Simple SMT Bridge Circuit Mimics Ultra-Broadband Coupler

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Directional couplers are often used in microwave systems to sample or combine signals, and an RF version can be quite useful. Traditional microwave couplers are only a few octaves wide, and are unsuitable for the many decades of frequency range used in the RF world. RF transformers are generally not useful up to the GHz frequency range. The design presented here is a unique implementation of a resistive (Wheatstone type) bridge, with loss, coupling and directivity closely matching coupler characteristics over a frequency range of kilohertz to gigahertz. This circuit was entered in the 1991 RF Design Awards Contest.

Directional couplers have the characteristics of low loss in the through path, flat frequency response in the coupled path, and high isolation in the reverse coupling path (directivity), Figure 1. Ideal couplers are lossless, that is, no energy is absorbed in the coupler. An ideal, lossless coupler with 16 dB coupling factor would have only 0.11 dB of loss. In practice, all couplers have through arm loss. For applications other than high power, this loss, often about 1 dB, is acceptable. These applications include power leveling, and signal sampling for phase- and frequency-locked loops.

The Resistive Bridge

The two key characteristics of directional couplers, as the name implies, are the ability to sample (or couple) signal flow, and to do so in only one direction. A resistive bridge, if driven in the proper way, also has this directional property. Figure 2 shows a bridge structure. A sample of the drive voltage is present across each resistor. If the bridge is balanced, $R_1 \times R_3 = R_4 \times R_5$, then no voltage appears across R_2. For balance, a bridge often has all the resistors the same value, say 50 ohms, but balance only requires that the ratios of each string be equal ($R_1/R_5 = R_4/R_3$).

Figure 3a shows a bridge with non-symmetric resistors, driven in the forward signal flow direction. In this case the voltages across certain nodes have been labeled consistent with the coupler in Figure 1. For the resistors chosen, V_{coup} is 16 dB down from V_{p1} (16 dB coupling), and V_{p2} is 1.5 dB down from

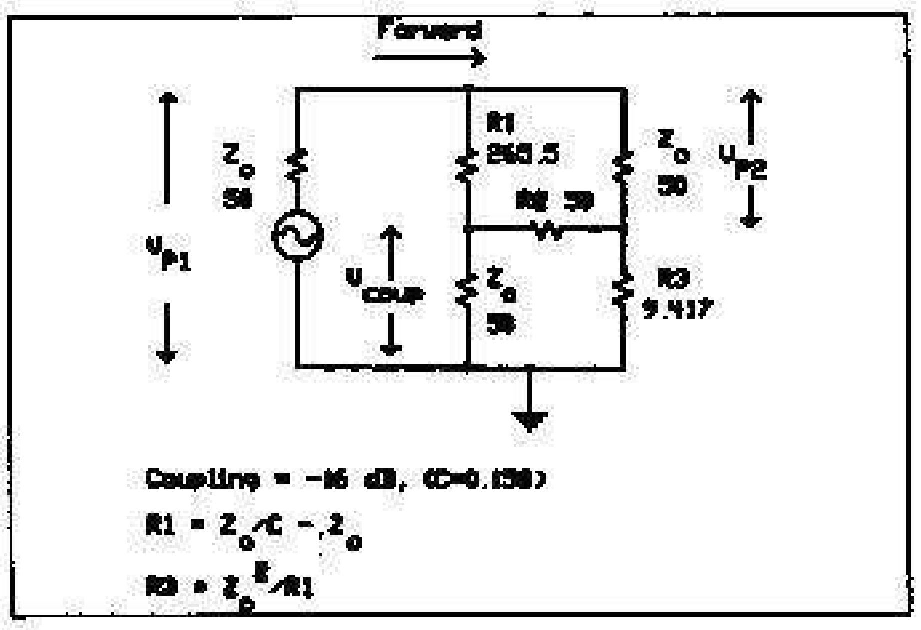


Figure 3a. Bridge/coupler driven in the forward direction.

