A CROSS-SHAPED HORN AND A SQUARE WAVEGUIDE POLARIZER FOR A CIRCULARLY POLARIZED SHAPED BEAM ANTENNA FOR A BROADCASTING SATELLITE

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Abstract

A cross-shaped horn and a square waveguide polarizer for a circularly polarized antenna for a broadcasting satellite are designed using a finite difference method and a beam contour of an offset parabolic reflector fed with three cross-shaped horns is given.

Introduction

The shaped beam antenna of the medium-scale broadcasting satellite for experimental purpose (BSE), with linear polarization, was shown by experiment to be effective for covering the whole land of Japan which comprizes main lands and two clusters of remotely isolated islands. On the other hand the world broadcasting satellite administrative radio conference (WARC-BS) held in 1977 decided later that the antenna of operational satellites must be circularly polarized and that the radiated power of both co-polar and cross-polar components from satellite antenna must be below the maximum allowable levels which are specified in the Final Acts of the WARC-BS.

The side lobe level of a reflector antenna can be lowered by using an offset parabolic reflector but further reduction of cross-polar levels is desirable for the type fed with three conical horns which are similar to the BSE antenna. In this regard this paper introduces a new technique which has been developed to meet the performance requirements, using cross-shaped horns and square waveguide polarizers as a primary feed for a circularly polarized shaped beam antenna.

Basic requirements assumed for antenna design

The radiated power from the antenna toward a specific direction depends, of course, not only the antenna sidelobe or cross-pole gain to that direction but also the output power of the transponder. Taking into account the successful achievements of the experimental satellite it is assumed in this paper that the antenna requirements for the follow-on operational satellite are
(1) the service area is the same as that of the BSE,
(2) levels of both co-polar and cross-polar components outside the beam area are less than the specified levels of the Final Acts of the WARC-BS on the basis of power flux density on the earth,
(3) the bandwidth covers any two channels of the eight assigned to the broadcasting satellite service for Japan in the WARC-BS,
(4) the weight of the satellite is same as that of the BSE, that is 350 kgs.

In order to obtain low off-axis cross-polar radiation levels in circularly polarized reflector antennas, feed horn radiation pattern symmetry is necessary as well as low cross-polar levels radiated by the horn itself when excited by linearly polarized waves. A corrugated horn satisfies both requirements but the dimension of the aperture of a corrugated horn is 20% or 30% larger than that of a conical horn. Therefore, it cannot mechanically be adopted for the primary feed of the shaped beam antenna because the beam separation distance of the each horn required for the multiple beam type shaped beam antenna is very small.

In order to satisfy the above mentioned basic requirements it is necessary to develop a horn whose off-axis cross-polar components are small and whose aperture dimension is also small and convenient for arranging a multiple horn feed.

Cross-shaped horn

A newly designed cross-shaped horn is shown in Fig. 1. It has two merits compared with a conventional conical horn or a square horn.

(1) When configuring a multibeam horn feed, the distance of each horn can be made small.
(2) An off-axis cross-polar component is small when excited by circularly polarized waves.

Its specific feature is in the aperture shape. Its input waveguide is square. In calculating the radiation pattern, the aperture field method[1] is used.

$$\mathbf{E}(p) = \frac{-jke^{-jkR}}{4\pi R}\mathbf{R}_1\times[(n\times\mathbf{R}_1)\times\int\mathbf{E}_a\cdot e^{jk\boldsymbol{\rho}\cdot\mathbf{R}_1}ds] \quad \text{.......(1)}$$

Here, E_a is the aperture field of the cross-shaped horn. In order to calculate (1) we need E_a. Assuming that the length ℓ of the horn is large compared with the aperture dimension p, E_a is approximately equal to the dominant TE mode of a cylindrical waveguide whose cross section is same as the aperture of the horn.

The field distribution of such a waveguide cannot be solved in a closed form, but a numerical solution can be obtained using the finite difference method[2].

