NRL REPORT 3750

GROUND-STATION EQUIPMENT FOR THE PROPOSED BEAM-RIDING SYSTEM

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WASHINGTON, D.C.

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GROUND-STATION EQUIPMENT FOR THE PROPOSED BEAM-RIDING SYSTEM

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ABSTRACT

A beam-riding missile-control system providing reduced complexity within the missile and suitable control without internal modification of the tracking radar has been proposed. Investigation showed that a c-w microwave transmitter separated by 50 megacycles from the operating frequency of an S-band missile-tracking radar can, by suitable insertion techniques, be fed into the radar antenna system. By f-m modulation of the c-w carrier at the antenna nutation rate, a simplified beam-rider control signal is made continuously available to the tracked missile. Two suitable c-w transmitters and a practicable injection system for the SP-1M radar are described.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

NRL Problems R05-16D (now closed) and R05-48R
NR 505-480

GROUND-STATION EQUIPMENT FOR THE PROPOSED BEAM-RIDING SYSTEM

INTRODUCTION

A proposal has been made by Mr. J. P. Spalding, Radio Division III, NRL, to modify the Lark missile-control system to allow a more simple missile-borne receiver to be used by concentrating most of the inherent complexity of the system at the surface control point. Further, the control point equipment would be connected externally to the tracking gear allowing easy conversion of existing radars. One method for applying this principle would utilize a frequency-modulated c-w transmitter to produce the control signal. By suitable insertion techniques, it was hoped this signal could be directed to the missile through the antenna system of the associated tracking radar and thus eliminate the heavy burden of a separate radiator system. By this method, the c-w signal would be frequency-modulated at the scanning rate of the jointly used antenna and thus would serve as a control reference for the amplitude modulation frequency developed in accordance with the position of the missile within the scanned area. These f-m and a-m components of the c-w signal would furnish the necessary guidance information to the missile receiver and control system. The radar in this case serves only to give tracking and range information and thus plays an indirect role in controlling the missile.

One solution of the insertion problem would entail installation of a dual-feed antenna. To keep modification to a minimum, however, methods of inserting the c-w signal directly into the SP radar waveguide were first explored. This would require a c-w generator to be operated enough off frequency from the radar to allow suitable rejection filters to be employed to separate the two signals and prevent interaction. The part of the problem concerned with the surface installation was analyzed and broken down into two separate phases as follows:

(a) The design, development, and construction of an S-band c-w generator capable of being frequency-modulated at a 24-cycle rate.

(b) Research leading to the development of techniques permitting the c-w signal to be efficiently inserted into the radiation system of the tracking radar without compromising normal radar or c-w performance.

F-M TRANSMITTER DESIGN

Two possible types of f-m transmitters were considered for producing the injection signal. One was an M.O.P.A. type using a klystron oscillator with klystron amplifiers, and the other was a c-w magnetron. For purposes of demonstrating principles, long-time frequency stability of the transmitters was ignored, although such would be required in a

practical system. At the inception of this problem, little was known about the linear frequency-modulation characteristics of a c-w magnetron, but such characteristics of the reflex klystron were available.

M.O.P.A. Klystron Transmitter

The klystron approach was followed after making some modulation measurements on a Sperry type 2K41 klystron oscillator used in a Sperry Microline signal generator. It was found that the observed frequency-modulation characteristics checked with the published data on the tube. The observed data was obtained by introducing controlled d-c voltage at the reflector electrode where the periodic voltage would be normally introduced and then noting the frequency shift on a TS-186/UP frequency meter for each voltage change made. Without isolation, however, the frequency meter tended to "pull" the klystron frequency, making precise measurements impossible.

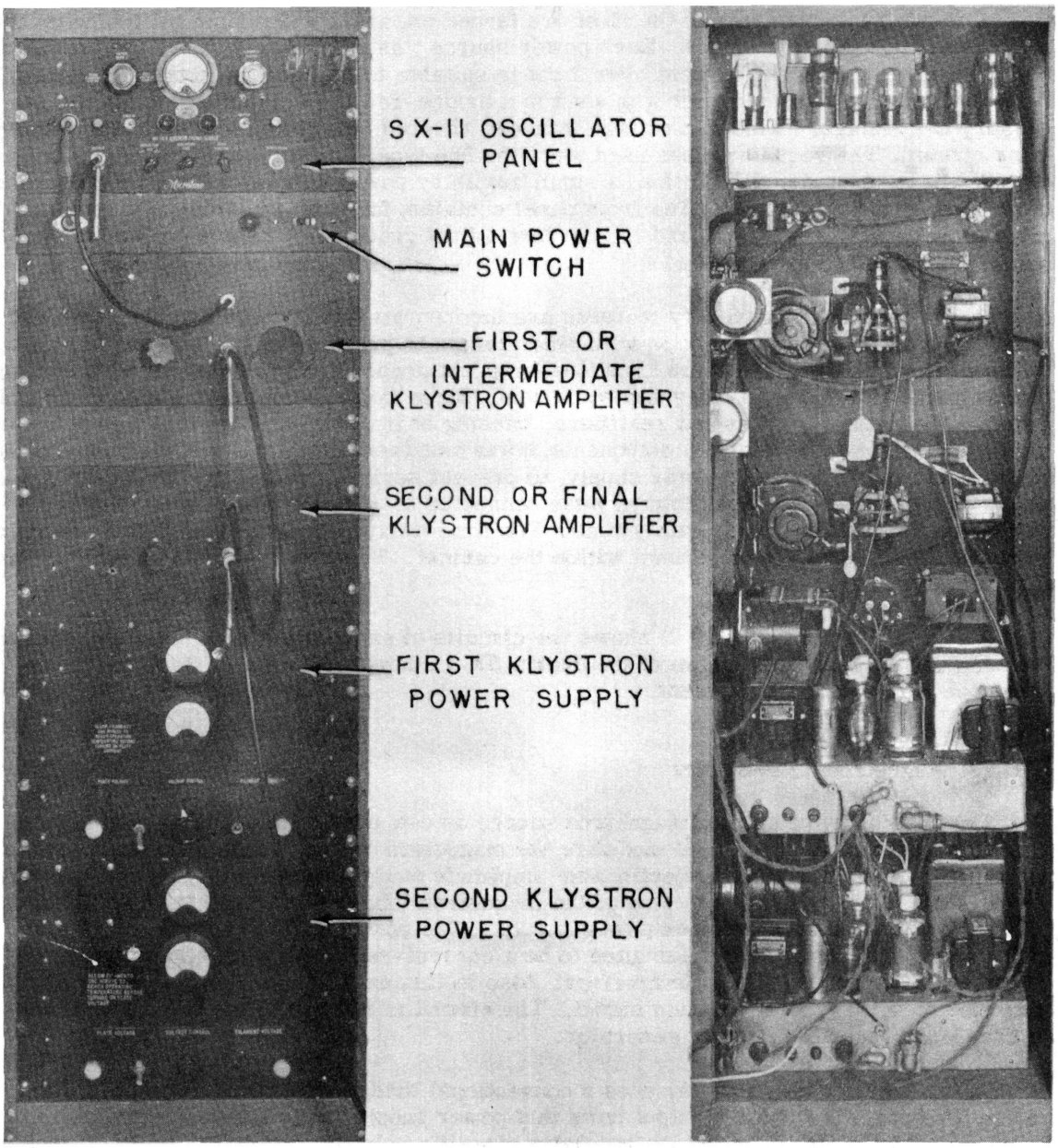
The frequency change of the type 2K41 tube was also checked after feeding into a type 3K33 klystron amplifier and then into the frequency meter. Since the oscillator would normally feed into an amplifier, this measurement had more meaning. Under these conditions the frequency shift for five volts supply change was 0.8 megacycle. Larger deviations could be obtained (up to approximately plus or minus ten megacycles) with larger voltage change introduced at the reflector. As indicated by the data published by Sperry, these results confirmed the feasibility of using the klystron as a signal source for the c-w injection system; however, output from the 2K41 oscillator would have to be amplified to produce sufficient power to be of any use to the proposed system. It was proposed to do this through klystron amplifiers, thereby simultaneously gaining short-time frequency stability.

