# Selecting the right signal combiner

As systems become more complex, choosing how best to combine two or more RF signals has become a far more difficult question to answer. This article is intended to highlight the benefits of the many options available to today's system engineers. And, thereby, attempts to help the designer in selecting the right signal combiner for the desired application.

By Tony Ramsden

The choice of an active or passive combining system might be an early consideration, especially as minimizing combining loss, associated with passive components, is usually high on the priority list. However, passive combining does not necessarily involve loss, and if signals can be combined using passive networks, the benefits in reliability and cost are likely significant.

The first question to answer is how many signals need to be combined. The more the signals, more likely the loss will increase. But, it is not necessarily so. If there are just two signals to combine and they are well separated in frequency, then a diplexer filter system can combine the signals with minimum loss as shown in Figure 1. (These are not to be confused with duplexer filters that separate transmit and receive signals). Simple low-cost diplexers, which usually use suspended substrate, will offer around 50 dB of input isolation. If more isolation is required then one has to resort to cavity filter designs, but these are much larger and more expensive. There are also the triplexers, and even quadraplexers, which combine the signals from three and four different frequency bands, but these become increasingly complex.

Many times, the signals occupy the same frequency band and cannot easily be filtered, in which case, a solution using a hybrid coupler or a Wilkinson power divider, which adds signals without mutual interaction, is usually required.

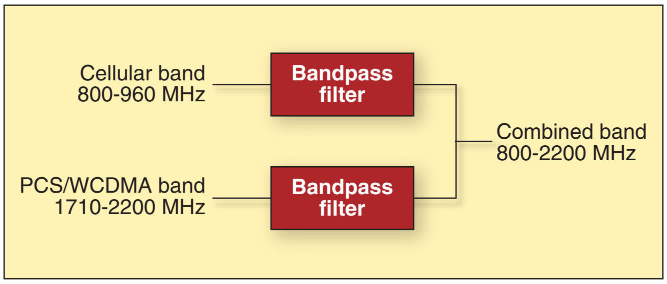


Figure 1. A typical two-input diplexer filter system.

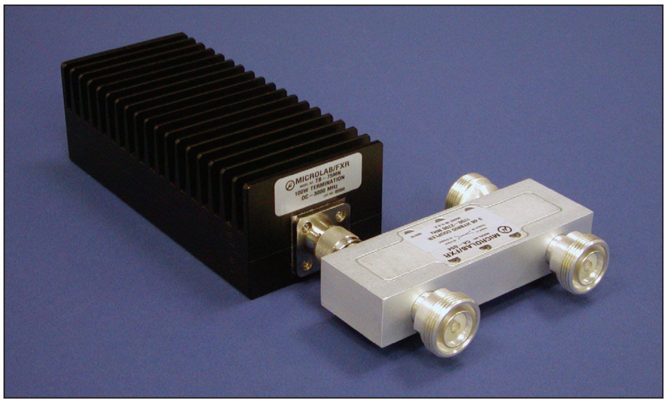

Figure 2. High-power hybrid combiner with 100 W load for base station combining.

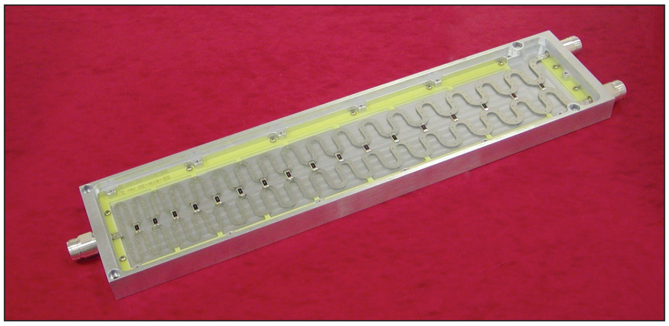

Figure 3. Ultrawideband 70 MHz to 2700 MHz Wilkinson divider/combiner using 17 sections with an air dielectric for minimum loss.

### Hybrid or Wilkinson?

Choosing between the hybrid coupler and the Wilkinson divider is primarily a matter of the power levels of the two signals. In either case, assuming the two signals are not coherent, half the power of each will be dissipated as heat.

