SEMINAR SUBJECTS

COMBATING SPURIOUS OUTPUT AND OVERLOADING WITH CAVITY FILTERS.

AN ELEMENTARY AND GRAPHIC EXPLANATION

TX RX SYSTEMS INC.®

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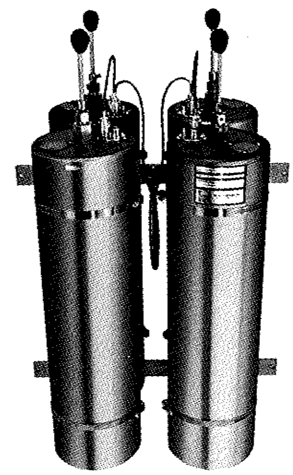
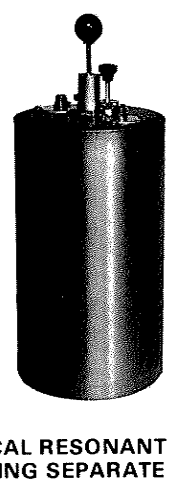
Y501 F7

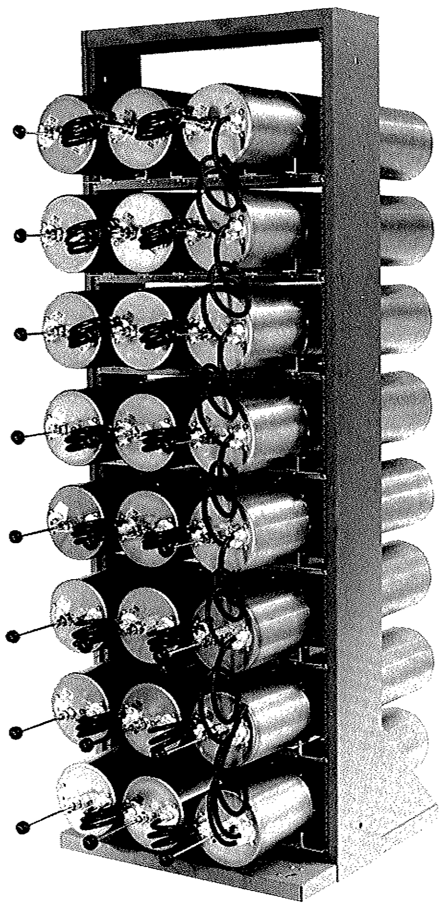
MULTICOUPLER SYSTEMS
DUPLEXERS
CAVITY FILTERS
RF SYSTEM PRODUCTS



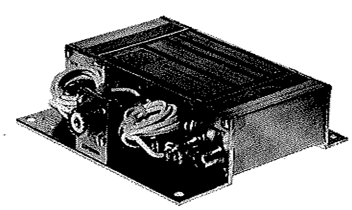
TYPICAL DUPLEXER RACK MOUNT
USING FOUR
6.625" DIAMETER CAVITIES



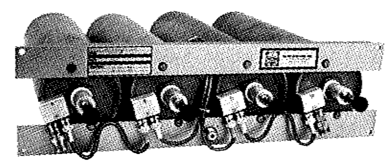
TYPICAL RESONANT CAVITY
SHOWING SEPARATE COARSE
AND FINE TUNING CONTROLS



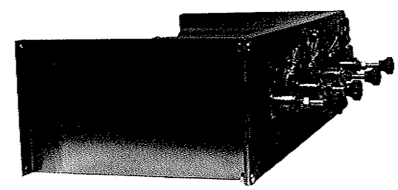
TYPICAL T-PASS™
EXPANDABLE MULTICOUPLER



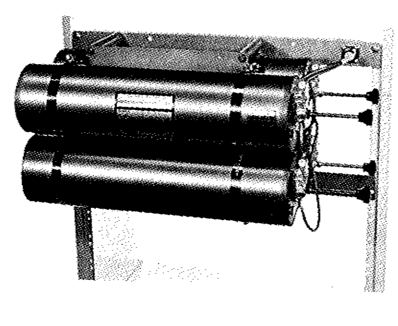
TYPICAL VHF MOBILE CONFIGURATION
FOUR CAVITY VERSION



TYPICAL DUPLEXER RACK MOUNT
USING FOUR 4" DIAMETER CAVITIES



"-A" ALTERNATE UHF MOUNT
USING BRACKETS FOR REAR MOUNTING



TYPICAL CROSS MOUNT DUPLEXER
USING FOUR 4" DIAMETER CAVITIES

VARI-NOTCH® SYSTEMS, INC. — T-PASS™ CHANNELS — SERIES NOTCH™

The following set of illustrations and text explain the function of TX RX filters, duplexers, and multicouplers by showing how they affect the equipment they work with, that is, receivers and transmitters.

The device used to show this is a piece of fictitious test equipment called an "ideal spectrum analyzer." This ideal analyzer is not unlike the real thing except that it has unlimited dynamic range (ability to handle very strong and very weak signals simultaneously) and an extremely low noise floor which allows us to see even the weakest of receive signals. A real analyzer has a typical noise floor of about -120 dbm and a dynamic range of 80 db. However, a theoretically ideal instrument, such as the one we will use, serves nicely for showing the principles of filtering.

The face of our ideal spectrum analyzer is calibrated in dbm, from +60 dbm (1000 watts) to -160 dbm, the noise floor of this analyzer. The dynamic range of this instrument is 220 db, the difference between +60 and -160 dbm.

Two signals appear on the face of our analyzer in **figure 1**. To the right is a .3 microvolt (-117 dbm) signal at 465 MHz. This is a typical full quieting receive signal for a modern-day FM communications receiver. A 100 watt (+50 dbm) transmitter carrier appears at 460 MHz. The signal displayed is an ideal one because no spurious (noise) emissions appear at any power level. A more realistic transmitter signal will appear in a later illustration.

The lines that appear on the face of our analyzer in **figure 2** are not ones that would normally be visible on the CRT of a spectrum analyzer. This information might be marked on the analyzer graticule with a grease pencil and represents the ultimate selectivity or receive window of three different receivers at 465 MHz. Information such as this could be obtained from the receiver manufacturers' data sheets. These lines indicate the signal level of an off-channel signal that will cause 1 db degradation of a receiver's 12 db SINAD sensitivity.

An ideal receiver would respond only to its desired channel and reject all off-frequency channel signals, no matter how strong. This ideal receiver window is depicted in figure 2. The bottom portion of this window represents the receiver's noise floor or weakest signal level that can be heard (-137 dbm).

Real receivers respond to strong off-frequency signals somewhat differently. When these signals have sufficient strength to cross the line, some form of audible response will be detected in the receiver. As with most real equipment, some receivers are better than others in their ability to handle high level interference. This is primarily determined by the amount of RF selectivity used ahead of the receiver's first RF amplifier and mixer and the overloading characteristics of these stages.

Suppose we connected our 460 MHz, 100 watt transmitter and the 465 MHz receiver to a common antenna as shown in **figure 3**. (Caution: Do not try this as damage would occur to a real receiver.) Two random length cables from the RX and TX are connected to a three-way tee which connects to the antenna feed line. The analyzer is also connected to this feed line. It is readily evident that the transmitter carrier is getting into the receiver window and causing interference (I). This interference is characterized by receiver desensitization and the amount of interference will be greater with a receiver of lower ultimate selectivity. Also, spurious signals can be generated in the receiver front end (IM products) depending on the frequencies involved.