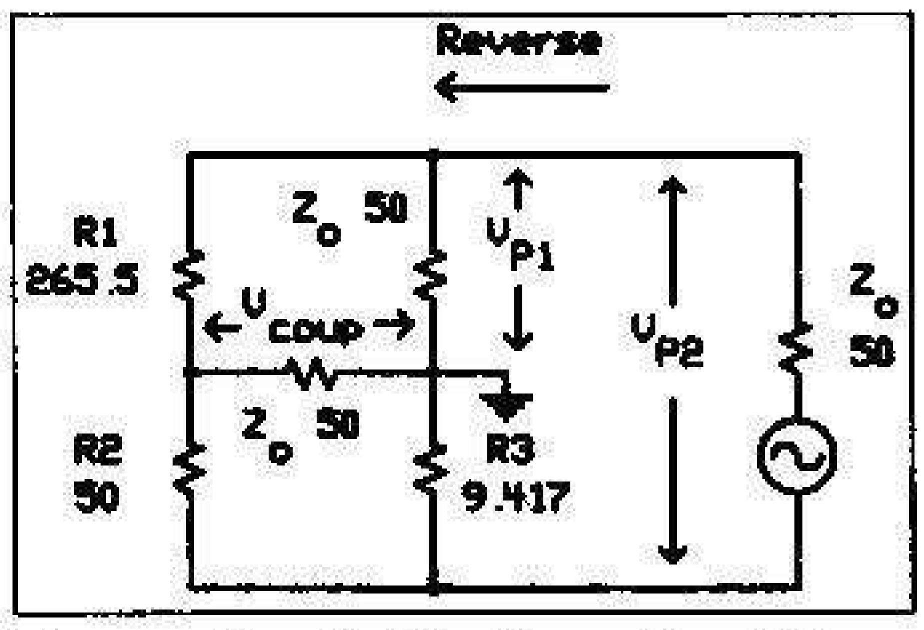


Figure 3b. Bridge/coupler driven in the reverse direction. Note that V_{coup} is across the balanced node.

