A Wideband Compact Parallel-Strip 180° Wilkinson Power Divider for Push–Pull Circuitries

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***Abstract*—A Wilkinson power divider with a differential output implemented in parallel-strip-line (PSL) is proposed. Taking full advantages of the PSL technology and a three-stage cascaded design, more than 170% impedance and isolation bandwidths are obtained. Inherent to the PSL structure, the 180° differential output is frequency-independent. A class-B push–pull power amplifier employing the devised concept is designed, showing a peak efficiency of 44% over a 4-GHz bandwidth. Without exploiting any extra and external low-pass filters, the proposed design can produce startling second-harmonic suppressions (more than 50 dB) over the whole working dynamics and operated bandwidth.**

***Index Terms*—Harmonic suppression, parallel-strip line (PSL), push–pull amplifier, wideband Wilkinson power divider.**

I. Introduction

DEMAND for microwave components with low profile and high efficiency has been increasing for both commercial and military applications. Power splitters and combiners show fundamental importance in microwave engineering and appear in most microwave and millimeter-wave systems. By employing a power divider/combiner, a balanced circuit can be implemented. A pair of devices forming a balanced circuit seems to be doubling the cost; however, the performance enhancement can be more than double. A power divider and combiner act as interconnection of the devices and are indispensable components in balanced circuits such as push–pull amplifiers and balanced mixers. The Wilkinson power divider and hybrid coupler are two typical circuits for these applications. Their design rules and characteristics have been documented in [1]. For some applications such as push–pull type circuitry, the 180° hybrid coupler is preferred to the Wilkinson power divider with delay line because the devices have to be fed 180° out-of-phase with high isolation and the hybrid coupler is very phase balanced. However, the hybrid coupler is electrically large compared with other component because of its one and a half guided wavelength circumference. We propose a Wilkinson power divider using parallel-strip line (PSL) with the push–pull characteristic, which tries to alleviate the tradeoff between the size, phase, and magnitude balances.

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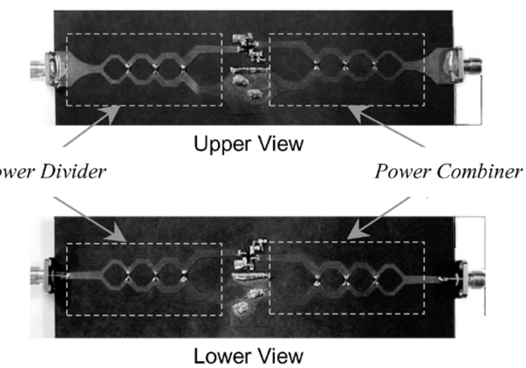

Fig. 1. Photograph of the proposed push–pull power amplifier.

A conventional parallel-strip line (PSL) is a balanced transmission line which consists of two signal lines separated by a dielectric substrate. Unlike the microstrip line (MSL), PSL has inherent advantage of easy realization of balanced configuration which is suitable for balance designs, especially for high power applications. PSL is convenient for the mounting of shunt and series lump components. The symmetrical characteristic implies that we can swap the "ground" and "signal" lines freely in circuit designs and the flexibility of swapping leads to novel structures with low profile and performance enhancement. There have been many applications of PSL, e.g., double balanced type circuits such as mixers [2]. Double balanced type and balanced type circuits are employed frequently in high performance communications systems and they can be directly and easily fed by PSL. By employing PSL, the proposed Wilkinson power divider not only keeps its original wideband and magnitude balance characteristics but also achieves 180° phase balance property. The proposed power divider/combiner is integrated into a push–pull amplifier which is realized in Fig. 1.

II. 180° Wilkinson Power Divider/Combiner

In this letter, a three-section wideband PSL 180° Wilkinson power divider is proposed. Multisection is an effective approach to extend the bandwidth of the Wilkinson power divider. The divider is a two-sided structure, which consists of three sections with each arm approximately a quarter wavelength long. Three shunt resistors are connected between these arms on each side of the dielectric as shown in Fig. 2. Therefore, the nulls in the return loss and isolation are separated but are close by in the

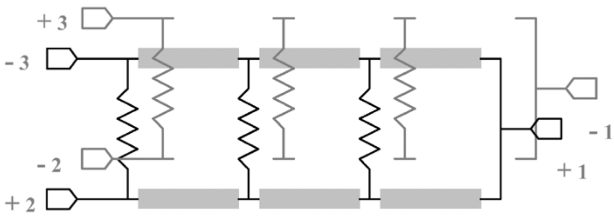

Fig. 2. Geometry of the three-section PSL power divider.

