ABOUT COMBINERS

(A pamphlet published by Decibel Products, Incorporated)

This booklet has been written for the many people engaged in two-way radio communications who are NOT radio engineers. A non-technical presentation of a rather complex subject has been attempted in an effort to bring about a better understanding of combiners used in two-way radio systems.

You can hardly expect to become an expert on combiners just by reading this, but if some of the fog is lifted and the picture seems a little clearer . . . we shall feel amply rewarded for our effort.

ABOUT COMBINERS

The need for combiners has long been recognized and is now growing at an accelerated rate. More and more land mobile radio systems are being equipped for simultaneous operation on several frequencies from a common site. A combiner can eliminate the need for separate antennas for each radio system. In addition to reducing the number of antennas, better performance can usually be realized if the highest antenna site is selected with the optimum combiner.

A single "master" antenna and its transmission line may be shared by two or more transmitters, receivers, or simplex base stations by connecting them to the antenna through a combiner. Sharing of a single antenna is not limited to a single system operator. When a multiplicity of base stations, operated by different users, are located at the same site, they can often share a common antenna, depending on the frequencies used.

Most radio systems utilizing independent antennas and transmission lines when operating at a common site, require multiple interference protective devices. These usually are ferrite isolators for reducing transmitter intermodulation to an acceptable level; bandpass or band-reject cavity filters (installed between transmitters and antenna) for reduction of transmitter noise, and bandpass or band-reject cavity filters for receiver desensitization protection from transmitter carrier frequencies. These devices introduce losses to transmitter power and received signal strength. These losses, if interference free radio systems are to be achieved, can approach those of a combiner and yet not afford an optimum "R.F. clean" antenna site.

Combiner Requirements. A combiner that enables use of a common antenna by two or more transmitters should cause a minimum of insertion loss (transmitter power loss) and should provide a high degree of isolation between the transmitters so that potential transmitter produced intermodulation frequencies are minimized. *Transmitter intermodulation is the primary factor that must be considered when two or more transmitters are combined into a common antenna.* A combiner that enables use of a common antenna by a number of both transmitters and receivers must in addition to the preceding, reduce to an acceptable level receiver desensitization by each transmitter carrier and transmitter noise at each receiver frequency.

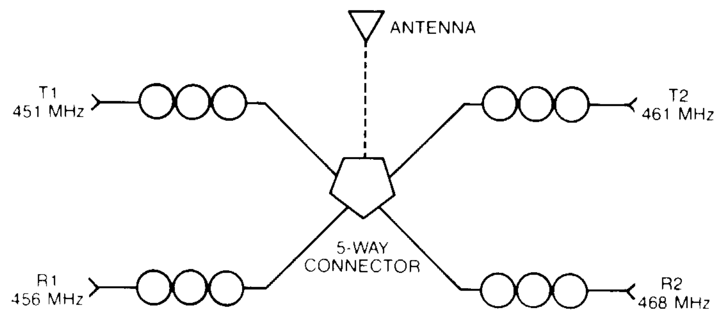
When the transmitters and receivers share a common antenna through a combiner, the only practical method of protection for transmitter noise and receiver desensitization is by use of resonant cavity filters between the transmitters and receivers. Should the frequencies be separated by a reasonable amount (the radio manufacturer's duplex operation curves can provide the proper isolation required for any given frequency separation) a simple cavity filter combiner configuration can be used for two or more systems. If the transmitter frequencies are extremely close, then the hybrid-ferrite isolator combiner is normally used. A discussion of these various type combiners follows.

Cavity Type Combiners. The cavity type combiner is one of the most common types of combiners used to couple transmitters and/or receivers into a single antenna. This type of combiner is generally more economical and less lossy than hybrid/ferrite combiners and is used normally when the frequency separation between the channels to be combined are separated at least 150 KHz at low band, 500 KHz in the 150 MHz band, and 1 MHz in the 450 MHz band. Also, as mentioned previously, if there are receivers in the systems to be combined, cavities must be used since hybrid/ferrite combiners have unidirectional devices (isolators) as components.

The cavity-type combiners can be composed of all bandpass cavities, all notch (band-reject) cavities, or a combination of bandpass and notch filters. A discussion of these types follows.

All Bandpass Combiners. This type of combiner is used when a fixed number of stations which have relatively wide frequency separation between them are combined into a single antenna.