Wilkinson dividers usually have small milliWatt resistors, mounted on printed circuit boards, which limits their ability to combine any signal higher than the value of the resistor power. On the other hand, the hybrid coupler has an external load to absorb the power, so it is useful up to power levels of several hundred Watts. A typical stripline design on microwave dielectric will have a power limit of 100 W per input, and many such hybrid combiners with an attached 100 W load are used in base station applications. (Figure 2).

For low power applications, the Wilkinson divider also has the benefit that it can be designed for very broad bandwidths. Although, the more common components cover the standard 800 MHz to 2500 MHz, they are now available for wireless applications down through VHF in bandwidths that cover from 70 MHz to 2,700 MHz (Figure 3) using an air dielectric stripline approach to minimize loss on this 17 section design, and from 350 MHz to 6,000 MHz (Figure 4) using a microstrip design to cover the existing commercial wireless bands and the many new frequency bands for Wi-Fi and WiMAX.

Wilkinson dividers also have the benefit that they can readily be designed for multiway applications. Common combining/division ratios are two-, three-, four-, six- and eight-way, however, they can also be produced to divide into other less common ratios such as five- and 10-ways. For minimum cost, most Wilkinson designs use microstrip, however, for far lower loss a stripline design approach using air or low-loss dielectric is desirable.

Hybrid couplers are usually designed with a single $\lambda/4$ section

Figure 4. From 350 MHz to 6000 MHz Wilkinson divider/combiners in two- and four-ways using a microstrip design.

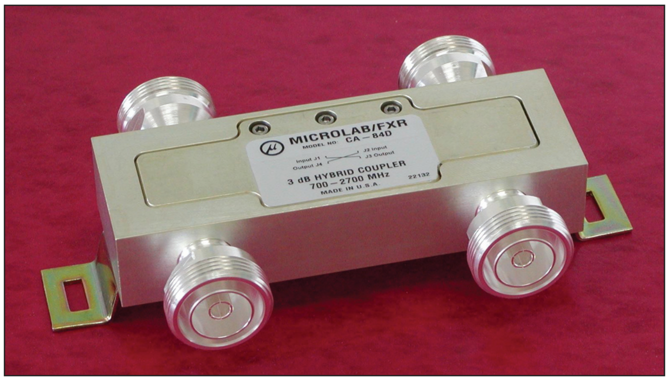


Figure 5. A multiband 700 MHz to 2700 MHz hybrid coupler with >30 dB of input isolation.

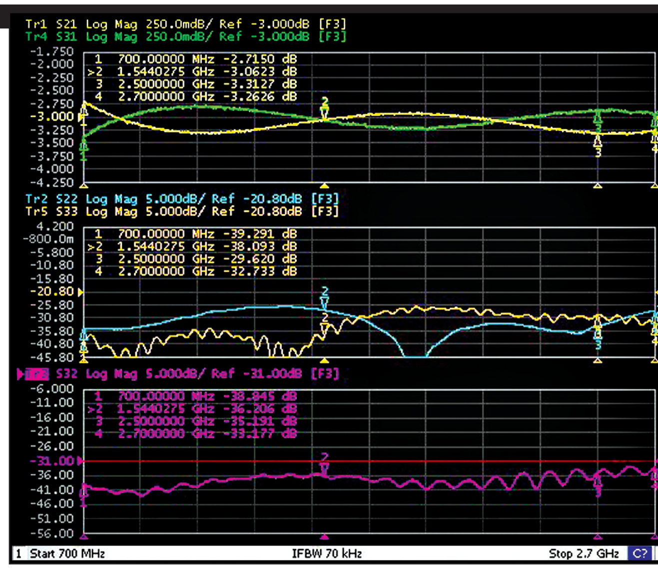


Figure 6. Hybrid coupler's typical characteristics for coupling (top), return loss (center) and isolation (bottom).