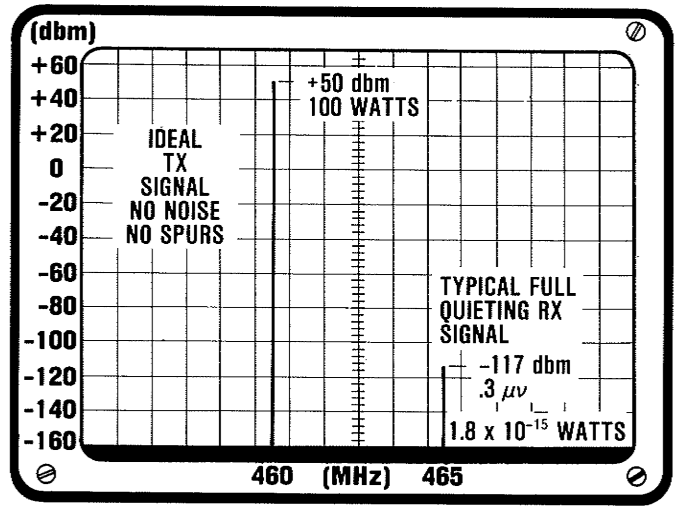


FIG. NO. 1

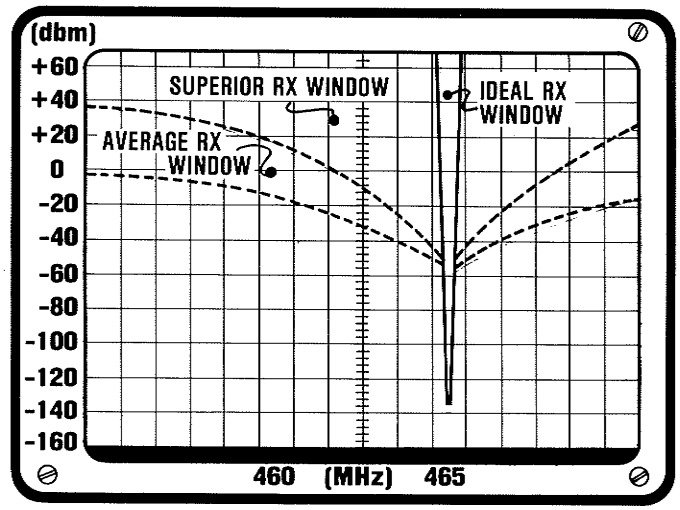
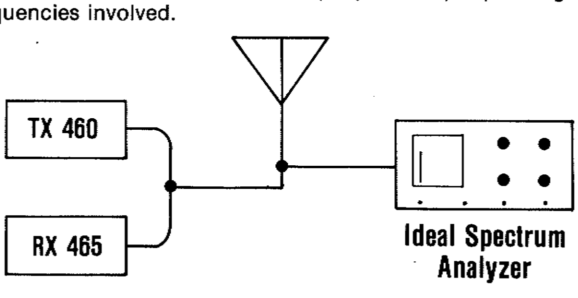


FIG. NO. 2



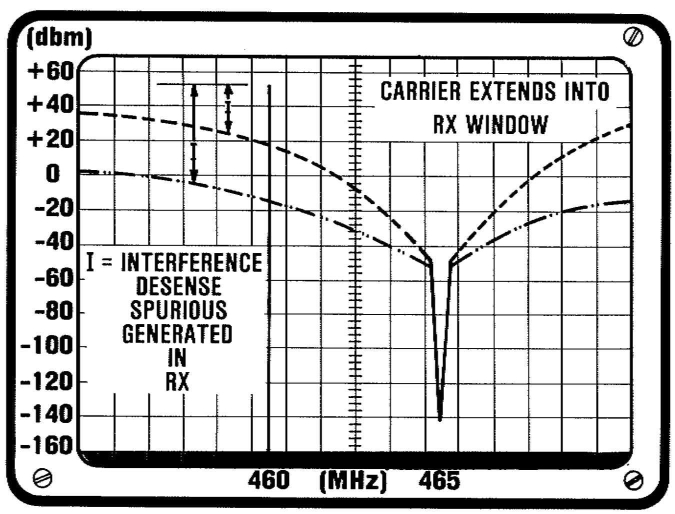


FIG. NO. 3

Enlarged Analyzer Display

A more realistic way of coupling a receiver and transmitter to a common antenna is shown in **figure 4.** A **Series Notch™** cavity filter has been inserted in the receive line and is tuned to reject (notch out) the transmitter carrier frequency. The notch filter modifies the receive selectivity curve as shown in the accompanying analyzer display. The notch appears upside down on the display. This filter makes the receiver 30 db less sensitive at the transmitter frequency. The receive signal passes by this filter with negligible attenuation and successful duplex operation would result if all transmitters were ideal.

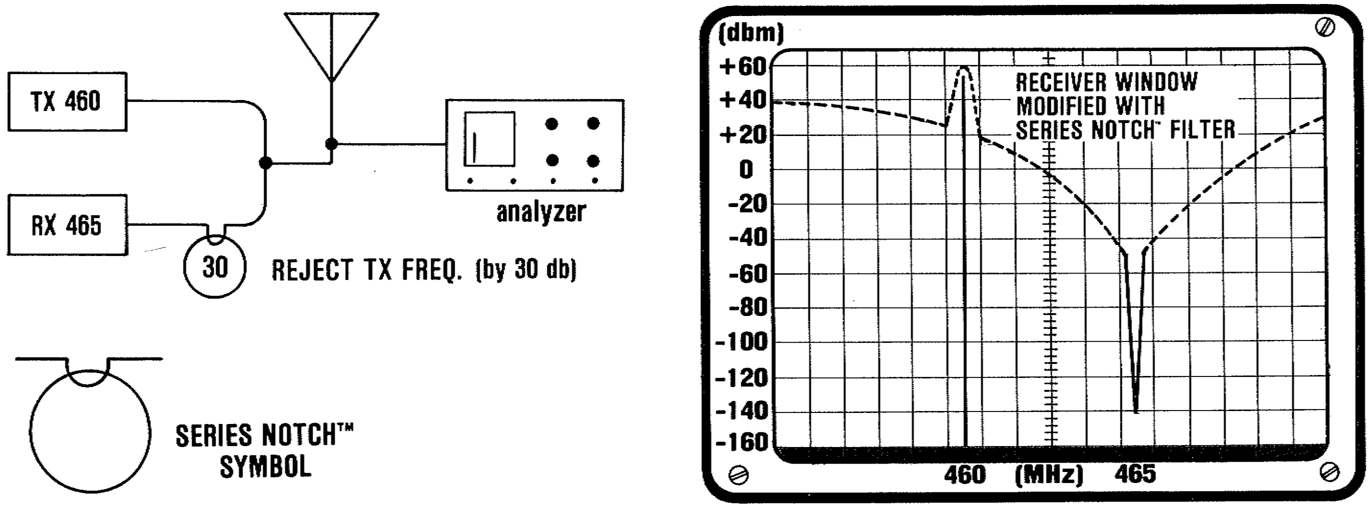


FIG. NO. 4

The output spectrum of a typical transmitter is shown in **figure 5.** (Do not connect a real spectrum analyzer as shown because damage could result.) Our ideal analyzer reveals that more than our clean ideal transmitter carrier is present. Noise and spurious output always accompany the signal from even the best transmitter, and result from a number of processes in a transmitter that produce an FM modulated signal at UHF frequencies. The spurious spikes are usually some harmonic of the carrier oscillator frequency which is multiplied many times to get to the operating frequency. The non-linear action in frequency multipliers also tends to generate mixing products (IM) due to the various harmonic frequencies present in each stage. When direct FM modulation is applied to the oscillator (or phase modulation to an amplifier) all these individual harmonics also deviate in frequency. These modulation noise sidebands combine with the harmonic, IM spurious and white noise output to form a transmitter signal noise floor.

