Choosing the Best Power Divider for the Task of Signal Combining

A variety of Passive Components for Signal Combining

As systems become more and more complex, choosing how best to combine two or more RF signals has become a far more difficult question to answer, and this application article is intended to highlight the benefits of the many options available to today's system engineer.

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 signals then the more likely the loss will increase, but 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. (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 have 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 Triplexers, and even Quadraplexers, which combine the signals from three and four different frequency bands, but these become increasingly complex.

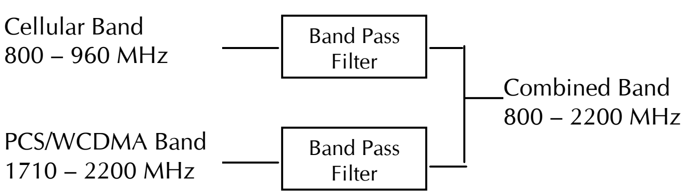

Fig. 1 Typical Diplexer Filter Combiner

Fig. 2 Typical Diplexer Combiner

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.

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 to powers of several hundred Watts. A typical stripline design on microwave dielectric will have a power limit of 100W per input, and many such hybrids combiners with an attached 100W load are used in base station applications. (see Fig 3).

Fig 3 High Power Hybrid Combiner with 100W load for base station combining

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 – 2500 MHz, they are now available for wireless applications down through VHF in bandwidths that cover from 70 to 2,700 MHz (fig 4) using an air dielectric stripline approach to minimize loss on this 17 section design, and from 350 – 6,000 MHz (fig 5) using a microstrip design so as to cover the existing commercial wireless bands and the many new frequency bands for WiFi and WiMAX.

Fig 4 Ultra wideband 70 to 2700 MHz Wilkinson Divider/Combiner using 17 sections with an air dielectric for minimum loss

Wilkinson Dividers also have the benefit that they can readily be designed for multi-way applications. Common combining/division ratios are 2, 3, 4, 6 and 8 way, however they can also be produced to divide into other less common ratios such as 5 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.

Fig 5 From UHF to WiMAX 350 to 6000 MHz Wilkinson Divider/Combiners in 2 and 4 ways using a microstrip design

Fig 6 Typical low cost 800 – 2500 MHz Wilkinson Dividers/Combiners, shown with opposed connectors for easier installation

Hybrid Couplers are usually designed with a single λ/4 section which 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 to 2500 MHz. As a result the most commonly recommended hybrid is a multi-section, stripline design, covering 700 – 2700 MHz which includes the present and future cellular, PCS, 3G and 3G/4G extension bands. (Fig 7 shows such a broadband hybrid and Fig. 8 its typical coupling response). Other units extend frequency coverage with flat response from 380 to 2500MHz, but at the cost of greater size and weight.

Fig 7 Common multi-band 700 – 2700 MHz Hybrid Coupler with >30 dB of Input Isolation

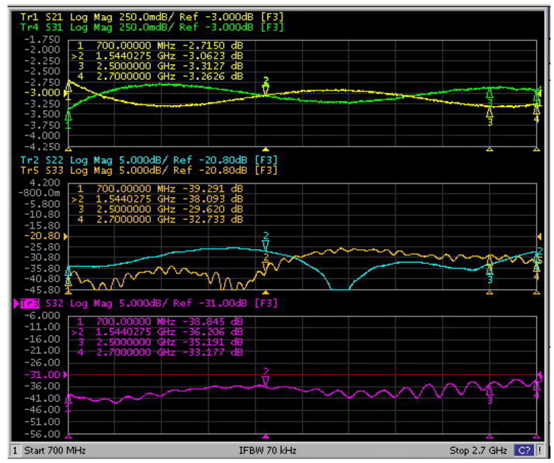

Fig.8 Hybrid Coupler's Typical Characteristics for Coupling *(top)*, return loss *(center)* and Isolation *(bottom)*

Hybrid Couplers can also be designed into multi-hybrid matrices with 3 or 4 isolated inputs with one or more outputs. Combining 4 inputs to 2 outputs is simply feeding two standard 3 dB Hybrid Couplers into a third hybrid (Fig 9), 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

Fig 9 Simple 4 input 2 output multi-band 700 – 2700 MHz Combining Matrix using three Hybrid Couplers and two external loads

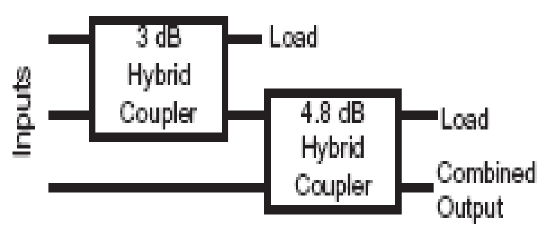

Fig 10 Schematic of a 3:1 Hybrid Combiner with 4.8 dB loss in each signal path

Fig 11 Innovative 3 input 1 output multi-band Combining Matrix using two Hybrid Couplers and external loads

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 (fig 10 block diagram). These two hybrids are more conveniently packaged as a single unit together forming a 3:1 Combining Matrix (fig 11).