Figure 1 shows a block diagram of a bandpass combiner. Two transmitters and two receivers are combined into a single antenna through the use of bandpass cavities and a 5-way connector. The bandpass cavities in the transmitter lines protect the receivers from transmitter sideband noise radiation by attenuating the output of the transmitters at the receiver frequencies. Those in the transmitter lines also mutually isolate the transmitters reducing the possibility of transmitter intermodulation product generation. The bandpass cavities in the receiver lines protect the receivers from receiver desensitization by attenuating the transmitter carriers before they reach the receivers.



ALL BANDPASS COMBINER

Figure 1

The number of cavities in each system in the combiner is dependent on the frequency separation between the systems. In figure 1, if the frequencies were closer together, four or possibly five bandpass cavity filters would be needed to mutually isolate the systems.

The length of interconnect transmission line from the cavity to the 5 port junction is electrically an odd quarter-wave length (including the electrical length of the cavity coupling loop) such that the other

three frequencies are presented a high impedance (open circuit) at the 5 port junction. Consequently, very little coupling loss is added to the insertion loss of the triple bandpass cavity for each frequency.

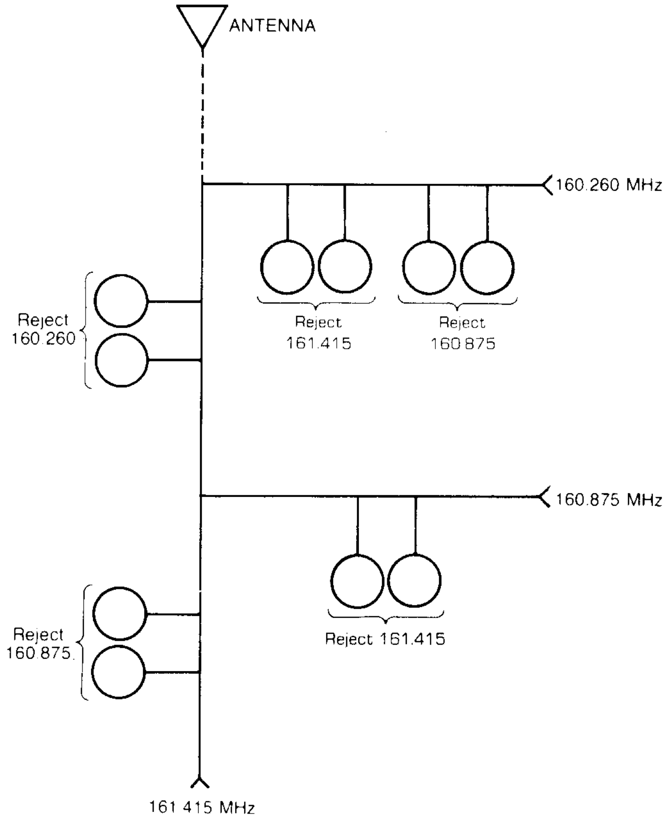
The number of systems in this type of combiner is not limited to four. The limitation as to number of systems depends upon the frequency separation between the sysems, the bandwidth of the antenna, and the maximum insertion loss which can be tolerated, i.e. desired E.R.P. The all bandpass combiner can be used when the frequency separation between systems is at least 500 KHz in low band, 1 MHz in the 150 MHz band, 2 MHz in the 450 MHz band, and approximately 5 MHz in the 806-960 MHz frequency band.

The main advantage of an all bandpass cavity combiner is the added protection to the receivers from the carriers of other transmitters in the general area as well as those in the combiner. Likewise the bandpass cavities in the combiner provide added protection against transmitter noise to other receivers in the area as well as those in the combiner.

Compared to hybrid type combiners, the bandpass type generally has lower insertion loss per channel. The disadvantages include its relatively large physical size, its inability to operate satisfactorily at very close frequency spacings, and the fact that the combiner is not readily expandable to more systems.

Notch Filter Combiner. The all notch filter combiner is used normally when the frequency separation is too close for bandpass filters, yet is still wide enough that ferrite isolators are not needed. This type combiner is one of the most widely used combiners, especially when only two systems are combined. When two closely spaced systems are to be combined, the simplest device to use is a standard band-reject type duplexer, which can combine two transmitters or two simplex systems as well as the normal duplex transmitter and receiver to a common antenna.

