A New Form of High-Power Microwave Duplexer*

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***Summary*—A new form of microwave duplexer, capable of handling twice as much power as an equivalent balanced duplexer is described. It consists of a microwave bridge circuit and a power-sensitive half-wavelength phase shifter. A simple gas-discharge tube is used in the phase shifter, which changes the length in one arm of the bridge circuit by a half-wavelength for high-power and low-power microwave pulses, respectively.**

The performance of one form of phase-shift duplexer has been measured over a frequency range from 8500 mc to 10,000 mc. The vswr is less than 1:2 and the receiver isolation is greater than 30 db over most of the waveband. This is comparable to the performance of a balanced duplexer using the same components. The power handling capacity of the phase-shift duplexer is intrinsically twice as great as that of the balanced duplexer. For example, at a wavelength of 3 cm the phase-shift duplexer will operate unpressurized at a peak power level of 200 kw with a 2:1 safety factor on breakdown, whereas performance of a balanced duplexer at this power level is marginal.

INTRODUCTION

THE FUNCTION of a microwave duplexer in a pulsed radar is to switch power, first from transmitter to antenna and then, within a few microseconds, from antenna to receiver. A rapid switching action is generally achieved with gas discharge devices ionized by the microwave power from the transmitter.

Two methods of using TR cells in microwave circuits have been described by Smullin and Montgomery.[1] These are the branched and balanced duplexers. The balanced duplexer has advantages over the branched duplexer with respect to bandwidth and power handling; furthermore, its performance is independent of the transmitter impedance. The power handling capacity of a balanced duplexer is restricted to half that of the waveguide itself. This is due to the large standing wave existing between the gas discharge cells and the hybrid junction.

One method of improving the power handling of this type of duplexer has been described by Jones[2] and is referred to as an A-TR balanced duplexer. Standing-waves in the main waveguides are avoided with this arrangement but the bandwidth is restricted by the relatively high-Q A-TR circuits. Improvements in bandwidth may be achieved by using four or six A-TR cells but the arc loss is then two or three times as great.

The total-coupler duplexer described by Milosevic,[3] is capable of handling high powers but includes nineteen discharge tubes. However, the advantages of this form of duplexer are apparent and improvements in design will no doubt follow.

Another method of improving the power handling without increasing the number of tubes has been sought by using a microwave bridge circuit consisting of two hybrid junctions and a power-sensitive phase shifter.[4]

The principle of this method is illustrated in Fig. 1. The transmitter is connected to arm 1 of the first hybrid junction, so that the power splits equally into arms 3 and 4. If the path lengths from the first to the second junction are equal, then the power will pass into arm 7, which is connected to the antenna. If the total path length from arm 6 to 3 is now increased by one half-wavelength, power entering arm 7 from the antenna, after dividing into arms 5 and 6 will recombine into arm 2, the receiver. A method of increasing the electrical path length for low-power signals with respect to that for high-power signals has been devised. This phase shifter, together with its application in a phase-shift duplexer, is described.

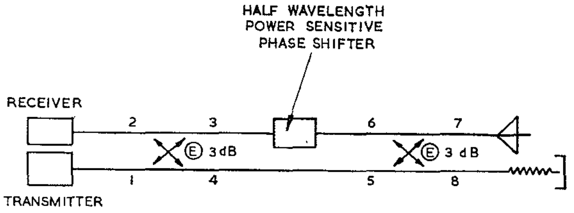

Fig. 1—Principle of the phase-shift duplexer.

THE POWER-SENSITIVE HALF-WAVELENGTH PHASE SHIFTER

Principle

The power-sensitive half-wavelength phase shifter is a waveguide device which provides path lengths differing by a half-wavelength for high-power and low-power microwave pulses. It consists of a hybrid junction, which is used in conjunction with two gas discharge tubes. Metal shorting plates are placed an effective quarter-wavelength behind these switches. The principle is shown in Fig. 2, where gas discharge tubes are placed across arms 3 and 4 of a hybrid junction. A

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[1] L. D. Smullin and C. G. Montgomery, "Microwave Duplexers," M.I.T. Rad. Lab. Ser., McGraw-Hill Book Co., Inc., New York, N. Y., vol. 14; 1948.

