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Abstract

This report presents a new planar, wideband feed network for a slot spiral antenna, and the subsequent design and performance of a VHF antenna utilizing this feed design. Both input impedance and radiation pattern measurements are presented to demonstrate the performance and usefulness of this feed. Almost all previous designs have utilized wire spirals, requiring bulky, non-planar feeds with separate baluns, and large absorbing cavities. The presented slot spiral antenna feed integrates the balun into the structure of the slot spiral antenna, making the antenna and feed planar. This greatly simplifies the design and construction of the antenna, in addition to providing repeatable accuracy. It also allows the use of a very shallow reflecting cavity for conformal applications. Finally, this feeding approach now makes many of the known miniaturization techniques viable options.

A New Planar Feed for Slot Spiral Antennas

1 Introduction

Spiral antennas are particularly known for their ability to produce very wide-band, almost perfectly circularly-polarized radiation over their full coverage region. Because of this polarization diversity and broad spatial and frequency coverage, many different applications exist, ranging from military surveillance, ECM, and ECCM uses, to numerous commercial and private uses, including the consolidation of multiple low gain communications antennas on moving vehicles.

For the typical wire spiral antenna, the performance advantages mentioned above come at the price of size and complexity. While the radiating elements of a wire spiral may be planar, the feed network and balun structures generally are not, and combine to add weight, depth, and significant complexity to the system. Furthermore, because the spiral antenna radiates bi-directionally, an absorbing cavity is generally used to eliminate the radiation in one direction, adding even more depth to the antenna. While some designs exist [1] that integrate the feed and balun into the cavity and reduce the complexity somewhat, the cavity is still at least a quarter-wavelength deep at the lowest frequency of operation, adding significant thickness to the antenna [2].

A slot spiral is not burdened with many of these difficulties. As is demonstrated in this report, the balun and feed structure may be integrated into the planar radiating structure. This greatly simplifies the construction and increases the accuracy of the antenna by allowing standard printed circuit techniques to be used throughout the entire fabrication process. Also, while the slot spiral also radiates bi-directionally, a deep, absorbing cavity is not necessary. In fact, for conformal mounting, a very shallow reflecting cavity is sufficient, and also serves to increase the gain somewhat.

2 Design of the Planar Feed

The front and back sides of a slot spiral antenna utilizing the new planar feed are shown in Figures 1a & 1b, respectively. The balun structure consists of

a microstrip line that winds towards the center of the spiral antenna, much like the infinite balun developed by Dyson [3]. At the center of the antenna, the feed is executed by breaking the ground plane of the microstrip with the spiral slot. To maximize the transfer of energy from the microstrip line to the slotline, the impedance of the slotline is chosen to be twice that of the microstrip line. At the feed point, the microstrip line views the slotline as a pair of shunt branches, and thus this choice of slotline impedance yields a perfect match at the feed. In Figure 1a, the microstrip line is continued some distance past the feed point, and then terminated with an open circuit. The microstrip line may also be directly shorted to the opposite side of the slot, as will be discussed later.

3 Experimental Results

To verify the operation of this new feed, and the antenna in general, an 18-mil thick dielectric substrate with a dielectric constant of 4.3 was chosen (FR-4), and an archimedean slot spiral antenna with an outer diameter of 6" and a growth rate of .166 was designed and fabricated. The microstrip feed was designed to have an impedance of $50\ \Omega$, and to make a perfect match at the feed, the slot-line was designed to have an impedance of $100\ \Omega$. As was discussed above, a quarter-wavelength open-circuit microstrip stub was used to maximize the coupling at the feed. An idealized view of the spiral slot arm termination used is shown in Figure 2. While this feed was well-matched, and the slot termination seemed to be effective, as can be seen in Figure 3, the radiation patterns show rather high axial ratio. This was largely attributed to coupling between the microstrip feed line and the slot line.