In the block diagram of figure 2, we see three systems coupled together by use of a notch filter combiner. Note that the frequency separations are 540 kHz and 615 kHz. Each system is mutually protected from the other by a series of two cavity notch filters having about 50 dB isolation. The insertion loss of each system measured at the antenna port (output) is approximately 2.5 dB.



NOTCH FILTER COMBINER

Figure 2

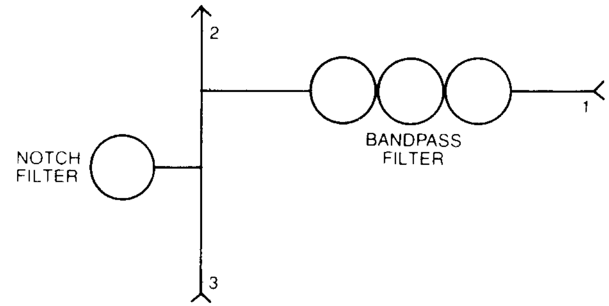
The addition of another system to the above example is possible but economically impractical since the number of cavities would nearly double. The reason for this is that each system must be protected from the new system, while the new system needs protection from the existing systems. This would add eight more cavities.

Because of the above reasoning, the band-reject type combiner is best suited for combining 2 or 3 but rarely 4 systems.

The advantage of the band reject combiner is its use in combining systems with close frequency separations. These minimum separations are approximately 150 kHz at low band, 500 kHz in the 150 MHz band and 1 MHz in the 450 MHz band.

An important disadvantage is its lack of interference protection from other systems located nearby geographically.

Bandpass - Notch Combiners. This class of cavity type combiner uses the combination of bandpass and notch filters to allow many transmitters and/or receivers to be used with a single antenna. This type is a modular system in that each channel consists of a bandpass filter and a notch filter, as shown in figure 3.



BANDPASS - NOTCH MODULE

Figure 3

The purpose of the bandpass filter is to isolate the system from others in the multicoupler. The notch filter is used mainly for matching the input terminal to the output. i.e., low insertion loss from port 1 to port 2 and vice versa.

The number of cavities in the bandpass filter will be dependent on the frequency separation between the systems and the maximum insertion loss which can be tolerated.

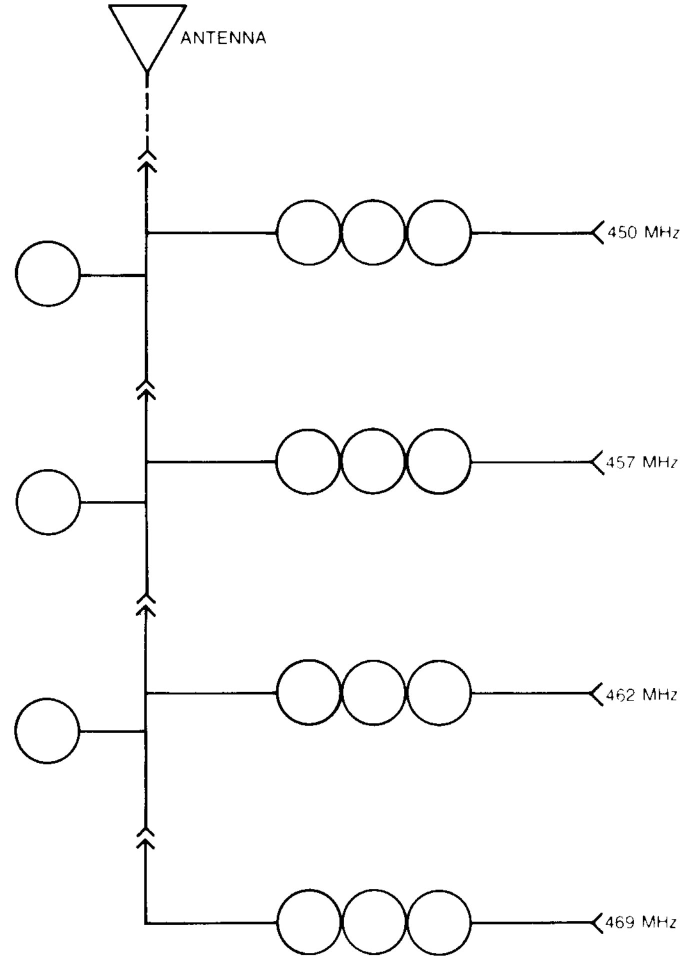
Figure 4 shows how these "modules" fit together to make a four system combiner. The last system does not need a notch filter for matching since it is the terminal system. However, if another system were to be added at a later date, a band-reject filter for system No. 4 would be needed.