[2] C. W. Jones, "Broadband balanced duplexers," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 4–12; January, 1957.

[3] L. Milosevic, "Duplexeurs a grande puissance," *Le Vide*, vol. 67, pp. 109–116; January/February, 1957.

[4] C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications—the microwave gyrator," *Bell Sys. Tech. J.*, vol. 31, pp. 1–31; January, 1952. A duplexer is described here which is similar in principle to the phase-shift duplexer; a directional phase-shifter of ferrite is used instead of the half-wavelength power-sensitive phase shifter.

high-power microwave pulse entering at arm 1 is divided equally between arms 3 and 4 by the hybrid junction and ionizes the gas discharge tubes. The pulse is then reflected and if the tubes are placed correctly with respect to the hybrid, all the power will pass into arm 2. Similarly a low-power microwave pulse, insufficient to ionize the discharge tube will be reflected by the metal short circuits and will pass into arm 2. However, the total electrical length of the device will be a half-wavelength longer for a low-power pulse than for a high-power pulse.

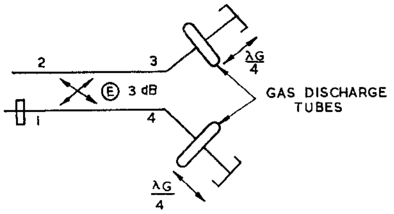

Fig. 2—Principle of the half-wavelength power-sensitive phase shifter.

The Hybrid Junction and Discharge Tube

The principle of the half-wavelength phase shifter has been established experimentally at a wavelength of 3 cm. A 3 db directional coupler, known as a binomial-slot hybrid[5] has been selected as a convenient form of hybrid junction for the phase shifter. It is a branched waveguide directional coupler with five branched waveguides, the voltage coupling coefficients of which are arranged according to the coefficients of a binomial series, as shown in Fig. 3. The voltage coupling is such that power divides equally into arms 3 and 4, there being a 90 degree phase difference between the fields in the two waveguides. Thus if an electrical short circuit is placed across any plane at right angles to arms 3 and 4, all the power entering arm 1 will be reflected into arm 2.

The high-power switching is achieved with a gas discharge tube shown in Fig. 4. This consists of a silica tube containing a gas filling, optimized for low microwave breakdown and arc loss. The tube, which is transparent to low-power microwave pulses, is mounted parallel to the E field across the center of the waveguide. A high-power microwave pulse will ionize the gas in the tube placing an effective short circuit across the waveguide. Loss of power by radiation along the axis of the tube is prevented by means of microwave chokes.

The geometrical configuration of the binomial-slot hybrid is such that a common tube may be used for both arms of the phase-shifter. This is shown in Fig. 5. In this phase shifter a microwave choke is also used to prevent interaction from one waveguide to the other by conduction along the discharge tube.

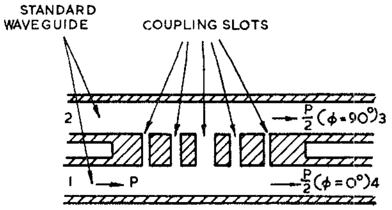

Fig. 3—Binomial-slot hybrid.

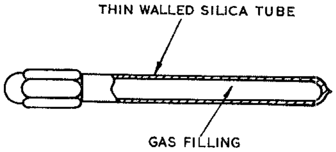

Fig. 4—Gas discharge tube.

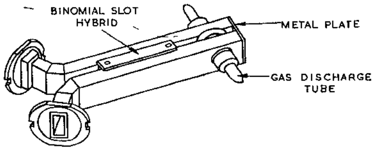

Fig. 5—A power-sensitive phase shifter for the 3-cm waveband.

