From the patterns in the plane of the board, the mirror image symmetry is evident. This design, therefore, had the most significant diversity benefits from spatial and polarization diversity.

Multi-Band Tuning Techniques (2.4 & 4-6 GHz)

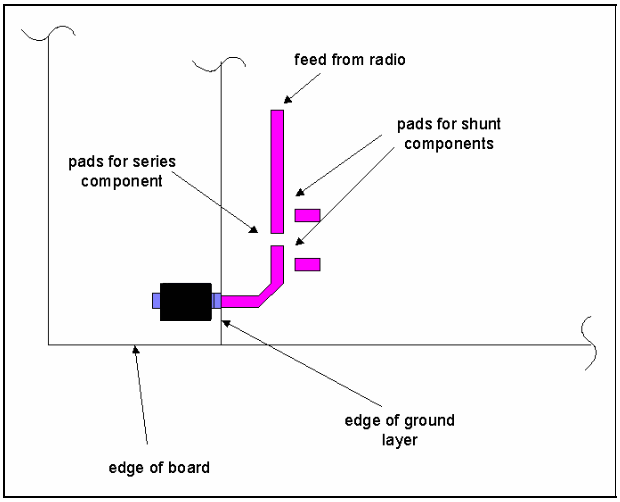
Centurion has developed a patent-pending design which couples a second element to a meander element such as the BlackChip. As shown earlier in the Evaluation Board section, this second element can be optimized to give a very large bandwidth with good gain in the region from 4.5 GHz to 6 GHz.

A parallel patch is put on the PCB directly connected to the feed of the meander line, causing the very large bandwidth enhancement. This patch can be directly beneath the chip, as shown here, or on the opposite side of the PCB or in an intermediate layer. Note that the patch is not part of the ground layer but rather is part of the antenna.



In this diagram, the patch is shown on the same layer of the PCB as the feed trace, and extends part way beneath the BlackChip. The exact size of the patch depends on many factors similarly to the other tuning factors mentioned earlier in the single band section. However, if the patch is laid out the bottom of the PCB, it can easily be trimmed with the BlackChip in place. Thus, after an initial turn of the PCB is made based on the preliminary mockup, the pad can be adjusted in size to find a solution.

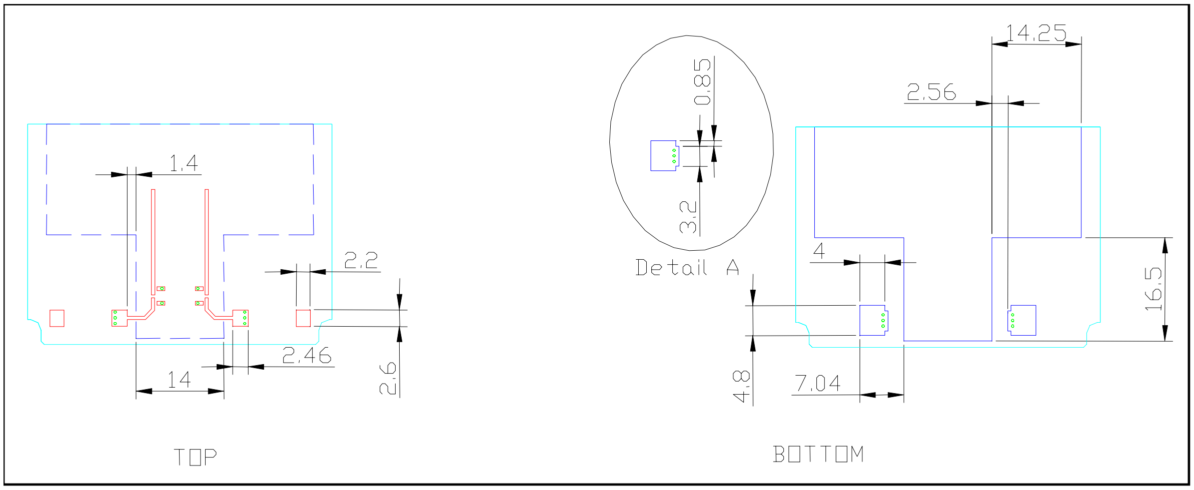
In most cases, given all the variables required in a multi-band solution, a matching network will prove very beneficial to finish the design quickly. A typical layout is given here:



Here, provision has been made for 3 components including 2 shunt and one series component in a PI configuration. The matching network is fairly compact and is fairly close to the feed point of the antenna.

