Coupled-Resonator 3-dB Power Divider

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Power dividers are passive devices used to divide an input signal into two or more signals of lower power. T-junctions and Wilkinson dividers are examples of widely used power dividers. Here we present a technique to synthesise a coupled-resonator power divider. The synthesis of multiport microwave coupled-resonator networks has been presented in [1]. N-port devices formed from magneto-inductive waveguides based on coupled loop resonators have been reported in [2]. The design of the power divider proposed here is based on coupling matrix optimization for multiple coupled resonators with multiple outputs. The synthesis employs coupling matrix optimisation techniques similar to those developed for coupled resonator filters. The realisation of such dividers is possible using microstrip resonators, waveguide cavities, or other types of resonators.

Fig. 1 (a) depicts a proposed structure of the power divider. It consists of *n* coupled resonators arranged in a T-topology; it is a 3-port network and will be designed with a Chebyshev filter response for S_{12} and S_{13}. The order of the filtering function at each output is equal to (*n*-1), where *n* is the total number of resonators. The coupling coefficients $m_{(n-2),(n-1)}$ and $m_{(n-2),n}$ determine the power division ratio. These coefficients will have equal values in case of 3-dB power division, and different values for arbitrary power division. An X-band 3-dB power divider has been realized using 4 waveguide cavity resonators to demonstrate the approach.

The coupling matrix of *n* coupled resonators in an *N*-port network has been derived from the equivalent circuit by formulation of impedance matrix for magnetically coupled resonators or admittance matrix for electrically coupled resonators in a similar way to the two port formulation in [3]. Each type of coupling has been considered separately and then a solution has been generalized for both types of coupling. A general normalized coupling matrix [*A*] in terms of coupling coefficients, and external quality factors, for any coupled resonator structure with multiple outputs, has been derived as shown in equation (1).

$$[A]=\begin{bmatrix} 1/q_{e1} & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 1/q_{e(n-1)} & 0 \\ 0 & \cdots & 0 & 1/q_{en} \end{bmatrix} + P\begin{bmatrix} 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 1 & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} - j\begin{bmatrix} m_{11} & \cdots & m_{1(n-1)} & m_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ m_{(n-1)1} & \cdots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \cdots & m_{n(n-1)} & m_{nn} \end{bmatrix} \quad (1)$$

where q_{ei} is the scaled external quality factor of resonator *i*, *P* is the complex lowpass frequency variable, m_{ij} is the normalized coupling coefficient between resonators *i* and *j*, and the diagonal entries m_{ii} represent the self coupling coefficients for asynchronously tuned filter. The scattering parameters have been also derived as a function of the general coupling matrix as shown in (2).

$$S_{11}=1-\frac{2}{q_{e1}}[A]^{-1}_{11},\quad S_{21}=\frac{2}{\sqrt{q_{e1}q_{e(n-1)}}}[A]^{-1}_{(n-1)1},\quad S_{31}=\frac{2}{\sqrt{q_{e1}q_{en}}}[A]^{-1}_{n1} \quad (2)$$

The synthesis procedure of coupling matrices of the proposed coupled-resonator power divider using optimization is based on minimization of a cost function that is evaluated at frequency locations of reflection zeros. The derived equations (1) and (2) have been utilized in the optimization algorithm.

A gradient-based local optimization technique that is used in coupled resonator filters synthesis has been employed here similar to the two port method described in [4].
A 4 resonator 3-dB power divider has been designed, fabricated and tested to evaluate the techniques. It is designed at X-band with a centre frequency of 10 GHz, a bandwidth of 570 MHz, and a reflection loss of 20 dB at the passband using waveguide cavity resonators coupled together using inductive irises. Fig. 1 (b) shows the synthesized coupling matrix (normalized), and Fig. 1(c) depicts the divider structure. The input and output external quality factors ($Q_{ei}=q_{ei}/FBW$) and the coupling coefficients ($M_{ij}=m_{ij}.FBW$), where *FBW* is the fractional bandwidth, are computed for a *FBW* =5.7% and found to be M_{12}= 0.0590, M_{23}=M_{24}= 0.0417, and Q_{e1}= Q_{e3}= Q_{e4}=14.94.

