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Broadband TE_{10} to TE_{20} Mode Transformer for X Band

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Abstract

This paper deals with a broadband TE_{10} to TE_{20} mode transformer in a WR90 rectangular waveguide with more than 35 dB suppression of the fundamental mode and only 0.4 dB of maximum transformation loss. Two fin lines are employed with appropriate configuration in order to obtain a broadband mode transformation. The proposed mode converter can be suitably employed in Spatial Power Combining amplifier to increase the number of parallel combined devices.

1. Introduction

Into waveguide systems, usually, only the fundamental propagation mode is used because the input power is not equally distributed for each mode and high order mode power may be lost. In some applications [1], [2], instead, the high order modes fields' distribution is a requirement for best working and the fundamental mode is the unwanted one. In addition, only one mode may be preferred; thus others have to be suppressed. In such applications, the conversion efficiency and the suppression mode ratio are the key concepts. In this work, a broadband TE_{10} to TE_{20} mode transformer for the X band is presented. It employs the well-known fin line transitions in antipodal configuration, the standard WR90 waveguide and the WR90 waveguide with double width to allow the TE_{20} mode to propagate. In final instance, the application of the mode converter to the spatial power combining technique is shown. This application is exemplificative of the innovation provided by the proposed approach and clearly shows its potentialities.

2. Mode conversion principle

In a rectangular waveguide, the electric field of the first mode TE_{10}, has distribution like a half sine wave distribution; while that of instead the TE_{20} follows an entire sine wave. Usually, the conversion mode is achieved with several dielectric rods placed along the waveguide [3][1]. In order to accomplish the mode conversion, the fundamental mode must be spatially divided in two equal parts, one shifted by 180° in phase with respect to the other. The innovation presented in this work is the strategy for achieving this phase shifting [4].

The dividing operation is obtained through two cards with single fin line in antipodal configuration. By means of the opportune field-rotating performance of the antipodal fin line, it is possible to get the right phase shifting. The two cards have different topology because they have different tasks. One card (Figure 1) rotates the electric field (from left to right) first in the clockwise for 90° and then in the counter clockwise for 90° (hence, the output electric field has the same polarization of the input). The second card (Figure 2) rotates the electric field in the clockwise for 180°, obtaining the desired phase shifting between the two cards.

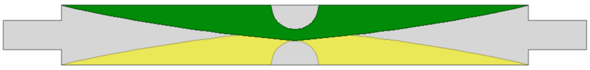

Figure 1: The card that rotates the electric field of 0°. Green trace is on the top of the substrate and the yellow one is on the bottom.

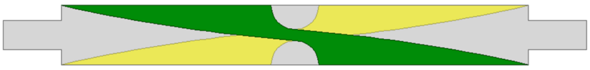

Figure 2: The card that rotates the electric field of 180°. Green trace is on the top of the substrate and the yellow one is on the bottom.

At this point, a TE_{20} mode is formed and it can propagate only if the waveguide dimensions (or the operating frequencies) allows for. In this work, an oversized waveguide, where the long side of the waveguide is twice the standard value, it has been preferred. The fin lines have the same length, allowing for a so the broadband behavior.

3. Fin lines and waveguide designs

The operation of this mode transformer (Figure 3) relies on opportune fin lines design. They have been designed starting from the exponential shape (1):

$$\begin{cases} W(x) = A\left[\exp\left(\dfrac{x\ln w_f}{L_{Fin}}\right)-1\right] \\ A = \dfrac{b+W}{2\left(w_f-1\right)} \end{cases}, \qquad (1)$$

where b is the waveguide height, W is the paired strip lines width, L_{Fin} is the transition length and w_f is the form factor.

Two latter parameters are subjected to optimization process and their values are reported in Table 1.

Table 1: Optimized values of the fin line tapers.

w_f	L_{Fin} [mm]	$\lvert W(x)\rvert$ [mm]
0.4	40	$10.13\left\lfloor \exp\left(-22.9\cdot 10^{-3}x\right)-1\right\rfloor$

The paired micro strips lines are needed to join the two fin line tapers and they are required to be as wide as possible in order to reduce losses. The upper limit is due to the high order modes propagation which is frequency- and dielectric permittivity-dependent. In fact, the line width must be lower than a quarter of the wavelength in the medium. For this work, it must agree with the (2) by assuming $W/H_{sub}>1$, $H_{sub}=0.508$ *mm*, $\varepsilon_r=9.8$ (Alumina substrate), $f=12$ *GHz*. It has been approximated as a microstrip line [5].

$$\begin{cases} W < \dfrac{\lambda}{4\sqrt{\varepsilon_e}} = 2.27mm \\ \varepsilon_e = \dfrac{\varepsilon_r+1}{2} + \dfrac{\varepsilon_r-1}{2}\left(1+12\dfrac{H_{sub}}{W}\right)^{-\frac{1}{2}} = 7.59 \end{cases} , \quad (2)$$

Hsub is the substrate thickness.

