Automated Design of a Novel Dual Mode Coupler for Compact Dual Polarization Beam Forming Networks

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Abstract
A new dual mode coupler has been recently proposed in[1]. This component functions as two independent directional couplers for the TE_{10} and the TE_{01} modes of a rectangular waveguide. The component is very attractive for the realization of compact dual polarization beam forming networks for satellite applications. In order to provide an effective tool for the design of such a device an equivalent circuit and synthesis formulas are presented here. The equivalent circuit has been used to obtain a program for the automatic design of the structure. A number of different designs of the component showing the good performance of this novel component are presented in this paper.

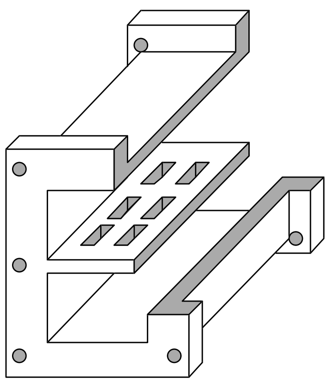

Fig.1, The dual mode coupler.

Introduction
Satellite antennas commonly use two linear orthogonal polarizations in order that two different signals can be transmitted in the same frequency band. By using a feed array illuminating a reflector two shaped orthogonal polarization beams are obtained. Two beam forming networks are used to obtain the prescribed amplitudes and phases of two signals at each feed. By using orthomode transducers the two signals are injected into the feeds in orthogonal polarization. A beam forming network uses a cascade of directional couplers to divide the power among the feeds. The structure of the dual mode coupler consists of two rectangular waveguides coupled by two rows of aligned rectangular slots on the common wall (Fig.1). The symmetry of the slots with respect the vertical and longitudinal central plane ensures that the TE_{10} and the TE_{01} mode are decoupled. The two modes correspond to two linear orthogonal polarizations of the field. The dual mode coupler allows the same beam forming network to be designed for both polarizations. Therefore a big reduction of the size and weight of the overall structure can be achieved. If dual mode directional couplers, with different values of the coupling for the two modes are used, the same beam forming network gives different array factors for the two polarizations. In this way two different shaped beams are obtained. An equivalent circuit of the component is presented in this paper. The circuit is used to design periodic directional couplers. In this case simple synthesis formulas can be derived. The components obtained with this procedure result near the optimum. Few optimization steps are required to obtain the design of non periodic structures.

The equivalent circuit
The dual mode coupler has two longitudinal planes of symmetry. The vertical plane splits the slots into two symmetrical rows. The horizontal plane parallel to the common wall allows one to analyze the coupler in terms of odd and even modes. By considering both symmetry planes only one forth of the structure can be analyzed.

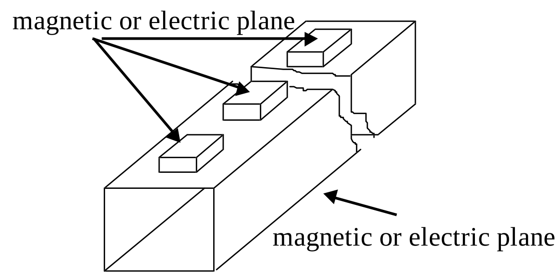

Fig.2, One forth of the structure used for the analysis.

In Fig.2 the reduced structure for the analysis is shown. The vertical symmetry plane corresponds to a magnetic plane or to an electric plane when the structure is excited by the TE_{10} mode or the TE_{01} mode respectively. Such a symmetry property ensures that the two modes are decoupled, so that the two cases can be represented by two independent couplers. The following analysis is referred to both the couplers. The reduced structure is a cascade of building blocks consisting of rectangular waveguide sections loaded with open or shorted stubs. The length of the stubs is one half of the common wall thickness. The stubs are short circuited for the odd mode of the coupler or open for the even mode of the coupler. The equivalent circuit used for a building block is shown in Fig.3.

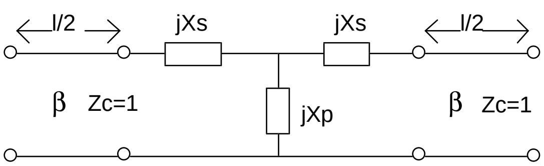

Fig.3, Equivalent circuit of a building block.

