Power Dividers/Combiners

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Introduction

A power divider is ideally a lossless reciprocal device which can also perform vector summation of two or more signals and thus is sometimes called a power combiner or summer. Two forms of power dividers are generally constructed by cascading two-way dividers. These two-way dividers are typically either terminated 180° hybrid (for RF frequency units) or Wilkinson or tapered line dividing structures (for microwave frequency devices). N-way dividers are devices which split signals in ways that are not 2^N. M/A-COM offers a variety of 3 way and other N-way dividers that incorporate proprietary and patented circuit designs.

Although power dividers could be composed of 90° hybrids, the term “power divider” normally refers to a device that splits an input signal into two or more in-phase outputs. The purpose of this article is to provide the designer with basic information describing the function of these devices and to define the performance parameters and trade-offs critical to specifying a power divider.

Functional Description Binary Power Dividers - RF Frequencies (up to 2 GHz)

A binary power divider at RF frequencies in an internally terminated 180° hybrid. Figure 1 shows the standard diagram for a 180° hybrid with a termination at Port A.

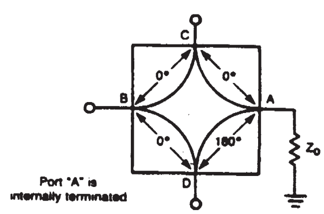


Figure 1. 1-Way, In-Phase (0°) Power Divider/Summer, or ISO-T

Physically, the 2-way power divider appears to be a three terminal device, since the Z_O termination at Port is normally mounted inside the package. Also, although a conventional 180° hybrid can be used as a power divider, the usual form of 2-way power divider does not have a Z_O impedance level at all four ports. Higher order binary power dividers, such as 4-way and 8-way power dividers, are realized by cascading 2-way power dividers of various configurations. The functional diagram for a 4-way divider is shown in Figure 2, while the 8-way diagram would simply have the “B” port of additional 2-way dividers connected at ports 1, 2, 3 and 4.

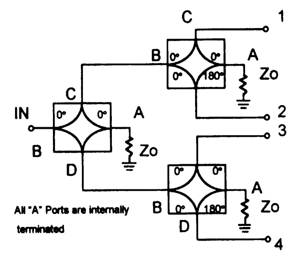


Figure Figure 2. 4-Way Divider Functional Diagram

Binary Power Dividers - Microwave Frequencies (500 MHz and up)

At microwave frequencies, the binary divider is typically realized as a microstrip or stripline Wilkinson power divider. A Wilkinson power divider consists of a series of cascaded quarter-wavelength transformers which transform the impedance of a single input, which is typically 50 ohms, to the impedance associated with the parallel combination of the multiple outputs. The input VSWR of this divider is primarily influenced by the quality of these impedance transformers and the VSWRs of the loads which terminate the outputs of the device. To facilitate low output VSWRs and provide isolation between these outputs, resistors are placed at the ends of each of the quarter-wavelenght transformers. The value of these resistors is determined by odd-mode analysis. The simplest Wilkinson divider is the single-section 2-way. This device consists of two 70.7 Ohm quarter-wavelength transformers with a 100 Ohm resistor between them. (See figure 3)

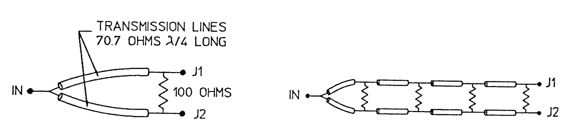


Figure 3. Simple and Broadband Wilkinson Power Dividers

The simple Wilkinson divider is useful for limited bandwidth applications. To increase the useful bandwidth of the device, additional quarter wave transformers and isolation resistors are added. The general rule is that the greater the bandwidth, the greater the number of required transformers. Consequently the unit becomes larger and more lossy.

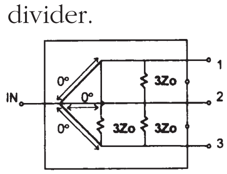
Practical isolated power dividers are built in octave bandwidth and also extremely wide bandwidths of decades and greater. Octave band units are of the Wilkinson type, using discrete lumped resistors. VSWR increases outside of the band specified. The broadband units are of a tapered design which provides semi-infinite bandwidth in principle. That is, there is no upper frequency limit to operation, however, in practice there is an actual upper limit due to increasing VSWR and loss.

The Wilkinson and tapered line dividers are cascaded to create higher order devices. These devices are typically realized as printed structures on low-loss teflon based laminates with chip resistors.

Isolation
The output ports of a divider (or the input ports if it is being used as a combiner) are isolated from each other. When a typical Divider is splitting a signal or combining coherent signals, the voltage present on each side of the isolation resistor (see Figure 4) is of equal potential and therefore no current flows through the resistor and no power is dissipated. However, when combining non-identical signals, the residual signal that does not appear at the input travels towards the other outputs and reaches the opposite side of the isolation resistor 180° out of phase with the incident signal. This voltage differential causes a current flow through the resistor and power is dissipated. The signal is attenuated significantly, achieving isolation.

