A Dual-Band 3-dB Three-Port Power Divider Based on a Two-Section Transmission Line Transformer

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***Abstract*—A new dual-band 3-dB three-port power divider with arbitrary impedance terminations is presented in this paper. The structure is composed of a two-section transmission line transformer and an isolation resistor. The transmission line's electrical length is $\pi/3$ each at fundamental frequency, resulting in a $2\pi/3$ total length. The proposed circuit's design equations and graph obtained from analytical results are also given. The technique is validated by the experimental results on 3-dB 900/1800 MHz power divider with Z_s=100 Ω and Z_L=50 Ω. Good performances of the proposed power combiner/divider at both frequencies are obtained.**

I. Introduction

The emerging of 3G mobile communications has resulted in the need for wireless communications. Also, the prospects for wireless LAN products, such as IEEE802.11a and IEEE802.11b, are very encouraging. These products and their extensions to the personal applications are expected to be popular. With the advanced technology of semiconductor, a system with small-size, low-power, low-cost and multi-function performances is in demand.

Multi-function applications, such as the Global Positioning System (GPS), would be considered as one of the wireless specifications in WCDMA that need to be integrated into a mobile phone. A dual-band RF front-end is one of the possible solutions to fulfill this task [1]. A smart antenna for dual-band mobile applications needs a dual-band phase-array antenna to counterfeit interference signals. Consequently, dual-band components are needed for multi-function applications in wireless communications.

A power combiner/divider [2] has a lot of applications in RF and microwave subsystems, for example in phase-array antenna [3], high power amplifier, vector modulator [4], mixer [5], to name a few. Recently, a dual-band power divider/combiner, based on lumped element approach for multi-band mobile phone operating at fundamental frequency and its first harmonic, was proposed [6]. This lumped approach provides a compact circuit and suits for low frequency applications. In practice, parasitic elements in lumped elements significantly degrade circuits' performances. At higher frequency, distributed element's size is very small and inherently wideband. Consequently, it is preferable to design a circuit on distributed element than a lump design based at high frequency regimes.

One of the most popular microwave power combiner/dividers is a Wilkinson combiner/divider [7] due to its simple design and topology. The concept of the Wilkinson divider is based on a quarter-wave transformer, which its major drawback is narrow bandwidth. Bandwidth extension can be achieved by using a multi-section quarter-wave transformer topology. Recently, a two-section impedance transformer was proposed [8] and its analytical derivation [9] was laterally reported. This technique provides an impedance transformer operating at two simultaneous frequencies, fundamental and its first harmonic. In this paper, we use this technique to obtain a dual-band 3-dB three-port power combiner/divider.

This paper first presents a technique to design a dual-band three-port power divider with arbitrary impedance terminations based on a two-section transmission line impedance transformer. Each transmission line section is $\pi/3$ electrical length at its fundamental frequency. Analysis results of the structure, design graphs and design flowchart based on an ideal transmission line model are shown in Section II. The technique was then designed to operate at two mobile GSM bands, 900 MHz and 1800 MHz. The designed circuit was implemented on microstrip transmission line on a low-cost printed-circuit board. The experimental results on S-parameters of the circuit are discussed in Section III.

II. A Dual-band Technique

Fig.1 shows the dual-band three-port power divider with arbitrary impedance terminations proposed in this paper. The topology is similar to a cascaded power divider [10], except only a single isolation resistor R is connected between both output ports (Z_L). A two-section transmission line transformer is used to replace a quarter-wave transformer in a conventional Wilkinson divider to attain a dual-band operation.