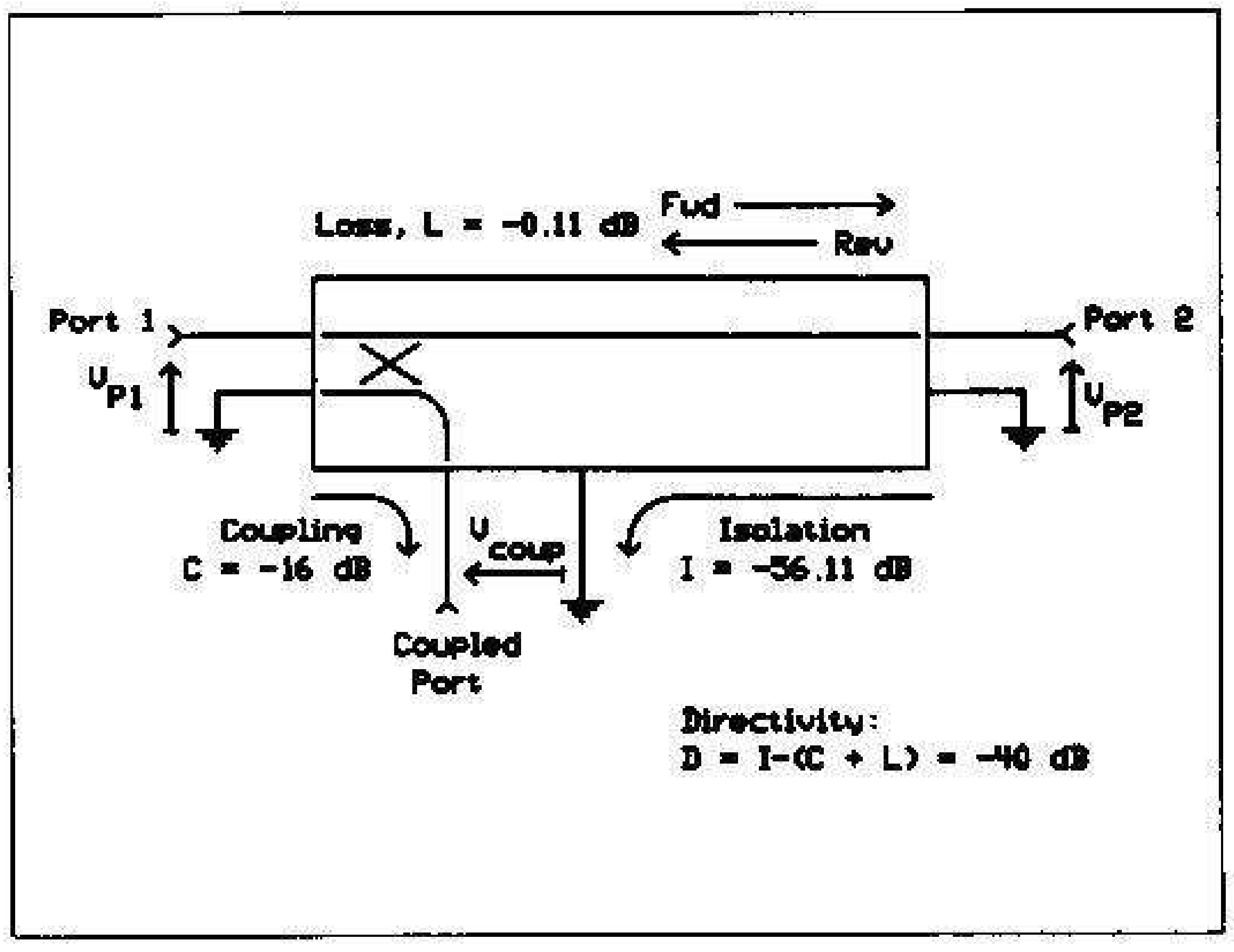


Figure 1. Definition of terms for a directional coupler.

