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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

DUAL-FREQUENCY EHF GROUND-TERMINAL ANTENNA

M. L. BURROWS

Group 64

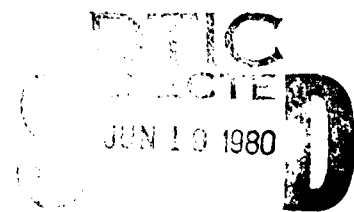
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ABSTRACT

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A design is presented for an EHF ground-terminal antenna in the form of a dual-frequency 2-ft dish. The 20 GHz receive horn is at the prime focus. The 44 GHz transmit feed is a focussed array of 32 square horns at the vertex of the dish illuminating a dichroic ellipsoidal Cassegrain sub-reflector. The sub-reflector is nominally transparent at 20 GHz and nominally a perfect reflector at 44 GHz. The directive gains at the two frequencies are estimated to be 39.0 dB and 44.9 dB, respectively. The dichroic surface is a single-layer metal sheet whose periodic perforations are designed to exhibit a two-frequency resonant behavior giving near perfect reflection at 44 GHz and near-perfect transmission at 20 GHz.

This design allows some 32 W of transmitter power to be generated by combining the power of 32 individual 1 W solid-state amplifiers. The combining losses (and the hardware) of a waveguide combining tree are avoided by space-combining the fields radiated by the 32 individually fed horns.

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I. INTRODUCTION

The EHF frequency band offers the possibility of providing worldwide jam resistant communication to small terminals, both fixed and mobile. However, to obtain its full benefits, it is necessary that we design the terminals to be inexpensive. A large part of the cost of the terminal, using conventional technology, is taken up by the steerable antenna mount and the power amplifier.

The purpose of this study was to explore a method of using solid-state devices instead of the more usual travelling wave tube to provide the radiated power. The potential advantages are, first, a reduction in acquisition cost, because solid-state technology is more amenable to the savings of quantity production and because the power supply requirements are much less stringent and, second, a reduction in maintenance costs because of the reliability of solid-state devices and because the use of multiple devices provides an inherent redundancy.

A difficulty with solid-state amplifiers in the EHF band is that their output power is only of the order of a watt or so. To obtain several tens of watts total output, we must combine the power of several tens of individual devices. This has the advantage of providing the inherent redundancy mentioned above. It has the disadvantage of multiplying the cost and adding the problem of combining the power of the individual devices in a phase-coherent manner.

One approach to the combining problem is let the antenna be an array of radiating elements each fed from its individual dedicated solid-state amplifier. But this approach is not amenable to the inclusion of a receive function in addition to the transmit function. So the design being proposed here is a dual-frequency reflector antenna consisting of a 32-element array feeding a Cassegrainian configuration at the 44 GHz transmit frequency and a prime-focus configuration at the 20 GHz receive frequency. The diameter of the main reflector was assumed to be 2 feet.

II. DESCRIPTION

The geometrical details of the antenna design are presented in Fig. 1. It was assumed, for the purposes of this study, that no waveguide combining would be employed. It may well be possible to combine in a waveguide the power of several amplifiers over the necessary 2 GHz bandwidth, and in that case fewer horns would be needed in the feed array to obtain the same total radiated power.

The Cassegrain configuration was chosen because it allows the more complicated array feed to be placed conveniently at the vertex of the dish, and the gain expected of a 2-ft dish at 44 GHz is certainly well within the range over which the Cassegrain focus performs well [1].

To give as much room as possible in the square cylindrical space behind each horn element of the feed array, the array face was made as large as aperture blocking considerations would allow. This leaves enough room to include an isolator between each amplifier and its feed horn, should that be necessary.

The array is focussed towards a point 477 mm from the vertex of the main dish. If it were focussed at infinity, the sub-reflector diameter would have to exceed the width of the array, giving more aperture blockage. If it were focussed at a point closer to the prime focus of the main dish, the laws of geometrical optics would place the sub-reflector very close to the prime focus, leading possibly to matching problems with the receive horn at the prime focus.

