RADIO ENGINEERING
MOBILE RADIO
TRANSMISSION
TRANSMITTER COMBINING NETWORKS

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1. GENERAL

1.01 This section provides information on the requirements, characteristics, and application of transmitter combiners in the design and layout of base station transmitters for multiple-channel mobile radiotelephone systems.

1.02 Engineering a single-channel base station transmitter installation is relatively simple if there are no other radio transmitters operating or planned in the same frequency band at or near the same location. The antenna and transmitter locations are interdependent, but usually it is practical to select an elevated location for the antenna which will give adequate coverage of the desired service area and at the same time provide suitable space for the transmitter to allow a relatively short transmission line between the two.

1.03 In multiple-channel systems providing a separate antenna for each transmitter becomes increasingly difficult as the number of channels increases. Where several channels of either an MJ or an MK system are assigned at the same location, providing separate antennas may often involve excessive costs, loss of desired uniform radiation patterns or service areas, too close coupling between transmitters, or a combination of these problems.

1.04 One technique for reducing or eliminating these problems is the use of combiners which can be arranged so that a single antenna may be used for radiating multiple transmitter output signals within the same frequency band. Combiners, however, will often introduce other disadvantages, such as added initial cost, space requirements, loss of RF power at the antenna, susceptibility to loss of service on all channels when the antenna system fails, and if improperly used, the generation and radiation of signal products on unauthorized frequencies.

1.05 Transmission considerations do not, of themselves, justify the universal use of combiners. Each multiple-channel radio system must be examined on its own merits, giving due consideration to future channels likely to be added at the same location. An engineering evaluation must be made of the cost in dollars versus the costs in dB losses or practical service coverage area.

1.06 In some cases, if multiple transmitters are required, it may be prudent to consider a compromise plan using several antennas but less than the number of channels. This could increase the radiated power per channel and therefore the effective service area at the expense of slightly less than identical coverage.

2. REQUIREMENTS

A. Service Area Coverage

2.01 In all multiple-channel IMTS systems, identical service areas on all operating channels in one system are essential for consistent, reliable service and maximum traffic handling capability. Each mobile unit within the service area can then originate or receive calls on any marked idle channel. Identical or near-identical service areas for all channels are most practical when all transmitting antennas are located in close proximity to each other or when one antenna is used for all transmitters by interconnection through a transmitter combiner.

B. Transmitter Isolation or Coupling Loss

2.02 The principal requirement in connecting multiple transmitters to a common antenna is to provide a suitably large coupling loss between transmitters while maintaining a low loss path to the antenna. Without adequate isolation between transmitters, the mixing of transmitter outputs will lead to creation and radiation of intermodulation (IM) products on frequencies different from, but related to, the frequencies of the transmitters involved. These can be a serious source of interference to reception on other communications channels. Transmitter combining schemes which provide good channel isolation at close frequency spacing almost unavoidably introduce a significant loss between each transmitter and its antenna, thereby sacrificing useful output power which could be delivered to the antenna. In many instances, however, this loss may be at least partially offset by using an antenna with more gain, or one more favorably located than would be possible with multiple antennas.

2.03 The degree of isolation required between the transmitter outputs depends on the need for suppressing IM products in a particular location. There is no single value for the permissible power level of IM products for all situations.

2.04 It has been the usual custom in the Bell System to consider a radiated IM product power level of −43 dBW as the maximum permissible at base station transmitters. This is covered in depth in Section 940-230-115. It seems prudent, however, to suppress transmitter IM products below this level (−43 dBW) to the possible extent consistent with cost to ensure a margin by which transmitter installation will be free of responsibility for any IM interference. A capability for further suppression of transmitter IM products should be planned for future addition, if it becomes needed.

2.05 It is evident that the primary consideration in determining the extent of additional transmitter decoupling required is an examination of the frequencies of the principal IM products, and of the present and likely future occupancy of these frequencies in that locality as well as the areas of primary usage. In a populous area it is prudent to over-engineer this parameter to avoid complaints of interference, and to know that the particular system design affords the best possible protection consistent with needs and costs. It is reasonable to assume that suppression of IM products to below −70 dBW will afford an adequate margin of protection against interference for all but the most proximate stations.

3. COMBINER COMPONENTS AND CHARACTERISTICS

A. General Principles

3.01 A combiner is an assembly of passive devices usually mounted in a single cabinet. It consists primarily of ferrite isolators, low-pass filters, and radio-frequency hybrids which provide the isolation and decoupling between the separate transmitters and additionally provides coupling and combining of the transmitters to the antenna. Usually the combiner unit contains a metering panel and switching circuit together with directional couplers arranged to measure forward and reflected power and VSWR at significant test points for lineup and test measurements and to operate alarm circuits when trouble occurs. Ordinarily the combiner as furnished by the supplier is equipped and wired for the actual transmitting frequencies and the number of antennas to be used. The internal RF connections are usually made with semirigid solid shield coaxial cable to prevent leakage of signals or "cross talk" coupling between channels.

