DESIGN OF HIGH ISOLATION DUPLEXERS AND A NEW ANTENNA FOR DUPLEX SYSTEMS

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Summary

A Duplexer design technique will be described which uses nominal size cavities and a single additional lump circuit element per cavity to produce transmitter to receiver isolations far greater than that produced by the cavities themselves. The lumped circuit element produces a notch in the cavity response curve which may be moved along the curve. The original design work on these duplexers was concentrated on units having approximately 5 Mc separation between the transmit and receive frequencies. It will be shown however that this design technique is applicable to other frequency separations. An antenna designed for duplex operation will also be described.

Reference Duplexer for 150 Mc Band

To establish a reference design in the 150 Mc band, a duplexer was fabricated using three 1/4 wavelength long six inch diameter cavities. Each of the cavities was equipped with coupling loops which produced 0.5 db insertion loss per cavity. Figure 1 illustrates the general layout of the duplexer. One cavity was placed in the transmitter side and two in the receiver side of the duplexer. The response curves of this duplexer are also shown in Figure 1. The dotted line represents the isolation between the transmitter and the antenna connector of the unit, the dash line the isolation between the antenna and the receiver. The solid line shows the total isolation between the transmitter and the receiver connectors of the duplexer. The transmitter to receiver isolation is approximately 60 db at the transmit frequency. The isolation between the transmitter and the receiver at the receive frequency is approximately 38 db. These isolations were obtained with 0.5 db loss in transmitter power and 1.0 db in the received signal.

The reference duplexer was disassembled and a search was made for a technique which would increase the isolation between the transmitter and receiver at the respective frequencies. It was desirable that no increase in insertion loss be allowed at these frequencies, and, if possible, the insertion loss should be decreased. The response curve of a single cavity as used in the above duplexer is shown as the dotted line in Figure 2. The insertion loss at the resonant frequency is 0.5 db.

As a first step in the design program and in line with the desire to produce a duplexer having less than 0.5 db loss, new coupling loops were made. These loops had 0.3 db loss at the resonant frequency. The solid curve in Figure 2 is a response curve of the unit with these loops in place. The response curves in this Figure are those of typical high Q resonant circuits.

In a normal low Q lumped constant resonant circuit it is of course possible to produce an anti-resonant point by adding an additional circuit element. A series resonant circuit may be made to exhibit this characteristic by simply placing an inductor or capacitor in parallel with it. Figure 3 shows a series circuit and its response curve as the solid line. A parallel capacitor and the total circuit response curve are dotted. The possibility of using a resonant anti-resonant technique was tested using one of the 6" diameter cavities with 0.3 db loops as the resonant circuit. The first test was made by simply placing Tee connectors in the cables feeding the loops and producing an external capacitive circuit around the cavity with two closely spaced solid copper wires, one inserted into the open leg of each Tee. This test produced a response as shown in Figure 4. In this test the cavity was tuned to 158 Mc.

When the shunt circuit was placed on the cavity, the resonant response frequency of the cavity shifted slightly. Throughout this work the resonant cavity has been retuned to have peak response at its original resonant frequency. As may be seen in Figure 4, an anti-resonant spot or notch in the response curve was produced by this shunt capacitive circuit.

A second test was made. In this test the shunt circuit around the cavity was a simple coil. The cavity was tuned to 153 Mc. As anticipated, the notch in the response curve moved to the opposite side of the resonant frequency. Figure 5 illustrates the response of the cavity with its shunt inductor.

Two Cavity Notched Duplexer for the 150 Mc Band

Two of the original cavities were modified to provide shielded mounting facilities for the external shunt circuits. A duplexer unit was assembled with one cavity in each side, one with the shunt capacitor and one with a shunt inductor.

In the shunt circuits it was desirable to have units which were variable and could be mounted with all circuit components above ground. In the capacitive side a standard butterfly steatite insulated unit was chosen. The inductor was fabricated on a steatite coil form which had an adjustable copper core. The duplexer, when properly adjusted, had the response curves shown in Figure 6. As in Figure 1 the dotted line represents the isolation between the transmitter and the antenna, the dash line the isolation between the antenna and the receiver and the solid line the total isolation between the transmitter and the receiver. The isolation at the two critical frequencies is 70 db. An improvement of 30 db at the receive frequency and 10 db at the transmit frequency. This increase in isolation has been accomplished with only two cavities in place of the three used in the Reference Duplexer.

