Multi-Section Wilkinson Power Splitter with Tuned Quarter-Wave Transformers to Compensate for Different Velocities in Even and Odd Mode

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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 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. Various examples of Wilkinson splitters have then been developed through the algorithm, simulated using SONNET® and other electromagnetic software tools, and finally manufactured and tested to confirm the practicality of the proposed solution.

Keywords: Wilkinson Power Splitter, Phase Velocities, Beamforming Network, Even-Odd Mode, Suspended Stripline, SONNET®

1. 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.

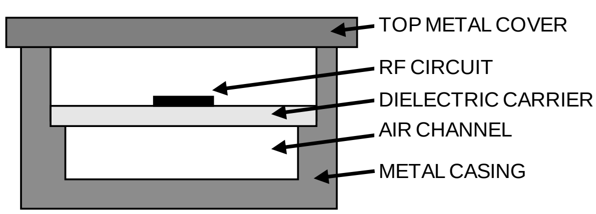


Figure 1. Cross-section (stack-up) of an RF component realized in suspended airline technology.

2. **Design Issue To Be Solved**

An important phase in the development of such a beamformer is the design of a corresponding Wilkinson power splitter [1]. If the splitter consists of coupled quarter-wave impedance transforming sections 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). 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. This creates a design obstacle that is very difficult to overcome resulting in a poor functionality of the corresponding splitter.

3. **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 [2], but rather pulled toward the T-junction (Figure 2a). In even mode (Figure 2b), this technique would still result in a traditional multi-section quarter-wave transforming network optimized through the use of Chebyshev polynomials [3]. In odd mode (Figure 2c), 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.

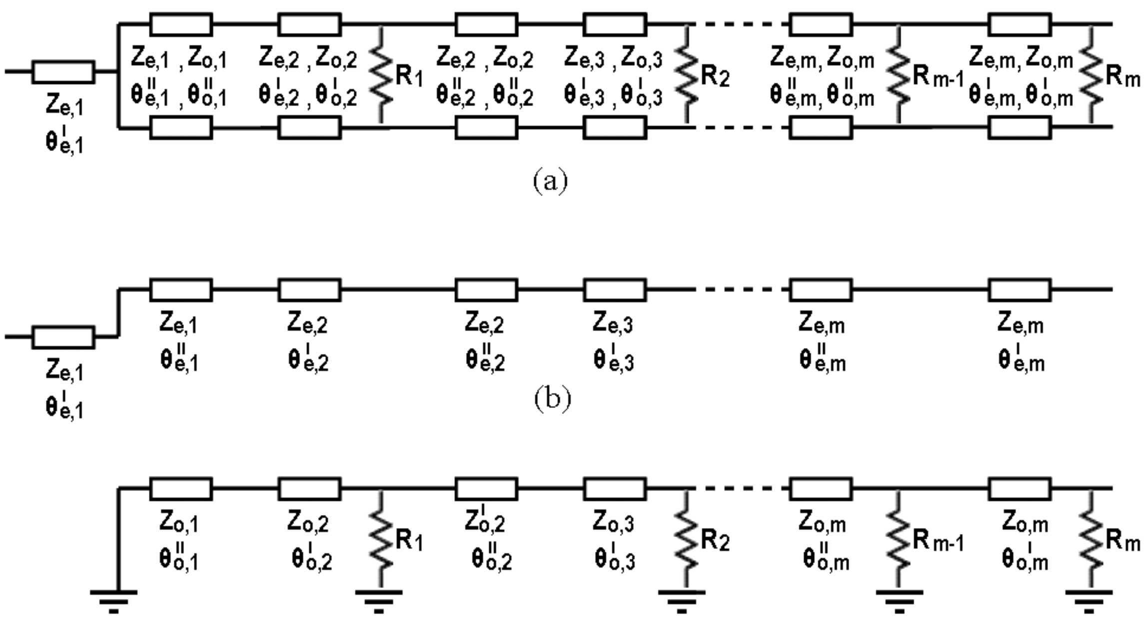
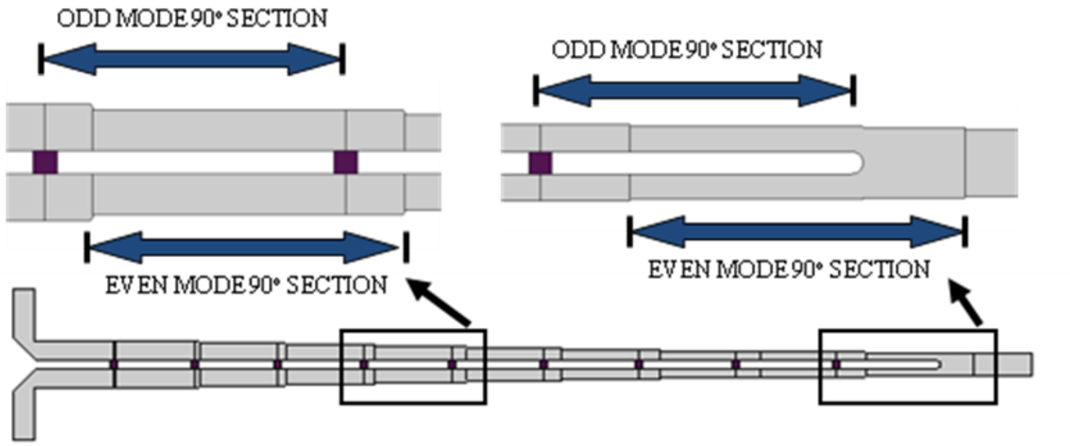
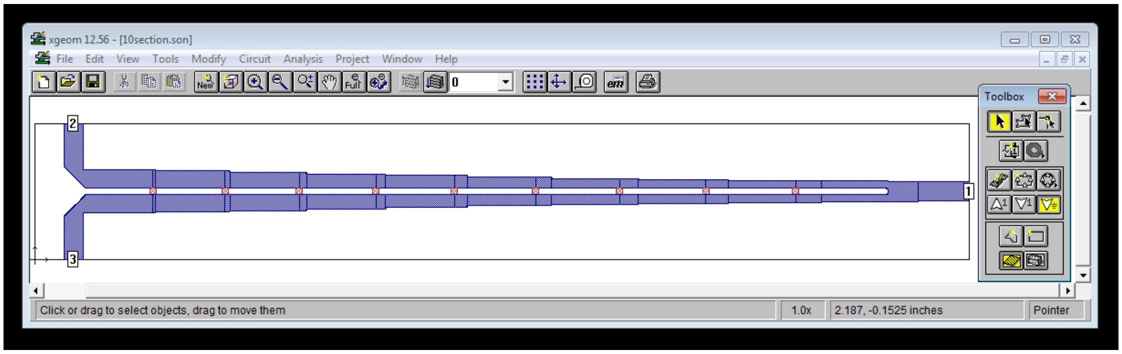


