This designers' note written by Minicircuits looks at how power splitters work, what parameters are critical, and how to select the best value for your application.

Understanding power splitters

Basically, a 0° splitter is a passive device which accepts an input signal and delivers multiple output signals with specific phase and amplitude characteristics.

Theoretically, the output signals possess the following characteristics:

- equal amplitude
- 0° phase relationship between any two output signals
- high isolation between each output signal
- insertion loss as in the **Table**.

Since the 0° power splitter is a reciprocal passive device it may be used as a power combiner simply by applying each signal singularly into each of the splitter output ports. The vector sum of the signals appears as a single output at the splitter input port.

The power combiner exhibits an insertion loss that varies depending on the phase and amplitude relationship of the signals being combined. For example, in a two-way 0° power splitter/combiner, as outlined in **Fig. 1**, if the two input signals are equal in amplitude and are in-phase then the insertion loss is zero.

However, if the signals are 180° out of phase the insertion loss is infinite. And, if the two signals are at different frequencies, the insertion loss will equal the theoretical insertion loss shown in the Table.

The power combiner also exhibits isolation between the input ports. The amount of isolation depends on the impedance termination at the combiner output or sum port. For example, in the two-way 0° power splitter/combiner of Fig. 1, if port S is open then the isolation between ports A and B would be 6dB. And, if port S is terminated by a matched impedance for maximum power transfer, then the isolation between ports A and B would be infinite.

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

- Add or subtract signals vectorially.
- Obtain multi in-phase output signals proportional to the level of a common input signal.
- Split an input signal into multi-outputs.
- Combine signals from different sources to obtain a single port output.
- Provide a capability to obtain rf logic arrangements.

Basic power splitter analysis

The most basic form of a power splitter is a simple 'T' connection, which has one input and two outputs, **Fig. 2**. If the T is mechanically symmetrical, a signal applied to the input is divided into two output signals, equal in amplitude and phase.

This arrangement is simple and it

Table. Theoretical power splitter insertion losses for different numbers of output ports.

Ports	Loss
2	3.0dB
3	4.8dB
4	6.0dB
5	7.0dB
6	7.8dB
8	9.0dB
10	10.0dB
12	10.8dB
16	12.0dB
24	13.8dB
48	16.8dB

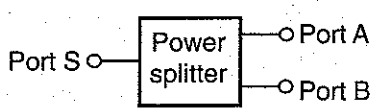

Fig. 1. When the combiner/splitter is used as a 0° power splitter, the input is applied to port S and equal outputs appear at ports A and B. When used as a power combiner, both inputs are applied to ports A and B and the sum taken from port S.

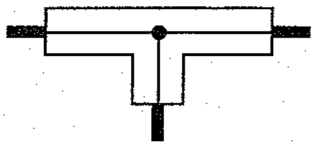

Fig. 2. Basic two-way or power splitter is a simple 'T'.

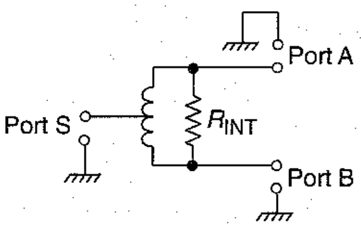

Fig. 3. In two-way splitter/combiner, equal and opposite currents flow through the internal resistor and transformer and cancel each other. This provides high isolation between ports A and B.

works, but with limitations. Two obvious limitations are impedance mismatch and poor isolation.

In a 50Ω system, each output would be connected to a 50Ω impedance, resulting in a 25Ω impedance to the input port. Thus, the impedance looking into the common or input port would present a mismatch in a 50Ω system. To correct this mismatch, a 25 to 50Ω matching transformer is 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.

However, a properly designed power combiner would provide high isolation between inputs so that the antenna 'short condition' at one input would have little influence on the other input and would cause approximately a 3:1 vswr mismatch at the output port – in this case, the receiver input.

In a simple T-circuit power combiner the isolation between input ports depends on the impedance termination at the output port. If the output port is open then the input ports would have zero isolation between them. And, if the output port is terminated by a matched impedance the isolation would be 3dB.

Improving upon the simple T circuit, consider the basic lumped element power splitter/combiner circuit of **Fig. 3**. The transformer has an equal number of turns from the centre tap to each end. Therefore, as an auto transformer with a 2-to-1 turns ratio, the impedance across the output ends is four times larger than the impedance across the centre tap to one end.

Let's examine how this circuit enables high isolation between ports A and B. As a power combiner, an input signal applied to port A causes a current to flow through the transformer and experience a 180° phase shift by the time it arrives at port B. Similarly, a current will also flow through R_{INT} and will not experience a phase shift by the time it arrives at port B.

When R_{INT} equals the impedance value across the transformer ends then, the currents appearing at port B will be equal in amplitude but opposite in phase and cancel. The net result is that no voltage appears at port B from the input signal applied at port A. Thus, there is theoretically infinite isolation between the ports.

Find insertion loss

Further examining the circuit of Fig. 3, let's determine the theoretical insertion loss between port S and ports A and B. As a power splitter, a signal applied at port S will be split so that identical signals appear at ports A and B, due to the circuit symmetry.

If the impedance values are matched then maximum power transfer will take place and half the input power would appear at each port resulting in a 3dB theoretical loss at each port. Furthermore, under the conditions described the circuit is lossless since the voltage across R_{INT} is zero.

Let's take an example to illustrate the concepts described. Suppose we have a 50Ω system so that ports A and B are each terminated in 50Ω. They appear across the transformer in series so that a 100Ω transformer impedance is required for optimum power match. Since the transformer has a 4 to 1 impedance ratio, the impedance at port S is 25Ω.

In this example we have to add a 2 to 1, i.e. 50 to 25Ω, transformer at port S so that its impedance is matched to the 50Ω system. Remember that to obtain maximum isolation the value of R_{INT} equals the transformer impedance, i.e. 100Ω.

We have now completely specified the circuit values of the 50Ω two-way 0° power splitter.

How does mismatch affect 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 port S, minus a 3dB loss in the internal resistor; since isolation is perfect, none of the input signal will reach the other input port.

Now, if port S is properly terminated, the sum signals will be absorbed and nothing will be reflected back to the input ports. This is fine, as long as port S is properly terminated and there is thus no mismatch.

Now, let's consider two examples of mismatch at port S, one slight, the another large. Assume a + 20dBm signal is applied to port A; with perfect isolation, none of this signal reaches port B.

Since there is a 3dB loss between input A and port S due to the loss in the internal resistor, +17dBm arrives at port S ignoring any slight transformer loss. If a slight impedance mismatch exists at port S, which causes a –20dB signal refection, then a signal of –3dBm, i.e. + 17dBm attenuated by 20dB, is sent back to ports A and B. This –3dBm signal experiences a 3dB loss as it is fed to port B, and the mismatch has now resulted in a –6dB signal at input B from port A.

Now, isolation between both input ports is not infinite; there is a +20dBm signal at port A and a –6 dBm signal at port B for an isolation of 26dB. Reason? Slight impedance mismatch at port S.

What about a more serious mismatch? Suppose the +17dBm signal arrives at port S and a mismatch produces a –10dB signal reflection. Now +7dBm is fed back to port B (+17dBm with 10dB loss); add the additional return 3dB loss, and a +4dBm signal appears at port B.

Now isolation is only 16dB – the difference between port A's 20dBm and the 4dBm signal at port B due to the mismatch.

It is important to make sure that 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. ■