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Transmission Loss of a Millimeter Wave Pulse Through a Waveguide Window

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Abstract: *Millimeter waves have become increasingly important in wireless communication today. It is well known that a waveguide window exhibits almost perfect transmission for the center frequency of millimeter waves. However, this might not be true for a pulsed wave. In this work, we study the transmission loss of a millimeter wave pulse centered at 35 GHz traveling through a rectangular waveguide window. The transmission function of a continuous wave within the bandwidth from 0 to 100 GHz has been obtained using the transfer matrix method. The millimeter wave of 35 GHz pulsed from 100 ps to 1 us in time domain has been Fourier transformed to the frequency domain so that the transmittance of the pulsed wave in the frequency domain can be calculated. The transmission loss has been analyzed for various pulse durations. After inverse Fourier transform of the transmittance in the frequency domain back to the time domain, one can compare the result with the incident pulse to see the pulse distortion and transmission loss. A finite difference time domain simulation has been performed to verify the calculated results by the transfer matrix method combined with Fourier transform. Detailed methodology and analysis of the study will be presented.*

Keywords: transfer matrix method; waveguide window; millimeter wave pulse; Fourier transform

Introduction

In microwave tubes, ceramic microwave windows are used to separate the high vacuum of such devices from atmospheric pressure. The rectangular waveguide windows have been studied and extremely attracted much attention in recent two decades. Due to the development of electromagnetic technology, microwave tubes have transitioned from the traditional centimeter waves into the millimeter waves for a variety of applications such as satellite communication, radar, and so on. Consequently, the frequency becomes higher and the wavelength is relatively shorter, which makes the geometric size of the microwave window smaller and thinner. In principle, the thickness of a dielectric window is $\lambda_g/2$, where the value λ_g is the wavelength in the material of the vacuum seal. In order to obtain the microwave maximum output, the optimized transmission is crucial in microwave tube system. For better understanding, there are many numerical methods have been developed and applied to the analysis and investigation of the microwave window, including the finite-difference frequency-domain/finite-difference time-domain (FDTD) method, the finite-element method (FEM), the transfer matrix method, and others. In spite of successful computations in the frequency domain or the time domain for single frequency (wavelength), there are several problems of the pulsed waves with a high bandwidth penetrating the microwave window. The power loss and distorted wave profiles can be expected.

In this work, we present the quantitative analysis of sine-wave pulse centered at 35 GHz in the time domain and frequency domain transmitting though a waveguide window. In order to determine the power loss of the sine-wave pulse, we calculate the transmittance of a waveguide window using the transfer matrix method. At the same time, the wave profiles of the incident and penetrated waves are compared to exhibit the difference. This methodology can be applied to different configurations of microwave waveguide windows for use in wireless communication.

Physical model and calculation

Let us consider a waveguide with its rectangular cross section of sides a and b, and the enclosed a dielectric slab, as shown in Figure 1. A transfer matrix approach is employed to discretize the dielectric function profile of the slab. Additionally, we simplify the computation that of the discretized Helmholtz's equation into quasi-one-dimension problem, for the pth region with constant permittivity ε_p and constant permeability μ_p. The boundary conditions for TE modes and TM modes at the interface between layers p and (p+1) at position $z=z_p$ where p=1,2,…,(n+1), respectively. The transfer matrix approach can be used to solve the transmittance and reflectance for the analysis of the electromagnetic wave transport properties. In our model, there is an optimum transmission to determine the thickness of the dielectric window [1, 2],

$$d = \frac{\lambda}{\sqrt{\varepsilon_d \mu_d - (\lambda/\lambda_c)^2}}, \tag{1}$$

where λ_c is the cutoff wavelength.

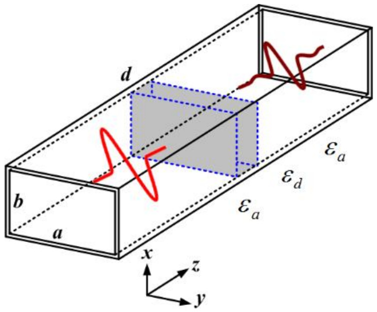

Figure 1. Schematic of a rectangular waveguide window of sides *a* and *b*. The incident sine-wave pulse propagates through the window. One can observe the transmitted wave is distorted.

