The Folded Horn Antenna

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Abstract – We introduce here a new antenna, the folded horn. This antenna was first proposed by C.E. Baum for radiating high-power mesoband (medium-bandwidth) signals from a very compact package with high efficiency and moderate gain. These antennas are intended to operate at a frequency of a few hundred megahertz, for the application of upsetting electronics at a distance. The advantage of folded horns over other antennas, such as pyramidal horns, is that they have no dimension larger than 2 wavelengths. The requirement to keep the antenna size small becomes increasingly apparent at lower frequencies. In this paper, we build and test the first prototype low-power folded horns, operating at a nominal operating frequency of 3 GHz. We describe several iterations, resulting in a design that satisfies our requirements over 3–5 GHz. We also describe alternative configurations, and we suggest further improvements that could result in either improved performance or a more compact size. We begin now with a description of the folded horn.

2. Folded horn design and analysis

We describe here the basic design and operation of the folded horn, and we provide an analysis of its performance. A sketch of the folded horn, is shown in Fig. 1, and photos are shown in Fig. 2. This device consists of three parts: the Feed Section, the Parabolic Bend, and the Aperture Section. At its design frequency of 3 GHz, this antenna has an aperture of 0.5 \( \times \) 2 \( \lambda \), and a depth of 1.75 \( \lambda \).

The folded horn works as follows. The antenna is driven by an SMA connector that is positioned at the focus of the parabolic bend. Waves in the Feed Section expand in the H-plane until they reach the Parabolic Bend. After reflecting off the Parabolic Bend, the waves are focused in both E- and H-planes. The waves then proceed into Aperture Section, in which the fields are expanded in the E-plane. The fields remain focused in the H-plane, because of the parabolic bend. The fields in the E-plane are only slightly out of focus, because there is little difference in ray path length between the central and extreme rays.

A sketch of the aperture electric fields appears in Fig. 3. On the left, we see that the electric fields protrude only slightly from the aperture, due to a slight defocus in the E-plane. On the right, we observe that the electric field magnitude varies approximately as a cosine function across the aperture, because of the metal walls on either side.

We begin the analysis by calculating the level of defocus in the aperture fields. We do so by calculating the path length difference between a central ray and an extreme ray in an E-plane cut through the Aperture Section, which has a length of 3/4 \( \lambda \). We find the ex-

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treme ray has a length of 0.79 \( \lambda \), compared to a direct path length down the center of 0.75 \( \lambda \), resulting in a path length difference of 0.04 \( \lambda \). So the aperture is essentially in focus.

![Fig. 1. The folded horn, model FH-1E](image1)

Next, we calculate the boresight gain of such an aperture field distribution, assuming a focused aperture of size 0.5 \( \times \) 2 \( \lambda \). We use the standard formula

\[
G = e \frac{4 \pi}{\lambda^2} A,
\]

where \( A \) is the aperture area, \( \lambda \) is the wavelength, and \( e \) is the aperture efficiency. Because of the cosinusoidal field distribution, \( e = 8/\pi^2 = 0.81 \), according to [1]. For this aperture, \( A = \lambda^2 \), so we have \( G = 32/\pi = 10.2 = 10.1 \) dBi at the design frequency.

If one assumes a focused aperture, then the fields are similar to those of an open-ended waveguide (OEWG) [2]. In this case, the pattern functions are described by

\[
\begin{align*}
F_h(\theta) &= \frac{1+\cos(\theta)}{2} \left[ \frac{\beta a}{\pi} \sin(\theta) \right] \frac{a}{b} \sin(\theta), \\
F_e(\theta) &= \frac{1+\cos(\theta)}{2} \left[ \frac{\beta b}{\pi} \sin(\theta) \right] \frac{b}{a} \sin(\theta),
\end{align*}
\]

where the long and short aperture dimensions are \( a \) and \( b \), respectively; \( \beta = 2\pi/\lambda \), and \( \theta \) is the angle from boresight. We plot these pattern functions later in the paper, next to our experimental data. A more accurate formulation would take into account the defocusing in the E-plane, using the expressions for the E-plane sectoral horn [2]. This has the same H-plane expression, but a different E-plane expression, which may be useful for larger E-plane opening angles.