Figure 2. (a) The transmission line model of the proposed power splitter, (b) The corresponding model in even mode, (c) The corresponding model in odd mode.

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 [4]. This optimization is realized through an algorithm developed for this purpose and tested through multiple examples. 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 designed, manufactured, and tested. Excellent results have been achieved that confirm the novelty and success of the proposed technique.



(a)



(b)

Figure 3. 10-section 10-chip Wilkinson power splitter with tuned quarter-wave transformer lengths: (a) geometry (b) SONNET model.

Figure 3, for example, shows a design of a 10-section, 10-chip equal-split Wilkinson power splitter developed using the proposed technique. For this design, we have used 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.

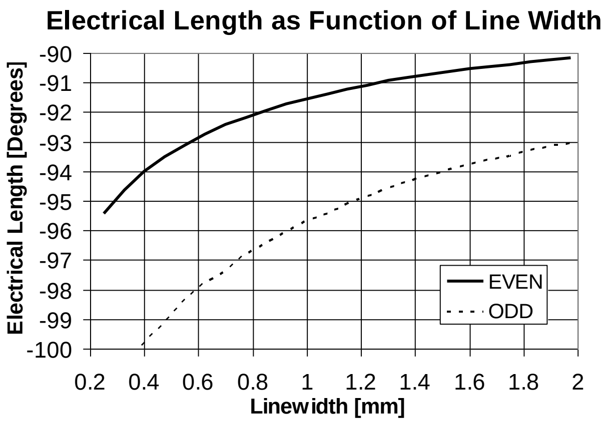


Figure 4. Electrical lengths of coupling sections in even and odd modes as a function of transmission line width (physical length of the section=7.5mm, coupling gap=0.625mm).

Figure 4 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. A significant difference in this length in the two modes is observed. Based on determined values for physical lengths in even and odd mode, each impedance transforming section is pulled toward the T-junction for a certain amount, as shown in Figure 3a. Based on this data, a circuit model of the power splitter has been built and values of the resistive elements optimized. This optimization resulted in an extremely high value of the resistor closest to the two output legs of the power splitter. This resistor has therefore been removed from the circuit.

Figure 3a shows the geometry of the splitter with the clear indication of the impedance transformation location shift due to the previously described reasons. Figure 3b 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. 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.

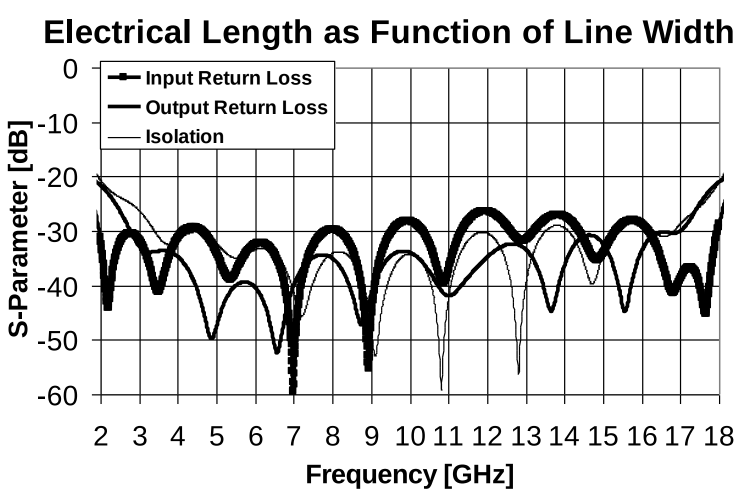


Figure 5. Simulated performance of the 10-section 10-chip Wilkinson power splitter with tuned quarter-wave transformer lengths shown in Figure 3.

The simulated performance of this power splitter is shown on Figure 5. Slight asymmetries that can be seen on the performance curves are 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).

7. Conclusions

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. It has been tested and confirmed on a multiple practical examples. The authors hope that this idea will find a successful application by RF engineers who design low loss beamforming networks and other systems on inhomogeneous platforms.

References

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