A PHASE-SHIFT DUPLEXER FOR THE 3-CM WAVEBAND

Description

One form of phase-shift duplexer has been designed for use at a wavelength of 3 cm. The duplexer, which is composed of four binomial-slot hybrids is shown diagrammatically in Fig. 6. Power from the transmitter, incident on arm 1 of hybrid *A*, divides equally into hybrids *B* and *C*. The former is the phase shifter and the latter a balancing hybrid. From *B* and *C*, the power recombines into the antenna on arm 8 of *D*. On the other hand, incident power from the antenna travels an extra half-wavelength through the phase shifter and hence recombines into the receiver on arm 2 of hybrid *A*. The purpose of the balancing hybrid is to maintain symmetry through the system and hence extend the over-all bandwidth.

One advantage of the binomial-slot hybrid is that it facilitates the use of a common discharge tube for both arms of the phase shifter. This is technically important in that it insures a common position of electrical short circuit for both arms of the phase shifter. Another advantage is that it can be constructed by milling and this enables the whole duplexer to be machined in a single block of metal. A method of doing this is indicated in Fig. 7. Alternatively, the binomial-slot hybrid may be used in conjunction with the short-slot hybrid,[6] in which the narrow walls of the waveguide are adjacent. Power is coupled through a short slot cut in the common walls of the two waveguides. The performance of

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[5] P. D. Lomer and J. W. Crompton, "A new form of hybrid junction for microwave frequencies," *Proc. IEE*, vol. 103, pt. B, pp. 261–264; May, 1957.

[6] H. J. Riblet, "The short-slot hybrid junction," PROC. IRE, vol. 40, pp. 180–184; February, 1952.

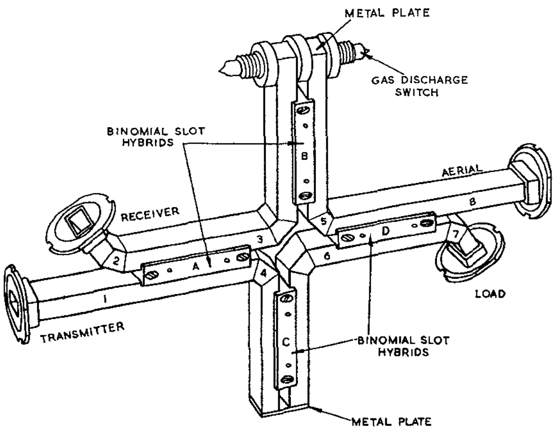

Fig. 6—An experimental phase-shift duplexer for the 3-cm waveband.

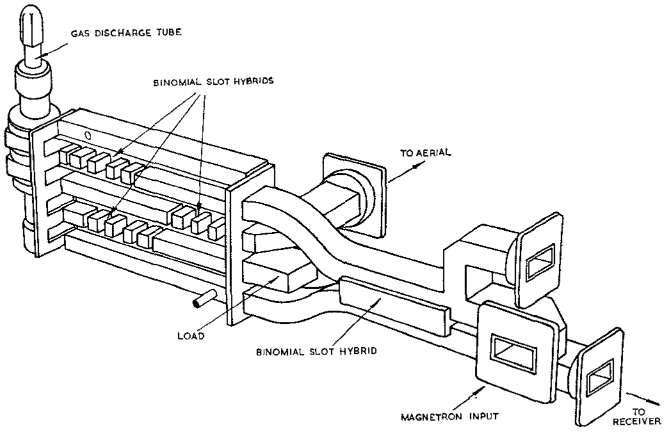

Fig. 7—A phase-shift duplexer milled out of a solid block of metal

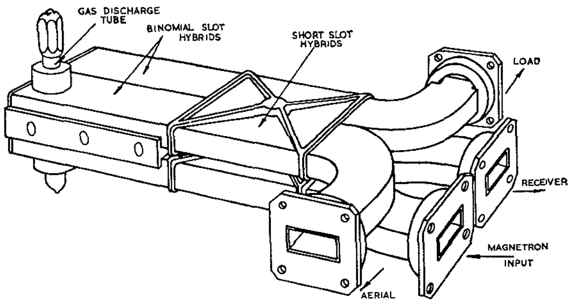

Fig. 8—A phase-shift duplexer using short-slot hybrids and binomial-slot hybrids.