At this point the possibility was considered of using as a power oscillator a higher power klystron of the dual-cavity type. The tube selected for this purpose was the Sperry type 3K33. After construction of a power supply of suitable design, this tube was put into an oscillator circuit consisting of a line stretcher feeding back from the output cavity to the input cavity. The oscillations obtained from this setup were not satisfactory.

The results of these experiments indicate that the use of a master-oscillator power-amplifier system would be the most satisfactory klystron source of injection signal. With careful adjustment of the tubes, a power output of 3 to 5 watts can be obtained from such a system, and with another amplifier in cascade, a power output of about 15 watts or more appeared probable. Accordingly, a transmitter was built which utilized a standard Sperry type SX-11 signal generator containing a type 2K41 oscillator tube. This generator is connected to the first or intermediate amplifier which is a type 3K33 klystron. The output from the intermediate amplifier is in turn fed into another type 3K33 klystron operating as the final amplifier stage. A separate power source is necessary for operating each 3K33 tube because the power requirements differ slightly from tube to tube.

The units are installed in a six-foot standard-rack cabinet. Figure 1 shows a front and rear view of the complete equipment. The units are installed in the following order from top to bottom: The SX-11 oscillator unit, main power switch panel, first or intermediate klystron amplifier, a blank panel, the second or final klystron amplifier, and, at the bottom, the first and second klystron power supplies.

The two 3K33 amplifier klystrons, each with their proper tuning mechanisms, are mounted on a separate panel with suitable blowers for cooling. A filament transformer is also mounted on this panel along with a cathode bias resistor and the r-f jacks.



Front view Rear view

Figure 1

The two power supplies are made alike, with the exception that the supply for the second amplifier has no filament switch. The filaments of the second power supply are turned on when the filaments of the first are turned on, at the same time switching on the blowers for both klystron tubes. Each power source was current regulated and provided with a facility to vary the current over a range suitable to operate the klystrons without selection. A power transformer was used in a bridge-rectifier circuit to obtain the necessary d-c voltage. This d-c voltage was well filtered before application to the regulator circuit. The rectifier tubes used were the 866 type, and the regulator tube was a type 813 beam pentode. In addition, a small auxiliary power supply was used for operating part of the regulator circuit. The front panel contains, for each power supply, the filament switch, the plate switch, and the current-adjust control, together with two meters—a milliammeter and a voltmeter.

Several necessary auxiliary features are incorporated in this equipment. A time-delay relay operates in connection with other relays to prevent the application of high voltage before the rectifiers and klystrons have had proper heating time. This precaution avoids possible damage to tubes and equipment. Since there is considerable power dissipated in the regulator tubes and rectifiers, causing heat which must be removed to prevent overheating of the relative components, it was found necessary to install additional blowers in the cabinet, one for each power supply, to prevent serious overheating of the tubes and power transformers. These blowers were connected to come on when the time-delay relay has allowed the proper safety time. The time-delay relay and its relative switching components are mounted on a panel within the cabinet. Terminals on this assembly connect directly to the other units.

A circuit diagram (Figure 2) shows the circuits of each unit and the interconnections between units. For the diagram of the Sperry SX-11 unit, reference is made to the instruction book for this equipment.

CW-FM Magnetron Transmitter

The possibility of using a magnetron source as c-w power for injection was also investigated. It is necessary to modulate the magnetron over the required frequency excursion without producing objectionable amplitude modulation. A magnetron transmitter developed for the purpose consisted of the magnetron tube (type QK-59), and its tuning assembly operated with a proper power supply . The power supply comprises the main part of this equipment; it was designed to be a current-regulated supply with the facility to introduce modulation to the magnetron. Also in this unit a square-wave generator was provided to supply the modulation signal. The circuit is similar to the one found in the Sperry Microline SX-12 signal generator.

The magnetron power supply uses a conventional bridge-type circuit with rectifiers of the 866 type. The voltage output from this power supply, after filtering, is about 3,000 volts, and this is fed into a series regulator circuit employing a type 813 tube. The output terminal facility is negative; that is, the positive terminal of the supply is connected to the chassis.

The circuit is so arranged that modulation voltage is introduced at the grid of the regulator tube, while the current control is accomplished by varying the cathode bias of the regulator tube. The power supply feeding the regulator is filtered by an input choke and a brute-force filter. There is an auxiliary supply which provides power for the screen grid of the regulator, and it is controlled by a relay so that power is supplied only when the main plate power is turned on. The voltage of this auxiliary power supply is

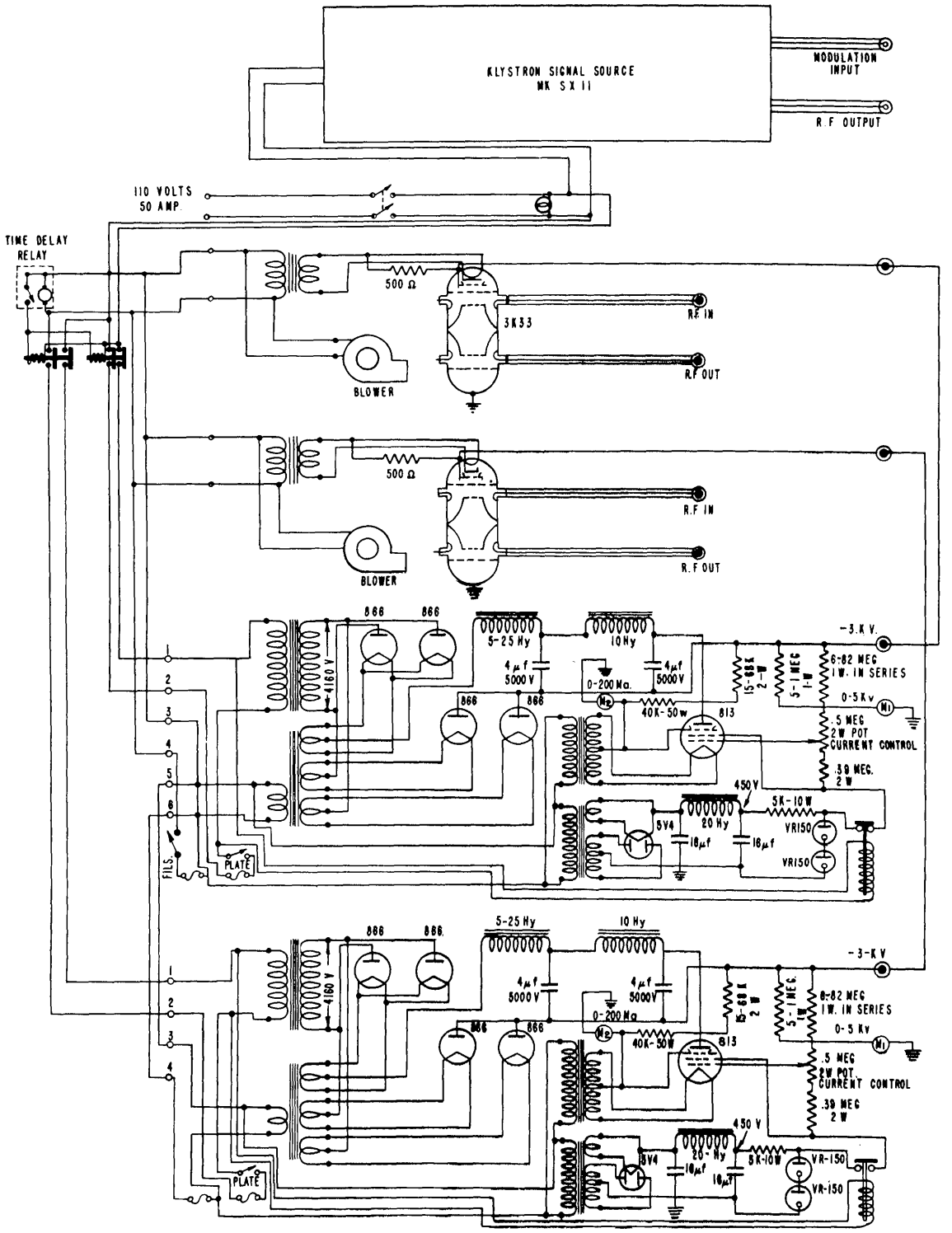


Figure 2 - Schematic diagram, klystron f-m transmitter

also regulated to improve the performance of the magnetron. Again, a time-delay relay is provided to prevent the application of high voltage to the circuits before tubes have had time to reach operating temperature. When the power supply is operating, the regulator tube dissipates sufficient energy to warrant a blower for forced ventilation.

