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OPTIMIZED MICROSTRIP RING-STAR 5-PORTS FOR BROADBAND 6-PORT MEASUREMENT APPLICATIONS

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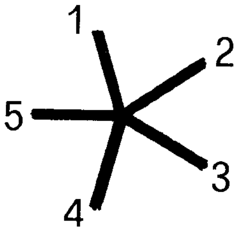
Summary

Results of computer-aided analysis and optimization of symmetrical 5-port microstrip rings with external matching and inner star coupling are presented. Over one octave operational bandwidth with power balance within 1dB and matching better than -20dB has been achieved in theory and measurement for two different design concepts.

Introduction

Well matched broadband couplers could be of great practical significance for 6- resp. 5-port measurement systems (1). Stripline or microstrip techniques may be used to construct compact, cheap and simple 5-ports up to the K_u-band frequency range. Superposition of high impedance star- (fig. 1) and ring-5-ports (fig. 2) may be used (2,3) to achieve over one octave bandwidth. Dielectrical separation (Mylar-spacer) of the two coupler components has been used (2), producing capacitive resonance coupling of the ring- and the star-element, thus broadening the device bandwidth. However, most significant design parameters for broadband operation are the external matching circuits at the ports, together with 'inner' coupling (matching) of the star component to the ring.

Fig.1 star 5-port



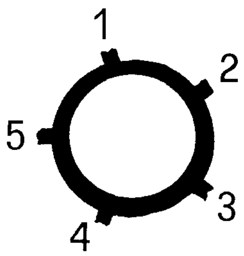


Fig.2 ring 5-port

The use of one of the matching concepts alone reveals much lower intrinsic bandwidth (4) under the condition of 20dB return loss. We have made a complete circuit analysis and optimization of ring-star 5-port components including specifically the effect of 'inner' coupling between star and ring combined with additional external matching by line segments and lumped capacitances.

The 5-port coupler design

Lossless 5-ports with a unitarian scattering matrix according to the condition:

$$\underset{\sim}{S}^{*t} \cdot \underset{\sim}{S} = \underset{\sim}{E} \qquad (1)$$

intrinsicly feature equal power split $|S_{ik}| = 0.5$ with a phase relation of +/- 120deg between port 2 and 3 or port 4 and 5 when symmetry, reciprocity and ideal matching at all ports is assured. The 'q-points' (1) for such a 5-port then are ideally situated in the complex power detection plane for 6-port measurements. For simple ring-type 5-ports this is achieved only at a single center-frequency (βl = 75,53deg) and with a characteristic ring-impedance of Z=44,72 Ohms, when Z_e=50 Ohms microstrip-line system is presumed for the coupler ports. An ideal star-type coupler provides balanced power-split at all frequencies, but does not fullfill the 120deg phase condition, hence cannot be matched at all ports simultaneously. However, significant improvement of bandwidth is obtained by a combination of these ring- and star-type couplers. We have optimized this 5-port device using computer aided design methods. Calculations have been performed on the basis of standard microstrip transmission-line theory including dispersion of the effective dielectric constant in microstrip. The interaction of ring and star, mainly determined by the value of coupling C's, is simplified as following: Optimum matching will be obtained with dominant ring operation ($C_g' \to 0$ with $Z_i \gg Z$), but going along with small matching bandwidth known

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from isolated ring structures. On the other hand the superposition of the star effects (60 Ohms > $X_C=1/\omega C_g' > 27$ Ohms) will lead to a broadband power balance and return loss niveau, albeit at the expense of the ideal matched condition.

A microstrip ring-star device has been developed (fig. 3) with the inner star rotation angle and coupling capacitances C_g, C_g' as additional parameters for coupler design. Best performance has been achieved with symmetrically centered star position (36^o) between the outer ports. Optimum broadband operation of the device in fig.3 has been found with the high-impedance star (Z_i=114 Ohms) coupled to the ring (Z=69 Ohms) by lumped capacitances C_g' = 1pF for 'internal' matching purposes. The stubs ($Z_S = Z_i$) are used for fine-tuning the electrical length ratio $\beta l/\beta l_i$ of ring and star.