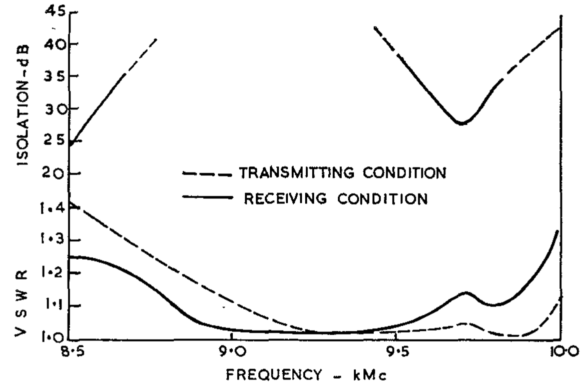

Fig. 9—Performance data for the experimental phase-shift duplexer.

this junction is similar to that of the binomial-slot hybrid and the two are in effect complementary. If hybrids *A* and *D* of the duplexer are short-slot hybrids and hybrids *B* and *C* are binomial-slot hybrids, a very compact design may be achieved as shown in Fig. 8.

Performance

Performance data have been obtained from an experimental duplexer in waveguide W.G.16 (0.9×0.4 inch ID) of the type shown in Fig. 6. Measurements were made over a frequency range from 8500 mc to 10,000 mc. The important properties of the duplexer are its impedance in both the transmitting and receiving conditions, the isolation between the transmitter and receiver, and the insertion loss during transmission and reception. Another property, the recovery time, is determined by the characteristics of the gas discharge tube.

The impedance is measured in terms of the voltage standing wave ratio (vswr) which is determined by the reflections from the binomial-slot hybrids and the waveguide corners. The binomial-slot hybrid reflects very little power at the center of the band, from 9000 to 9500 mc and since the waveguide corners are also good over this range the vswr of the complete duplexer is less than 1.1. Over most of the 15 per cent frequency band, the vswr is less than 1.2 as shown in Fig. 9.

The isolation between transmitter and receiver is determined by the directivity of the first hybrid *A*. It is modified however by any reflections which enter the receiver arm from the rest of the duplexer. For example, a vswr of 1.1 may limit the receiver isolation to 26 db. The experimental results of isolation against frequency are given in Fig. 9.

Although reflections within the duplexer affect the isolation, reflections from the antenna pass directly into the transmitter arm. In this respect, the phase-shift duplexer differs from the ferrite circulator, in which antenna reflections go into the receiver arm.

The insertion loss of the complete duplexer is less than 0.5 db over the 15 per cent band.

The performance of the duplexer at high power levels has been determined by measurements at a frequency of 9475 mc. The loss in the discharge tube is of the order of 0.2 db. The position of the effective electrical short circuit of the tube is independent of power level so that the performance of the complete duplexer does not depend on the peak power. Measurements on a phase-shifter alone have shown that it will withstand peak power up to 200 kw with the waveguide unpressurized. This corresponds to a power handling of 400 kw for the complete unpressurized phase-shift duplexer. The recovery time of the duplexer is defined as the time after the transmitted pulse for the attenuation between antenna and receiver to drop to 3 db. This is determined by the rate of change of electron temperature and electron density in the afterglow of the discharge. In conventional duplexers, the effect of the afterglow on attenuation is the only important factor, but with the phase-shift duplexer, the phase of the signal is also important. However, measurements have shown that with this gas discharge tube, the recovery time of both phase shift and attenuation are similar. The recovery time of the duplexer is of the order of 5 to 10 μsec to an attenuation of 3 db.

Comparison with a Balanced Duplexer

In order to obtain a direct comparison between the balanced duplexer and phase-shift duplexer, the performance of a balanced duplexer consisting of two binomial-slot hybrids and the same discharge tube has been determined. The arrangement of the balanced duplexer is illustrated in Fig. 10 and its vswr in both the transmitting and receiving conditions is given in Fig. 11. The isolation provided by the second hybrid of the balanced duplexer is given in the same diagram. There is no significant difference in the low-level performance of the two forms of duplexer.