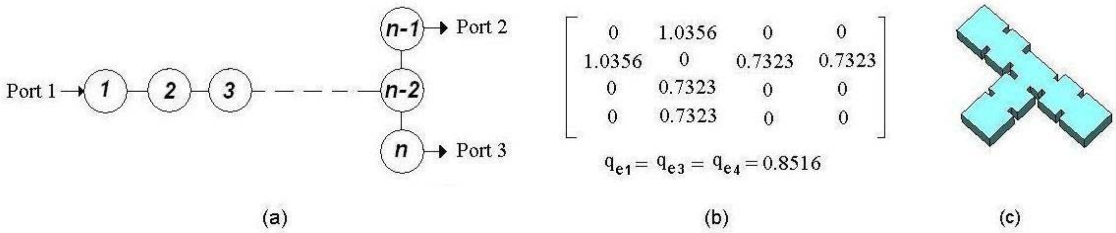

Fig. 1 (a) Resonator topology, (b) Normalized coupling matrix, n=4, (c) Divider structure, n=4.

The simulated and measured results of the power divider are given in Fig. 2. The measured response has been tuned using the metal screws and the result is in good agreement with the simulated response. The experimental results show that the maximum return loss within the passband is 20 dB and the minimum insertion loss is 3.3 dB. The bandwidth of the measured response is 1.23% narrower than the simulated response and the measured isolation S_{23} within the passband is around 6 dB as expected. The proposed divider is not matched at all ports, and the output ports are not isolated, which is typical for lossless reciprocal 3-port junctions.

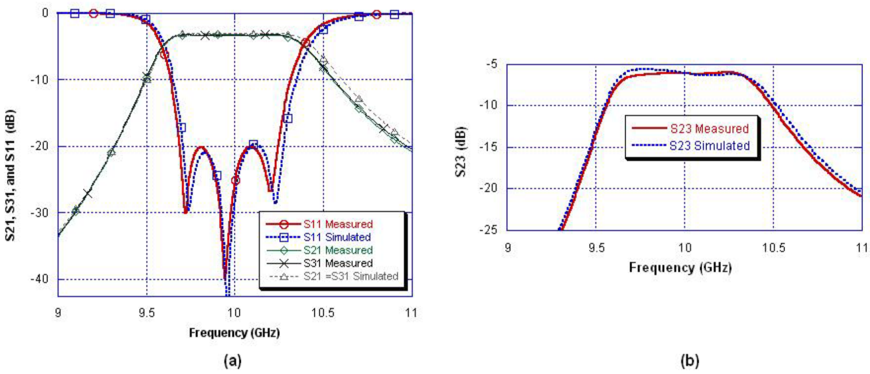

Fig. 2. Measured and Simulated results, (a) S_{11}, S_{21}, S_{31} (dB), (b) S_{23} (dB).

To conclude, a Coupled-Resonator 3-dB power divider has been synthesised using coupling matrix optimization. An X-band power divider has been designed, fabricated and tested to demonstrate the new approach.

References

[1] A. Garcia-Lamperez, M. Salazar-Palma, and T.K. Sarkar, "Analytical synthesis of microwave multiport networks," IEEE MTT-S International Microwave Symposium digest, vol. 2, pp. 455-458, 2004.
[2] R.R.A. Syms, E. Shamonina and L. Solymar, "Magneto-inductive waveguide devices", IEE Proc.-Microw. Antennas Propag., vol. 153, No. 2, April 2006
[3] Hong, J.S. and M.J. Lancaster, Microstrip filters for RF/microwave applications. 2001, New York: Wiley.
[4] A.B. Jayyousi, and M.J. Lancaster, "A gradient-based optimization technique employing determinants for the synthesis of microwave coupled filters," IEEE MTT-S International Microwave Symposium, USA, vol. 3, pp. 1369-1372, June 2004.