$q/p = 1$ corresponds to a square aperture and the beam width of the E plane is narrower than that of the H plane as well known. When $q/p \ll 1$ the aperture becomes a cross slot shape and the beam width of the H plane is narrower than that of the E plane. We looked for the value of q/p where the beam width of the both planes becomes very close by calculating the radiation pattern changing the ratio q/p, and finally we got the radiation pattern shown in Fig. 2. As seen in the figure the beam width of the E plane and the H plane is very close. The ratio q/p is 1/2 and the cutoff wavelength is 1.79p which is 10.5% shorter than that of the square waveguide of the dimension p. A calculated beam contour of this horn for circular polarization is shown in Fig. 3. Because of low cross-polar components radiated at wide ranges of angle off boresight, this particular shape of the aperture was adopted for a cross-shaped horn.

Square waveguide polarizer

An input waveguide of a cross-shaped horn is square, so a square waveguide polarizer is desirable rather than circular ones for exciting circularly polarized waves. Fig. 4 shows the structure of the designed polarizer. By putting a small metal piece shown

(a) on the two corner of a square waveguide to make the waveguide cross section hexagon (b), vertically larized input waves can be resolved into two orthogonal modes. A and C are $\lambda/4$ matching sections. The total length of the polarizer ($\ell_1+2\ell_2$) is decided to obtain 90 degree phase difference between the two orthogonal modes.

A prototype is made at the design center frequency of 12GHz. The propagation constants of the TE dominant mode of the two orthogonal modes can be calculated by the numerical method as used in calculating the aperture field of the cross-shaped horn. Calculated examples of the guide wavelength for the two modes are shown in Fig. 5. These values are used for calculating the phase difference between the two modes.

In order to evaluate the error of the computation several resonant cavities of different h's whose length was 38.16 mm were made and their resonant frequencies were measured by measuring the absorption notch of the cavities using a network analyzer. As shown in Fig. 6 the differencies between the calculated values and measured ones are less than 0.1%.

Measurement of the axial ratio of the designed polarizer were done by the experimental setup shown in Fig. 7. Results are shown in Fig. 8. The bandwidth of less than 1dB axial ratio is about 150MHz, and the center frequency is 100 MHz higher than the designed frequency. The reason for the narrow bandwidth is due to the reflected power from the horn aperture rather than the mismatch of the polarizer itself. Further study on improving the bandwidth is in progress.

Shaped beam antenna electrical design

The designed antenna is elliptical in shape, as shown in Fig. 9. The major and minor axis lengths of the aperture are 159 cm and 103 cm which are the same as that used in the antenna of the experimental satellite. The focal length is 85 cm. The significant difference is that the designed antenna uses an offset parabolic reflector. The arrangement of the horns is shown in Fig. 10. It was decided to satisfy the requirements that the beam separation radiated from these horns matches the required coverage area and also that the horn aperture sizes are large enough to illuminate the offset parabolic reflector efficiently. The power ratio among the three horns is 82:10:8.

Calculated beam contours of the designed antenna are shown in Fig. 11 and 12. Fig. 11 shows a righthand circular polarization pattern which is a co-polar component, and Fig. 12 shows a lefthand circular polarization pattern which is a cross-polar component. The peak gain is 40.9 dB. The map on the figure shows the Japanese main lands and remote islands seen from the satellite in the geostationary orbit of 110° East.

As seen in the figure, the main lands are covered by the 37 dB contour level and all the remote islands are by the 29 dB one. The maximum cross-polar level is -28 dB which is 1 dB below the required cross-polar level for the operational satellite. Therefore, the designed antenna satisfies the assumed antenna requirements for the follow-on operational broadcasting satellite.

The calculation of the far field of the antenna is done by the current distribution method.[3] The current on the reflector is given by the total field of the vector sum of the three cross-shaped horns. In order to simplify the calculation, only the phase difference due to the path length of the three horn and the gain difference due to the horn aperture sizes were taken into account. The field vector orientations of the three horns on the reflector were assumed to be equal.

Conclusion

A cross-shaped horn and a square waveguide polarizer design and their performances together with an electrical design of the shaped beam antenna for a broadcasting satellite using three cross-shaped horns are shown.

The calculated beam contour of the designed antenna satisfies the assumed requirements of the antenna of the follow-on operational satellite for Japan. These contour levels also satisfy the WARC-BS power limit.