In Fig.3, **l** is the length of the waveguide section in the longitudinal direction, **β** is the propagation constant of the waveguide mode. A full wave model based on the mode matching method has been used to compute the parameters of the equivalent circuit. In practical cases, for small thickness of the common wall, the reactance Xs is negligible. Moreover for the odd mode the short circuited stub represents a small perturbation of the rectangular waveguide section, therefore Xp can be also not considered. The equivalent circuits for the even and the odd modes of the coupler are shown in Fig. 4.

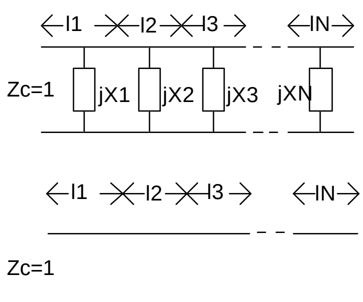

Fig.4, Equivalent circuits for the even and the odd modes of the coupler.

The electric model for the odd mode is a transmission line of the same length of the coupler. If the coupler is periodic (Xi=X, li=l for i=1,2.. N) also the even mode can be represented by a transmission line with characteristic parameters:

$$1)\ \beta_p = \frac{1}{l}\cdot\cos^{-1}\left[\cos(\beta\cdot l)+\frac{1}{2X}\cdot\mathrm{sen}(\beta\cdot l)\right]$$

$$2)\ Z_p = \sqrt{\frac{\mathrm{sen}\beta\cdot l+\frac{X}{2}-\frac{X}{2}\cos\beta\cdot l}{\mathrm{sen}\beta\cdot l-\frac{X}{2}-\frac{X}{2}\cos\beta\cdot l}}$$

For a matched structure Zp=1.

The transmission scattering parameters of the two structures of Fig.4 composed by N cells are:

$$3)\ S_{21}^{e} = e^{-j\beta_p\cdot N\cdot l}$$

$$4)\ S_{21}^{o} = e^{-j\beta\cdot N\cdot l}$$

The value of the coupling of the associated four port directional coupler is:

$$5)\ C = \frac{S_{21}^{e}-S_{21}^{o}}{2} = \frac{e^{-j\beta_p\cdot N\cdot l}-e^{-j\beta\cdot N\cdot l}}{2}$$

By using (5) and (1) the reactance X is computed as a function of C, l and **β.** By using (2), l and **β** can be optimized to improve the return loss. Note that **β** depends on the waveguide width for the TE_{10} mode and on the waveguide height for the TE_{01} mode. This allows both the modes to be matched in the respective operative bands. The problem is now reduced to realize the reactance X with the building block. The design parameters are the distance of the slot with respect the lateral wall, the length and the width of the slot. We found that the building block has enough free parameters to realize the required reactances for both the TE_{10} and the TE_{01} modes. The distance from the lateral wall is the key parameter to obtain also different values of the reactance X. Because the field of the TE_{01} is constant in the horizontal direction this parameter has a weak effect on the X related to the TE_{01} mode. On the contrary this distance has a strong effect on the X related to the TE_{10} mode. As an example the scattering parameters of the building block of a 7 branch 3dB coupler for both the modes computed by using the equivalent circuit and the full wave model are shown in Fig.5. By cascading 7 building blocks a periodic coupler is obtained. In Fig. 6 the scattering parameters of the periodic coupler computed with the full wave model are shown. The coupler response is near the optimum and few optimization steps are required to obtain the final design.

Results

A number of different couplers has been designed by using the synthesis procedure presented here. In Fig.7 the comparison between theory and experiment for a 3dB coupler for both the TE_{10} and TE_{01} modes is shown. In Fig. 8 and 9 two examples of dual mode couplers with the same frequency bands for the two modes are presented. In Fig. 10 and 11 two examples of dual mode couplers with different frequency bands for the two modes are presented.

Conclusions

A synthesis procedure for a new dual mode coupler has been derived. A program for the automatic design of the coupler has been developed and extensively used to investigate the performances of the component. Dual mode couplers with independent values of the couplings and of the operative bands have been obtained. The possibility of using the component to realize compact dual polarization beam forming networks is confirmed by the results presented here.