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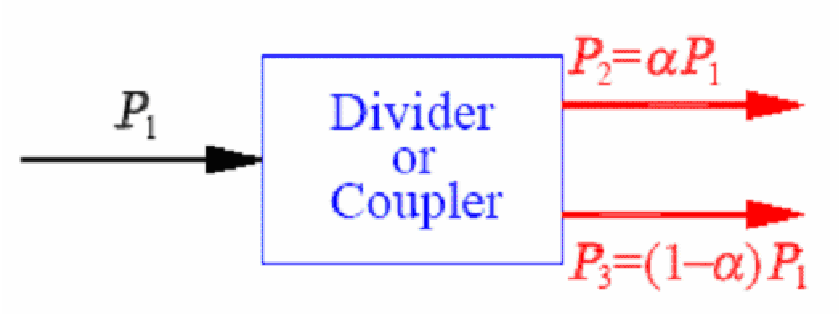
Power Dividers (Review)

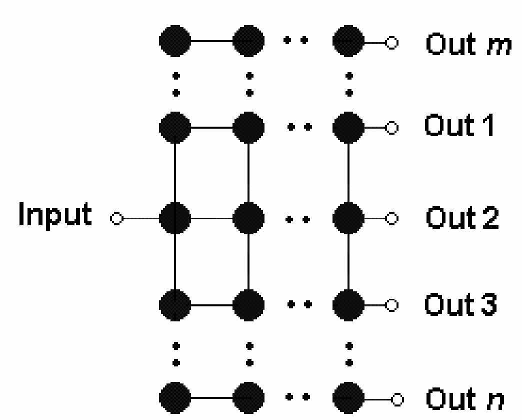


- Power dividers are passive components.
- Divide input signal into two or more signals of less power.
- Widely used power dividers are Wilkinson dividers, T-Junctions and hybrid couplers.
- Used in antenna feeds, balanced amplifiers, other applications.

Proposed Power Divider

- Multiple coupled resonators with multiple outputs.
- Introduces filtering in addition to power division.
- Chebyshev and Elliptic filter response.
- Possible realization by microstrip resonators, waveguide cavities, or other resonators.
- Synthesis employs coupling matrix optimization techniques of coupled resonator filters.
- 3-dB power division, unequal power division also possible.
- Output ports not matched, not isolated.

General Coupling Matrix



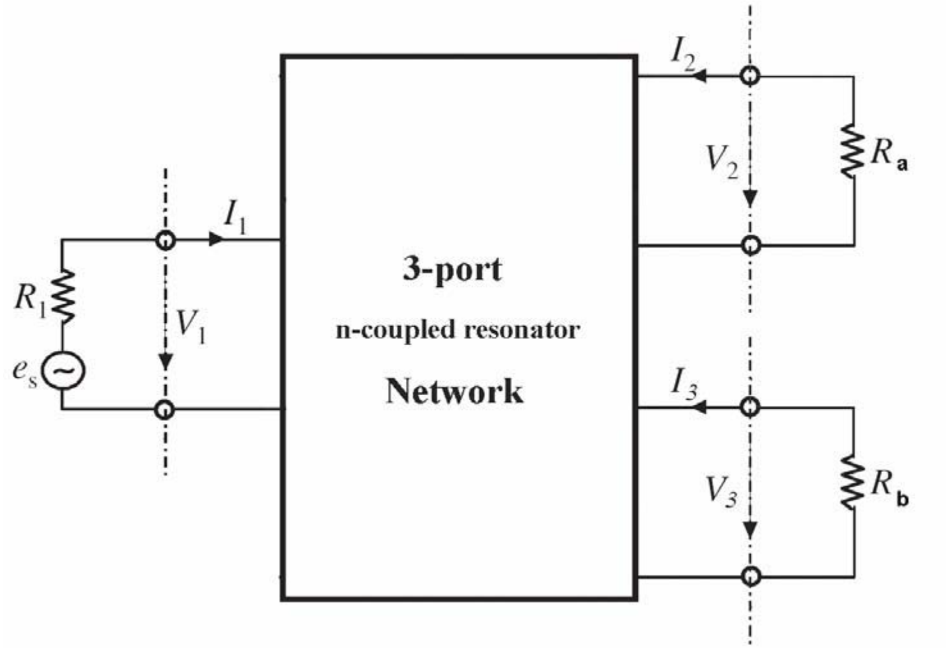
$$[A]=\begin{bmatrix} 1/q_{e1} & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 1/q_{e(n-1)} & 0 \\ 0 & \cdots & 0 & 1/q_{en} \end{bmatrix} + P\begin{bmatrix} 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 1 & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} - j\begin{bmatrix} m_{11} & \cdots & m_{1(n-1)} & m_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ m_{(n-1)1} & \cdots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \cdots & m_{n(n-1)} & m_{nn} \end{bmatrix}$$