To minimize this coupling, a new antenna was designed and constructed, making the substrate as thin as possible, and the microstrip line narrower. The $90\ \Omega$ radiating spiral slot is 28 mils wide, with a slot center-to-center separation of 205 mils. At the connector, the $50\ \Omega$ microstrip is 18 mils wide. It tapers to $65\ \Omega$ (11 mils wide) in the active portion of the spiral, thereby minimizing its width, and then tapers back out to $45\ \Omega$ to match the impedance of the radiating slot line. For the previous design, the ratio of the widths of the ground plane to the microstrip line was approximately 5:1. In the new design, this ratio was approximately 16:1.

As shown in Figure 4, this feed is again very well-matched. Figure 5

shows the radiation pattern and axial ratio at several frequencies throughout the operating range of the antenna. As can be seen, there is significant improvement in both the axial ratio and pattern shape with this second antenna, as compared with the original antenna (see Figure 3). The remaining axial ratio is attributed both to the non-symmetric ground plane around the antenna, and to a lesser extent, to the unmatched slot arm termination.

Patterns for the cavity-backed configuration are also shown in Figure 6. The cavity was 200 mils ($.015 \lambda$ @ 900 MHz) deep, and the patterns in Figure 6 clearly demonstrate that low axial ratios can be achieved with the proposed antenna and feed combination. They also show that the axial ratio improves as the frequency is increased, and indicate that the compromise in the axial ratio at the lower frequencies is due to interference from the edges of the finite ground plane used in the measurements. The higher backlobes at the lower frequencies also support this conclusion. The size of the rectangular ground plane was approximately 12" x 15", making it only $.914 \lambda$ x 1.14λ at 900 MHz.

4 Current Work

The patterns shown in Figures 3, 5 & 6 are calibrated in dB_i, and show that the antenna has very low gain. This is mostly due to the lossy nature of the dielectric substrate. Both measurements and numerical simulations are currently being performed to determine how much of these losses may be attributed to the substrate and ohmic losses, and to determine the presence of any other loss mechanisms.

Further measurements are also being performed on the new feed. The extremely wide-band nature of S_{11} (Figure 4) demonstrates that, due to the almost perfect impedance match, the quarter-wave open-circuit microstrip stub does not play a significant role in the operation of the feed. Studies are underway to determine the validity of this assumption. A slightly different feed style, utilizing a short-circuit feed, as mentioned above and shown in Figure 7, was also tested, and found to be almost identical in both pattern and impedance performance.

5 Improved Antenna Design / Future Work

To remedy the difficulties discussed above, a new antenna should be designed, with the following modifications.

- The antenna should be constructed on a low-loss microwave dielectric.
- The antenna should be measured using a circularly-symmetric ground plane.
- A new, more symmetric and lossy slot & ground plane termination should be used.

6 Conclusions

By virtue of its planar construction, the new slot spiral antenna feed structure presented here not only simplifies the construction and increases the accuracy of the slot spiral antenna, but also makes possible a much thinner design. This greatly increases its applicability, especially in conformal mounting applications. Furthermore, although the slot spiral has always been a prime candidate for various miniaturization techniques, it has often been avoided due to feeding difficulties. By providing a cost-effective, efficient, and accurate feeding technique, this feed now makes many of these miniaturization techniques viable options, creating a whole new series of possible applications.

7 References

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2. R.G. Corzine, J.A. Mosko, "Four-Arm Spiral Antennas," Artech House, 1990 .
3. J.D. Dyson, "The Equiangular Spiral Antenna," *IRE Trans. Antennas Propagat.*, Vol AP-7, Apr 1959, pp. 181-187.



Figure 1a. Top of Slot Spiral,
Showing Microstrip Feed.

