NOVEL ANTENNA TOPOLOGIES FOR SDR

Mike Pilcher (Manager, RF and Reconfigurable Systems Section: Southwest Research Institute, San Antonio, TX, USA; mpilcher@swri.org); Travis Thompson (Research Engineer, RF and Reconfigurable Systems Section: Southwest Research Institute, San Antonio, TX, USA; tthompson@swri.org

ABSTRACT

Southwest Research Institute® has developed and demonstrated two new antenna topologies with excellent characteristics for SDR applications. The stub-shorted cylindrical meander is an electrically small, narrow-band, but electrically tunable antenna and the tapered-aperture small helix (TASH) is a mechanically sturdy, decade-bandwidth antenna with little sensitivity to an imperfect ground plane. These patented topologies have application to standard mobile radio, but can be particularly beneficial to band-selectable SDRs.

This paper and presentation will present depictions of the antenna topologies, simulation results, and laboratory measurements. The relative performance of the latest Numerical Electromagnet Code (NEC-4) simulation will also be discussed. The simulated behavior of the TASH antenna was very close to the actual laboratory measurements, but the simulated behavior of the cylindrical meander was very different. One problem with modeling electrically small antennas (like the cylindrical meander) is that they often have close-coupled conductors which act differently than predicted by NEC.

1. INTRODUCTION

Commercial companies have been rapidly developing electronic hardware components for use in future SDR systems. This includes improvements in RF front-ends (better lower noise amplifiers, more flexible filters, additional programmability) and analog-to-digital and digital-to-analog converters (wider bandwidths, higher dynamic ranges, faster sampling rates). There has also been considerable work in software architecture design. Although the hardware and software components have seen role migration in SDRs or other reconfigurable radio systems, all radio transmission systems will always require some antenna. The research described by this paper describes two antenna topologies aimed at the need for the innovative antennas for SDR systems.

2. TAPERED-APERTURE SMALL HELIX (TASH)

The TASH antenna topology is excellent for broadband designs to be used in uncontrolled environments. The next three subsections describe the simulated performance, the measured performance, and the survivability after ballistic events. The TASH antenna is covered by US Patent #6,339,409, filed January 24, 2001. Figure 1 shows an unencapsulated TASH antenna prototype for the 225 MHz to 2,000 MHz band.

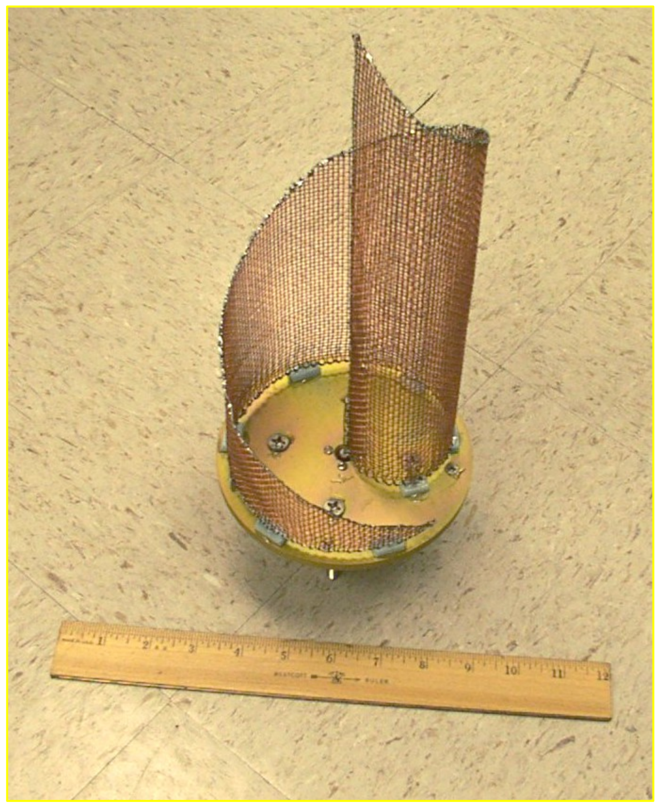

Figure 1 – TASH Antenna Prototype

2.1 Simulation Results

Figures 2, 3, and 4 illustrate the simulated VSWR, low-end frequency antenna pattern, and high-end frequency antenna pattern, respectively. The VSWR plot indicates a good broadband match for all frequencies over 225 MHz, and the relatively omni-directional pattern is desirable for mobile radio communication.

