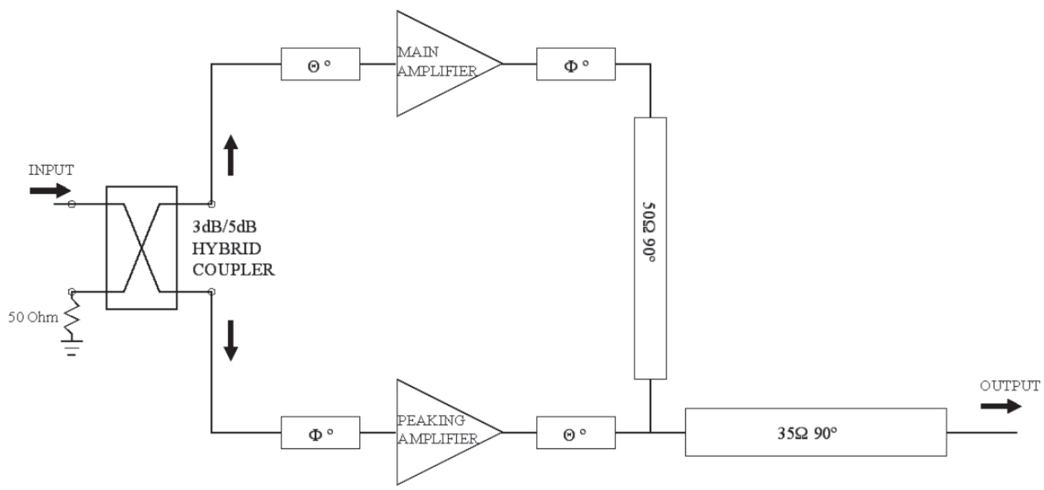
Design Considerations for Surface Mount Couplers

2-Way Splitter for Doherty Power Amplifier

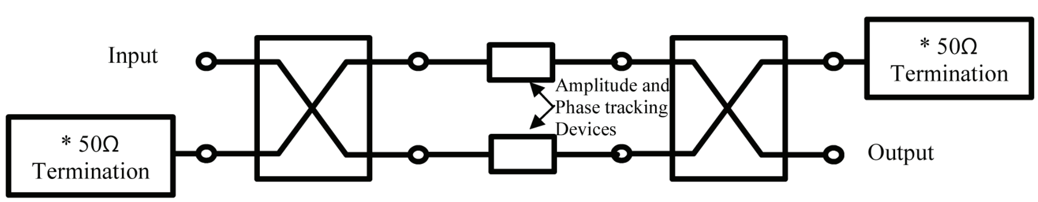


Hybrid coupler can be used in Doherty power amplifier to split the input power into the desired power ratio and phase delay. In above symmetrical Doherty power amplifier (main and peaking amplifier delivers equal amount output power at max drive condition), 3dB hybrid splits the input power into 1:1 ratio with 90 degree phase difference.

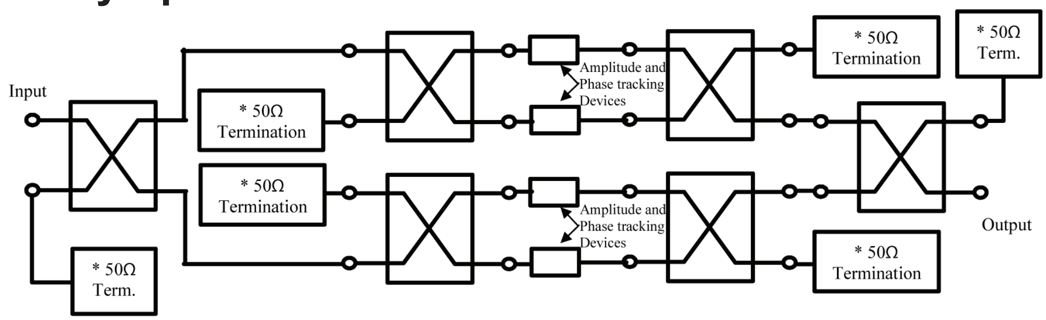
When the peaking amplifier is off, or when peaking amplifier is dramatically different than main amplifier due to bias, matching, difference between transistors, the 3dB hybrid coupler does not see equally unmatched termination, the mismatch is then reflected not only to isolated port, but also shows up at input port as return loss mismatch.

