POWER SPLITTER/COMBINERS

Understanding the Basics of Power Splitters... How they Work, What Parameters are Critical, and How to Select the Best Value for your Application

Basically, a 0° splitter is a passive device which accepts an input signal and delivers multiple output signals with specific phase and amplitude characteristics, see Fig. 1. The output signals theoretically possesses the following characteristics:

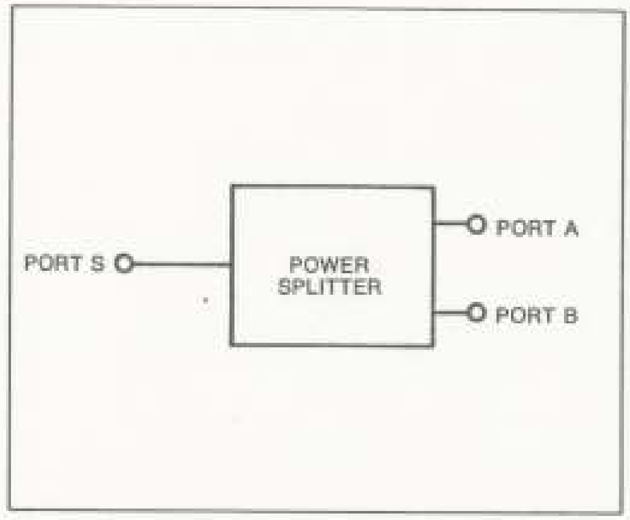
- equal amplitude
- 0° phase relationship between any two output ports
- high isolation between each output signal
- insertion loss as follows:

No. of Output Ports	Theoretical Insertion Loss (dB)
2	3.0
3	4.8
4	6.0
6	7.8
8	9.0
16	12.0
24	13.8

A 0° power splitter can be used as a power combiner by applying the signals to be combined into the ports A and B and then delivering the vector sum to port S. Now the device provides a single output equal to the vector sum of the inputs reduced in power by the theoretical insertion loss. An important characteristic of a power combiner is the high isolation between inputs.

The following signal processing functions can be accomplished by power splitter/combiners:

1. Add or subtract signal vectorially.
2. Obtain multi in-phase output signals proportional to the level of a common input signal.
3. Split an input signal into multi-outputs.



1. When used as a 0° power splitter, the input is applied to port S and equal outputs appear at ports A and B. When used as a power combiner, both inputs are applied to ports A and B and the sum taken from port S.

4. Combine signals from different sources to obtain a single port output.
5. Provide a capability to obtain RF logic arrangements.

Let's analyze a basic power splitter

The most basic form of a power splitter is a simple "T" connector, which has one input and two outputs. If the "T" is mechanically symmetrical, a signal applied to the input will be divided into two output signals, equal in amplitude and phase. The arrangement is simple and it works, with limitations.

The two obvious limitations are impedance mismatch and poor isolation. In the 50-ohm system, both outputs would be tied to 50-ohm loads, thus offering a 25-ohm impedance to the input port. Thus, the impedance looking into the common or input port would present a mismatching 50-

ohm system. To correct this mismatch, a 25 to 50-ohm matching transformer would be necessary for the simple "T".

Now, consider the second serious limitation of a simple "T", poor isolation. Suppose, for example, that two antennas were fed to a receiver input using a simple "T" as a combiner. If one antenna appears as a short at its resonant frequency, it would load down the other antenna and, in effect, wipe out the receiver input. A properly-designed power combiner would provide high isolation between inputs so that the above condition at one input would have little influence if any, on the other input nor the output port, in this case, the receiver. In a simple "T" without an impedance matching transformer, there will be 3 dB isolation between one port to the other, since the input signal is split in half.

To improve isolation and to provide proper matching, the basic lumped element power splitter circuit of Fig. 2 is used. The transformer centertap is where the input to the power splitter is applied and outputs are taken at each end. When used as a power combiner, inputs are fed to each end and the sum port is at the center tap.

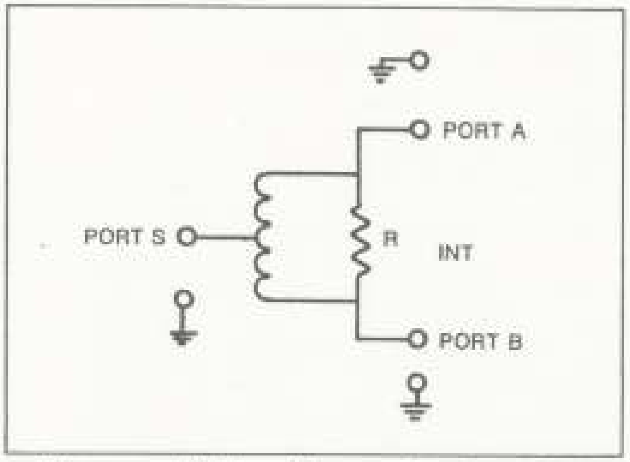
Now consider the device as a power combiner. An input signal applied to port A will flow through the transformer and experience a 180° phase shift by the time it arrives at input port B. A second current will flow from input port A to B through internal resistance R_{INT}, but will not experience any phase shift. The impedance of the total transformer winding is 100 ohms and the internal resistor is also 100 ohms. Thus, both currents, being equal in amplitude but opposite in phase, cancel. The net result is that no voltage appears at input port B from the input signal applied to port A. Thus, there is theoretically infinite isolation between both input ports.