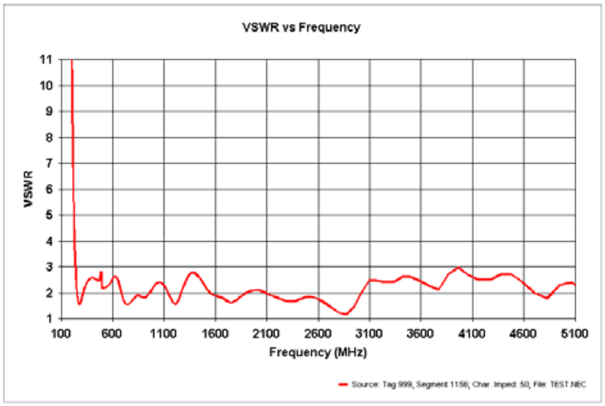

Figure 2 – TASH Antenna Simulated VSWR

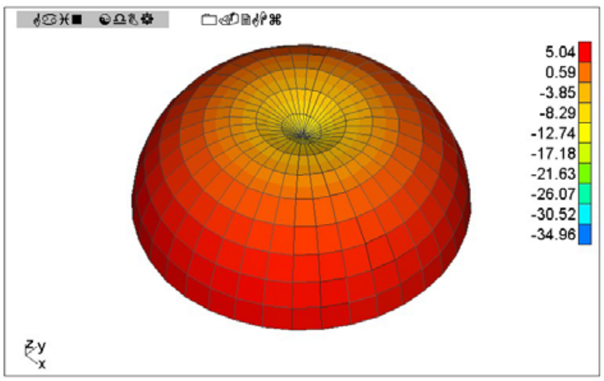

Figure 3 –Simulated Beam Pattern at 225 MHz

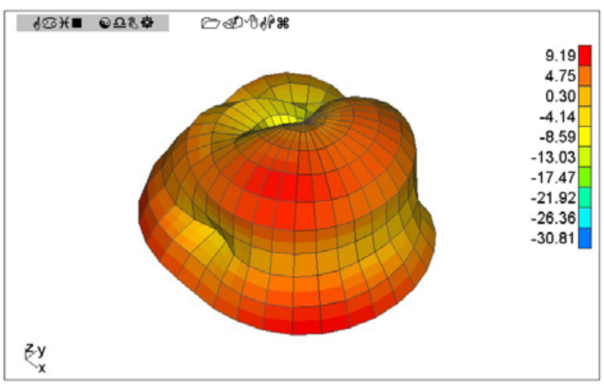

Figure 4 –Simulated Beam Pattern at 2 GHz

2.2 Laboratory Results

Figure 5 displays the measured VSWR using a network analyzer. Note the VSWR is less than 2.5 for the entire 225 to 2,500 MHz range, and less than 2.0 for the vast majority.

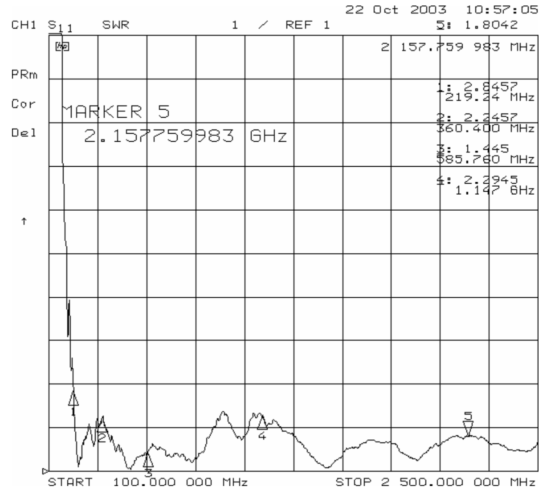

Figure 5 – Measured VSWR

Figure 6 shows the horizontal antenna pattern at 0º elevation – roughly omnidirectional.

