

High Power Waveguide-Fed Reduced Lateral Wave Antenna



Abstract

This research focuses on the development of a high-power waveguide-fed microwave antenna that has a reduced level of lateral radiation (radiation that travels along the supporting ground plane, potentially causing serious coupling, interference, and diffraction problems). A particular design is proposed, and simulations of this design verify the reduced lateral radiation behavior of the antenna.

Introduction

High-power microwave antennas are used for a variety of applications including radar and communications, and also for military purposes such as directed-energy weapons. These antennas are faced with one major challenge: they produce high levels of lateral radiation. This is radiation that travels away from the antenna laterally along the surface of the ground plane or other supporting structure, which can then couple to other antennas in an array environment, or into other systems via apertures or cables, etc., as well as diffract off the edges of the supporting structure.

The proposed antenna is shown in Fig. 1. It consists of a circular metal disk radiator fed by a circular slot (aperture) in the top wall of a rectangular waveguide, operating in the usual TE_{10} mode. A waveguide is used as the feeding source since most high-power microwave systems employ waveguide due to its lower losses and higher power-handling capabilities compared with transmission lines such as coaxial cables.

The disk radiator, being a horizontal metallic structure, will inherently radiate low levels of lateral radiation according to image theory, which predicts that a horizontal electric current over a metallic ground plane (modeling the supporting structure) will not produce lateral radiation far away from the current. The radiating disk is surrounded by a protective radome that allows the system to operate in a gas-filled environment, e.g., using pressurized SF₆, to increase the dielectric breakdown strength of the system [1]. The sharp edges at the outer edge of the radiating disk and the edge of the aperture are smoothed out into toroidal-shape edges, as shown in Fig. 2, to minimize breakdown and increase the power-handling capability.

The antenna has an equivalent circuit model that is approximately that of a series impedance located on the transmission line model of the TE_{10} mode of the waveguide. The resonance frequency is defined as that where the real part of the series impedance is maximum (called $R_{\max}$). In this transmission-line model the characteristic impedance of the transmission line is taken to be the power-voltage impedance of the waveguide mode.

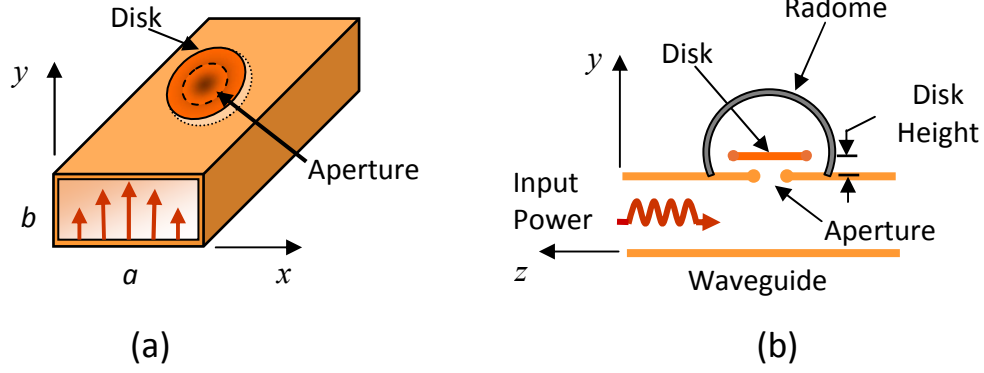


Fig. 1. Waveguide-fed reduced lateral wave antenna. (a) Oblique view (radome not shown). (b) Side view (showing radome).