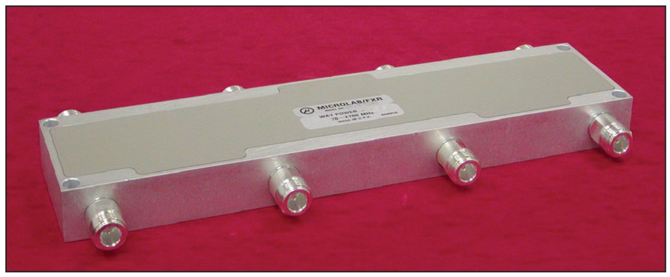

Figure 7. Simple four-input, two-output multiband 700 MHz to 2700 MHz combining matrix using three hybrid couplers and two external loads.

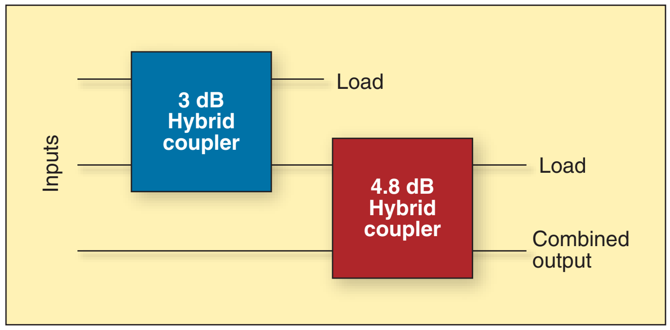


Figure 8. Schematic of a 3:1 hybrid combiner with 4.8 dB loss in each signal path.

that accommodates 15% of center frequency bandwidth. This usually satisfies the requirements for single wireless bands, such as GSM-850/900. However, this becomes a real limitation in most combining subsystems because the typical requirement includes signals from multiple wireless bands, from 800 MHz to 2500 MHz. As a result, the most commonly recommended hybrid is a multisection, stripline design, covering 700 MHz to 2700 MHz, which includes the present and future cellular, PCS, 3G and 3G/4G extension bands. Figure 5 shows such a broadband hybrid and Figure 6 its typical coupling response. Other units extend frequency coverage with flat response from 380 MHz to 2500 MHz, but at the cost of greater size and weight.

Hybrid couplers can also be designed into multihybrid matrices with three or four isolated inputs and one or more outputs. Combining four inputs to two outputs is simply feeding two standard 3 dB hybrid couplers into a third hybrid (Figure 7), but a common requirement in wireless systems is to combine just three high-power signals with the minimum of loss. Using a standard four-way configuration would expend 6 dB of loss, however, using a 3 dB hybrid coupler in combination with a 4.8 dB hybrid coupler results in a single output with just 4.8 dB of loss in each of the three signal paths as shown in Figure 8. These two hybrids are more conveniently packaged as a single unit together forming a 3:1 combining matrix.

Another important advantage of the matrix of hybrid combiners is that they naturally produce as many outputs as there are inputs. So, if a system can use multiple outputs, as in an in-building distributed antenna system or DAS, then the hybrid matrix could be theoretically considered as a 'lossless' combiner (Figure 9). Such combiners are presently available as the standard 2 x 2, 4 x 4 and more recently 3 x 3 networks, all covering single and broadband (700 MHz to 2700 MHz) requirements.

In the case of an in-building DAS, which could easily be configured to use three or even four feeds to different sections of a building, a passive combiner system can be designed to be essentially lossless. Now, since signals being combined are grouped in discrete frequency bands, it is possible to combine the advantages of diplexers or triplexers in a 'lossless' configuration. Figure 10 shows how nine inputs can be combined onto three feeds with practically no loss. In practice, of course, the number of inputs is rarely such a convenient number, but with careful selection of hybrid matrices and the use of diplexers and triplexers, can minimize the loss and provide adequate input isolation at a reasonable price.

## Other passive combiners

There are also two other forms of passive combiners that need to be considered: the simple resistive network and the reactive splitter/combiner.