In order to achieve high precision and convergence, the time base of the sine-wave pulse and the sampling number in frequency domain via Fourier transform are carried out with Nyquist sampling theorem. The frequency range below the cut-off frequency is not considered. The transmission, reflection, and field profiles can be easily obtained using an inverse Fourier transform.

Results and discussion

The microwave window of dimensions 7.11 mm x 3.55 mm in a rectangular waveguide is shown in Figure 1. A transfer matrix approach is employed to discretize the dielectric function profile as ε_a, ε_d, and ε_a, respectively. For this case, the dielectric constant ε_d is 3.8 and the corresponding thickness *d* is 2.311 mm. The transmission function has been calculated for wave pulses centered at a frequency of 35 GHz by matching the boundary conditions at each interface. The thickness of the dielectric window with optimum transmission can be determined by Eq. (1). In Figure 2, the field profiles of incident and transmitted sine-wave pulses are shown. As one can see, the transmitted wave is distorted and the corresponding amplitude is reduced to 41.76%.

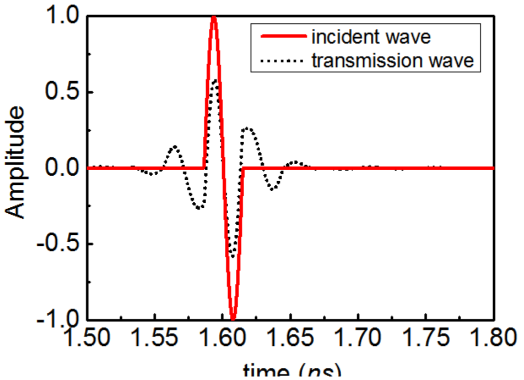

Figure 2. Profiles of the incident sine-wave pulse (red line) and transmitted wave pulse (dotted line).

The bandwidth of the incident sine-wave pulse of one period is about 31.43 GHz, which is larger than that of the dielectric window. In addition, the incident sine-wave pulse propagating in a rectangular waveguide suffers the cutoff effect, i.e., some power loss from the filtering out of lower frequencies. Figure 3 shows the multi-period sine-wave pulse propagating in a dielectric window. As one can see, the power loss decreases from 58.24*%* to less than 1*%*, when the number of periods of the sine-wave pulse is increased to *71*.

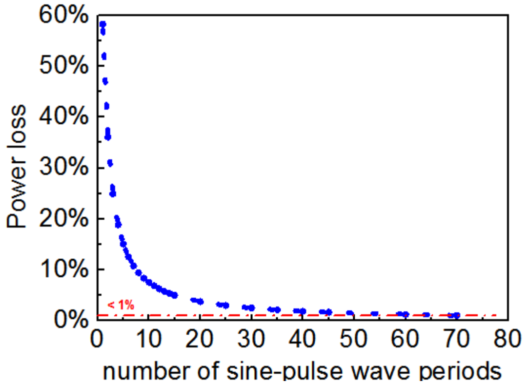

Figure 3. Power loss of a sine-wave pulse versus its pulse length.

Conclusions

In this work, the transmission loss and distortion of a millimeter wave pulse through a waveguide window have been studied using the transfer matrix method combined with Fourier and inverse Fourier transforms. It is found that power loss of a sine-wave pulse of one cycle can be very large (58%). Therefore, this loss issue should be considered in short pulse communication. The methodology is general and can be applied to a variety of system configurations.

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References

1. M. C. Lin, "A multilayer waveguide window for Wide-Bandwidth millimeter wave tubes," Int. J. Infrared Milli. Waves **28**, 355-362 (2007).
2. M. C. Lin, H. M. Chung, and A. Burke, "An analytical approach for the fast design of high power waveguide windows," Wave Motion **37**, 183-188 (2003).