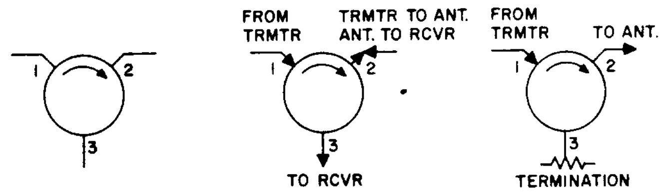
B. Ferrite Isolator

3.02 The ferrite isolator is a conventional 3-port ferrite circulator with one port terminated. Figure 1(a) is a schematic representation indicating its one-way or nonreciprocal transmission feature. Figure 1(b) shows the physical arrangement of its parts. In the center is a "Y" shaped stripline center conductor which may be on or within a layer of dielectric material. For VHF or UHF frequencies the stripline may be thick enough that its own rigidity permits omission of the dielectric as a support or stiffener. The center of the "Y" is sandwiched between two pieces of ferrite material, usually circular in shape, and these in turn are covered by conductive (but nonmagnetic) "ground plane" plates. External circuits are connected through coaxial fittings from which each center conductor becomes one leg of the "Y" and the outer conductors are extended to become the ground plane plates. Outside of the ground plates are permanent magnets which produce a dc magnetic field through the layers, and the whole assembly is clamped together to resemble a tight sandwich. The physical dimensions, the type of ferrite material, and the magnitude and direction of the magnetic field determine the effective frequency range of operation and the direction of "circulation" of the signal from one port to the next. As an isolator it is a one-direction device with a very low loss in the desired forward direction and a high loss in the reverse direction. Figures 2 and 3 show typical insertion (forward) loss and isolation (backward) loss as a function of frequency for units designed to be operated at 152 MHz and 460 MHz, respectively. A critical factor in their design is the spacing or dielectric characteristic of the space between the stripline and the ferrite. Early designs with no spacing between the two materials had a nonlinear response, generating excessive levels of second harmonics and, to a lesser degree, third-order intermodulation products when operated within normal power levels, for example, in the range of 20 to 250 watts. The magnitude of the distortion products varies with input power indicating that the level of the signal magnetic field in the ferrite is at least one factor causing nonlinearity. This field is reduced by dielectric loading in the form of a thin layer (in the order of 0.01 inch) of teflon or mylar placed between each side of the stripline and the ferrite. The greater the thickness of the dielectric, the lower the second harmonic level that is generated, but it has little effect on the IM products. The added dielectric load detunes the magnetic resonance of the ferrite which is corrected by changing the dc field provided by the external magnets. When an isolator is so modified and retuned, the effective isolation bandwidth is reduced, but it is still much wider than required for a 150-MHz or 450-MHz public mobile service frequency band.

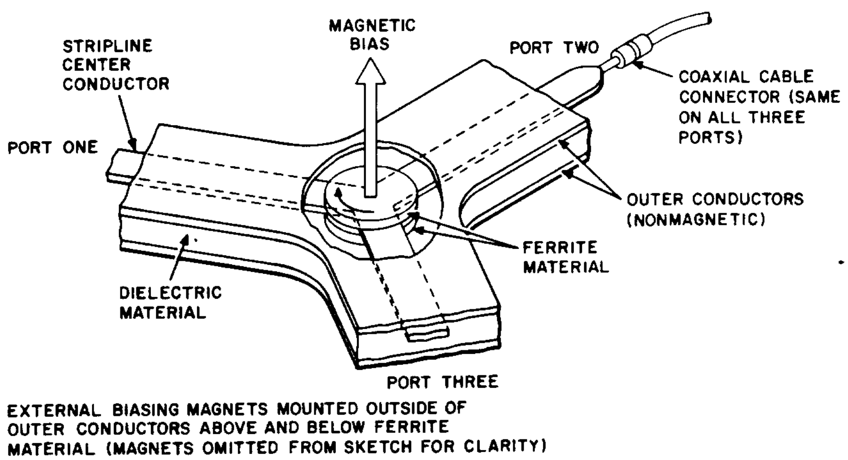
C. Hybrid

3.03 The RF hybrid, shown symbolically in Fig. 4, is a coaxial cable unit analagous to a wire-line voice-frequency hybrid used to join 4-wire to 2-wire circuits. As with the wire-line version, isolation between the two inputs depends on the degree of balance or impedance match between the two input circuits and between the output load and the balancing network. The hybrid network resistance element must not only match the transmission line input resistance, but must be capable of dissipating as heat about half the ***total*** input power. It may also include a tuning arrangement, such as an adjustable LC pi network by which the reactive component of the load impedance can be cancelled or balanced out. The trans-hybrid loss, that is, the loss from one input terminal to the other, is critically dependent on matching the output load and the balancing network. Before adjusting the network, the VSWR looking into the transmission line should be verified by test as not greater than 2:1, preferably below 1.5:1. If it is not, steps should be taken to improve it. Icing on an antenna will usually alter its radiation resistance and VSWR which in turn will degrade the hybrid balance and the isolation it provides. Where conditions warrant, either for additional intertransmitter decoupling or for varying hybrid balance due to antenna ice, etc., an additional isolator (Fig. 5) could be added to each transmitter output line, but not to exceed a total of two isolators (including one within the transmitter if so provided). Isolators should ***not*** be placed in the transmission line which connects directly to the antenna except when a single transmitter is feeding a single antenna and additional isolation from another nearby antenna or transmitter is desired.