Reference Duplexer for 450 Mc Band

The same design technique was applied in the 406-470 Mc frequency range. It was decided that these units should be designed for standard rack panel mounting and kept as small as possible consistent with acceptable isolation characteristics. The initial unit was designed for mounting in a 3 1/2" panel space. The duplexer height was held to 3 1/4". The 17" dimension between the support angles of the rack cabinet limited the width of the unit. This dictated a cavity cross-section of approximately 3 1/4 x 5 5/8" if a three cavity unit was needed. The length of the cavity was made 8 1/2" to minimize any end effect at 406 Mc. As at 150 Mc, initial reference tests were made on a typical three cavity duplexer. Coupling loops were designed which had 0.3 db loss per cavity and complete duplexer response curves were plotted. Figure 7 shows these curves. The total isolation between the transmitter and the receiver connectors is shown as the solid line.

Two Cavity Notched Duplexer for the 450 Mc Band

The shunt capacitor required for 5 Mc separation in the 406-470 Mc range was quite small. It was made as a two plate disc type unit with one fixed plate and one variable plate. The variable plate was moved by a differentially threaded plastic screw. One end of the screw was threaded 1/4-20 and the other 1/4-28. One complete turn of the screw therefore moved the plate only 1/64". The shunt inductor was fabricated in much the same manner as in the 150 Mc unit. At 406-470 Mc the variable portion of the inductor must be made as large a part of the total shunt inductive circuit as possible. The coil was made of relatively large wire and the fixed inductance of the connecting leads was minimized by the use of 3/8" wide copper strip. A two cavity duplexer with notching circuits was assembled and adjusted for operation at 453 and 458 Mc and the response curves were plotted. Figure 8 shows these curves. Here again, the same convention is used with total isolation between the transmitter and the receiver being shown as the solid line. Isolation at the receive and transmit frequencies is 50 db. This isolation is 30 db and 10 db respectively better than with the unnotched three cavity reference duplexer.

Three Cavity Notched Duplexer for the 450 Mc Band

A three cavity duplexer was fabricated with an additional unnotched cavity placed between the receiver connector and the two cavity duplexer. Figure 9 shows the response curves of this unit. The isolation at the receive frequency is 50 db. The isolation at the transmit frequency is 70 db. At both frequencies the duplexer utilizing the notched circuitry is 30 db better than an unnotched duplexer assembly having the same number of identical cavities.

Three Cavity Notched Duplexer for the 150 Mc Band

The design system having proved effective at both 150 and 450 Mc and with two and three cavity duplexers designed and tested at 450 Mc, the last remaining item necessary to complete a duplexer line was a three cavity unit for the 150 Mc band. It was decided that all three cavities should have notching circuits. During the initial tests of this assembly, it was discovered that if the rotor of the butterfly capacitor was grounded, the notch moved to the opposite side of the resonant frequency. Thus, in the final design of the 150 Mc duplexers both the transmit and receive notching circuits consist of shunt capacitors. The rotor of the capacitor is either grounded or left ungrounded depending on the position of the notch frequency with respect to the resonant frequency of the particular cavity involved. Figure 10 presents the response curves of the three cavity 150 Mc duplexer. The isolation between the transmitter and the receiver is 100 db at the transmit frequency and 70 db at the receive frequency.

Notched Duplexer Flexibility

To demonstrate the flexibility of the final design a 150 Mc two cavity unit was tuned for operation at 3 Mc separation between the transmitter and the receiver. It was then retuned for 7 Mc separation. Figure 11 shows the response of the duplexer tuned for 3 Mc and 7 Mc separation. To avoid confusion only the notch portions of these curves are shown. The complete 5 Mc separation curve as presented in Figure 6 is shown for reference.