The width of the paired lines has been chosen with 2 mm to get a certain safety margin. The Bal-un has a semicircle shape with radius of 4.08mm.

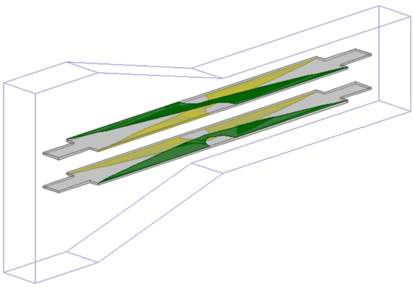

Figure 3: TE_{10} to TE_{20} mode transformer.

Two 8 mm length Quarter Wave Transformers (QWTs) have been implemented on the card topology in order to improve the return loss. The two cards have been placed at 4 mm of distance from the waveguide center in order to correctly distribute the dielectric load.

The waveguides design has been performed by joining two WR90 waveguides together: a standard 22.86x10.16 mm^2 waveguide and a 45.72x10.16 mm^2 one. The junction interface has been linearly tapered and its length has been chosen as the same as that of the fin line. Accordingly, the waveguides junction interfaces are placed in the middle of the paired lines. The performances obtained in X band show 15 dB of return loss in TE_{10} and TE_{20} terms, at the input and at the output ports respectively, with 0.3 dB ±0.1 dB of transformation loss (Figure 5), corresponding to the insertion loss. The efficiency mode conversion has a mean value of 96.6% in the whole X band, so a bandwidth of 40% has been achieved. At the output port, where only TE_{20} mode is desired, TE_{10} is 35 dB attenuated, TE_{30} is 50 dB and TE_{40} is 25 dB (Figure 6). In Figure 7 the E-field distribution is shown in order to prove the correctness of the field transformation.

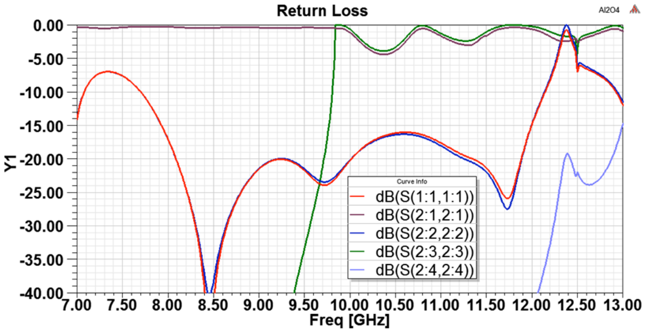

Figure 4: Return loss for the fundamental mode at the input port and for the first 4 modes at the output port (from TE_{10} to TE_{40}). dB(S(PortX : ModeX, PortY : ModeY)) indicates the S(PortX,PortY) parameter considering ModeX at PortX and ModeY at PortY.

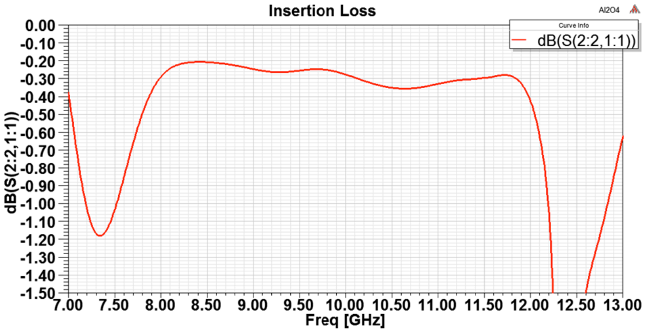

Figure 5: TE_{10} to TE_{20} transformation loss. It is the S_{21} when at the port 1 there is the first mode and at the port 2 the second mode is wanted.

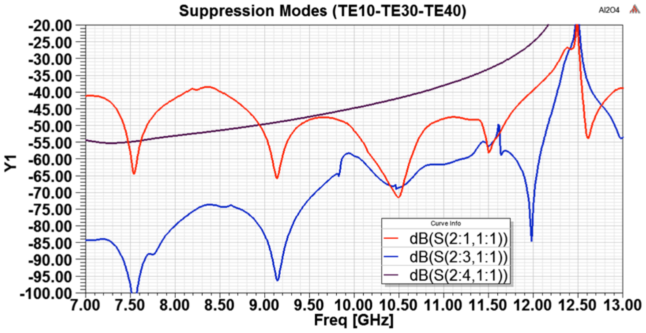

Figure 6: TE_{10}, TE_{30} and TE_{40} suppression at the output port. They are the S_{21} parameters when at the input port the fundamental mode is excited and at the output port other modes are investigated.