The F.C.C. says that this noise and spurious must be suppressed by a factor of 43 + 10 log of the output power (watts) of the transmitter at ±250% of the authorized bandwidth. This means that all spurious from our 100 watt, 460 MHz transmitter must be suppressed by 63 db or greater below the 100 watt level to be acceptable. However, this means that this noise can be some 124 db above the noise floor of our 465 MHz receiver. A .3 microvolt signal is shown to be buried in transmitter noise in figure 5.

As with any kind of real equipment, different transmitters will have various amounts of noise and spurious in their output, although all of them meet F.C.C. specifications.

Obviously, something has to be done to this noise if we are to achieve successful duplex operation.

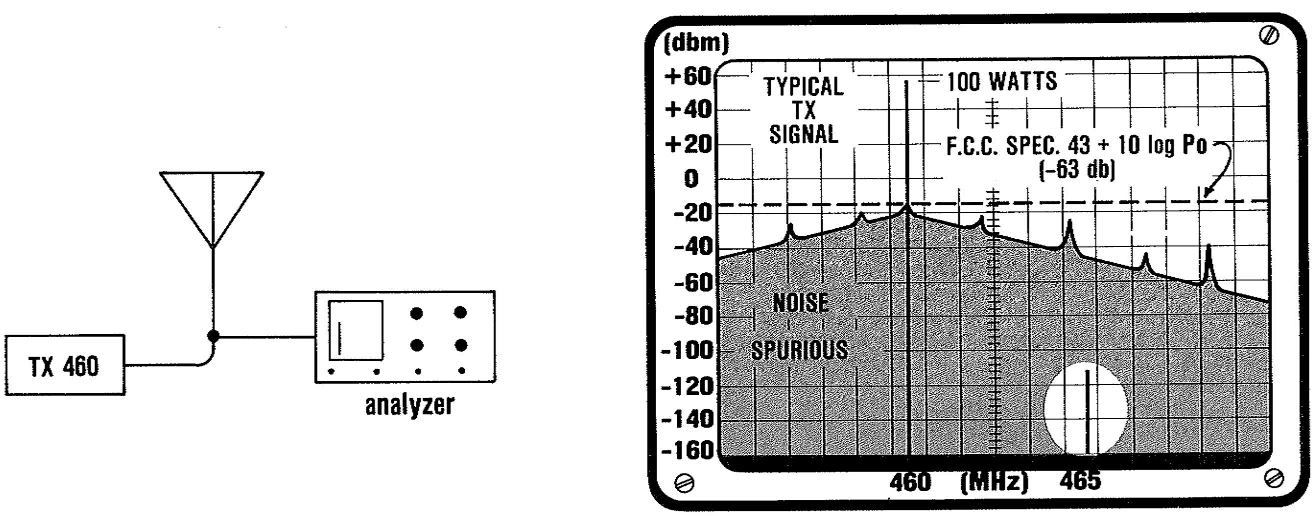


FIG. NO. 5

Series Notch™ filters can be used to suppress transmitter noise as illustrated in **figure 6.** Here, two Series Notch™ filters are used to provide some 65-70 db of transmitter noise suppression. These cavities are connected to the transmitter output and are tuned to produce a notch at the receive frequency. The results are readily apparent on the analyzer display. The transmitter noise is notched out around the receive frequency and is no longer strong enough to enter the receive window.

With the receiver being protected from carrier desense, and the transmitter noise being filtered with Series Notch™ cavities, a successful duplex operation will result. The resultant duplexer is referred to as an unsymmetrical notch duplexer owing to the unequal number of cavities in the receiver and transmitter sections. This type of duplexer has been in common use for many years, particularly in mobile duplex applications.

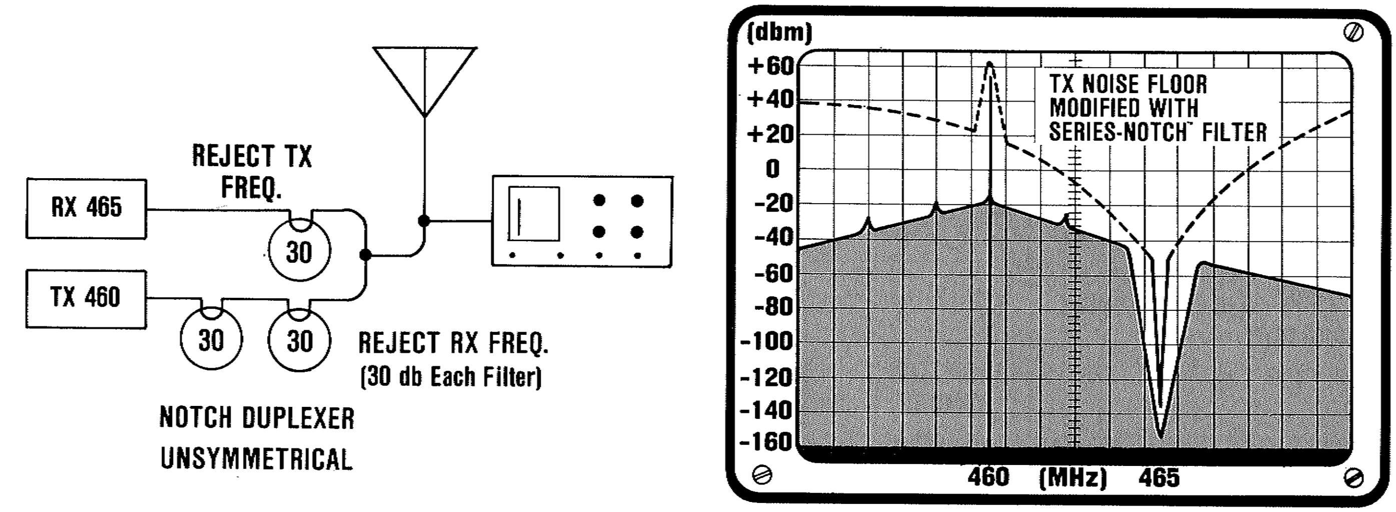


FIG. NO. 6

Notch duplexers do have failings that have become very apparent since the appearance of all-solid-state radios. **Figure 7** shows an average transmitter and receiver duplexed to a common antenna with a four-cavity notch-type duplexer. The ideal spectrum analyzer display indicates that less than quiet operation will occur. Transmitter noise is entering the receiver window both above and below the receiver channel frequency causing noise interference and desensitization. This occurs because the noise suppression notches of the transmitter notch cavities are too narrow to suppress the noise over a sufficient frequency spread for this particular transmitter receiver pair. Although no damage will occur to the receiver in this situation, the full receiver sensitivity cannot be utilized. The degree of desense will depend on how noisy the transmitter is and also on the front end selectivity and overload characteristics of the receiver.