The front panel of the power-supply unit contains a milliammeter, current control, a plate power switch, and the filament switch (see Figure 3). Also, on this panel is located a modulation-input terminal which permits modulation to be used from the associated square-wave generator. This generator is operated independently of the magnetron system; that is, it may be used to generate square-wave signals for other equipments as well. Controls for this section are the power switch,.frequency control, and output control.

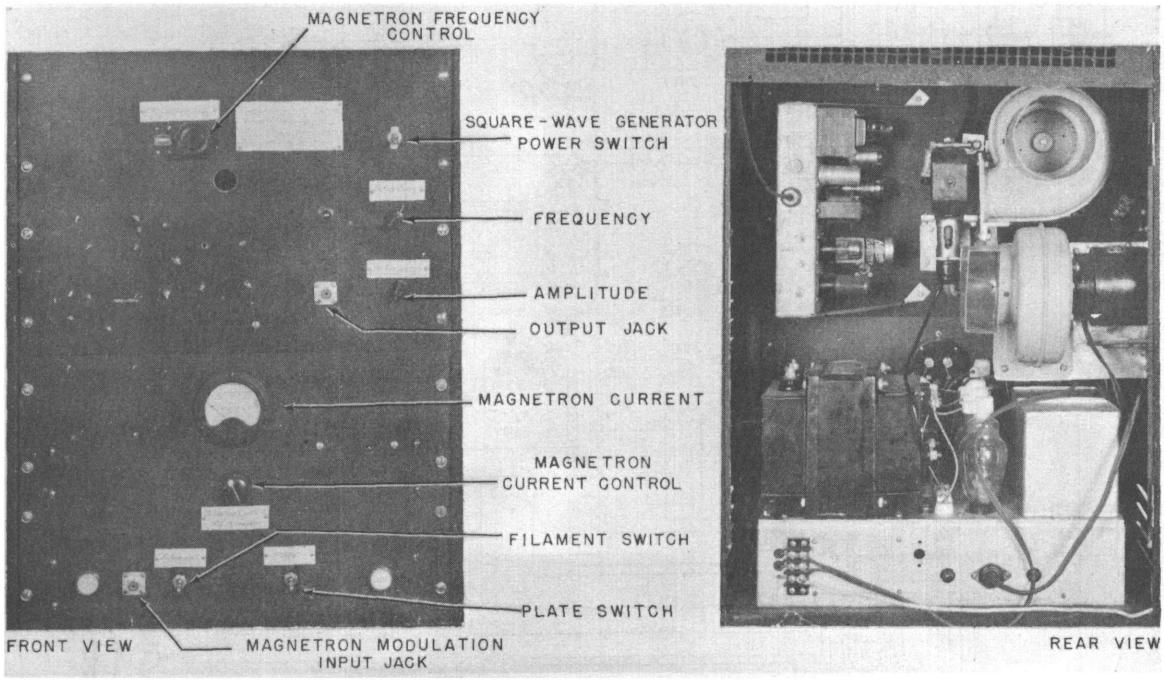


Figure 3 - F-M c-w magnetron transmitter, front and rear views

The magnetron is mounted on a shelf rigidly mounted to the back of the panel. The tuning wheel of the magnetron is geared to a shaft that comes forward through the panel to a knob. Also on the panel is a counter indicator geared to this shaft to provide some means of frequency calibration. A filament transformer, mounted on the rear side of the panel, supplies the necessary filament power for the magnetron. The high voltage from the power supply is connected to the magnetron through that side of the filament transformer which is wired to the cathode. The magnetron is a c-w type (Raytheon QK-59) capable of about 50 watts power output. A series of these magnetrons is available for this unit, each covering a different frequency range in the S-band, but all having the same operating characteristics. The blower which cools the magnetron is turned on with the filament; it draws in cooler air from outside the cabinet.

The circuit diagram (Figure 4) shows the circuit of the power-supply unit and the associated controls. The magnetron connections and the square-wave generator appear at the upper portion of the diagram.

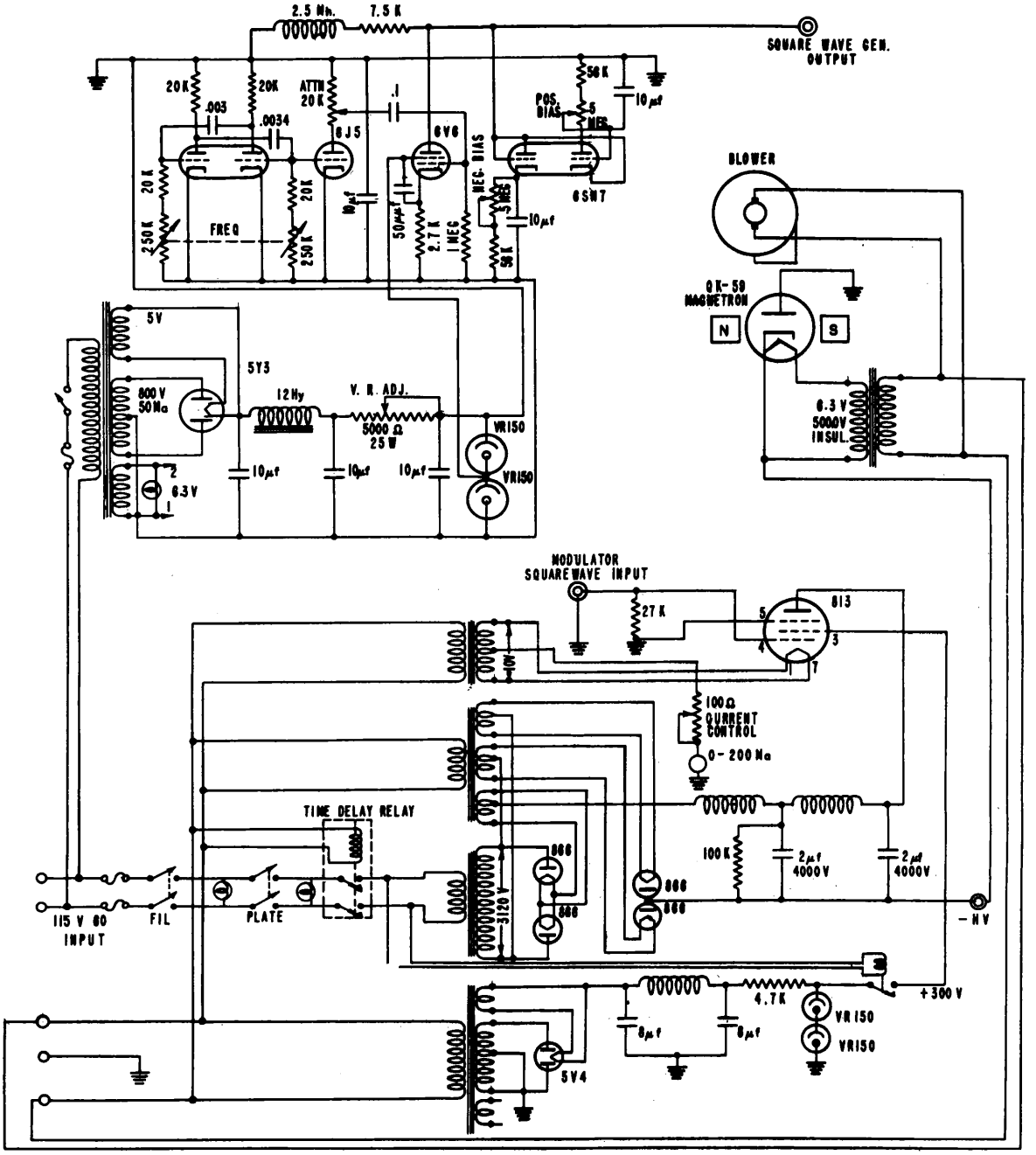


Figure 4 - Schematic diagram, "S" band f-m c-w magnetron transmitter and square-wave generator

INJECTION SYSTEM DEVELOPMENT

Theoretical Considerations

The general requirements which the problem imposes on the c-w injection system are:

1. Normal radar operation on transmission and reception not to be impaired.

2. Generation and transmission of sufficient c-w power to the radar antenna system to provide a usable range of 50 miles. (Voltage standing-wave ratios encountered in a typical SP-1M system range from 1.1 to 1.2 at the operating frequency and from 1.5 to 1.6 when 50 megacycles off frequency. The power gain of the SP-1M antenna is approximately 2900.)