References

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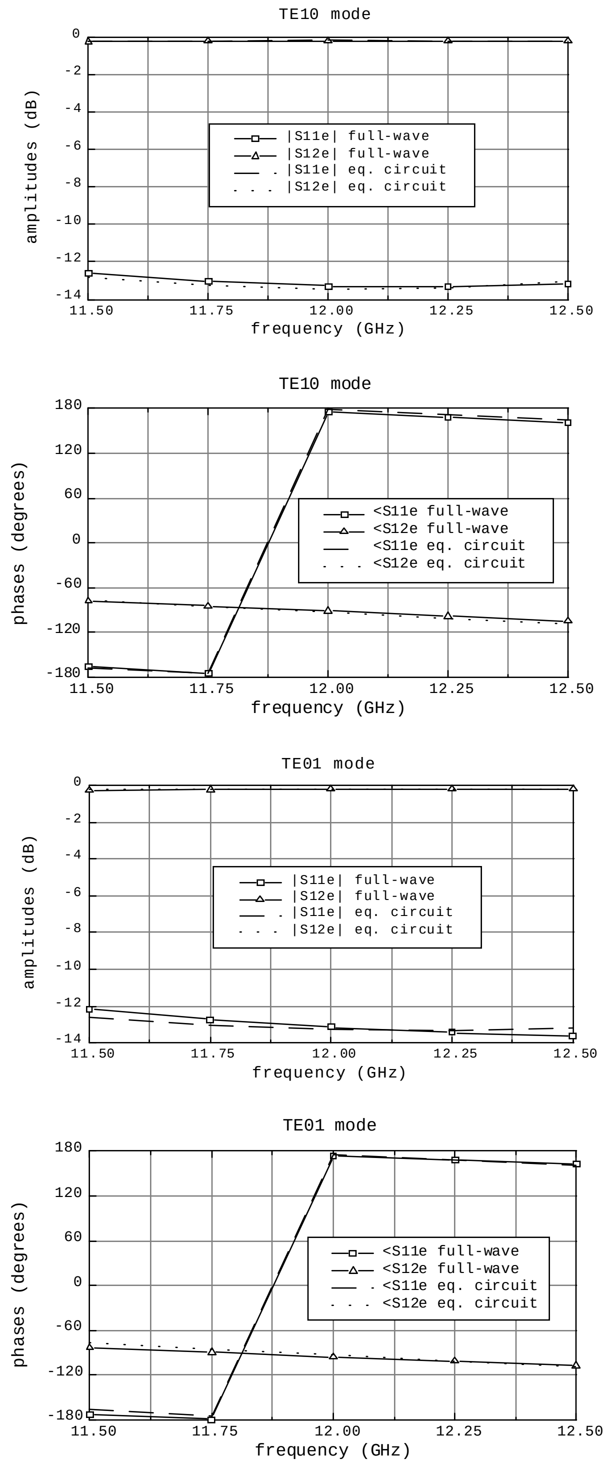

Fig.5, Scattering parameters of the building block of a 3dB seven sections coupler.

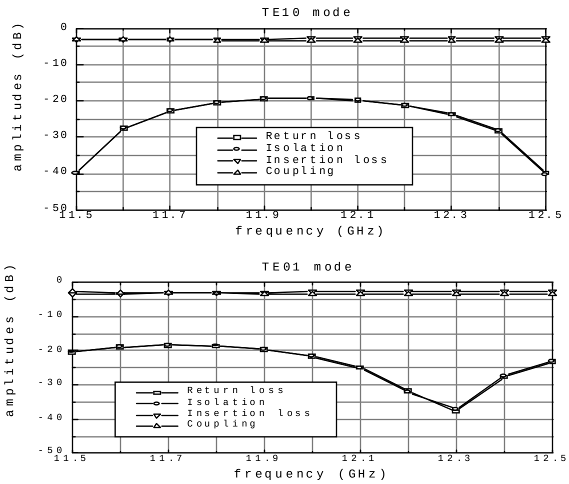

Fig.6, Response of the periodic seven sections 3dB coupler.

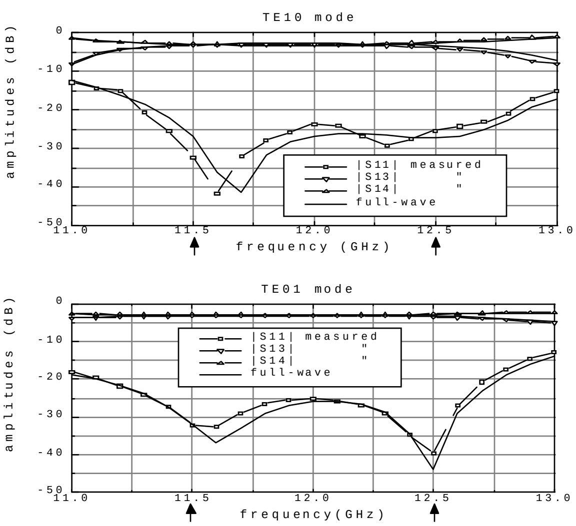

Fig.7, Comparison theory experiment for a 5 sections 3 dB coupler.

