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A Practical Approach to a Compact, Wide-Band SMT Directional Coupler

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Here is a useful approach to improving the bandwidth of directional couplers that use the coupled-line method of construction

To date, directional couplers operating below 100 MHz are most easily implemented using a lumped-element approach. While the lumped element implementation has appeal for specific applications, there are some drawbacks. The most notable drawbacks are reduced power handling and temperature sensitivity. As future requirements evolve, these drawbacks can leave the lumped element coupler a step behind.

If designed properly, coupled line directional couplers can address these shortcomings. A traditional coupled line directional coupler requires two transmission lines in close proximity to one another to achieve desired coupling at the center frequency. The transmission line length is typically a quarter wavelength. Figure 1 is a common schematic representation of a coupled line directional coupler. The coupling factor is a function of the line impedances, separation “s” and transmission line length “L.”

The single drawback of a distributed backward wave directional coupler is the “quarter-wave syndrome.” This occurs when the operating frequency is low, causing the physical component size to approach the size of a finished PCB. For example, a 30 MHz quarter wavelength microstrip transmission line on Alumina is roughly 1 meter! Not only is this quite large (and not surface mountable), but this transmission line section would introduce approximately 1.0 dB of insertion loss. With an input of 100 W, more than 20 W would be dissipated in the coupler!

The intent of this paper is to describe a method to “right-size” a low-frequency (<1 GHz) coupler in a pick and place, surface mount package. Although not discussed in this paper, this method can also be used at higher frequencies to increase the usable coupler bandwidth. It is assumed the reader has basic understanding of coupled line theory. For more information on coupler theory, the reader is encouraged to study a reference text such as *Microwave Engineering* by David Pozar.

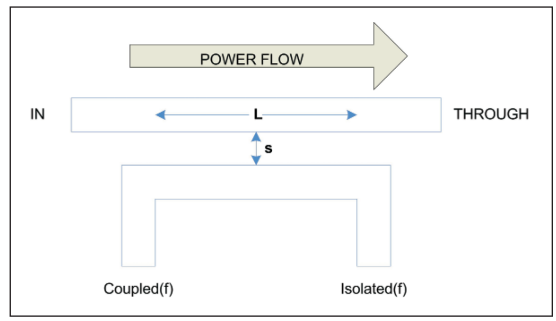


Figure 1 · The basic coupled-line directional coupler

In the 100 MHz to 500 MHz band, Figure 2 and Figure 3 describe the effect of coupling section length on coupler performance. This specific example is a thick-film, symmetrical, edge-coupled directional coupler printed on 0.025" Alumina. The line lengths in the legend are referenced to a fraction of a wavelength at the center frequency of 300 MHz (λ ~38 cm). Predictably, as the line length increases, the mean coupling increases and wide-band directivity degrades. As the line length increases, the coupling response becomes more flat until the length approaches a quarter wavelength at center frequency where the coupling response is optimized (see Fig. 2). This family

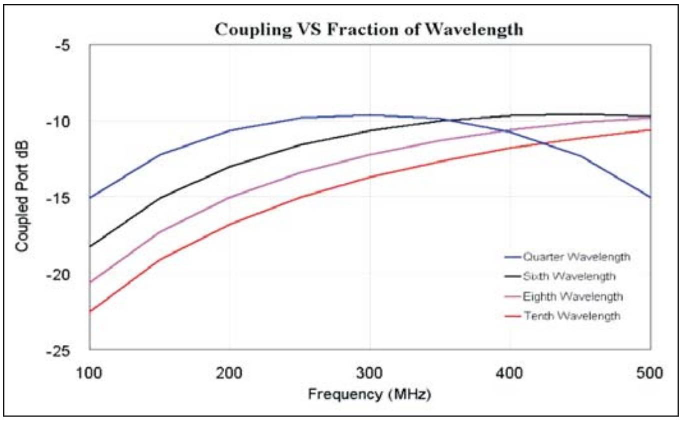


Figure 2 · Coupling vs. coupled line length.

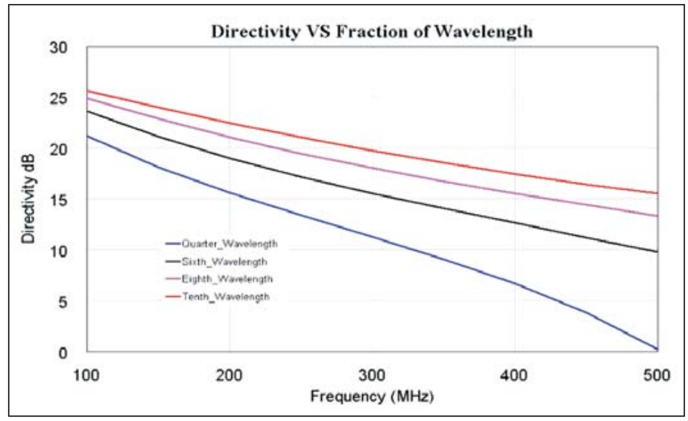


Figure 3 · Directivity vs. coupled line length.

of curves was generated by simulating a parametric sweep of the coupling section length "L" using a 2-1/2D EM solver. This simulation data correlates well with measured data.