- q_e : scaled external quality factor.
- P : lowpass frequency variable.
- m_{ij} : normalized coupling coefficient between resonators *i* and *j.*
- m_{ii} : *self coupling coefficients for asynchronously tuned filter.*

S-Parameters

3-port network with *n*-coupled resonators:

Port 1: Resonator 1.
Port 2: Resonator a.
Port 3: Resonator b.



S-Parameters in terms of general coupling matrix [A] :

$$S_{11} = 1 - \frac{2}{q_{e1}}[A]^{-1}_{11} \qquad S_{21} = \frac{2}{\sqrt{q_{e1}q_{ea}}}[A]^{-1}_{a,1} \qquad S_{31} = \frac{2}{\sqrt{q_{e1}q_{eb}}}[A]^{-1}_{b,1}$$

Coupling Matrix Optimization

- Synthesis based on minimisation of cost function.
- Cost function is evaluated at frequency locations of reflection and transmission zeros.
- Transmission zeros are prescribed in specification.
- Reflection zeros are found using Cameron’s recursive technique.
- Gradient based optimization technique has been used.

Cost Function

- Cost Function used in optimization:

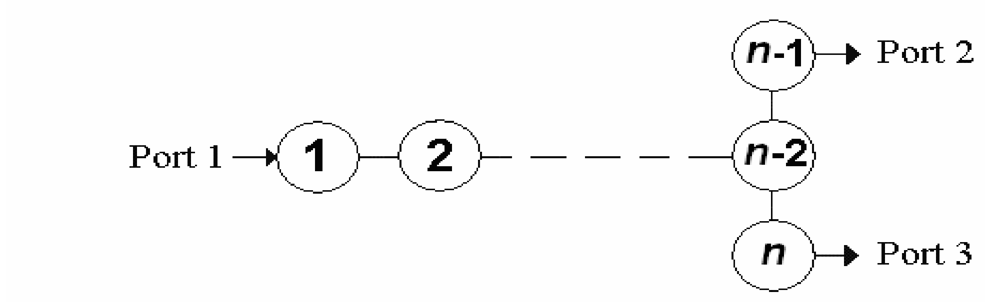
$$\Omega = \sum_{i=1}^{T} \left| \frac{2}{\sqrt{q_{e1} q_{en}}} . cof_{1n}([A(S_{ti})]) \right|^2 + \sum_{j=1}^{R} \left| \Delta_A(S_{rj}) - \frac{2.cof_{11}([A(S_{rj})])}{q_{e1}} \right|^2$$

T : Number of transmission zeros.
S_{ti} : Complex lowpass prototype transmission zeros.
R : Number of Reflection zeros.
S_{rj} : Complex lowpass prototype reflection zeros.
[*A*] : General coupling matrix.
$\Delta_A(S_{rj})$: Determinant of matrix [*A*], evaluated at S_{rj}.
$Cof_{mn}([A(s=a)])$: Cofactor of matrix [*A*] evaluated at *s*=*a*.