Each transmit horn is at least 40 mm long to avoid the gain loss that excessive aperture phase deviation would incur. The half-power beamwidth of each horn is about 12° , which means that the first grating lobe of the array, located 48° from boresight, is suppressed by the side-lobe ratio of the horn pattern.

The dichroic surface is a composite array of apertures and dipoles [2] rather than an array only of apertures [3] or of dipoles [4], because wide bandwidth reflection must occur at 44 GHz at the same time that transmission occurs at the relatively close receive frequency of 20 GHz. The apertures, if tuned to give good transmission properties at 20 GHz, can be expected to exhibit

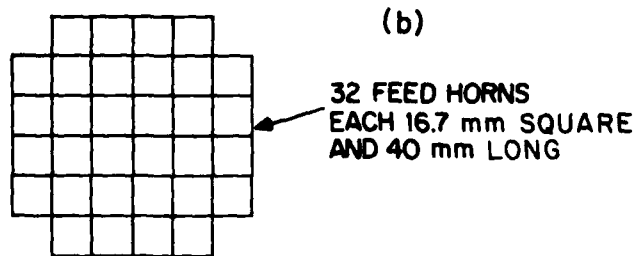
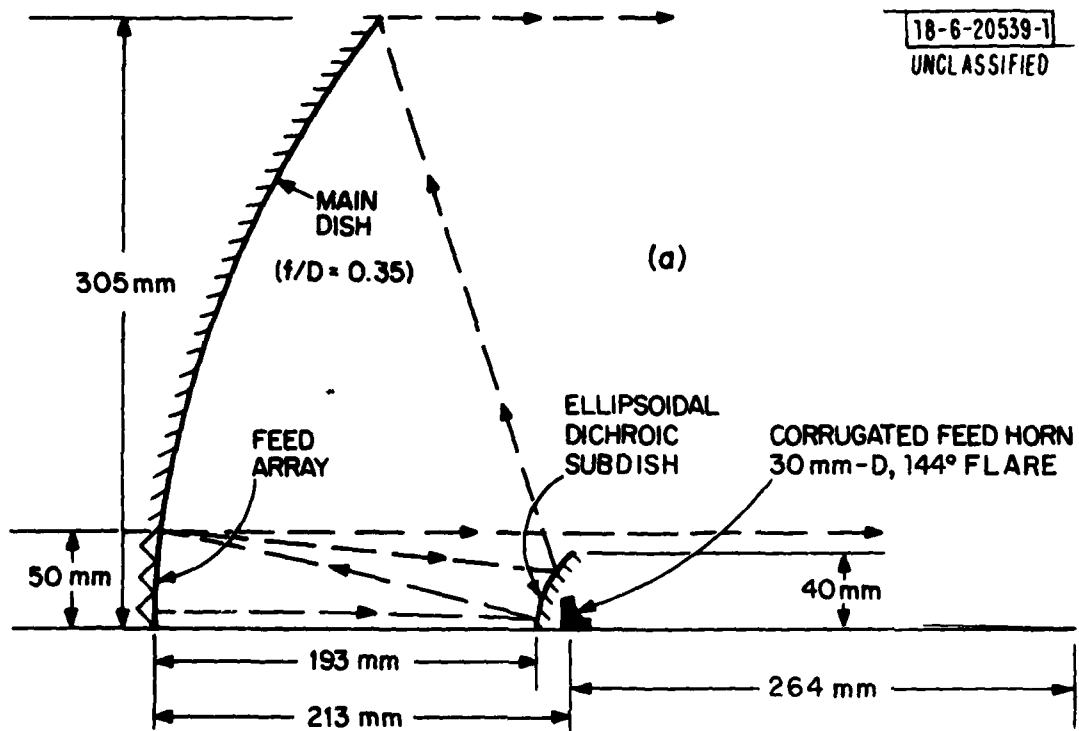


Fig. 1. The dual-frequency dish antenna: (a) reflector geometry, (b) feed-array face.

a second-harmonic transmission window near the transmit frequency of 44 GHz at which near-perfect reflection is required. On the other hand, the dipoles, if tuned to give good reflection at 44 GHz, would be expected to present a residual reflective behavior at 20 GHz because the wide skirts of the single resonance at 44 GHz would extend down to 20 GHz and below [5].

