Waveguide Horn Antenna Feed Considerations

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L3Com CSW, Jan 2009

X-Band Frequencies:

Receive (Down): 7.25 – 7.75 GHz
Transmit (Up): 7.9 – 8.4 GHz

Ka-Band Frequencies:

Receive (Down): 20.2 - 21.2 GHz
Transmit (Up): 30.0 - 31.0 GHz

Question:

Can the process of optimized taper on a waveguide horn be utilized to include more than one frequency band?

We have recently been considering the problem of optimizing feed horns to operate at both X- and Ka-bands. An optimized horn could be either corrugated or taper “shaped” to accomplish the goal, but we need to serve both bands simultaneously.

In doing research on this subject I ran across a 2002 paper by Jeff Nielson that shows how to design a superior NON-corrugated horn using optimization of the horn taper. It was at this point that I remembered another paper on horn taper optimization that we analyzed during an L3/UU clinic project in 2004 called a “serpentine-horn”. I have collected a description of these papers here along with some of my own multi-mode horn analysis from the early ‘90’s.

In reconsidering all this information it appears to me that any symmetric aperture pattern in circular waveguide can be constructed with basis modes made up of only TE1m and TM1m modes, and that the relative content of these modes in the pattern can be controlled using optimization of the horn taper.

The question here is can this be done for multiple frequencies at once.

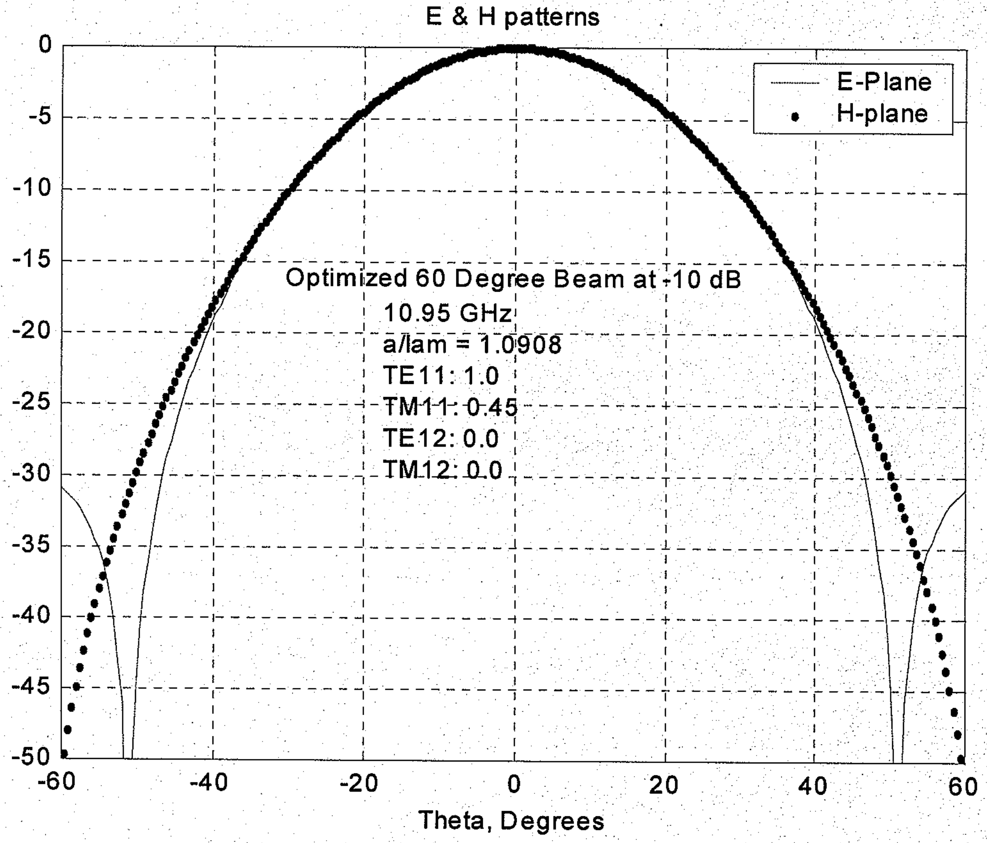
My own work on this subject came nearly 13 years ago in connection with the Tri-band Feed project. It became evident at that time that certain combinations of the TE1n and TM1n modes in circular waveguide produced highly desirable circular beam patterns with low side lobes and equal profiles in the E- and H-field planes. The horn aperture patterns that result can be Gaussian-like in their geometry which explains the desirable RF beam patterns.