Table 2: Performance comparison between other mode transformers works.

References	Bandwidth	Efficiency
[3]	13.2%	>95%
[4]	6.9%	>94.4%
[9]	12.8%	>95%
[10]	19.3%	>96.6%
This work	40%	>96.6%

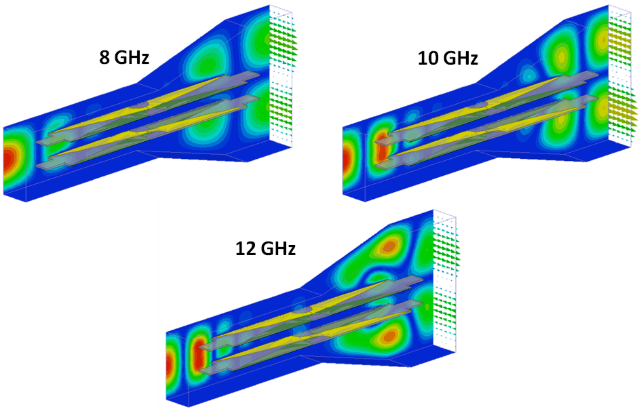

Figure 7: E-field distribution in the mode transformer at meanings frequencies.

4. Spatial Power Combiner application

The Spatial Power Combining (SPC) technique [6] is a suitable approach where the mode transformer (previously described) is used. When more cards are employed in a SPC, the feeding of each fin line must be seriously considered. In fact, the outermost fin lines capture less power than the innermost ones. In this way, the solid state power amplifiers placed on the fin lines work in different compression regions. The TE_{20} mode, in a rectangular waveguide, improves the feeding of the solid state power amplifiers placed far from the center of the waveguide (Figure 8).

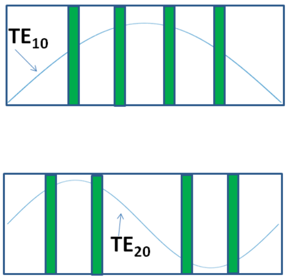

Figure 8: Field distribution for fundamental and second modes. Fin line cards are the green rectangular.

Several improvements are obtained on the feeding balance, which is each fin line receives the same power of the others. In addition, more space is available for MMICs placement.

In order to assess the improvements achieved from the proposed approach, an SPC has been designed (Figure 10).

It employees 4 Al_2O_3 cards with single fin lines printed on in antipodal configuration. The design procedure has been largely treated in [7] and it is frequency scalable. The propagation medium is a waveguide with the same dimensions of the mode transformer designed, which are 45.72x10.16 mm^2.

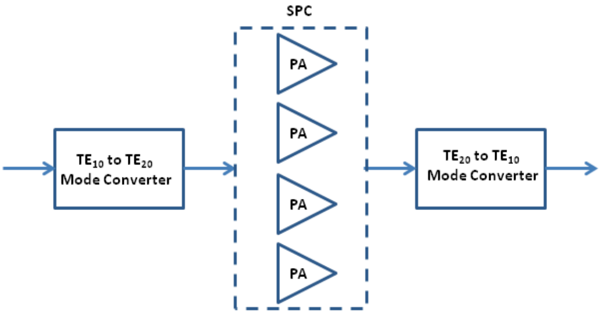

Figure 9: Blocks diagram of the SPC application.

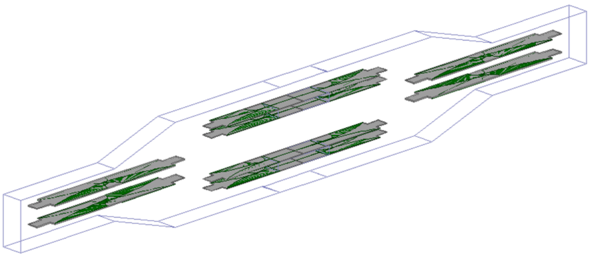

Figure 10: The SPC designed for the X band employing the broadband mode transformers.

The results of the simulation show a balanced power splitting within ±0.1dB (Figure 12). The two minimum in the splitting scheme are due to the intrinsic limits of the mode transformer. Two semicircular metallic traces have been applied in the slots places in order to bring the resonances away from the operative band [8].