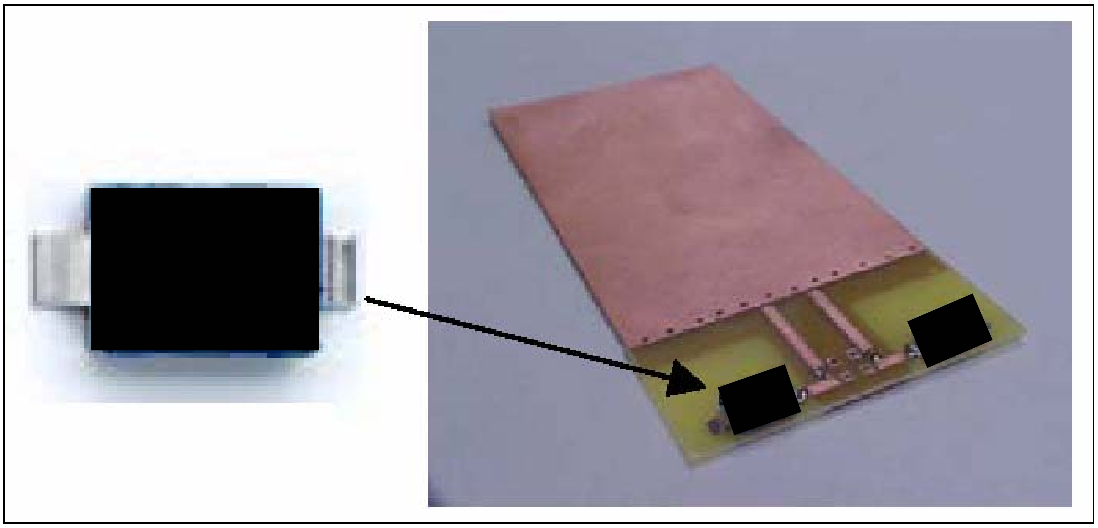
Multi-Band Application Examples

UWB PCMCIA Diversity Configuration

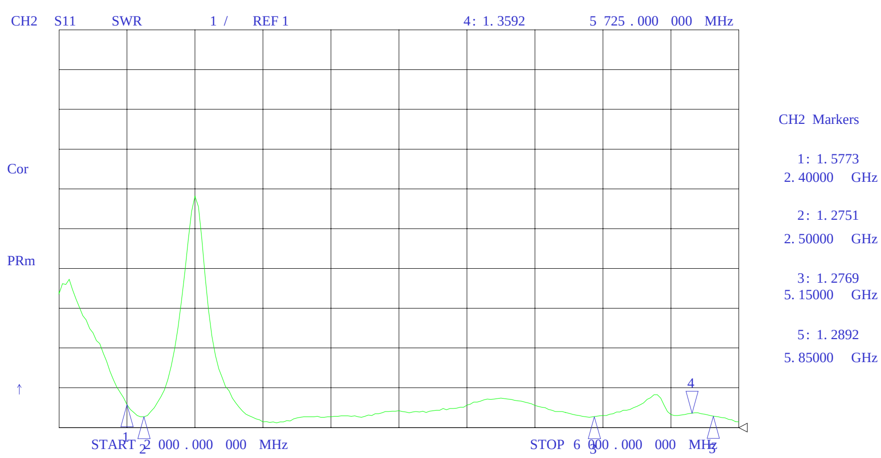


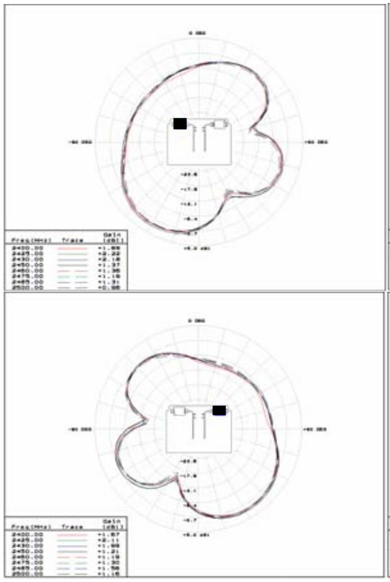
note: dimensions in mm

This design is similar to the previous single band layout. The antennas are oriented opposite each other with ground plane in between, resulting in minimal currents on the card shell and good pattern diversity. By adding the parallel patch to each antenna, a very large bandwidth was obtained above 3 GHz. The dimensions shown are for a multiplayer FR4 board of 0.03” total thickness with 0.008” layer thickness between the top traces and the RF ground plane.