The bandpass notch combiner should be used when a readily expandable system is needed and the minimum frequency separations are approximately 500 kHz in low band, 1 MHz in the 150 MHz band, 2 MHz in the 450 MHz band, and 5 MHz in the 806-960 MHz frequency band.

Like the all-bandpass combiner, the bandpass notch combiner has the advantage of added interference protection from other systems in the immediate area.

Its disadvantages include its relatively large physical size and its inability to operate satisfactorily at very close frequency spacings.

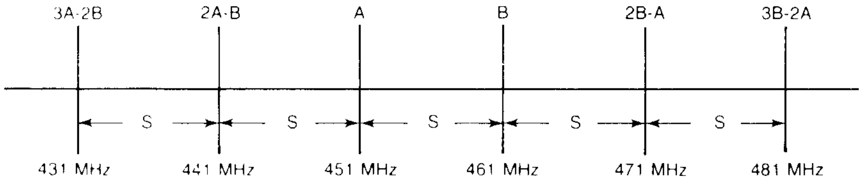
Transmitter Intermodulation. The all-bandpass combiner offers excellent protection for transmitter noise and receiver desensitization. But what about transmitter intermodulation products and/or receiver intermodulation products? Remember, we have stated, "Transmitter IM is the primary factor that must be considered when two or more transmitters are combined into a single antenna." All intermodulation products produced by mixing in the non-linear output of either transmitter, or the non-linear input stages of the receiver are a function of the frequency difference between the



BANDPASS/NOTCH COMBINER

Figure 4

mixing frequencies for any number of sums and differences of the fundamental frequencies and their harmonics. This is illustrated for the familiar 3rd and 5th order intermodulation products by figure 5.