It can be easily noted that with the implementation of this mode converter, the available volume where to insert parallel operating active devices is practically twice the volume of the connecting waveguide. This strategy allows for doubling the number of active devices that can be inserted in a single mode operating waveguide.

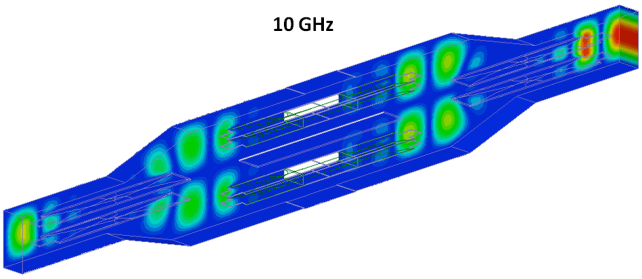

Figure 11: E-field distribution in the SPC at 10 GHz.

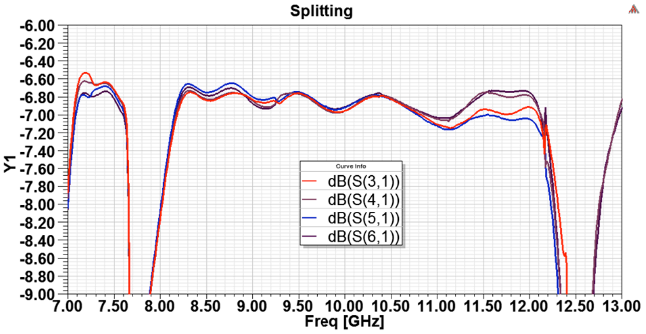

Figure 12: Balanced power splitting achieved by the Spatial Power Combiner fed by the TE_{10} to TE_{20} mode transformer.

5. Conclusions

In this paper, a new waveguide mode transformer has been presented. It operates in full X band applications with only 0.3 dB loss. An X-band SPC has been designed employing two mode transformers in order to proof the right behavior of the converters. Further improvements could be performed to reduce the length of the fin line taper in order to maximize efficiency in the transformation process. Moreover, the spatial combiner may be designed to eliminate the output transformer, by inverting the phase of two fin line cards. In this case, major attention should be given to the output waveguide section.

References

[1] J. Bae, T. Uno, T. Fujii, K. Mizuno, Spatial power combining of Gunn diodes using an overmoded waveguide resonator at millimeter wavelengths, IEEE IMS Digest, 1998, Vol: 3, pp:1883-1886

[2] J. Bae, M. Fujita, K. Mizuno, W-band overmoded-waveguide oscillator with Gunn diodes, Asia-Pacific Microwave Conference, 2000, pp: 1093 – 1096.

[3] Y. Kokubo, Frequency Range Dependent TE_{10} to TE_{20} Mode Converter, Microw. Opt. Technol. Lett., Vol. 52, No. 1, pp: 169–171, Jan. 2010.

[4] M. Belaid, R. Martinez, K. Wu, A Mode Transformer Using Fin-Line Array for Spatial Power-Combiner Application, *IEEE MTT-Transaction*, Vol. 52, No. 4, pp: 1191-1197, Apr. 2004.

[5] F. Di Paolo, Networks and Devices Using Planar Transmission Lines, *CRC Press LLC*, 2000, ISBN 0-8493-1835-1.

[6] D. Passi, A. Leggieri, F. Di Paolo, M. Bartocci, A. Tafuto, Spatial Power Combiner Technology, *PIERS Proc.*, Czeck Republic, pp: 932-938, Jul. 2015.

[7] A. Leggieri, D. Passi, F. Di Paolo, M. Bartocci, A. Tafuto, A. Manna, A Novel Ka-band Spatial Combiner Amplifier: Global Design and Modelling, *PIERS Proc.*, Czeck Republic, pp: 840-845, Jul. 2015.

[8] G. E. Ponchak, A. N. Downey, A New Model for Broadband Waveguide to Microstrip Transition Design, *NASA Technical Memorandum 88905*, Lewis Research Center Cleveland, Ohio, Dec. 1986.

[9] Qiang Zhang, Cheng-Wei Yuan, and Lie Liu, Theoretical Design and Analysis for TE20–TE10 Rectangular Waveguide Mode Converters, *IEEE MTT-Transaction*, Vol. 60, No. 4, pp: 1018-1026, Apr. 2012.

[10] A. A. Kirilenko, L. A. Rud and V. I. Tkachenko, Nonsymmetrical H-Plane Corners for TE10–TEq0-Mode Conversion in Rectangular Waveguides, *IEEE MTT-Transaction*, Vol. 54, No. 6, pp: 2471-2477, June 2006.