Since the circuit is symmetry along the horizontal line, for simplicity sake, we will analyze the circuit using even-odd mode technique [11]. The ideal transmission line model is used for analysis in this paper. The impedance ratio between Z_s and Z_L is denoted by k, where $k=Z_s/Z_L$. If both transmission lines have the same length ($\theta_1=\theta_2=\theta$) then; from the even-mode analysis approach, the return loss at port 1 (input return loss: s_{11}) and the insertion losses at port 2 and 3 (s_{21}, s_{31}) can be derived as shown in (1) and (2), respectively (at the bottom of the page). Note that f_0 appeared in (1) and (2) is the fundamental frequency. The frequency response of s_{11}, $s_{21}(s_{12})$, and s_{31} (s_{31}) can be made symmetry at $3f_0/2$ if θ is equal to $\pi/3$ at the fundamental frequency. It should be noted that this electrical length is the minimum electrical length of each transmission line for equal magnitude responses of s_{11}, s_{12}, and s_{13} at f_0 and $2f_0$. Substitute $\theta=\pi/3$ into (1) and solve for the perfectly matched condition at port 1 for f_0 and $2f_0$, we obtain Z_1 and Z_2 as follows:-

$$Z_1 = Z_L\sqrt{\frac{k}{3}(1-2k)+\sqrt{\left[\frac{k}{3}(1-2k)\right]^2+8k^3}} \quad (3)$$

$$Z_2 = Z_s Z_L / Z_1 \quad (4)$$

Fig.2 and 3 show the calculated frequency response of the return loss and insertion loss of the proposed divider with three impedance ratios (k=2,3 and 4). It is obviously shown that s_{11} is best matched at f_0 and $2f_0$. Also, at these frequencies, the power is equally split to output ports (port 2 and 3).

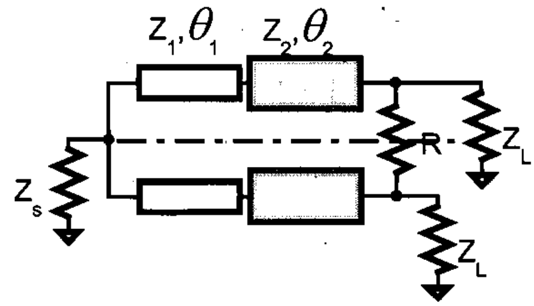

Fig.1 The proposed 3-dB dual-band power divider

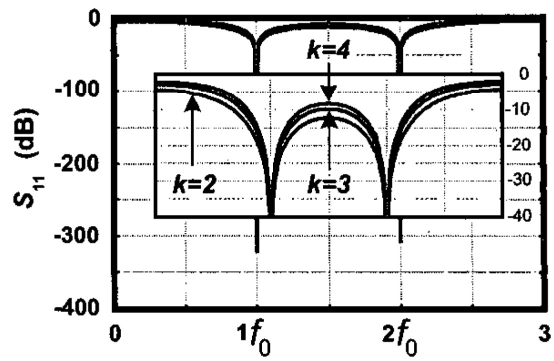

Fig.2 Frequency response of s_{11} of the proposed circuit with different transformer ratios (k=2, 3 and 4)

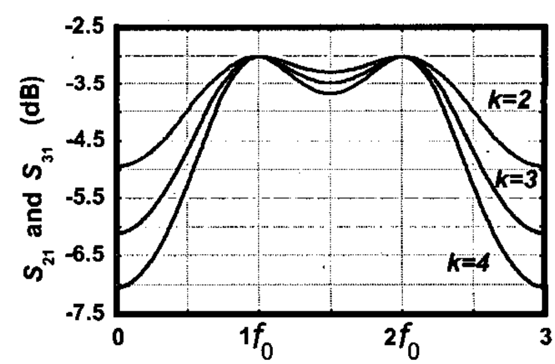

Fig.3 Frequency response of s_{21} (s_{12}) and s_{31} (s_{13}) of the proposed circuit with different transformer ratios (k=2,3 and 4)

$$s_{11}(f)=\frac{(1-2k)Z_1Z_2Z_S+(2kZ_2^2-Z_1^2)Z_S\tan^2(\theta f/f_0)+j(Z_1+Z_2)(Z_1Z_2-2kZ_S^2)\tan(\theta f/f_0)}{(1+2k)Z_1Z_2Z_S-(2kZ_2^2+Z_1^2)Z_S\tan^2(\theta f/f_0)+j(Z_1+Z_2)(Z_1Z_2+2kZ_S^2)\tan(\theta f/f_0)} \quad (1)$$

$$s_{21}(f)=\frac{2\sqrt{k}Z_1Z_2Z_S\sec^2(\theta f/f_0)}{(1+2k)Z_1Z_2Z_S-(2kZ_2^2+Z_1^2)Z_S\tan^2(\theta f/f_0)+j(Z_1+Z_2)(Z_1Z_2+2kZ_S^2)\tan(\theta f/f_0)} \quad (2)$$

