High Power Combiner/Divider Design for Dual Band RF Power Amplifiers

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***Abstract*—Design of low loss with an enhanced thermal profile power divider/combiner for high power dual-band Radio Frequency (RF) power amplifier applications is given. The practical implementation, low loss and substrate characteristics make this type of combiner ideal for high power microwave applications. The combiner operational frequencies are chosen to operate at 900 MHz and 2.14 GHz, which are common frequencies for concurrent dual band RF power amplifiers. The analytical results are verified with simulation results for various cases and agreement has been observed on all of them.**

***Index Terms*—Radio Frequency, amplifier, dual band, combiner, divider.**

I. Introduction

POWER combiners/dividers are commonly used in the implementation of microwave circuits to combine or split the power for various applications. The most prominent design typology being that of a Wilkinson power divider that achieves isolation between the output/input ports while maintaining a matched load condition on all ports. This can also be used as a combiner because passive elements are used in the design and are hence reciprocal.

In the last years much effort has been put into the design of concurrent dual band RF power amplifiers. In the design of such amplifiers input and output matching networks are optimized for the two different frequencies of operation [1]. It is advantageous in base stations to amplify two signals of different frequency concurrently. There are, however, disadvantages such as high power efficiency has to be achieved for signals at two frequencies; the design of the matching network is more difficult and often results in increased device size. Furthermore, two signals of different frequency fed through one transistor will cause cross-modulation products [2]. Linearization by digital predistortion requires for such amplifiers complex algorithms that compensate for the cross-modulation effects.

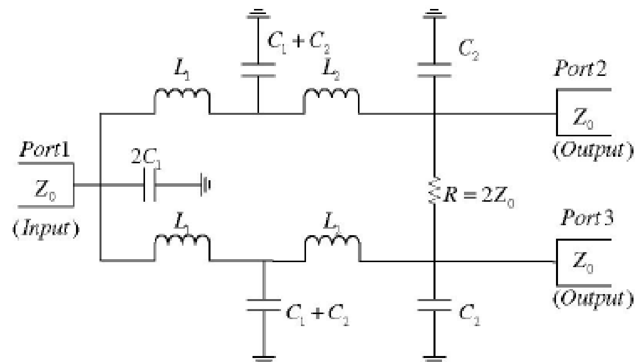

Figure 1: Lumped equivalent circuit for the Wilkinson power divider using π-type equivalent-circuit [6].

Although existing Wilkinson type power combiners can achieve quality isolation (>25dB), there is still forward insertion loss around the magnitude of -3dB. The common use high loss substrates with poor thermal profile also does not allow for efficient high power applications. Furthermore, most designs use a single stage design and no frequency selection on the output/input and therefore make it difficult for power amplifier designs and other frequency selective circuits [3].

In this paper, design of a combiner with high isolation and low insertion loss and good thermal profile at high frequencies operating in dual-band using a Wilkinson power divider design is detailed. It could be used to achieve concurrent dual band amplification with two transistors optimized for different single frequencies. The disadvantages with concurrent dual band amplifiers, mentioned above, would be avoided. By using design method introduced with optimization techniques, the insertion loss is significantly reduced for the frequencies of interest while a good isolation is maintained. Frequency selective filters are implemented at the input/output of the combiner/divider to improve the performance of the combiner and eliminate the need for additional filtering on the input/output of the base circuit that combiner would be connected to. The frequency selection also provides the ability for unequal power division based on the input/output needs and can be planned for with applying the hardware insertion loss characteristics of the component [4]. For high power applications, Alumina is used as substrate since it has superior thermal profile [5].

II. Formulation

Fig. 1 show the circuit typology adopted from [6] as lumped equivalent circuits for a Wilkinson power divider using π-type equivalent circuits. By using π-type and T-type equivalent circuits [4], the lumped passive elements can then be replaced by quarter wavelength transformers. The T-junction power divider is a simple three-port network that can be used for power division or power combining, and it can be implemented in virtually any type of transmission line medium [7].