3. Satisfactory isolation of the c-w transmitter from the radar receiver and of the c-w transmitter from the radar transmitter.

4. Transmission of one megawatt of radar peak power and at least 15 watts c-w power.

Theoretical considerations concerning the problem of c-w injection into the SP or SP-1M radar system further indicate that the over-all sensitivity of the SP receiver system (including main receiver unit and pre-amplifier unit) is such that two microvolts of c-w signal at 30 megacycles across the 70-ohm input terminal of the present amplifier unit will put noise on the video output of the receiver equal to the noise level of the receiver.

In terms of power this becomes:

$$P_R = \frac{E^2}{R} = \frac{2 \times 10^{-6} \times 2 \times 10^{-6}}{70} = 5.72 \times 10^{-14} \text{ watts} \cdot$$

The loss through the crystal mixer varies between 10 and 20 db depending on type of crystals, front-to-back ratio, mismatch, etc.

Assuming 10 db loss through the crystal mixer, the over-all sensitivity of the receiver to noise is approximately:

$$P_R = 5.72 \times 10^{-13} \text{ watts} .$$

If one desires to operate the c-w signal at some power level between 10 and 100 watts, the over-all isolation between the c-w source and the receiver must then be in the order of 150 decibels.

Assuming in general the following:

1. C-W rejection of T-R box	= 30 db
2. Undesired beat-frequency rejection of I-F system	= 40 db
3. Attenuation of filter designed to reject 50 ± 2 Mc and 80 Mc beat-frequencies	= 40 db

4. Isolation provided by waveguide insertion network = 40 db,

then total isolation available = 150 db.

The foregoing figures for the receiver were assumed to be representative of an SP receiver, and are based on the assumption that no leakage occurs in the r-f plumbing system or in power leads to various units concerned. The exact coupling factor of the system is not known, but it must be small for a successful system.

System Investigation and Evaluation

Since at the time work was started on this problem, little test equipment was available for making precise measurements at S-band, it was decided to set up a low-power system for experimental purposes. The r-f plumbing, the main receiver unit, and preamplifier unit from an SP radar system with laboratory-type power supplies constituted the radar receiving system. Also, since an SP main receiver unit was available occasionally only, the i-f amplifier portion of an SPR-1 receiver and a laboratory-type video amplifier were substituted for the main receiver unit for many measurements. An S-band pulsed transmitter was set up using a type 718-AY magnetron and an MIT Model 12 modulator unit. A variable-frequency c-w transmitter was built using a type QK-59 c-w magnetron and suitable power supply. Experimental c-w injection systems were then inserted between the end of the radar r-f plumbing and a dummy load. An echo box was coupled by means of a probe into the waveguide feeding the dummy load to secure reference (echo) signal indication on the radar receiver video output which was monitored with a servo scope. Figure 5 shows the laboratory setup.

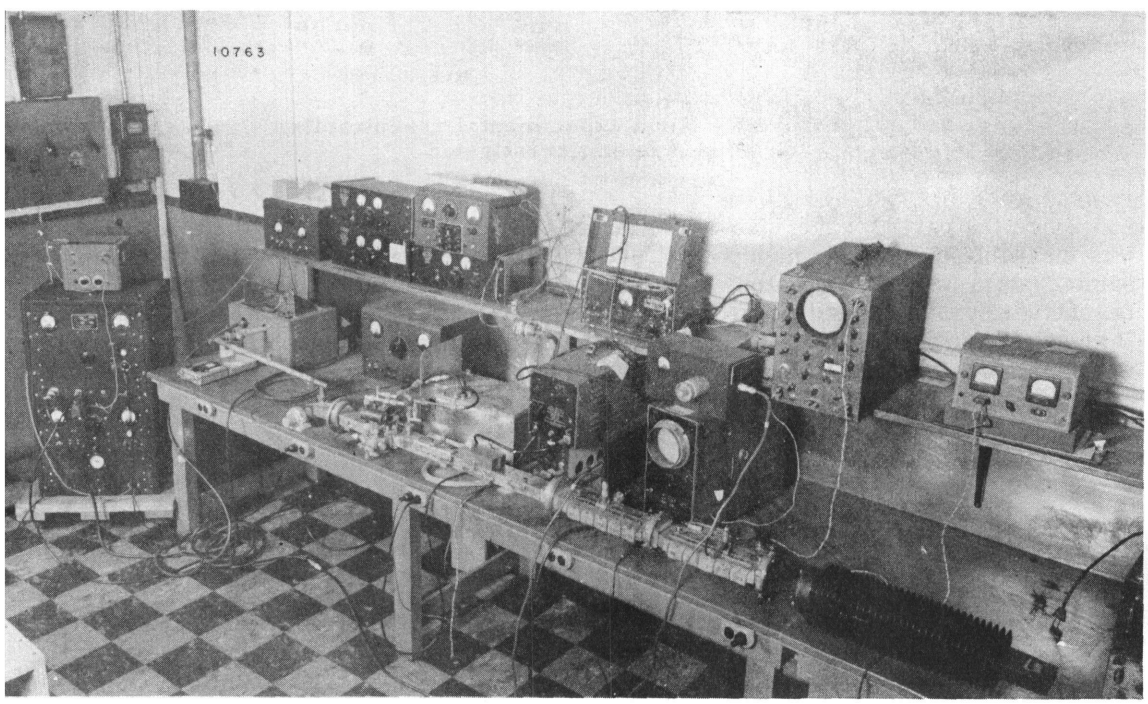


Figure 5 - Laboratory test setup

The first arrangement tried for the c-w injection system was that of a fed-type re-entrant line using a three-terminal hybrid junction. It was also desired that the preliminary system be tunable for experimental purposes in order to vary the c-w signal frequency and effect some matching. This arrangement, tried out with a partial waveguide and partial coaxial setup (Figure 6), indicated the possibility of a workable system.

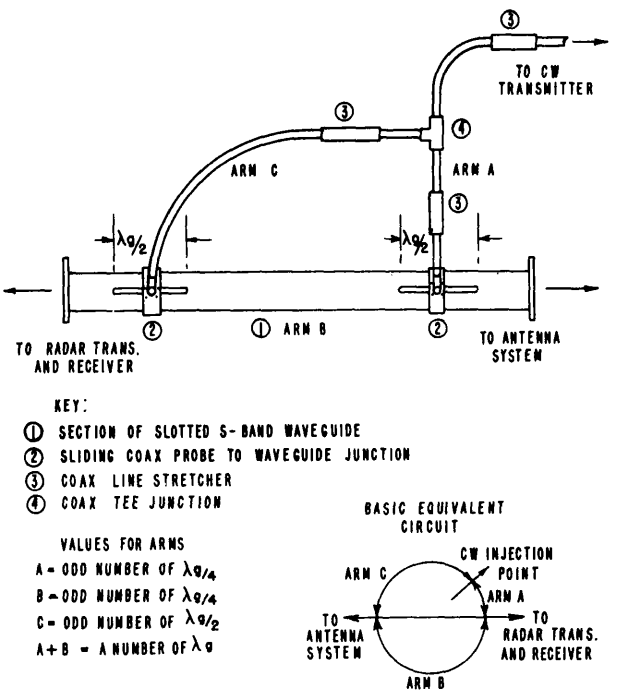


Figure 6 - First experimental re-entrant line system investigated

Since the partial waveguide-partial coaxial arrangement of the re-entrant system was incapable of handling high power, several other waveguide-equivalent versions of the same system were investigated. A shunt-junction arrangement of the three-terminal re-entrant systems was designed and built using BTL type phase-shifters to tune arms B and C (Figure 7). To accommodate the phase-shifters (20 inches long), the arm lengths were made as follows (λg = guide wavelengths):

$$A = \frac{11}{4} \lambda g$$

$$B = \frac{21}{4} \lambda g$$

$$C = \frac{38}{4} \lambda g$$

$$A + B = \frac{11}{4} \lambda g + \frac{21}{4} \lambda g = \frac{32}{4} \lambda g = 8 \lambda g.$$

