Miniature lumped element 180° Wilkinson Divider

Harvinder Singh Nagi[1]

Intarsia Corporation, UK

ABSTRACT

Abstract _This paper presents a novel way to design a 180° Lumped element Wilkinson divider. It uses a conventional Wilkinson divider, a negative and a positive phase shifter. It presents an example at C-band with its measured and simulated results showing a good agreement

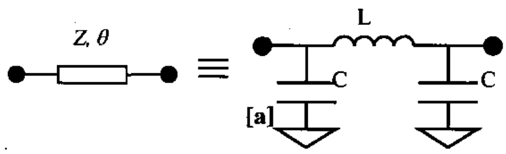
I INTRODUCTION

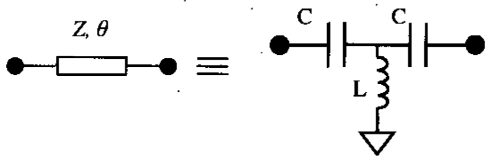
The 180° power divider, such as rat-race divider, is a common component of many microwave systems. The majority of commonly used dividers employ a quarter-wave transformer or multiple sections of quarter wavelength in their designs. A quarter-wavelength is easily realisable in microstrip using distributed element structures for microwave frequencies. Unfortunately, this is not possible with MMIC or thin film technology where the quarter-wavelength is unreasonably long, for frequencies below 8GHz, and the long lengths of the transmission lines results in increased conductor losses.

A usable option is to use the lumped element equivalent for the quarter-wavelength, for space saving. Using the properties of the lumped elements, a quarter wave transformer with positive phase and negative phase may be designed [1]. This technique could be applied to any design, which requires phase shift. Samuel Parisi [2] has already used this to produce 180° lumped element hybrid. This paper provides an example for a 180°-phase shift Wilkinson divider [3].

II THEORETICAL ANALYSIS

The lumped element equivalent of the transmission line with characteristic impendence, Z, and electrical length, θ, [4],[5] is shown in Fig. 1(a) and Fig. (b). Fig. 1(a) shows the equivalent circuit as low pass "**π**", network and Fig. 1(b) shows equivalent circuit as high pass "**T**" network.





[b]

Fig1(a) Shows lumped elements equivalent of the quarter wavelength using π-network (b) Shows lumped elements equivalent of quarter wavelength using T-network

Using the ABCD matrix the solution is obtained for θ=λ/4. The equation (1) and (2) gives the values of L and C for the **π** and **T** networks [4], [5].

$$L = \frac{Z}{2\pi f} \qquad (1)$$

$$C = \frac{1}{2\pi f Z} \qquad (2)$$

Using equations (1) and (2) and substituting the value in equations (3) and (4) given below, it proves that **π** and **T** network, will give positive phase resulting in θ_π with a positive sign and negative phase resulting in θ_T with a negative sign.

$$\theta_\pi = \tan^{-1}\left[\frac{2\pi f L}{Z}\left(\frac{1}{1-(2\pi f)^2 LC}\right)\right] \qquad (3)$$

$$\theta_T = \tan^{-1}\left[\frac{1}{2\pi f C Z}\left(\frac{1-2(2\pi f)^2 LC}{(2\pi f)^2 LC - 1}\right)\right] \qquad (4)$$

Where:

θ_π (Radians)	*Electrical length for π network*
θ_T (Radians)	*Electrical length for T network*
L (Henry)	*Equivalent inductor value*
C (Farads)	*Equivalent capacitor value*
f (Hertz)	*Centre frequency required for the quarter-wavelength*
Z (Ohm)	*Required impedance for the quarter-wavelength*

[1] Author is currently with Thales-MESL Ltd, Edinburgh, UK.