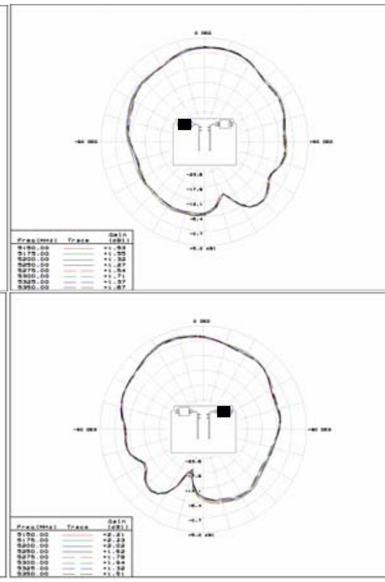


Here, the VSWR plot shows the 2:1 bandwidth is > 300 MHz in the 2.4 GHz band and from 3 to 6 GHz in the upper band. Measurements were made of the patterns in each band and typical results are given below. The low frequency patterns are similar in character to the layout using the single band solution, and show excellent pattern diversity. In the upper frequency bands, the patterns in the plane of the antennas are relatively omnidirectional and will provide some degree of spatial diversity. However, when the card is inserted into laptops or other devices, additional pattern diversity will be obtained due to shifts in the patterns caused by interaction with the device.