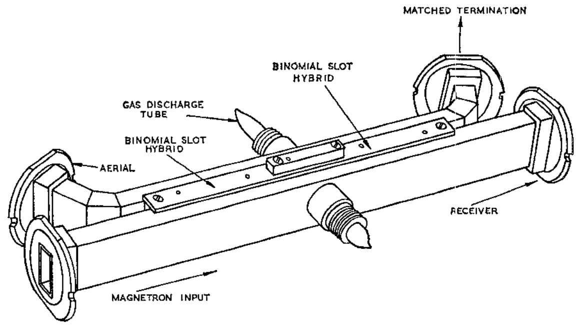

Fig. 10—A balanced duplexer with binomial-slot hybrids and gas discharge tube.

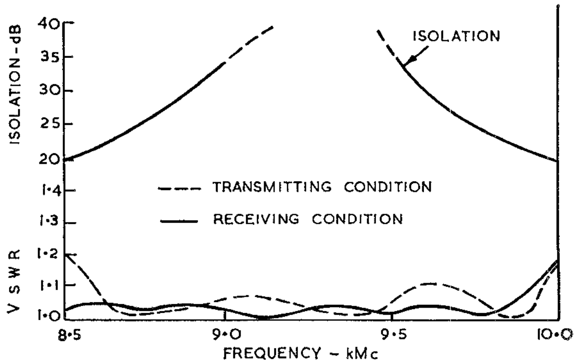

Fig. 11—Performance data for the balanced duplexer.

At high-power levels there is a fundamental difference in the leakage power into the receiver arms of the respective duplexers. In the case of the phase-shift duplexer, the leakage is determined by the isolation provided by the first hybrid, modified by any reflections from the phase shifter and the balancing hybrid. In general from 30 db to 50 db isolation may be achieved depending on the bandwidth required. This is equivalent to a peak power leakage of 2 to 200 watts with a 200-kw transmitter. The leakage from the balanced duplexer is a function of the discharge tube and is in the form of a spike and flat leakage.[1] This leakage is reduced by the second hybrid junction but owing to small variations in the formative time of the discharge in the two arms of the duplexer, it is difficult to achieve a greater cancellation than 15 to 20 db. In practice this means that with the duplexer described a spike leakage of about 500 watts peak will enter the receiver arm; thus, in this respect also there is no great advantage in either form of duplexer. In either case it is necessary to use a TR cell or pulsed attenuator to protect the receiver.

The great advantage of the phase-shift duplexer is its power handling ability. The switching system of the phase-shift duplexer is very similar to that of the balanced duplexer but operates at half the input power. The power incident on each section of the discharge tube is only a quarter of the transmitted power, compared to half the transmitted power for a balanced duplexer. Similarly the hybrid used in the phase shifter is handling only half the power. The first and fourth hybrids of the phase-shift duplexer handle the full power but have matched impedances on all arms. It is known that under these conditions a hybrid junction will handle twice as much power as a hybrid with short circuits on two arms. Thus, whether the power handling capacity is limited by the hybrid junction or by the discharge tube, it is intrinsically twice as great for the phase-shift duplexer as for the balanced duplexer.

In general a balanced duplexer operating at 200 kw at a wavelength of 3 cm is working near its maximum power handling capacity and for satisfactory performance in equipment it must be pressurized. The equivalent system using a phase-shift duplexer will operate with a 2:1 safety factor at 200 kw and will not require pressurizing equipment. The advantage of the phase-shift duplexer is as great at higher power levels, since the degree of pressurizing may be reduced, and the life of the discharge tube extended.

Conclusion

The power handling capacity of a phase-shift duplexer is twice that of a balanced duplexer using the same components. The other properties of the two forms of duplexer are similar.

Acknowledgment

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