Omnidirectional Antenna Module

An innovative design for the Space Station Freedom resulted in an omnidirectional antenna utilizing a broadside suspended-stripline and balun to feed a balanced element with provision for mounting of active circuitry in MMIC or Hybrid MIC form.

R.W. Shaw
Shason Microwave Corporation,
Houston, Texas

The Space Station Multiple Access Communications system will allow simultaneous communications to a multitude of users. These users, such as Extravehicular Activities (EVA), Orbital Transfer Vehicles (OTV), Orbital Maneuvering Vehicles (OMV), Space Transportation System Vehicles (STS) and free flyer satellites, require their multiple access antenna system to be constrained to a minimum size and power consumption.

This design addresses the needs of the Space Station Multiple Access Communications System.

Typically these antenna systems must be mounted on a backpack, astronaut space suit, or small pod and have full spherical coverage, usually necessitating multiple antennas and locations. The optimum performance of the antenna system can be achieved by having the front-end active circuits as close to the antenna element as is mechanically and electrically feasible.

This design has addressed the problems associated with the integration, implementation and definition of the multiple access user antenna system. The integration of candidate antenna elements (i.e. microstrip patch, conical spiral, equiangular spiral, etc.) to planar active circuits, either monolithic or hybrid, and the associated implementation of the antenna feed network is a multi-faceted problem.

The innovative part was the merging of three functions: circuitry, feed network and antenna.

The innovative solution to this problem was to merge the three key functions; circuitry, feed network and antenna, into a common design suitable for mounting as a modular plug-in component. The primary objective of this effort was to demonstrate the ability of the feed network to interface a planar transmission line circuit to the input of a balanced antenna.

Numerous techniques have been described in the literature to effect transitions from balanced to unbalanced transmission lines. Each of these methods has its own drawbacks and advantages, however for the the multiple access user system, the broadside coupled transition offers the greatest flexibility and manufacturing capability.

This module consisted of a mateable coaxial input connector, planar transmission line, balun, feed topology and access to a balanced antenna input as shown in Figure 1.

The equivalent circuit description of the transitioning balun is shown in Figure 2, and the physical realization in Figure 3. The input of the network consists of a 50 ohm microstrip (unbalanced) transmission line followed by an unbalanced-to-balanced transition circuit (balun).

The output of the balun is a broadside-coupled suspended stripline balanced transmission line with one conductor on the top and the other on the bottom of the board. The transition section can perform not only the balun function, but an impedance transformation from 50 ohms to the antenna input resistance (ZANT) as well.

The transitioning balun not only mates unbalanced and balanced lines but effects an impedance transformation as well.

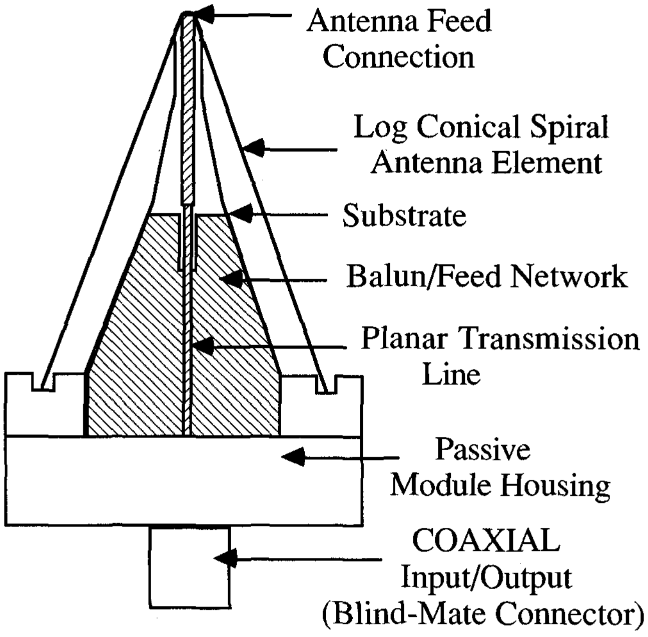


Figure 1. Passive Antenna Module Configuration.