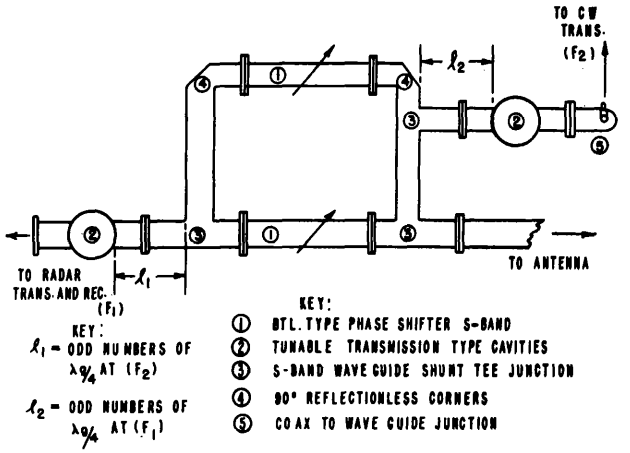


Figure 7 - 3-terminal re-entrant junction with tunable cavity filters (shunt junction)

A series arrangement of this system (Figure 8) was also designed and built using the smallest workable dimensions, namely, three guide half-wavelengths mean ring circumference and a normalized ring impedance of 0.707 (Z_0 of the other three impedance arms) for symmetrical matching.

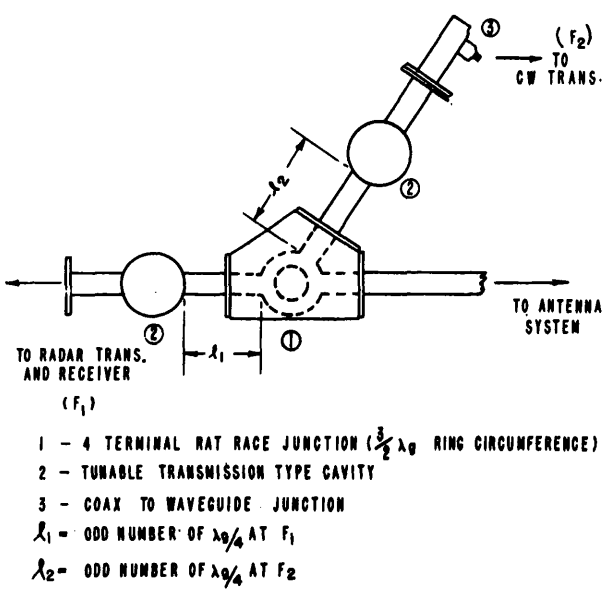


Figure 8 - 3-terminal rat-race junction with tunable cavity filters (series junction)

After considerable experimentation, it was concluded that either one of the latter two versions of the system could be adjusted to give either maximum c-w rejection or maximum echo return through the system. A compromise adjustment was necessary because these conditions did not obtain simultaneously. Further, it was apparent that more c-w signal isolation was required for optimum radar performance.

During this stage of the development, several means of obtaining increased selectivity in the system were considered. It was believed that more selectivity could be built into the SP radar receiver by adding tuned-cavity filters, designing a T-R box with suitable bandpass characteristics, and inserting filters in the i-f input circuit between the crystal mixer and the present amplifier unit to eliminate undesirable beat frequencies generated in the mixer.* Another attack, not detailed in this report, was that of using separate antenna systems to decouple the two signals, perhaps by using X-band energy for the c-w signal and illuminating the SP antenna dish with separate feeds. This procedure would remove the necessity for guide-coupling means, but nutation, feed, and antenna-pattern problems would then become paramount and would have to be investigated. Nevertheless, it was decided to proceed with the common radiator idea and thus modify the radar system itself as little as possible.

Two transmission-type tunable-cavity filters were designed and constructed capable of insertion in S-band waveguide using circular iris coupling windows (Figure 9). Review of literature on waveguide filters designed to carry high peak powers revealed little of practical value. Observations by W. W. Balwanz † were found useful. In a study of the two re-entrant systems, one cavity was placed in the waveguide feeding the radar transmitter and receiver and tuned to the SP radar frequency, and one was placed in the c-w insertion waveguide and tuned to the c-w signal frequency. The Q of the cavities employed was approximately 200 to 300 under loaded conditions. The filter attenuation characteristic is shown in Figure 10. The cavities were so placed in their respective waveguide positions as to allow maximum rejection of undesired signals (Figures 7 and 8).

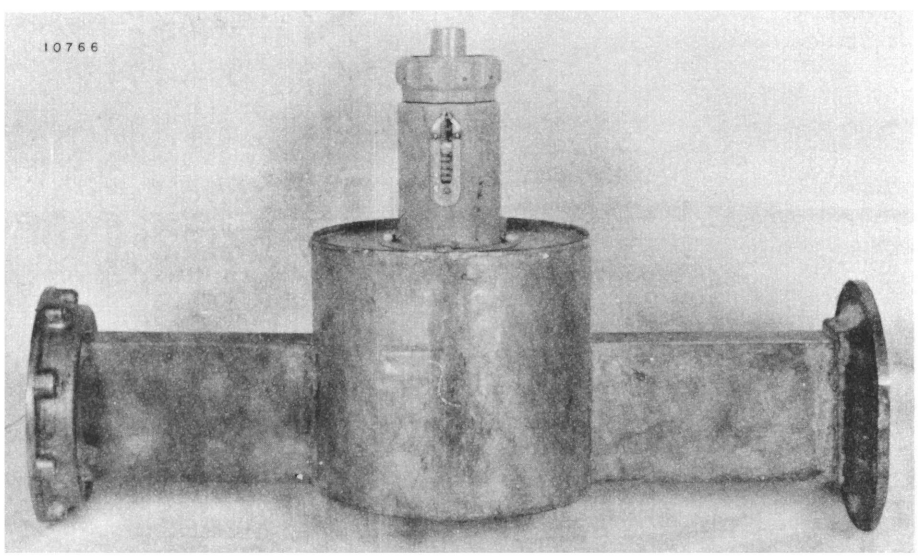


Figure 9 - Transmission-type tunable-cavity filter

* Discussion of some filters of this type is covered subsequently in this report.

† Balwanz, W. W., "The Resonant Frequency of a Cavity-Type Filter as a Function of the Size of the Coupling Iris," NRL Report R-3399, April 3, 1949

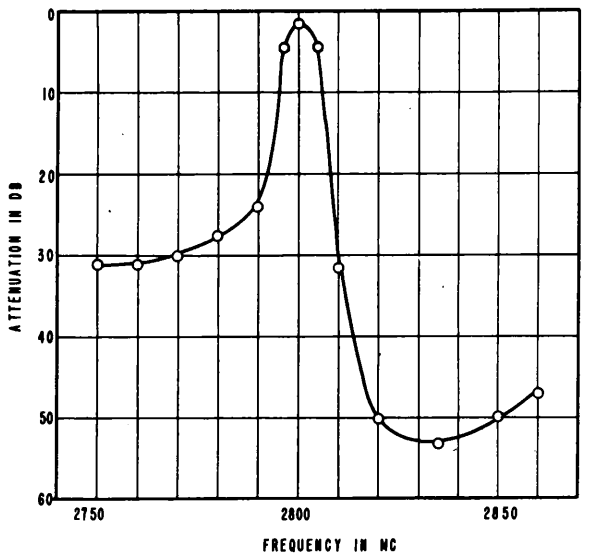


Figure 10 - Attenuation characteristic; transmission-type filter no. 1 tuned to 2800 Mc, insertion loss 1.5 db, loaded Q = 310

Both the shunt- and series-junction arrangements, with the addition of the two cavity filters appropriately placed, gave good performance in the low-power laboratory setup (approximately 70 to 80 kilowatts peak power). Isolation of the c-w signal from the radar T-R section was approximately 60 db, and isolation of the radar signal from the c-w source was of the order of 40 db. Under these conditions, the VSWR of the injection system was 1.5 to 1.61 when tuned, and about 15 or 20 watts of c-w power could be inserted into the plumbing leading to the antenna system. However, when the series-junction arrangement was inserted in an SP radar system using a one-megawatt magnetron and a type B modulator, arcing occurred in the system when the cavities were tuned to resonance, and some pulling of the magnetron was noted. A maximum of about 300 kilowatts peak power could be passed through the system.