3.04 The "tuning" of the hybrid balancing network circuit can be adjusted for a sharp peak of the output signal power, with an isolation loss in the order of 40 dB, but this adjustment is usually so critical that small changes in the VSWR will severely upset the balance and result in excessive



(a) APPLICATION SCHEMATICS OF FERRITE CIRCULATOR



(b) PHYSICAL ARRANGEMENT OF 3-PORT COAXIAL CIRCULATOR

Fig. 1—Ferrite Isolator for Coaxial Cable Applications

reflections from the antenna back toward the transmitters. An off peak tuning to a point where no pronounced changes in power or voltage results from normal variations in the ambient environment of the transmission line or antenna except from heavy icing is obviously preferable. This adjustment will normally reduce the isolation to about 20 dB while the through loss (3.5 dB) will not be significantly changed.

D. Filters

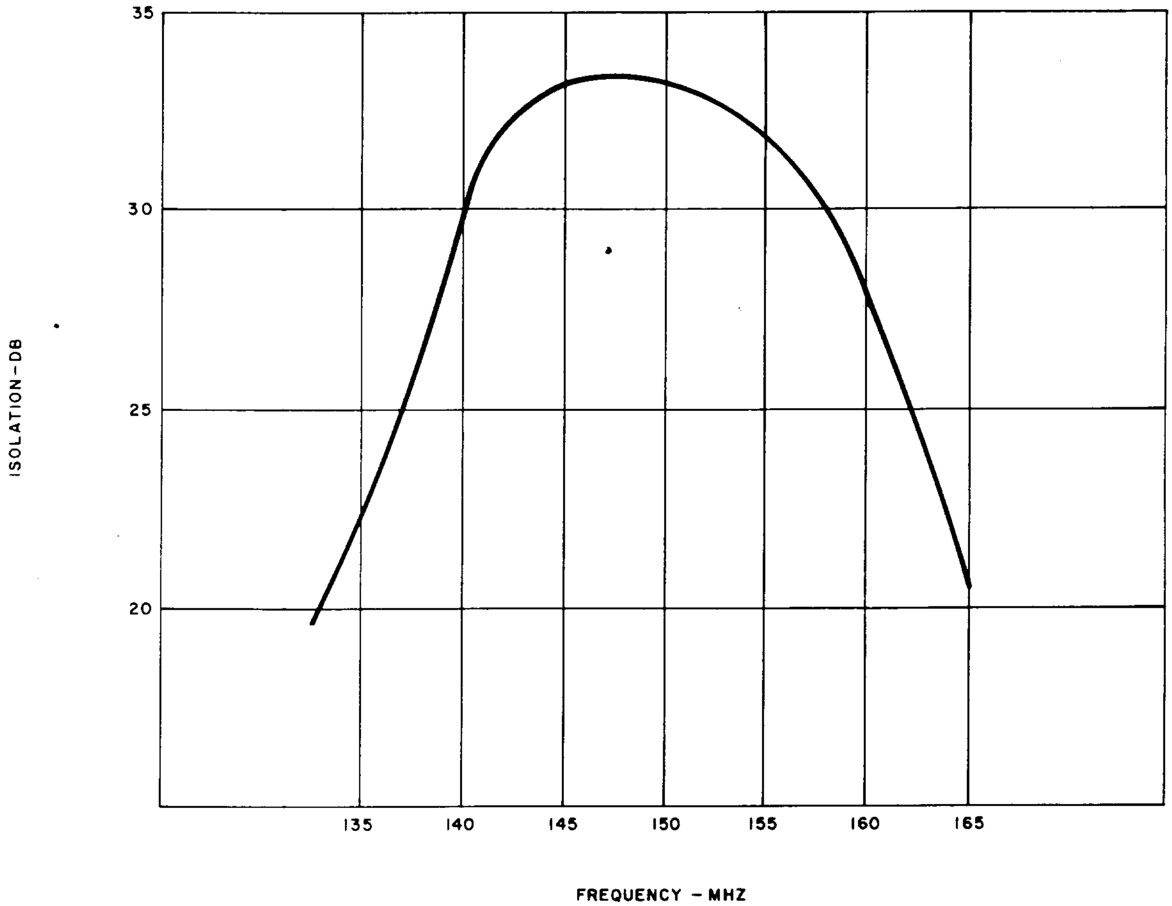
3.05 Low-pass filters are included in combiners to attenuate harmonics of the signal frequencies. This is necessary for suppressing harmonics and any higher frequency spurious signals generated before they are radiated or reach a point where they can prove a detriment. It must be recognized that ferrite units are ***passive*** but are not ***linear,*** and will generate some IM products as well as second harmonics. To a much lesser degree, some RF hybrids produce harmonic and IM products. The low-pass filters are used to suppress the harmonic components.