As can be seen in Figure 2, if the output of the balun is Z*ANT = ZANT (resistance with no reactance), then the characteristic impedance of the broadside suspended stripline must be ZANT, for an impedance match condition to occur independent of length "L". An added difficulty in the design of this balun structure is the large step discontinuities associated with the planar transmission line-width changes. This can be seen in Figure 3 as the wide microstrip is narrowed in the transition section.

Empiric modeling is needed to determine the length and widths of the transition gap spacings.

Without accurate models at these high frequencies, it is necessary to determine empirically the appropriate length and widths of the gap spacings in the transition section. The specific design param-

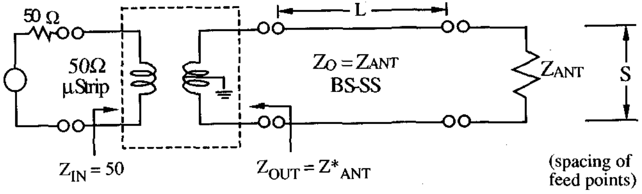


Figure 2: Circuit Description of Transitioning Balun

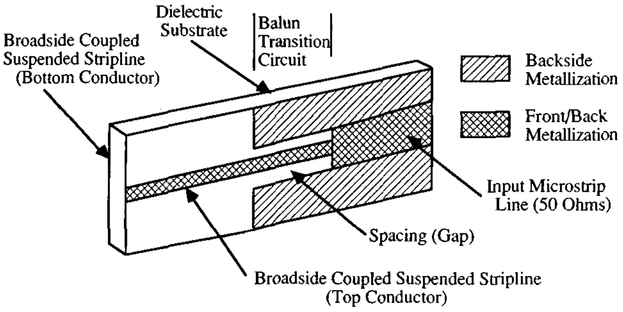


Figure 3: Physical Realization of Transitioning Balun

eters can be calculated from the model shown in Figure 4. This shows a back-to-back balun and is labeled A through D and A' through D'.

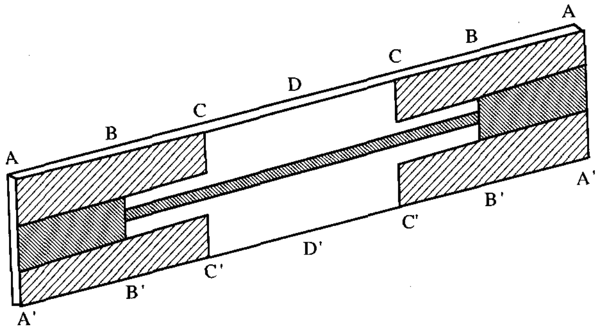


Figure 4: Back-to-Back Balun Model

Microstrip Line

The section of line from A-A' to B-B' is a standard 50 ohm microstrip transmission line. The physical geometry is given in Figure 5. For this project the substrate used was Rogers 5880 [TM] with a dielectric constant of 2.2 and a thickness of 0.010 and 0.020 inches.

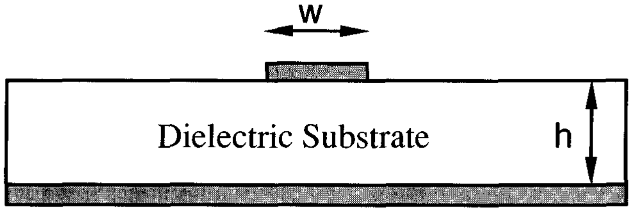


Figure 5: Microstrip Transmission Line

Transitioning Balun

The Section of line B-B' to C-C' is the balanced-to-unbalanced transformer. The balanced-to-unbalanced transformer should convert microstrip to broadside coupled suspended stripline and perform the impedance transformation of 50 ohms to ZANT ohms. The physical geometry and equivalent schematic representation can be seen in Figure 6. As shown, the section appears as two coplanar transmission lines in parallel.

