A NOVEL WIDEBAND TM01-to-TE11 MODE CONVERTOR

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ABSTRACT

A novel, state-of-the-art design is presented for a TM01-to-TE11 circular waveguide mode convertor, providing over 30% bandwidth of extraneous-mode-free operation at a conversion loss of less than 0.5 dB. The design philosophy is based upon the unique use of two intermediate modes, a coaxial TEM and a rectangular waveguide TE10, which provide input-output isolation of the converted modes.

INTRODUCTION

Microwave systems often need to take the energy generated in an inconvenient field configuration (mode) and convert it to a more useful one. One of the most common mode conversion requirements in high power systems is from the TM01 to the TE11 in circular waveguide. The TM01 circular waveguide (CWG) mode is generated by sources with axial electron beams, which are most of the very high power (>Megawatt) sources. This mode has a transverse electric field null on the axis, producing a donut-shaped beam when radiated rather than the preferred solid beam. The desired mode is the TE11. In order to best use these power sources, it is necessary to convert the TM01 mode to the TE11 CWG mode.

The original contribution in this design is the unique incorporation of two intermediate modes to isolate the two port modes, eliminating extraneous mode contamination in both ports. The significance of this is high conversion efficiency over a broad bandwidth.

REQUIREMENTS

Although mode conversion is the primary need, there are some additional aspects which are highly desirable and should be considered in the design. These are listed below:

a) Well matched - Better impedance match gives higher conversion efficiency and reduced loading effects on the source.

b) Bandwidth - The wider the bandwidth, the greater the applicability of the convertor, avoiding customizing designs for individual sources.

c) Input (TM01) mode purity - It is desirous to avoid excitation of extraneous modes (particularly the fundamental TE11) to increase conversion efficiency and to avoid negative effects on the source.

d) Output (TE11) mode purity - Again to increase conversion efficiency and to generate a "clean" radiated pattern for fluence characterization when used in measurements.

e) Input and output co-aligned on the same axis, often important in system layouts.

f) Provide e-beam collection - Since the sources with the axial electron beams are the ones which generate the TM01 mode, it is desirable to have a collector built into the convertor so that it may be integrated directly with the source.

DESIGN DISCUSSION

The fact that in CWG the TM01 mode has a higher cutoff frequency than the fundamental TE11 mode makes it impossible to convert directly without exciting some reflected TE11 energy. The novel approach taken was to convert initially to the TEM coaxial mode which has a cutoff frequency equal to zero. The wide mode separation of the coaxial line could then be used to isolate the input and output modes from each other. This split the design into two new ones, first a TM01-to-TEM convertor and second, a TEM-to-TE11 convertor. Unfortunately, the TEM-to-TE11 could not support the bandwidth required because of the low ratio between the cutoff frequencies of the TE11 and TM01 CWG modes. A second split was then made using an intermediate TE10 rectangular waveguide (RWG) mode. Therefore, a TEM-to-TE10 convertor feeding a TE10-to-TE11 CWG convertor was needed. The frequency ratio in the RWG for the TE10-to-TE11 is sufficiently high (2.24) to accommodate the required band. The result is then triple mode conversion; i.e. TM01-to-TEM-to-TE10 and then to TE11.

A cross-section of the total TM01-to-TE11 convertor is shown in Figure 1. Considering a TM01 mode incident from the left, the energy is first transitioned into a coaxial section that tapers to a smaller diameter. This technique provides a broadband TM01-to-TEM transition. A length of straight coax at this smaller diameter feeds an excitation loop in the rectangular waveguide, acting as the TEM-to-TE10 convertor. A short section of this RWG then feeds into a smooth tapered transition out to the circular waveguide for the TE10-to-TE11 conversion at the output. The straight coax section blocks the TE11 mode that is excited in the RWG from coupling back to the input, and the RWG blocks the TEM mode from coupling to the output as a TM01. Note in Figure 1, the electric field patterns are displayed for the appropriate modes in each type of waveguide used.