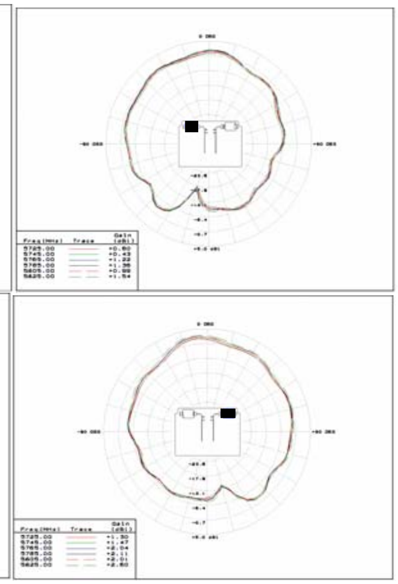




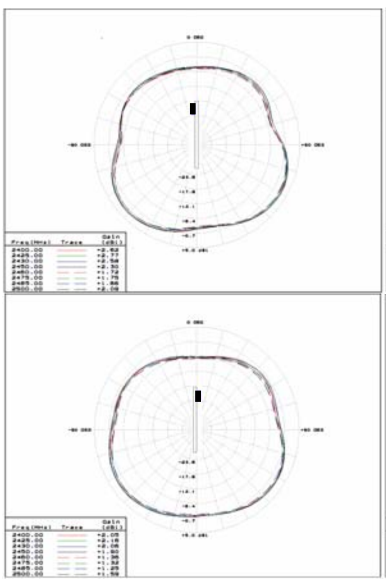
2400-2500 MHz
2.2 dBi



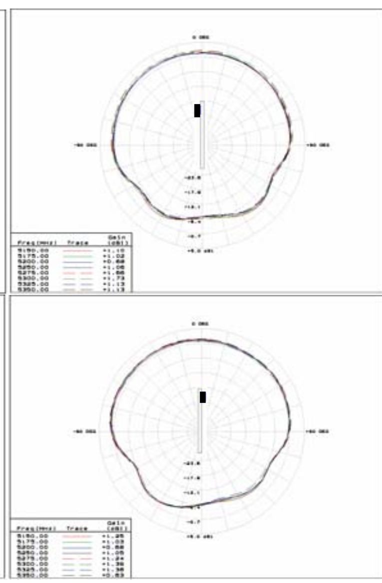
5150-5350 MHz
2.2 dBi



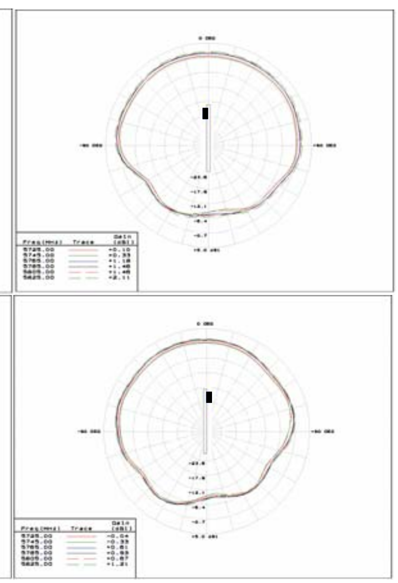
5725-5825 MHz
2.6 dBi



2400-2500 MHz
2.8 dBi

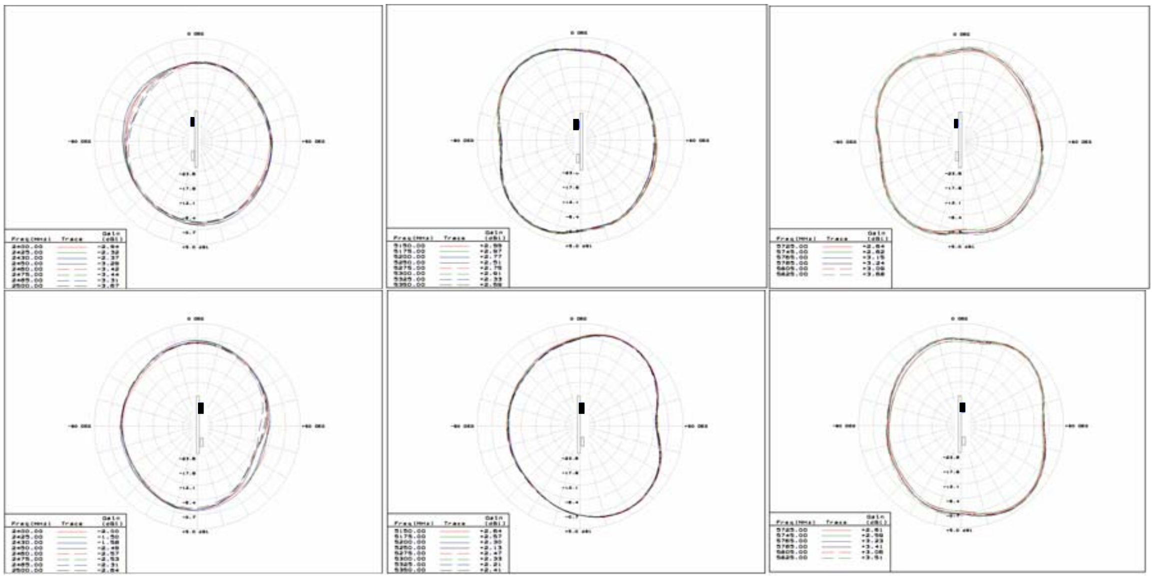


5150-5350 MHz
1.7 dBi



5725-5825 MHz
2.1 dBi

CENTURION
WIRELESS TECHNOLOGIES, INC.



2400-2500 MHz	5150-5350 MHz	5725-5825 MHz
-1.5 dBi	3.0 dBi	3.7 dBi

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