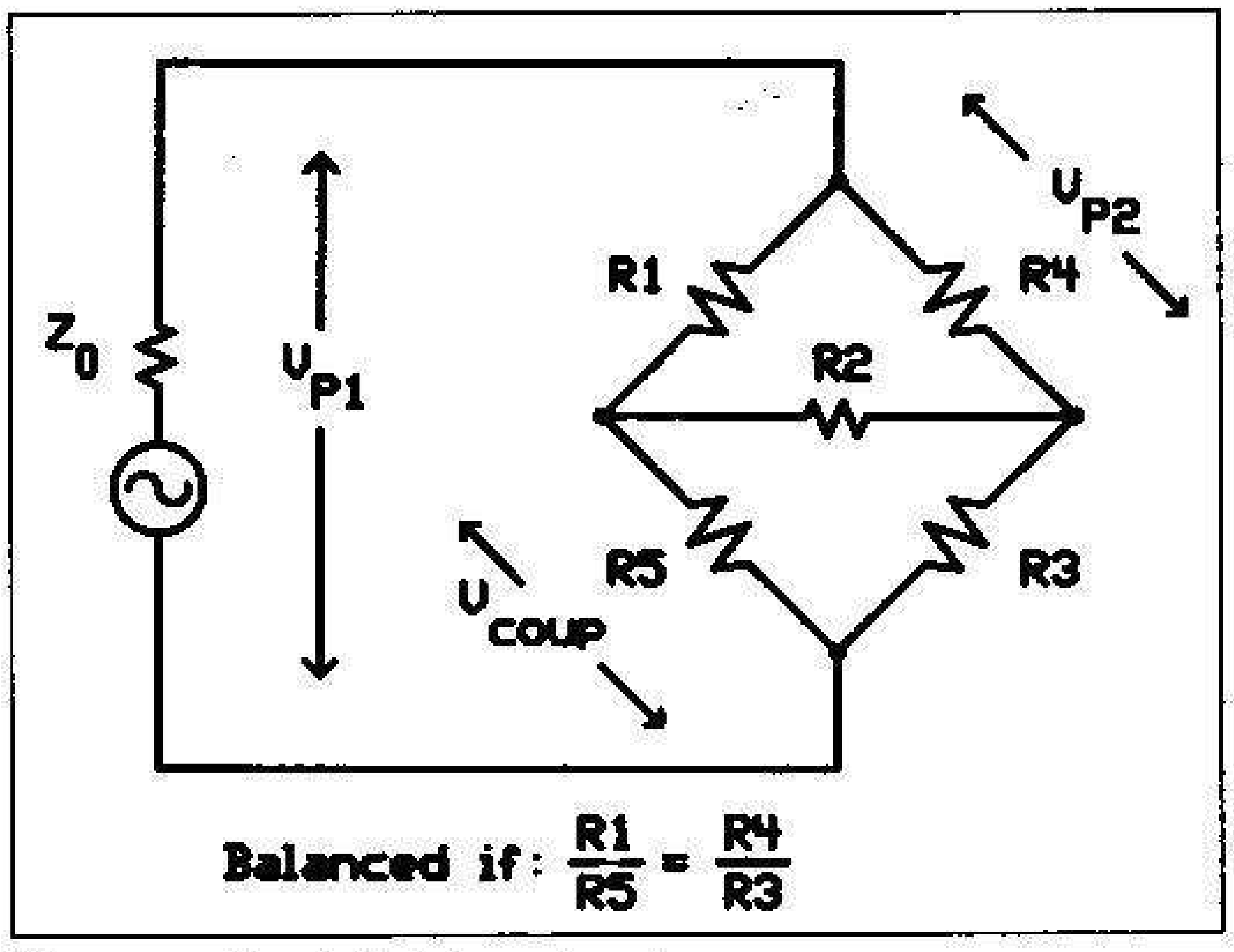


Figure 2. Basic bridge structure.

V_{p1} (1.5 dB loss). The equations shown in Figure 3a demonstrate how to calculate resistance values for any coupling factor. The directional nature of the bridge is demonstrated by redrawing the figure to put a voltage source in series with the V_{p2} resistor, and "stretching" the remaining elements about to achieve Figure 3b. Note that none of the connections have been changed, except moving the drive voltage from port 1 (V_{p1} resistor) to port 2 (V_{p2} resistor). Drawn this way, it is easy to see that no voltage appears across the coupler port (V_{coup} = 0), as the bridge is balanced when driven in this fashion.

In the RF implementation of this bridge, the V_{p1} resistor represents the port 1 impedance (50 ohms in this case), the V_{coup} resistor represents the coupled port impedance, and V_{p2} resistor represents the port 2 impedance. The difficulty with this structure is that port 2 must be isolated from ground; this may be accomplished with a transformer of some sort. Figure 4 shows a diagram of the bridge, with the port 1 and coupled port represented by coaxial transmission lines, and port 2 isolated by a transformer. The 1:1 transformer may be realized in a clever way by using a ferrite loaded coaxial transmission line balun.

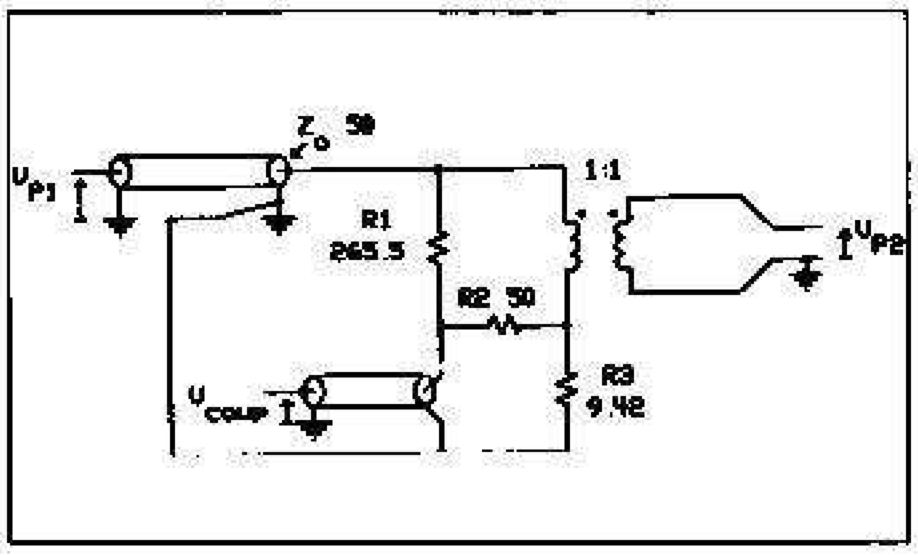


Figure 4. Bridge/coupler realization with coax ports on port 1 and coupled port and transformer on port 2.