It is believed that a more favorable type of matching and coupling, or a different mode of operation in the cavities, might result in greater power-handling capabilities. But it was also felt that, if a system could be evolved which eliminated the use of tuned cavities in the main waveguide handling high power, it would minimize tuneup operations and be more effective for service use. The three-terminal hybrid junction networks investigated were not alone capable of good isolation of the two signals, a fact borne out both by experiment and by theoretical analysis and confirmed by other investigators.*

The four-terminal Hybrid "rat-race" junction was then investigated. The straight magic-tee junction was discarded, since it was believed the matching network involved would not handle as high peak powers as the four-terminal rat-race junctions. Several systems using the four-terminal rat-race junctions were investigated and evaluated as follows:

(a) A single four-terminal rat-race junction was connected in a manner similar to the c-w duplexer used in Doppler radars (Figure 11). This system was workable, but it had a 6-db over-all loss, as far as the SP radar system was concerned, and a 3-db loss to c-w transmission. Approximately 40-db isolation was provided between the two signals.

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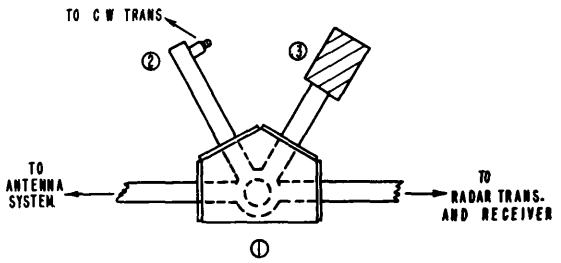
*Tyrell, W. A., "Hybrid Circuits for Microwaves," Proc. IRE, 35, 1294 (1947)



KEY:
① - 4 TERMINAL RAT RACE ($\frac{3}{2}\lambda_g$ RING CIRCUMFERENCE)
② - COAX TO WAVEGUIDE JUNCTION
③ - MATCHED LOAD

Figure 11 - Single 4-terminal rat-race junction used as c-w duplexer

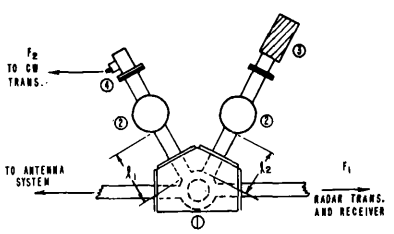
(b) A modification of the above system was made using the tunable transmission-type cavities (Figure 12). This system introduced lower loss to the SP radar system (2 to 3 db) and 3-db loss to the c-w system. It was difficult, however, to tune and match properly. Isolation provided between the two signals was approximately 40 db.

(c) After some further investigation, it was decided that two four-terminal rat-race junctions could be incorporated in a system (Figure 13) which would eliminate two cavities in the main waveguide and give 40-db or greater isolation of the two signals. Since, of those investigated, this arrangement best met the requirements imposed on the c-w injection system, a detailed description and evaluation is given below.

The Selected System

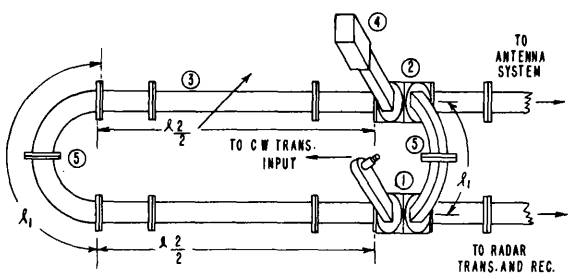
For a mathematical analysis of four-terminal rat-race hybrid junctions, the reader is referred to the work of Gerwin and Hastings.* Explanation of the equivalent circuit of the system (Figure 14) is as follows.

The r-f power coupling into arm 1 is 180 degrees out of phase with the r-f power coupling into arm 2 when excitation is applied to terminal 1 of rat race A. The r-f power coupling into arm 1 is in phase with the r-f power coupling into arm 2 when excitation is applied at terminal 3 of rat race A. Since the two signals from separate sources differ in frequency, the length of arm 2 can be made such that it is an even number of half-wavelengths at the signal frequency applied to terminal 1 of rat race A, and an odd number of half-wavelengths at the frequency of excitation applied to terminal 3. Then the two signals coupling into terminals 1 and 3 of rat-race junction B via arm 1 and arm 2 will be in phase at these points and couple via terminal 4 into the antenna system. By reciprocity, reflections presented to the two signals at the load (antenna) due to mis-match will be returned to their respective separate sources.



KEY:
① - 4 TERMINAL RAT RACE
② - TRANSMISSION TYPE TUNABLE CAVITIES TUNED TO CW SIGNAL
③ - MATCHED LOAD
④ - COAX TO WAVEGUIDE JUNCTION
ℓ_1 AND ℓ_2 ODD NUMBER OF QUARTER WAVE LENGTHS AT f_1

Figure 12 - Modification of c-w duplexer system



KEY:
① - RAT RACE A
② - RAT RACE B
③ - BTL TYPE PHASE SHIFTER S-BAND
④ - MATCHED LOAD
⑤ - 180° H BEND USING 2-90° BENDS

Figure 13 - Injection system using two 4-terminal rat races

*Gerwin, H. L., and Hastings, A. E., "Further Design and Development of Components for Simultaneous Lobing Radar TAB," NRL Report 3221 (Confidential), February 12, 1948

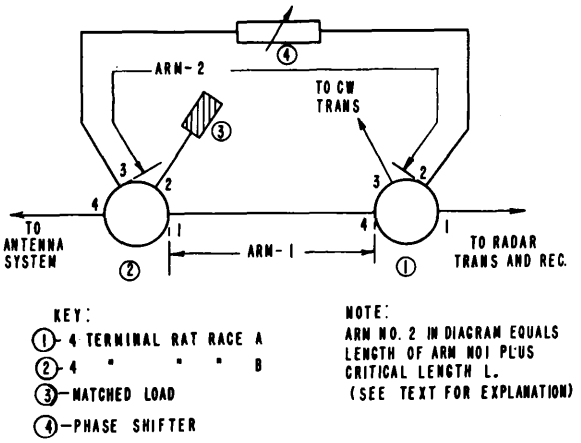


Figure 14 - Equivalent circuit of injection system using two 4-terminal rat races

Table 1 presents data and a sample calculation for determining the critical length of waveguide in arm 2. This length is equal to the length of arm 1 plus additional length "L" calculated for a frequency difference of 50 megacycles between the two signals. It will be noted that the calculated length "L" is the electrical length required in inches or feet; variation of this length is accomplished with the phase shifter (Figure 14). The variation of electrical length effected by the phase shifter is about 0.6 guide-wavelength, which allows tuning of the system over a range approximately plus or minus 1 percent from 2800 megacycles.

TABLE 1
Data Used for Calculating Length of Waveguide Section "L"

F used	F_0(Mc)	λ_0(CM)	λ_g(CM)	$\lambda g/2$ (inches)
F_1	2800	10.71	16.0	3.15
F_2	2850	10.52	15.35	3.02
F_3	2750	10.91	16.65	3.28
F_4	2780	10.79	16.25	3.20
F_5	2830	10.6	15.6	3.07

F used	L ($\lambda g/2$)	L (ft)
F_1 and F_2	23.2	6.1
F_4 and F_5	23.6	6.3
F_3 and F_1	24.25	6.62

Note: Sample calculation of length L using F_1 = 2800 Mc and F_2 = 2850 Mc:

$$\ell\,(3.15) = (\ell + 1)\,(3.02)$$

$$\ell = 3.02/0.13 = 23.2\,\lambda g/2$$

$$\ell = 23.2\,(3.15) = 73.1 \text{ inches} = 6.1 \text{ ft}$$

Since ℓ has to be an even number of half wavelengths at F_1, length L is made either 22 or 24 half wavelengths long at F_1.

Since the isolation efficiency of the system is dependent on the frequency sensitivity of the four-terminal rat races, the system as shown in Figures 13 and 14 is employed when the radar transmitter frequency falls between 2770 and 2800 megacycles with consequent operation of the c-w f-m transmitter between 2820 and 2850 megacycles. The local oscillator in the receiver in this case is then operated 30 megacycles below the radar transmitter frequency.