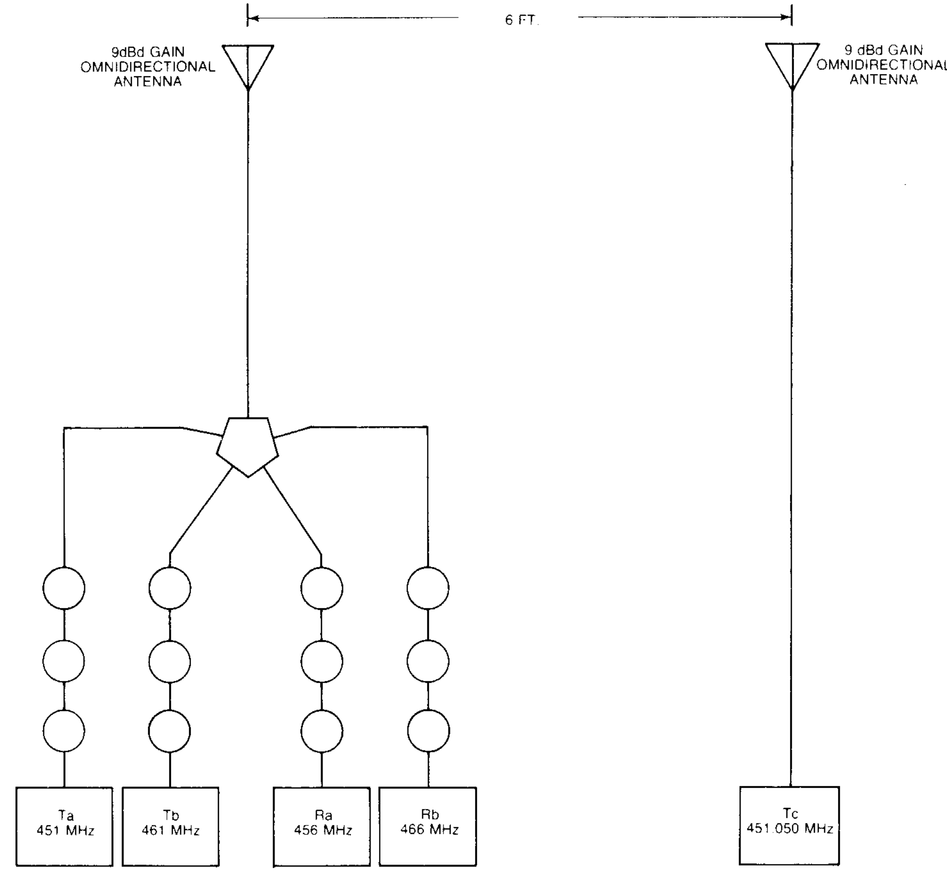
INTERMODULATION FREQUENCIES

Figure 5

Typical System Analysis. The following example illustrates the 3rd order intermodulation protection provided by the all-bandpass combiner of figure 1, A is frequency T1, B is frequency T2, and their frequency difference is S. Third order intermodulation frequencies 2A-B, 2B-A and 5th order 3A-2B, 3B-2A are depicted. There are an infinite number of intermodulation frequencies having a frequency difference S. However, normally only the 3rd order products are of sufficient power levels to cause interference problems. The attenuation to each intermodulation product by the triple bandpass cavities can be determined from the cavity response curves. The energy coupled into transmitter A from transmitter B is attenuated approximately 70 dB (10 MHz frequency difference) by the cavities. Likewise, from transmitter B into transmitter A. After mixing in the non-linear output of transmitter A or B, the 3rd order intermodulation product, being 20 MHz off resonance of the cavities, is attenuated by more than 70 dB. Consequently, the 3rd order intermodulation products are greater than 140 dB below the transmitter carrier(s). A most insignificant level.

However, suppose this is not the only system at this location. Further suppose another 9 dBd gain antenna radiating 250 watts, at a frequency 2 channels higher is located horizontally from our systems 9 dBd gain antenna, as shown by figure 6.

The frequency difference being 50 kHz, the transmitter carrier frequency from transmitter C into A is attenuated essentially only



CLOSE COUPLED SYSTEMS
WITH 3RD ORDER INTERMODULATION EMISSION

Figure 6

by the space coupling loss between the antennas and transmission line loss. The cavities offer practically no attenuation other than the insertion loss at this frequency separation.

Let us determine the approximate power of the radiated 3rd order intermodulation frequency from transmitter A.

Coupling loss

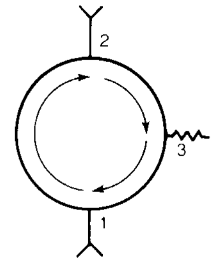
Antenna space coupling loss	=	–25 dB (Antenna 1 to 2)
Transmission line loss	=	–1 dB (Transmitter A & B)
Cavity loss at +50 KHz	=	–2.5 dB (A)
Total		–28.5 dB

3rd Order Intermodulation Product radiated from A

Transmitter Power (250 watts)	=	+24 dBw (from C)
Coupling loss	=	–28.5 dB (C to A)
Power in final (Tx A)	=	–4.5 dBw
Transmitter conversion loss	=	–6.0 dB (assumed)
Cavity loss at +100 kHz	=	–3.0 dB
Antenna gain	=	+9.0 dB (antenna A)
Transmission line loss	=	–1.0 dB (A)
ERP of IM product	=	–5.5 dBw (reference to half-wave dipole)
		or 0.28 watts

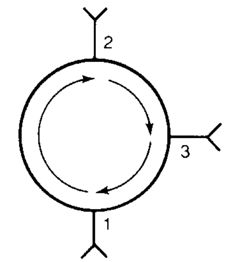
This radiated power could be a problem to some mobile system that might be in the vicinity of the antenna site and could easily occur if our site were a building roof top.

The Ferrite Isolator. The ferrite isolator (figure 7) is a three port circulator (figure 8) with a matched resistive load connected to port 3. The ferrite circulator is a 3 port non-reciprocal device consisting of ferrite material, magnets, and three short lengths of transmission line terminated at a common junction. The basic ferrite material commonly used is an oxide of yttrium iron garnet (YIG) commonly called garnet. The garnet is cut to the proper shape



FERRITE ISOLATOR

Figure 7



FERRITE CIRCULATOR

Figure 8

in a manner like the crystals as used in the two-way radio. The proper combination of incident rf field and dc magnetic field cause what is called "gyromagnetic resonance". For one direction, dispersion and resonance absorption, whereas the response for the opposite direction is flat. It is from these opposite effects that permit isolation between the ports of the circulator. Power entering port 1 is "rotated" and emerges at port 2. Power entering at port 2 emerges at port 3 and is absorbed by the resistive load. The load at port 3 should always be of adequate wattage rating to absorb the maximum expected reflected power from the subsequent antenna system.