The resistive network is usually configured as a star network. Hence, in a typical 10-arm network, with the resistance value in all arms chosen to provide 50 Ω to each connector, any arm can serve as an input or an output with isolation equal to the loss. Such networks are naturally low power and very lossy, and in the case of the 10-arm example shown,

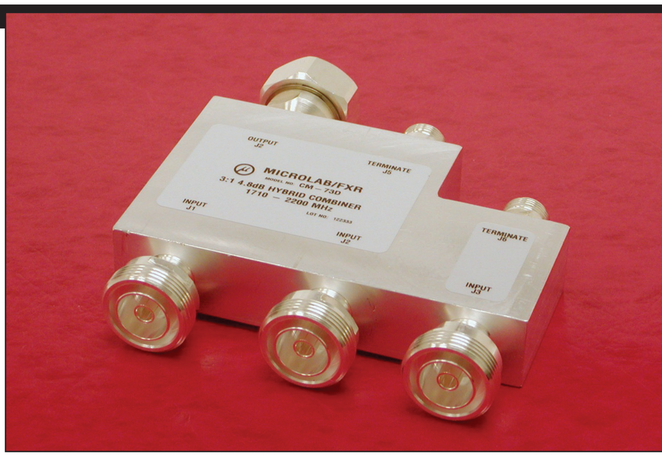


**Figure 9. Simple 2 x 2 example of a hybrid coupler being used as a lossless combiner.**

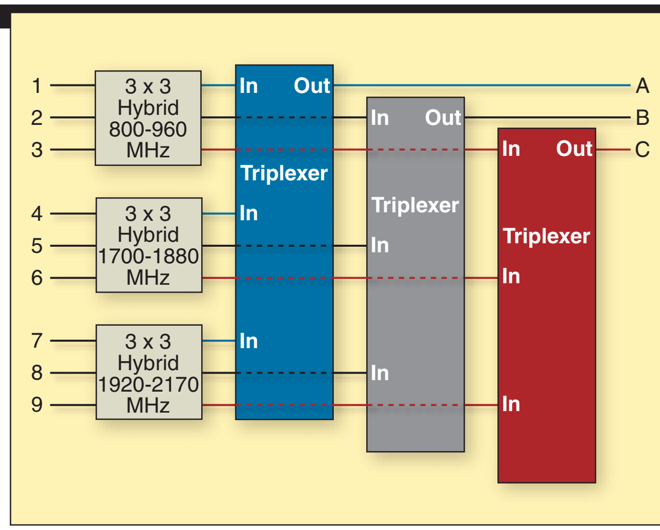


**Figure 10. Lossless combining of nine inputs to three distributed antenna feeds, as might be used in an in-building system.**

the loss is around 19 dB. However, since the design is theoretically purely resistive the frequency response is flat down to dc and is limited in top frequency by the reactance of the resistors, with a typical limit around 1,500 MHz. Because of the loss, such networks are generally used primarily for connection of multiple signal paths to one or more measuring instruments to monitor system performance.

The reactive power splitter, sometimes known as an airline splitter, is also popular and is used as a combiner in duplex systems because it has the lowest loss of all the combiners. It is essentially a coaxial impedance transformer, made in aluminum by a series of transmission impedance changes. In times past, it would be two or three sections, and limited to an octave band. Today, thanks to 3-D modeling programs, bandwidths of reactive splitters have been greatly expanded, without increasing the length of the transformer, by using filter modeling. Such splitters have a bandwidths extending from 380 MHz to 2,500 MHz and 700 MHz to 3,600 MHz, almost three octaves in each case.

Reactive splitters are sometimes ignored because their benefits are not well understood when compared to a Wilkinson or hybrid splitter/combiner. In the transmit direction, the input of a reactive splitter has an excellent VSWR, typically <1.15:1, so power is not reflected, and the dissipated loss is typically ~0.05 dB. In the receive path, where the splitter acts as a combiner, the VSWR presented is not good, and in a simple two-way example, 25% of the receive signal will be reflected, and 25% will be directed to the other receive path. The result, however, is that 50% of the receive signal is passed to a combining port, no different from a Wilkinson or hybrid coupler. Under the law of reciprocity, the loss in one direction is equal to the loss in the opposite direction. So the benefit over the alternatives is by far the lowest loss with an ability to handle high power. Plus, the product is practically indestructible, able to withstand the roughest of installation abuse and environments.