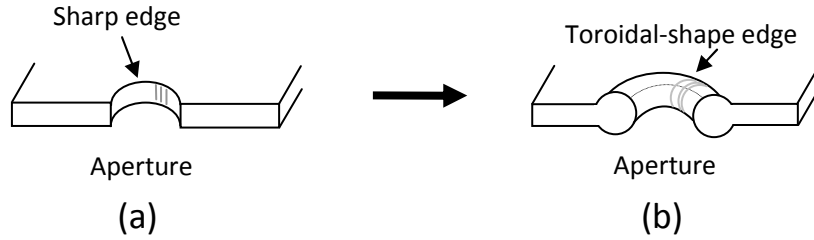


Fig. 2. Cross-sectional views of the circular aperture in the top wall of the waveguide. (a) With sharp edges. (b) With a toroidal-shape edge.

Antenna Design and Results

The performance of the antenna is simulated by using the Ansoft High Frequency Structure Simulator (HFSSTM) software, which can simulate the input impedance of the antenna (as seen from the feeding waveguide) as well as the radiation patterns. Also, a simple CAD circuit model has been developed for the antenna, based on similar models that have been used for aperture-fed patch antennas [2]. The simple CAD circuit works well to predict the input impedance of the antenna, though details are omitted here.

Input power from the waveguide is coupled to the disk, which essentially acts as a circular microstrip antenna on an air substrate, via the coupling aperture. The radius of the aperture is controlled to reduce lateral radiation. As the size of the aperture decreases the lateral radiation also decreases, as well as the coupling to the disk, which lowers the input resistance of the antenna ($R_{\max}$) at resonance; therefore a compromise aperture size needs to be selected to satisfy the required design specifications for the antenna. This is demonstrated in Fig. 3, and Fig. 4, respectively (these results are for no toroidal edge smoothing, though the edge smoothing has little effect on these results). Figure 3 shows the level of lateral radiation (with respect to the power density radiated at broadside) vs. aperture radius for various disk heights. Figure 4 shows $R_{\max}$ vs. aperture radius. Other results (not shown) reveal that the bandwidth increases as the disk height increases.

However, increasing the disk height also increases the lateral radiation and lowers $R_{\max}$ (due to weaker coupling) as seen in Figs. 3 and 4.

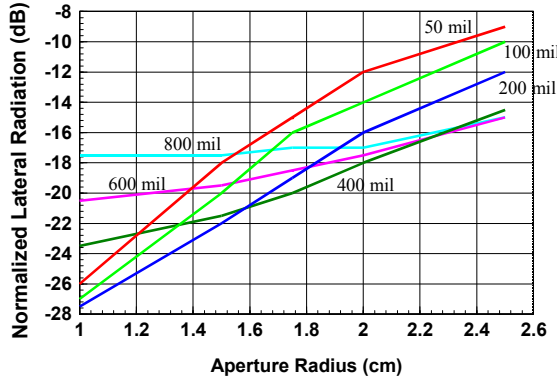
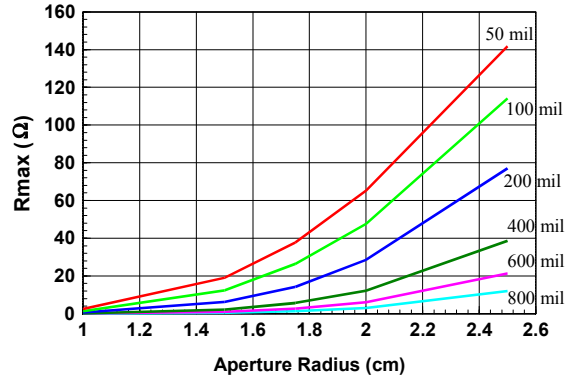


Fig. 3. Lateral radiation level vs. aperture size for various gap thicknesses: 50, 100, 200, 400, 600, and 800 mils.

Fig. 4. $R_{\max}$ vs. aperture size for various gap thicknesses: 50, 100, 200, 400, 600, 800 mils.