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III Design Methodology and Practical Implementation

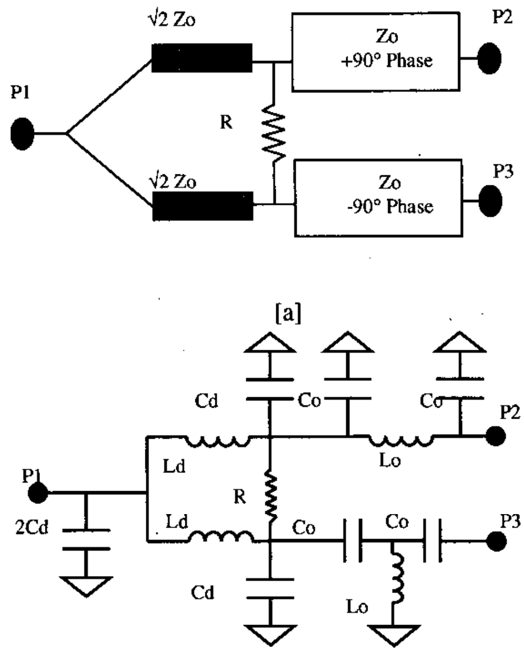

Fig.2(a). Showing the block diagram for 180° Wilkinson divider [b] lumped element equivalent of 180° Wilkinson divider.

Using the theory in section II, a 180° phase shift divider may be designed. Fig.2 (a) shows a block diagram of the 180° Wilkinson divider. It consists of a conventional lumped element divider [2]-[10], a section of characteristic impedance quarter wave transformer for negative and positive phase shift as shown in the figure 2(b).

A 180° Wilkinson divider was designed at C-Band. The values for 5.5GHz are given below:

Z_o [Ω]	L_d [nH]	C_d [pF]	R [Ω]	L_o [nH]	C_o [pF]
50	2	0.41	100	1.45	0.57

The divider was implemented using thin film technology on glass with two metal layers process. The top layer is, Copper, which is 5.4μm thick with Aluminium as bottom layer, which is 3.75μm thick. These two layers are separated by a 5.4μm thick layer of benzocyclobutene (BCB) with ε_r of 2.7. This technology is intended for integrating passives for high-density microwave circuits. The quarter-wavelength for this technology at C-band is greater than 9mm long, hence making it long for high-density circuits and it would have added metal losses, which were measured at 0.12dB/mm.

The inductors L_d and L_o was realised as 30μm width and 30μm spacing spiral inductors. The Capacitors C_d and C_o was realised Silicon Nitride capacitor, which offered 100pF/mm^2. The 100Ω resistor was realised as Tantalum Nitride thin film resistor. Microstrip and coplanar structures were used as interconnects for the passive elements. The equivalent models of the spiral inductors and the Silicon Nitride capacitors were absorbed as part the circuit. The design was simulated and optimised for the best results, using modern Computer Aided Engineering packages. Fig.3 shows the image of the actual 180° Wilkinson divider with size of 1.6mm x 1.5mm.

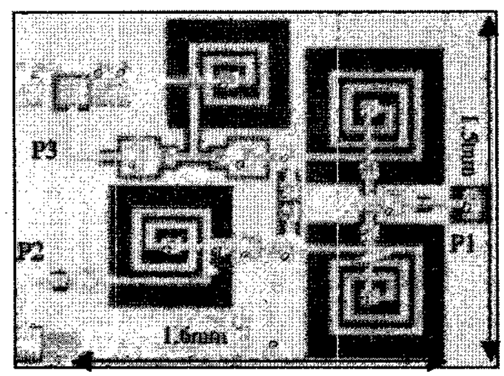

Fig.3. Showing the image of actual 180° Wilkinson Divider on glass using thin film technology.

IV Simulated Vs Measured Results and Discussion

The structures were measured using RF on wafer (RFOW) measurement using an Agilent 8720D network analyser. The Figs. 4, 5 and 6 show the simulated and measured results of the divider for insertion loss, port matches, isolation and phase difference.