The ferrite isolator is the most effective solution to transmitter produced intermodulation when the frequency separation between the transmitter frequencies are as close as adjacent channels. When installed between the transmitter and subsequent combining network, or between transmitter and antenna, the ferrite isolator acts like an rf diode. It passes transmitter power from its input (port 1) to its output (port 2) with very little loss, perhaps –0.5 dB but attenuates energy in the opposite direction by 25 to 30 dB.

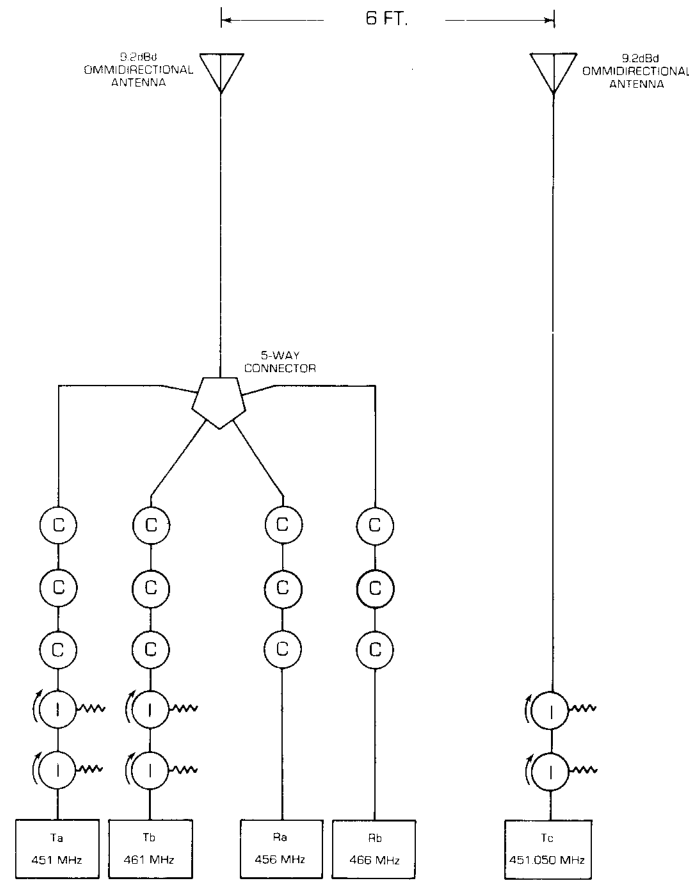
Low Loss Type Transmitter Combiner. To prevent radiation of transmitter intermodulation products from our all bandpass cavity combiner of figure 6, we can add a pair of tunable ferrite isolators to each transmitter leg as shown by figure 9. The coupling loss of figure 9 is now increased by an additional 60 dB, and with this added insertion loss, the power radiated by the 3rd order intermodulation frequency is 0.28 microwatts. An insignificant amount. It must be pointed out that the ferrite isolators must also be in transmitter C of figure 9 if we are to reduce intermodulation products from transmitter C due to transmitters A and B.

Low Loss Transmitter Combiner For Close Frequency Spacing. Utilizing extremely high Q bandpass cavities and ferrite isolators, the all-bandpass combiner of figure 1 can be used for extremely close transmitter frequency separations. A four channel low loss transmitter combiner is shown schematically by the block diagram of figure 10.

The primary function of the high Q cavity is to match the impedance at the junction so that the signal from each transmitter passes through the junction to the antenna at a minimum loss. The higher the cavity Q — or the greater the cavity selectivity — the closer frequency separation between channels we can use and still maintain low insertion loss per channel.

In an extremely high Q coaxial cavity the input impedance rapidly approaches a low impedance as the frequency moves off resonance. In the 150 MHz frequency band, the impedance at 60 kHz off resonance is low enough such that by using the proper length of cable between the cavity and the N-way junction (quarter-wavelength less the electrical length of the coupling loop) a high impedance is presented at the junction allowing all of the signals from the other transmitters to pass through the junction at a minimum loss.