The analytical formulation for the lumped element values shown in Fig. 1 can be given by

$$l_1 = l_2 = \frac{n\pi}{\beta_1 + \beta_2} \tag{1}$$

$$Z_2 = Z_0\sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + 2}} \tag{2}$$

$$Z_1 = \frac{2Z_0^2}{Z_2} \tag{3}$$

$$R = 2Z_0 \tag{4}$$

$$C = \frac{\frac{B}{\omega_1} - \frac{A}{\omega_2}}{\frac{2\omega_2}{\omega_1} - \frac{2\omega_1}{\omega_2}} \tag{5}$$

$$L = \frac{\frac{2\omega_2}{\omega_1} - \frac{2\omega_1}{\omega_2}}{B\omega_1 - A\omega_2} \tag{6}$$

where

$$\alpha = (\tan(\beta_1 \cdot l_1))^2 \tag{7}$$

$$\beta = \frac{2\pi}{\lambda} \tag{8}$$

$$p = \tan(\beta_1 \cdot l_1) \tag{9}$$

$$q = \tan(\beta_2 \cdot l_1) \tag{10}$$

$$A = \frac{Z_2 - Z_1 \cdot p^2}{Z_2 \cdot p \cdot (Z_1 + Z_2)} \tag{11}$$

$$B = \frac{Z_2 - Z_1 \cdot q^2}{Z_2 \cdot q \cdot (Z_1 + Z_2)} \tag{12}$$

III. Simulation Results

For verification of the combiner working at 900MHz and 2.14GHz, the typology was inserted into Agilent ADS. Simulation was run on the initial design using calculated values for components. Fig. 2 shows the initial design setup for simulation. Another stage was added to the circuit proposed in Fig. 1 at simulation point to improve reflection coefficients and isolation. The 200Ω resistor was placed in this position to maintain high isolation. The transmission lines were added in to improve the reflection parameters and were tuned using ADS tuning capabilities. A high pass filter was implemented on the 2.14GHz branch to pass only the high frequency input on to the load and a low pass filter was implemented on the 900MHz branch to only pass the low frequency content. The additional content is illustrated in Fig. 2. Ideal lumped elements were used for simplicity of illustration for the concept and were switched to distributed elements shown later due to parasitics of high frequencies. Detailed views of the stages of the initial combiner are shown in Fig. 3, Fig. 4, and Fig. 5. Fig. 6 proves the calculated values provide a very reliable design. Insertion losses peaked at -4.291dB at the 900MHz frequency. The isolation characteristics in this design are impressive when the least isolation is -33.398dB at a frequency that is not transmitted in this system.

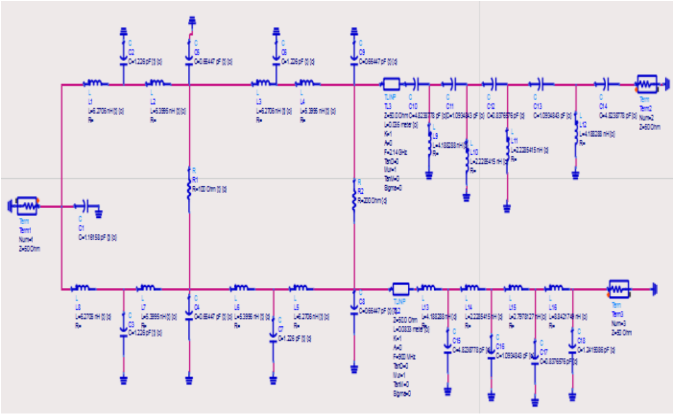

Figure 2: Overall design containing the Combiner and the high pass and low pass filters.

To attempt for higher performance characteristics, optimization techniques were implemented using the capabilities in ADS. Optimization goals were set up to reduce insertion loss and to maintain quality isolation. The optimization has been performed by separating the complete circuit into three sections. Simulation results for the circuit that were not optimized is illustrated in Fig. 3 and Fig. 4. The results in Fig. 3 show insertion loss and isolation between the ports under consideration. Fig.4 illustrates the results for the return loss.

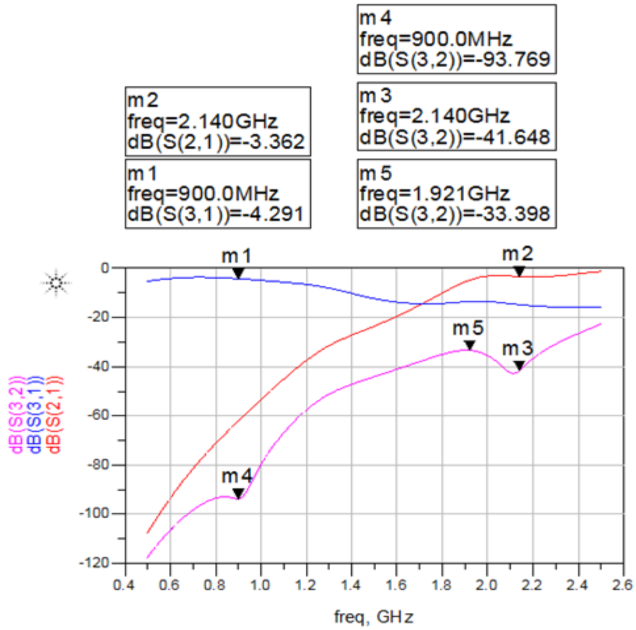

Figure 3: Simulation results of the initial design. S(2,1) and S(3,1) are the transmission coefficients for 2.14GHz and 900MHz respectively. S(3,2) is the isolation coefficient between the two ports.