TX RX Systems has developed a new type of notch filter to solve the problems of wide band noise suppression. The new **Vari-Notch®** filter exhibits an extremely wide and deep rejection notch and a narrow passband (pseudo-bandpass response) while retaining the lower cost benefits and compactness of notch duplexer designs.

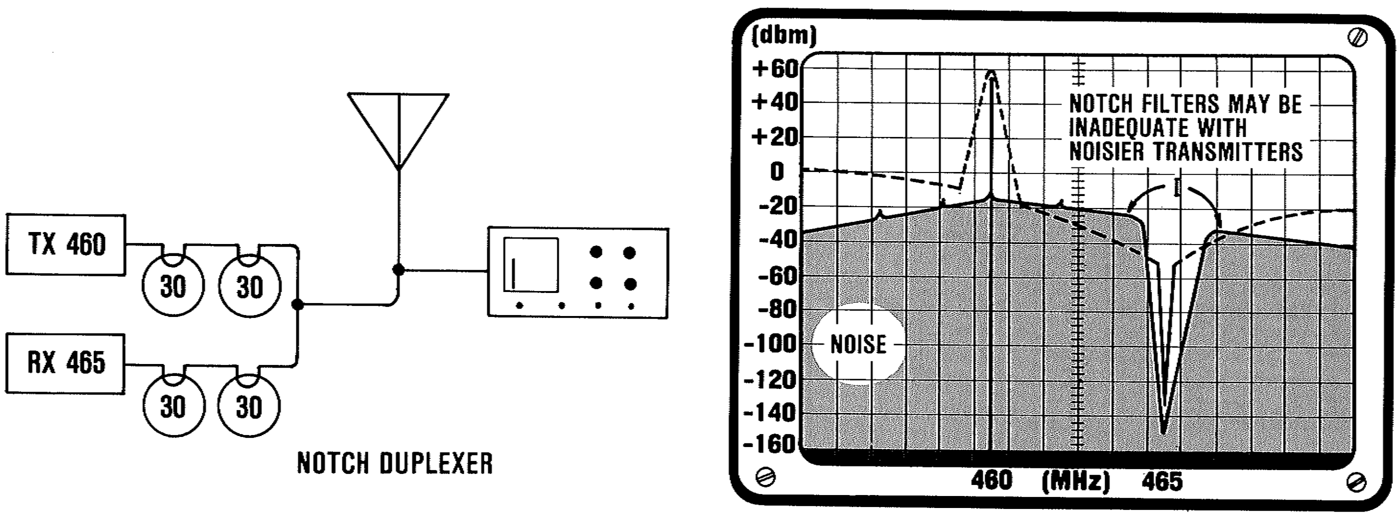
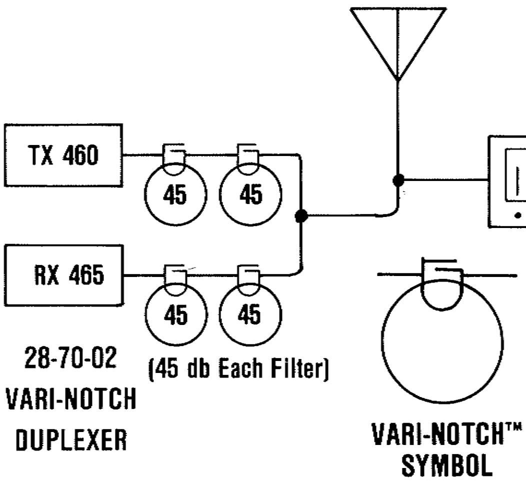


FIG. NO. 7

Figure 8 shows the transmitter and receiver of figure 7 connected to a common antenna by a Vari-Notch® duplexer (Model 28-70-02). The effect of **wide band noise filtering** that is provided by Vari-Notch® filters is readily evident from the analyzer display. Noise and desense-free duplex operation results. This will also yield greater radio system range as compared to the figure 7 conditions.



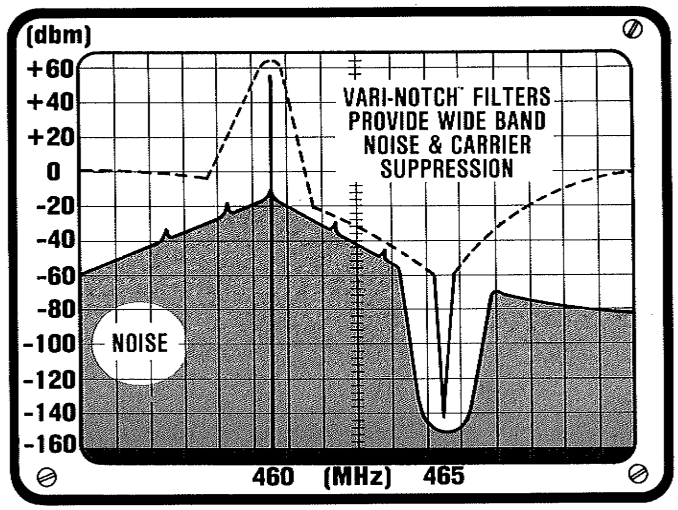
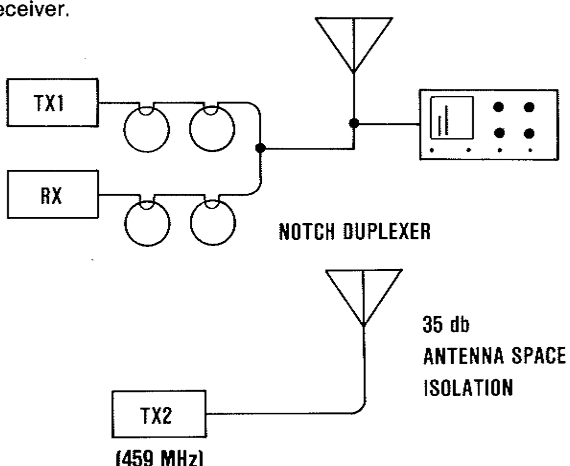


FIG. NO. 8

The narrow notch characteristic of notch duplexers is also a disadvantage at multi-transmitter antenna sites, **figure 9.** A second 100 watt transmitter (TX2) is connected to its own antenna which is spaced to provide 35 db of space isolation to our original repeater antenna (TX2 would probably be one half of another repeater pair). Because this second transmitter is 1 MHz away from TX1, the notch filters that protect the RX from the TX1 carrier do not provide any protection against the TX2 signal. The analyzer display shows that the TX2 signal is sufficiently strong to cause desense interference to the receiver.