This is not new. A well known circular waveguide horn that uses this concept is the Potter Horn where a single circular waveguide step is used to enlarge the waveguide above the cutoff of the TM11 mode and to create a combination of the TE11 and TM11 modes. When the step height is adjusted to create the right proportions of the two modes, a Gaussian-like waveguide field pattern forms at a fixed position beyond the waveguide step. Then, if this position is used as the opening for a waveguide horn, a very desirable RF beam pattern results. Corrugated horns produce similar RF beam results based on the HE11 hybrid mode.

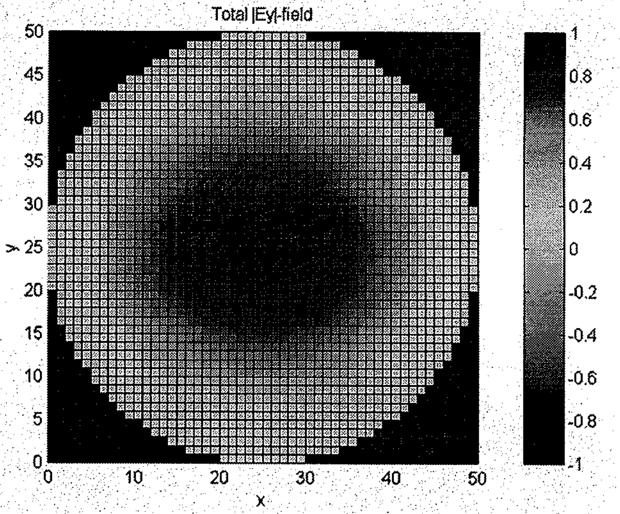
The next two slides show some numerical experiments that I performed to see if combinations of TE1n and TM1n modes could be found that produced the same size RF beams for two widely separated RF bands. The reason for the experiments was to determine the possibility of achieving full secondary dish illumination from a single feed radiating two widely separated frequency bands. The two frequencies I picked for my numerical experiment were 10.95 and 14.5 GHz which, coincidently, have a fractional separation close to that of the two Ka-band frequencies.

RF Beam Patterns for the Sum of TE11 and TM11 Modes At 10.95 GHz

The mode amplitudes were optimized to provide E- & H-plane beam patterns with 60 degree beam widths at - 10 dB edge.



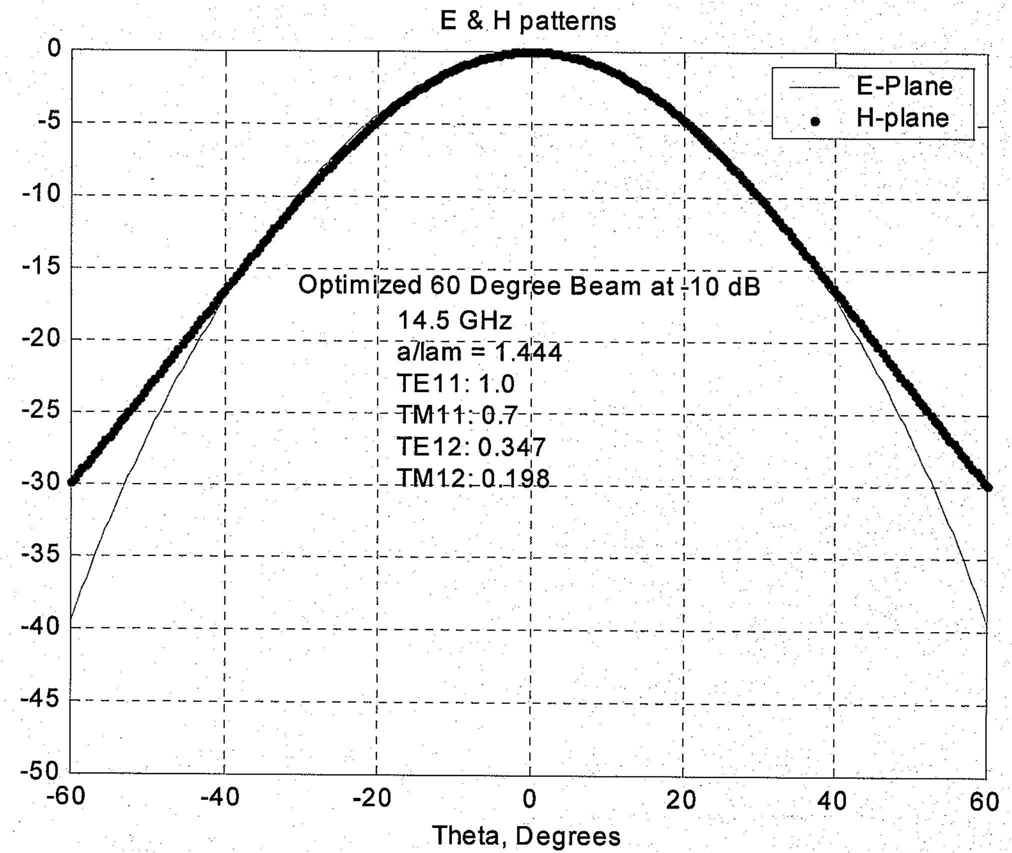
Ey-field Map at the waveguide aperture is Gaussian-like



