Printed Circuit Technology in Base Station Antenna Design

Designing antennas with consistent performance.

By John Dobrick, Rogers Corporation
Today's designers of base station antennas have at their disposal three proven technologies from which to engineer a design: air dielectric (all metal construction), cable, and printed circuit. There are many hybrids of these three basic approaches. Their choices rest on antenna performance, cost, and a host of other considerations. This article explores the advantages of the printed circuit option and offers ten points to consider when seeking a design solution.
Printed circuit technology allows for the design of antennas with consistent performance. Antenna manufacturers are able to take advantage of the economies of scale provided by the electronics industry's established vendor base for printed circuits. This technology requires fewer parts, which in turn simplifies the manufacturing process while reducing labor. The printed circuit board (PCB) antennas typically consist of a feed network on one circuit and either a series of individual elements or an array of elements on one large sheet of dielectric material. In some cases both the feed network and radiating elements can be printed on a single sheet of low-loss, copper clad, dielectric laminate. The properties of the dielectric material used in the feed network are most demanding in terms of Dk (dielectric constant) value, Dk tolerance and loss tangent. The radiating elements are actually much less demanding in terms of loss performance and tolerances. In many cases, the element for the PCB antenna may consist of stamped metal parts or a series of small, discrete, printed circuit elements.
The phase and amplitude relationship of the signals arriving at the radiating elements from the feed network are critical to the antenna's performance. In order for the antenna to exhibit the proper gain radiation pattern and to satisfy requirements like VSWR (Voltage Standing Wave Radio), low-side lobe levels and proper null fill, the feed network must be tightly controlled. Element spacing is also critical to these requirements. The inherent accuracy of printed circuit patterns lends itself to repeatable control of these values. As a result, PCB antennas can be built with a minimum of labor and do not require tuning nor adjustment.

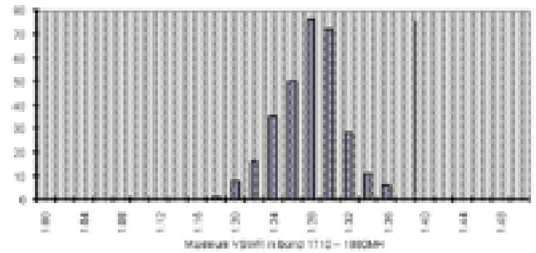

Figure 1. Histogram of maximum VSWR of members of a batch of 300 PCNA 115-19-2 antennas.

The figures accompanying this article illustrate the performance consistency that can be expected from antennas produced using printed circuit technology. Figure 1 is a histogram of maximum in band VSWR readings on a batch of 300 antennas of the same model. The histogram shows the excellent consistency obtained by employing printed circuit technology. Half of the results lie between 1.27:1 and 1.31:1, and not a single antenna exceeds the specified maximum.

Figure 2 illustrates the high degree of antenna gain pattern control that is exhibited with printed circuit antennas. This graph shows the measured elevation patterns of ten different antennas, which have been overlaid to show just how little difference there is between samples. The measurements were made on samples randomly chosen from a large production batch. Specifications for null fill to the right of the main beam and the upper side lobe suppression to the left of the main beam are consistently met. At elevation angles within 60&#176he main beam the ten results are essentially identical to within the width of the plotting pen. Beyond 60&#176 there is more variation, but this is at levels more than 30 dB below the main beam and are the effect of signal pickup at these low levels from active cell sites in the vicinity of the test location.

Ten Points Closer to a Design Solution

The following ten points illustrate the key benefits in printed circuit board design which you may wish to consider when seeking a design solution:

1. Printed circuit boards are single monolithic copper circuits. Generally, there is only one electrical connection from the input connector to the printed circuit which should result in greater stability of performance. It avoids the use of metal-to-metal junctions which can degrade over the life of the antenna due to oxidation, corrosion, and mechanical stress and lead to instability in terms of patterns, gain, return loss, and PIM (Passive Inter-modulation) values.
2. Typically manufacturing imperfections show up in the elevation gain patterns of these panel antennas. These patterns are affected by the amplitude and phase of the signals at each of the elements. The phase and amplitude control offered by the printed circuit feed network is far better than even the most painstaking cable assembly process which offers variations in cable length of &#177 100 mils. *At 2 GHz a 1 degree phase error is caused by only 13 mils of length variation from nominal. At only 50 mils the phase error is about 4 degrees.* The performance variation caused by cold flow of the PTFE dielectric in cable bends and terminations is eliminated. *Over the life of the antenna the change can range from 5 to 30 degrees for each bend.*
3. With microstrip printed circuit power distribution networks, the fields are tightly coupled through the dielectric circuit material due to the higher dielectric constant and close proximity of the line to the ground plane. The feed lines then have a minimal effect on the far field pattern of the antenna.
4. Microstrip-fed, printed circuit antennas have proven to be capable of 200 and 500 watt power levels in cellular applications. This is due to the close proximity of the antenna chassis, which acts as a heat sink.
5. The assembly process for PCB antennas is clean and repeatable. Common or standardized assemblies and tooling can be developed for a large number of antenna types through the use of generic circuit board outlines. There can be a lot of assembly commonality from one design and frequency set to another.
6. PCB antennas have only a fraction of the number of parts found in a metal or