***Note**: calculation q_e and setting its value in the optimization cancels the need to invoke the ripple in the algorithm.*

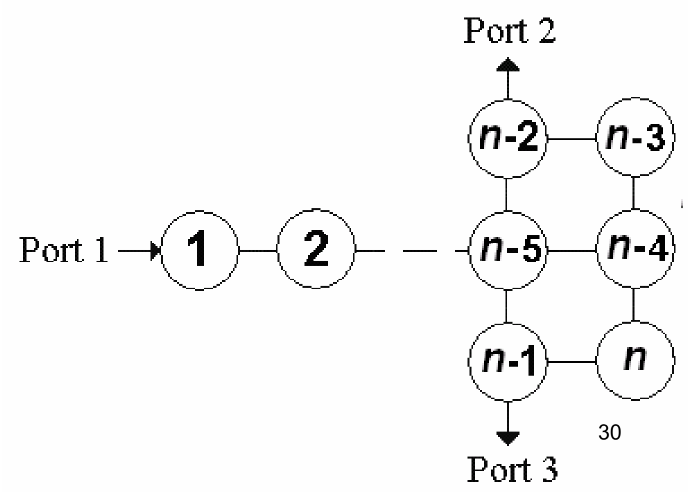
Topologies

A structure with chebyshev filtering response:



Order of filtering function is *n*-1

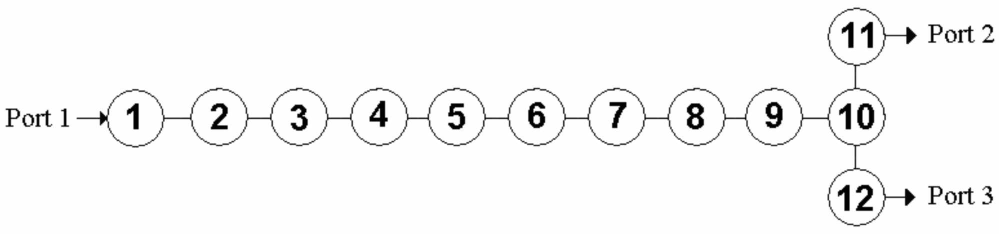
A structure with elliptic filtering response:

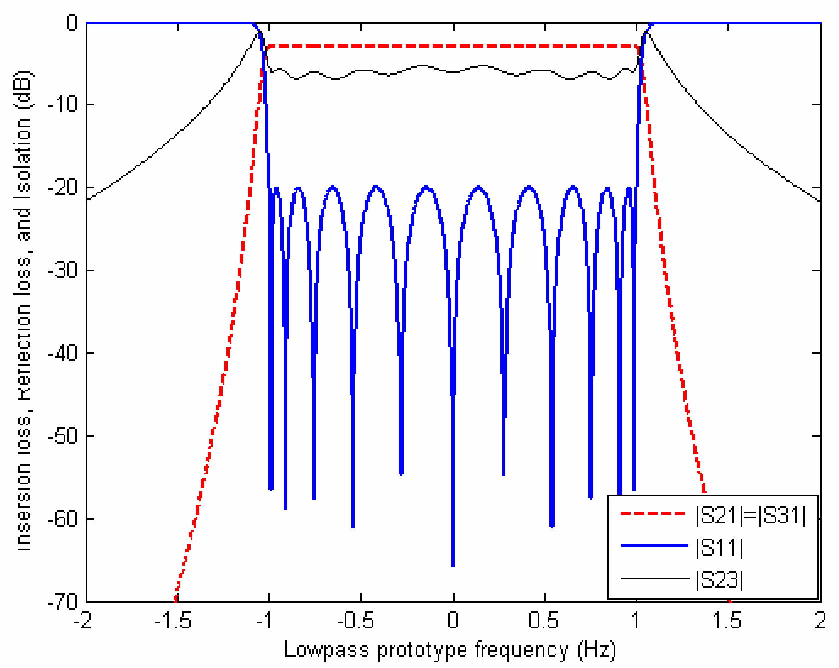


Order of filtering function is *n*-2

Example 1

Power Divider with Chebyshev response.