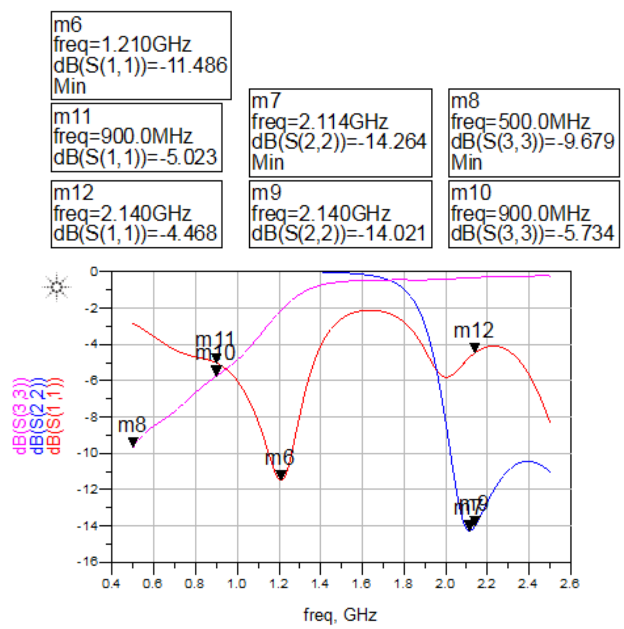

Figure 4: Reflection parameters for each port for the original design.

After optimization is implemented, the performance drastically improved as shown in Fig. 5 and Fig. 6. The isolation experienced a slightly negative impact decreasing to a peak of -28.772dB. However, the insertion losses experienced a drastic improvement. The insertion losses improved to -0.223dB and -0.421dB at 2.14GHz and 900MHz respectively.

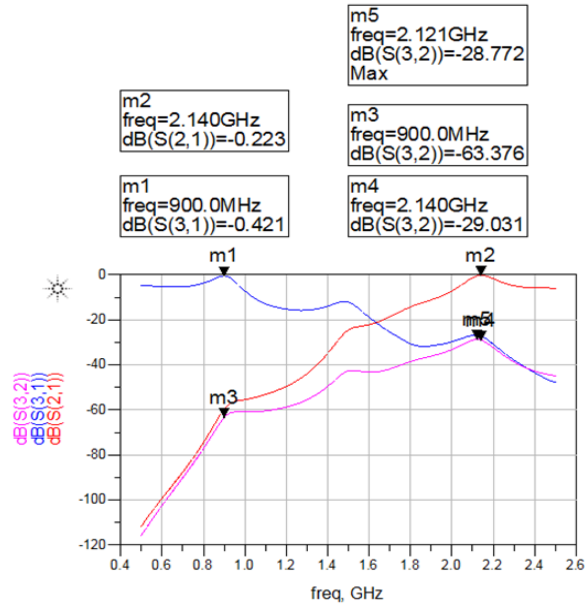

Figure 5: Simulation result of the optimized design.

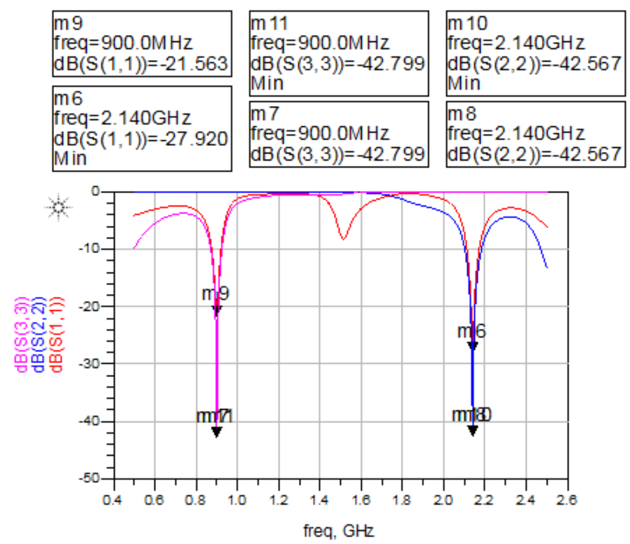

Figure 6: Reflection parameters for each port of the optimized design.