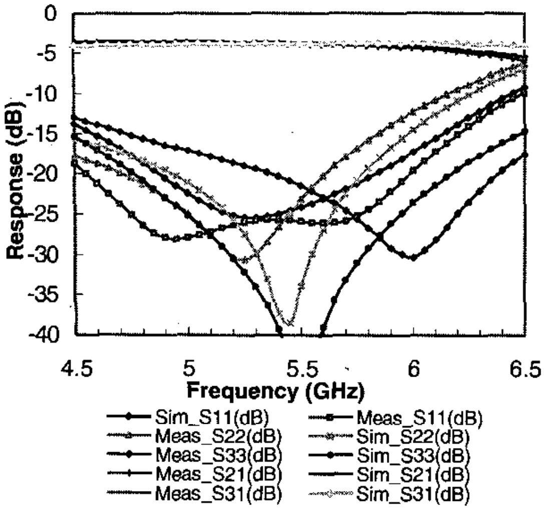

Fig.4. Showing the measured and simulated S21, S31, S11, S22 and S33, of 180° the Wilkinson splitter

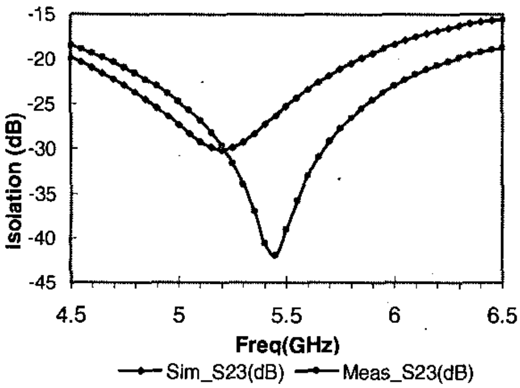

Fig.5. Showing the measured and simulated S23 of the 180° Wilkinson splitter

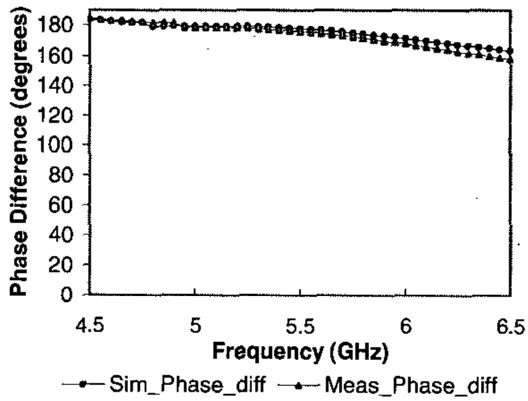

Fig.6 Showing the measured and simulated Phase difference of the output ports of the 180° Wilkinson divider

As the Wilkinson divider is a 3-port device, all the structures using MMIC technology were converted to two ports by terminating the unused port in 50Ω with a thin film resistor. The thin film technology had an inaccuracy of ±4% due to process tolerances; hence, a small mismatch was observed.

The results showed a good consistency between the simulated and measured results. The insertion loss of the divider was simulated and measured to be <1.1dB and the difference between the output ports was simulated and measured to be <0.35dB across the 1.75 GHz bandwidth. Similarly the port matches measured were >12dB and the isolation between the output ports was measured to be >18dB across the same bandwidth. The phase difference was simulated and measured within the expected range of ±10° for 1.75GHz bandwidth

Cascading two λ/8 "π" or "T" sections to give a second order quarter wave transformer can increase the bandwidth of the lumped element quarterwave transformer [5], [7].

IV Conclusion

This paper presents a novel way to convert a conventional lumped element Wilkinson Divider to give a 180° phase shift. It showed that using lumped elements. A lot of space can be saved especially on the MMIC technologies where space is directly proportional to cost. It shows that using "π" and "T" lumped element network a phase shifter could be designed to give negative phase or positive phase for any required impedance. This method could be used for the frequencies where quarter wavelength is too long and the metal losses hinder the design specification therefore an equivalent response could be easily achieved using commonly available discrete lumped elements or thin film lumped elements.

This technique could be easily applied to lower frequencies such as UHF band where the quarter-wavelength on FR4 (ε_r 4.8 and h: 1mm) is over 7.5cms long.

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