3. Folded horn description

We now provide the details of our folded horn, model FH-1E. A sketch of the configuration was shown earlier in Fig. 1, and photos are shown in Figs. 2 and 4. This antenna is designed to operate at 3 GHz, or a wavelength of \( \lambda = 0.1 \) m. Thus, the aperture is 0.05 \( \times \) 0.2 m (0.5 \( \times \) 2 \( \lambda \)), which makes the antenna small enough to allow easy construction and testing. The FH-1E was designed so it could be constructed entirely from flat pieces of sheet metal, with bends only in a single plane of curvature.

A number of features near the feed point require clarification. The feed point is located at the center of...
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A cylinder, which is also the apex of the Feed Section and the focus of the Parabolic Bend. The radius of the cylinder surrounding the feed point was chosen to be \(\lambda/4\) at the design frequency, 3 GHz, in air. This was chosen so the short circuit at the edge of the cylinder would look like an open circuit at the feed.

Fig. 4. Feed point detail of the FH-1E, before (top) and after (bottom) adding the dielectric disk

We tried a number of different feed point designs before arriving at the final design, shown in Figs. 1 and 4. The feed point initially consisted of simply extending the center pin of the SMA connector all the way through the cavity, with a solder connection to the other side. In this configuration, we found that the antenna worked best near 5 GHz, which was well above our target frequency of 3 GHz. To reduce the operating frequency, we increased the electrical size of the disc by filling it with a dielectric material (Teflon, \(\varepsilon_r = 2.1\)). However, this still left us with an impedance spike at the feed point, as was apparent from TDR measurements. Thus, we replaced the straight pin with a cone embedded within the dielectric disc. The impedance of the cone was \(\approx 50\ \Omega\) in the presence of the dielectric, using the standard expression for a cone above a ground plane. Details of the evolution of the feed point, including data obtained at intermediate steps, are provided in [3].

The shape of the parabolic bend also requires some clarification. The height of the feed section was \(\lambda/8\), and it was desirable to keep the entire feed section within the \(\lambda/2\) height of the aperture. To conserve space, the bend was implemented as an abrupt 180° bend, using two 45° reflectors, as shown in Fig. 5. The dotted arrows show the path of a typical ray. With this configuration, all rays have the same path length around the bend, which keeps the wavefront in focus.

Fig. 5. Detail of the 180° bend, showing a typical ray path

4. Data

We characterized the antenna on our PATAR® time domain antenna range. The source for this system is a Pico-second Pulse Labs model 4015C step generator, which drives a Farr Research model TEM-1-50 sensor. The 4015C is a high-speed pulser with a negative 4 V voltage step, with a fall time of 20 ps. The antenna under test was placed 4 m from the aperture of the TEM sensor. The output of the AUT was recorded using a Tektronix model TDS8000 sampling oscilloscope, with a model 80E04 sampling head.

In Fig. 6 we provide the TDR, \(S_{11}\), and boresight realized gain of the FH-1E. Recall that realized gain is the gain reduced by return loss. The TDR at the feed point tapers smoothly from 50 ohms to 0 ohms, as it should. The \(S_{11}\) has a dip near 3 GHz, the intended operating frequency. The realized gain is \(\geq 10\ \text{dBi}\) over a frequency range of 3–5 GHz, which is consistent with our earlier predictions at 3 GHz. The frequency range over which the return loss is \(-10\ \text{dB}\) or better is 2.8–3.35 GHz.
The antenna patterns in the H- and E-planes are shown in Fig. 7 at 3, 4, and 5 GHz. Alongside these, we plot the theoretical patterns of an OEWG with similar aperture dimensions. We see that the H-plane pattern is much narrower than the E-plane pattern, which we expect because of the aperture shape. The measured patterns are quite similar to the theoretical predictions, however, we observe higher H-plane sidelobe levels in our experimental data than in the OEWG theory.

5. Conclusions

We have built and tested a folded horn, which is a compact antenna with moderate gain. After a number of iterations, we achieved a realized gain of 10 dBi or greater over a frequency range of 3–5 GHz. This was quite close to our predictions at 3 GHz, and it might be considered to be quite good performance for such a small antenna. The return loss was below –10 dB over a frequency range of 2.8–3.35 GHz. The measured antenna pattern was quite close to that of an OEWG, except that the experimental data had higher H-plane sidelobe levels than predicted by the theory. Future work will concentrate on adapting the design to higher powers.

References

Note: Sensor and Simulation Notes are available from www.ece.unm.edu/summa/notes