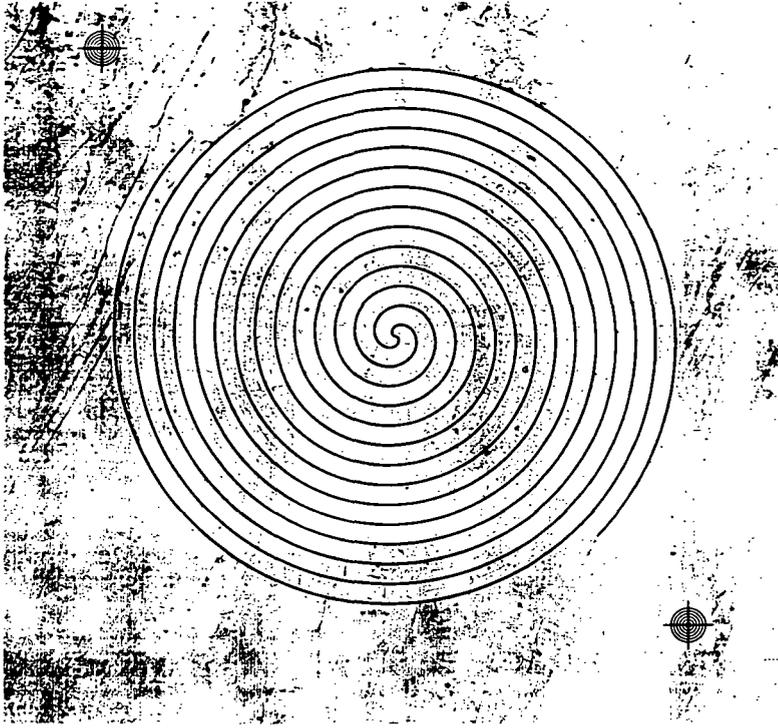


Figure 1b. Bottom of Slot Spiral,
Showing Radiating Slots.

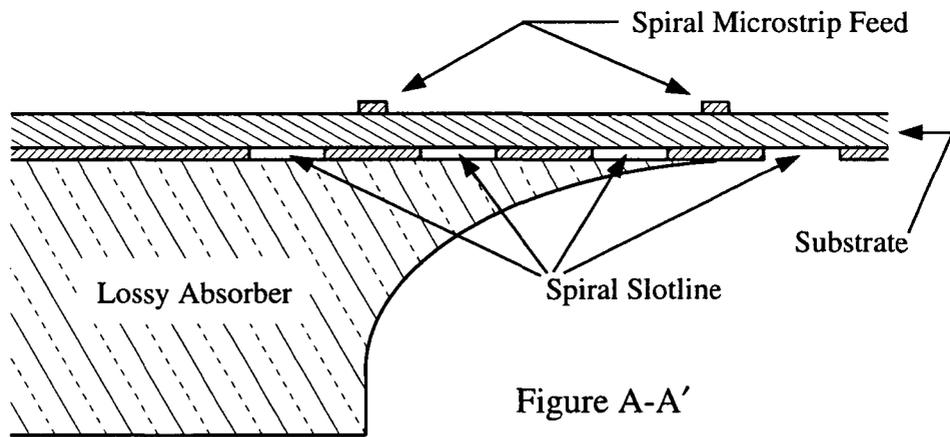
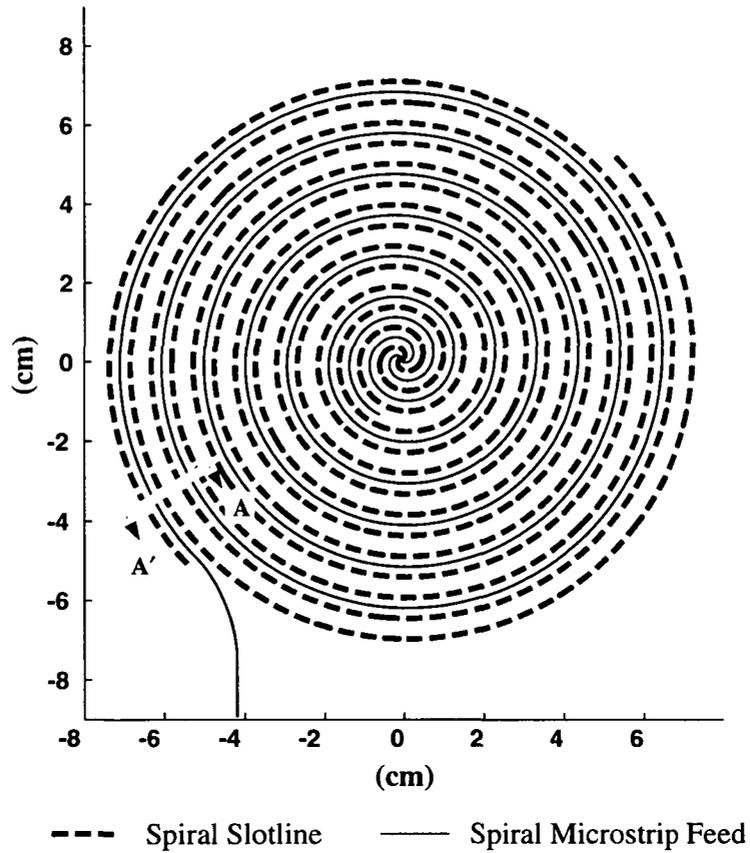