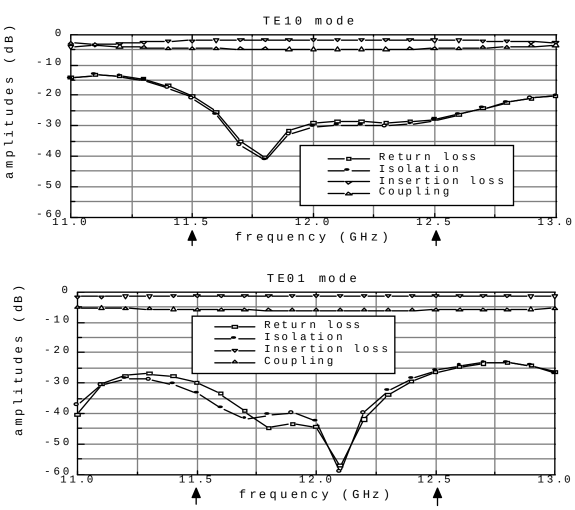

Fig.8, Seven sections 4.77dB-6dB coupler.

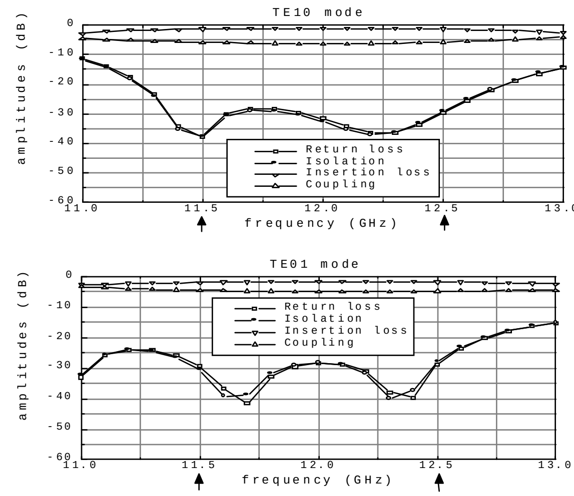

Fig.9, Seven sections 6dB-4.77dB coupler.

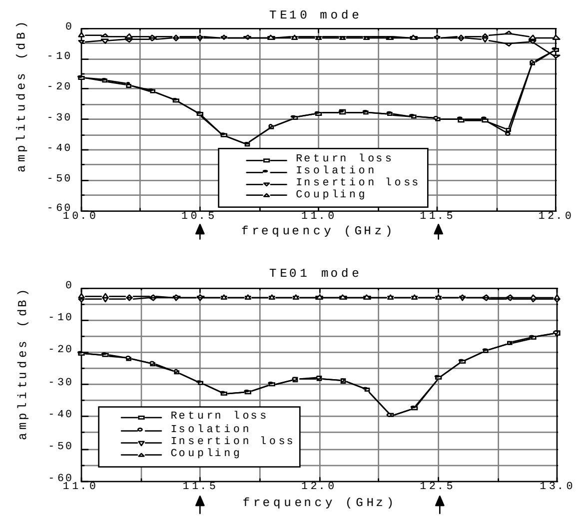

Fig.10, Seven sections 3dB coupler.

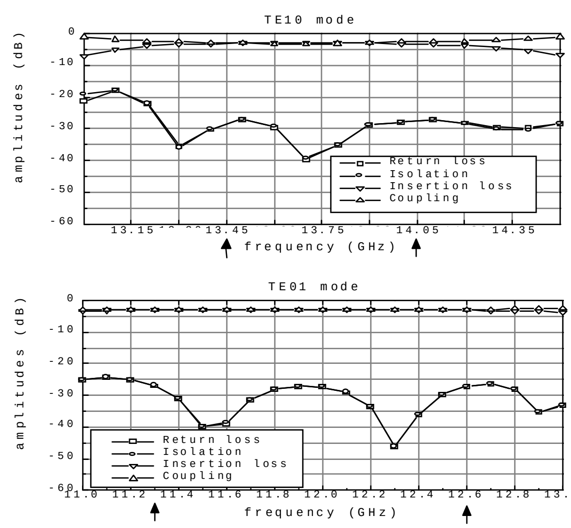

Fig.11, Nine sections 3dB coupler.