E. Metering and Test Panel

3.06 For proper alignment, test, and maintenance a metering and test panel is usually included in combiner cabinets as shown in Fig. 6. Directional couplers are placed in each transmitter output line and the line to the antenna to permit observation of forward and reflected RF power at the significant test points, as well as the VSWR toward the antenna(s). The VSWR test circuit may be connected into an appropriate alarm system.

F. Cabling

3.07 Combiners are usually completely assembled within a cabinet. For 450-MHz systems, combiners are available meeting KS- specifications; for 150-MHz systems, appropriate components must be ordered separately. In either case, the manufacturer



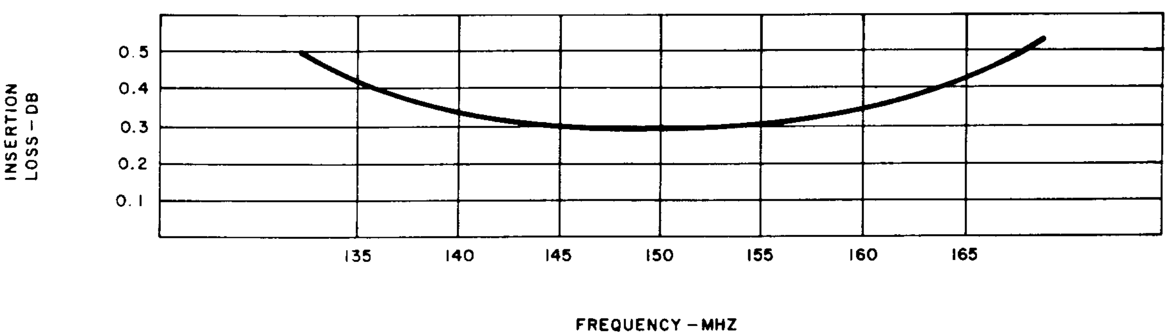


Fig. 2—152-MHz Isolators—Isolation and Insertion Losses

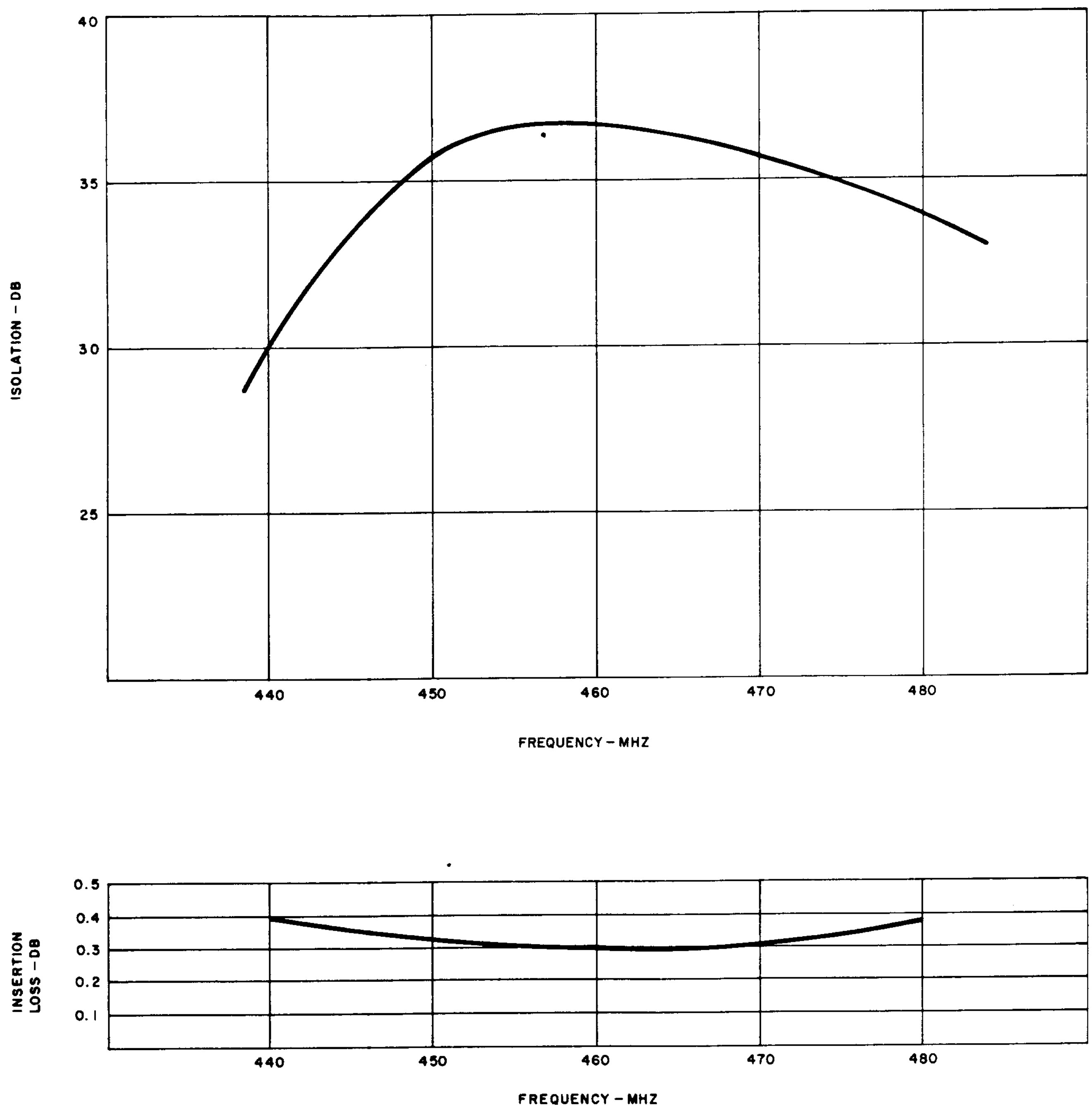


Fig. 3—460-MHz Isolators—Isolation and Insertion Losses

will assemble the complete unit, tested and adjusted for the specific frequencies and number of antennas to be used.

4. APPLICATION

4.01 The power loss in the combiner will usually penalize the coverage and transmission performance but this loss may be compensated for by using a gain-type antenna. The antenna gain is limited by such practical considerations as size and weight; in general, omnidirectional antenna gains will be limited to about 5 to 6 dB over a half-wave dipole, on 150-MHz channels and to about 10 dB on 450-MHz channels. Loss of each channel signal in the combiner will vary somewhat from