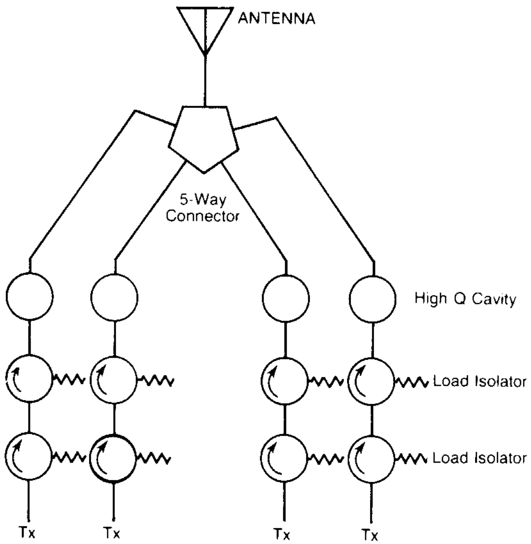
A definite advantage that the low loss combiner of figure 10 offers, is the additional filtering from the high Q cavities in the line. At 5 MHz from the transmitter frequencies (where the receiver frequencies usually fall) transmitter noise and spurious responses are usually reduced at least 50 dB from the output of the transmitter.



C = CAVITY
I = FERRITE ISOLATOR

CLOSE COUPLED SYSTEM WITH FERRITE ISOLATORS
Figure 9

The low loss type combiner of figure 10 is readily expandable to a 5, 6, 7, or 8 channel unit. The loss through the combiner does not appreciably increase unless the frequency separation between channels is decreased.

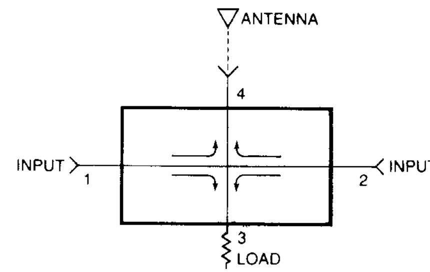


BLOCK DIAGRAM OF LOW LOSS 4 TX COMBINER

Figure 10

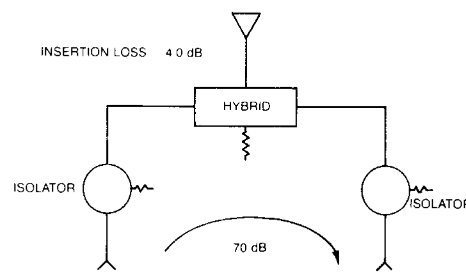
The Hybrid Coupler. (Figure 11) is a four port stripline 3 dB directional coupler. When the hybrid is properly terminated with matched loads, isolation is provided between port 1 and port 2 of up to 40 dB. Energy entering port 1 and/or port 2 splits with half going to port 3 and half to port 4. Consequently, the termination at port 3 must be able to absorb half of each transmitter's power.

Hybrid Combiner. The hybrid two-transmitter combiner (figure 12) utilizes a 3 dB stripline hybrid, ferrite isolators and low pass (harmonic) filters to combine two transmitters at adjacent channels or up to a frequency separation as determined by the bandwidth of the hybrid and/or ferrite isolators. The harmonic filter is required because the ferrite isolator may itself produce harmonics. (The bandpass cavity rejects harmonic energy in the low loss type combiner).



