Modeling and Simulation of Wilkinson Power Splitter in Suspended Stripline

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Abstract ─ This paper offers one possible solution to the problem of different phase velocities in even and odd mode during the design of Wilkinson power splitters. This topic is especially important in the design of modern beamforming networks for military and space applications where low insertion loss is required and obtained through a use of suspended stripline and other extremely (ultra) inhomogeneous platforms. A new approach is proposed where even and odd mode quarter-wave transforming sections of a multi-section Wilkinson splitter do not end at the same locations. The approach has been implemented through an algorithm that calculates all critical parameters of the splitter. In order to confirm the practicality of the proposed solution, various examples of Wilkinson splitters have then been developed through the algorithm and then simulated using SONNET® and other electromagnetic software tools. The developed configurations have, also, been compared to the conventional ones to evaluate the improved performance.

Index Terms ─ Beamforming network, Chebyshev polynomials, even-odd mode, phase velocities, SONNET®, suspended stripline Wilkinson power splitter.

I. INTRODUCTION

Modern radar and satellite systems often require a low insertion loss performance of their integral parts to accommodate for a stringent loss budget and long communication paths. This restriction is imposed on the corresponding beamforming networks, as well. In order to meet this design requirement, the beamformers are very often realized in suspended airline technology (Figure 1) that provides for a low effective dielectric constant and consequently low insertion loss.

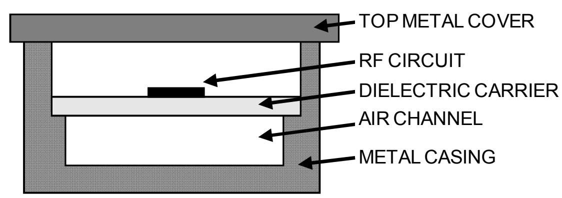

Fig. 1. Cross-section (stack-up) of an RF component realized in suspended airline technology.

II. DESIGN PROBLEM

An important phase in the development of such a beamformer is the design of a corresponding Wilkinson power splitter [1]. Wilkinson power splitters have been treated by many authors and through many different configurations. An overview of these configurations can be found in [2]. Demir et al. for example recently proposed a model of efficient wideband power divider for planar antenna arrays that used Klopfenstein impedance taper for a significant reduction of the physical dimensions of the component [3]. This work as well as many others in the past didn't take into consideration output parameters of the splitter such as output return loss and isolation between the two output

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ports. Certain applications such as antenna arrays require good isolation between the two output ports of the splitter in order to avoid undesired coupling between the elements of an antenna array. In order to meet this design requirement, odd mode must, also, be considered and resistors must be incorporated into the design of the power splitter. In that case, isolation and output return loss of the power divider is calculated as follows

$$\text{Isolation} = -20\log\left|\Gamma_e - \Gamma_o\right| \quad [\text{dB}] \tag{1}$$

$$Out\ \text{Re}t\ Loss = -20\log\left|\Gamma_e + \Gamma_o\right| \quad [dB], \tag{2}$$

where Γ_e and Γ_o represent reflection coefficients in even and odd mode, respectively.

If the splitter consists of coupled quarter-wave impedance transforming sections, then the characteristic impedances of these coupled sections in odd mode would determine the values of the resistors that are to be used in the power splitter design [4]. In addition to that, if the splitter is designed in an inhomogeneous environment such as a suspended stripline then these sections would have different electrical lengths in even and odd modes due to different phase velocities of the two modes. This effect is further strengthened at the chip resistor locations due to a high dielectric constant of the material the chips are built from (usually alumina, BeO, etc).

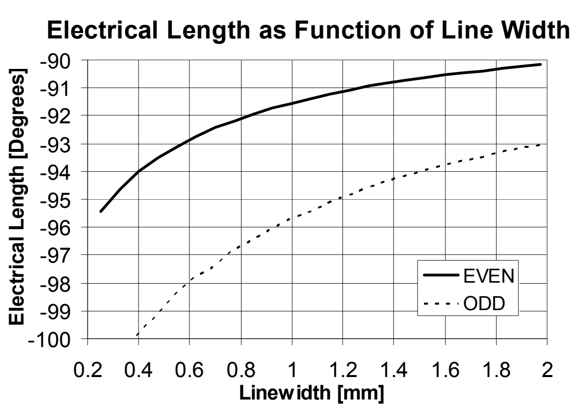


Fig. 2. Electrical lengths of coupling sections in even and odd modes as a function of transmission line width (physical length of the section=7.5mm, coupling gap=0.625mm).