Temperature, Humidity and Vibration Tests

The duplexers have been subjected to severe laboratory tests and have met specifications between -30°F and +160°F and over humidity ranges of 5 to 95% at 100°F. Each production prototype duplexer has been vibrated for one hour on each of the three mutually perpendicular axes.

The duplexer units were mounted to a test fixture which was, in turn, secured to a Vibration Machine. The test units were then vibrated over the frequency range of 5 cps to 60 cps at an applied vibration level of 0.01 inches double amplitude. The entire frequency range of 5 cps to 60 cps and return to 5 cps was traversed in a period of ten minutes. The above vibration was conducted for a period of one hour along each of the three mutually perpendicular axes.

Throughout the vibration tests all mechanical resonant frequencies of the duplexing units were noted and recorded. The resonant frequencies were determined by means of a hand held velocity type vibration pickup. At the completion of each hour of vibration, the units were visually examined for evidence of physical damage. No evidence of physical damage was present on any of the units.

No mechanical resonances were observed in the 450 Mc duplexers.

The maximum resonant amplitude in the 150 Mc units occurred as end to end motion of the upper cavity in the three cavity assembly. This amplitude at 42 cps was ±3/32 of an inch.

The electrical performance of all units was unchanged when checked following the vibration tests.

Commercial Units

Figure 12 shows the complete line of duplexers as packaged for commercial application. The 450 Mc units are shown in the lower portion of the figure with the 150 Mc units above them. The 150 Mc duplexers are rated at 330 watts input. The use of 0.3 db loops in the transmit side limits the power loss in the transmitter cavity to less than 25 watts. The 450 Mc duplexers are rated at 250 watts and the loss in the transmitter cavity is less than 17 watts. All of the duplexers are shipped tuned to the customers specified frequencies and may be installed as received without field tuning being required.

Field Tuning of Duplexers

The duplexers may be tuned to new frequencies in the field with equipment normally available in the 2-way service shop. A signal generator capable of operating on the new frequencies, and a base station receiver and a mobile receiver each tuned to the new frequencies will be required. If the receivers do not have matched 50 ohm inputs a 6.0 db pad should be inserted between the duplexer and the receiver input connectors.

Antennas for Duplex Operation

A new series of High Gain Base Station Antennas for use with the above duplexers has been designed.

These antennas consist of a plurality of collinear shunt fed coaxial dipoles. The dipoles are mounted on a centrally located semi-flexible large diameter coaxial cable. The cable is 7/8 inch diameter 50 ohm Foamflex. It consists of .288 inch diameter inner conductor, foam polyethylene dielectric and a 7/8 inch O.D. by .037 wall aluminum outer conductor. The cable has a velocity of propagation of .81. Thus an inphase condition exists every .81 wavelengths inside the cable. This distance is 20.9 inches at 460 Mc. If holes are drilled through the sheath at this spacing, probes inserted into the holes would indicate an inphase condition existing at these points.

The outer conductor of the Foamflex cable used in the new antenna series is drilled in this manner. A one-half inch drill is used to penetrate the outer and to drill through the foam to the inner conductor. The inner conductor is then drilled with a smaller diameter drill and tapped for a number ten machine screw. A teflon insulating bushing is inserted into the hole and the radiating element is positioned over the cable.

Figure 13 shows the construction used of each radiating element. The center of the element is grounded to the Foamflex outer conductor and a machine screw is used to attach one end of the radiating element to the inner conductor of the cable.

As shown the element is fed at its highest impedance point. The measured value of impedance at this point is approximately 200 ohms resistive. This would indicate that the final input impedance of the six element array should be approximately 35 ohms. Figure 14 is the plot of the six element antenna as initially assembled. The resistive component at 460 Mc is approximately 35 ohms. The impedance plot is such that a single one-quarter wavelength matching transformer located slightly less than one-half wavelength from the first element feed point may be used to bring the total VSWR plot inside the 1.5 to 1 circle. Figure 15 shows the final impedance plot of the antenna.