Figure 2. Illustration of the Tapered Lossy Foam Absorber for Spiral Arm Termination.

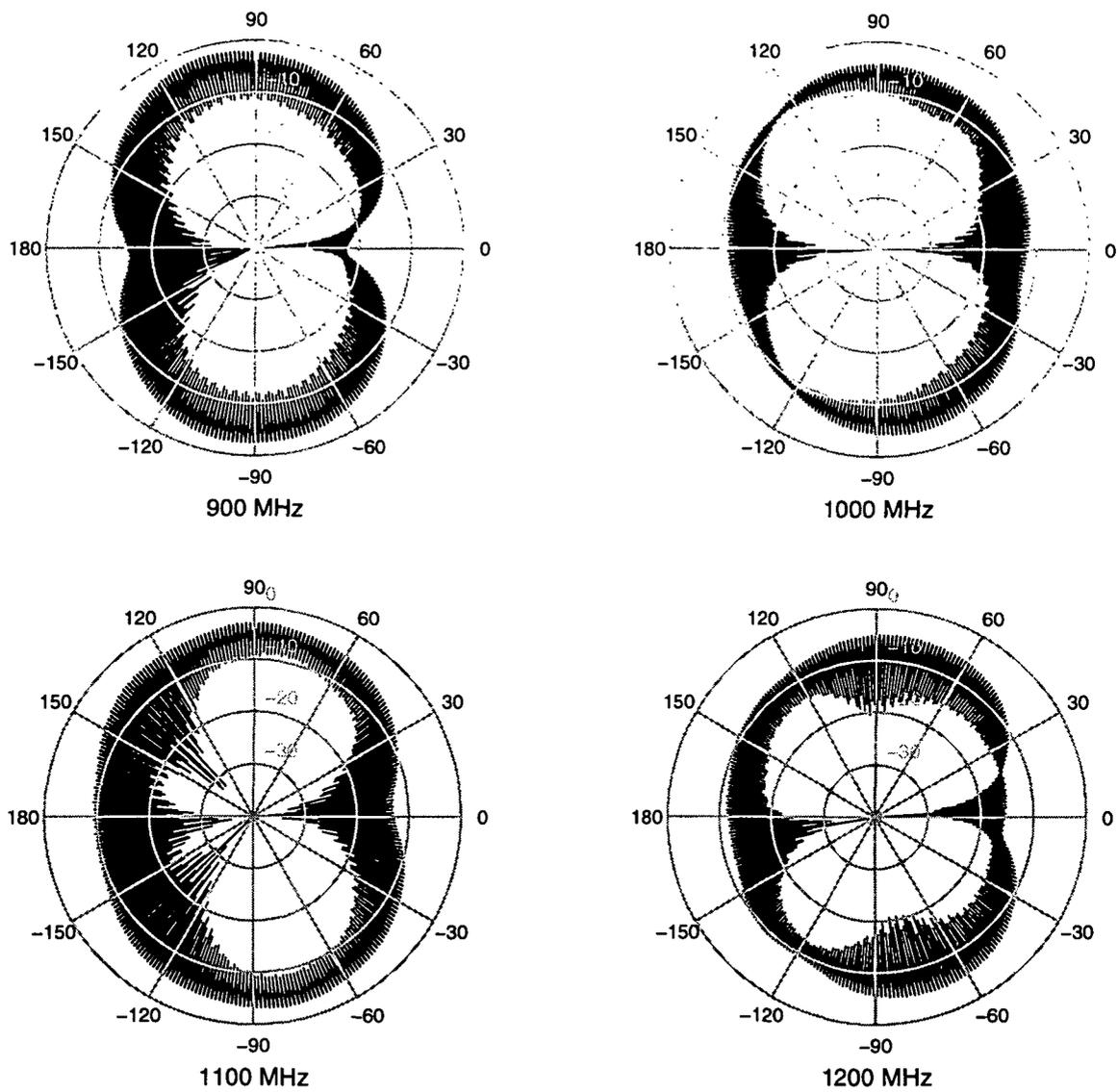


Figure 3. Radiation Patterns of the Free Standing Slot Spiral.

(Patterns are Radiated Power, Displayed with 40 dB of Dynamic Range.)