Therefore, if physical lengths of quarter-wave impedance transforming sections are tuned to be equal to quarter-wave lengths in even mode, the same physical lengths would not represent 90^o sections in odd mode. They would most probably be longer than 90^o due to a higher dielectric constant of odd mode. Figure 2 shows electrical lengths of coupling sections of the same physical length (7.5mm) in even and odd modes as a function of transmission line width for a suspended stripline stackup that consists of 0.125mm thick Taconic TLE-95 substrate as a dielectric carrier and two 0.625mm deep air channels on the top and bottom of the carrier (see Figure 1). Significant difference in the length in the two modes is observed ($5\text{-}8^o$).

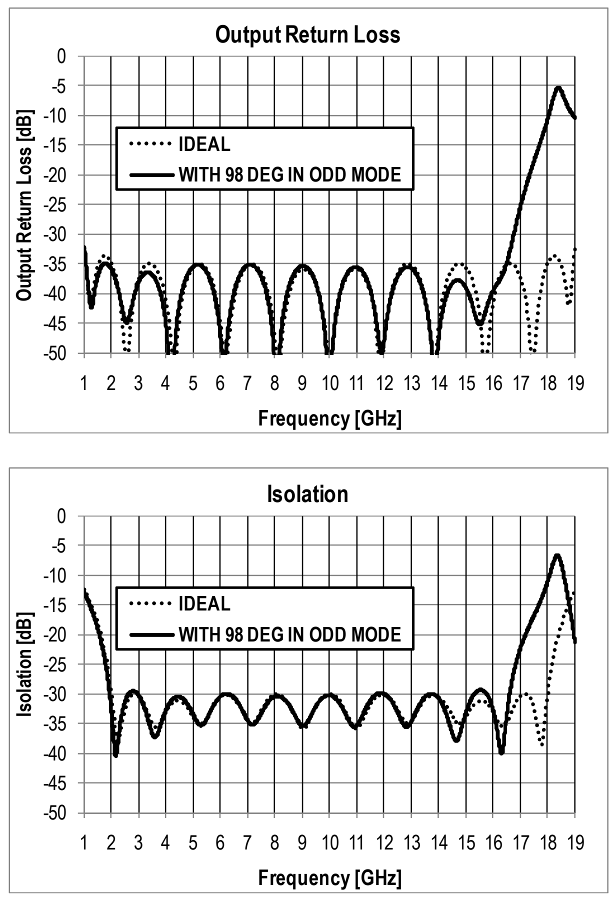


Fig. 3. Performance comparison of the ideal power splitter and splitter with 98^o long transforming sections in odd mode (for a 10-section Wilkinson splitter centered at 10GHz realized in suspended stripline - 0.125mm Taconic TLE-95 dielectric carrier and two 0.625mm deep air channels): analysis done in Ansoft Designer®.

Different electrical lengths of the transforming sections of the power divider affect the performance of the power divider. Figure 3 compares performance of the 10-section power divider in an ideal case (electrical lengths of even and odd mode equal) and a power divider in which transforming sections are 8^{o} longer in odd mode compared to even mode. As a result, a significant deterioration of the output return loss and isolation performance at the higher end of the frequency band may be noticed.