After performing simulations, a final antenna candidate was selected having the following configuration: a 600 mil (1.524 cm) disk height, giving a bandwidth of 10.88%, and a 2.5 cm radius aperture giving an $R_{\max}$ of 18.2 Ohms (after toroid edge smoothing and the radome were introduced). The far-field radiation pattern in Fig. 5 (which includes the effects of the edge smoothing and the radome) shows a lateral radiation of about -19 dB in the E plane. The radome is an FR4-epoxy (dielectric constant of 4.4) hemispherical radome of 3 mm thickness. Interestingly, it was observed that the radome actually helped to improve the pattern (lower the lateral radiation and improve the symmetry of the pattern). The maximum electric field level in the antenna system was 1206 V/m, assuming an incident power in the waveguide of 1 W. The antenna radiated power for a 1 W incident power is -14.33 dBW. With the relative breakdown field for SF6 gas being $89 \text{ V m}^{-1} \text{ Pa}^{-1}$ [3], the breakdown of SF6 gas at 1 atmosphere pressure, or $1.01 \times 10^5 \text{ Pa}$, is calculated to be $8.989 \times 10^6 \text{ V/m}$. As a result, the maximum radiated power of the antenna operating in SF6 gas under 1 atmosphere is given by

$$P_{\text{rad}}^{\max} = 10 \log_{10} \left((8.989 \times 10^6 / 1206)^2 \right) - 14.33 = 63.12 \text{ dBW} = 2.05 \text{ MW}.$$

For illustration, it is assumed that this antenna is designed to be in a three-by-nine array that has the capability to handle at least 1 GW peak power. With a factor of safety of 50 percent, each antenna has to be able to radiate about 56 MW, a power level that can be accommodated by means of pressurization of the SF6 gas. The required pressure level is determined to be: $p_{\text{SF}_6} = \sqrt{56 / 2.05} = 5.23 \text{ atm} = 5.23 \times 10^5 \text{ Pa}$.

The maximum electric field level in the air region on the outside surface of the radome for this operating condition was 2.59×10^6 V/m, found at the radome/conductor/air junction, which is less than the air breakdown value of 3×10^6 V/m for atmospheric air.

Conclusions

A high-power waveguide-fed reduced-lateral-wave antenna is proposed. The design (shown in Fig. 1) consists of a circular radiating metal disk fed by a circular coupling aperture, protected by a radome that may contain a pressurized gas such as SF₆. The breakdown is minimized by smoothing out the sharp edges on the aperture and the disk. The antenna realizes low levels of lateral radiation while being able to handle high levels of peak power.

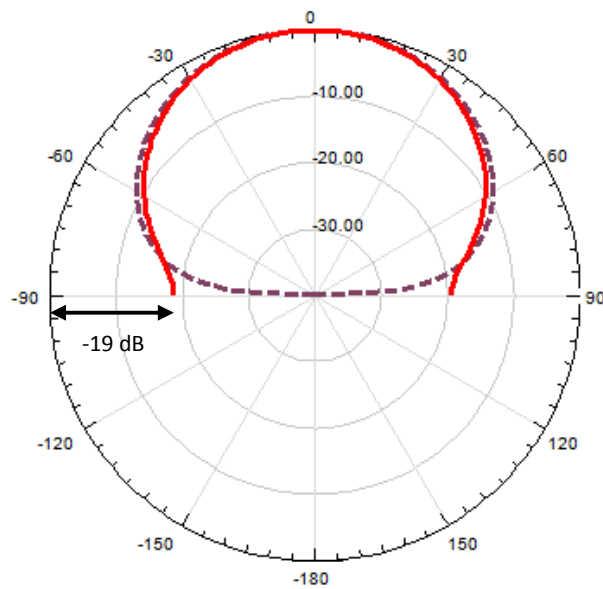


Fig. 5. E- and H-plane patterns (solid and dashed curves) for the proposed antenna (with radome). The level of lateral radiation is -19 dB.

References

- [1] L. P. Babich and T. V. Loiko, "Peculiarities of electrical breakdown in dense electronegative gases at high overvoltages," *Doklady Physics*, vol. 50, no. 5, 2005, pp. 241–243.
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