The Spiral was Constructed on a Rectangular Substrate with Thickness $t=18$ mils and Relative Dielectric Constant $\epsilon_r = 4.3$.

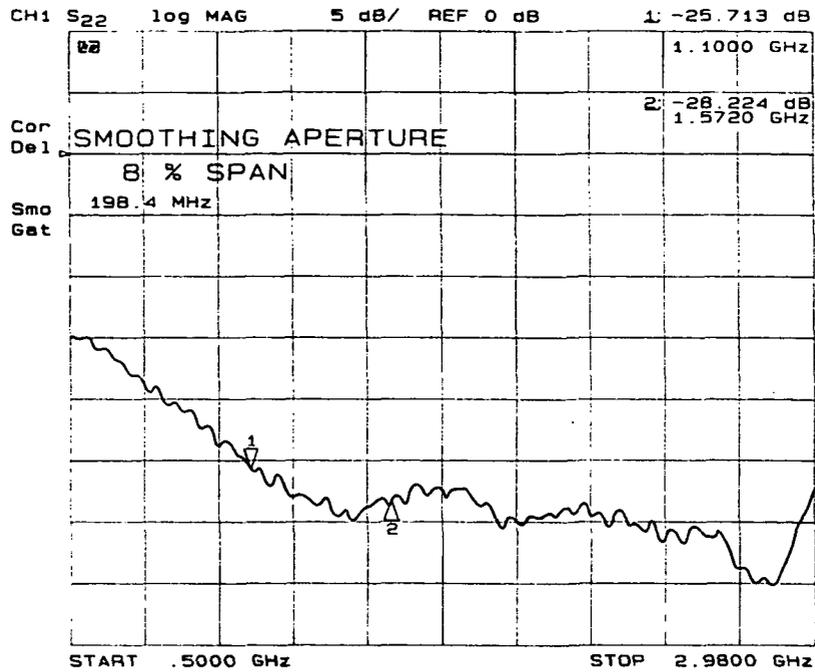


Figure 4. S_{11} Measurement of the Fabricated Slot Spiral with the Microstrip Feed.