A two way device used to combine two non-coherent signals will deliver half of each signal to the common port and half of each signal will be dissipated in the isolation resistor. Consequently, a 4-way device combining 4 non-coherent signals will deliver 1/4 of each signal to the input and dissipate the rest.

N-Way Dividers
Power dividers having an odd number of outputs (3,5,7, etc.) are sometimes classified as N-way power dividers. The circuit actually used to realize a true 3-way divider, as opposed to a terminated 4-way power divider, is a unique transformer circuit covered by U.S. patent number 3,428,920. It is beyond the scope of this article to review in detail the transformer operation of this circuit, however, Figure 4 shows a functional diagram of a 3-way power divider.



Internal Terminators are connected between Outputs 1 and 2, 1 and 3, and 2 and 3.

Figure 4. 3-Way Power Divider Functional Diagram

The transformer circuit is interconnected in such a manner as to produce three mutually isolated outputs. Three internal terminations of value 3 Z_O must be connected between ports 1 and 2, 1 and 3, and 2 and 3 in order to maintain port match and port-to-port isolation.

Performance Parameters
The critical parameters in selecting a power divider are normally frequency range, insertion loss, isolation and VSWR.

Isolation
This term defines the isolation between any set of output ports. It is the ratio, expressed in decibels, of the output power of one output port to the imput power ot any other output port, with matched terminations on all other ports.

Insertion Loss
This term defines the measured loss through the device excluding the power division factor. It is the ratio of power output to power input, expressed in decibels and assumes a matched source and load circuit is used for the measurement. Microwave frequency dividers have line losses that increase with frequency. The values specified have a minimum value at the lowest frequency and linearly increase at a rate determined by the power divider length. For example, the 2090-6205-00 unit has a low frequency attenuation of 0.3 decibels, and at the highest frequency of operation, 1.46 decibels. The RF dividers tend to exhibit a similar characteristic except the loss tends to increase at the lowest frequencies approaching the low frequency cut-off of the device.

Output Amplitude Tracking
The difference in the signal amplitudes at the output ports is called output amplitude tracking error or output amplitude unbalance. It is the ratio of the maximum signal at any port to the minimum signal of any other port, expressed in decibels. Typically, the maximum output tracking specified is very low, for example, 0.3 dB, for two-way dividers, and increases with a higher number of output ports, to 1.0 dB for the eight-way power divider

Output Phase Tracking
The difference in the signal phase at the output ports is defined as the output phase tracking error or unbalance. It is the maximum deviation that is specified, usually the average phase is much less, especially at low frequencies.

In addition to these parameters the following two parameters are often specified and are related to the power rating of the internal load resistors.

Matched Power Rating or Input Power
This is the highest level power that can be applied to the input and still maintain other performance limits. It is specified for RF components with Z_O terminations on all outputs to avoid reflected signals from unbalanced loads which may exceed the limit for power dissipation in the internal termination. The microwave frequency components are specified at a maximum input power level assuming a 2:1 load VSWR on each output port. This VSWR yields a condition where 10% of the input power is reflected and must be dissipated within the unit. If load VSWR's are greater than 2:1, the unit must be derated per the equations in section III below.

Internal Load Dissipation
This is simply the power rating of any one of the internal terminations. These two parameters are related and the input power rating is normally several times larger than the internal load dissipation. The reason for this is intuitively obvious since most of the input power is delivered to the output loads, not the internal termination.

There are three considerations affecting the amount of input power that a power divider can withstand.

1. Insertion Loss

The first consideration is the total power dissipated in the power divider. Total power dissipation in a power divider under matched conditions can be determined to a reasonable approximation from the insertion loss and the known input power as follows:

Insertion Loss (dB) = 10 log $P_{IN}P_{OUT}$

Therefore:

$$P_{OUT} = \frac{P_{IN}}{10^{(\text{Insertion Loss} / 10)}}$$

$$P_{DISSIPATED} = P_{IN} - P_{OUT}$$

$$P_{DISSIPATED} = P_{IN} - \frac{P_{IN}}{10^{(\text{Insertion Loss} / 10)}}$$

As an example, consider a power divider with the following conditions

Insertion Loss = 0.5 dB

P_{IN} = 2 Watts

$$P_{DISSIPATED} = 2 - \frac{2}{10^{\frac{0.5}{10}}}$$

= 0.218 Watts

Most of this power will be dissipated in the wire and ferrite cores making up the transformer circuits and not in the internal load.

