INTEGRATED ACTIVE ANTENNA MODULE FOR SPACE STATION MULTIPLE ACCESS COMMUNICATION

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ABSTRACT

The development of an integrated module applicable for use on the Space Station Freedom mulitple access communication system (MACS) is presented. The innovative design of this module was found in the ability to merge the three key functions of circuitry, feed network and antenna element into a common unit capable of being mounted on a MACS user platform. The design utilizes a broadside suspended-stripline and balun to feed a balanced antenna element and still allow the active circuitry to be implemented in MMIC or hybrid MIC technology.

INTRODUCTION

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. 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 mechanically and electrically feasible.

This work 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 solution to this problem was found in the ability to merge the three key functions; circuitry, feed network and antenna, into a common design capable of being mounted as a modular plug-in component. The primary objective of this effort was the successful demonstration of the feed network to interface a planar transmission line circuit to the input of a balanced antenna. Numerous techniques have been used throughout the literature to achieve transitions from balanced to unbalanced transmission lines. Each of these various methods offers its own drawbacks and advantages, however for the specific application of 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.

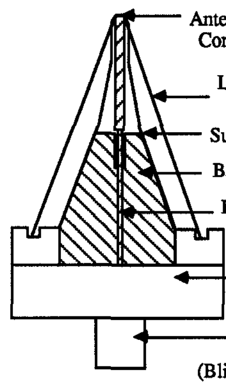

Figure 1: Passive Module Configuration

DESIGN APPROACH

The basic circuit description of the transitioning balun is shown in figure 2. The physical realization of this circuit topology can be seen in figure 3. The input of the network consists of a 50 ohm microstrip transmission line. This unbalanced line is followed by the unbalanced-to-balanced transition circuit. The output of the balun is a broadside-coupled suspended stripline balanced transmission line with one conductor on the top of the board and the other conductor on the bottom of the board. The transition section can perform not only the balun function, but also yield an impedance transformation from 50 ohms to the antenna input resistance (Z_{ANT}). As can be seen in figure 2, if the output of the balun is $Z^*_{ANT} = Z_{ANT}$ (resistance with no reactance), then the characteristic impedance of the broadside suspended stripline must be Z_{ANT}, 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.

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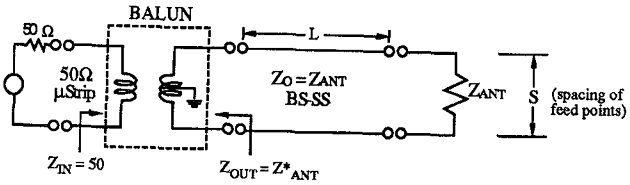

Figure 2: Circuit Description of Transitioning Balun

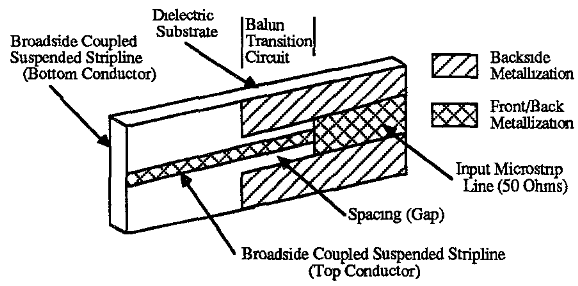

Figure 3: Physical Realization of Transitioning Balun

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

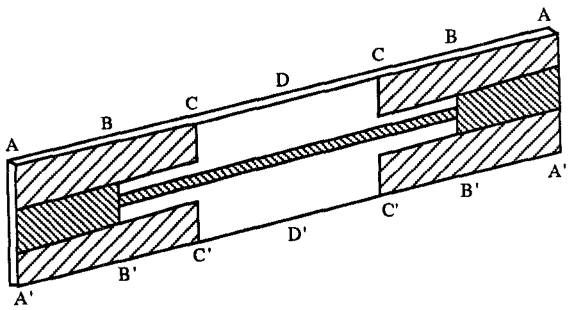

Figure 4: Back-to-Back Balun Model

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 with a dielectric constant of 2.2 and a thickness of .010 and .020 inches.

