A REFLECTOR ANTENNA LOG-PERIODIC FEED FOR 1-10GHZ FREQUENCY RANGE

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Abstract

The application of unidirectional log-periodic antenna as feeds for reflectors to cover 10:1 bandwidth is described. The trapezoidal-tooth sheet structures are analyzed using moment method and information on the primary patterns, input impedance, and active region of them is given so as to allow the design of feeds for a variety of reflectors. A tapered microstrip transmission line can be used to provide matching to the antenna. Measurements and experimental results are presented for Validation of analysis.

1. Introduction

There are many applications in the communications, search, and ECM fields where it is quite desirable to have a high-gain antenna, which will work over an extremely wide frequency range. Reflector type antennas are often used; but their bandwidths have been limited by the primary feed. The bandwidths of previous primary radiators have usually been on the order of 2 or 3:1. However, the discovery of log-periodic and angular antennas [1] with essentially frequency independent operation over bandwidth of 10 or 20:1 provides the basis for wide-band primary radiators. Log-periodic antenna [2] is a well-known and attractive antenna due to its frequency independent nature.

In this paper, one type of log-periodic structures named trapezoidal-tooth log-periodic antenna has been used as reflector antenna feed. In the first section, the simulation results of antenna characteristics have been presented. Next, general feed requirements such as feed radiation pattern (E and H-plane beamwidth vs. the F/D ratio) are described; and a special log-periodic structure that covers all required parameters is offered. Finally, experimental results are given for checking the performance of design.

2. Trapezoidal-Tooth Log-Periodic Antenna

Fig. 1 is a sketch of a sheet trapezoidal-tooth log-periodic antenna, which will be consider as a feed in this article. As can be seen, the angles α, β, and Ψ define the extremities of the teeth, the tooth support section and the angle between the two half structures (arms), respectively.

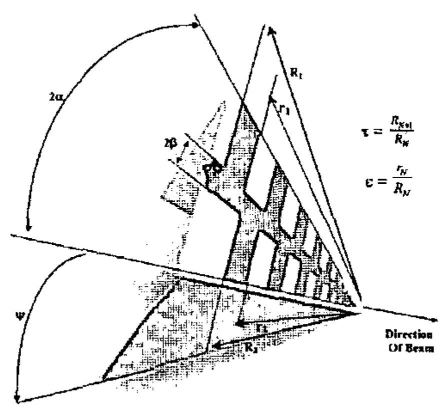


Fig. 1: trapezoidal-tooth log-periodic structure

The design ratio τ is defined as R_{N+1}/R_N, where R_N is the distance from the vertex to the outer edge of a tooth. The ratio ε (ε is a measure of the tooth width) is set equal to $\sqrt{\tau}$. Since these antennas have been described previously [2], only a brief description of them will be given here.

The moment method [3] has been used for analyzing the structure. The equation solved by moment method technique is generally a form of the electric field integral equation (EFIE) or the magnetic field integral equation (MFIE). Both of these equations can be derived from Maxwell's equations by considering the problem of a field scattered by a perfect conductor [4]. The form of the integral equation used determines which types of problems a moment method technique is best suited to solve; for example one form of the EFIE may be particularly well suited for modeling thin-wire structures, while another form is better suited for analyzing metal plates. In arbitrary surface modeling the EFIE has the advantage of being applicable to both open and closed bodies, whereas the MFIE applies only to closed surfaces. For this reason, the wire-grid modeling approach [5] has been used for modeling the considered antenna structure. The detail of analyzing has been described in [6].

Fig. 2 shows the variation of the E and H-plane 10-dB beamwidth of the structure as a function of Ψ for several values of angle α.

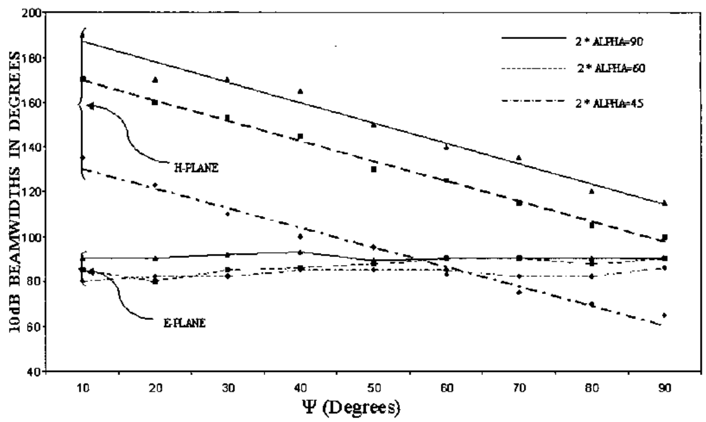


Fig. 2: E and H-plane 10-dB beamwidths as a function of Ψ (2β=10°, τ=0.84) [6]

If the input impedance of this structure is plotted on a smith chart over a frequency range of several periods, it will be found that the locus forms a circle with the center laying one zero reactance line. The characteristic impedance of the antenna is defined as the geometric mean of the maximum and minimum real values on the locus (the circle center)[7]. The VSWR referred to this characteristic impedance is then simply equal to the ratio of the maximum impedance to the characteristic impedance. The variation of the characteristic impedance and VSWR with the angle Ψ for specified parameters is illustrated in Fig. 3.