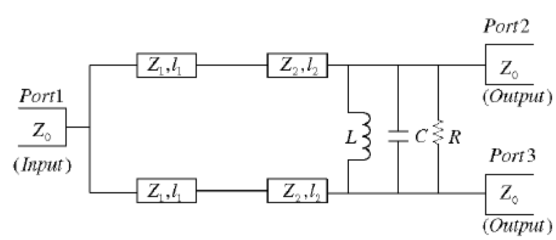

Figure 7: Distributed element model [6].

It is required to convert the lumped element values calculated and optimized to their corresponding distributed models as shown in Fig. 7 to operate at microwave ranges. The second stage in the combiner with distributed model was added to increase the isolation and decrease the insertion losses. Filters were implemented and also converted to distributed elements. The final circuit is shown in Fig.8.

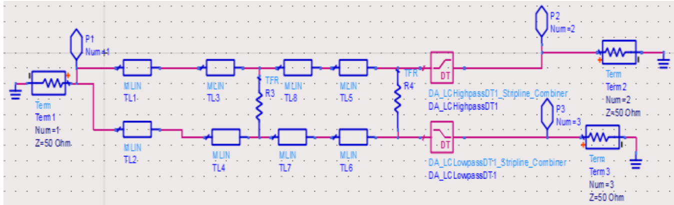

Figure 8: Conversion of the design in distributed elements in ADS.

Once optimization processes were run on this typology, significant improvements were made and can be seen in Fig. 9 and Fig.10.

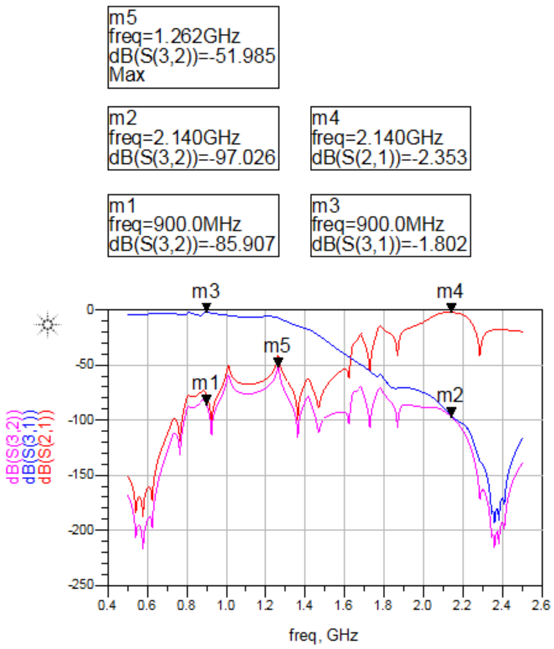

Figure 9: Simulation results of the final design.

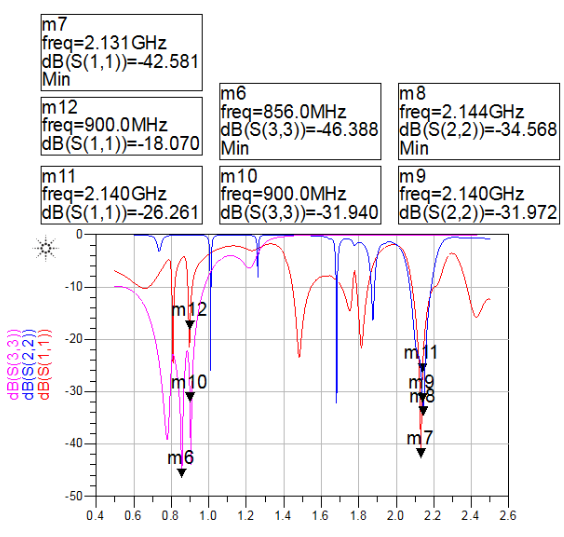

Figure 10: Reflection parameters of the final design.

IV. CONCLUSION

In this paper, design and simulation of high power dual band combiner/divider with good thermal profile using Alumina substrate is given. The added stages including filters improved performance characteristics of the combiner drastically. Optimization techniques of the simulation software, along with implementing high and low pass filters for frequency selection, a new combiner can now achieve excellent electrical performance as well as a wide bandwidth at each center frequency for dual band RF power amplifier operation. Improvements versus existing combiner designs are evident with insertion losses less than -3dB and isolation maximum of -50dB. Implementation using Alumina substrate with a relative permittivity of 9.6 in order to handle high power applications makes this combiner design excellent for high power RF power applications.

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