Figure 16 presents the vertical field strength pattern of the final antenna. The integrated gain of this pattern at 460 Mc is 8.2 db. The antenna, being an end-fed device, is subject to pattern tilt when it is operated away from its design center. The deviation from design center is only ±10 Mc or ± 2.2%. The tilt over this range is less than ±2°. This represents a gain variation of minus 0.1 db at each end of the operating band. The Foamflex cable has extremely low loss and since only 12 feet are needed from the base of the antenna to the last element the loss attributable to it is 0.12 db. The combination of integrated gain, feed cable loss and pattern tilt yield a final antenna gain of approximately 8 db. The length of the completed antenna exclusive of support pipe is 12 ft. 6 inches.

In the 150 Mc band the length of an antenna which can be easily handled in the field limits the unit to a four element structure. This antenna is designed in the same manner as the 450 Mc unit. Figure 17 shows the vertical field strength pattern of the antenna. The antenna has a usable bandwidth of 6 Mc. This is only ±2% of the design center and since this antenna has fewer elements than the 450 Mc unit the pattern tilt loss is no greater. The feed cable loss is of the same general nature. The integrated gain of the pattern shown in Figure 17 is 6.2 db. The final antenna therefore has a gain of approximately 6 db. The length of the 150 Mc antenna exclusive of support pipe is approximately 19 feet.

LIGHTNING PROTECTION

The use of a relatively large diameter aluminum conductor running the length of the antenna has been used to advantage in the reduction of possible lightning damage. The feed cable outer conductor is grounded at the base of the antenna and extended through the top of the fiberglass antenna housing by means of a stainless steel rod which serves as a lightning spike. The antenna has been tested and has been fully operable after being subjected to repeated current surges in excess of 190,000 amperes.

The heavy wall custom fabricated fiberglass housings into which the above antennas are assembled provide complete weather protection. The fiberglass housings are designed to give the antennas operating capability in winds of 100 MPH.

Figure 18 shows the complete antenna as supplied to the field.