5dB hybrid splits the input power into 1:2 ratio with 90 degree phase difference. It can be used in asymmetrical (1:2) Doherty power amplifier architecture as splitter. 5dB hybrid is also used in some symmetrical Doherty power amplifier to compensate the gain difference between main and peaking amplifiers. It is worth noting that 3dB and 5dB hybrid react differently to the termination mismatch, resulting in different return loss at input port.

2-Way Splitter/Combiner Network



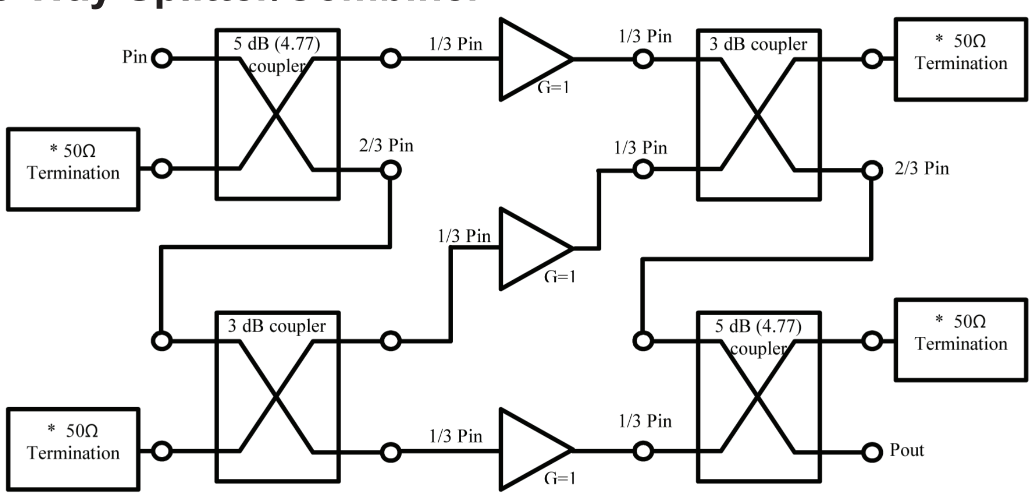
4-Way Splitter/Combiner Network



The splitter/combiner networks illustrated above use only 3dB (hybrid) couplers and are limited to binary divisions (2 number of splits, where n is an integer). Splitter/combiner circuits configured this way are known as "corporate" networks. When a non-binary number of divisions is required, a "serial" network must be used. Serial networks can be designed with [3, 4, 5, ….., n] splits, but have a practical limitation of about 8 splits.

A 5dB coupler is used in conjunction with a 3dB coupler to build 3-way splitter/combiner networks. An ideal version of this network is illustrated below. Note what is required; a 50% split (i.e. 3dB coupler) and a 66% and 33% split (which is actually a 4.77dB coupler, but due to losses in the system, higher coupler values, such as 5dB, are actually better suited for this function). The design of this type of circuit requires special attention to the losses and phase lengths of the components and the interconnecting lines. A more in depth look at serial networks can be found in the article "Designing In-Line Divider/Combiner Networks" by Dr. Samir Tozin, which describes the circuit design in detail and can be found in the White Papers Section of the Anaren website, www.anaren.com.

3-Way Splitter/Combiner

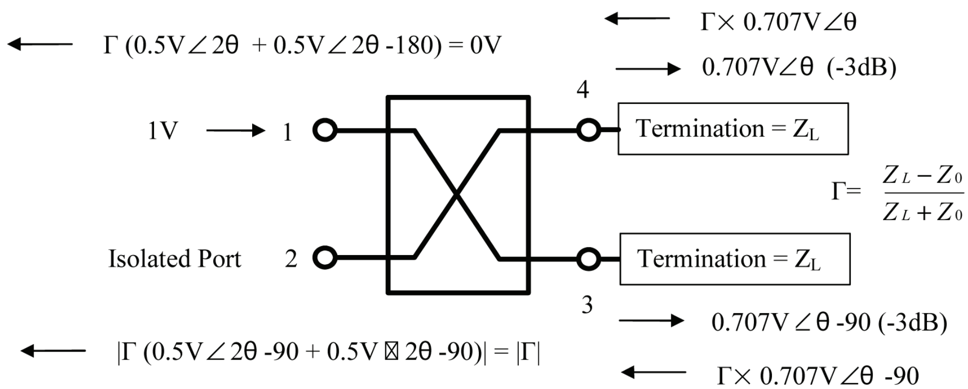


***Recommended Terminations**

Power (Watts)	Model
8	060120A15Z50-2
10	C10A50Z4
16	C16A50Z4
20	C20N50Z4
50	C50A50Z4
100	C100N50Z4
200	C200N50Z4