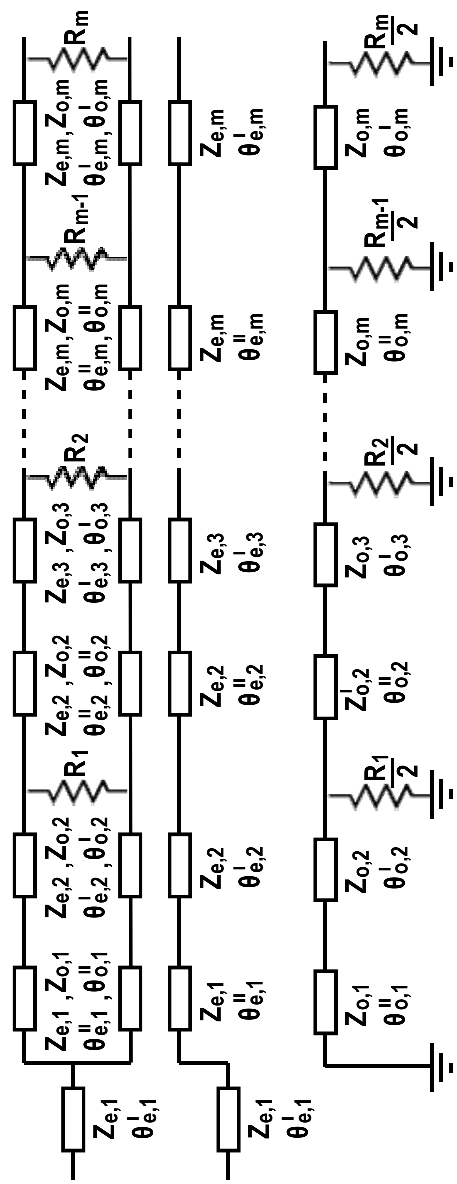
The problem of different lengths for even and odd modes has been treated by many authors in the past. March [5] used lumped elements to achieve phase velocity compensation in the two modes while Podell [6] proposed use of teeth-like or sawcut-like shapes in the "wiggly" coupler for the same purpose. The use of anisotropic substrates [7] or dielectric overlays [8] has also been suggested as a solution to the problem described above. All these solutions are related to specific application and would not be suitable to the case of Wilkinson power splitter in suspended stripline, either because the solution would be too bulky or would not be compatible with the suspended stripline as a choice for the material platform in this particular application.

III. PROPOSED SOLUTION

As a result of this research, an elegant approach has been offered to the problem described above. The main idea used in the proposed solution is to have the quarter-wave transforming sections not necessarily being separated by the shunt resistive elements, as is the case in the conventional Wilkinson power splitter [1], but rather pulled toward the T-junction (Figure 4a).

In even mode (Figure 4b), this technique would still result in a traditional multi-section quarter-wave transforming network optimized through the use of Chebyshev polynomials. In odd mode (Figure 4c), however, each transmission line section between the two consecutive shunt resistors will consist of two elements with different characteristic impedances, but their electrical lengths would add up to a total of 90^{o}.

The values of the shunt resistors then need to be optimized in order to satisfy matching conditions in a newly arisen odd-mode transforming network [9]. This optimization is realized through an algorithm developed for this purpose and tested through multiple examples.



(a) (b) (c)

Fig. 4. (a) The transmission line model of the proposed power splitter, (b) even mode, (c) odd mode.

The desirable performance of the Wilkinson splitter is achieved if reflection coefficients in even and odd mode, Γ_e and Γ_o, have the same zeros. The reflection coefficient in odd mode can be written as a quotient of two polynomials

$$\Gamma_o = -\frac{w^m + c_{m-1}w^{m-1} + ... + c_o}{w^m + d_{m-1}w^{m-1} + ... + d_o}, \quad (3)$$

where c_i and d_i are determined by the parameters $Z_{o,i}$ and R_i of the odd mode network shown in Figure 4(c). Equation (3) is derived by considering this odd mode network as a cascaded network of *m* two-port elements with the first element being shorted.

Similarly, the reflection coefficient of the even mode network is represented by

$$\Gamma_e = \frac{w^m + a_{m-1}w^{m-1} + ... + a_o}{w^m + b_{m-1}w^{m-1} + ... + b_o}, \quad (4)$$

where a_i and b_i are determined by the parameters $Z_{e,i}$ of the even mode network shown in Figure 4(b). Values of $Z_{e,i}$ are optimized through the use of Chebyshev polynomials and $Z_{o,i}$ are so determined to satisfy requirements for the desired physical gap between the two branches of the splitter. At last, forcing Γ_o in (3) to have the same zeros as Γ_e in (4) results in a system of *m* equations from which *m* resistances R_i are found.