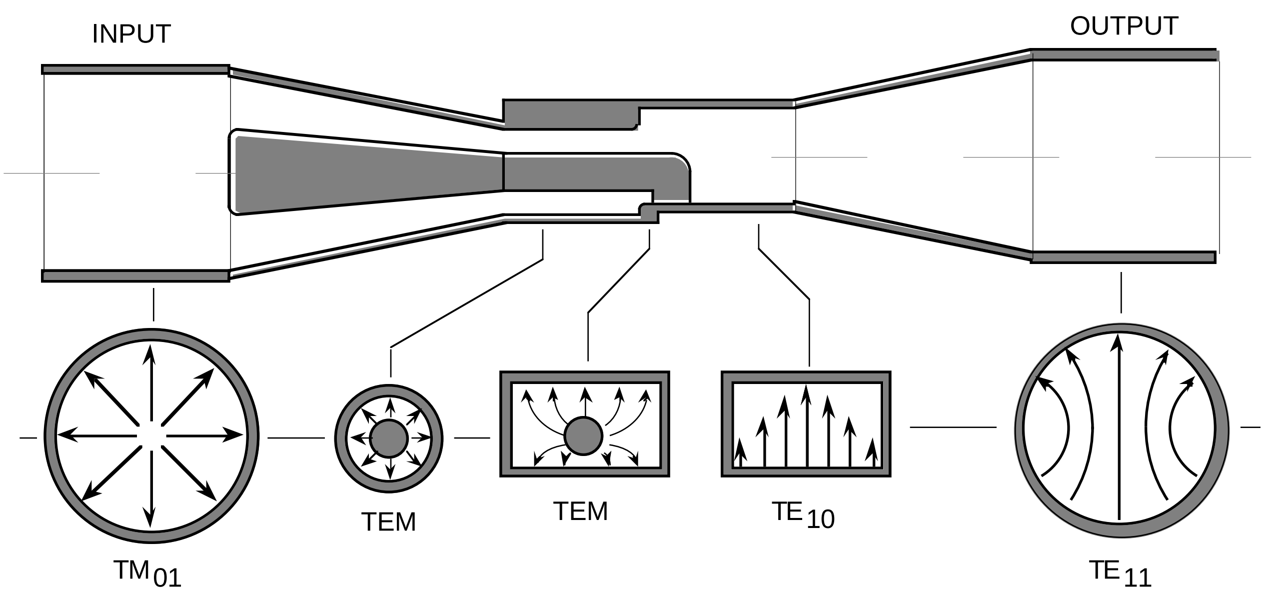

Figure 1. Mode Convertor Cross-section and Electric Field Patterns in the Various Waveguides

A more detailed description of the significance of the intermediate modes can be given by considering the following chart, shown as Figure 2. This chart relates the waveguide cross-section to the mode cutoff frequencies for that waveguide. Waveguide A is an L-band, 10.5 inch diameter circular waveguide with the incident TM01 mode. The graphic for A shows the cutoff frequencies for all the various modes on that waveguide, up to the first mode (TM12) above the desired operating band. These cutoff frequencies represent the lower band edge where that particular mode can propagate. The scale below the A-line shows the frequency spread, normalized to the cutoff of the mode of interest, the TM01. Note that five (5) other modes can exist in that waveguide. To convert to the TE11 directly would also excite the TE21, TM11 and the TE31 as well as the TE11 and they would be reflected back into the input waveguide. (The TE01 would not be excited.) These would be the extraneous modes previously mentioned, absorbing energy and in general degrading performance. All of these modes are, however, avoided by converting to the TEM. The next higher mode that would be excited by this means is the TM02 but it has a cutoff frequency of 3 times the TM01, or way above our band.

The TEM region begins in the convertor at the same diameter as waveguide A which is then tapered down to the smaller diameter of waveguide B. The smaller diameter is necessary to push the TE11 coaxial mode above the operating band and can now act as a block to the TE11 when it is excited in the output waveguide. The isolation is determined by the ratio of the upper limit of the operating band