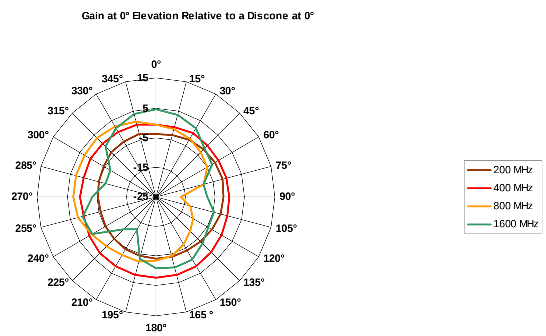

Figure 6 – Measured Pattern Relative to Discone

2.3 Encapsulation and Survivability

Encapsulation for survivability without performance degradation required several attempts. Figure 7 shows the degradation during an early attempt at encapsulation, and Figure 8 shows a successful attempt.

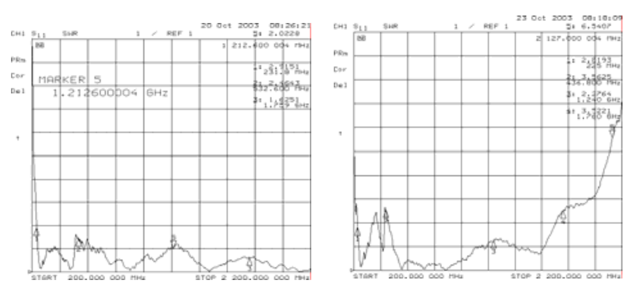

Figure 7 – VSWR Before and After Early Encapsulation

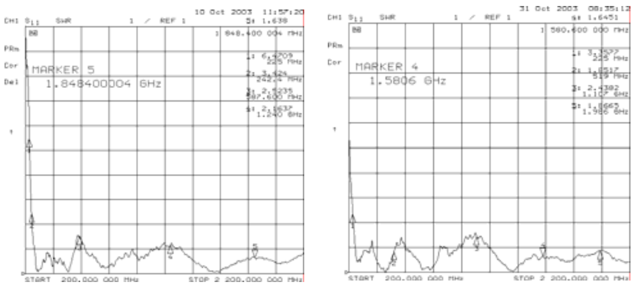

Figure 8 – VSWR Before and After Later Encapsulation

The first encapsulated antenna was also subjected to small arms fire. Figures 9 and 10 show the encapsulated antenna and the VSWR performance, respectively. Each is shown before and after being hit by 5.56 mm round. Note that there is very little difference in the electrical performance.

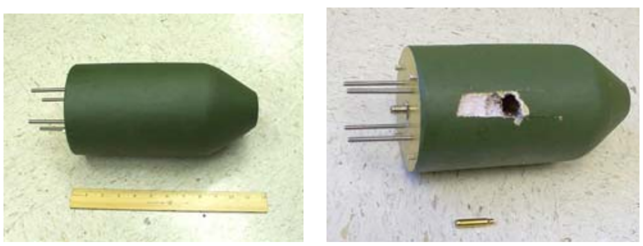

Figure 9 – Antenna Before and After 5.56 mm Round

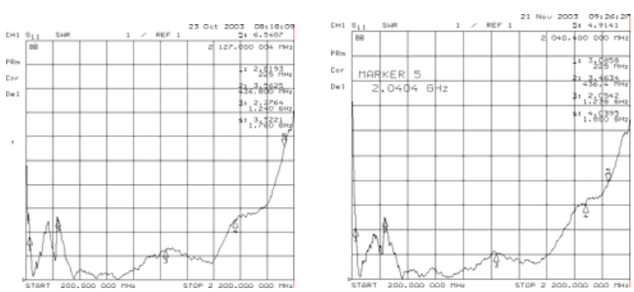

Figure 10 – VSWR Before and After 5.56 mm Round

3. CYLINDRICAL MEANDER

The Cylindrical Meander antenna topology is excellent for electrically-small, narrowband designs. The next three subsections describe the simulated and measured performance of the basic topology and two variants for band-selectivity.

3.1 Basic Topology

The basic cylindrical meander antenna is covered by US Patent #5,754,143, filed October 29, 1996. Figure 11 shows a 7.5 cm prototype cylindrical meander antenna, and Figure 12 shows the VSWR plot. Note that the resonance occurs at 90 MHz, which would correspond to a dipole of roughly 80 cm. Although the VSWR is rather high at this resonance, it will be reduced in the variants described in the next sections.