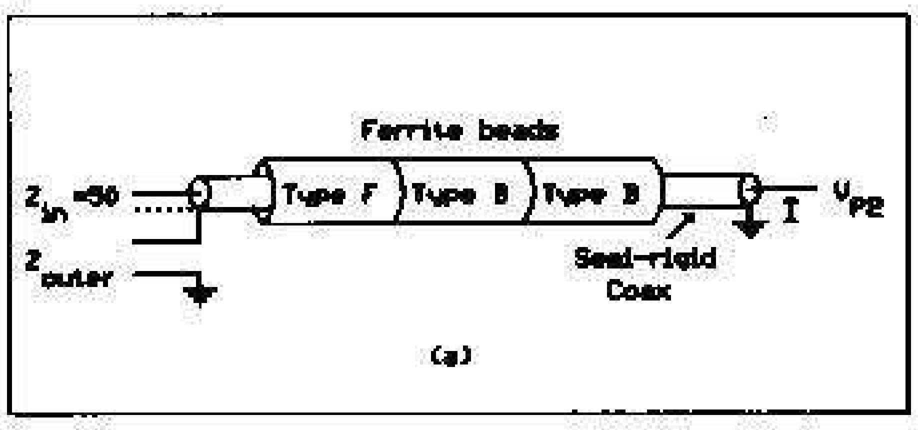


Figure 5a. Coax balun.

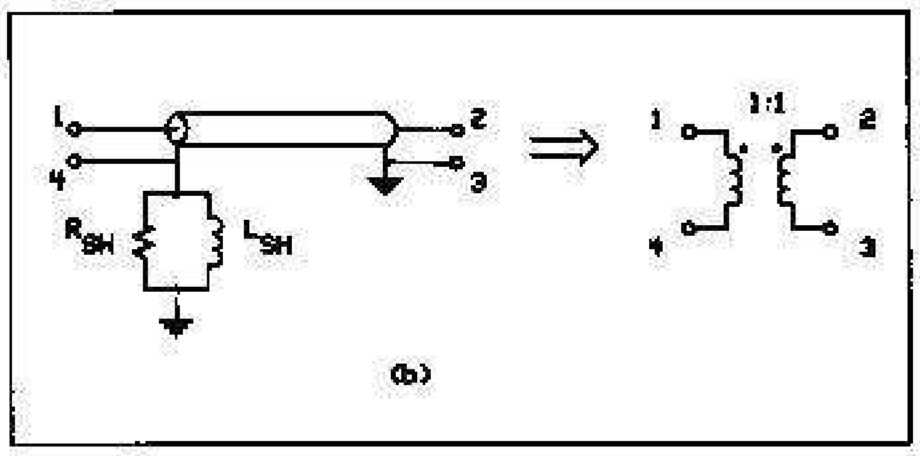


Figure 5b. Coax balun implementation of a 1:1 transformer showing parasitic shunt impedance.

Coax Balun Structure

The implementation of the 1:1 transformer might use a simple wire-wound core, but the low frequency response is limited by the mutual inductance, and it is difficult to maintain a constant impedance at high frequency. The 1:1 transformer function can be approximated by using a length of coaxial cable, with a ferrite bead on the outer conductor, Figure 5a. This forms a balun, which has a constant 50 ohms impedance from the inner to outer conductor. One or more