Two different forms of the surface pattern are shown in Fig. 2. The critical dimensions are the length and width of the side members of each cell, and the width of the narrow capacitive gaps. They would have to be determined experimentally.

III. DIRECTIVE GAIN

The directive gain at 44 GHz was calculated using the "equivalent-paraboloid" method of Hannan [6], assuming that each horn in the array feed has an on-axis gain of 17.8 dB [7]. The directive gain was found to be -3.7 dB with respect to that of a uniformly illuminated 2-foot-diameter aperture, without taking into account sub-reflector losses and aperture blockage. The sub-reflector losses are expected to be of the order of 0.1 dB, as discussed above. The aperture blockage is estimated to cause an additional loss of about 0.3 dB calculated as follows. The loss due to the blockage of the array feed alone would be some 0.13 dB, if the aperture were uniformly illuminated. Since it is not, however, the loss is increased by the ratio of the average field strength in the blocked area to the average field strength over the whole aperture. We can estimate from the calculated power density distributions, shown in Fig. 3, that this ratio is about 1.5, implying an aperture-blockage loss due to the array of some 0.2 dB. To this we must add the loss -- say 0.1 dB -- due to the blockage presented by the sub-reflector support struts. The net directive gain is therefore -4.1 dB with respect to the ideal, or 44.9 dB in absolute terms.

The phase-error distribution along the two principal planes of the aperture, also presented in Fig. 3, indicates that it is apparently everywhere less than $\pm 10^\circ$, and does not measurably degrade the directive gain.

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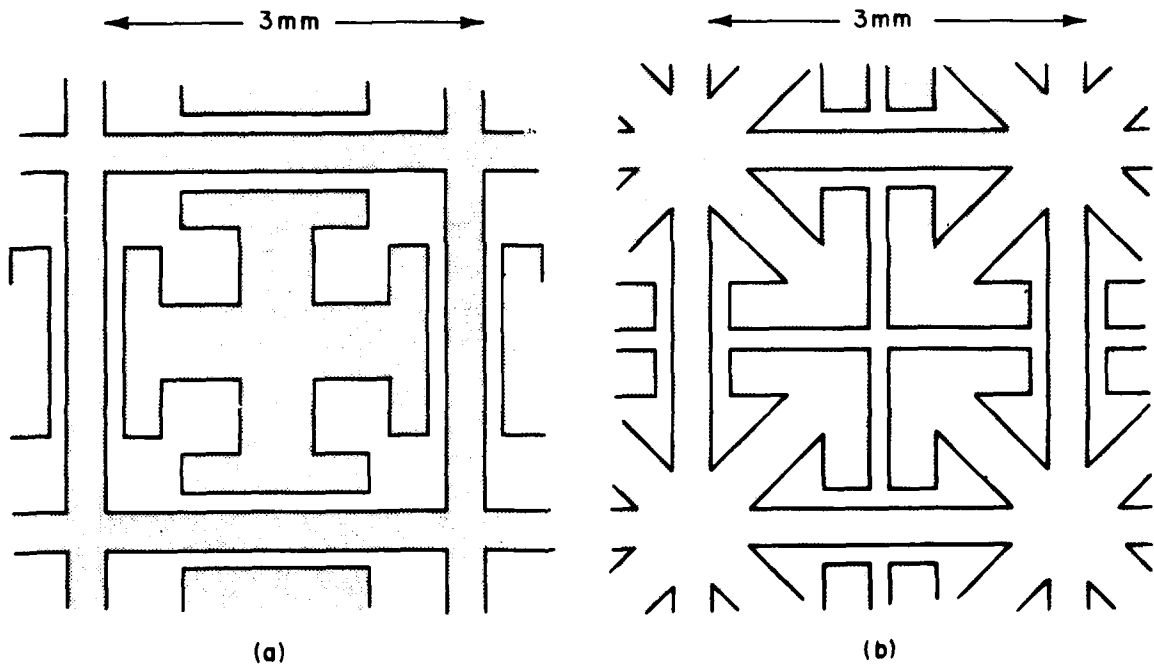