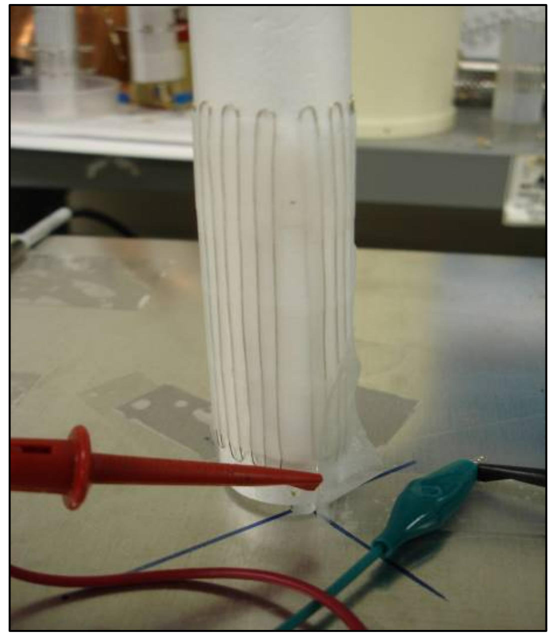

Figure 11 – Basic Cylindrical Meander Prototpye

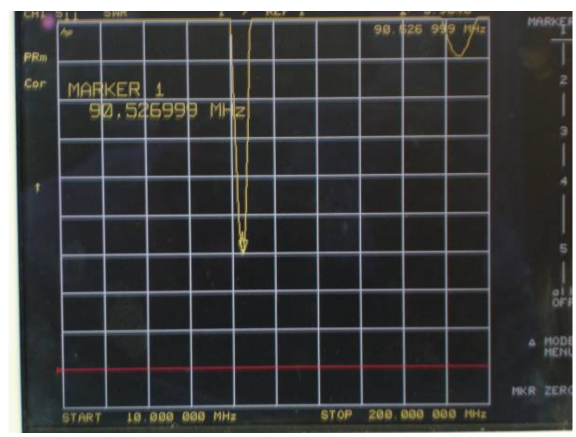

Figure 12 – VSWR for Basic Cylindrical Meander

3.2 Stub-shortened Variant

One method of changing the cylindrical meander resonance is by half-shorting one or more of the meander loops. In order to short out some subset of loops diodes were added so that a DC voltage injected into the antenna could be used to tune the antenna. Figure 13 shows a prototype stub-shortened cylindrical meander, and figure 14 shows the resonant frequency and VSWR variation with control voltage.