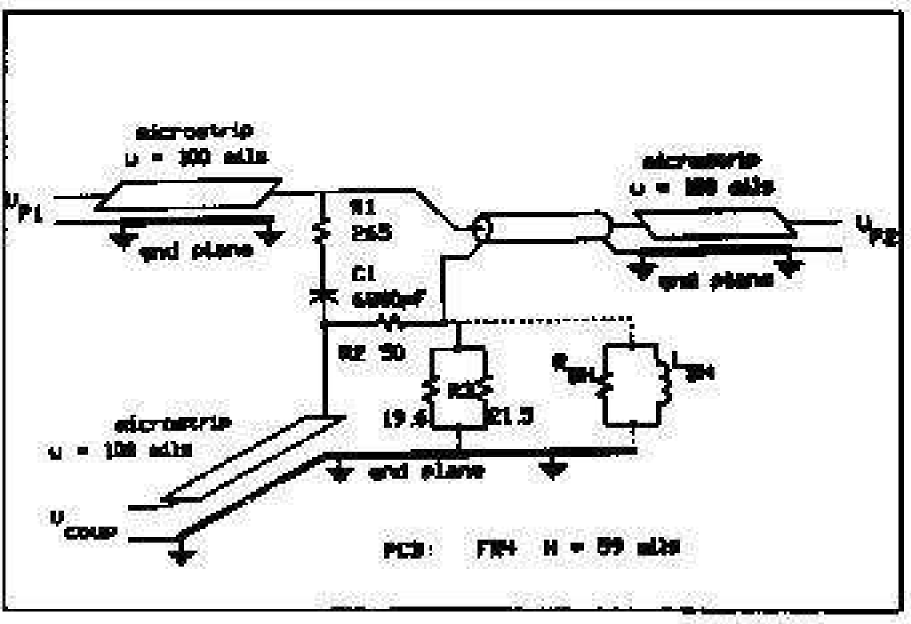


Figure 6. Final microstrip implementation of the bridge coupler.

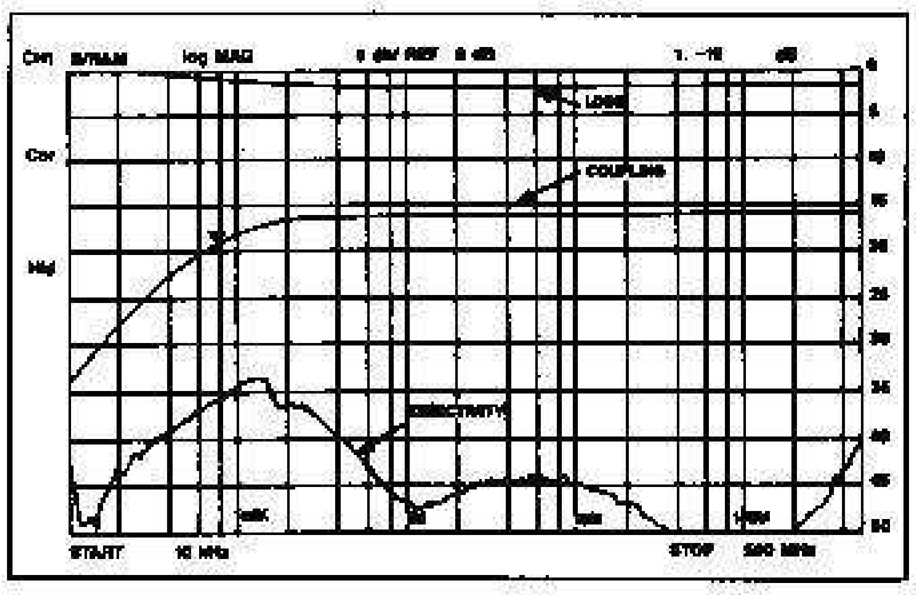


Figure 7. Low frequency response of the bridge/coupler.

ferrite beads raises the impedance of the outer conductor to ground by the impedance of the bead. In the bridge structure, this is a parasitic impedance which may be modeled as a resistor in parallel with an inductor, from the outer conductor to ground, Figure 5b. In the implementation used, the beads were of varying inductive index, with one Ferronics type F bead (#21-083-F), and three type B beads (2 of 21-129-B, and 1 of 21-083-B). These beads were chosen because they fit on standard 0.086 semi-rigid coax. Varying the inductive index allows using a high frequency, low permeability (μ) bead (type F) near the bridge structure, with a low frequency, high μ bead following to raise the low frequency inductance.