The outgoing lines (Z_e = 50 Ohms) can be broadband matched to the ring-star device by short line-segments (Z_h = 114 Ohms) and lumped capacitances $C_g \leq$ 1pF. Calculations result in over one octave bandwidth (fig. 4) for the port transmission S_{ik}. Input reflection S_{ii} under -20dB is observed in a range of 4-8 GHz. Fig. 5 shows good power balance of the ports ($S_{12}:S_{13} <$ 2dB) and extremely flat characteristic of the port-phase-condition for exactly one octave (4-8 GHz), proving the broadband matched condition.

Our optimization analysis has revealed the following design criteria for ring/star-type couplers:

-center frequency is determined by the choice of the ring-segment length l.

Best microstrip coupler performance is observed for $\beta l/\beta_i l_i$ = 1,4 with βl=110deg, $\beta_i l_i$=80deg, which requires a slightly smaller l_i compared to simple geometric consideration: $l/l_i=2\pi/5=1,256$. For optimum matched condition the relation of the characteristic impedances Z/Z_i has to be chosen in such a way that a parallel connection of the two results in the characteristic impedance Z=44,72Ohms of the ideal ring coupler. Additionally the highest Z_i forms the best design with the restriction $Z_i<120$ Ohms, due to microstrip technological constraints.

The coupling elements Cg,Cg' play a key role for broadband, low reflection operation, since for low frequencies the 120deg phase relation requires a rather compact reactance. The coupling C's should be in the order of 0,5-1,5pF, $X_C=0,4\cdot Z$ at the low frequency end.

In addition to these 'inner' coupling effects, 'external' matching is necessary for smooth broadband performance: The short high impedance line-segments $Z_H \approx Z_i$ with optimum βL=7,4deg are used for fine-tuning the coupler matching characteristics.

A modified 5-port design is shown in fig.6, where the inner coupling capacitances are replaced by linear taper sections, thus simplifying the 5-port construction and eliminating the parasitics and tolerances of lumped elements. Matching bandwidth, power balance and phase condition is found excellent also over one octave, fig. 7,8. In constrast to the first design the resonance at the low frequency end of the operational band has been removed due to broadband matching instead of resonance matching the star and the ring.

Conclusion

Microstrip 5-port ring-star-type devices can be designed to operate as broadband detection devices for use in 6-port measurement systems. An analysis of the influences of all parameters has clarified the operational principle of these 5-port-devices. Computer aided optimization of 5-port parameters result in two design concepts that reveal one octave operational bandwidth in theory and experiments. These elements are ideally suited for the integration of detector diodes, then forming a compact detection device for small and cheap 6-port measurement systems.

References

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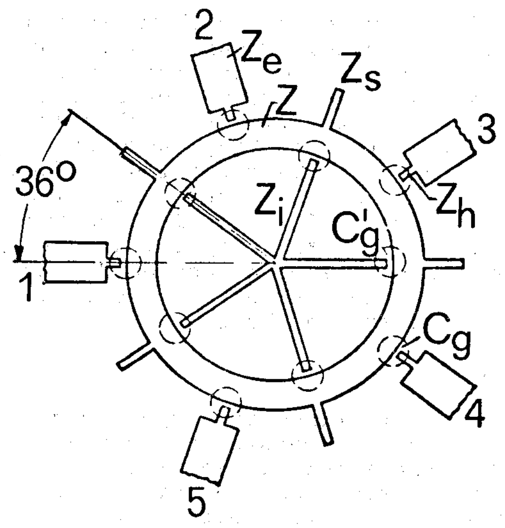
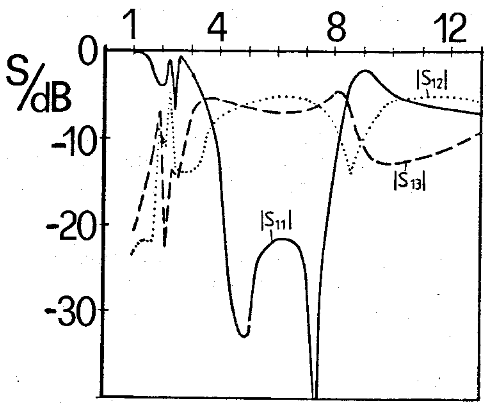