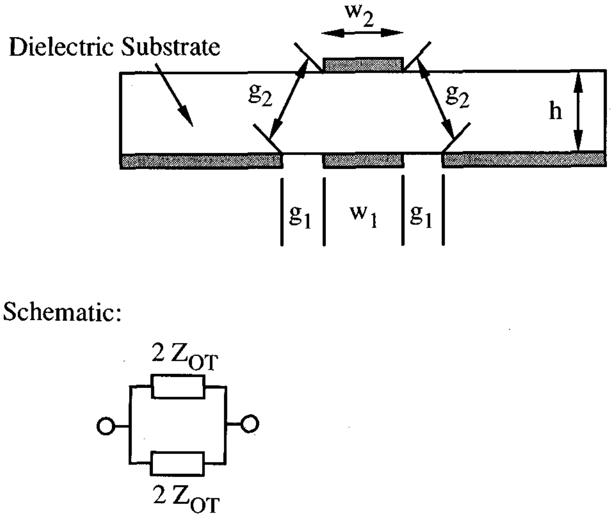


Figure 6: Transitioning Balun's Equivalent Physical Geometry

The equivalent impedance (ZT) of the two lines in parallel can be made to form a quarterwave transformer by setting this impedance equal to the geometric mean value of 50 ohms and ZANT. The input impedance generally found for a log conical spiral antenna is 120 ohms, so ZANT = 120. Also, the length of the two coplanar lines must be a quarterwave. Although these equations are well defined, the effect of the line discontinuities are not modeled. An empirical determination of the lengths and widths of the lines must be made. Several iterations on a computer program can be used to aid in determining the equivalent impedances of various line widths and gap spacings.

Broadside Coupled Suspended Stripline

The section of transmission line from C-C' to D-D' is a broadside coupled suspended stripline. The physical geometry and schematic representation are shown in Figure 7. The balun achieves an approximate odd-mode excitation which causes the two conductors to have equal but opposite polarity potential.

Therefore, a plane of zero potential ($V=0$) lies halfway between the two conductors. This $V=0$

plane is a ground plane located at one half the thickness (H) of the substrate. Each conductor can be modeled as a microstrip line with characteristic impedance of ½ Z0 and on a dielectric of ½ H.

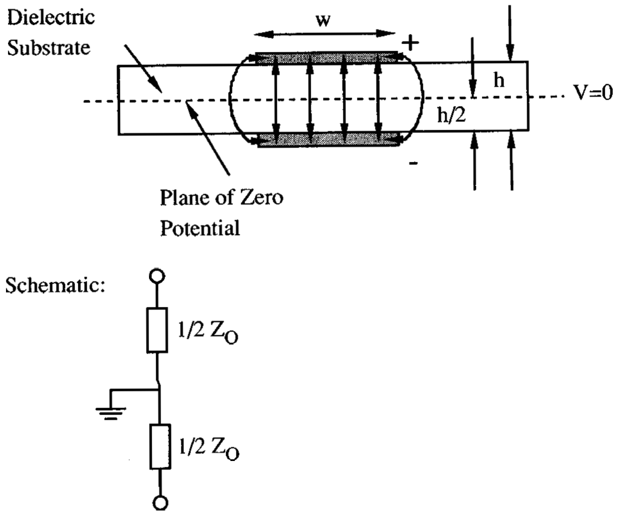


Figure 7. Broadside Coupled Suspended Stripline Physical and Schematic

Mechanical Configuration

A cylindrical shape for the passive module housing was determined to have the most non-constraining configuration. The "tube" shape can be easily integrated to the various user system architectures. The diameter of the module was set at 0.75 inches as it was felt that this size could accommodate the active components required in the full-duplex T/R configuration. The passive module also made use of the OSP (plug-in) connector, rather than a threaded, screw-type mating connector (i.e. SMA or K-connector). This is an enhancement to the maintainability of the module.

> *Use of a push-on connector enhances the maintainability of the module.*

With the OSP connector, replacement of the module requires only "unplugging" the unit. There is no need for a torque wrench or system access to the mating connector with this plug-in configuration. The implementation of the balun and feed requires that the board extend through the inner cone of the log conical spiral antenna element (see Figure 1). The feed board was machined to fit inside the cone and maintains a "safe" distance between the feed conductor lines and the radiating conical element. Typically this safe distance is one third the cone width.

Performance Results

Figure 8 shows a photograph of the various parts of the passive module assembly. On the far left is the transition feed board, the bottom right shows the log conical spiral antenna, and the top shows the complete passive module with the antenna connected to the feed output. Figures 9, 10 and 11 show performance curves for the module.

