Investigation of a Simple Truncated Waveguide Phase Shifter

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Abstract— The design, fabrication, and performance of simple phase shifters based upon truncated circular and square waveguide cross-sections are presented. An emphasis is placed upon validation of simple analytical formulae that describe the propagation properties of the structure. A test device was fabricated and tested at 30 GHz. We find that the return loss bandwidth for a given phase shifter volume can be maximized by setting the average of the two cutoff wavelengths in the delay section equal to that of the parent homogenous waveguide structure. The concepts explored and validated here can be directly applied to improving the performance of dual-mode millimeter and sub-millimeter waveguide components.

***Index Terms*— Circuit Synthesis and Modeling, Phase Shifter, Polarization, Waveguide Components**

I. Extended Abstract

In symmetric square and circular waveguides, homogeneous propagation occurs for both polarization states. Truncating the cross-section of the waveguide introduces an asymmetry between the cutoff wavelengths in the structure's dominant modes of propagation. In this phase shifter design approach, the overall phase delay between the two modes is controlled via the degree of asymmetry in the propagation constants and the overall length of the truncated guide used in the structure. For dual-mode phase shifters it is desirable to achieve minimal and balanced reflection performance for both polarizations states. In this paper we propose and validate a design approach that achieves this goal using simple truncated square and circular waveguides as a worked example.

To realize a balanced reflection match for both polarization states, we investigate phase shifters for which the cutoff wavelength of the parent waveguide is equal to the average of those for the modes propagating in the truncated guide. This can be contrasted with the simplest traditional adiabatic phase shifter design wherein the cutoff wavelength for one mode typically is set equal to that of the parent guide for manufacturing simplicity. As a result, a mismatch occurs between the differing polarizations. In such an adiabatic phase shifter design, the overall length of the phase shifter must be increased in order to mitigate this increase in return loss for one of the polarizations. The proposed matching condition yields propagation constants that are homogeneous on average with respect to the parent guide and enables use of a shorter phase shifter length.

We explore and present calculations for the cutoff wavelengths of truncated square and circular waveguides as a function of the cross-section's degree of truncation. Analytic expressions for the truncated guide's eigenvalues are derived via perturbation theory and compared with numerical simulations. We find that the analytical expressions are of sufficient accuracy to be used to enable design of the structure when used in a simple transmission line circuit model that incorporates the phase shift due to additional impedance matching steps added to the guide cross-section.

Using this approach, we have designed and fabricated a test device based on a truncated circular waveguide design. The test results are compared to a full-wave simulation of the device. The prototype device was found to work as expected given the fabrication tolerances held in manufacture. The concepts explored and validated here can be directly applied to improving the performance of dual-mode millimeter and sub-millimeter waveguide components.

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