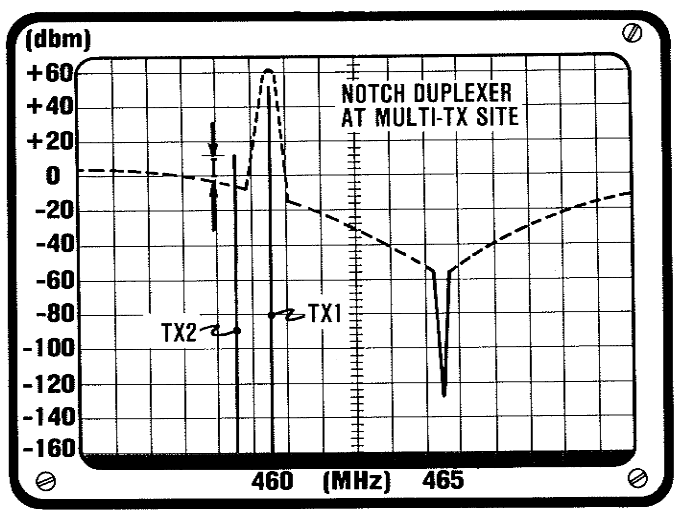
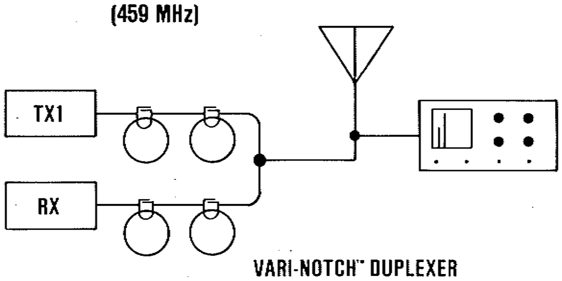


FIG. NO. 9



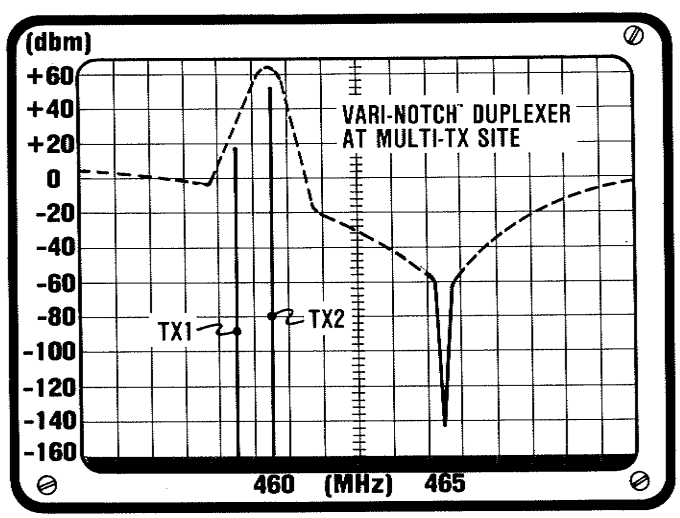


FIG. NO. 10

If the same duplex pair had been connected to a Vari-Notch® duplexer, this problem would not have occurred, **figure 10.** The wide notches of the Vari-Notch® filters protect the receiver from both transmitter carriers. Although transmitter noise has been left out of the last two analyzer displays, it has become obvious that wideband noise suppression would also be an advantage at an antenna site where a number of repeaters are operating simultaneously. If all the repeaters used a Vari-Notch® duplexer, the chance of mutual interference would be lessened.

As good as the Vari-Notch® filter/duplexers are, they may not be the best duplexer choice when the antenna site becomes quite crowded and little room exists for spacing antennas vertically for some minimum value of space isolation. The **figure 11** analyzer display illustrates the problem. Although the receiver is protected from its associated transmitter carrier at 460 MHz and the transmitter carrier at 461 MHz, some desense would occur from the transmitters @ 462 and 463 MHz. If the frequencies for these transmitters could have been chosen to fall within the 460-461 area, this problem may not have occurred. Unfortunately, the ability to pick and choose optimum frequencies has long since disappeared in all but the rural areas of the country.

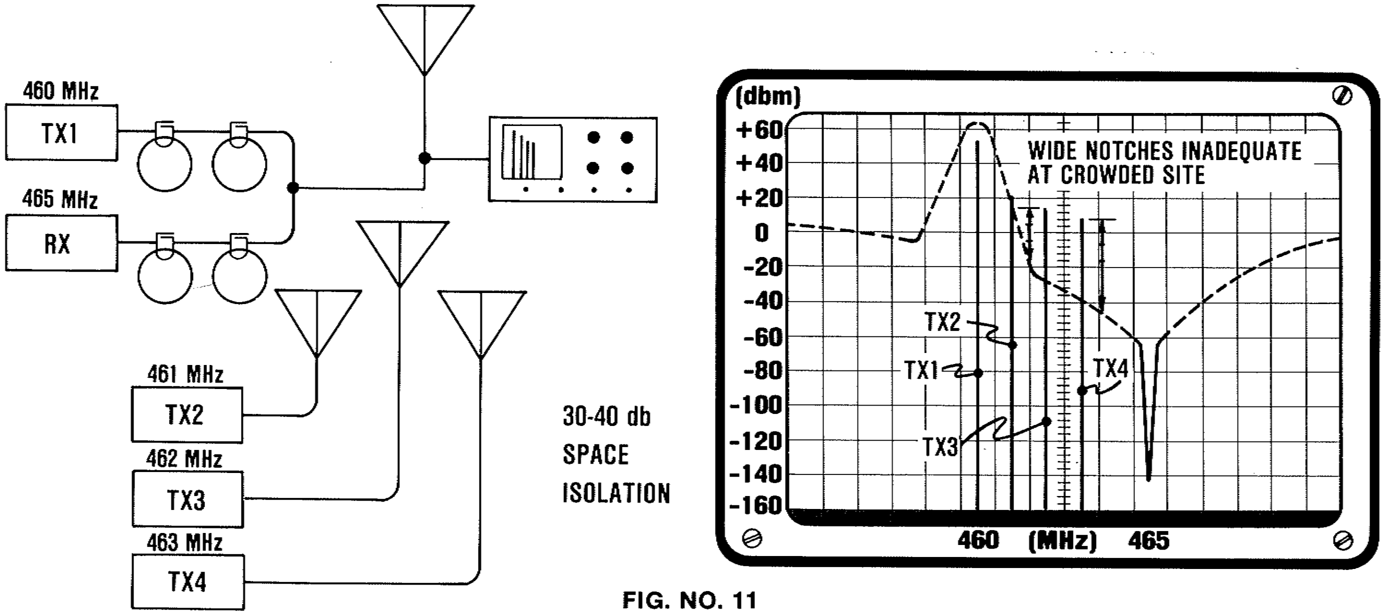


FIG. NO. 11

Figure 12 shows another type of duplexer/filter combination that may be used in this situation. The bandpass duplexer (**T-Pass™** duplexer is a special form of this duplexer that is designed for expansion capabilities but works exactly like the more familiar form shown below) utilizes bandpass filters which provide increasing attenuation both above and below the pass frequency. This overall sharpening effect on the receiver response window is shown on the analyzer display of figure 12. A word of caution is in order here because a bandpass filter is **not inherently** better than a Vari-Notch or notch filter. The performance of the bandpass (T-Pass) duplexer illustrated is also due in part to the fact that the cavities used are much larger than in the Vari-Notch duplexer (6⅝" dia. vs.4" dia.). Also, the loss (insertion loss) through a bandpass duplexer is usually greater than with its Vari-Notch counterpart (1.5 db vs. 0.6 db). A bandpass duplexer using 4" diameter cavities would require at least eight cavities (four for the TX, four for the RX) and would have a 4 db insertion loss.