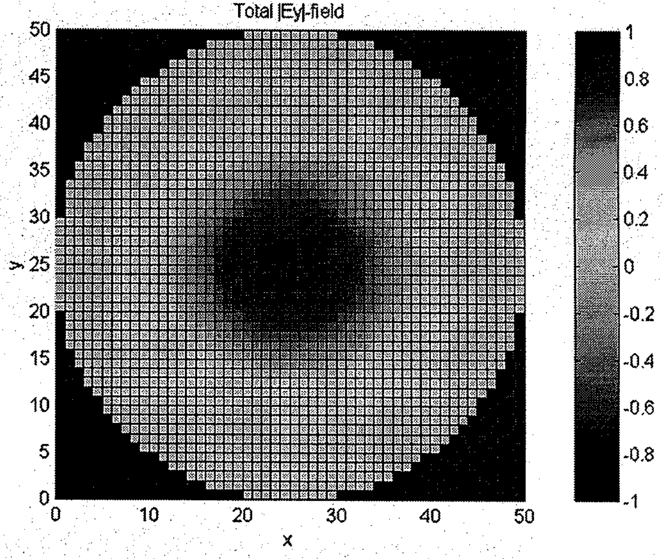
The optimized mode ratio is 1 to 0.45

RF Beam Patterns for the Sum of TE11, TM11, TE12, TM12 Modes At 14. 5 GHz

The relative mode amplitudes were optimized to provide E- & H-plane beam patterns with 60 degree beam widths at - 10 dB edge.



Ey-field Map at the waveguide aperture is again Gaussian-like

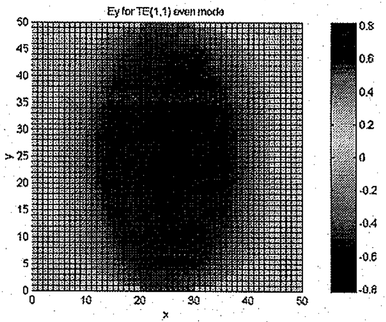


The optimized mode amplitudes are respectively: [1.0, 0.7, 0.347, 0.198]

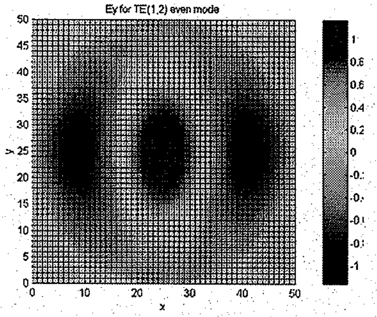
The modes utilized in this optimization are the natural set of modes required to mode match the fields that result from a radial step in a circular waveguide wall for the fundamental TE11 mode. These consist of the TE1n modes (for either the even or odd symmetry) and the TM1n modes (with the opposite odd or even symmetry).

For a perfect step in an ideal waveguide, no other circular waveguide modes will be excited. The comparative field geometries of these modes are shown in the next slide.