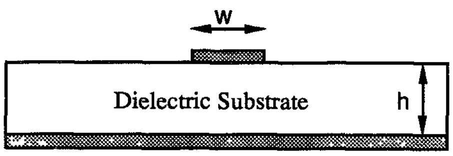

Figure 5: Microstrip Transmission Line

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 Z_{ANT} ohms. The physical geometry and equivalent schematic representation can be seen in figure 5. As shown, the section appears as two coplanar transmission lines in parallel. The equivalent impedance (Z_T) 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 Z_{ANT}. The input impedance generally found for a log conical spiral antenna is 120 ohms, so Z_{ANT} = 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 modelled. 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.

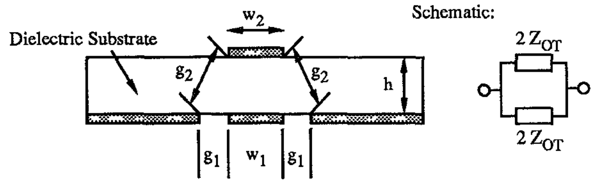

Figure 6: Transitioning Balun's Equivalent Physical Geometry and Schematic

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 can be seen in figure 7. The balun achieves an approximate odd-mode excitation which yields 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 modelled as a microstrip line with characteristic impedance of 1/2 Z_O and on a dielectric of 1/2 H.

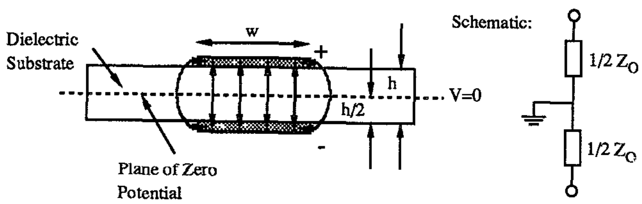

Figure 7: Broadside Coupled Suspended Stripline Physical and Schematic

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 accomodate 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 was viewed as an enhancement to the maintainability of the module. With the OSP connector, replacement of the module involved only to "unplug" 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 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 of 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 is being achieved. Figure 11 shows the radiation pattern of the module at the design frequency of 14.5 GHz.