Referring back to figure 12, it can be seen that bandpass filtering would also protect the 465 MHz receiver from signals higher in frequency, a distinct advantage when a tower is shared with a UHF television transmitting antenna. Receivers operating in the 455 MHz to 460 MHz range that have individual bandpass windows would be isolated from transmitters in the 450-455 MHz band and in the 460-465 MHz area. Protection against all off-channel signals is provided by bandpass filters and they may be used to back up an existing notch duplexer that is suffering from a lack of off-channel isolation.

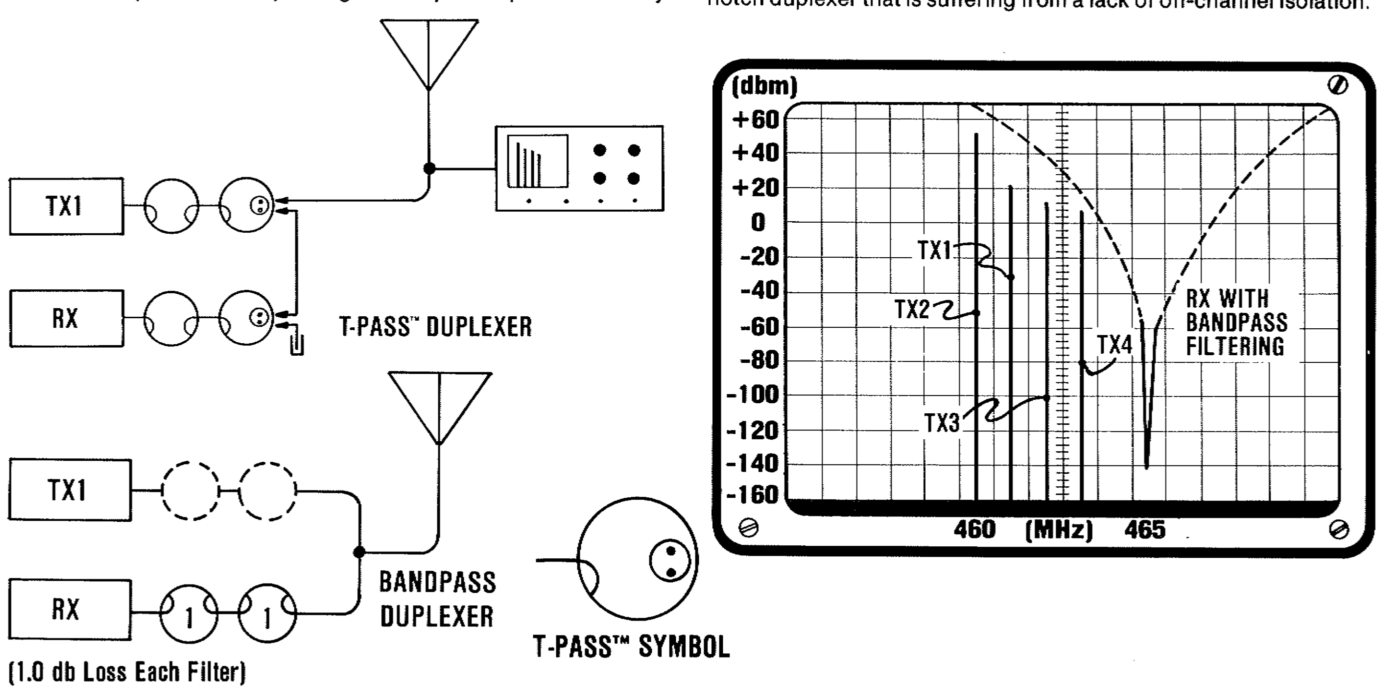


FIG. NO. 12

The same benefits of off-channel protection afforded receivers by bandpass filters also extends to transmitters. The analyzer display of **figure 13** shows how the noise spectrum of each transmitter is suppressed when each transmitter output is filtered with bandpass filters. Transmitter noise is attenuated both above and below the channel frequency, with the attenuation increasing with frequency separation.

To the left of analyzer display (figure 13) are the four transmitters and their associated receivers, 5 MHz higher in frequency. Each is shown with individual bandpass filtering and the dotted filter is used to indicate that a different number of filters may be required with each piece of gear. This will depend on the filtering requirements of the individual radios, which may be obtained from the radio manufacturer. Manufacturers usually test all transmitters and receivers that are intended for use in repeater systems. The data are usually presented in the form of isolation curves which shows the amount of TX noise suppression and receiver carrier isolation required for various frequency separations. Data for radios not originally intended for duplex operation may not be available and caution is advised when considering them for repeater use. The manufacturer should be consulted for advice in these instances.

Output connections for filters shown in figure 13 have been deliberately left out because a number of options exist. Of course, each transmit-receive pair could be connected to its own antenna with bandpass filters in a T-Pass/Bandpass duplexer configuration as shown previously. However, when a large number of duplex pairs are involved, a more efficient way of connection is available.

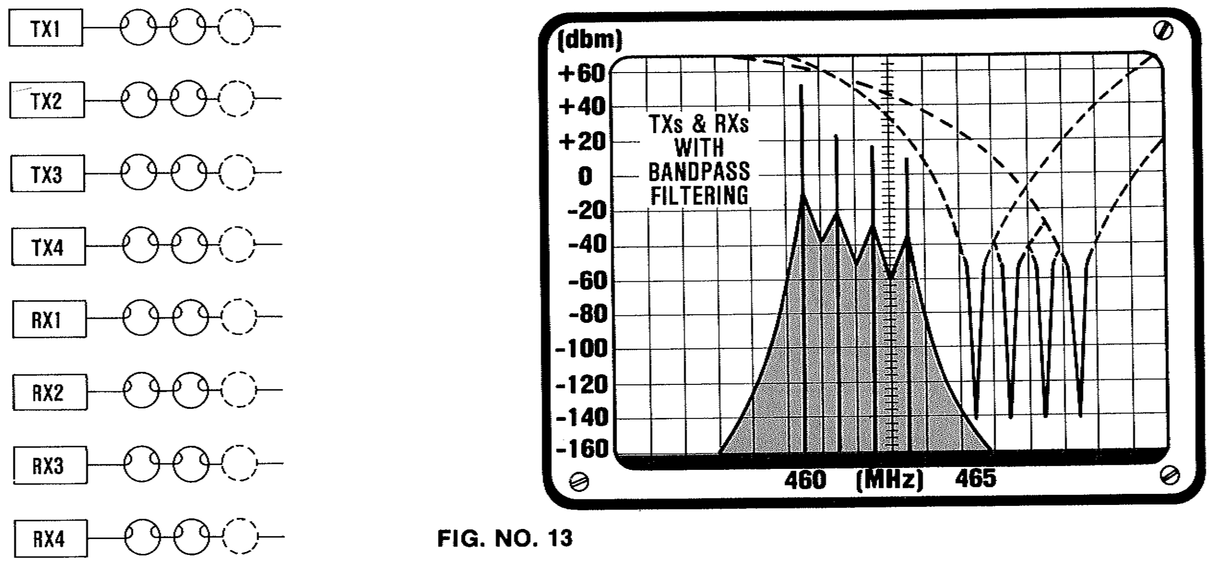


FIG. NO. 13

One such way of connecting bandpass filters is shown in **figure 14.** This is a full-fledged T-Pass multicoupling system drawing on the expansion capabilities mentioned earlier for a T-Pass duplexer. In this example, all transmitters are coupled to one antenna and all receivers are coupled to their own separate antenna. Although it is certainly possible to couple all radios to one antenna, a more efficient use of filters results, particularly when four or more duplex pairs are to be coupled.