In the case where radar transmitter magnetrons fall between 2800 and 2830 megacycles, the loads of terminals 2 and 4 of rat race B are reversed, and the output to the antenna system is taken at terminal 2 of rat race B with the matched load terminating at

terminal 4. In this case the c-w f-m transmitter is operated between 2750 and 2780 megacycles with the local oscillator in the receiver operated 30 megacycles above the radar transmitter frequency.

The four-terminal rat races A and B were designed using a center frequency of 2800 megacycles since investigation indicated the majority of SP magnetrons in production centered about this frequency within plus or minus 1 percent. The VSWR of the system is within 1.03 over 1 over the frequency range of 2750 to 2850 megacycles. The isolation provided between the two signals is at least 40 db over the frequency range of 2750 megacycles to 2850 megacycles and as much as 47 db at 2800 megacycles. The power-handling capability of the system is practically equal to that of the S-band waveguide (1-1/2 x 3 inches). Measurements on the system were made using high-power-type matched loads (VSWR 1.1).

Two directional couplers of the same type used in the present SP plumbing (30-db Bethe hole coupling) were designed and constructed for insertion between the injection-system plumbing and the antenna-system plumbing. They are used for tuning up the injection system, monitoring the c-w transmitter output, etc. Working drawings for the directional-coupler plumbing and the four-terminal rat race have been made.

I-F Filters for the SP Radar System

An i-f filter, capable of insertion in the i-f cable between the i-f pre-amplifier unit and the crystal mixer unit, was designed to attenuate undesired beat frequencies generated in the crystal mixer by the combined action of the radar pulses, of the c-w f-m leakage, and of the receiver local oscillator. The i-f filter was designed to pass 30 megacycles (the i-f frequency) and reject 50 megacycles plus or minus 3 megacycles and 80 megacycles plus or minus 5 megacycles. These latter are the first-order undesired frequencies generated in the mixer where the two desired signals are separated by 50 megacycles. For example, when the radar transmitter frequency is 2800 megacycles plus or minus 3 megacycles, the receiver local oscillator is at 2770 megacycles, and the c-w f-m transmitter signal is 2850 megacycles plus or minus 1 megacycle.

The first low-pass i-f filter was designed using 5 m-derived sections of a basic T-network prototype. Three of the shunt sections were tuned to 80 megacycles, and two were resonated at 50 megacycles. The equivalent circuit is shown in Figure 15 together with a table of values used. Curves of attenuation versus frequency are shown in Figure 16 for two experimental models. The shunt sections were more carefully resonated in filter number 2. Insertion loss of the filters was 1.5 to 2 db at 30 megacycles (i-f frequency). A photograph of the filter is shown in Figure 17.

Additional R-F Filters for the SP Radar Receiver

Considerable thought was given to getting additional r-f selectivity into the SP radar receiver with the minimum amount of modification. One idea for doing this was that of inserting a beacon-type tunable cavity between the output of the T-R box and the crystal mixer assembly. By reversing the coupling loops in a beacon cavity, the Q is lowered to approximately 700 to 900, which allows a bandpass of about 3 or 4 megacycles.

Another idea for increasing the skirt steepness of the T-R box response curve was that of using a double T-R box, which can be made up fairly simply with two standard-type T-R boxes. Adjustment of the coupling window size can be made to change the bandpass characteristics of the T-R boxes. Certain limits of response have to be retained to compensate for

magnetron drift, etc., but it is believed the selectivity of the T-R boxes can be improved to advantage. Of course, design of a new T-R box with the desired bandpass characteristics would also be a worthwhile improvement.

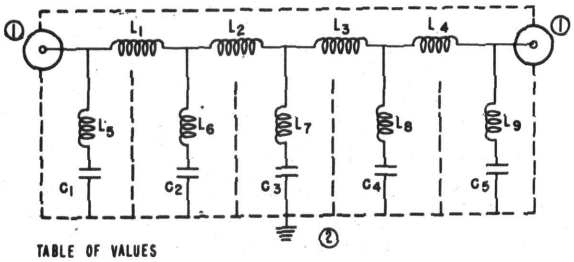


TABLE OF VALUES

① TYPE N FEMALE CHASIS CONNECTOR

② SHIELDED BOX ($1\frac{1}{4}'' \times 2\frac{3}{8}'' \times 6''$)

L_1 = 0.292 μh	L_7 = 0.029 μh	C_4 = 138 μμf
L_2 = 0.345 μh	L_8 = 0.029 μh	C_5 = 47.7 μμf
L_3 = 0.345 μh	L_9 = 0.212 μh	
L_4 = 0.292 μh	C_1 = 47.7 μμf	
L_5 = 0.212 μh	C_2 = 138 μμf	
L_6 = 0.029 μh	C_3 = 138 μμf	

Figure 15 - Low-pass i-f filter, equivalent circuit

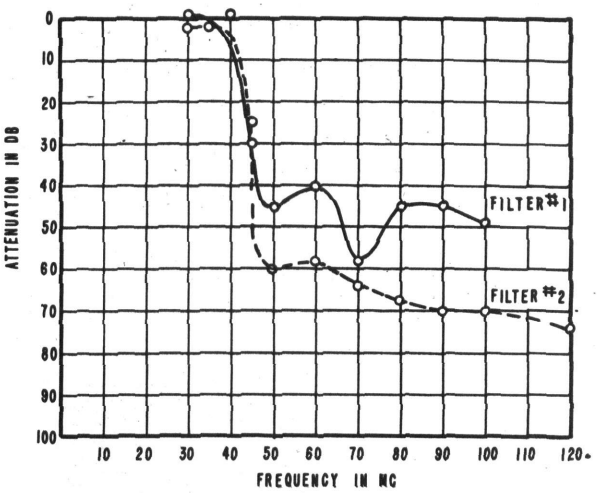


Figure 16 - Attenuation characteristic of 5-section M-derived i-f filter

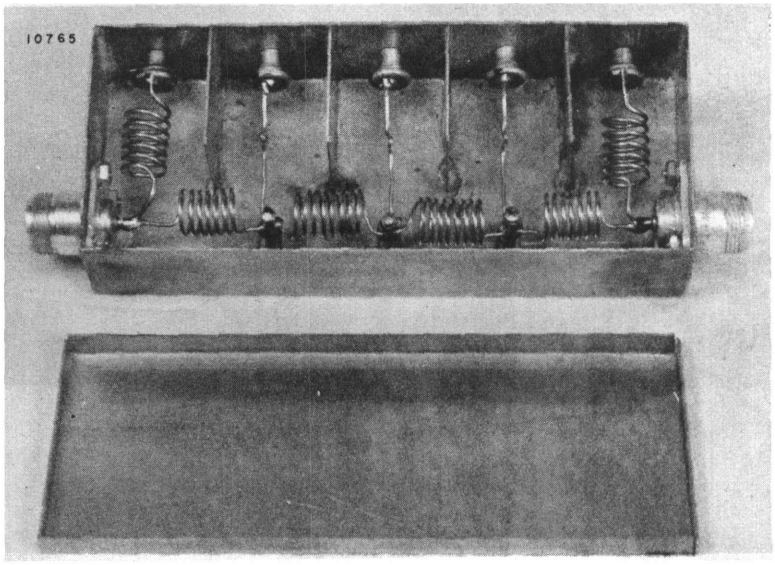


Figure 17 - I-F filter

It may be noted that if undesired beat frequencies, generated in the mixer by the combination of signals present there, result in any noise or beat frequencies at 30 megacycles, the i-f filter will not be effective. Further r-f selectivity will then have to be obtained, probably by methods similar to those described in the above paragraphs.

A large amount of undesired sideband generation can be tolerated with the SP system used strictly as radar. However, with the f-m transmitter added, excessive sidebands will cause undesired beat frequencies. Thus, a magnetron which is frequency modulated by a sloping modulator pulse, which is improperly matched to the antenna system, or which is moding may cause trouble with this system.

SYSTEM PERFORMANCE

Some performance measurements have been made at the Chesapeake Bay Annex using the double-rat-race injection system and the c-w f-m magnetron transmitter. The injection system was installed, with the additional plumbing required, alongside the SP-1M transmitter unit (Figures 18 and 19). Source of modulation of the f-m c-w transmitter was an audio oscillator (Jackson Model 652) set at 24 cycles.