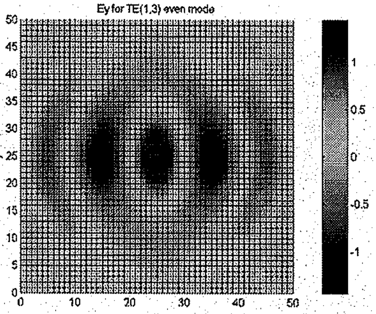
Plots of E_y in Circular Waveguide for TE(1,n) Even & TM(1,n) Odd Modes



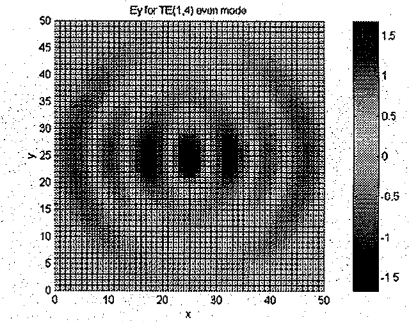
TE(1,1)



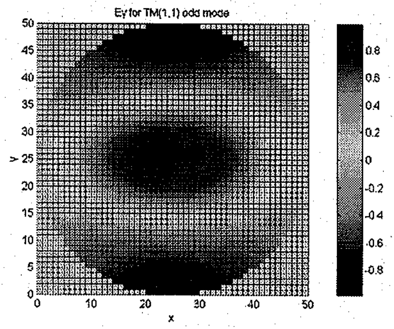
TE(1,2)



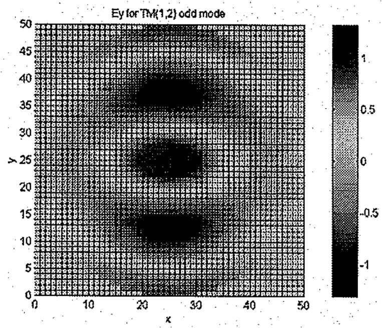
TE(1,3)



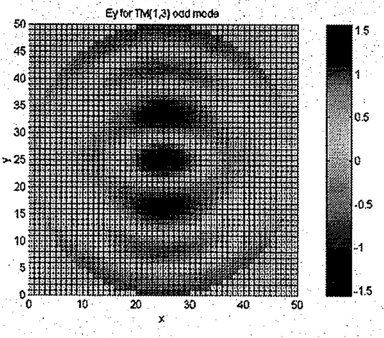
TE(1,4)



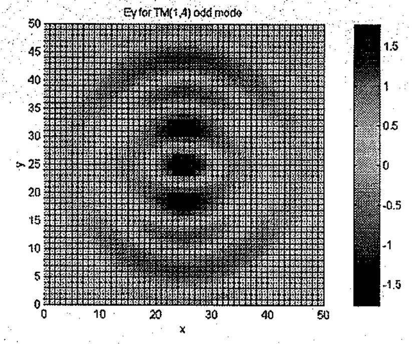
TM(1,1)



TM(1,2)



TM(1,3)

