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Antenna System Supporting Multiple Frequency Bands and Multiple Beams

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***Abstract*—A multiband antenna system supporting multiple communication services and multiple beams is presented. Key component of the antenna is the smooth-walled horn that has efficient radiation patterns over three frequency bands that are spread over an octave bandwidth and provides optimal illumination on the reflector at all the frequency bands. Results of the feed horn and the antenna are discussed.**

***Index Terms*—Multiband antenna, multiple beam antenna, reflector antenna.**

I. Introduction

Dual-band antenna systems for multiple beam applications at 20 GHz and 30 GHz have been well documented in the literature. There is a need to extend these dual-band systems for both space and ground applications to include the 45 GHz EHF band for future military communications. A corrugated horn supporting these bands has been reported earlier for single beam applications. However, for multiple beam applications the corrugated horn is not suitable due to thick walls supporting the corrugations. Dielectric loaded hybrid-mode horns are not suitable for space applications due to electro-static discharge, material out-gassing, and thermal effects. This paper discusses the development of a multibeam antenna system, and in particular design and development of a compact smooth-walled horn, supporting three communication bands that are spread over more than an octave bandwidth.

II. Tri-Band Antenna

The tri-band antenna consists of an offset reflector antenna being fed with either a single horn or a cluster of horns suitable for satellite as well as ground communications. The antenna needs to provide coverage over the K-band (20.2 – 21.2 GHz), Ka-band (30.0–31.0 GHz), and EHF-band (43.5–45.5 GHz) with dual circular polarizations. The coverage beams are 1.0° diameter at K and Ka bands, and 0.5° diameter at EHF. The offset reflector antenna geometry shown in Fig. 1 has a projected aperture of 44 in diameter, focal length of 54 in, and an offset clearance of 18 in. The reflector is gimbaled in order to steer the beams over the global coverage while the feed/feed array is stationary for satellite applications, and the whole antenna can be steered for ground applications. The reflector surface can be parabolic or shaped to minimize the scan loss over the global field-of-view for satellite applications. The lower bands require a single feed while a 7 horn cluster is required at the EHF band to adapt the beam in presence of interferers. Key component of the antenna is the tri-band horn. A tri-band corrugated horn that has excellent performance has been presented earlier [1], and a smooth-wall horn with spline profile has been presented recently [2]. The smooth-wall horn [2] is too bulky with about 2.6 in diameter and about 9 in long. Secondary patterns are also not discussed in the previous publications. A compact tri-band feed horn with smooth walls has

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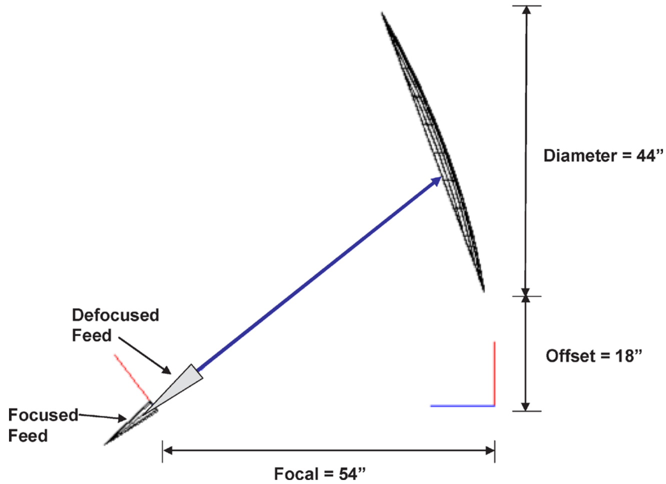

Fig. 1. Reflector antenna geometry.

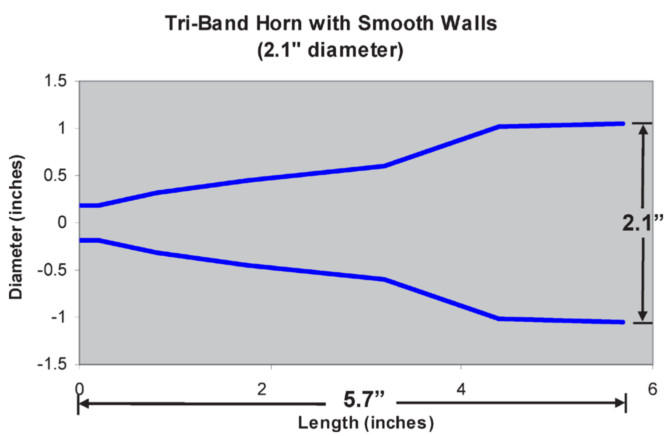

Fig. 2. Geometry of the tri-band smooth-wall horn synthesized using “slope-discontinuities” to yield a compact configuration.