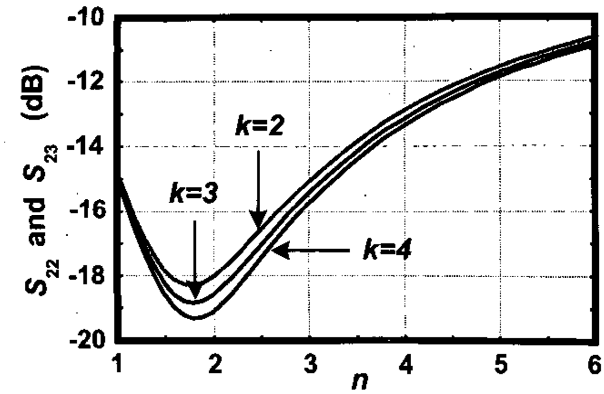

Fig.4 Output return loss and isolation loss characteristics at f_0 and $2f_0$ versus n at different impedance ratios (k=2,3 and 4)

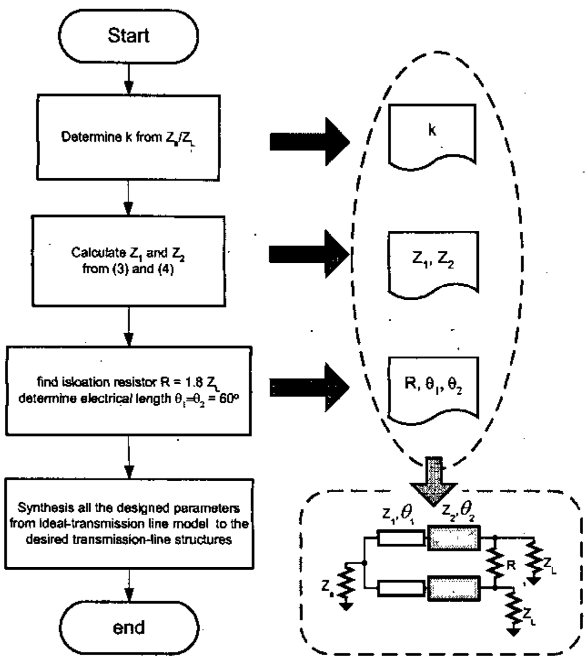

Fig.5 Design flowchart of the proposed dual-band power divider

Using the obtained k, Z_1, Z_2 and θ to calculate the output return loss (s_{22}) and isolation loss (s_{23}), the optimum isolation resistor that provides the minimum return losses and isolation loss at f_0 and $2f_0$ can be obtained. Fig.4 shows the calculated $s_{22}(s_{33})$ and s_{23} (s_{32}) at two frequencies versus n at different k. n is the ratio between R and Z_L, i.e. $R= nZ_L$. Note that the magnitudes of the output return losses and isolation loss at f_0 and $2f_0$ are equal.