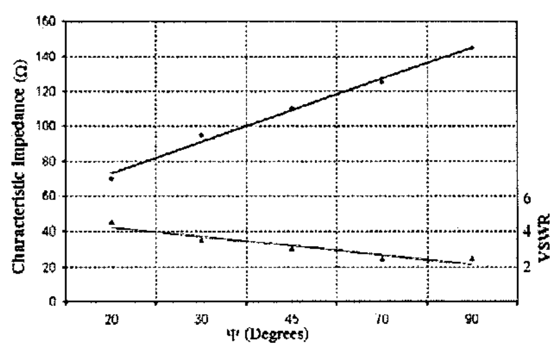


Fig. 3: Characteristic impedance as a function of Ψ (2α=60°, τ=0.84, 2β=10°) [6]

The infinite structure is seen that has a frequency-independent behavior. Fortunately, this finite LP structure provides frequency-independent operation above a certain low-frequency cutoff and down a high-frequency cutoff. Most of the radiation takes place in the active region where the teeth length is about between $\lambda/5$ and $\lambda/4$ (when the angle β is small). Therefore, for design a LP antenna in a special frequency range, the longest and the shortest tooth must be considered equal to $\lambda_{max}/4$ and $\lambda_{min}/5$, respectively.

3. General Feed Requirement

Obviously, for a very wide frequency range, the electrical characteristics of the feed should be essentially independent of frequency. The important electrical characteristics are the feed radiation pattern, input impedance, phase center, and the aperture blocking. The radiation pattern should be unidirectional and should have E and H-plane beamwidths, which give optimum gain for a given dish. These beamwidths will depend upon the shape of the dish, the F/D ratio and the desired illumination taper.

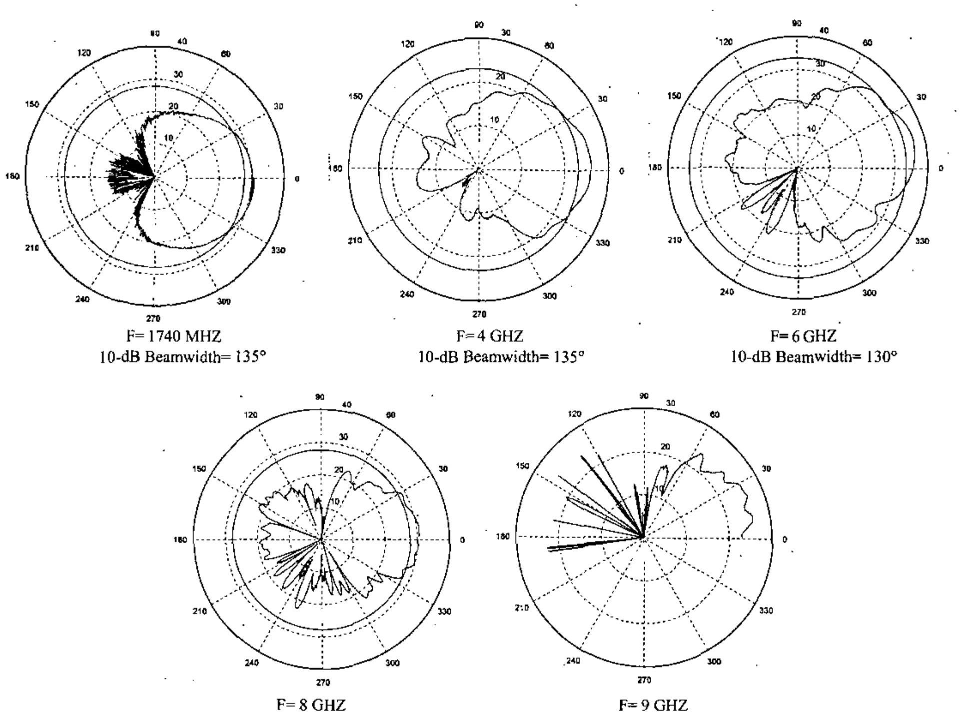
$$\delta = 4\cot^{-1}\left(\frac{4F}{D}\right) \qquad (1)$$

Eq. 1 is a formula of the angle δ, (the angle between focal point and edges of parabolic surface), subtended by a parabolic reflector as a function of the F/D (front to diameter) ratio. In order to obtain high gain and low side lobes with a dish antenna, it is desirable to taper the aperture illumination. The optimum amount of the taper is a rather insensitive function of the F/D ratio with an average value of about 9 to 10 dB [7]. Thus, for more cases, Eq. 1 can be used directly to determine the desired 10-dB beamwidth of a feed for a given F/D ratio. The requirements on the input impedance would depend upon the application, but in general, it may be said that the VSWR should be at least less than 3:1. Aperture blocking due to the feed can lead to increased secondary pattern side lobes and beamwidths. For extreme bandwidth applications using log-periodic feeds, this can become a serious problem since the feed is many times the required size at the high end of the frequency range.