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. (Fig 12 Lossless Hybrid Combining) 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 – 2700 MHz) requirements.

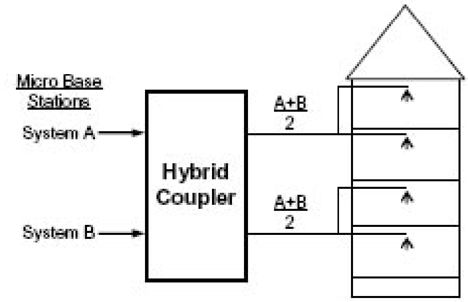

Fig 12. Simple 2 x 2 example of a Hybrid Coupler being used as a 'Lossless' Combiner

In the case of an in-building Distributed Antenna System, 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 13 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.

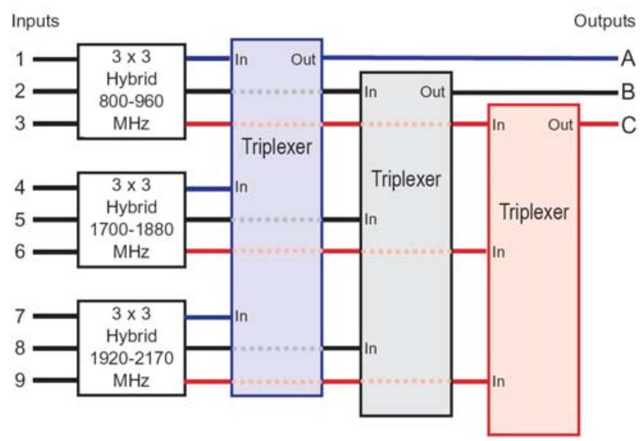

Fig 13 'Lossless' combining of 9 inputs to 3 distributed antenna feeds, as might be used in an in-building system.

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, fig 14 shows a typical 10 arm, with the resistance value in all arms chosen to provide 50Ω 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

Fig 14 Resistive Network with 10 arms

very lossy, and in the case of the 10 arm example shown, 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 air-line splitter, is also popularly 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 3D modeling programs, bandwidths of reactive splitters have been greatly expanded, without increasing the length of the transformer, by using filter modeling. The splitters shown in Figure 15 and 16 have a bandwidths extending from 380 to 2,500 MHz and 700 to 3,600 MHz, almost three octaves in each case.

Fig 15 The latest in Broadband Reactive Splitters now covering 380 to 3600 MHz

Fig 16 Inner Conductor of Broadband Reactive Splitter

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 direction, 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 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 and an ability to handle high powers, plus the product is practically indestructible, able to withstand the roughest of installation abuse and environments!

For any passive combining network with combined signals powers above 10W, 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 both 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 a 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, and the results shown as in Figure 17.

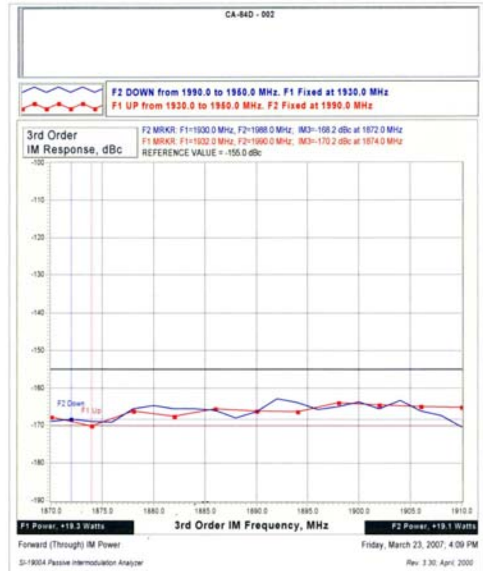

Fig 17 Actual PIM performance of a Wideband Hybrid Coupler

In summary, there are many ways to combine signals, some right, some wrong for the particular intended application. In the table below the choices and their benefits are listed:

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	2 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 200W	Useful up to 700W	Limited to a few Watts	Variable from 10W to ~250W	Variable from 10W to ~250W
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 – 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