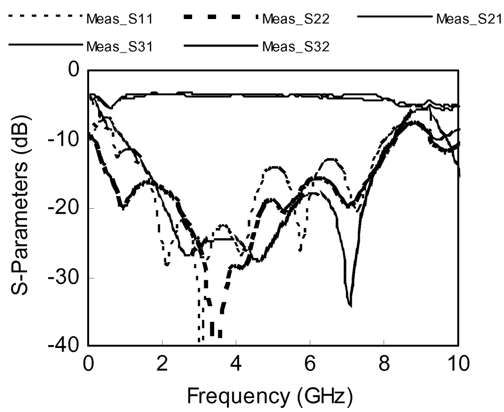

Fig. 3. Measured S-parameters of the proposed power divider.

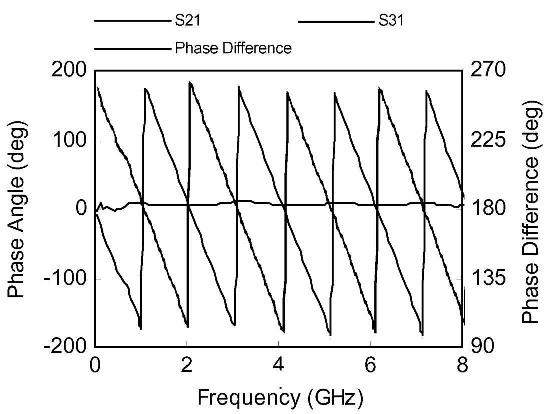

Fig. 4. Measured phase balance of the proposed power divider.

frequency spectrum as shown in Fig. 3. Both the impedance and isolation bandwidth are more than 170%.

The design approach is based on that described in [3] but all characteristic impedance and substrate thickness should be divided by two due to the use of PSL. The power divider (combiner) is shown in the right (left)-hand side of Fig. 1. By tapering the lower (upper) line in Port 2 (3), the PSL-to-MSL transition which is used for feeding devices and measurement is formed [2]. The frequency independent 180° differential phase between Ports 2 and 3 is shown in Fig. 4.

III. Novel Push–Pull Power Amplifier

The push–pull power amplifier has been extensively studied because of its good performance. Many configurations realizing the push–pull characteristic have been reported, i.e., integrated

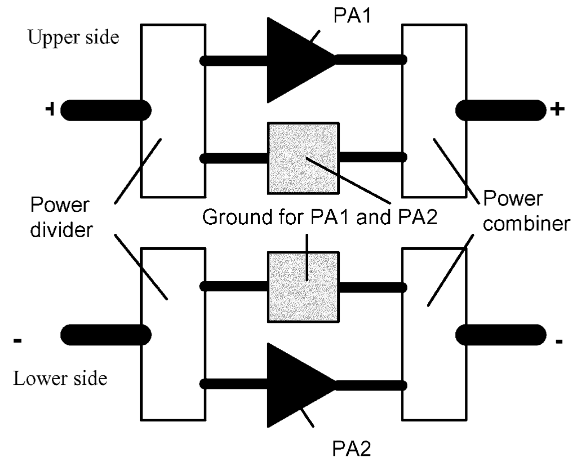

Fig. 5. Schematic diagram of proposed power amplifier.

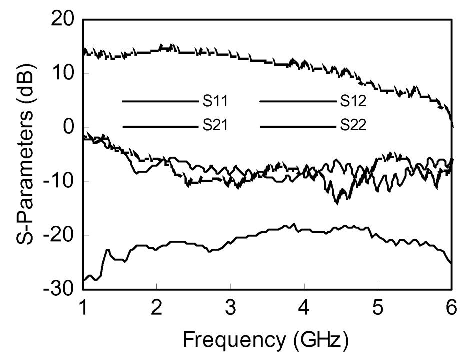

Fig. 6. Measured S-parameters of proposed power amplifier.

antenna [4], complementary transistor pair [5], extended resonance technique [6], dielectric resonator based [7], and conventional transformer [8]. A power amplifier becomes highly nonlinear under the large signal condition and is characterized by nonlinear equations [9]. Equations (1) and (2) describe nonlinear characteristics of the two power amplifiers shown in Fig. 5

$$i_1 = g_1 v + g_2 v^2 + g_3 v^3 + \cdots \quad (1)$$
$$i_2 = g_1 v e^{-j\pi} + g_2 (v e^{-j\pi})^2 + g_3 (v e^{-j\pi})^3 + \cdots \quad (2)$$

where v is the input, i_1, and i_2 are the outputs and g_is are constants which determines the transfer function of the amplifier. The two amplifiers are excited with 180°phase shift and the amplified signals are combined with the same phase shift. Equation (3) shows the output of the push–pull amplifier, the even order terms of i_{total} are eliminated, resulting in suppression of the second harmonic

$$i_{\text{total}} = i_1 + i_2 e^{-j\pi} = 2g_1 v + 2g_3 v^3 + 2g_5 v^5 + \ldots \quad (3)$$

