Interstage Coupling With an Edge-Coupled Line

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Cascading of active RF devices typically requires the use of a coupling capacitor as a DC block between stages. Unfortunately, this capacitor may exhibit reactive effects detrimental to circuit function. This article, an entry in the 1988 RF Design Awards contest, presents a simple technique for achieving interstage coupling in microstrip assemblies, which passes only the desired signal component and costs nothing but knife-blades. Performance of the proposed coupling circuit is evaluated, and a MMIC amplifier application example is presented.

The conventional method of coupling signals between active stages while blocking any DC bias component which might be present is illustrated in Figure 1. The coupling capacitor mounts to, and becomes part of, the transmission line connecting the stages. The chip capacitor employed is considered a short to RF, an open to DC and, for purposes of analysis, is treated as an extension of the microstripline on which it is installed. For this assumption to hold, it is vital that the installation of the chip cap not alter the characteristic impedance of the microstripline in any way.

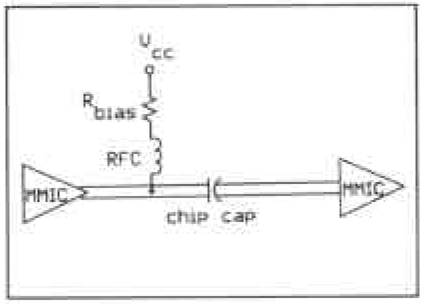

Figure 1. Typical capacitive interstage coupling network.

The single most critical parameter in determining microstrip characteristic impedance on a given substrate is trace width. If the impedance of the interstage coupling network is to remain constant, the physical width of the chip capacitor must match that of the microstrip on which it is installed. Impedance discontinuities caused by differences in widths will result in reflections, which may degrade stage gain, contort frequency response, increase intermodulation distortion, induce oscillation or, if taken to extremes, damage active devices.

Even a chip cap of optimal dimensions, however, is not without limitations. A capacitor need not have wire leads to exhibit inductance, and since a transmission line is often modeled as series L, shunt C, it can readily be seen that the additional series L of a chip cap can indeed alter microstrip characteristic impedance. Often, an attempt to minimize this impact is made by selecting the largest practical value of capacitance for a DC block, on the theory that this will swamp out any stray inductance in the chip. Unfortunately, because of the physical constraints of manufacturing multi-layer chip capacitors, the higher the value of capacitance, the higher the residual inductance is likely to be. The process is thus self-defeating.

One solution to the inductance problem is to design for self-resonance. Given the capacitor dimensions required to physically match a given strip, it is possible to calculate the residual inductance of the component. To accomplish this, a capacitance value which will resonate with that particular inductance at the operating frequency is selected.

For example, a 50 ohm microstrip on 1/16 in. fiberglass-epoxy circuit board is roughly a tenth of an inch wide. A chip cap in a 1/10 in. cube should exhibit perhaps 0.5 nH of inductance. At a frequency of 1 GHz, this represents approximately +j3 ohms of reactance. This is not much, but it can be negated by selecting a capacitor with −j3 ohms of reactance, which at 1 GHz works out to about 53 pF. A 50 pF, 0.1 in. cube chip cap is not an atypical choice for 1 GHz interstage coupling.

Even if a chip capacitor of proper dimensions, with negligible inductance, is selected, the fact remains that capacitive reactance varies inversely with frequency. Thus any capacitive interstage coupling network is, unavoidably, a high-pass filter. This can only serve to degrade the harmonic content of any signal being processed. Since nonlinearities in active devices always generate harmonic distortion, it appears that, in the interest of spectral purity, what may actually be desired is not a high-pass but a low-pass coupling network. For narrow-bandwidth applications, a bandpass response would be even better.

Resonator Coupling

Consider the popular edge-coupled microstrip bandpass filter, shown in Figure 2. The circuit, which passes a narrow band of frequencies centered on its resonant frequency, provides significant harmonic suppression and (most important here) affords a DC block between input and output. If properly designed, such a circuit maintains a uniform characteristic impedance across

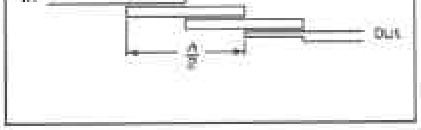

Figure 2. Edge-coupled microstrip bandpass filter.