Fig. 2. Alternative patterns for the dichroic surface resonant at two frequencies. Pattern (b) can be fabricated as a single self-supporting metal sheet.

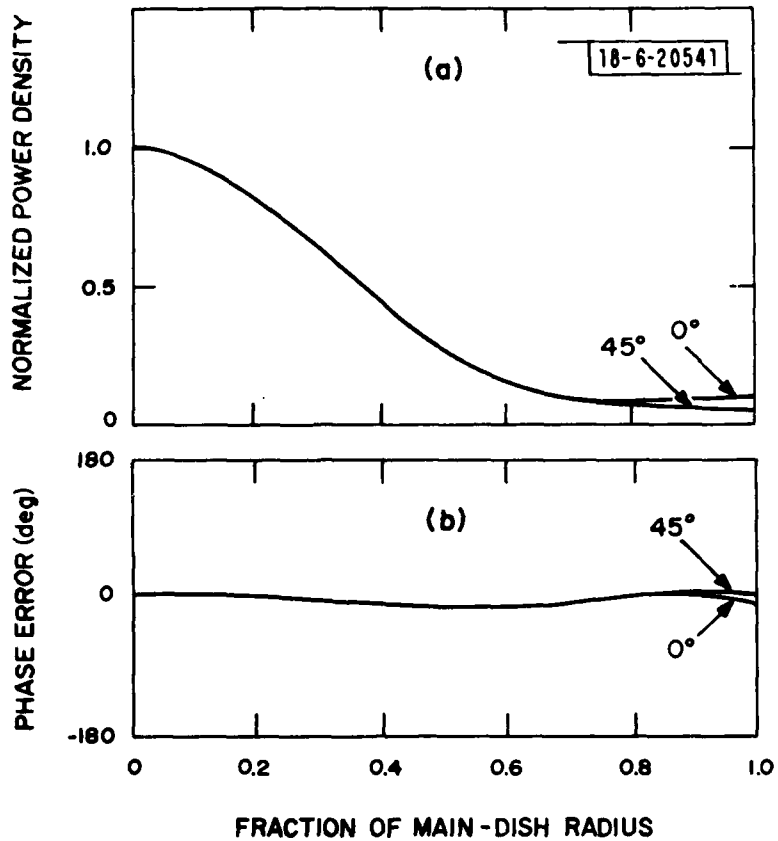


Fig. 3. Field distribution along the two radials of the main dish parallel with the principal planes of symmetry of the feed array: (a) power density, (b) phase error.

Since the equivalent-paraboloid model for computing the gain does not use a sub-reflector, it is necessary to examine the field distribution over the one selected to ensure that spill over around the sub-reflector will not invalidate the calculations. The calculated power distributions shown in Fig. 4 are reassuring in that respect. The field is concentrated towards the center of the sub-reflector as a result of using a focussed feed array, and becomes extremely small at the reflector edge. The peripheral circle of rays, by geometric optics, has a radius at the sub-reflector which is only about 72% of the radius of the sub-reflector, as noted in Fig. 4. This means that the sub-reflector is probably unnecessarily large. However, reducing its diameter would not decrease aperture blockage, because it blocks only that part of the aperture already blocked by the face of the feed array. Moreover, its large diameter can help mitigate edge effects, which are likely to be larger for a cellular dichroic surface than for a smooth metal one.