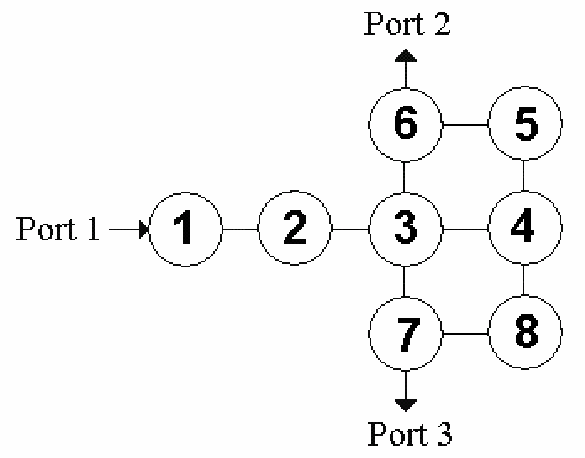


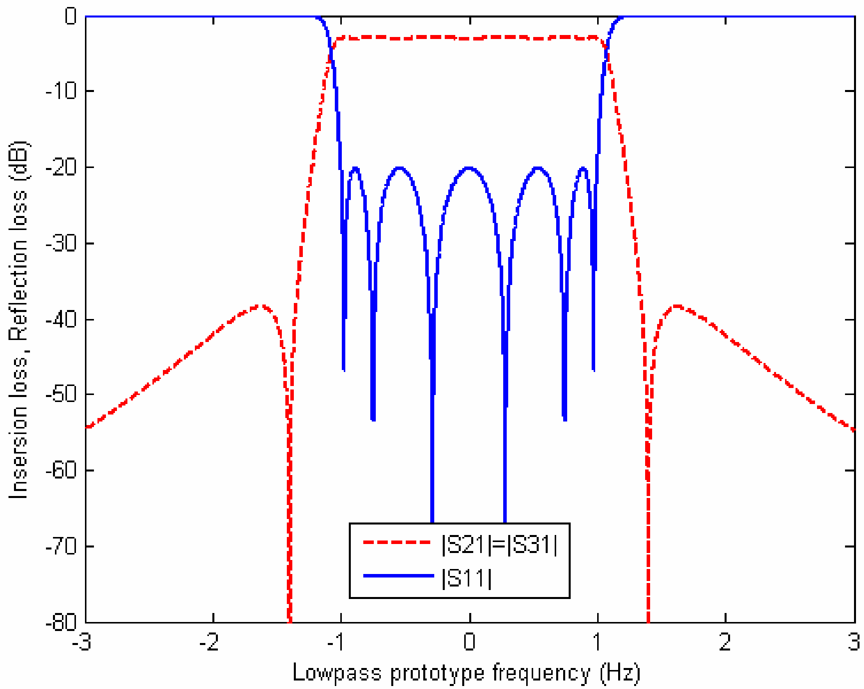
qe=1.0331

0	0.8103	0	0	0	0	0	0	0	0	0	0
0.8103	0	0.5817	0	0	0	0	0	0	0	0	0
0	0.5817	0	0.5419	0	0	0	0	0	0	0	0
0	0	0.5419	0	0.5289	0	0	0	0	0	0	0
0	0	0	0.5289	0	0.5245	0	0	0	0	0	0
0	0	0	0	0.5245	0	0.5244	0	0	0	0	0
0	0	0	0	0	0.5244	0	0.5290	0	0	0	0
0	0	0	0	0	0	0.5290	0	0.5418	0	0	0
0	0	0	0	0	0	0	0.5418	0	0.5817	0	0
0	0	0	0	0	0	0	0	0.5817	0	0.5730	0.5730
0	0	0	0	0	0	0	0	0	0.5730	0	0
0	0	0	0	0	0	0	0	0	0.5730	0	0

Example 2

Power Divider with elliptic response.