2. Amplitude Balance

In a power divider operating under matched conditions, a second consideration for input power dissipation is the dissipated power in the internal load. If we consider a 2-way power divider similar to that shown in Figure 1, we observe that ideally no power would be dissipated in the 2 Z_O load between Ports C and D, because the voltages at C and D would be equal. In practice, a small differential may occur because of imperfect Amplitude Balance. The approximate dissipation due to this unbalance can be shown to be:

$$P_{INT}\ LOAD \cong P_{OUT}^{\ (10\ (Amp\ Bal\ /\ 20) - 1)}$$

A very small amount of power normally is dissipated due to this effect. Consider the following example:

Let

Amplitude Balance = 0.25 dB

P_{OUT} = 2 Watts

$P_{INTLOAD} \cong 1/2^{\ (10\ (0.25\ /\ 20) - 1)}$

= 0.4 mW

3. Mismatched Loads

When determining input power limits, the third and perhaps most important case to consider is the condition of mismatched loads at the outputs of the power divider. Reflections from these mismatches can cause a considerably larger voltage differential to appear across the internal load. If the VSWR of the two loads is K1 and K2, the limit on the input power P_{IN}, is given in the following:

$$P_{IN} \leq \frac{\text{Internal Load Rating (Watts)}}{\frac{(K1-1)^2}{K1+1} + \frac{(K2-1)^2}{K2+1}}$$

As an example, if the internal load rating is 0.5 Watts and the VSWR of K1 and K2 is 2:1 then :

$$P_{IN} \leq \frac{0.5}{\left(\frac{2-1}{2+1}\right)^2 + \left(\frac{2-1}{2+1}\right)^2}$$

$$\leq 2.25 \text{ Watts}$$

This is the worst case formula, which assumes that the two load reflections are out of phase at the output port. If they are identical impedances, P_{IN} may be several times larger without causing damage.

From the preceding discussion of power divider input power ratings, we can draw two conclusion:

1. Under the matched loading conditions ($Z_O$terminations at all ports) the input power is limited by heating effects. This is especially true for the RF frequency components which use the wire wound ferrite cores as transformers. Absolute maximum temperatures for ferrite core transformers are limited by the curie temperature for the ferrite, generally in 130°C to 500°C range, and the temperature rating of the magnet wire which is usually 130°C. It is advisable to stay well below the temperature limits (20°C or more) to avoid performance degradation, particularly increased insertion loss. The actual temperature rise in the ferrite core is dependent upon the heat transfer path from the core to the heat sink or surrounding air. This determination involves measuring or calculating the thermal resistance, q, expressed in °C/Watt of this path. Thermal resistance will be highly dependent on the mounting of the power divider as well as its internal construction. For this reason, manufacturers normally provide a very conservative maximum input power rating that applies under absolute worst case conditions with no specific heat sinking of the unit. In many instance power several times higher than this rating can be applied with little, if any performance degradation.

2. Under conditions where mismatches are present at the power divider output, the internal load power dissipating rating may limit the input power that can be applied. A simple worst case calculation can be performed to determined if this is the case using the provided formulas.

A final point relative to power ratings that should be considered is the application as a power summer. In this case signals are applied to the parts we have been calling outputs (for example Ports C and in Figure 2) with the vector sum appearing at the input or S port (Port B in Figure 6). In this case equal signals are normally applied, and little if any power is dissipated in the internal load. A possible condition may occur where one or more if the signal sources fails or is removed. For example, if two equal sources are applied at Ports C and D and the source at D fails, 50% of the power supplied by the source at C will be dissipated in the 2 Z_O internal load. Thus the power injected at each port should not exceed twice the rating of the internal load to avoid this condition.

Length Vs Frequency Range Considerations

There are many generally recognizable trade-offs that can help the power divider user in choosing the type of divider to use in a given application. In general, for a given design technique, the lower the operating frequency the longer the unit must be. Also, a narrow band unit will be smaller than a broadband unit operating at the same center frequency. However, an ultra-broadband unit operating from 2 to 18 GHz will be only three times as long as a very narrow band unit operating at 2GHz.

Conclusion

Power dividers are often considered the simplest of the many RF devices that may be required in designing a system, and in some respects this is true. Despite the functional simplicity of power dividers and generally rugged and reliable components used in the construction, their specification and application in systems can still lead to unexpected problems.

In this article we have presented some basic information to give the system designer insight into the internal construction for power dividers and how this influences the operation of the device and its function in the real world of imperfect matches and less that ideal physical installation. On this latter point, the consideration for power dividers was dealt with both analytically and in terms for expected results in the normally mounted configuration.

Many of the points made and expressions derived for the operation 180° hybrids can be applied to power dividers, particularly 2-way power dividers, and questions that may arise pertaining to points not covered in this article, such as isolation in the presence of mismatch or other signal flow relationships, can be analyzed by reference to the tables contained in that article.