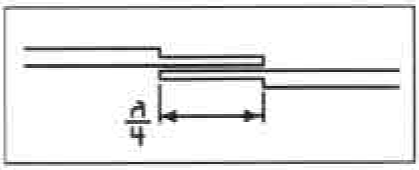

Figure 3. Edge-coupled interstage coupler provides DC blocking, with uniform impedance and low insertion loss over a narrow range of frequencies.

its operating band. Further, it contains no components other than those etched on the substrate; thus its only cost is in circuit board real estate.

That is, however, a significant cost. The individual resonators are each one-half wavelength, and they are overlapped at their midpoints, creating a rather sprawling structure. The number of poles of filtering employed is a function of the required filter Q. For interstage coupling applications, where the coupling network is not depended on for primary control of frequency response, real estate can be conserved by making the number of resonators small, or even zero.

Resonator-Less Coupling

Notice in Figure 2 how coupling into and out of the half-wave resonators was achieved. Edge coupling is accomplished with a quarter-wave matching section, narrower (thus with a higher characteristic impedance) than the input and output lines. This section can be thought of as a quarter-wave matching transformer, with its characteristic impedance the geometric mean of the low impedance of the system and the considerably higher impedance of the resonator.

Why can't two such matching sections couple into each other? They can, of course, as shown in Figure 3. Seen here is an impedance step from the system impedance (say 50 ohms) up to a higher coupling impedance, then back down through an identical section to the system impedance again. Note that the entire coupling circuit occupies only a quarter-wavelength of board space, has a moderate Q response centered on some design frequency, and maintains DC isolation between input and output.

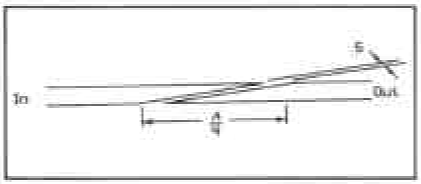

Figure 4. Tapered, edge-coupled resonator provides DC blocking and interstage coupling over a one octave bandwidth.

The Tapered, Edge-Coupled Resonator

The coupling structure described above shares two major drawbacks with all quarter-wave matching transformers. It is effective only for continuous trains of waves (not for pulses), and it functions only over a fairly narrow range of frequencies, centered on the design frequency. For applications requiring wider bandwidths (such as typical interstage coupling), the favored solution has long been the tapered matching section. By gradual transitioning between impedances to be matched, reasonable performance can be achieved over perhaps an octave of bandwidth. And there is no reason not to edge-couple between tapered transformers, just as was done for quarter-wave sections.

The basic topology proposed for interstage coupling is illustrated in Figure 4. Two quarter-wave, tapered, matching transformers are edge-coupled at distance s. The exact spacing is not particularly critical. Loose spacing increases both Q and insertion loss, so for wideband, low-loss coupling, a narrow dimension for s is indicated. For the previously described 50 ohm line on 1/16 in. glass epoxy, the line width is about 2.5 mm, and a spacing of about 0.1 mm is acceptable.

By no coincidence whatever, a tenth of a millimeter is about the thickness of a razor blade cut! This means that once a 50 ohm trace is etched, the coupling network can be fabricated directly on the pc board with a straight edge and an

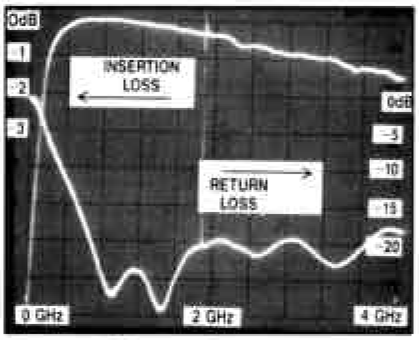

Figure 5. Swept frequency response of a coupling capacitor, self-resonant at 2 GHz.

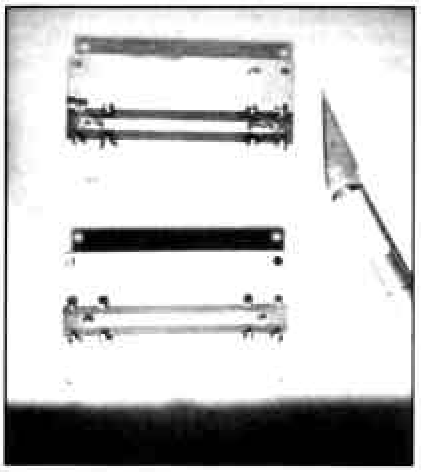

Figure 6. Test substrates before (top) and after (bottom) making the required blade cut.

