Recent Investigations on the Volcano Smoke Antenna

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The Volcano Smoke Antenna  
By John Kraus

In 1945 at the Harvard University Radio Research Laboratory, I was developing broadband direction-finding antennas. Inspired by the broadband ideas of my group leader, Andrew Alford, I constructed a 20-cm tall antenna of the type shown in the sketch of Fig. 1. I made the bulb and curved ground plane out of modeling clay and coated it with silver paint. It had a very low VSWR over a very wide bandwidth and when I showed the model to Alford, he said, “Oh, volcano smoke!” And “volcano smoke” it has been ever since.

Fig. 1. Cut-away view of the volcano smoke antenna.

In this article Prof. Warren Perger and his students, in collaboration with Rockwell-Collins, Inc., analyze the shape-performance characteristics quantitatively with the objective of determining the optimum shape. This is an interesting challenge because the antenna by its very nature is an extremely non-critical structure.

I. INTRODUCTION

With the advent of modern digital spread-spectrum communication techniques, the need for higher-bandwidth antennas has correspondingly grown. In contrast with traditional approaches to solving the problem of developing wide-band antennas, recent research at Michigan Technological University, in conjunction with Rockwell-Collins, Inc., has investigated the volcano smoke antenna. It is believed that the volcano smoke antenna (VSA) topology offers the unique advantages of simplicity, exceptional bandwidth (BW), and azimuthal omni-directionality over and against the other current approaches to broadband antennas. A recent work on the VSA [1] has made a case for
further investigation of this structure. An omni-directional antenna with a 5:1 BW was constructed and described as a simplified form of the VSA. The device described in that work had a well-defined shape, while the shape of the conventional volcano smoke antenna is currently not so well defined. It is the purpose of this article to investigate and present the fundamental characteristics of the VSA, particularly regarding bandwidth.

The combination of low-VSWR and stable radiation patterns is difficult to achieve with current approaches for bandwidths greater than 5:1 or even 3:1.

No specific design equations/parameters were available for the VSA, but the assumption was made, based on Fig. 15.1 of ref. [2, p. 692, 694], that the height of the VSA bulb should be approximately $\frac{\lambda}{4}$ (of the longest wavelength) above the highest point on the base. Thus, the constructed prototypes were 10cm tall and 20cm in diameter. Using the method of curvilinear squares and attempting to improve the horizontal/azimuthal gain, a new topology was generated. This topology was simulated in Ansoft HFSS; additionally, an aluminum prototype was constructed. Simulated and experimental VSWR results are given in Fig. 2.

Two approaches were taken for reducing the designed VSA to practice. The first technique consisted of utilizing a rapid prototyping machine from the Mechanical Engineering department at Michigan Tech University (MTU). A wax model was produced by the machine and then coated in silver conductive paint (following in the steps of Kraus’ original work on the VSA in the 1940s). The second prototype was turned on a lathe from a block of aluminum.

II. RESULTS

A. Experimental

The RCI measured co-polarized elevation ($\theta$) cuts are shown in Fig. 3 from 800MHz to 15GHz. The standard IEEE spherical coordinate system is used [3, p. 16]. The bulb axis of the VSA corresponds to the Z-axis (zenith) of the RCI anechoic chamber’s coordinate system.

The measured radiation patterns exhibit several striking features. The VSA antenna operates very similar to an extremely broadband monopole antenna on a finite circular ground plane. At lower frequencies the “half donut” pattern of a monopole on an infinite ground plane is seen, and as the frequency is increased, pattern variations, characteristic of monopoles on finite ground planes, is readily apparent [4], [5]. The sharp zenith null characteristic of a monopole is retained throughout the frequency band.

The measured VSWR of the VSA prototype is illustrated in Fig. 2. The plot shows the general trend of an extremely broadband radiating element, but with a higher overall VSWR than expected with several parasitic resonances.

B. Simulation

1) VSWR: When determining operating bandwidths for wide-band antennas, a general rule of thumb used is a VSWR of 3:1 or better [6]. Simulation results demonstrate that the VSA has a minimum bandwidth of 10:1 (i.e. from 1.5 GHz up to 15 GHz). From the obvious trend in the data, it is believed that the true simulated BW could reach much higher, however, computing limitations at MTU restricted the researchers to an upper limit of 18 GHz. Only the fundamental TEM mode was included in the finite-element modeling (FEM) VSWR simulations.
2) Radiation Patterns: The vertical radiation patterns in Fig. 3 show that at higher frequencies the finite ground plane can be seen to effect similar changes upon the basic radiation pattern as is evidenced in a typical monopole over a finite ground plane. As frequency increases, very few significant lobes appear (with the exception, perhaps of the 10 GHz pattern), and majority of the pattern remains above the horizontal. The azimuthal radiation patterns simply demonstrated the omni-directionality due to device symmetry and are not included. Cross-polarization patterns were typically -20dB below the vertical-plane patterns and therefore also not included here.

III. Conclusions

We have demonstrated that the volcano smoke antenna described has conservatively a 10 to 1 bandwidth for both VSWR and antenna far-field pattern. Simulations over the same frequency range show excellent agreement with the experimental data, supporting the original idea that the volcano smoke antenna is a potentially very wide-band device.

REFERENCES


Fig. 2. Simulated and experimental VSA VSWR.
<table>
<thead>
<tr>
<th>VSA Radiation Patterns</th>
<th>MTU Ansoft Simulations</th>
<th>RCI Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>800 MHz</strong></td>
<td><img src="#" alt="Simulated" /> vs. <img src="#" alt="Vertical (Degr)" /></td>
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<td><strong>10 GHz</strong></td>
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<td><strong>15 GHz</strong></td>
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Fig. 3. Comparison of simulated (on the left) and experimental (on the right) radiation patterns at 800MHz, 5GHz, 10GHz, and 15GHz. The scales are in dB. See Fig. 1 for the orientation of the graphs relative to the VSA.