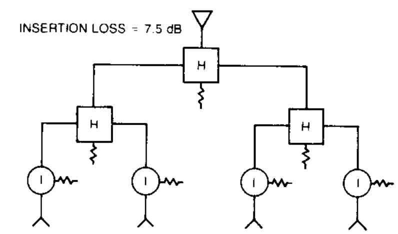
3-dB STRIPLINE HYBRID COUPLER

Figure 11



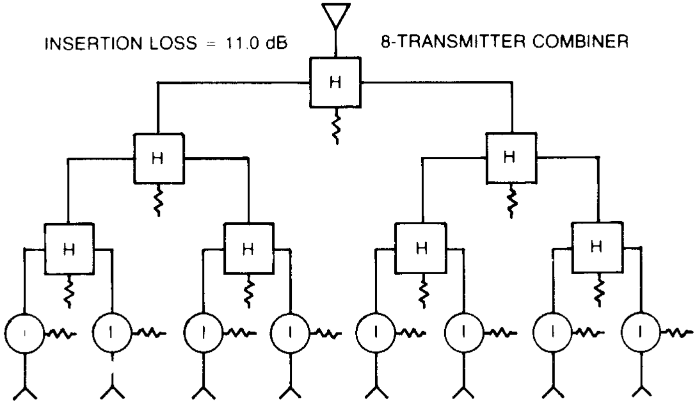
HYBRID TWO-TRANSMITTER COMBINER

Figure 12



HYBRID FOUR-CHANNEL COMBINER

Figure 13



HYBRID EIGHT CHANNEL COMBINER

Figure 14

The use of additional hybrid couplers and two-transmitter combiners allows the expanding to either a four channel transmitter combiner (figure 13) or an eight transmitter combiner (figure 14). The nominal isolation between transmitters is 65 to 70 dB when a single isolator is used and can approach a 100 dB when two isolators are used per channel. However, as the number of transmitters increase in these combiners the insertion loss for each transmitter is increased. For example, the two-channel combiner has a loss of approximately 4 dB, the four-channel approximately 7.5 dB and the eight channel is approximately 11 dB.

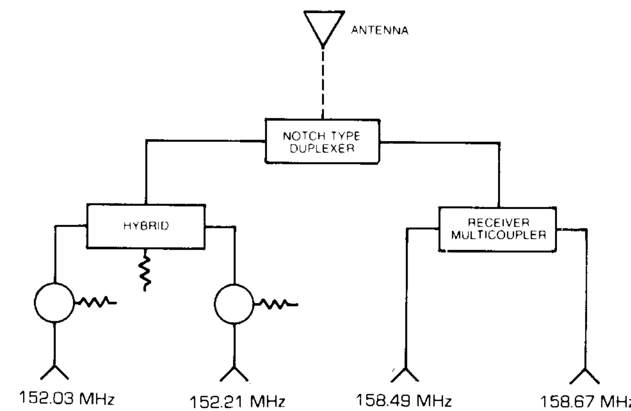
A disadvantage, besides the transmitter power loss, of the hybrid type combiner is that the isolation of the hybrid is a function of how well the hybrid is matched to the antenna system. An input VSWR of 1.5:1 to the transmission line antenna system can cause up to a 25 dB loss in isolation. However, most hybrid couplers have built-in matching circuits to match up to a 1.5:1 VSWR, thereby maintaining at least 40 dB isolation.

The main advantage of a ferrite combiner is its ability to isolate and combine any channel assignments within its frequency band. Its relatively small size is another advantageous feature. Multiple channel combiners can be packaged in standard 19″ rack space.

The Receiver Multicoupler or Combiners. Normally, each transmitter, unless it is for paging only, has a receiver associated with it. If the transmitters are combined into a single antenna, then logically we should couple all the receivers from a common antenna.

Usually, the receiver multicoupler for close frequency spacing will consist of a 2, 4, 8, 16, etc. hybrid splitter and an amplifier.

The critical aspects of a receiver multicoupler are the stringent requirements for an active device with enough gain to recover the splitting losses and yet have an extremely linear gain characteristic. Otherwise, a non-linear mixing stage is present to generate receiver intermodulation products that could mask the desired signals.



TWO CHANNEL TRANSMITTING & RECEIVING COMBINING SYSTEM

Figure 15

A Complete System Configuration. Figure 15 depicts a two-channel hybrid type combiner operating through a duplexer with a two port receiver coupler. The criterion with this configuration is that the duplexer have a bandwidth that will accommodate the required frequencies.

In order for the combiner to operate efficiently, the transmitter frequencies must be spaced close enough to allow the notch type duplexer to adequately isolate the transmitters and receivers. In other words, the notch width of the duplexer at the required isolation will dictate the maximum transmitter frequency separation. This criterion also applies to the receiver frequencies.

In many systems, such as the RCC, taxi, and mobile telephone channels, bandwidths up to 600 kHz are needed to combine all or most of the available channels. In cases such as these, the low Q, rack mount, notch type duplexers are needed in the combiner because their wide notch widths allow adequate isolation across the entire frequency band. Also, a bandpass duplexer would not be practical since a relatively broad band of frequencies are to be "passed" through the duplexer.

Combiner Selection. The optimum type of combiner for a particular system depends upon separation of frequencies, antenna system gain, number and power output of transmitters, number of receivers (if any), proximity to other systems, and other local factors. A combiner should be designed to meet the requirements of a specific system.

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