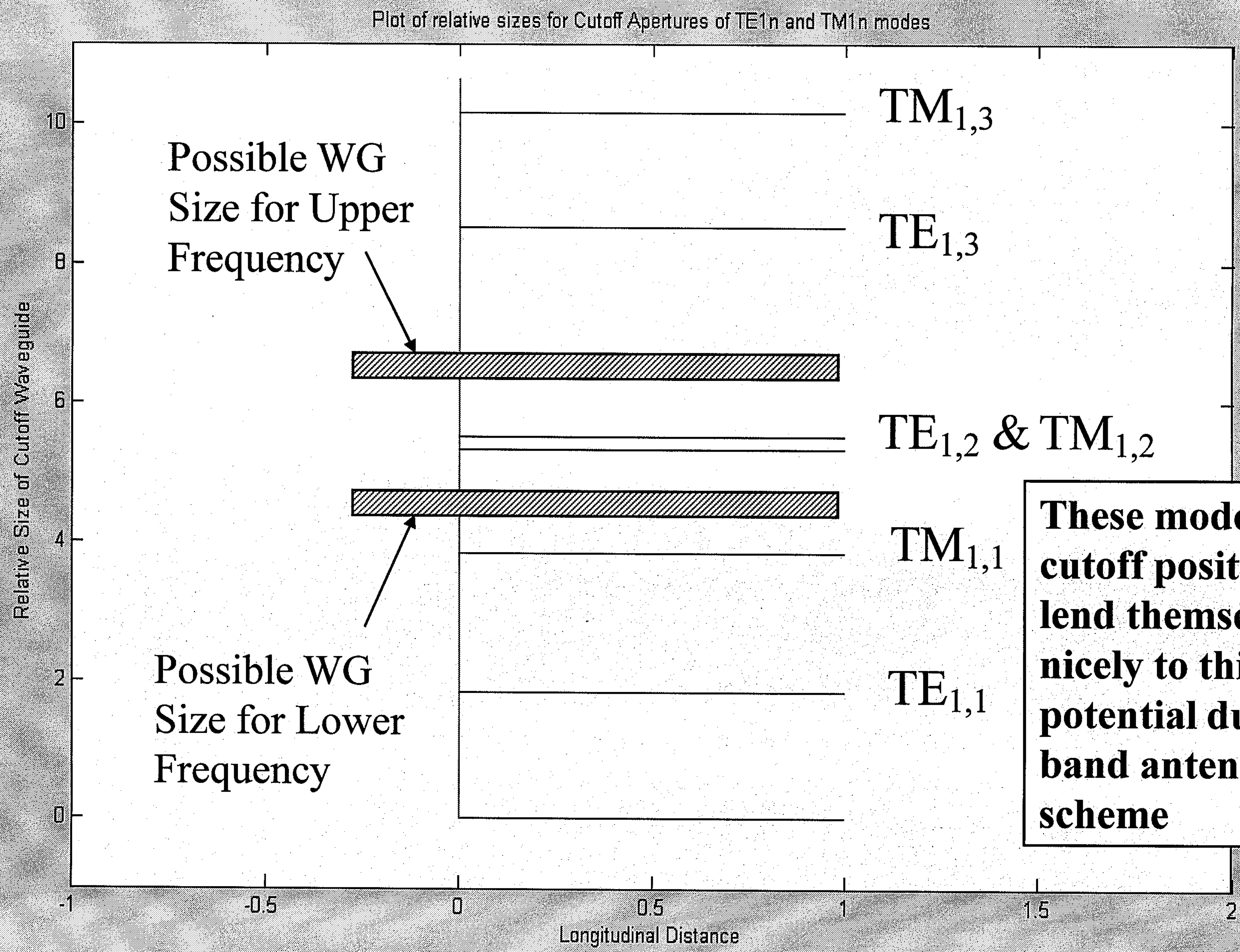


TM(1,4)

The relative waveguide cutoffs for the first few TE1n and TM1n modes are illustrated in the next slide. Note that a single aperture size will serve nicely for propagating the first 2 modes at the lower frequency and then 4 modes at the upper frequency. This is illustrated in the next slide.

Then, the remainder of the slides here describe the two papers previously noted.

Relative Sizes of Waveguides at Cutoff



Possible WG Size for Upper Frequency

Possible WG Size for Lower Frequency

These mode cutoff positions lend themselves nicely to this potential dual band antenna scheme

A paper published in 2002 describes a high performance Multimode NON-corrugated horn which claims to provide performance superior to that of a corrugated horn.

An Improved Multimode Horn for Gaussian
Mode Generation at Millimeter and
Submillimeter Wavelengths

Jeffrey M. Neilson, *Member, IEEE*

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 50, NO. 8, AUGUST 2002

The ModeMatching analysis technique was used with small radial steps along the horn to optimize a profile to produce a "fundamental Gaussian mode power fraction of 99%" at the horn aperture. The resulting optimized radius versus axial distance is shown at the right.

It is claimed that this horn design works better than corrugated horns and that return loss and cross polarization performance also exceeded all other multimode horn designs.

The resulting horn taper is easily NC machineable and is less costly to build than corrugated horns; especially at short wavelengths like Ka, Q-band and above.

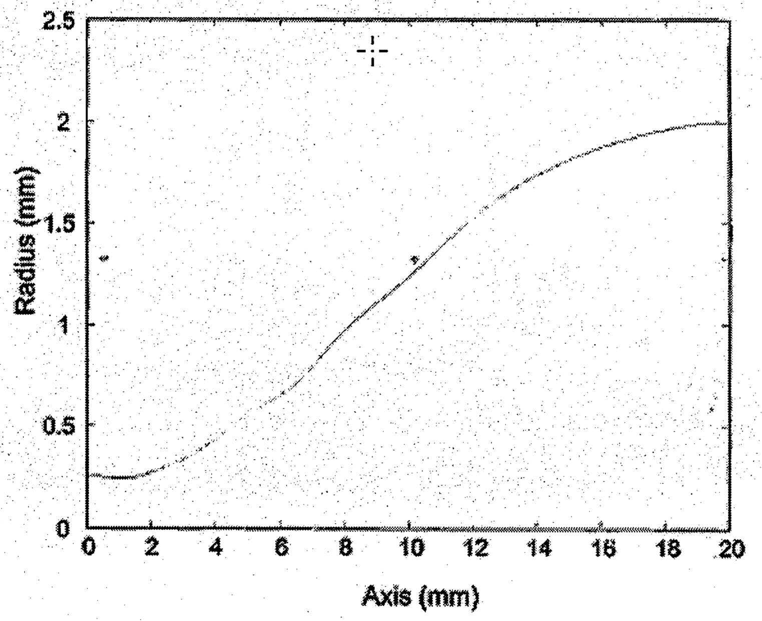


Fig. 3. Nonlinear wall variation used to generate multiple modes with high Gaussian content.