Of particular interest is the contrast of Figures 9 and 10. Figure 9 shows the feed with a 120 ohm load and Figure 10 shows the exact same network with

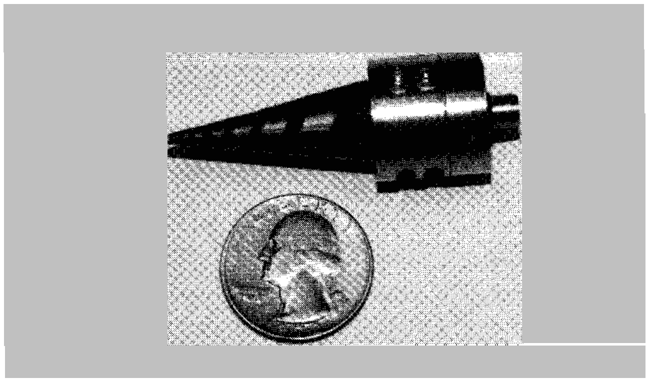


Figure 8. Passive Module Assembly

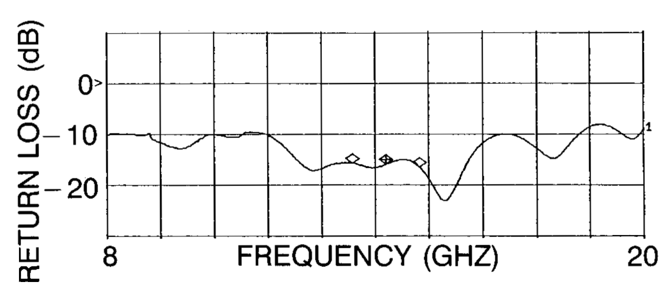


Figure 9. Return Loss of Feed with 120-ohm Load

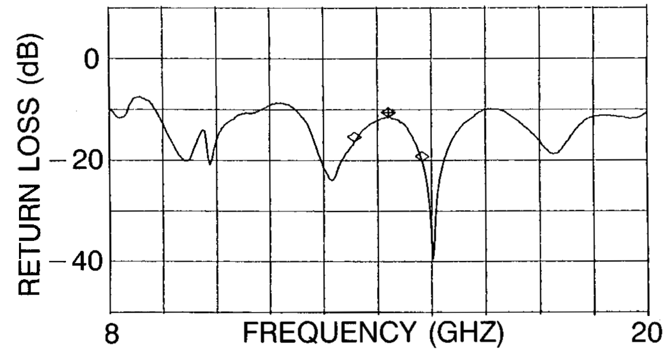


Figure 10. Return Loss of Feed with Conical Spiral Antenna

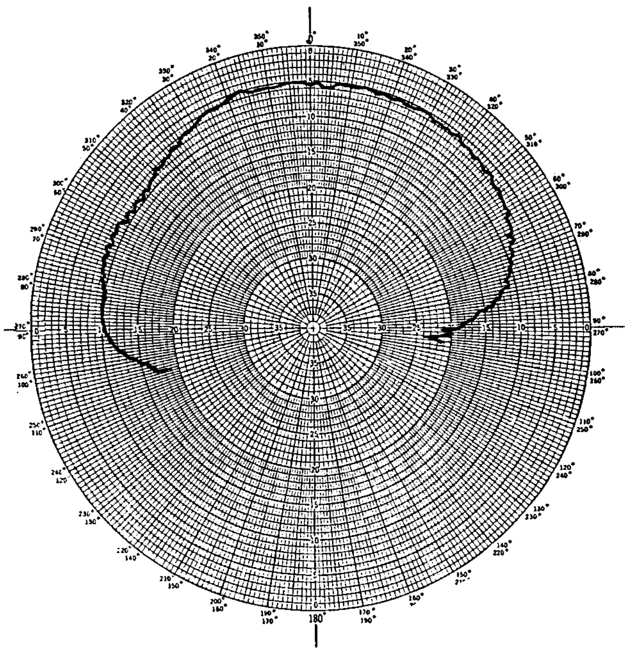


Figure 11. Passive Module Radiation Pattern (Azimuth) at 14.5 GHz

the conical spiral antenna element connected. Notice first that the broadband input impedance of the module has changed. This reflects the input impedance of the antenna element being different from the 120 ohm assumption.