The values of resistances R_i depend on the coupling between the coupled transforming sections. This coupling tends to increase the values of the resistances towards the outputs of the splitter. If the splitter contains more than five sections and more than five resistances, it is found that some of the resistor values closer to the outputs become so large (several times the characteristic impedance) that they can be entirely removed from the splitter without changing its performance. This has been done with the last resistor of the splitter in Figure 5. This provides an advantage because it reduces the cost associated with the chip resistors and reduces the overall length of the splitter.

Based on the optimized values of the shunt resistors, and previously determined values of characteristic impedances and electrical lengths of transforming sections, various Wilkinson power splitter geometries have been modeled and simulated. Excellent results have been achieved that confirm the novelty and success of the proposed technique.

Figure 5, for example, shows a design of a 10-section, 10-chip equal-split Wilkinson power splitter developed using the proposed technique. As observed in the geometry shown in Figure 5, there is a clear indication of the impedance transformation location shift due to the previously described reasons.

For this design, we have used a 0.125mm thick Taconic TLE-95 substrate as a dielectric carrier, with 0.625mm deep air channels on the top and bottom of the carrier (see Figure 1). Each transforming section has been individually simulated in SONNET® to arrive at the proper values of corresponding even and odd mode impedances as well as physical lengths of quarter-wave impedance transforming sections in even and odd mode.

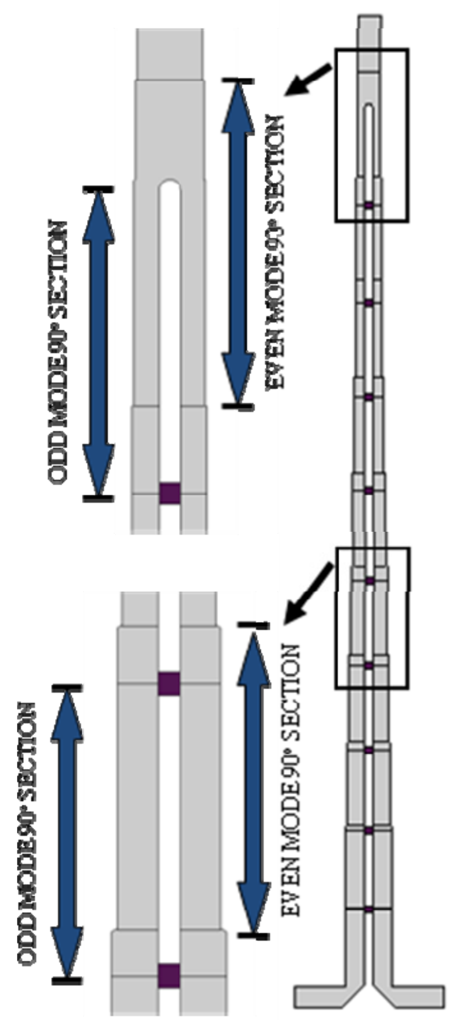


Fig. 5. Geometry of 10-section 10-chip Wilkinson power splitter with tuned quarter-wave transformer lengths.

Figure 6 presents a corresponding SONNET® model of the entire structure. The splitter has been simulated in different ways in SONNET®. It has been broken up into sub-models that have been analyzed with the use of co-calibrated ports.

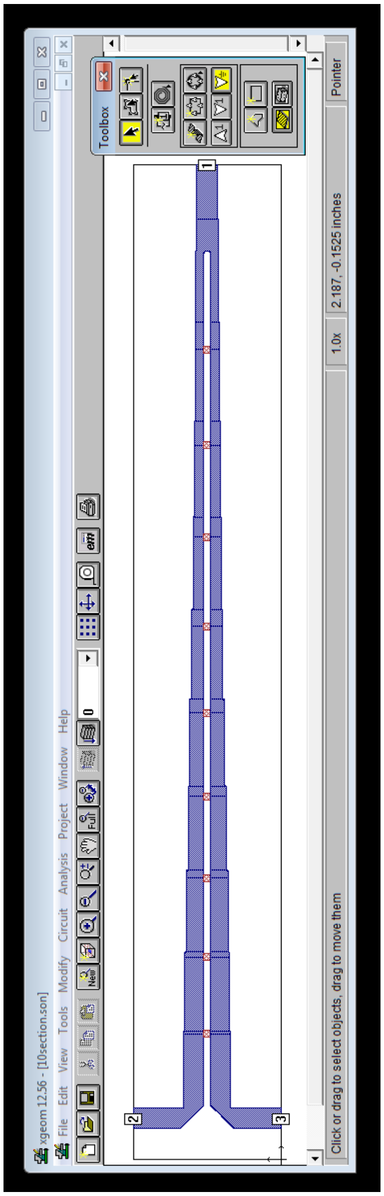


Fig. 6. SONNET® model of the 10-section 10-chip Wilkinson power splitter with tuned quarter-wave transformer lengths shown in Figure 3.