The optimum isolation resistor for minimum output return losses and isolation loss can be obtained from Fig.4,

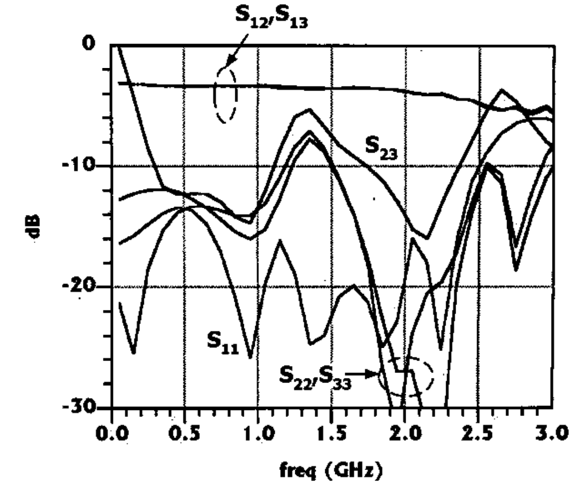

Fig.6 Measured performances of the 900/1800 MHz 100-50 Ω 3-dB power divider

which is $R\approx 1.8Z_L$, leading s_{22} and s_{23} to be −18 dB at both f_0 and $2f_0$.

With the design equations in (3)-(4) and the design graph for R, in Fig.4, a dual-band three-port divider having two functions, a dual-band power divider/combiner and a dual-band impedance transformer can be readily obtained. To summarize the design procedure, a design flowchart of the proposed circuit is shown in Fig.5.

III. IMPLEMENTATIONS AND EXPERIMENTAL RESULTS

To prove the validity of the proposed technique, a 900/1800 MHz 3-dB power divider was designed and realized on microstrip transmission line structure. The circuit was designed to transform a 100 Ω source to 50 Ω loads. The design procedure is followed from the steps shown in Fig.5. Here the impedance ratio k is equal to 2. From (3) and (4), the characteristic impedances of the first and the second sections transmission line are 125 and 80 Ω, respectively. Both transmission lines' electrical lengths are equal to $\pi/3$ at 900 MHz fundamental frequency. To obtain minimum output return losses and isolation loss, a 90 Ω isolation resistor was selected, which can be obtained from $R\approx 1.8(50)=90$ Ω. All these initial parameters based on ideal transmission line model were subsequently used to synthesis the physical parameters of microstrip lines on the FR4 substrate (ε_r=4.55, h=1.6 mm). A 90 Ω SMT resistor (0805 model) was used for the isolation resistor. The designed was then further optimized to yield the optimum performances at both bands by Genesys2002.

The measurement was performed on network analyzer (HP8510C). The SOLT calibration technique was used for our measurement. Three sets of two-port measured data (Port1-Port2, Port1-Port3 and Port2-Port3) were collected from the HP8510C by the HPVEE6.0 software via the GPIB port. Three-port data file was subsequently created from these three sets of two-port data. This three-port measured data was then normalized to a 100 Ω input impedance and 50 Ω output loads.

Fig.6 shows the measured performances of the experimental circuit after normalized to the desired impedances. The measured input return loss is well below -21 dB at both 900 MHz and 1800 MHz. The insertion loss (s_{12} and s_{13}) is -3.5 dB $\pm$ 0.2 dB at both frequencies. The amplitude balance between the output ports is excellent, which is less than 0.1 dB for 200 MHz-3000 MHz where the phase balance is less than 3 degree. The output return losses (s_{22} and s_{33}) are below -14 dB for both bands, where the isolation loss is well below -11 dB. The circuit's size is 45mm×33mm. The performance of the circuit is summarized in Table I.

IV. Conclusion

A new dual-band 3-dB three-port power divider based on a two-section transmission line transformer for arbitrary impedance terminations is proposed. The total circuit electrical length is $2\pi/3$. The closed form design equation and design graph are given to simplify the design task. The simple topology and design procedure make the proposed circuit very suitable for dual-band applications, which is more demanding at near future.

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Table I Summarized performance of the circuit

	900 MHz	1800 MHz
Insertion loss at port 2 and 3	-3.4	-3.7
Input return loss, s_{11} (dB)	-26.1	-21.2
Output return loss at port 2, s_{22} (dB)	-14.2	-19.7
Output return loss at port 3, s_{33} (dB)	-15.8	-19.5
Isolation loss, s_{23} (dB)	-14.5	-11.0
Amplitude balance (dB)	0.1	0.1
Phase balance (deg)	1.2	2.7
Circuit size (mm^2)	45×33	