For narrow-band applications, the family of curves in Figure 2 may not pose a problem; however, applications utilizing wider bandwidths will require a flatter coupling response.

Design Method

To compensated the undesirable coupling flatness of the coupled port, a frequency selective circuit, such as a filter or equalizer, can be cascaded with both the coupled port and isolated port. Figure 4 below is a block diagram of the concept. For this case, both equalizer frequency responses are identical to maintain coupler symmetry. This permits the compensated coupler to be used in a bi-directional application.

The equalizing network can take on many shapes. The goal of the equalizer is to provide the inverse frequency response to that of the coupler frequency response. To synthesize the equalizing network, $H(f)$, the coupled response must be characterized and deterministic. This is best accomplished through characterizing the stand-alone coupler using a VNA, however, this may not be the most practical approach. With some care, the coupler frequency response can be can be characterized with EM modeling.

To demonstrate this method, let's set realistic coupler design targets for the 100 to 500 MHz band. Assume the PCB layout constraints require the solution to occupy as little board space as possible, including peripheral components. Also, the circuit design requires the coupling to be –32 ±2.5dB, at least 13 dB of directivity and insertion loss <0.5 dB.

Refer to the set of curves in Figure 2. The $\lambda/4$ and $\lambda/6$ coupling sections have a stand alone directivity that is below the design requirements, so these line lengths will not meet the goals. The remaining lengths are $\lambda/8$ and $\lambda/10$. In order to minimize space, we must choose the shortest section possible. Therefore, this example will continue using the $\lambda/10$ section. PCB space is a critical requirement for this design, so a first order response will be synthesized to minimize component count. Practically speaking a higher order equalizer ($n > 1$) to represent an inverse function may be required which will require a slightly more complex equalizer synthesis. The exact equalizer requirement is dictated by the maximum allowable error and board space to accommodate supporting components.

Figure 5 is a plot of a 1/10 wave-

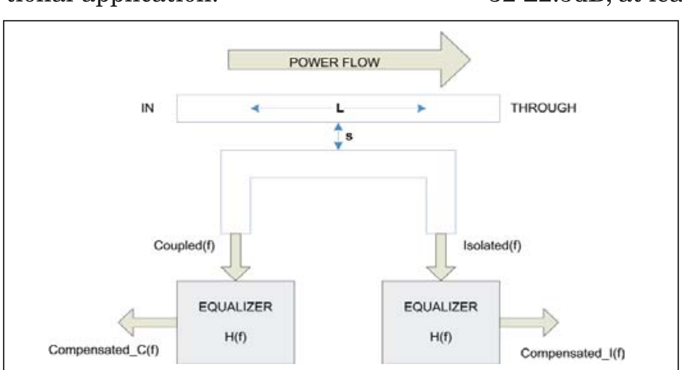


Figure 4 · Coupler diagram showing the additional equalizer sections.

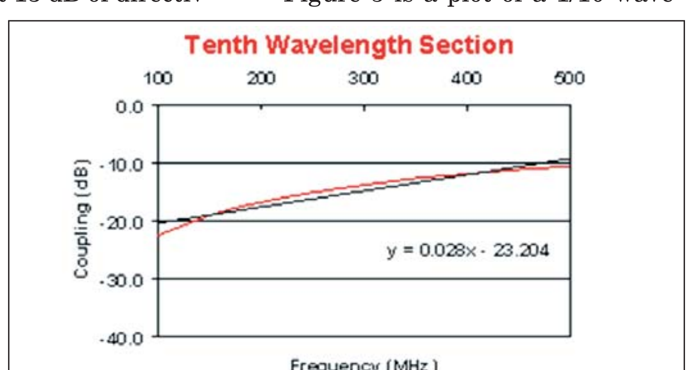
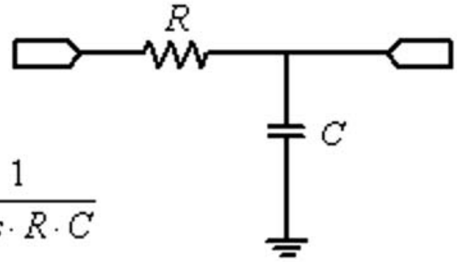