The splitter has then been simulated in its entirety. No significant difference has been observed in the performance of the full model relative to the performance of the combined sub-models. Simulating the splitter through multiple sub-models, however, significantly reduces the computational memory and time.

The simulated performance of this power splitter is shown in Figure 6. Slight asymmetries that can be seen on the performance curves are the result of the effects that are not accounted for in the optimization algorithm (finite size of the resistive elements, minor discontinuities at the impedance transformation locations, etc).

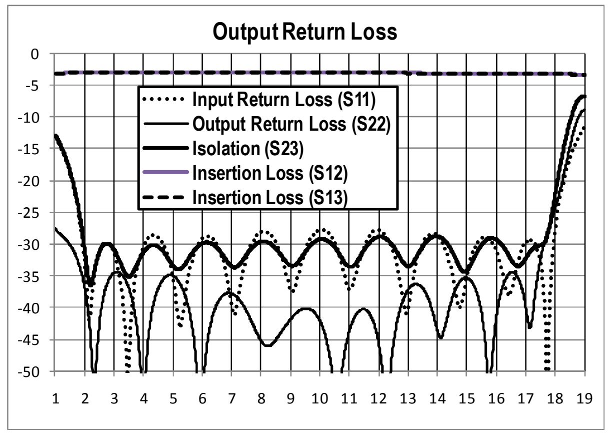


Fig. 7. Simulated performance of the 10-section 10-chip Wilkinson splitter with tuned quarter-wave transformer lengths shown in Figure 5.

IV. CONCLUSION

The proposed algorithm represents an elegant design solution to the problem of different phase velocities in even and odd mode during the Wilkinson splitter design in inhomogeneous stack-ups. It has been tested and confirmed on multiple practical examples. The authors hope that this idea will find successful application by RF engineers who design low loss beamforming networks and other systems on inhomogeneous platforms.

REFERENCES

[1] E. J. Wilkinson, “An n-way hybrid power divider,” *IEEE Trans. Microwave Theory and Techniques*, vol. 8, pp. 116–118, Jan. 1960.

[2] M. D. Abouzahra and K. C. Gupta, *Hybrids and power dividers/combiners, Analysis and Design of Planar Microwave Components*, IEEE Press, New York, 1994.

[3] V. Demir, D. A. Elsherbeni, D. Kajfez, and A. Z. Elsherbeni, “Efficient Wideband Power Divider for Planar Antenna Arrays,” ACES

Journal, vol. 21, no. 3, pp. 318–324, Nov. 2006.
[4] H. Y. Yee, F. C. Chang, and N. F. Audeh, "N-way TEM-mode broadband power dividers," *IEEE Trans. Microwave Theory and Techniques*, vol. 18, pp. 682–688, Oct. 1970.
[5] S. L. March, "Phase Velocity Compensation in Parallel-Coupled Microstrip," 1982 MTT Symposium Digest, pp. 410-412, June 1982.
[6] A. Podell, "A High Directivity Microstrip Coupler Technique," 1970 MTT Symposium Digest, pp. 33-36, May 1970.
[7] N. G. Alexopoulos and C. M. Krowne, "Characteristics of Single and Coupled Microstrips on Anisotropic Substrates," *IEEE Trans. Microwave Theory and Techniques*, vol. 26, pp. 387–393, June 1978.
[8] D. D. Paolino, "MIC Overlay Coupler Design Using Spectral Domain Techniques," *IEEE Trans. Microwave Theory and Techniques*, vol. 26, pp. 646–649, Sep. 1978.
[9] R. B. Ekinge, "A new method of synhesizing matched broadband TEM-mode three-ports," *IEEE Trans. Microwave Theory and Techniques*, vol. 19, pp. 81–88, Jan. 1971.

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