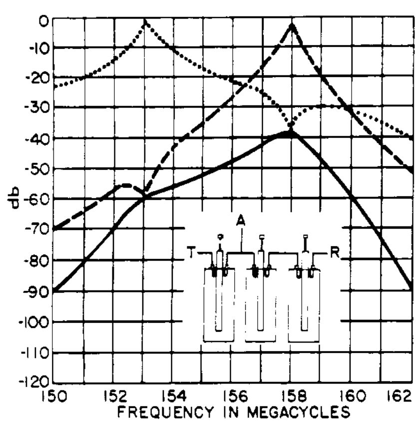


FIGURE 1. 150 MC THREE CAVITY REFERENCE DUPLEXER

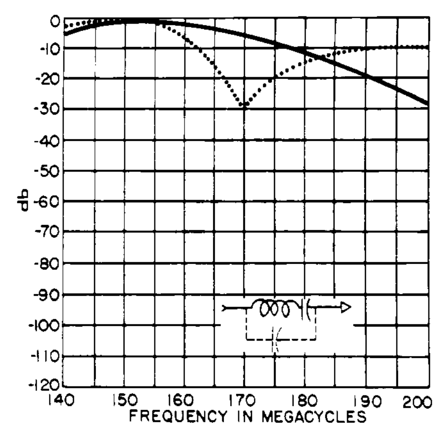


FIGURE 3. LUMPED CONSTANT RESONANT — ANTI-RESONANT CIRCUIT

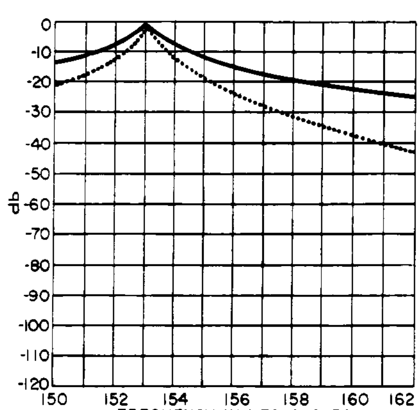


FIGURE 2 SINGLE 150 MC CAVITY RESPONSE CURVES

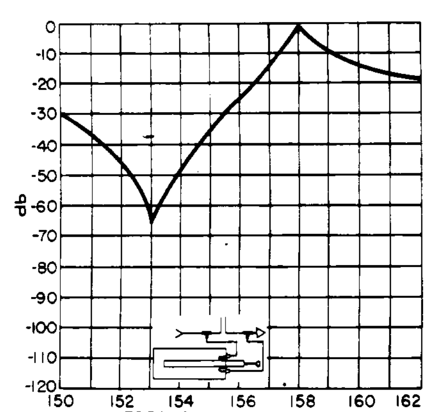


FIGURE 4 150 MC 0.3 DB CAVITY WITH SHUNT CAPACITOR

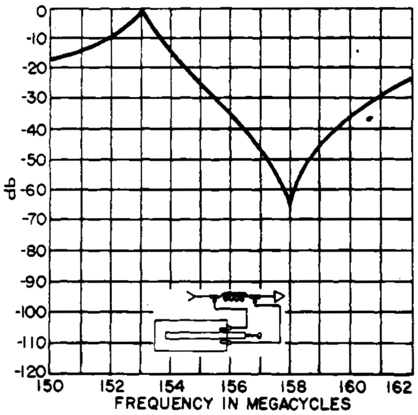


FIGURE 5 150 MC 0.3 DB CAVITY WITH SHUNT INDUCTOR

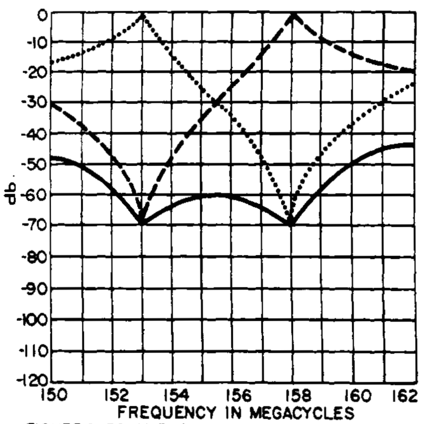


FIGURE 6. 150 MC TWO CAVITY DUPLEXER WITH NOTCH CIRCUITS.

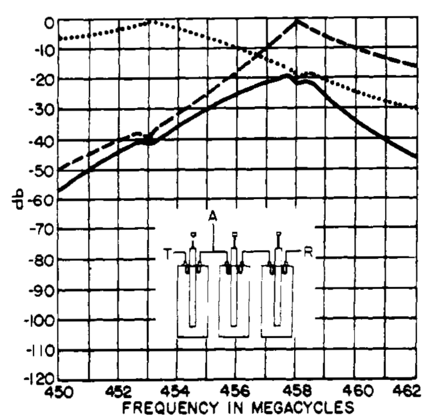


FIGURE 7 450 MC THREE CAVITY REFERENCE DUPLEXER

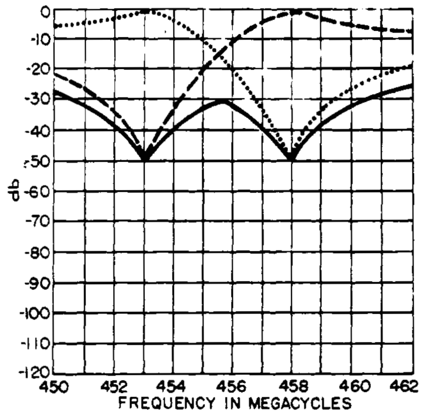


FIGURE 8. 450 MC TWO CAVITY DUPLEXER WITH NOTCH CIRCUITS.

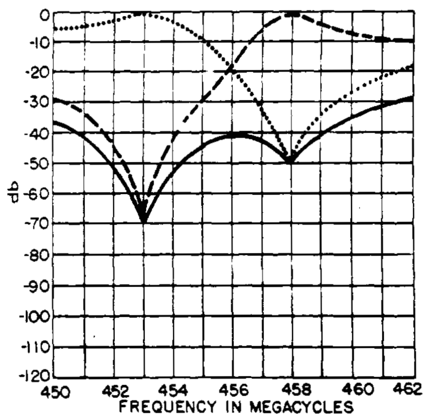


FIGURE 9. 450 MC THREE CAVITY DUPLEXER WITH NOTCH CIRCUITS.