Reflections From Equal Unmatched Terminations

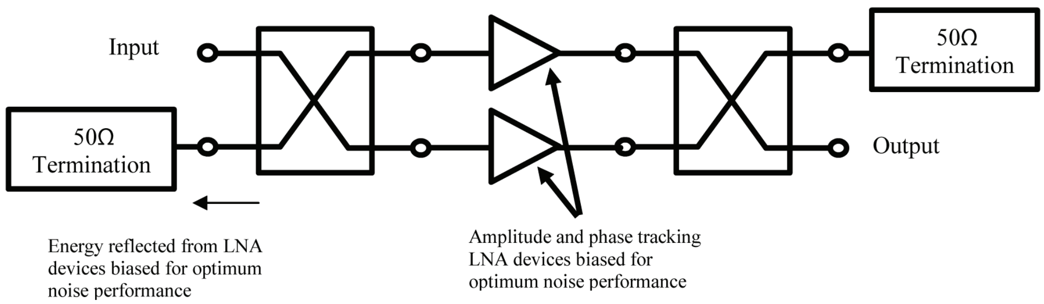
Referring to the illustration below, consider the following reflection properties of the 3dB coupler. A signal applied to port 1 is split and appears at the two output ports, ports 3 & 4, with equal amplitude and in phase quadrature. If ports 3 & 4 are not perfectly matched to 50Ω there will be some signal reflected back into the coupler. If the magnitude and angle of these reflections are equal, there will be two signals that are equal in amplitude and in phase quadrature (i.e. the reflected signals) being applied to ports 3 & 4 as inputs. These reflected signals will combine at the isolated port and will cancel at the input port. So, terminations with the same mismatch placed at the outputs of the 3dB coupler will not reflect back to the input port and therefore will not affect input return loss.



The reflection property of common mismatches in 3dB couplers is very beneficial to the operation of many networks. For instance, when splitter/combiner networks are employed to increase output power by paralleling transistors with similar reflection coefficients, input return loss is not degraded by the match of the transistor circuit. The reflections from the transistor circuits are directed away from the input to the termination at the isolated port of the coupler.

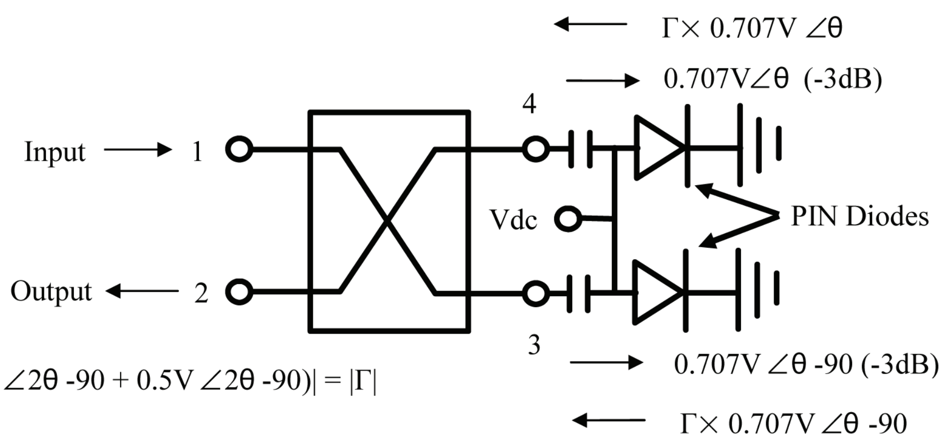
This example is not limited to Power Amplifiers. In the case of Low Noise Amplifiers (LNA's), the reflection property of 3dB couplers is again beneficial. The transistor devices used in LNA's will present different reflection coefficients depending on the bias level. The bias level that yields the best noise performance does not also provide the best match to 50 Ω. A circuit that is optimized for both noise performance and return loss can be achieved by combining two matched LNA transistor devices using 3dB couplers. The devices can be biased for the best noise performance and the reflection property of the couplers will provide a good match as described above. An example of this circuit is illustrated below:

LNA Circuit Leveraging the Reflection Property of 3dB Couplers



Signal Control Circuits Utilizing 3dB Couplers

Variable attenuators and phase shifter are two examples of signal control circuits that can be built using 3dB couplers. Both of these circuits also use the reflection property of the 3dB coupler as described above. In the variable attenuator circuit, the two output ports of a 3dB coupler are terminated with PIN diodes, which are basically a voltage variable resistor at RF frequencies (consult the literature on PIN diodes for a more complete equivalent circuit). By changing the resistance at the output ports of the 3dB coupler, the reflection coefficient, Γ, will also change and different amounts of energy will be reflected to the isolated port (note that the resistances must change together so that Γ is the same for both output ports).
A signal applied to the input of the 3dB coupler will appear at the isolated port and the amplitude of this signal will be a function of the resistance at the output ports. This circuit is illustrated below:

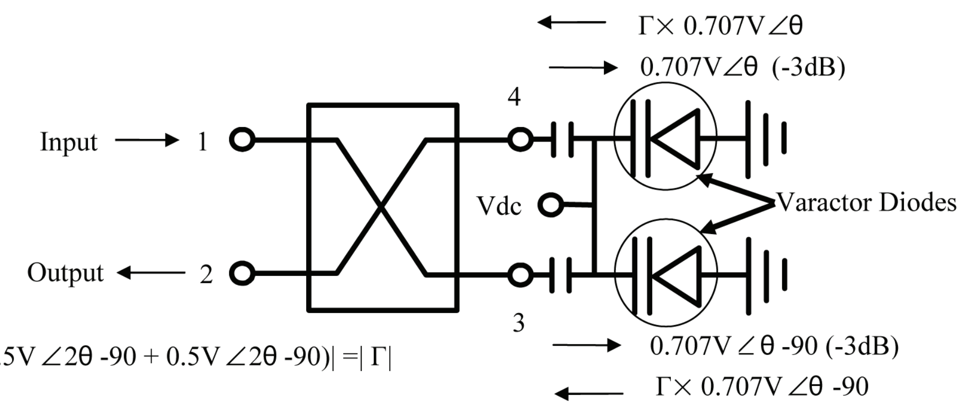


$|\Gamma\,(0.5V\angle 2\theta - 90 + 0.5V\angle 2\theta - 90)| = |\Gamma|$
and
$|Output| = |\Gamma| \times |Input|$

Variable Attenuator Circuit Utilizing a 3dB Coupler

If Γ=0, no energy is reflected from the PIN diodes and S21 = 0 (input to output). If | Γ | =1, all of the energy is reflected from the PIN diodes and |S21| = 1 (assuming the ideal case of no loss). The ideal range for Γ is –1 to 0 or 0 to 1, which translate to resistances of 0Ω to 50Ω and 50Ω to ∞Ω respectively. Either range can be selected, although normally 0Ω to 50Ω is easier to achieve in practice and produces better results. Many papers have been written on this circuit and should be consulted for the details of design and operation.

Another very similar circuit is a Variable Phase Shifter (illustrated below). The same theory is applied but instead of PIN diodes (variable RF resistance), the coupler outputs are terminated with varactors. The ideal varactor is a variable capacitor with the capacitance value changing as a function of the DC bias. Ideally, the magnitude of the reflection coefficient is 1 for these devices at all bias levels. However, the angle of the reflected signal does change as the capacitance changes with bias level. So, ideally all of the energy applied to port 1, in the circuit illustrated below, will be reflected at the varactors and will sum at port 2 (the isolated port of the coupler). However, the phase angle of the signal will be variable with the DC bias level. In practice, neither the varactors nor the coupler are ideal and both will have some losses. Again, many papers have been written on this circuit and should be consulted for the details of design and operation.



* $|\Gamma\,(0.5V\angle 2\theta\ -90 + 0.5V\angle 2\theta\ -90)| = |\Gamma|$

Variable Phase Shifter Circuit Utilizing a 3dB Coupler

* The phase angle of the signal exiting port 2 will vary with the phase angle of Γ, which is the reflection angle from the varactor. The varactors must be matched so that their reflection coefficients are equal.