4. Validation and Performance

The investigation of log-periodic feeds was directed toward the development of a feed for a dish with $F/D \approx 0.4$ to cover the frequency range of 1 to 10GHZ. According to the Eq. 1, the 10-dB beamwidth is 130° in both E and H-plane, approximately. The final design parameters chosen are $\Psi=55°$, $2\alpha=60°$, $\tau=0.84$, $2\beta=10°$, and the longest tooth of antenna was set equal to 8cm and $R_1=16$cm; Fig. 1 illustrates the made feed. The pattern characteristics of this feed are E and H-plane average 10-dB beamwidth of 95° and 130° respectively.

Fig. 4 shows the measured H-plane radiation patterns in several frequencies. As can be seen, approximately, the 10-db beamwidth has been fixed, and only the side lobes have variations.



F= 1740 MHZ
10-dB Beamwidth= 135°

F= 4 GHZ
10-dB Beamwidth= 135°

F= 6 GHZ
10-dB Beamwidth= 130°

F= 8 GHZ
10-dB Beamwidth= 125°

F= 9 GHZ
10-dB Beamwidth= 125°

Fig. 4: H-plane radiation patterns over a 10:1 frequency range

A microstrip tapered transmission line [8] is used to provide, over a wide frequency range, matching to the antenna, whose input impedance is about 115Ω (Fig. 3). For this reason, the each arms of the antenna has been printed on a "RO4000™ Series High Frequency Materials" substrate having a relative dielectric constant of 3.38 and a thickness of 1.52mm. Metal surfaces on the other side of substrates have been deleted. The microstrip tapered transmission line, that utilizes triangular mean section of one arm of the antenna as the ground plane and its tapered strip has been printed on bottom side of the substrate against that section, is connected directly to the other arm. The length of tapered microstrip transmission line is 17cm and its strip width at the end and begging points, are 3.26mm (correspond to 50Ω) and 0.42mm (correspond to 115Ω).

The measured return loss of the antenna has been illustrated in Fig. 5. As can be seen, the return loss is better than 6 dB (3:1 VSWR) over a wide bandwidth from 1 to 12GHZ. It should be noted that an improvement in the return loss is feasible with a better impedance transformer (longer tapered transmission line).

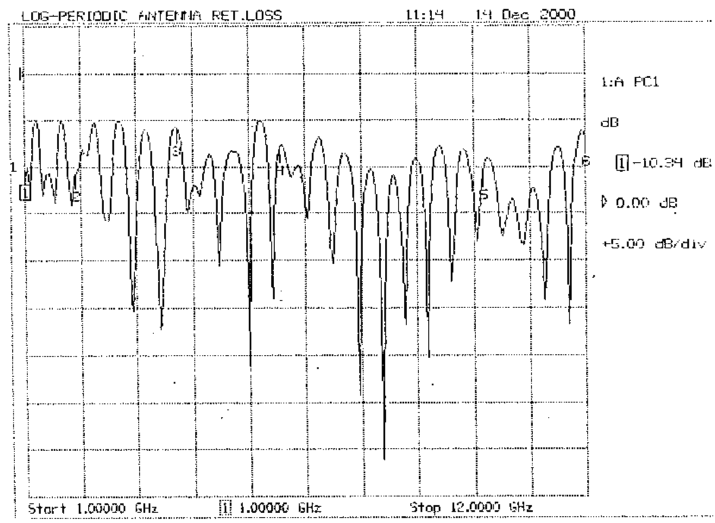


Fig. 5: return loss of the antenna as a function of frequency (with 115Ω characteristic impedance)

5. Conclusion

Log-periodic antennas are well suited as extreme bandwidth feeds for reflectors. A trapezoidal-tooth log-periodic antenna matched by a tapered microstrip line has been demonstrated. Antenna exhibited good radiation characteristics. More than 6-dB return loss and 10-dB return loss has been measured over all and 60% bandwidth from 1 to 10GHZ. The H-plane beamwidth for a feed consisting of two half structures may be varied over a wide range by changing the design parameters. Although the E-plane beamwidth is insensitive to these parameters, it may be decreased easily for large F/D ratios by using a multielement array.

References

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