Fig.3 Microstrip ring-star 5-port

Fig.4 Scattering parameters of 5-port in fig.3



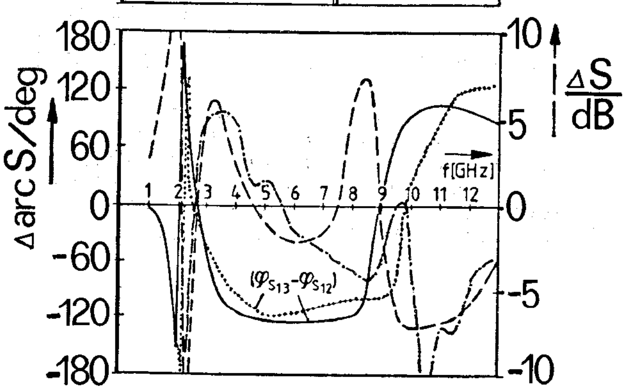


Fig.5 Power balance and phase condition of 5-port in fig.3

Theory ——— – – –

Exp. .... –·–·–

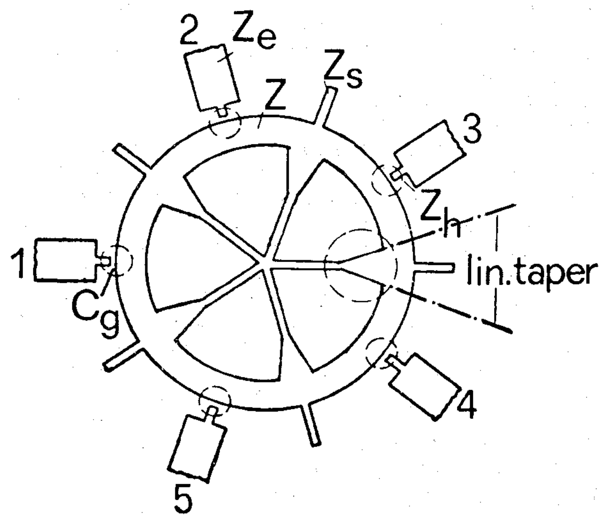
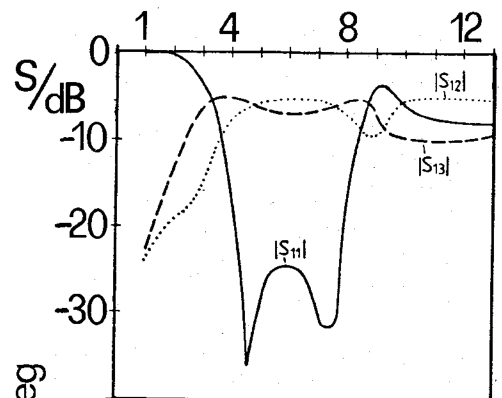


Fig.6 Microstrip ring-star 5-port

Fig.7 Scattering parameters of 5-port in fig.6



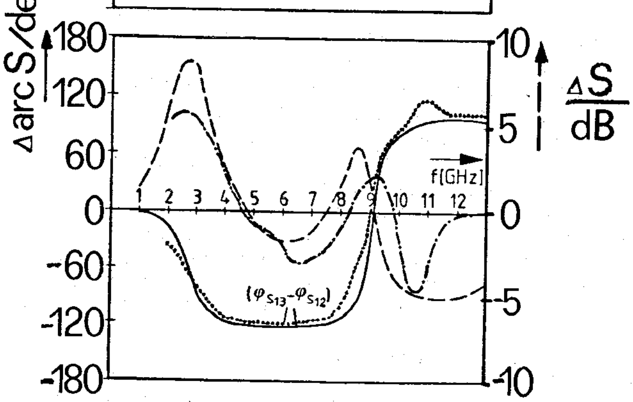


Fig.8 Power balance and phase condition of 5-port in fig.6

Theory ——— – – –

Exp. .... –·–·–