When dealing with a 50-ohm system, each of the two input ports appears across the full transformer thus requiring a 100-ohm transformer impedance for optimum power match. The input would, of course, require 50 ohms. Thus a 50 to 100-ohm transformer is placed between input and output ports.

Mismatch effect on isolation

Consider the ideal situation in a two-way power combiner where there is infinite isolation between the two input ports. A signal applied to port A will be routed to the port S, minus a 3 dB loss in the internal resistor; since isolation is perfect, none of the input signal will reach the other input port. Now, if the port S is properly terminated, the sum signals will be absorbed and nothing will be reflected back to the input ports. Fine, as long as the port S is properly terminated and thus no mismatch.

Now let's consider two examples of mismatch at port S, one slight and another large. Assume a



2. In two-way splitter/combiner, equal and opposite currents flow through the internal resistor and transformer, cancel each other, and provide high isolation between ports A and B.

+20 dBm signal is applied to port A; with perfect isolation, none of this signal reaches port B. Since there is a 3 dB loss between input A and port S due to the loss in the internal resistor, +17 dBm arrives at port S ignoring any slight transformer loss. If a slight impedance mismatch exists at port S, which causes a −20 dB signal reflection, then a signal of −3 dBm (+17 dBm attenuated by 20 dB) is sent back to ports A and B. This −3 dBm signal experiences a 3 dB loss as it is fed to port B, and the mismatch has now resulted in a −6 dB signal at input B from port A. Now isolation between both input ports is not ideal; there is a +20 dBm signal at port A and a −6 dBm signal at port B for an isolation of 26 dB. Reason? Slight impedance mismatch at port S.

What about a more serious mismatch? Suppose the +17 dBm signal arrives at port S and a mismatch produces a reflected signal attenuated by only 10 dB. Now +7 dBm is fed back to port B (+17 dBm with 10 dB loss); add the additional

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return 3 dB loss, and a +4 dBm signal appears at port B. Now isolation is only 16 dB, the difference between port A's 20 dBm and the 4 dBm signal at port B due to the mismatch.

Important point: make sure port S is properly matched to eliminate reflections and thus maintain high isolation. Mismatch at either port A or B is not critical if port S of a power combiner is properly matched. If cancellation through the transformer and internal resistor is taking place, there will not be any voltage drop across port A and B and thus no effect on isolation even if improper matching exists.

Let's take it one step further and assume port S and port A are properly terminated but port B is shorted. In a basic "T", a short across one input would obviously short everything. With a practical power splitter/combiner, a serious mismatch will result.

In a practical power splitter/combiner, if port A and port S are properly terminated, but port B is open, there will be a 2 dB or so (not 3 dB) loss at port A. This is because the signal fed to open port B will be reflected back to port S and Port A, adding to the signal level at A, thus slightly reducing the loss between port A and port S.

What limits the power rating?

The power handling capability of a power splitter/combiner is basically determined by the internal resistor across the transformer and the transformer's core and wire size. When used as power splitter, the core of the transformer may saturate at the lower frequency end of the operating band if the designated power rating is exceeded; signal distortion and reduction in isolation will result. In a power combiner application, the power loss across the internal resistor must also be considered in addition to the transformer core effects. At high RF frequencies, usually small diameter wire is used thus limiting the safe current level that can flow before failure.

If an application demands an internal resistor power rating larger than available as a standard catalog item, it is possible to request from Mini-Circuits a unit without an internal resistor. Then a higher power rating resistor can be outboarded; of course, the performance of the final combination will depend on the external resistor's characteristics, the way it is wired, and its capacitance to the board on which it is mounted.

Get tight specs at lower cost

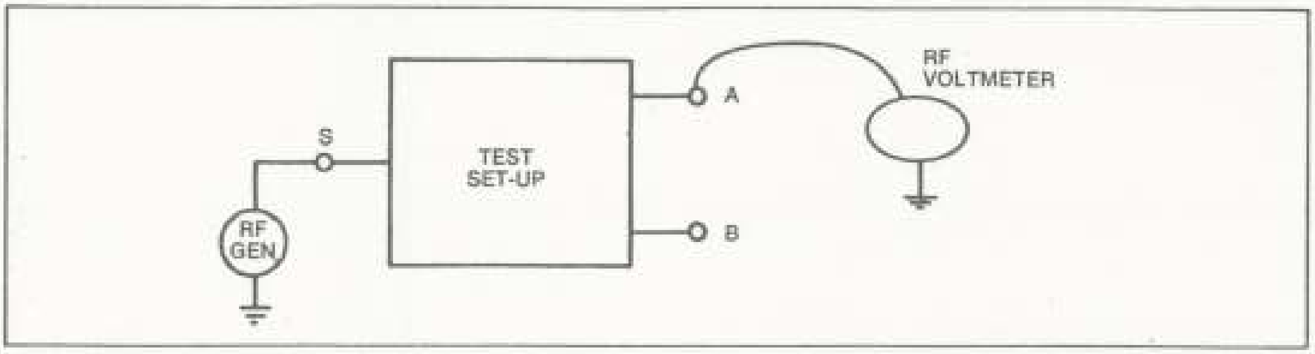
Generally, engineering designs exist in a world of tradeoffs. Mixers, for example, can be designed so that isolation can be improved at the expense of conversion loss; similarly, a mixer's noise figure can be improved if a reduction in dynamic range can be accepted in exchange.