Figure SNAGGED from paper.

An experimental horn antenna based on this design at 110 GHz showed the following results:

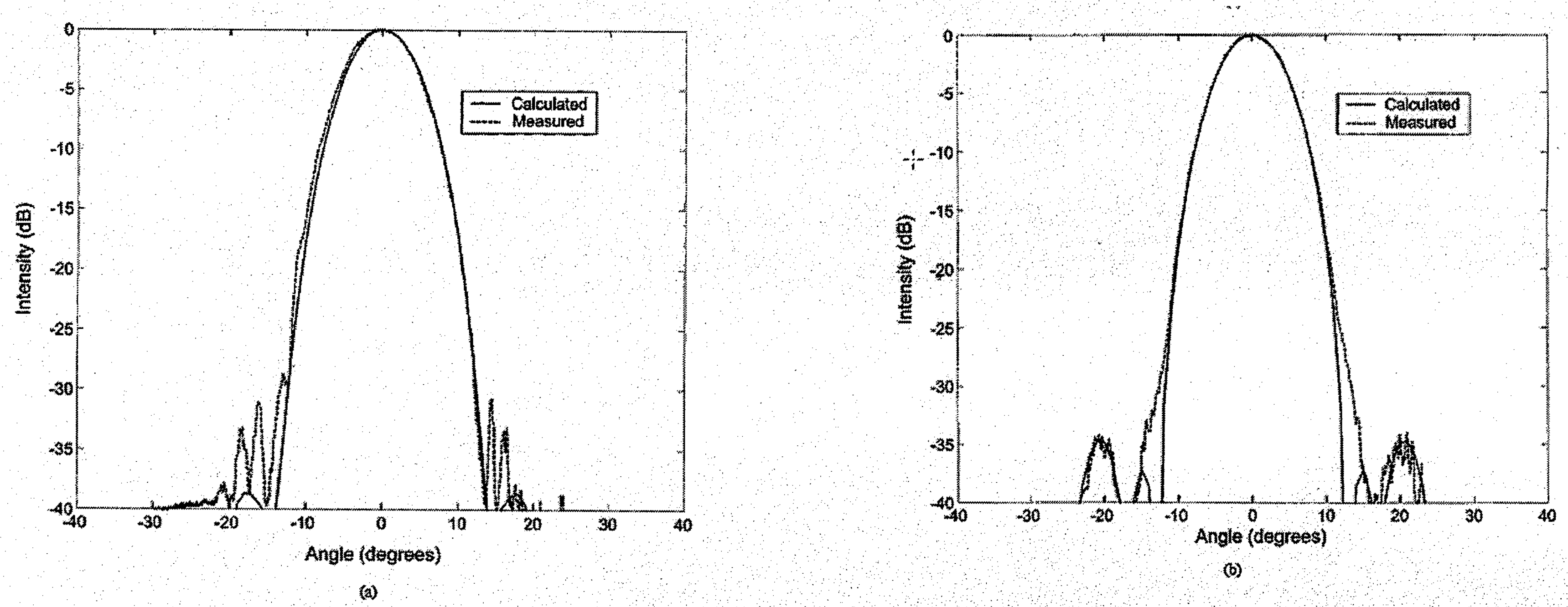


Fig. 6. Measured and calculated radiation patterns for Gaussian horn. (a) *E*-plane scan. (b) *H*-plane scan.

Figures SNAGGED from paper.

A **second paper** that lends credibility to this non-corrugated design approach comes from Mike Postma's Senior Thesis as an L3 Coop. Mike used data from Deguchi, etal., [1] to demonstrate that a horn optimized for gain and showing a "serpentine-taper" actually has a flattened field aperture distribution as would be expected.