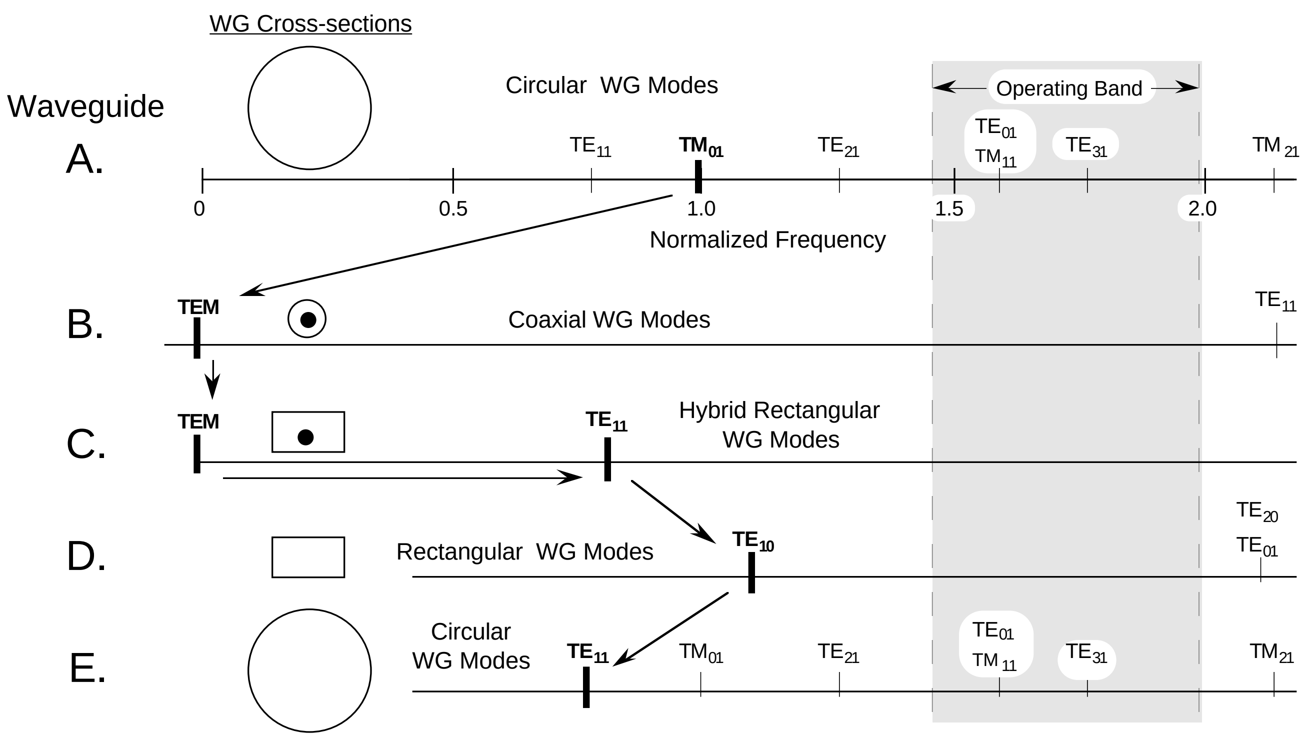

Figure 2. Mode Distribution over Frequency in the Various Waveguides

to the TE11 cutoff frequency, and is proportional to the length divided by the diameter of the section.

The energy then propagates along the center conductor into the hybrid rectangular waveguide C. As long as the center conductor is on axis, the mode is still TEM. At the bend where the center conductor shorts to the bottom of the waveguide, the TE11 coaxial mode is excited along with TE10 in the open rectangular waveguide D to the right of the bend. The coaxial TE11 mode cannot propagate back into the smaller diameter coaxial section and is trapped between the small coax and the bend. Proper dimensioning in this region provides a broadband match between the incident TEM and the launched TE10 of the RWG. RWG was used because the reduced height of the waveguide forced the higher mode cutoff frequencies above the operating band. The mode of particular concern was the TM11 in the rectangular guide that corresponds to the TM01 in CWG. The propagation cutoff of the TM11 is 2.24 times above the TE10 cutoff. The TM11 is still excited by the bent center conductor but is evanescent in the waveguide. Therefore, only the TE10 makes it to the end of the rectangular waveguide. A smooth transition to the full size circular waveguide and the corresponding TE11 mode (waveguide E) avoids exciting the many modes that could exist if such care were not taken.

RESULTS AND CONCLUSIONS

This design was first built and tested as a model in Ku-Band. The completed design was then built at L-Band and measured on an automatic network analyzer. Figure 3 shows the resulting typical insertion loss of 0.25 dB and less than 0.5 dB over a 30% bandwidth. This measurement was fully calibrated with proper mode launchers on each end and the results shown include the losses of the launchers. This represents the state-of-the-art in wideband, extraneous-mode-free operation, and has been patented as No. 5,399,999.

The importance of this paper to the MTT membership is not just in the application of the design but to demonstrate a creative approach which might be applied to other problems.

No references in the literature were found which discuss or suggest this approach.

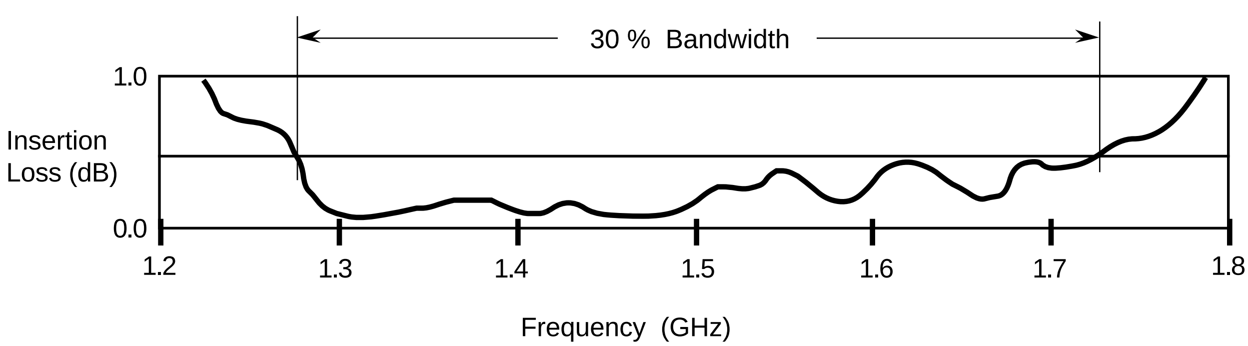

Figure 3. Measured Insertion Loss for the L-band Mode Convertor