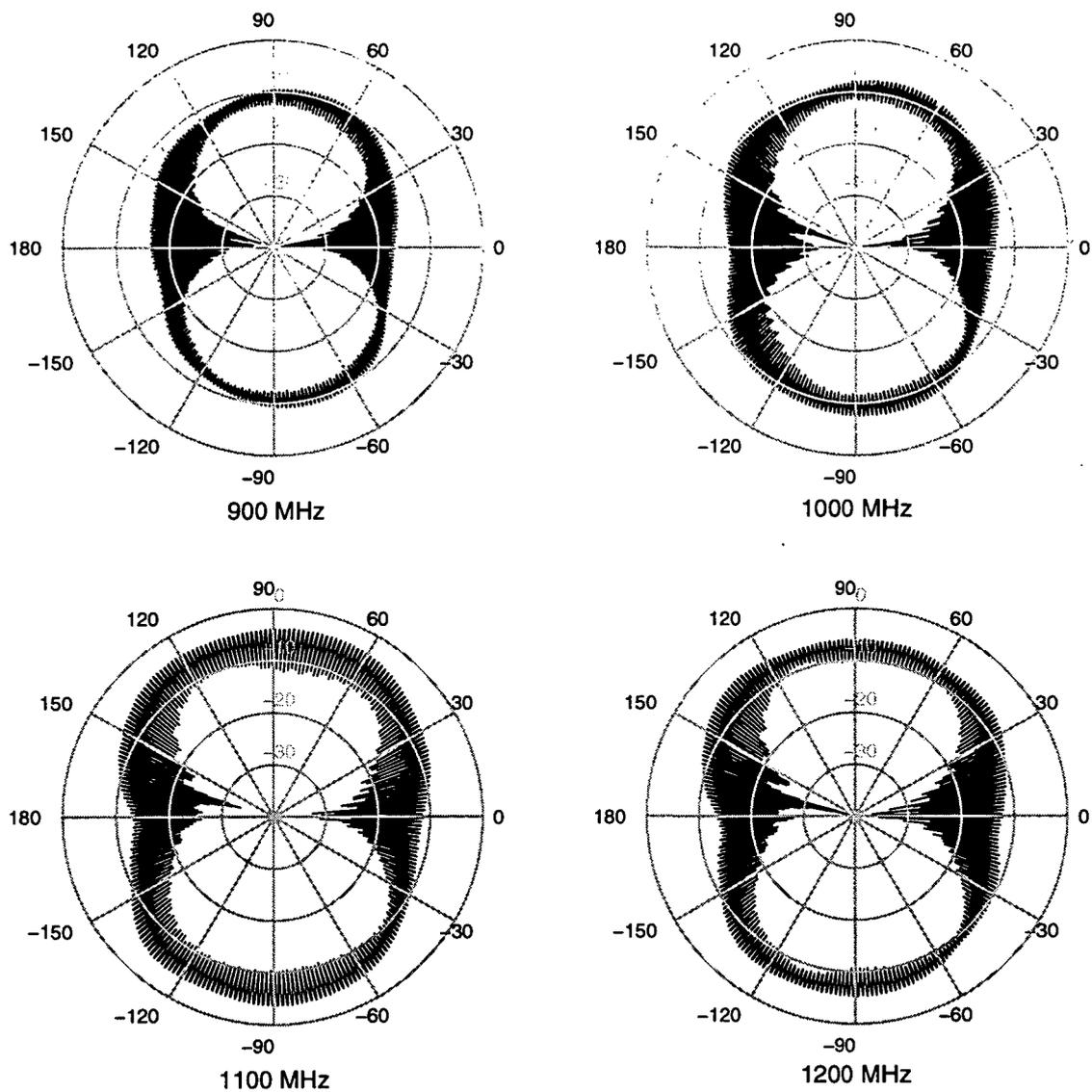


Figure 5. Radiation Patterns of the Free Standing Slot Spiral on a Thinner Substrate, with Tapered Microstrip Feed.

(Patterns are Radiated Power, Displayed with 40 dB of Dynamic Range.)

The Spiral was Constructed on a Rectangular Substrate with Thickness $t=10$ mils and Relative Dielectric Constant $\epsilon_r = 4.3$.