cable antenna. Assembly time and opportunities for error are therefore far lower with a printed circuit antenna. *A typical 2 meter PCB antenna would have 20 fewer parts than a cabled or bent metal antenna.*
7. Printed circuit designs lend themselves to speed in prototyping. Through the uses of automated CAD tools and an extensive PCB manufacturing infrastructure, it is routine to obtain a PCB prototype of a new PCB design variation in 3 to 5 days. Antenna designs are typically iterative, requiring many cycles of trial and adjustment in order to satisfy all design criteria, such as gain pattern, VSWR, beam width, side lobe levels, null fill, etc. The same kind of design iterations on all metal, air dielectric, antennas require longer lead times due to the need to produce manufactured parts. Economical production of an all metal, air dielectric, antenna requires the use of extensive production tooling. This tooling is generally expensive &#151 costing tens of thousands of dollars &#151 and can be a long lead item. As a result, time to market with a PCB antenna is much shorter and tooling costs are minimal. *For PCB antennas to reach a production state the required time is usually around 2-4 weeks while tooling for a cabled or bent metal antenna can require 6 - 12 weeks. Artwork for producing PCB antennas including multi-up charge are about $200.00 per antenna while the tool cost for cable and/or bent metal can easily exceed $1000.00 per antenna.*
8. PCB manufacturing is ideally suited to tighter tolerance requirements as frequency increases and geometries become smaller.
9. Printed circuit designs can be produced with very low profiles leading to less wind loading on the support tower structure.
10. Use of printed circuit designs make it easier to integrate other components (filters, amplifiers, etc.) into the antenna. This is gaining greater attention because of the desire for 'smart' antennas and multi-band antennas or distributed amplification built into the antenna.
Printed circuit antennas become more attractive as the level of antenna complexity increases. Cross-polarized antennas, for example, are really two linear antennas in one. The complexity presented by two feed networks and the number of elements required for the two polarizations present a significant challenge to the cable and air dielectric design methods. Parts count will increase accordingly, making assembly more complex. With the printed circuit antenna, parts count and complexity do not really increase. Both feed networks can be printed on a single circuit. Active antennas with distributed amplification also lend themselves to the printed circuit technique. The amplifier circuits can be incorporated on the same circuit board used for the feed network and/or radiating elements.

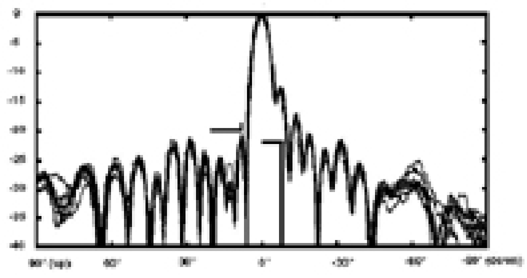

Figure 2. Superposition of measured elevation patterns of ten different production antennas.

A significant amount of progress has been made in the last five years toward reducing the cost of the high performance materials need for a printed circuit feed network. Traditionally, woven glass PTFE laminate has been used in printed circuit antenna designs because of material market cost factors and availability in large panels. There is a desire to produce these antennas with one large circuit rather than several smaller circuits. PTFE resin-based materials have been around for more than 40 years and have essentially reached the bottom of the cost reduction curve. Recently, however, new materials based on a novel thermoset resin system have been introduced. Due to inherently lower raw materials cost, these materials are priced significantly below traditional PTFE/glass materials. Lower material cost combined with improved processing characteristics over that of PTFE-based materials results in significantly lower circuit costs than previously possible. This is done while maintaining electrical performance similar to that of the PTFE-based materials. The new thermoset resin-based materials also have significantly improved mechanical and thermal performance.

Conclusion

While the printed circuit vs. bent metal or cable debate continues in the base station antenna market, both level of complexity and higher operating frequencies are factors which favor a printed circuit design. In general, it is agreed that single polarization antennas at frequencies below 900 MHz or less can be cost effectively produced using the cable or bent metal/air dielectric approach. It can be argued that performance variation on a printed circuit version would be improved. It is also generally agreed that for cross-polarized antennas and for antennas at frequencies above 2000 MHz, the printed circuit antenna will realize a more cost-effective solution. Antennas for PCS and GSM services operating at frequencies between 900 MHz and 2000 MHz fall into a gray area, where many other factors can affect the cost and performance decision. The availability of lower priced, high-performance materials has narrowed the cost gap. From a manufacturing standpoint, the inherent simplicity, low parts count, and resulting low labor content and tuning time required on the printed circuit antenna make it attractive for all frequency ranges. The printed circuit antenna will offer improved gain pattern control and null fill capability with a minimum of design iteration and faster time to market.

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Figures 1 and 2 were contributed by Jim Hartman, Vice President, News Business Development, at Tripoint Global.

*For a copy of complete article containing all charts and images, please e-mail Web Editor at jwalkup@cahners.com.