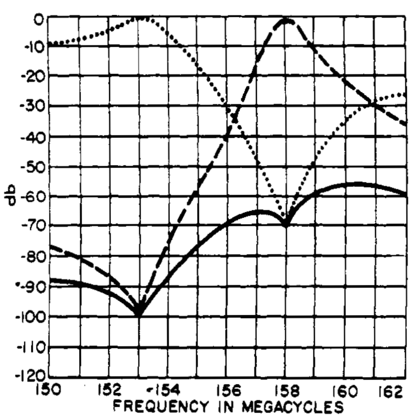


FIGURE 10 150 MC THREE CAVITY DUPLEXER WITH NOTCH CIRCUITS

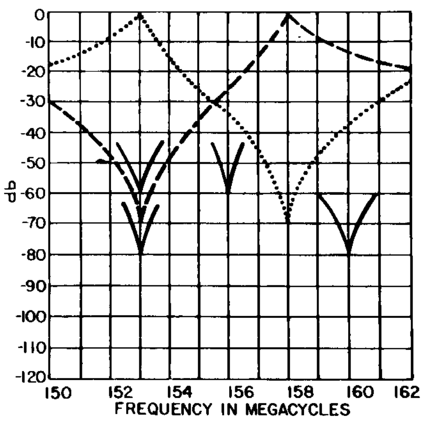


FIGURE 11 150 MC TWO CAVITY DUPLEXER WITH NOTCH CIRCUITS TUNED FOR 3,5,8,7 MC SEPFRATION

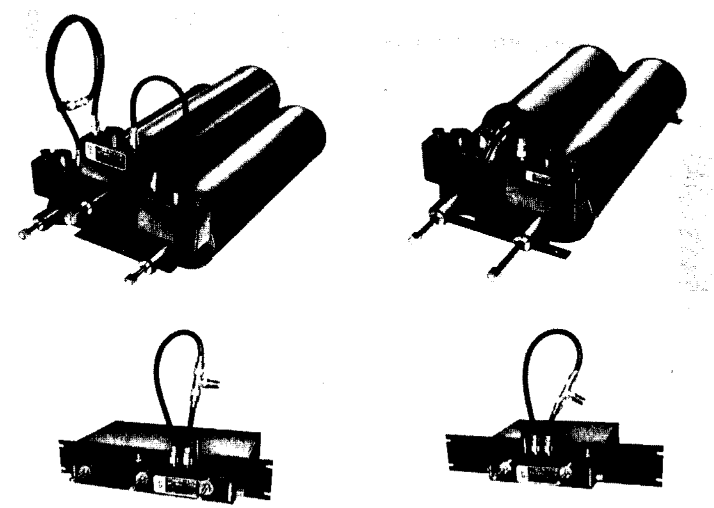


Fig. 12. Duplexers Packaged for Commercial Application.

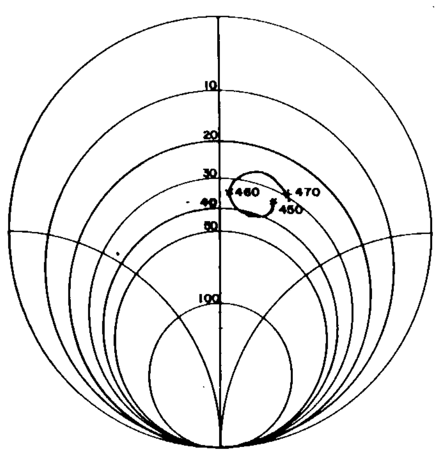


FIGURE 14 SMITH PLOT OF SIX ELEMENT 450-470 MC ANTENNA WITHOUT MATCHING TRANSFORMER

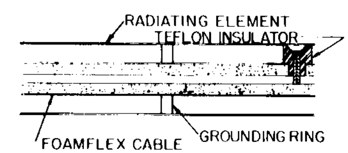


FIGURE 13 INDIVIDUAL ELEMENT FEED METHOD

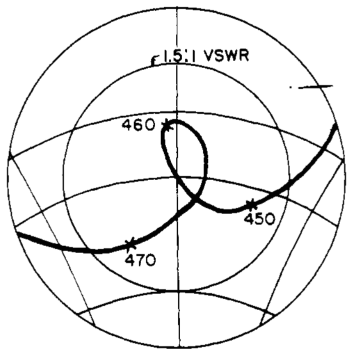


FIGURE 15. EXPANDED SMITH PLOT OF PRODUCTION 450-470 MC ANTENNA.