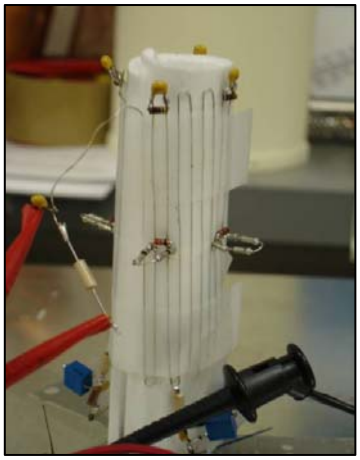

Figure 13 – Stub-shortened Cylindrical Meander Prototype

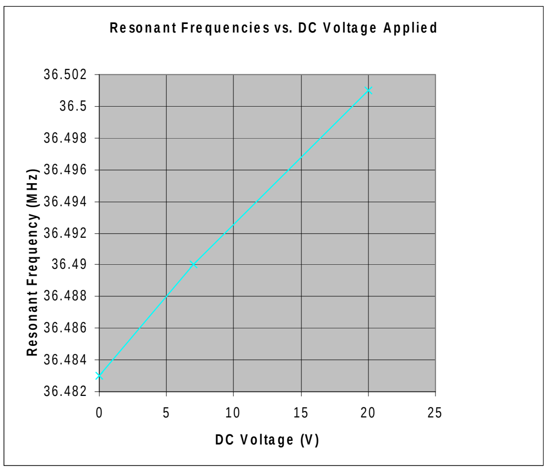

Figure 14 – Resonant Frequencies for Stub-shortened Meander

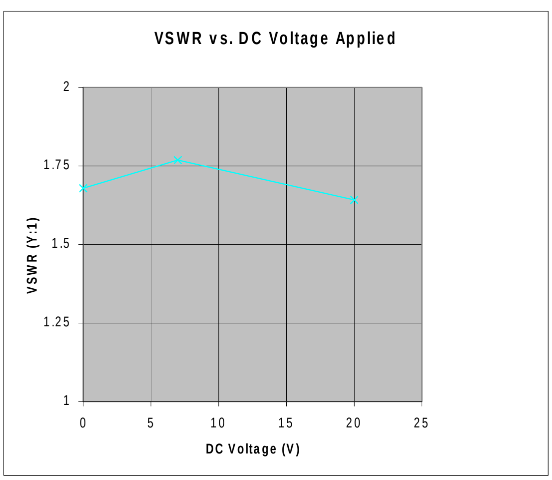

Figure 15 – Minimum VSWR Measurements

Unfortunately significant frequency deviation was not observed. However, we believe that this was a problem with our control system which resistively loaded the meander and widened the resonant bandwidth. The wider bandwidth caused two problems. The first problem was that it probably precluded accurate measurements of the effective narrowband resonant frequency. The second problem is that the real resistance results in real signal power loss. For example, if the real resistance is about equal to the radiation resistance, then the antenna will experience an additional 3 dB of loss on top of other system losses. More research will be necessary to overcome this issue.

3.3 Coil-Loaded Variant

A more successful method of changing the cylindrical meander resonance is by shorting one or more coils added to each of the meander loops. The coil loading further narrows the bandwidth and decreases the resonant frequency with only a slight increase in volume. Considering the trouble encountered using diodes to control the resonance of the stub-shortened meander, the research team simply used shorting connectors to manually tune the antenna. Figure 16 shows a prototype coil-loaded cylindrical meander, and figure 17 shows a typical VSWR measurements. Note that there are several resonances, and that the lower resonance is very narrowband.

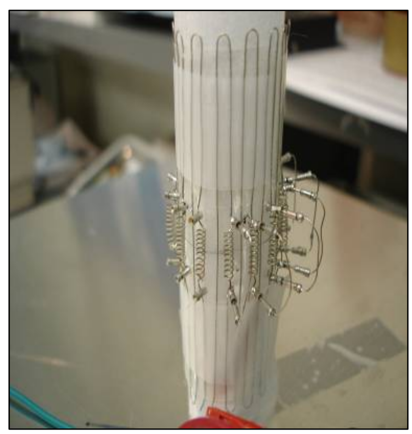

Figure 16 – Coil-loaded Cylindrical Meander Prototype

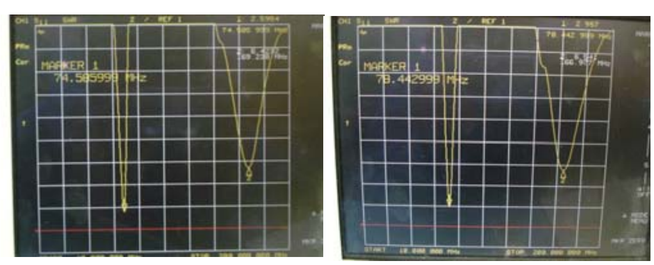

Figure 17 – VSWR Measurements for Coil-loaded Meander

Figures 18 and 19 show the resonant frequencies and corresponding VSWRs for each number of shorted coils.