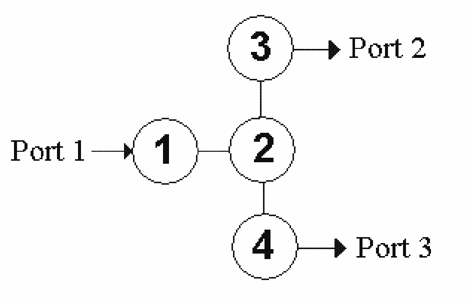




0	0.8317	0	0	0	0	0	0
0.8317	0	0.5987	0	0	0	0	0
0	0.5987	0	-0.5276	0	0.1591	0.1591	0
0	0	-0.5276	0	0.5282	0	0	0.5282
0	0	0	0.5282	0	0.8006	0	0
0	0	0.1591	0	0.8006	0	0	0
0	0	0.1591	0	0	0	0	0.8006
0	0	0	0.5282	0	0	0.8006	0

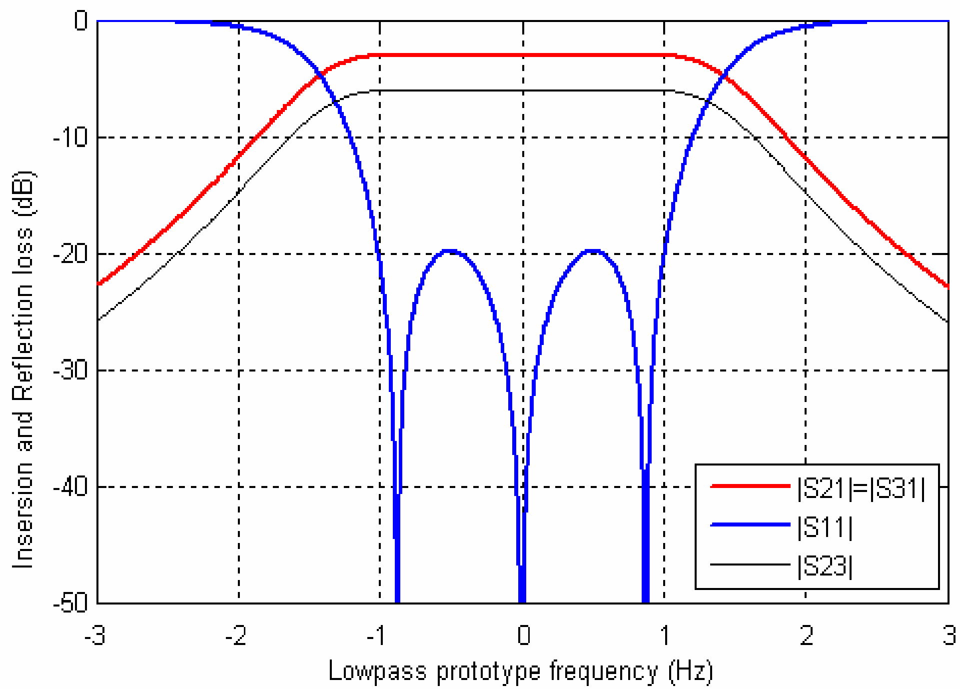
, qe=1.005

Implementation



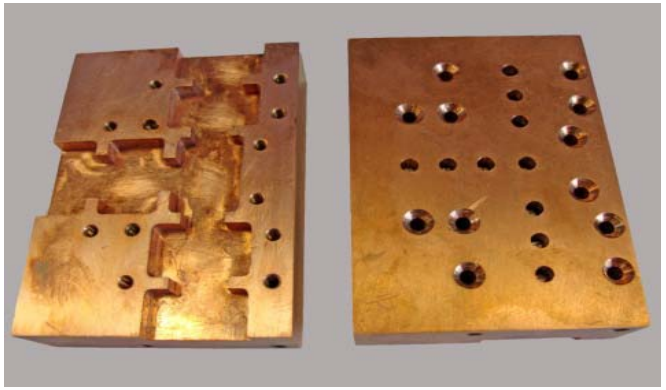
$$\begin{bmatrix} 0 & 1.0356 & 0 & 0 \\ 1.0356 & 0 & 0.7323 & 0.7323 \\ 0 & 0.7323 & 0 & 0 \\ 0 & 0.7323 & 0 & 0 \end{bmatrix}$$