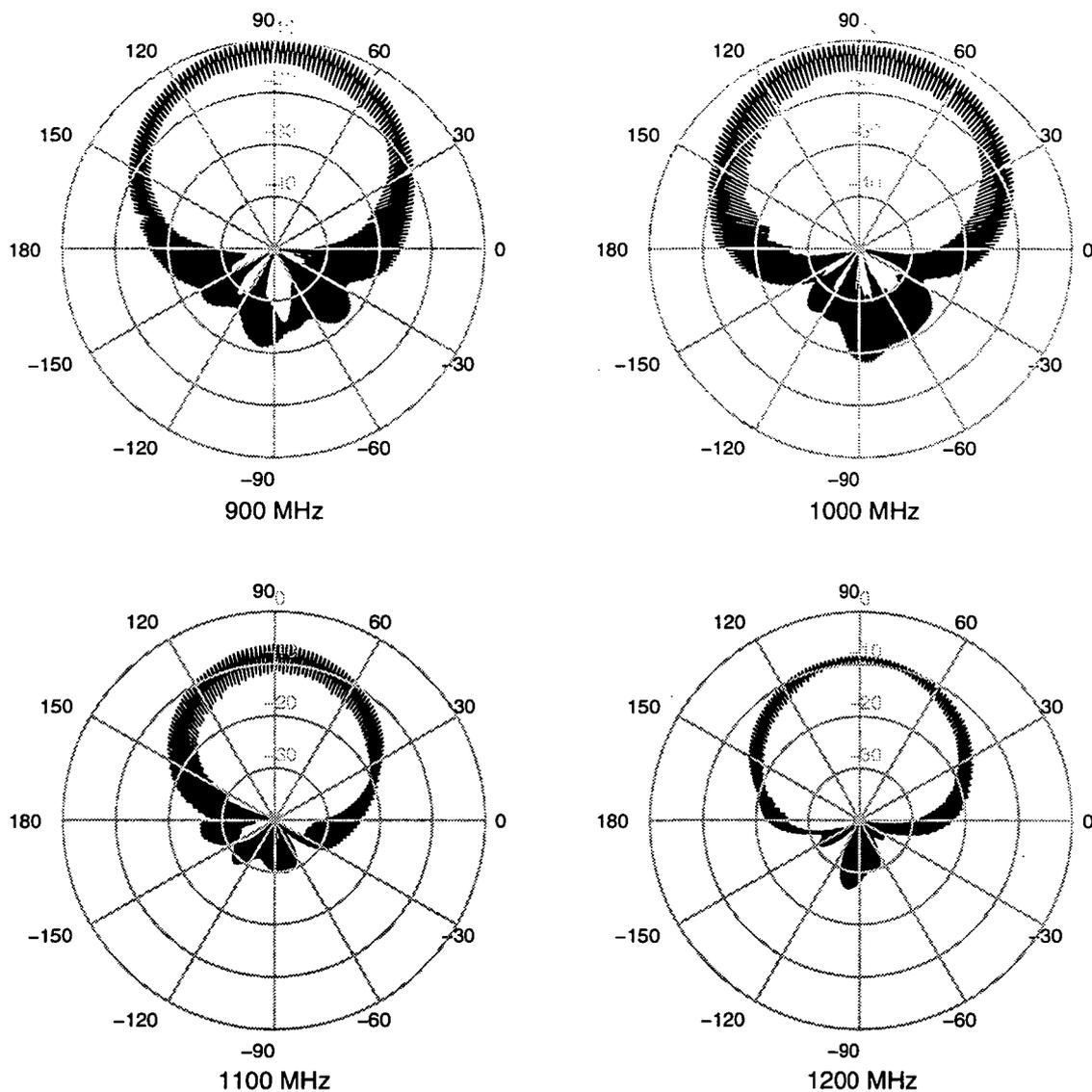


Figure 6. Radiation Patterns of the Cavity-Backed Slot Spiral with the Thinner Substrate and Tapered Microstrip Feed.

(Patterns are Radiated Power, Displayed with 40 dB of Dynamic Range.)

The Spiral was Constructed on a Rectangular Substrate with Thickness $t=10$ mils and Relative Dielectric Constant $\epsilon_r = 4.3$.

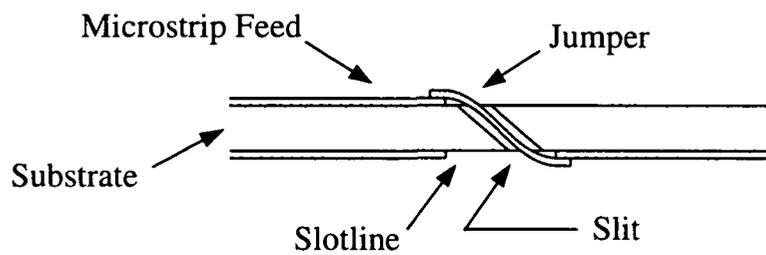


Figure 7. Alternate Feed Geometry Utilizing a Short Circuit Connection.