When separate TX and RX antennas are used, the antennas may be spaced for maximum space isolation (vertical separation). Because we are multicoupling, there are fewer antennas involved and this space is more likely to be available. This space isolation (measured in dbs) is free and eliminates the need for some filters that would be required if both receivers and transmitters were connected to a common antenna. Note the number of filters used on the receivers (figure 14) for carrier isolation. Two or three would be needed per receiver if a common antenna were used.

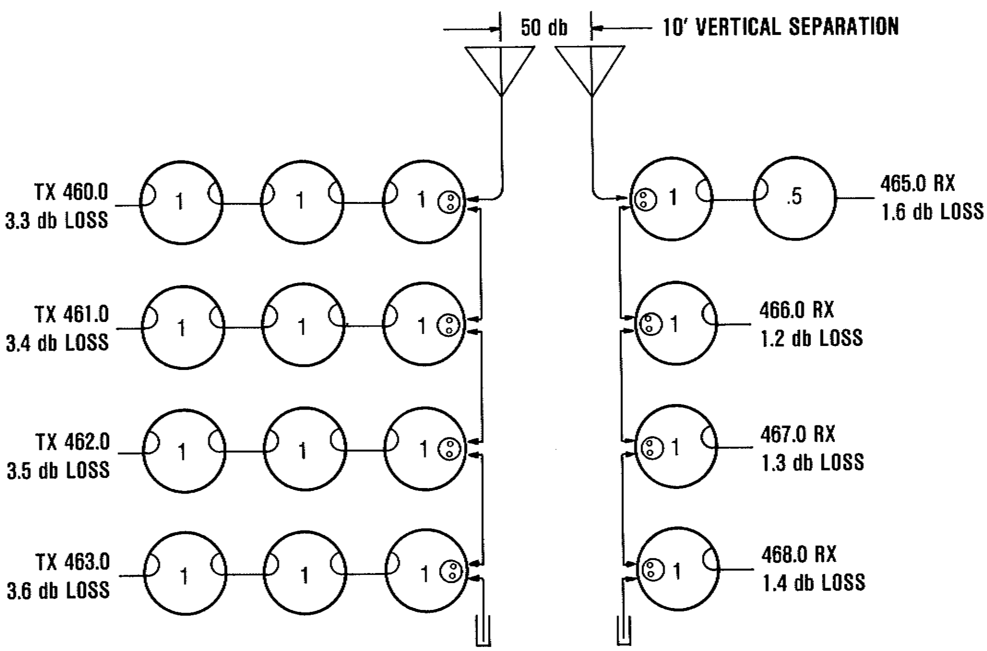


FIG. NO. 14

The filter chains connected to each radio are quite repetitive and additional duplex pairs could be added at any time by adding an appropriate string of bandpass filters (T-Pass channels). All cable lengths used are easily calculated and predictable when adding new channels so reconfiguration of a system is relatively easy. The number of channels that can be connected to a common antenna using T-Pass is limited mainly by the power handling capability of the common antenna thru-line cable. If a basic two channel T-Pass duplexer is used when the first repeater is put into operation, additional repeaters may be added with the original duplexer turning into two channels of a T-Pass multicoupler. After a number of repeaters are in service, the system is easily converted from a single to a two-antenna system. This sometimes frees enough filters so that an additional duplex pair may be accommodated for little more than the cost of the additional antenna and feedline.

To summarize, successful simultaneous operation of a transmitter and receiver when connected to a common antenna (or two closely spaced antennas) depends on two basic parameters. First, the receiver must be protected against overload and desensitization by the transmitter carrier. This may be accomplished by using tuned resonant cavity filters in the receive line to attenuate the transmitter carrier frequency by an amount that is sufficient to prevent overload.

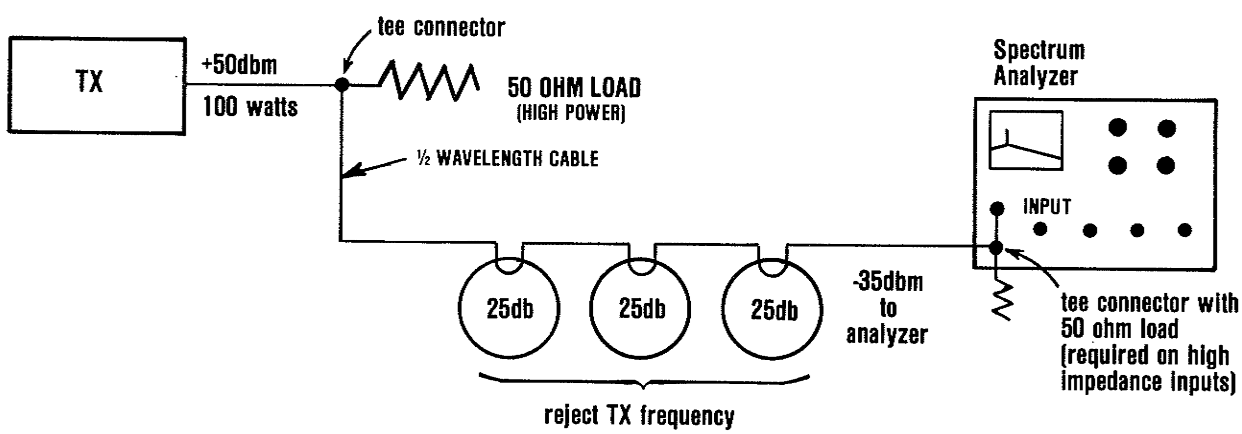
Second, transmitter spurious and sideband noise must be suppressed by a sufficient amount at the receive frequency to prevent interference to the desired receive signal. Again, resonant cavity filters in the transmit line should be used. The choice of filter/duplexer type will depend on the particular application, frequency separation, operating frequency, size limitations, and power rating.

Some thought should also be given to the possibility of future system expansion. An expandable T-Pass duplexer will not become obsolete which means a substantial cost saving in the long run.

SINCE OUR "IDEAL SPECTRUM ANALYZER" IS NOT YET A REALITY .....

The question arises: how can the output of a transmitter be displayed to show the phenomena of spurious output and noise? Shown below is a suggested circuit to observe the output noise spectrum of a typical transmitter using a real spectrum analyzer of the type being found on more and more service benches. In this application, a Series Notch type filter is desirable because we want a narrow notch to attenuate only the transmitter carrier frequency leaving the off-channel noise spectrum of the transmitter unattenuated. Use of a Vari-Notch type filter in this application would give a distorted view of the noise floor close to the carrier frequency. Notch filters are used to suppress the carrier to a level that will not overload the spectrum analyzer. Spurious products can be generated in the analyzer front end if the carrier level is too strong and be mistaken for transmitter spurious. The analyzer manufacturers should be consulted for data concerning the maximum input signal levels that will not generate internal spurs.