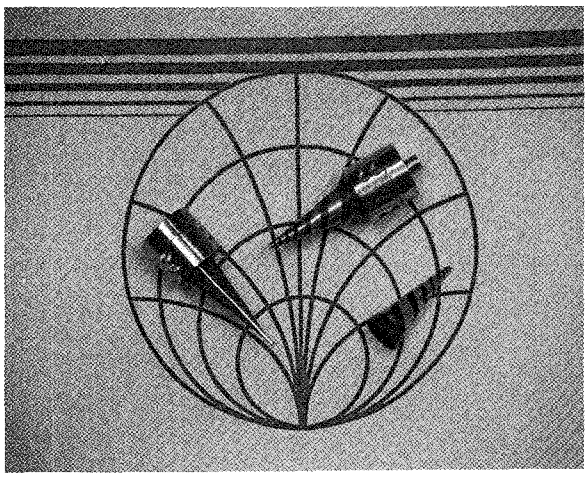

Figure 7: Passive Module Assembly

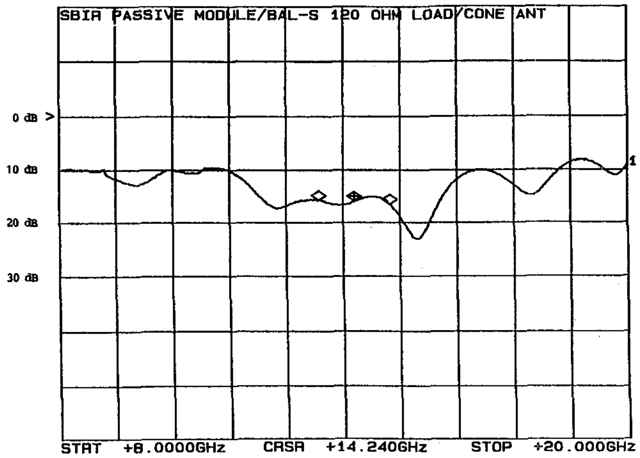

Figure 9: Return Loss of Feed with 120-ohm Load

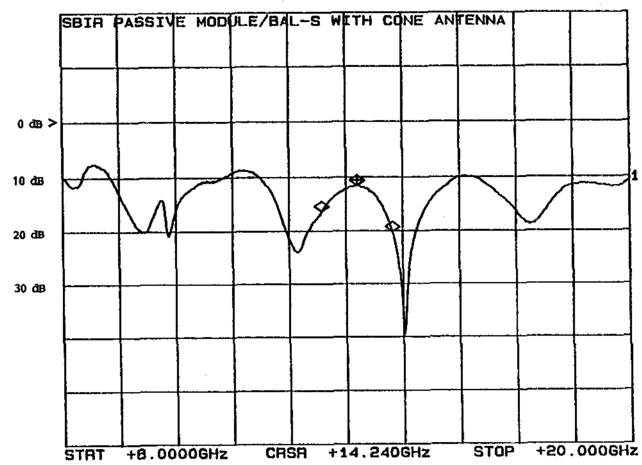

Figure 10: Return Loss of Feed with Conical Spiral Antenna

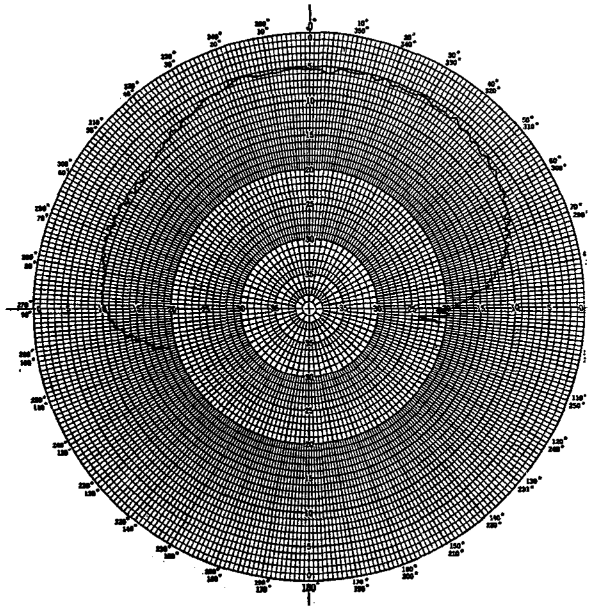

Figure 11: Passive Module Radiation Pattern (Azimuth) at 14.5 GHz

CONCLUSIONS

This work has addressed the problems associated with the integration, implementation and definition of the Space Station multiple access user antenna system. The integration of a candidate antenna element to a planar feed network suitable for use with hybrid or monolithic active components has been demonstrated. The innovative solution to this problem was found in the ability to merge the three key functions; circuitry, feed network and antenna element, into a common design capable of being mounted as a modular plug-in component. The module consisted of a mateable coaxial input connector (OSP designation), a planar unbalanced transmission line (microstrip), a transitioning balun, a balanced transmission line (broadside coupled suspended stripline) configured to the appropriate antenna feed topology, and a candidate (log conical spiral) antenna element. The successful development of this module can be highlighted by viewing table 1 which lists several of the features associated with this design concept.

Feature	Result
Wide Bandwidth	8 - 20 GHz
Ease of Fabrication	Repeatability
Planar Geometry	Active Circuit Integration
Miniature Size	Ease of Systems Integration
Plug-in Connectorized	Maintainability
Not Antenna Limited	Mateable to: 1) Log Conical Spiral 2) Equiangular Flat Spiral 3) Microstrip Patch 4) Waveguide Horn

Table 1: Key features of Design Concept

It has been shown that a broadside coupled suspended-stripline circuit can achieve a wideband (8-20 GHz) feed network capable of transitioning the planar transmission lines of the active circuits to the balanced antenna element input (balun). This feed network also acts as an impedance transformer to match the antenna input to the associated active circuits.

The development of this balun has prepared the foundation for the design and implementation of a miniature transmit/receive (T/R) module which will 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 mentioned above and has the flexibility to be adapted to the numerous system mounting configurations. In addition, the wideband response of the design allows the unit to be configured in any of the frequency division multiple access (FDMA) channels of the transmit or receive frequency band.

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