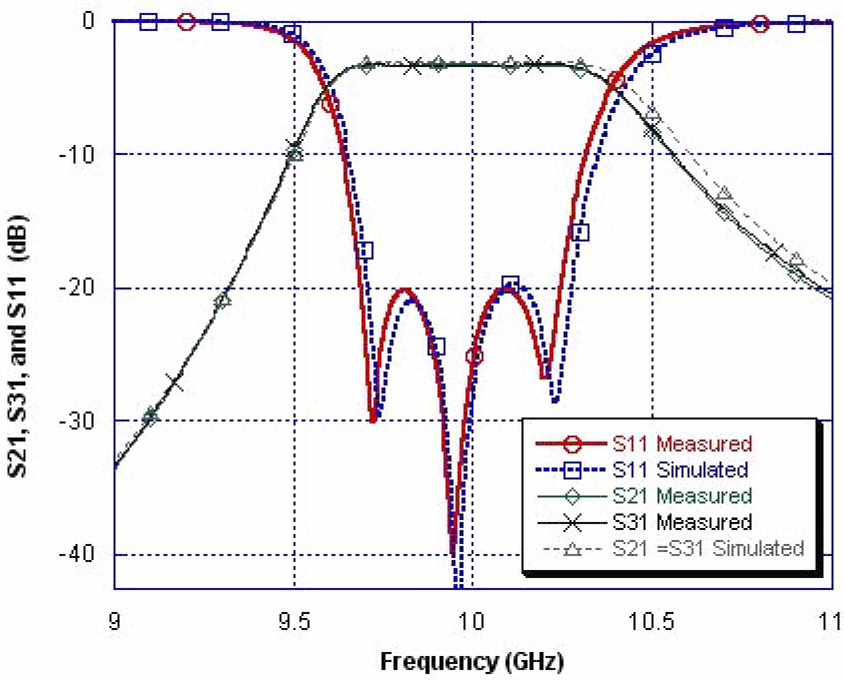
$q_e = 0.8516$

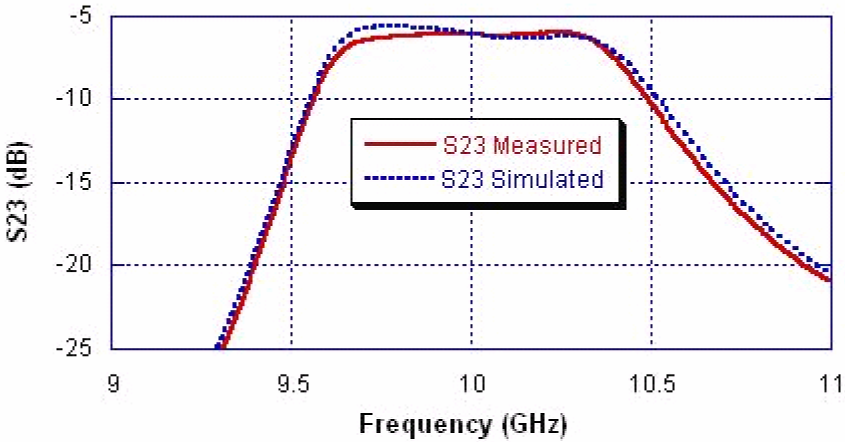


Simulation and Measurement

- X-band.
- Waveguide cavities.
- Centre frequency =10 GHz.
- Bandwidth 570 MHz.
- Reflection loss 20 dB.







Conclusion and Future Work

- Coupled-Resonator power dividers have been synthesised using coupling matrix optimization.
- An X-band 3-dB power divider has been designed, fabricated and tested to verify the proposed approach.

Future Work

- Implementation of a power divider with elliptic response.
- Synthesis of N-Way coupled resonator power dividers.
- Synthesis of multiplexers and couplers using the same design technique.

Thanks

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