The final implementation of the circuit is shown in Figure 6. Here, micro-strip transmission lines are used for port 1 and the coupled port. The coax balun described above is used as the 1:1 transformer to port 2. Surface mount resistors are used for the resistive elements. Note here that the 9.4 ohm resistor (R3) is replaced with two resistors in parallel, with values of 19.6 and 21.5 ohms. The parasitic effect of the ferrite beads on the outer conductor is shown connected across R_3 by dotted lines.

Another addition to the final implementation is a capacitor, C_1, in series with R_1. It will block DC from the main arm path, such that no current will flow in the resistors of the bridge. This is important as some situations may have DC bias at the center conductor of the main arm, such as at the output of an amplifier. In the actual implementation, C_1 was chosen to be the standard value of 6800 pF.

Figure 7 shows the low frequency performance of the bridge/coupler on a log frequency scale. It is remarkable that the directivity remains better than 30 dB down to 100 kHz. The "bump" in the low end directivity is due to changes in inductance of the ferrite beads. It may be reduced by selecting a better value for C_1. Above 300 kHz, the directivity is better than 40 dB to 500 MHz.

The loss and coupling are also shown,

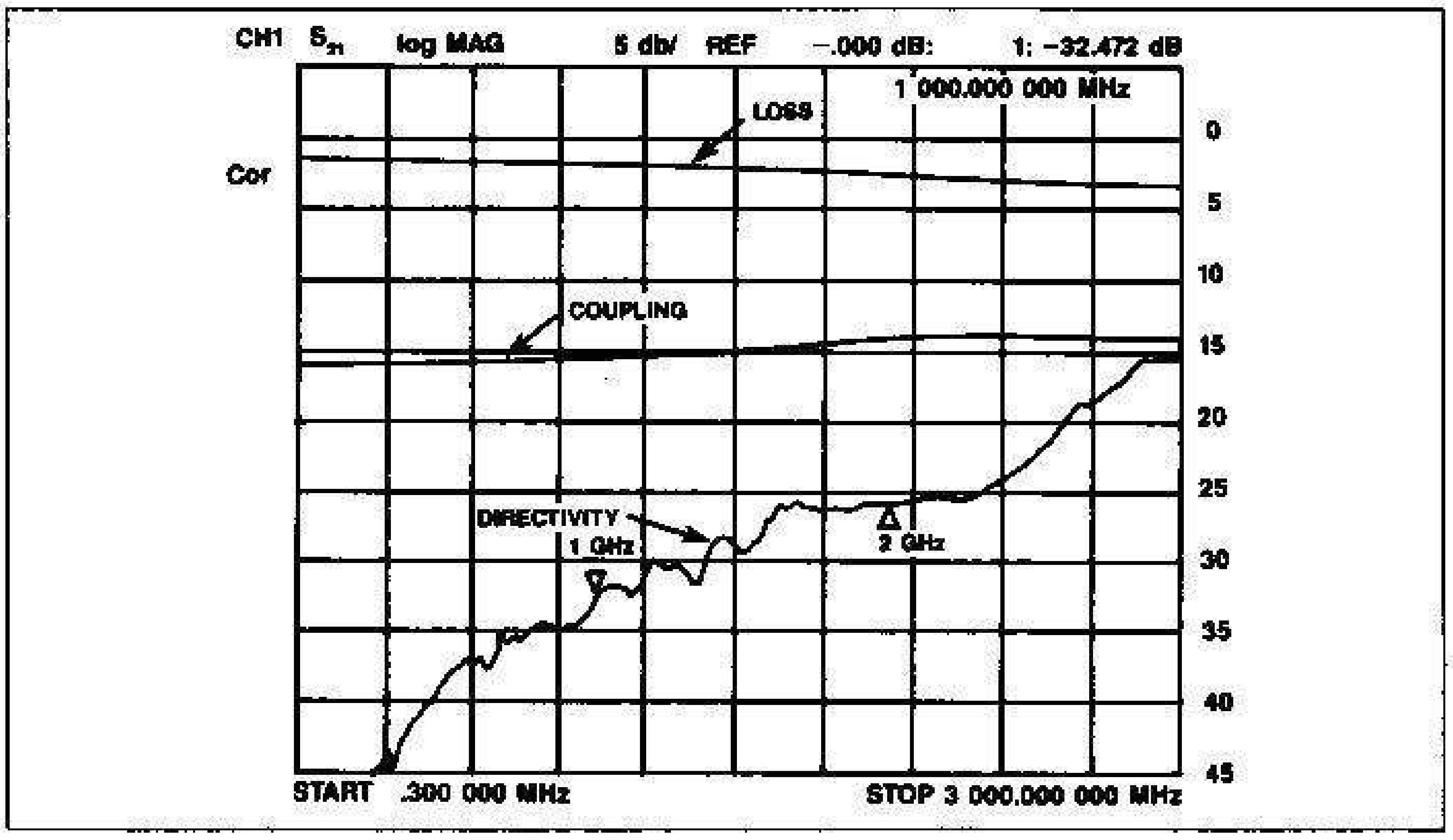


Figure 8. High frequency response of the bridge/coupler.

Figure 9. Photo of completed SMT bridge circuit.

in the range of 300 kHz to 500 MHz, there is less than 0.25 dB of rolloff in the through path, and less than 0.5 dB of rolloff in the coupled path. The -3 dB rolloff in the coupled path is below 80 kHz.