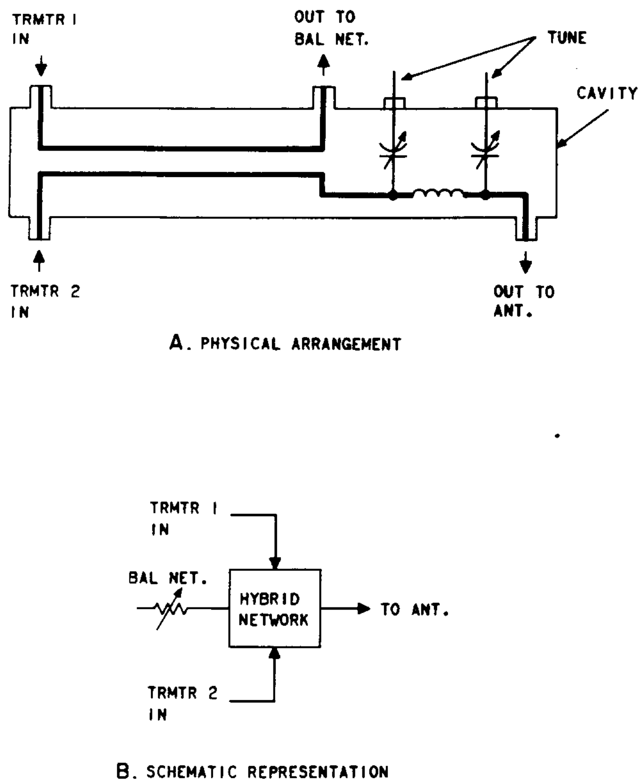


Fig. 4—RF Hybrid Unit for VHF or UHF

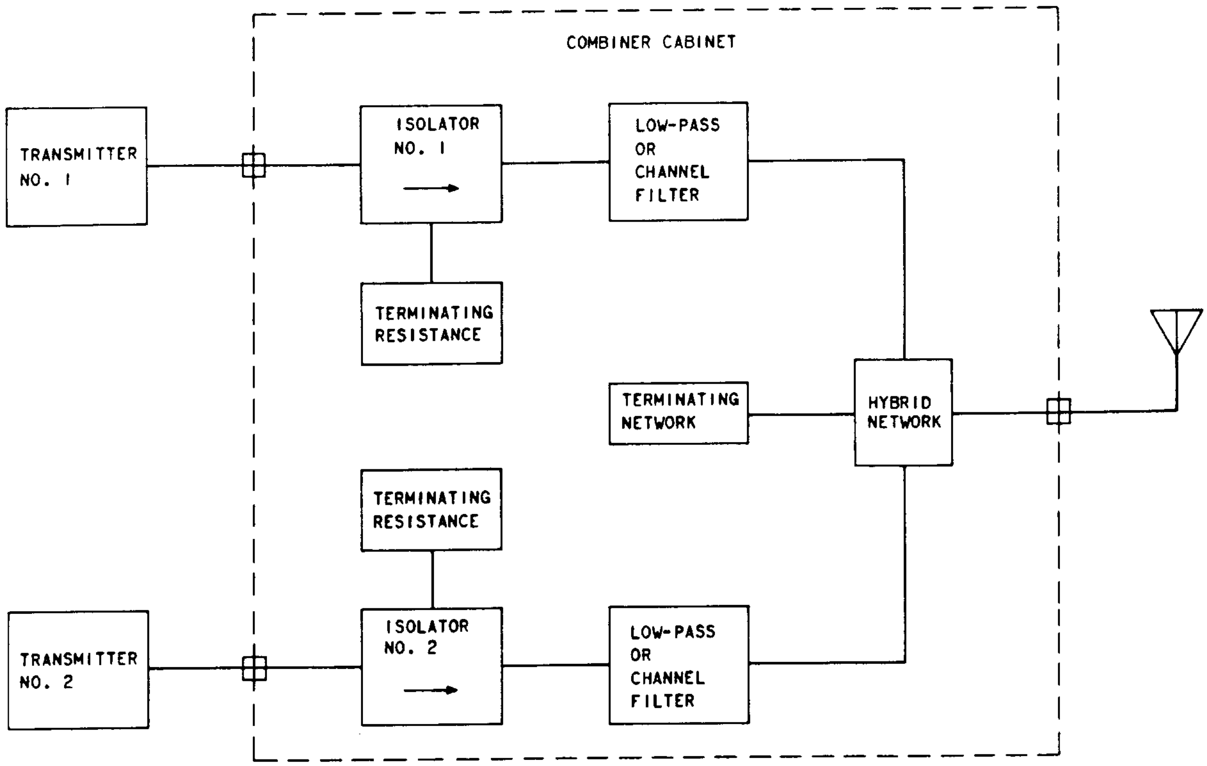


Fig. 5—Basic 2 Channel Combiner

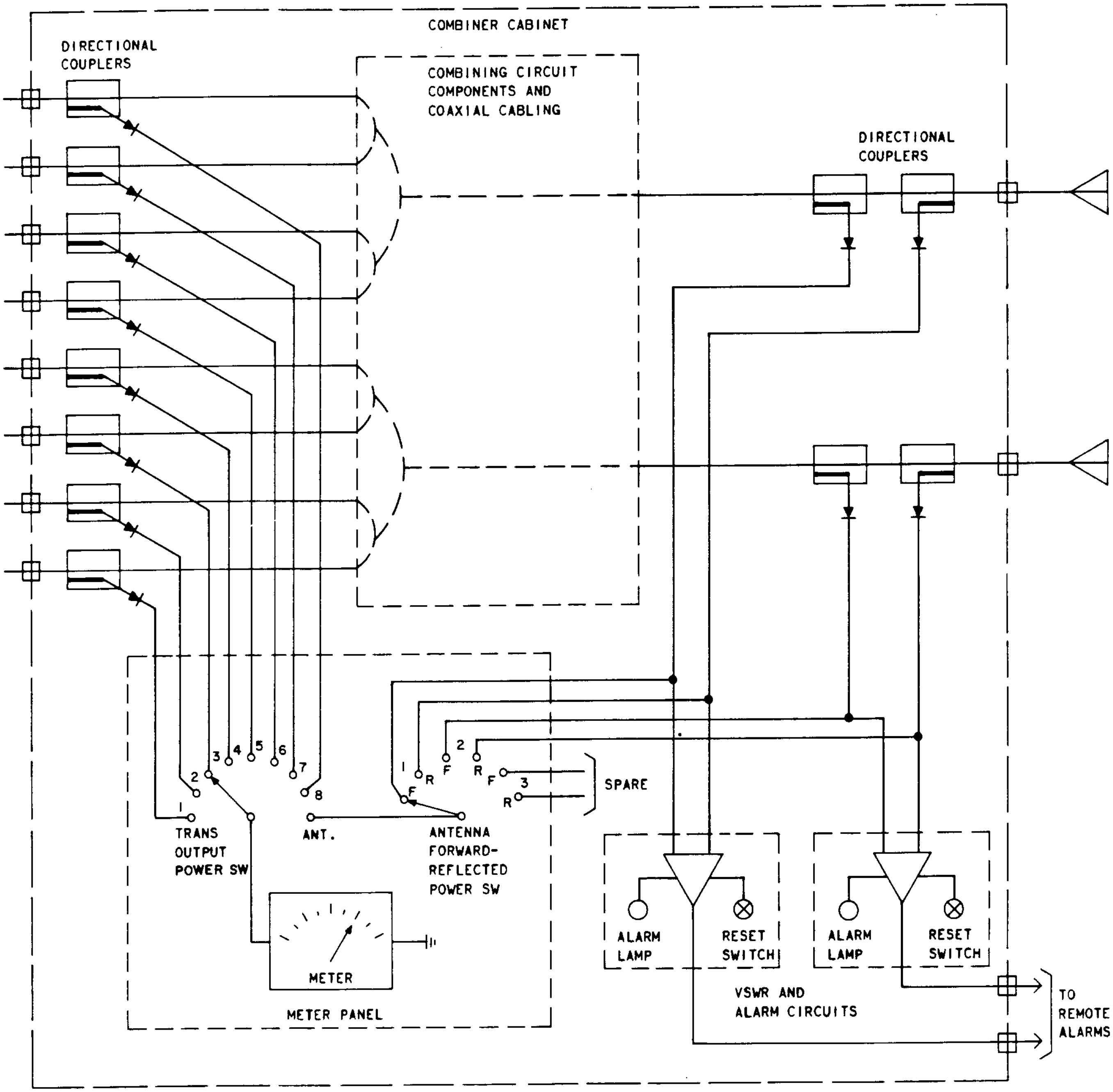


Fig. 6—RF Power and VSWR Metering Circuits With Directional Couplers in Combiner Cabinet

one unit to another, but usually will not exceed the following amounts:

NUMBER OF TRANSMITTERS ON ONE ANTENNA	LOSS – TRANSMITTER TO COMBINER OUTPUT
2	4.7 dB
3-4	8.4
5-8	12.1

Figure 7 shows the basic arrangement for combining any number of transmitters up to eight, with nominal and maximum losses of each type of component. Assuming that physical constraints will permit two antennas, the advantage of splitting the signals between two combiners driving two antennas reduces the maximum loss in each channel by about 3.7 dB.

4.02 The power losses within the combiner are dissipated as heat which could result in damage or faulty operation if the heat dissipating components are not well vented in some situations (nonair-conditioned space or high ambient temperatures). A cooling fan may be considered to circulate air through the cabinet. If only two or three transmitters are used, forced cooling may not be necessary.

4.03 The transmitter isolation obtainable with hybrids alone may not be better than that provided with colinearly placed individual antennas on a common mast. Where the latter is feasible, there is little advantage from an intermodulation standpoint in using a common antenna. Isolators will, of course, improve isolation to the same extent whether used with one common or separate individual antennas.

4.04 A suggested arrangement for the use of a single antenna for the transmitters and receivers of two low-power base stations is diagramed in Fig. 8. The only problem is that of rearranging the cabling of the two packages. The diplexer provided with either one of the packages may be used with minimal concern for its power handling capacity since, with the 3-dB loss in the hybrid, the total power fed to the diplexer will be the same as the direct output of a single transmitter.

4.05 The use of a single antenna is a means of providing the desired identical coverage for all channels of a mobile system, but particular care should be exercised in engineering such a system since all channels will be dependent on it for satisfactory coverage and continuity of service. Accessibility, serviceability, and availability of all components of the system are therefore of extreme importance.