References

1. S. Silver, "Microwave Antenna Theory And Design," McGraw Hill, 1949, p. 158
2. J.B. Davies and C.A. Muilwyk, "NUMERICAL SOLUTION of HOLLOW WAVEGUIDES with BOUNDARIES of ARBITRARY SHAPE," Proc. IEE Vol. 113 No.2, Feb. 1966, pp.277-284
3. Same as 1, p.144

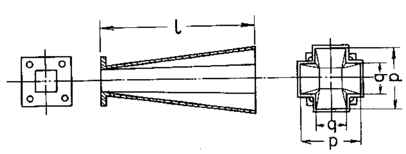
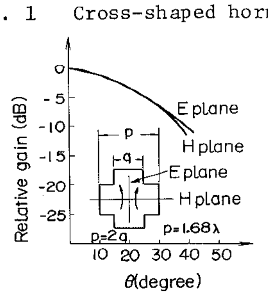


Fig. 1 Cross-shaped horn



θ Off-axis angle in the Eplane or Hplane

Fig. 2 Radiation pattern of a cross-shaped horn (linear polarization)

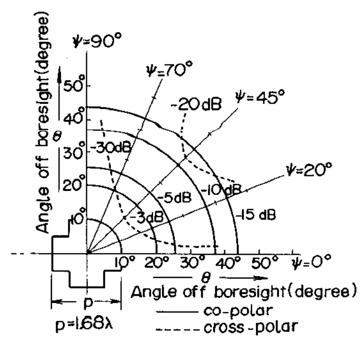
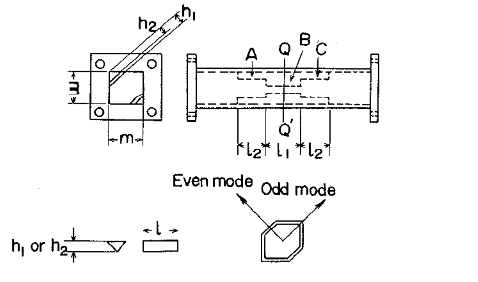


Fig. 3 Beam contour of a cross-shaped horn (circular polarization)



(a) a metal piece to be inserted

(b) Q-Q' cross-sectional view

Fig. 4 Structure of the designed polarizer

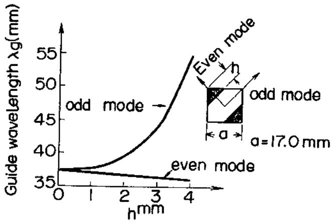


Fig. 5 Calculated guide wavelength of the two modes at 12GHz

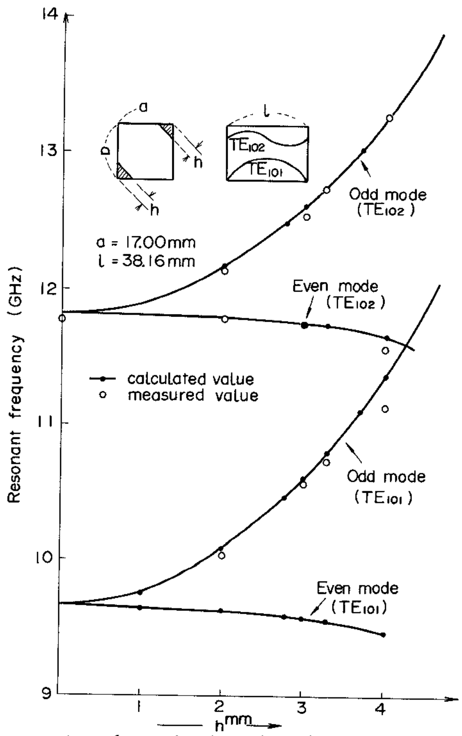


Fig. 6 Calculated and measured resonant frequencies of the cavities

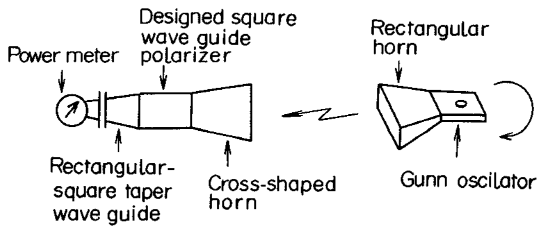


Fig. 7 Experimental setup for measuring the axial ratio of the polarizer

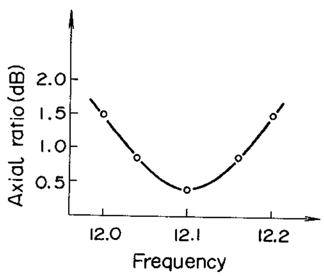


Fig. 8 Frequency characteristics of the square waveguide polarizer including the cross-shaped horn