Figure 8 shows the high frequency performance of the bridge/coupler on a linear frequency scale. The coupling rolls up by about 1 dB above 1 GHz, and 2 dB above 2 GHz. The through loss increases by about .5 dB/GHz. The directivity remains quite good, even at high frequencies, with 32 dB directivity at 1 GHz, and 26 dB directivity at 2 GHz. I must admit, though, that a small piece of copper tape was used to tune out discontinuities of the input connector to improve the match. A measurement of the source match of the bridge/coupler revealed better than 30 dB match to 1 GHz, and better than 21 dB match to 2 GHz.

The power handling capability is determined by the maximum power dissipated in the SMT resistors. In this case, R_1 has the highest dissipation. For R_1 rated at 0.125 watts, the drive power may be 0.937 watts, or 29.7 dBm. Of course, larger or multiple resistors would increase the power handling capability.

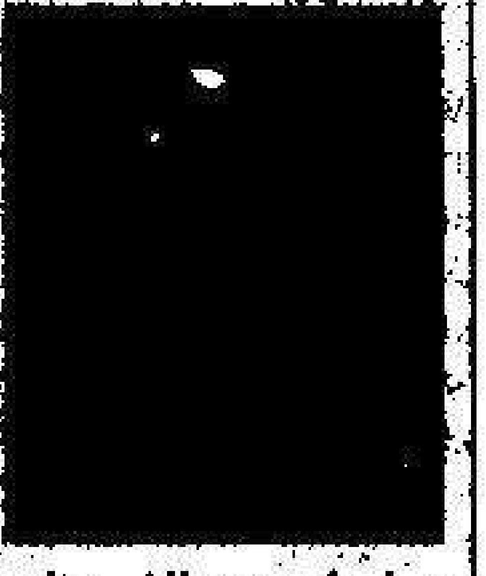
The bridge/coupler built with SMT parts, and using the standard available ferrites and coax line, can be built for less than $5.00, not including the connectors. Because it is built in PC board material, it can be integrated in an RF PC board for very low cost, while providing very nice performance.

The low frequency measurements were made on an HP 8751 Network Analyzer, and the high frequency measurements were made on an HP 8753C Network Analyzers.

Acknowledgements

I would like to thank Wayne Frederick for contributions to the thin film bridge detector which was the seed for a family of resistive bridge couplers. The ferrite beads were from Ferronics Inc. **RF**

About the Author



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