Secondly, notice the lower frequency resonance shown in Figure 10. This resonance was removed by placing absorber material (lossy) around the base of the conical antenna. The rf current in the spirals of the antenna should degenerate to zero at the base; the lossy absorber material assures that this occurs. Figure 11 shows the radiation pattern of the module at the design frequency of 14.5 GHz.

The successful development of this design can be summarized by the following list of advantages:

1) Wide Bandwidth (8-20 GHz)
2) Ease of Fabrication (Repeatable)
3) Planar Geometry (Active Circuit Integration)
4) Miniature Size (Ease of Systems Integration)
5) Plug-in/Connector (Maintainable)
6) Not Antenna Limited (Mateable to Log Conic Spiral, Equiangular Flat Spiral, Microstrip Patch, and Waveguide Horn antennas)

The development of this balun precedes the design and implementation of a miniature transmit/receive (T/R) module which is to be integrated with the antenna element. This T/R module could include the transmit amplifiers, receive low noise amplifiers, diplexer, balun, feed network and antenna element.

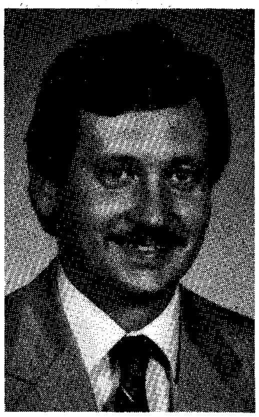
The miniature size and mechanical integrity of such a module has application to the multiple access users described and also has the potential to be adapted to numerous other system mounting configurations. In addition, the wideband response of the design supports any of the frequency division multiple access (FDMA) channels of the transmit or receive frequency band.

Acknowledgments

This work was supported by NASA Contract NAS 9-18106. The author would like to acknowledge Wayne Cope, Larry Dolson and Vince Karasack of Lockheed Engineering and Sciences for their many efforts and support in this project. Mr. Cope was involved in the circuit board fabrication, and Mr. Dolson and Mr. Karasack in the design and electrical testing of the conical spiral antennas.

References

1. Shaw, R.W.; Kovitz, J.K.: A Distributed Array Antenna System. IEEE MTT-S Digest, June 1986, pp. 315-318.
2. Shaw, R.W.; Kovitz, J.K.; Raffoul, G.; Johnson, L.: Waveguide Horn-to-Finline Transition Assembly. NASA Technical Briefs, vol. 11, no. 9, Oct. 1987.
3. Ho, Chen Y.; Traynor, Robert: New Analysis Technique Builds Better Baluns. Microwaves & RF, Aug. 1985, pp. 99-102.
4. Lavedan, L.J.: Design of Waveguide-to-Microstrip Transitions Specially Suited to Millimetre-Wave Applications. Electronic Letters, 1977, pp. 81-82.
5. Wheeler, Harold A.: Transmission-Line Properties of Parallel Strips Separated by a Dielectric Sheet. IEEE Transactions on Microwave Theory and Techniques, 1964, pp. 172-185.
6. Shaw, R.W.; Kovitz, J.K.; Johnson, L.; and Lu, B. Portions of this paper were presented at the IEEE MTT International Symposium, 1990, Dallas, Texas under the title "Integrated active antenna module for space station multiple access communications."



Roland W. Shaw *received his BSEE degree from Texas A&M University and his MSEE degree from Southern Methodist University in 1978 and 1983 respectively. His technical experiences have been with the Advanced Technology Laboratory of Texas Instruments, Inc. in Dallas, Texas and in support of the NASA - Johnson Space Center in Houston, Texas with Lockheed Engineering and Sciences Company.*

His most recent experience at JSC has been in the development of array antenna components for space-to-space communications and tracking radars. He is also active in the promotion of microwave technology in the professional and academic areas. He has developed a training course in introductory microwave circuit design and presents this material to professional engineers for practical use in their work.

Mr. Shaw serves as Director of Engineering and Development for Shason Microwave.