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Sponsored by L-3 Communications

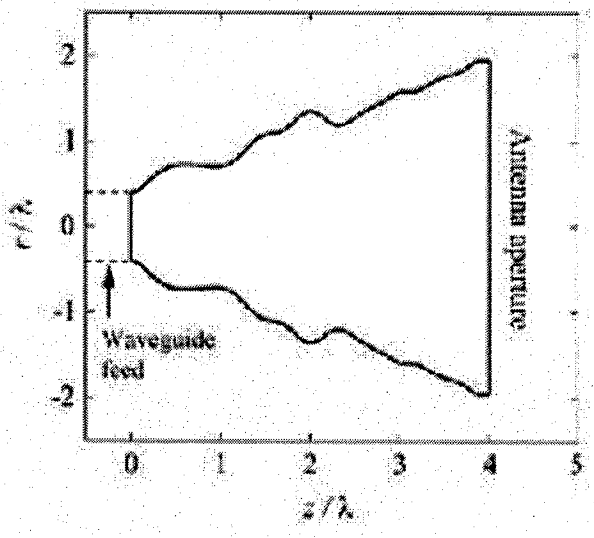

Figure 7 – Cross-sectional view of the serpentine-tapered horn

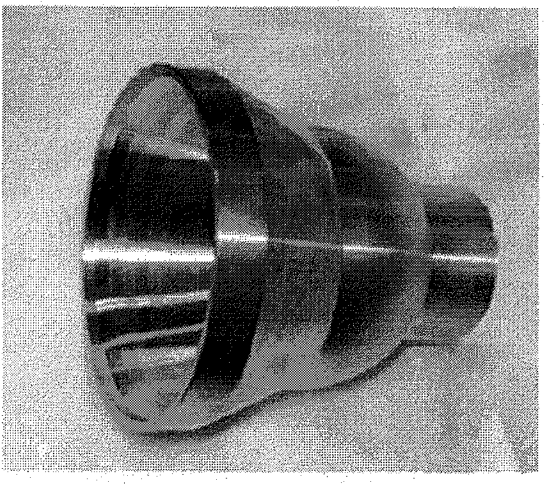

Figure 8 – Photo of the constructed serpentine-tapered horn

Figure SNAGGED from Postma's thesis.

[1] Compact Low-Cross-Polarization Horn Antennas with Serpentine-Shaped Taper by H. Deguchi, M. Tsuji, H. Shigesawa, IEEE Vol. 52, No. 10, Oct 2004

Mike Postma computed all of the serpentine-taper horn aperture modes (including amplitude and phase) that were given in the Deguchi paper and summed them together to form the aperture field distribution shown below. All of the modes cited are from the set previously shown. This demonstrates that Deguchi's optimization target of "maximum gain" produced a *flat-topped* field distribution in the aperture just as expected. A completely flat, uniform distribution is theoretically optimum (100% gain efficiency).

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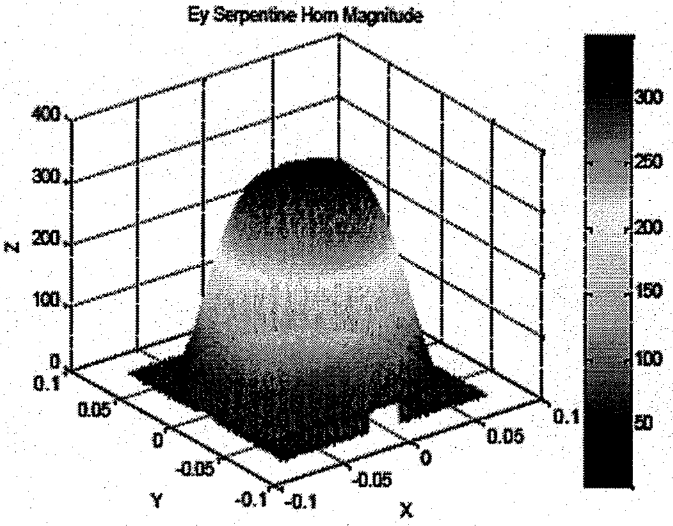

Figure 10 – E field y-component magnitude summation of serpentine-taper horn

I now believe that tapering a horn in circular waveguide only excites the TE1n and TM1n modes previously shown. This set of modes appear to be complete for all types of circularly symmetric aperture distributions that can be achieved through the step tapering of a circular horn antenna. It also appears that this technique can lead to superior horn designs that are easier to fabricate than corrugated horns.

It is yet to be determined to what extent designs exist that can be optimized simultaneously at two or more different frequencies so that multiband design requirements can be accomplished.