TABLE I
RF Performance Summary of the Horn

Frequency (GHz)	Return Loss (dB)	Edge Taper (dB)	X-pol (20°) (dB)	Efficiency (%)
20.2	25.5	17.1	-20.7	79
21.2	28.8	17.7	-21.6	79
30.0	45.0	15.8	-22.2	61
31.0	42.2	16.8	-23.1	61
43.5	41.1	25.0	-23.7	53
45.5	40.8	23.6	-22.8	51

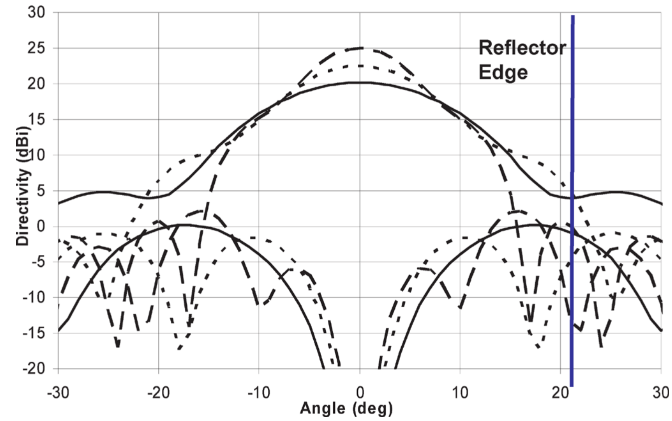

Fig. 3. Radiation patterns of the tri-band horn.

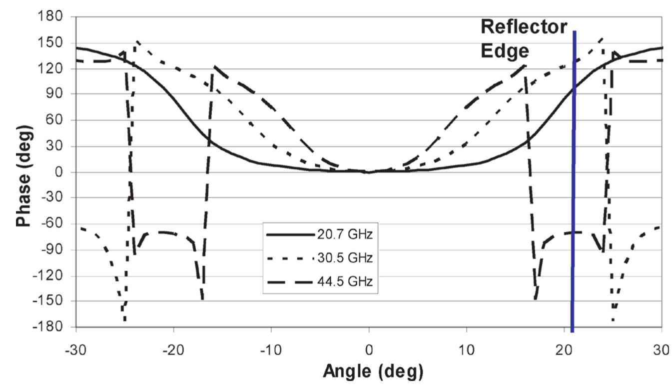

Fig. 4. Phase patterns of the horn with 0.0 in defocus.

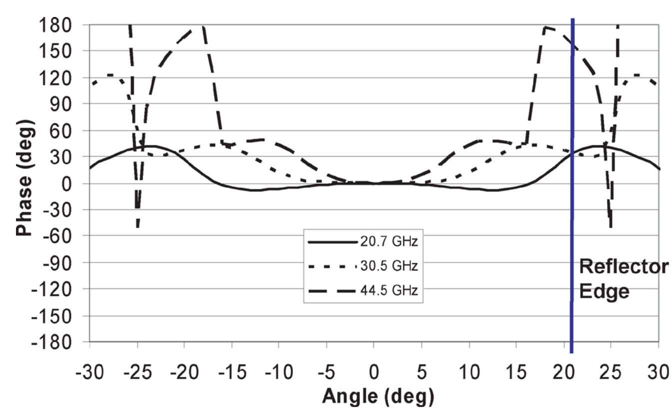

Fig. 5. Phase patterns of the horn with 1.5 in defocus.

been designed with “slope-discontinuities” using the mode-matching software that has been developed earlier [3], [4]. Fig. 2 shows the geometry of the synthesized horn. It has an aperture diameter of 2.1 in and is 5.7 in long (about 60% less volume than [2]) and uses 5 slope-discontinuities to generate the desired TE1,n modes for improved efficiency and better cross-polar performance. The horn performance is summarized in Table I. The tri-band horn provides an illumination taper of better than 15 dB at the edge of the reflector, has better than 25 dB return loss, and cross-polar levels that are lower than -20 dB relative to beam peak.

The computed copolar and cross-polar radiation patterns of the tri-band horn in the 45° plane (linear polarization) at center frequencies of the three bands are shown in Fig. 3. The patterns have low spill-over loss outside the illumination angle of the reflector and cross-polar levels that are better than -20 dB relative to peak copolar gain. Since the reflector is oversized at EHF frequencies, it is necessary to illuminate the reflector with first sidelobe of the horn pattern at EHF in order to broaden the secondary beam to 0.5°. The efficiency of the horn is rather high and is about 79% at K-band, 61% at Ka-band, and 51% at EHF band. These values are much higher than those reported earlier due to the excitation of proper TE1,n modes that make the aperture illumination more uniform. It is important to consider the angular phase pattern variation of the horn with frequency in order to optimize the secondary patterns with the reflector. Figs. 4–6 show the computed phase patterns for the three cases when the axis of rotation is at the center of aperture plane ($\text{defocus} = 0.0$ in), when it is 1.5 in inside the aperture center

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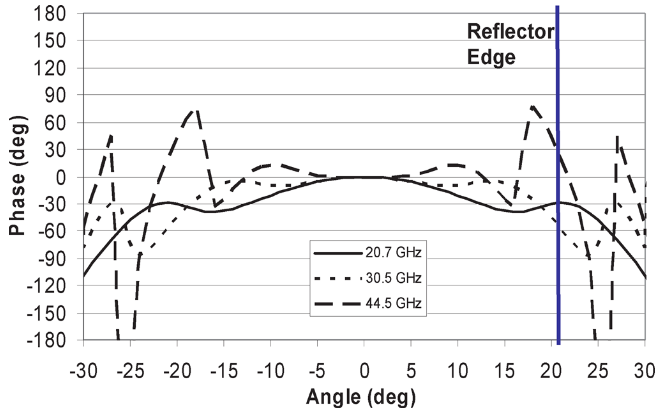

Fig. 6. Phase patterns of the horn with 3.0 in defocus.