Other manufacturers' notch filters can be used but may require a quarter wave cable to the tee junction at the high power load. This cable prevents the notch filters from short circuiting the transmitter output. The filter manufacturer should be consulted if in doubt.

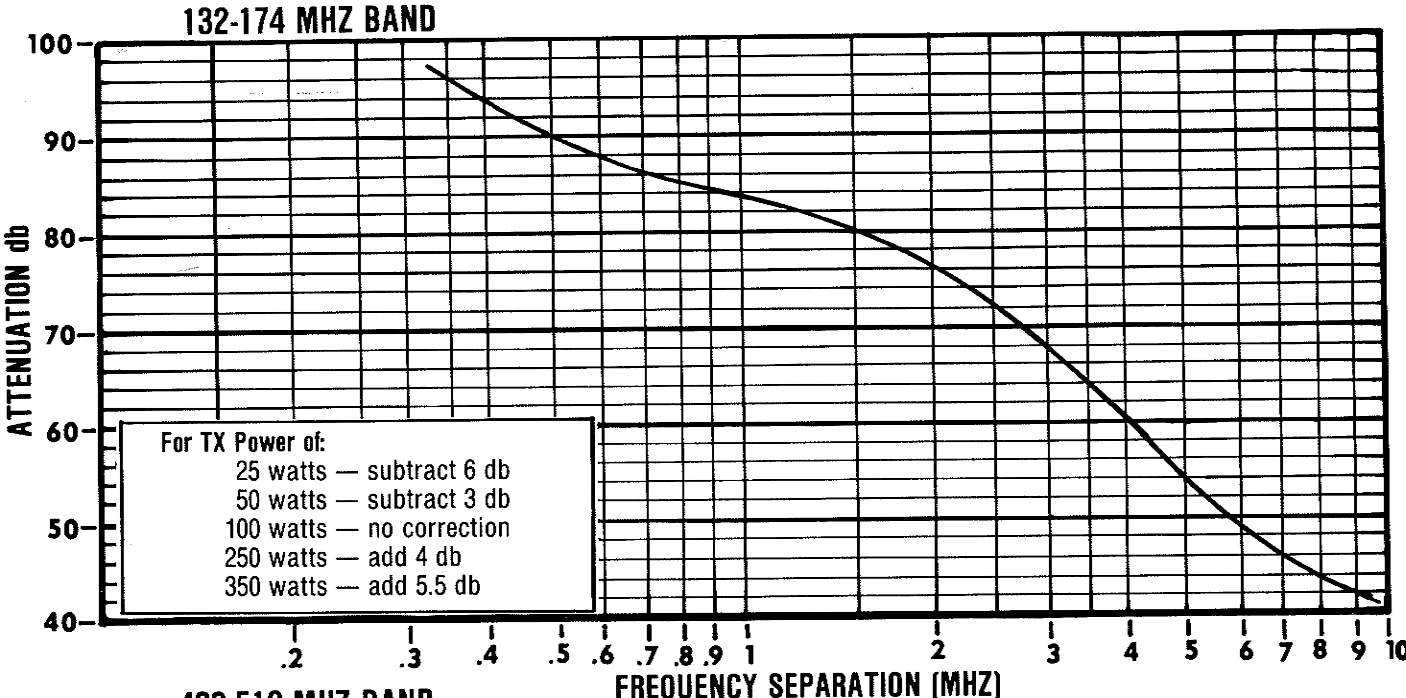


On the following page is shown a set of typical duplexer isolation curves. Only one curve is shown for both transmitter noise and carrier desense. They are assumed to be equal. This data is typical but should not be used when a high degree of accuracy is required. The radio manufacturer should be consulted for specific applications.

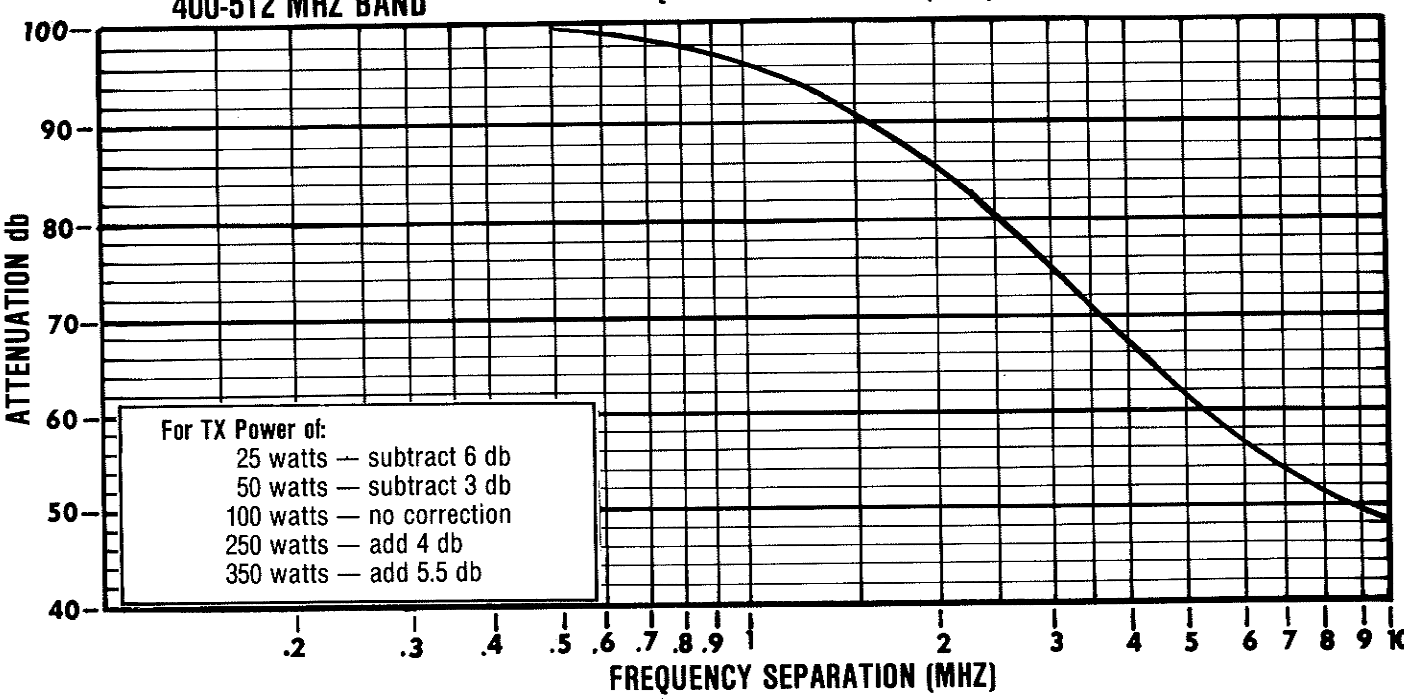
The curves shown below indicate the amount of isolation or attenuation required between a typical 100 watt transmitter and its associated receiver at the TX (carrier suppression) and RX (noise suppression) frequency which will result in no more than a 1 db degradation of the 12 db SINAD sensitivity.

Note: These are only "typical" curves. When accuracy is required consult the radio manufacturer.

132-174 MHZ BAND



400-512 MHZ BAND



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