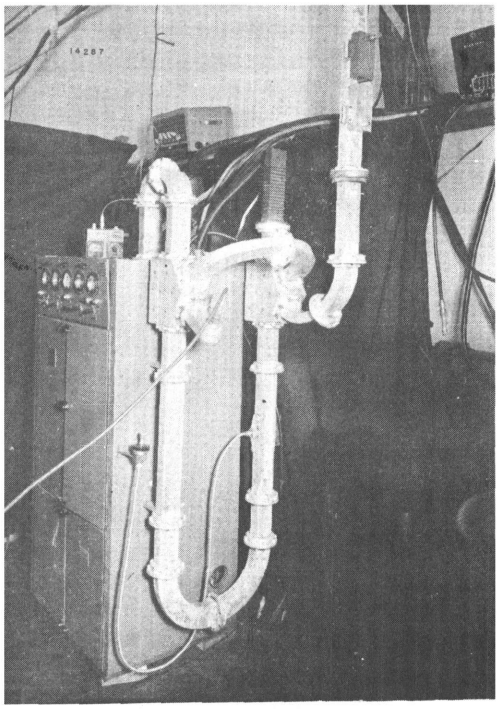


Figure 18 - Injection system plumbing as set up at CBA

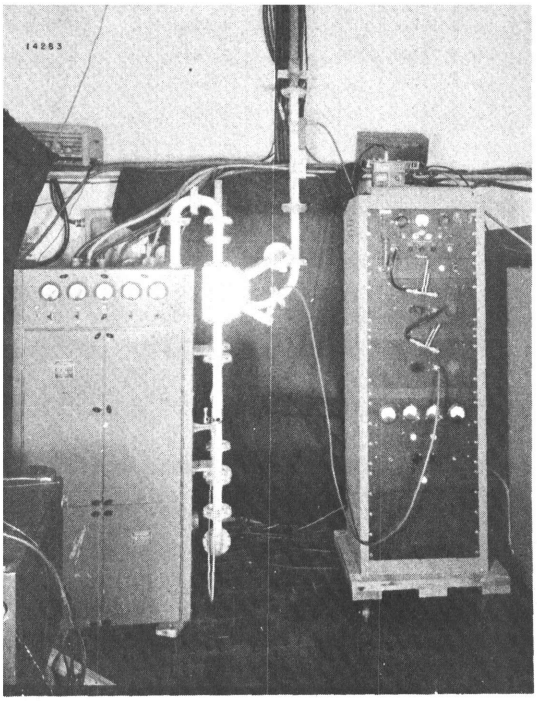


Figure 19 - CBA installation of equipment as set up with SP-1M transmitter

The first checks indicated that, with only the injection system and no additional filters in the SP-1M radar, good performance is obtained, noise observed on the A and R scope being negligible when approximately 10 to 30 watts c-w power was used. Over a period of several days, however, a steady decrease in isolation efficiency was noted, so that noise appeared on the A and R scope. When the i-f filters were inserted in the i-f cable between the crystal mixer and pre-amplifier unit, some reduction of noise resulted. Several performance checks were made and, after the plumbing was completely dismantled, it was observed that water was getting into the rat-race junctions feeding the antenna system.

It was not clear whether water was leaking through the waveguide from the antenna system on the roof, or whether hot, humid air, blown into the waveguide system by the blower on the transmitter magnetron, was condensing as it came in contact with the cold waveguide.

Since some of the waveguide sections in the experimental injection system were brass, while the rat races were made of dural, water caused considerable corrosion of the rat-race terminals. At the conclusion of these checks, the injection system was dismantled and returned to the NRL for clean-up and silver plating.

The output coupling from the f-m c-w magnetron transmitter originally consisted of a 7/8-inch stub-supported line-stretcher section with reduction connectors to feed RG-8U or RG-9U coaxial cable. This output coupling network and the RG-9U coaxial line was observed to heat excessively, undoubtedly causing loss of c-w power. The output coupling was modified to that of a sturdy coaxial magnetron connector, and a line of RG-14U cable was used to couple the transmitter to the waveguide "doorknob junction" at the insertion point.

Some frequency modulation of the c-w f-m magnetron at 60 cycles (due to filament field) was observed on measurements made with an experimental f-m receiver. This 60-cycle modulation was observed to frequency modulate the c-w f-m transmitter approximately 600 kc.

After reconditioning the c-w injection system plumbing unit, it was reinstalled in Building 4 at CBA (Figure 18), and further checks were made on system performance using the c-w f-m M.O.P.A. klystron transmitter. Results indicated that, in general:

(a) The c-w f-m M.O.P.A. klystron transmitter is tunable over a frequency range of 2700 to 3300 megacycles.

(b) The output of the c-w f-m M.O.P.A. klystron transmitter is 10 to 16 watts into the waveguide feeding the antenna system.

(c) The M.O.P.A. transmitter is capable of 0- to 1-megacycle frequency deviation over the audio range of 20 to 20,000 cycles.

(d) The injection system allows operation of the c-w f-m M.O.P.A. transmitter plus or minus 50 megacycles from the SP radar carrier frequency with negligible interference to normal operation of the SP radar.

(e) Amplitude modulation of the c-w f-m M.O.P.A. transmitter is negligible under frequency-modulation conditions.

(f) Nutation gives smooth sine-wave amplitude modulation to the M.O.P.A. transmitter carrier.

(g) The frequency stability of the M.O.P.A. transmitter is that of the 2K41 master oscillator tube, which Sperry gives as 0.12 megacycle per degree change in ambient temperature from minus 10 degrees to plus 40 degrees C.

CONCLUSIONS AND RECOMMENDATIONS

(1) From the results of laboratory and brief field tests, it is concluded that the proposed c-w beam-riding system is feasible.

(2) Investigation indicates that, of those tried, the double-rat-race injection system best meets the requirements.

(3) Investigation further indicates that the c-w f-m M.O.P.A. klystron transmitter meets the general requirements imposed for the c-w f-m signal source.

In adapting such a system to practical missile guidance, a few suggestions may be useful. Performance checks should be made with the companion FM/AM receiver developed for this problem in order to ascertain the practical range of the system. Antenna patterns and gain measurements should be taken with the SP dish antenna at plus or minus 50, plus or minus 75, and plus or minus 100 megacycles off frequency from 2800 megacycles to ascertain its characteristics over this frequency range.

If more power output is desired from the c-w f-m transmitter at least two possibilities exist. One is the addition of another type 3K30 klystron amplifier stage on the present M.O.P.A. transmitter which would give an estimated 20 to 30 watts power output. The other is further development of the experimental c-w f-m magnetron transmitter. If more power output is desired from the c-w f-m transmitter, further refinement will have to be added to the injection system, or else additional selectivity and isolation will have to be built into the SP receiver, since the addition of the beacon T-R box to the SP transmitter plumbing broadens the frequency response of this unit considerably. It is also suggested that tests be made to ascertain what beacon frequencies are feasible for use with this system if beacon operation is desired.

It has been proposed that further simplification of the missile-borne control receiver could be obtained by injecting two frequency-separated c-w signals into the tracking radar antenna. One would provide control as explained in this report, and the other would serve as a ground-based receiver local oscillator. A thorough trial of this method is strongly recommended.

Another proposal would utilize a c-w injection system to provide semiactive homing guidance. In this case homing control could be achieved by injecting a high-frequency c-w control signal to provide the illuminating energy for the target-seeker to a standard lower-frequency radar which would be used for target tracking. This method would allow high gain and a very narrow beam for target illumination while keeping the missile antenna small, without sacrifice of acquisition ability of the missile-tracking equipment.

There is one further possibility for utilization of the double-rat-race injection system. The present method of missile control utilizing the pulse frequency-modulation system with the SP-1M equipment could be used with the c-w injection system providing a strong c-w carrier, say 30 Mc off frequency, for two purposes. First, it could supply local oscillator energy to the missile receiver from the ground-based equipment, eliminating this function along with AFC problems from the airborne unit. Secondly, this c-w signal could, with relatively simple additions to the present gear, be used as a Doppler signal source to measure the velocity of the target or the bird and/or closing rates to the target.

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