| Combiner Type | Wilkinson | Hybrid Coupler | Reactive | Resistive | Diplexer Triplexer | Duplexer |
|---|---|---|---|---|---|---|
| Primary combining and dividing application | Low-power signal combining and dividing | Combining signals in same band | Radio base station and in-building DAS | Measurement and monitoring of multiple signal paths | Separation and combining of separated signal bands | Separation and combining of transmit and receive paths |
| Common design technology | Microstrip | Stripline | Coaxial impedance transformation | Star network of resistors | Either cavity suspended substrate filter | Cavity filter |
| Bandwidth | With many sections can be 5+ octaves | Up to 3 octaves | Up to 3 octaves | dc to ~1.5 GHz | Join sub-octave bands, with adequate guard band between | Join immediately adjacent transmit and receive paths |
| Ways in/out | Two to 12 ways to single common path | Commonly 2, 3 and 4 ways in and out | 2 to 6 ways from common path | Star can have up to ~12 identical arms | 2 or 3 ways to common path | 2 ways to common path |
| Power | As combiners limited to a few Watts | Useful up to 200 W | Useful up to 700 W | Limited to a few Watts | Variable from 10 W to ~250 W | Variable from 10 W to ~250 W |
| Dissipated loss | 2 way ~0.3 dB, 4 way ~0.5 dB | 2 x 2 ~0.2 dB 4 x 4 ~0.3 dB | ~0.05 dB | High, dependent on No. of arms | From ~0.2 dB to ~ 1 dB | ~0.2 dB |
| Input VSWR | ~1.3:1 | ~1.2:1 | ~1.15:1 | ~ 1.25:1 | ~ 1.25:1 | ~1.15:1 |
| Output VSWR | | | Poor | | | |
| Isolation | Typically ~20 dB | 30 dB – 35 dB available | Poor | High with many arms | From ~30 dB to 70 dB | ~70 dB |
| PIM performance | Not suitable | <-150 dBc | <-150 dBc | Not suitable | <-150 dBc | <-150 dBc |
| Environment | Generally indoor | Indoor/outdoor | Indoor/outdoor | Indoor | Indoor/outdoor | Indoors |

**Table 1. Available options in combining signals.**

### Interference and intermodulation

For any passive combining network with combined signals powers above 10 W, intermodulation is another extremely important specification that must be considered. Intermodulation is traditionally associated with active networks, which by their nature, have non-linear junctions that produce spurious signals. In a signal path that includes transmit and receive paths, so typical in wireless distribution systems, even the slightest non-linear junction will produce transmit spurious signals that can appear in the receive channel as interference.

Passive devices, which are generally considered to be linear devices, without careful design, will generate what is known as passive intermodulation or PIM. Sources of PIM are many, but they include any contact between dissimilar conductors, foreign particles, rough surfaces, chemical contamination and more. Correct design, materials, controlled processes and 100% testing of PIM are all essential elements of producing low PIM products. Use of passive products, which are not adequately specified for PIM performance, in any distribution network will jeopardize the correct functioning of the entire network. System designers need to find components specified adequately for the combined power so as to maintain the system PIM requirements, which are around -120 dBm. In component specifications, this is usually expressed in relative terms in 'dBc' when tested with two test tones each having a power of +43 dBm. Testing is most commonly performed using a pair of swept tones over a selected frequency band.

In summary, there are many ways to combine signals, some right, some wrong for the particular intended application. Table 1 lists the choices and their benefits. RFD


### ABOUT THE AUTHOR

Tony Ramsden is president of Microlab/FXR, a wholly-owned subsidiary of Wireless Telecom. Ramsden received his B.Sc. (honours) degree in electronics from the University of Southampton in the United Kingdom in 1966. He joined the Marconi Company and became involved in the design of many early instruments and ATE systems for the analysis of PCM communications systems. This eventually brought him to the United States in 1971 as an applications engineer with the U.S. division of Marconi Instruments. In 1985, he joined Merrimac Industries as vice president of marketing. Ramsden joined Microlab/FXR is 1997.