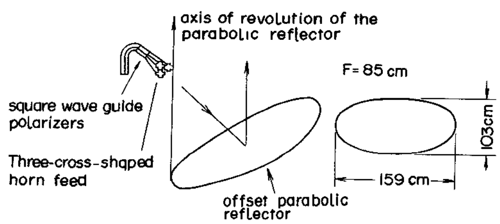


Fig. 9 Example of the whole configuration of a shaped beam antenna

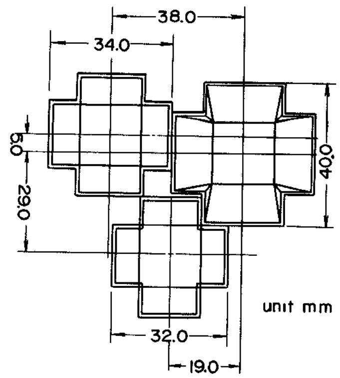


Fig. 10 The arrangement of the three horns

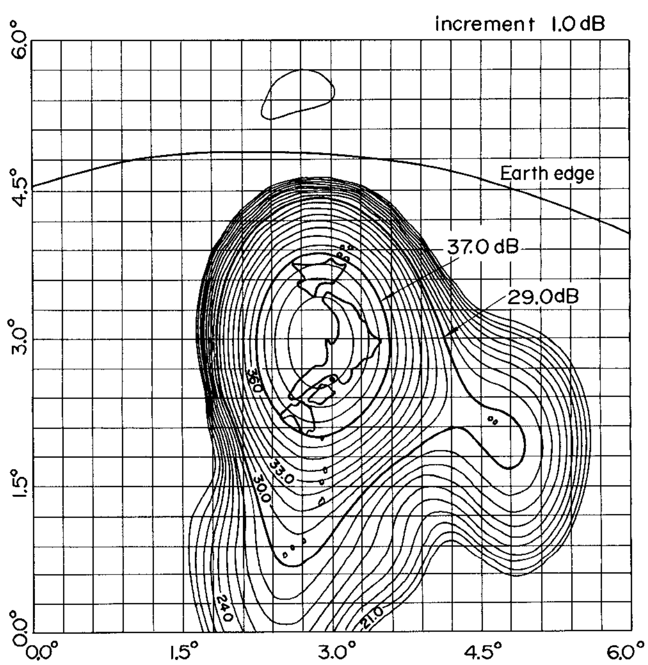


Fig. 11 Calculated beam contour of the designed antenna (co-polar component absolute gain)

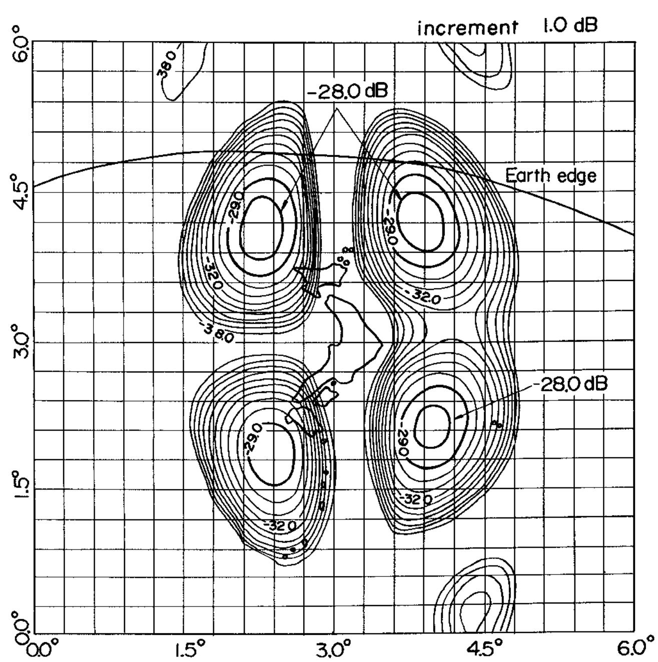


Fig. 12 Calculated beam contour of the designed antenna (cross-polar component relative gain)