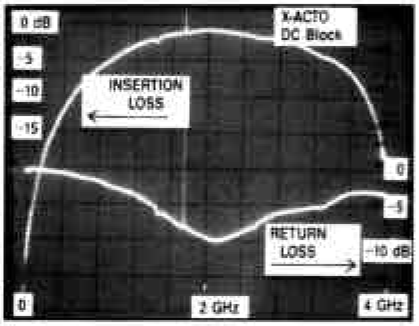

Figure 7. Swept response of the test coupler.

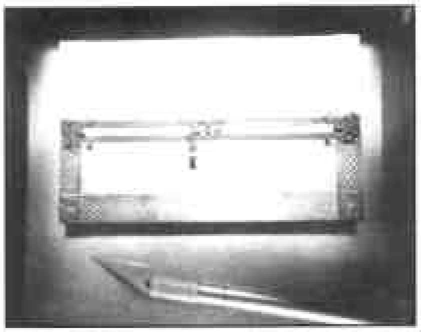

Figure 8. 1.5 GHz MMIC amplifier uses an Avantek MSA-0285.

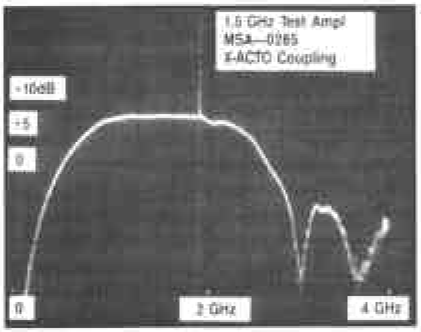

Figure 9. Swept gain response of the MMIC amplifier.

"approxo" knife (there's nothing exact about it).

Even-Harmonic Rejection

The tapered, edge-coupled resonator just described exhibits DC isolation and low insertion loss across a fairly broad band, centered on the frequency at which the tapered sections are a quarter-wave long. But what happens as frequency increases to, say, twice the design frequency? At f times 2, the coupled lines are a half-wave long, and parallel (i.e., not staggered) half-wave coupled lines exhibit a null. Since this null repeats for even multiples of a quarter-wave, it can be seen that the proposed coupling structure actually rejects all even harmonics. Thus, interstage coupling through quarter-wave, edge-coupled resonators has the hidden advantage of improving spectral purity.

Test Results

In order to establish a baseline for comparison, two identical 50 ohm microstriplines, each 3.5 cm long and terminated in SMA connectors at both ends, were fabricated from 0.059 in. thick fiberglass-epoxy printed circuit stock. The residual insertion loss of each was measured as 0.5 dB at 2 GHz. A self-resonant chip capacitor was installed in one microstrip, and swept measurements performed as shown in Figure 5. Note that the additional insertion loss of the capacitor at its resonant frequency is negligible, and that return loss is greatest at resonance.

Next, a knife cut, visible in Figure 6, was made in the other test substrate, to provide a DC block as described above, resonant at 2 GHz. Swept response indicates about 0.5 dB of additional insertion loss, and return loss which indeed optimizes at 2 GHz, although reflections are more pronounced than in the previous case. It is probable that varying the thickness of the knife cut will result in an optimum level of coupling, which should improve the observed return loss. Note the obvious dip at 4 GHz seen in Figure 7, indicating the expected null at twice the design frequency. The edge-coupled resonator performs about as expected.

Design Example

To verify the effectiveness of the proposed coupling device, a MMIC amplifier was built, with input and output coupling by knife cut, a quarter-wave long at 1.5 GHz. The test amplifier is shown in Figure 8, and its swept response in Figure 9. Again, the null at twice the design frequency is quite evident.

Conclusions

A simple knife cut on a microstripline can perform interstage coupling between active devices, afford a DC block, and provide a modicum of selectivity at virtually no cost. Although it is doubtful the technique will ever replace the ubiquitous chip capacitor, it functions as expected, and appears worthy of further study. rf

About the Author

Paul Shuch is founder and chief engineer of Microcomm, 14908 Sandy Lane, San Jose, CA 95124. He heads the Microwave Technology Program at San Jose City College, where he can be reached at (408) 288-3722. He will be spending the 1989-90 academic year as Hertz Fellow in Transportation Engineering at the University of California, Berkeley, where he will further the aviation safety research introduced in the May 1988 issue of *RF Design*.