However, for the push–pull amplifiers reported in [4], [6], and [7], the even harmonic components can never be suppressed because the operation bandwidth of push–pull characteristic circuitries is limited for providing an even-mode short circuit [8]. In [8], the push–pull characteristic is realized by a coil transformer which is very broadband at low frequency, e.g., audio band, and it covers both fundamental and second harmonic frequencies, implying at least a 67% 180° phase balance. In this

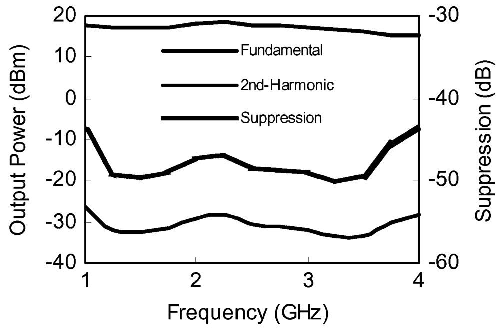

Fig. 7. Measured frequency responses of fundamental, second-harmonic signals and suppression.

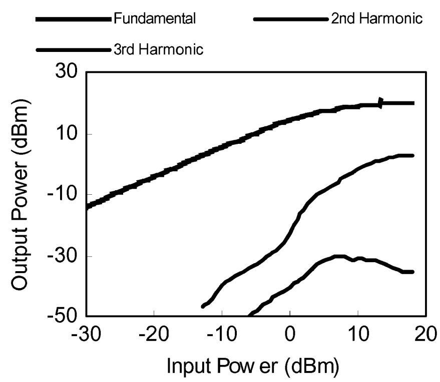

Fig. 8. Measured fundamental, second- and third-harmonic of proposed power amplifier.

letter, the 180° Wilkinson power divider/combiner provides a wideband second harmonic suppression in microwave and millimeter-wave regimes.

A commercial NPN Silicon BJT transistor (Infineon BFP640) was used in our design, which has a typical transition frequency (f_T) of 25 GHz. Fig. 6 shows the small signal S-parameters of the proposed amplifier. No matching network is installed as it limits the bandwidth. Wideband suppression in the second harmonic is obtained in Fig. 7, showing an averaged 48-dB suppression. A single tone test is performed at 2.1 GHz as shown in Fig. 8. The proposed amplifier approaches a 44 % power added efficiency (PAE) and 1-dBm compression point.

IV. Conclusion

A PSL Wilkinson power divider providing an 180° dividing and combining circuitry has been proposed in this letter, demonstrating an application in push–pull circuitries for the first time. Unlike hybrid couplers and other baluns reported in the literature, our design eradicates the traditional frequency dependency of both the magnitude and phase responses, resulting in a new methodology for push–pull amplifier realization. The PSL circuitry shows a reconfigurable structure leading to high performance and size reduction. The proposed power divider can be extended to other balanced circuitries such as balance mixer, harmonic oscillator, and phase shifter, to name a few.

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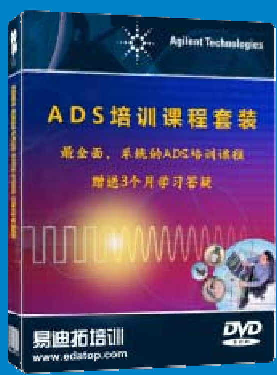

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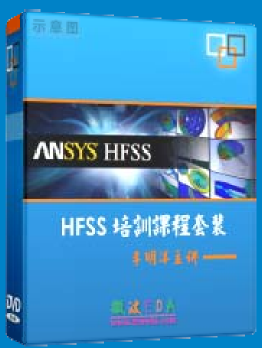

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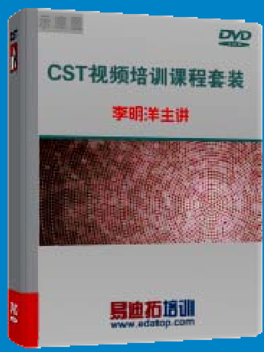

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