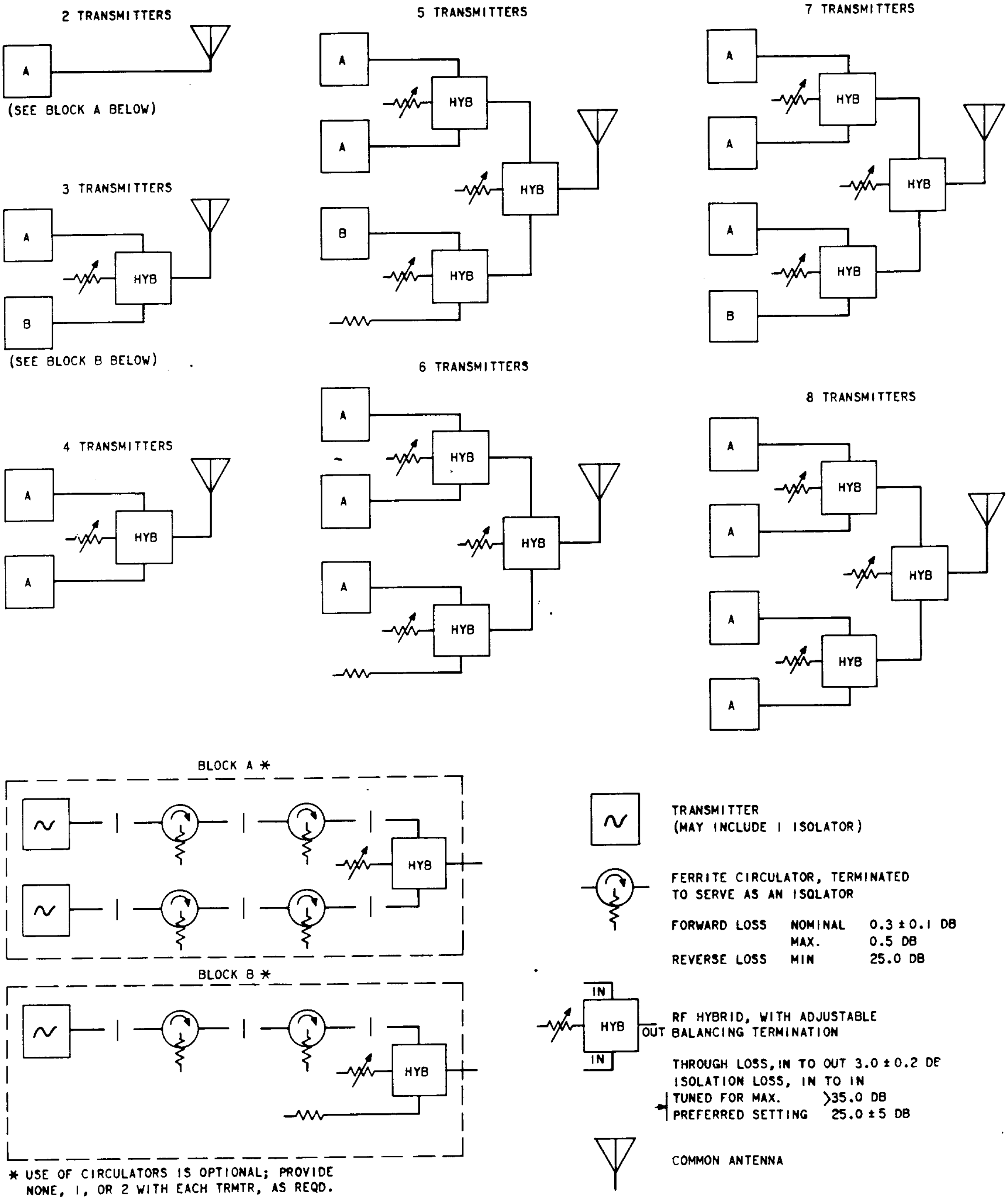


Fig. 7—Arrangements for Coupling From Two to Eight Base Transmitters to a Common Antenna

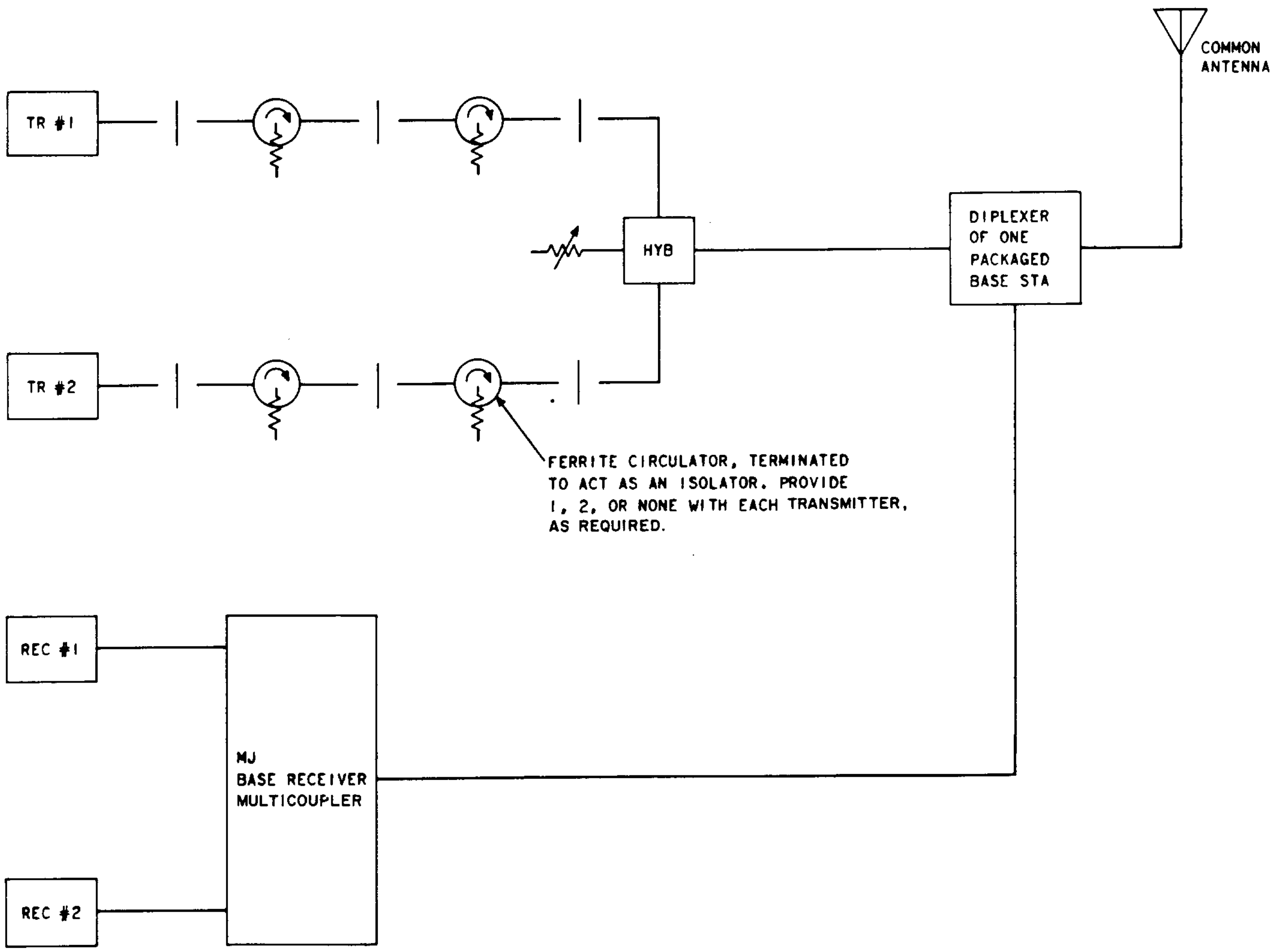


Fig. 8—Arrangement for Coupling Two Low-Power Packaged Base Stations to a Common Antenna