Not so, fortunately with power splitters. The key parameters are influenced in the same direction during the design stage. A well-designed power splitter will offer high isolation, low insertion loss and good VSWR. You just don't encounter a power splitter with high isolation and poor VSWR, nor high isolation with a poor insertion loss spec. Why? Because poor insertion loss specs generally result from an improper matching transformer (winding not exactly symmetrical) or slight variations in stray capacitances at each end of the transformer; these effects, however, adversely affect insertion loss as well as isolation.

This raises a significant point. There is no need to specify a number of tight spec parameters when you need a power splitter for a particularly stringent requirement. Simply specify a tight improved spec on the key parameter most critical to the task and you'll find the remaining specs will also be upgraded. If you insist on writing tight specs on a number of parameters, you may be paying extra money for a device you would have received anyway. Of course, you can specify one tight parameter, as suggested, and request support data on the other parameters to monitor their characteristics.

In some applications, it is possible for several parameters to be important. In other applications, only one parameter may be considerably significant while others are not. For example, in a power combiner used to add the outputs of two amplifiers, insertion loss is a critical factor while isolation may not be deemed an essential.

On the other hand, consider a test setup for two-tone, third-order IM measurement. Here it is common to operate two RF generators that are close to each other in frequency, resulting in one generator "talking to the other" or "pulling". To avoid this measurement pitfall, a power splitter is placed between both RF generators; here the isolation spec is very significant while other parameters, such as phase or amplitude unbalance, have no importance at all.



3. To improve insertion loss measurement, first a 3dB standard attenuation is placed between points A and S, and an RF voltmeter reading is taken. Then the attenuator is removed and the power splitter/combiner is connected to A, B, and S.

Again, you can lower your demands, and your cost, by analyzing what parameters must be met while understanding others that can be ignored.

How to measure insertion loss

To measure insertion loss, first terminate all ports properly with 50 (or 75) ohm pads and then set the RF generator to the test frequency. An RF voltmeter reading is then taken at port A and then at port S. The difference between the two levels, in dB, represents the insertion loss of the splitter. Repeat for ports B and S.

Although the above procedure is simple, the accuracy of the measurement is limited by the accuracy of the RF voltmeter. An improved technique requires a standard 3 dB attenuator placed between test points A and S (see Fig. 3) with the two-way power splitter disconnected from the test set-up. The RF generator level is set so that the RF voltmeter reading is near the top of the scale, its most accurate region. Then the 3 dB standard attenuator is removed and the power splitter is connected to test points A, B and S. The difference between the first and the new RF voltmeter reading represents the additional power splitter loss over the 3 dB theoretical value. Thus, the insertion loss is 3 dB plus this incremental RF voltmeter reading. Repeat for port B.

The procedure for measuring insertion loss for more than a two-way splitter is essentially the same as previously described. The difference is that the standard attenuator value should be close to the theoretical minimum insertion loss for the power splitter under test. Remember that all ports should be terminated in the correct value of impedance. Practically speaking, the terminations do not have to be perfectly matched depending on the accuracy required.

How to measure isolation

The isolation of the two-way splitter is obtained by measuring the attenuation between ports A and B when the common port is terminated in the correct value of impedance, generally 50 ohms. An RF generator signal is applied to port A and an RF voltmeter reading is taken at port B. The resulting attenuation in dB represents the isolation between the two ports.

When high isolations are encountered, in the range of 50 dB, the accuracy of the measurement can be improved by replacing the RF voltmeter with a spectrum analyzer and/or by inserting a filter between the port A (or B) and the RF voltmeter. The filter eliminates the possibility of harmonics from the RF generator and the variation of isolation as a function of frequency, which together produce measurement errors.

The technique for measuring isolation of more than a two-way splitter is exactly the same as that just described; just make sure all unused ports are terminated with the appropriate impedance. However, the accuracy of this termination impedance is not very critical since there is usually high isolation between ports.

It is quite important, however, that the terminating impedance at the common or S-port be very accurate. Deviations from the correct impedance value will cause significant errors. Typically, a termination impedance with a VSWR of 1.05 to 1 is used at Mini-Circuits for isolation testing.