Fig. 18. Completed 450-470 MC Antenna.

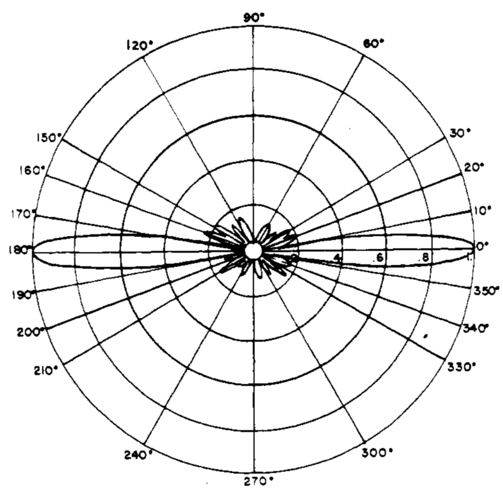


FIGURE 16. FIELD STRENGTH PATTERN OF 450-470 MC ANTENNA MEASURED AT 460 MC.

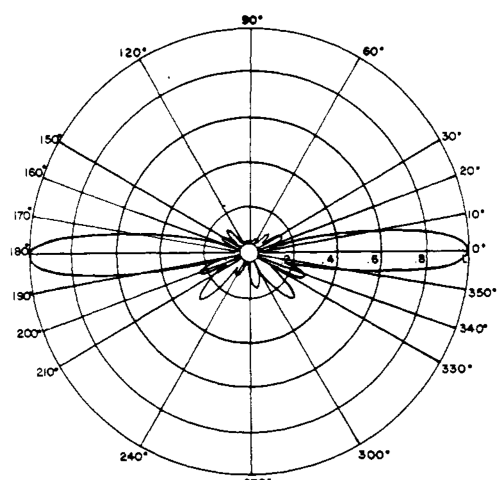
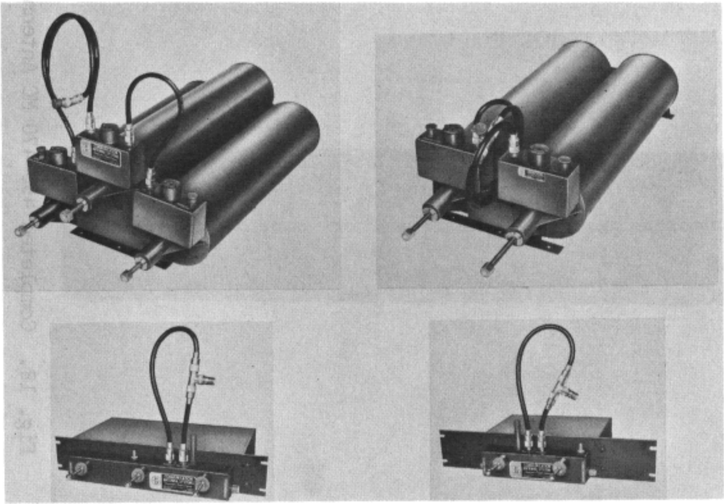


FIGURE 17. FIELD STRENGTH PATTERN OF 150-156 MC ANTENNA MEASURED AT 153 MC.



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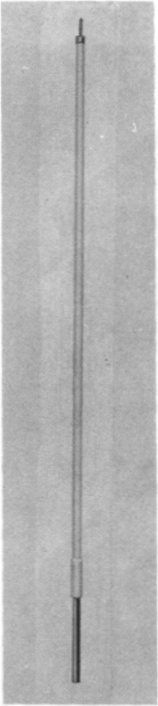

Fig. 18. Completed 450-470 MC Antenna.