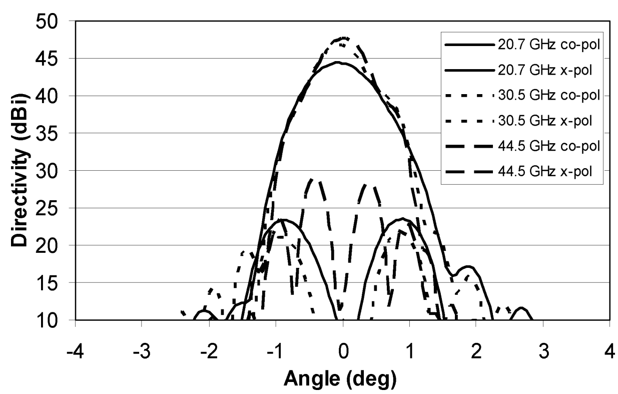

Fig. 7. Computed secondary patterns of the tri-band antenna (0.0 in defocus).

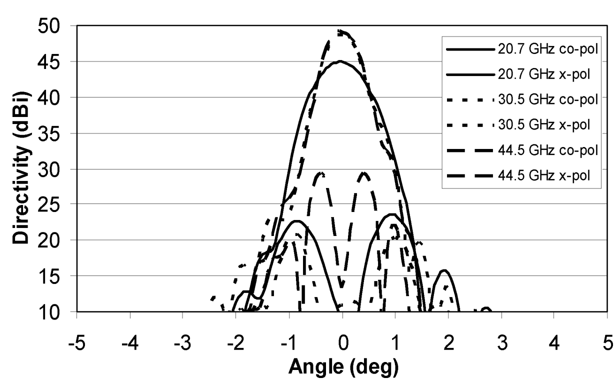

Fig. 8. Computed secondary patterns of the tri-band antenna (1.5 in defocus).

($\mathrm{defocus} = 1.5\ \mathrm{in}$), and when it is 3.0 in inside the aperture center ($\mathrm{defocus} = 3.0\ \mathrm{in}$). The performance of the secondary patterns can be optimized by the correct choice of the horn location relative to the focal plane of the reflector [5].

The secondary patterns of the offset reflector antenna have been computed for the three cases of feed defocusing using the TICRA software, and the results are shown in Figs. 7–9. The secondary patterns are better focused at the EHF band for the 3.0 in defocus case due to the fact that the phase center of the horn is close to the focal plane for this case. The antenna gain improves by about 1.7 dB for this case relative to the 0.0

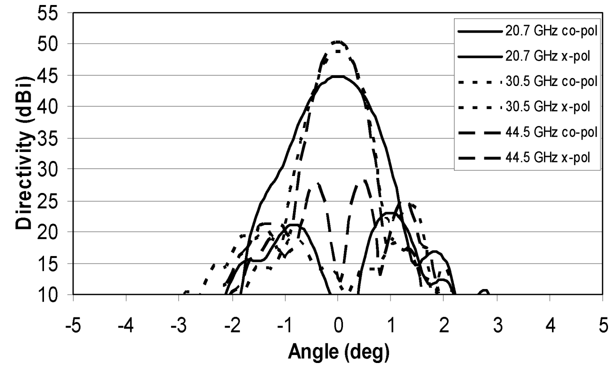

Fig. 9. Computed secondary patterns of the tri-band antenna (3.0 in defocus).

TABLE II
RF PERFORMANCE SUMMARY OF THE TRI-BAND ANTENNA

		Defocus=0"		Defocus=3.0"	
Frequency	Coverage	Co-pol	C/X	Co-pol	C/X
(GHz)	(degrees)	(dB)	(dB)	(dB)	(dB)
20.7	±0.5º	40.8	19.6	41.2	20.1
30.5	±0.5º	41.2	23.9	40.8	22.3
44.5	±0.25º	45.9	20.2	47.6	22.0

in defocus case. Table II summarizes the tri-band antenna performance for the three cases. For the selected case with 3.0 in defocusing, the antenna gain values over the beam coverage diameter are 41.2, 40.8, and 47.6 dBi at center frequencies of K, Ka, and EHF bands respectively. The cross-polar isolation (C/X) over the coverage regions is better than 20 dB. It is to be noted that there will be a cluster of horns that operate at EHF-band only that surround the central tri-band horn for beam adaptation at EHF. Antenna beam(s) can be located anywhere over the global coverage by gimbaling the reflector while keeping the feed cluster stationary.

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