Figure 5 · The $\lambda/10$ line coupling response and nearest straight line.



$$H(s) = \frac{\frac{1}{R \cdot C}}{s + \frac{1}{R \cdot C}} = \frac{1}{1 + s \cdot R \cdot C}$$

Figure 6 · Equalizer section and its transfer function.

length stand-alone coupler. Referring to Figure 5 the best fit linear approximation of the 1/10 wavelength coupler is: Coupling(f) = 0.028 f – 23.2, where f is in MHz and Coupling(f) is in dB. The inverse slope of this curve is easily obtained by negating the slope of the coupled response. In this case, the slope requirement of the equalizer is –0.028 dB/MHz (lowpass).

In Figure 5, notice the slope of the coupled response. Extrapolating the measured coupling performance to 1 GHz and calculating a linear approximation for this extrapolated curve yields a slope approaching +20 dB/decade. This is the same rate of roll off as a single pole, positive slope RC-equalizer.

A compensating RC network will be used to flatten the coupling slope. The network and Laplace transfer are depicted in Figure 6. To meet the design requirements, R is chosen to be 51Ω and C is chosen to be 82 pF, which are standard values.

In the frequency domain, the compensated coupled response of Figure 4, compensated_C(f), is determined by multiplying the two cascaded transfer functions.

Since the linear fit is in units of dB/Hz, the compensated response can be reduced to a simple mathematical addition of dBs in the frequency domain. This is represented graphically in Figure 7. The associated directivity and insertion loss of the compensated coupler can be seen in Figure 8.

Care must be taken when implementing this technique. For obvious reason, circuit layout is critical. Also, the resistor and capacitor selection is critical and be positioned properly on the PCB. The resistor used in the equalizer will dissipate energy and must be chosen to withstand the anticipated power dissipation. The capacitor must be a very stable dielectric to ensure the equalizer response is temperature invariant.

The most robust, flexible and cost effective implementation is a thick-film surface mount coupler. The coupling section and resistor can be screen printed to maintain the line resolution required to for a consistent, re-producible design. Further, the substrate and conductive material can be optimized for the application, allowing power ratings of up to 200 W while keeping the insertion loss less than 0.5 dB.

Author Information

Rob Torsiello earned a BSEE from the University of Central Florida and is currently pursuing a PhD in Communication Theory. Rob's career has carried him from communication equipment development through RF component design, where he is now an Engineering Manager for EMC Technology and Florida RF Labs, based in Stuart Florida. He can be reached by e-mail at: rtorsiello@rflabs.com, or by telephone at 772-600-1637

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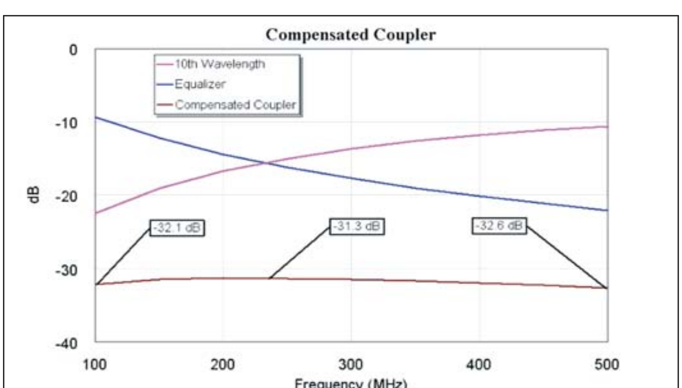

Figure 7 · Calculation of final response by addition of coupler and compensation circuit responses.

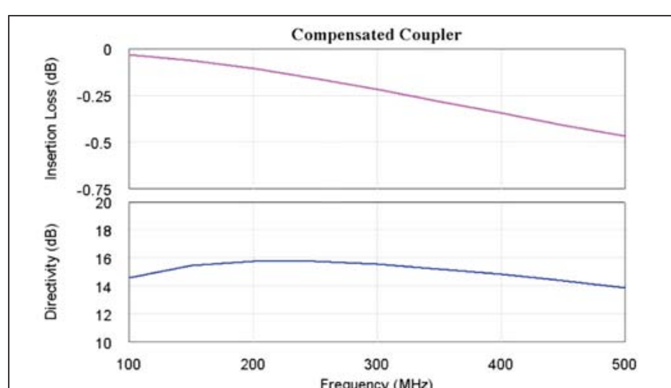

Figure 8 · Insertion loss and directivity performance of the final compensated design.