No calculations were made of the field distributions in the antenna's receive mode, because its performance is conventional, apart from the loss through the sub-reflector. For the simple dichroic surface assumed for this study, that loss is 0.1 dB [2], leading to a directive gain which is likely to be some 3 dB less than ideal, or 39 dB in absolute terms.

IV. CONCLUSION

The 2-foot-diameter dual frequency dish antenna proposed is estimated to have a directive gain of 44.9 dB at 44 GHz and 39 dB at 20 GHz.

This antenna, incorporating an array feed and an ellipsoidal sub-reflector, allows the power of 32 1-W solid-state amplifiers to be space-combined as an alternative to waveguide combining. The resulting ERP at 44 GHz is 59.8 dBW, allowing 0.2 dB loss in the circulator and polarizer.

Assuming that the receiver front end has a noise temperature of 800 K (a mixer, available now) or 600 K (an FET amplifier, expected in a year or so), the resulting G/T at 20 GHz is 10.0 dBK^{-1} or 11.2 dBK^{-1} , respectively.

These estimates suggest that the antenna design could be useful for small EHF terminals. The numbers need to be verified experimentally, however.

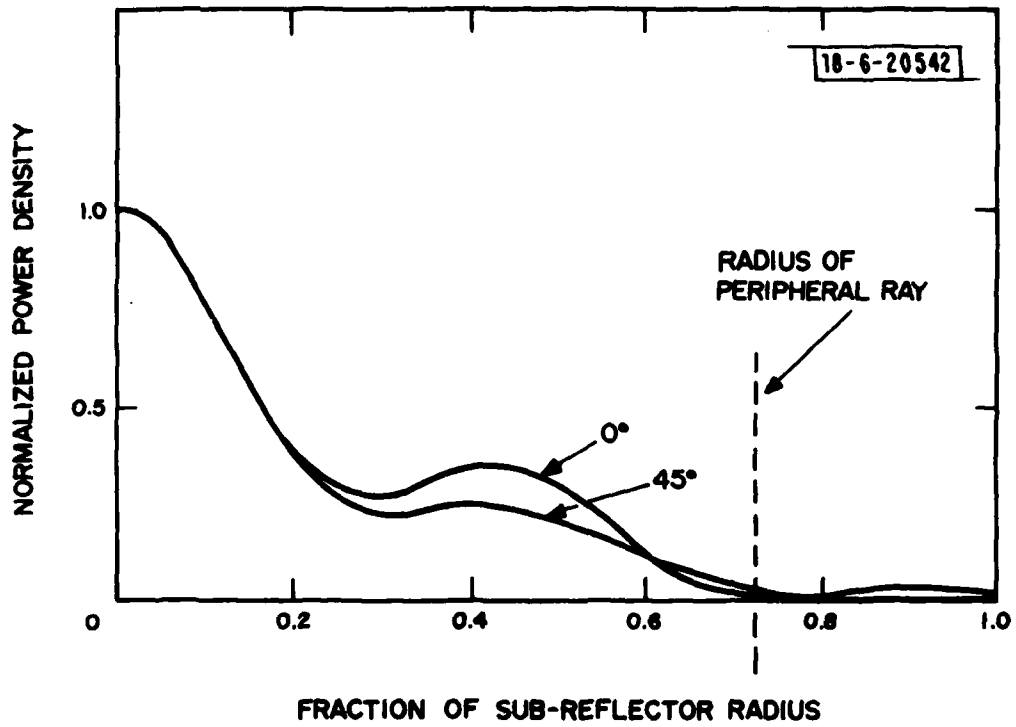


Fig. 4. Power-density along the two radials of the sub-reflector parallel with the principal planes of symmetry of the feed array.

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