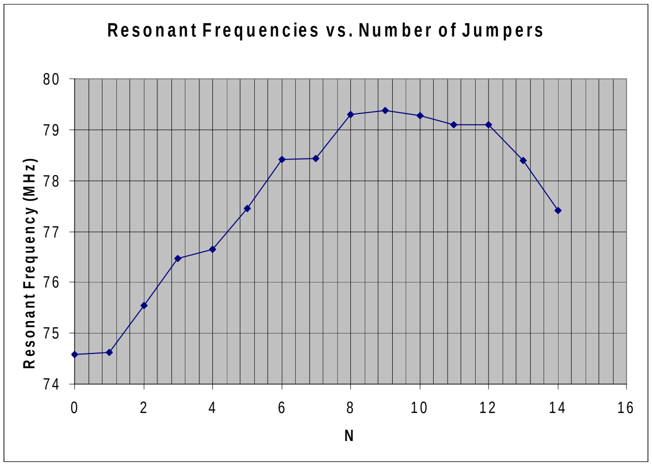

Figure 18 – Resonant Frequencies for Coil-loaded Meander

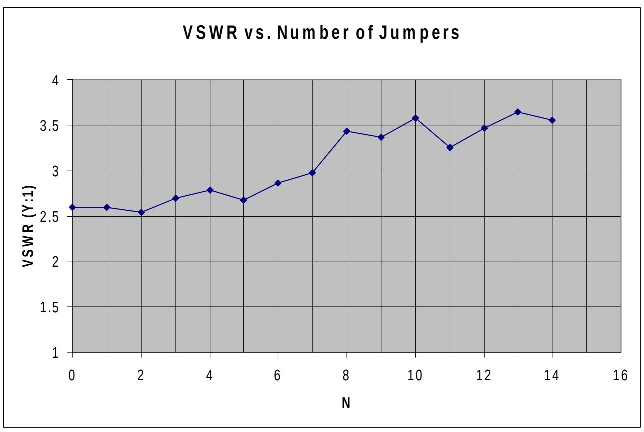

Figure 19 – Minimum VSWRs for Coil-loaded Meander

4. FURTHER RESEACH

Although the TASH antenna has sufficient real-world data corroborating the mathematical modeling to be a good candidate for current antenna designs, there is some further research that could be considered. For example, the TASH appears to radiate simultaneously in what are considered the large helix and small helix "modes" [1]. This is illustrated in figure 20. The advantages appear to include at least bandwidth and resilience to an imperfect ground plane. However their may be more.

The stub-shorted, tunable cylindrical meander requires some additional research before it can be fully productized. One issue with predictability, is the lack of corroboration between simulation and laboratory measurement. Although the basic cylindrical meander has an operating frequency which will scale with physical size in a predictable fashion with some linear factor from the simulated resonance frequency, and the actual laboratory VSWR is much more acceptable than the predicted one. The tuning stubs do not affect the resonant frequency as significantly as desired (see figure 14). Figure 21 shows the simulated resonant frequency tuning of a stub-shortened cylindrical meander.

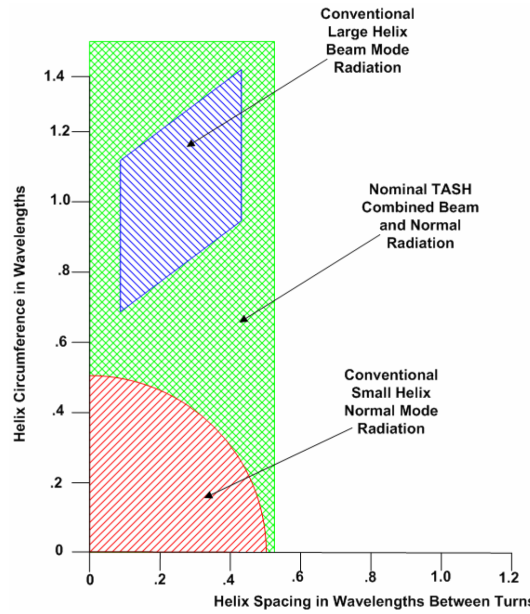

Figure 20 – Helix Radiation Modes

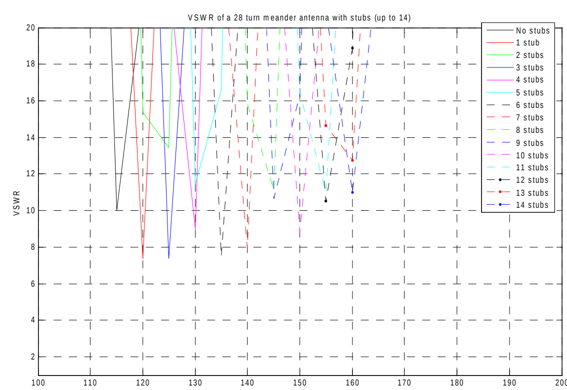

Figure 21 – Simulated resonant frequencies

The coil-shortened cylindrical meander shows promising tenability and VSWR levels that could readily be brought into useful ranges with narrowband matching.

5. REFERENCES

[1] Kraus, John. Antennas. McGraw_Hill. 1988. pp 288-295.

