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Sixth Bimonthly Report

On The

Automatic Transmitter Program

Period: 8-July- to 8-Sept.-1959

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TABLE OF CONTENTS

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I. Purpose

See Bimonthly Report No. 1.

II. Abstract

During the past reporting period several significant decisions have been made and conclusions reached concerning the final design of the transmitter and matching network. In the RF circuitry of the transmitter itself a broadbanding technique has been adopted due to the difficulty of operating Varicap type tuning devices at high power levels. Although electronic band switching is employed, it is of a considerably simpler nature than that described in previous reports. Considerable work has been performed in an effort to obtain a high output power from the special transistors supplied by the customer. These units have proved somewhat disappointing in that, on the travelling wave oscilloscope, it is possible to see that in Class B operation they do not have a fast enough turn off time to operate efficiently at 30 mc.

The electrical design of the antenna matching network has been essentially completed. Mechanical layout, which is a major consideration in a piece of equipment of this type, has been completed and construction of the control mechanism started. Modification of a currently available variable capacitor is being carried out, in order to provide a unit with the correct maximum and minimum capacitance values.

III. Factual Data

1. The Transmitter

A. Oscillator

(i) Specifications

(a) Operation from 3-30 mc.

(b) Two bands: manually switched covering 3-15 mc; 15-30 mc.

(c) Crystals are specified as covering the range from 3-15 mc oscillating in fundamental mode.

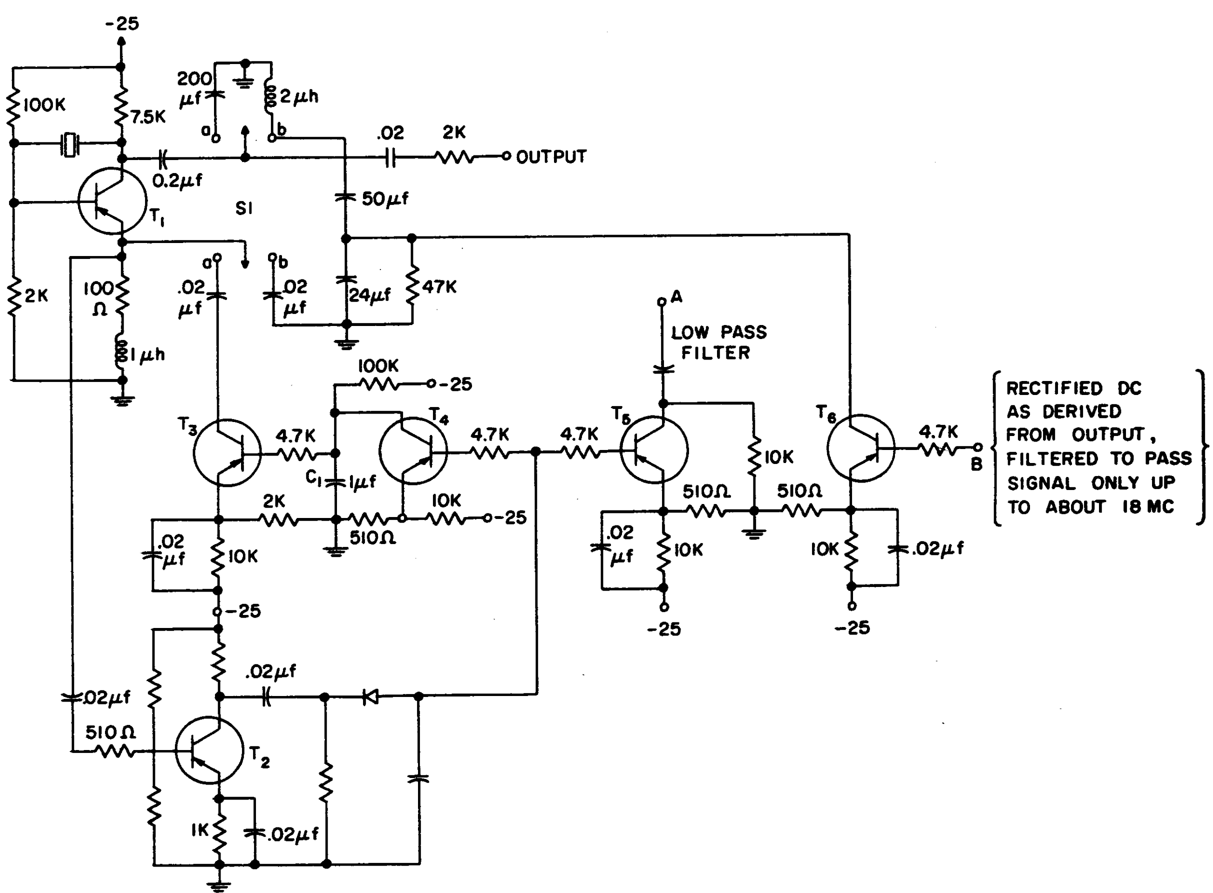
(d) The range from 15-30 mc will be derived by using the specified crystals in the shear or 3rd overtone mode.

(e) The oscillator circuit must ensure oscillation at either the fundamental or 3rd overtone. Thus the 3-15 band will be derived entirely from fundamental mode oscillation and the 15-30 band entirely from 3rd overtone oscillation.

(ii) Circuit Operation

A diagram of the oscillator and its auxiliary circuitry is shown in Figure 1. T_1 is a 2N384 used as the oscillator transistor. The oscillator has four bands; 3-7 : 7-15 : 15-18 : 18-30. The band switch S_1 (double pole - double throw) switches between 3-15 and 15-30, whereas the switching between 3-7 and 7-15, and 15-18 and 18-30 is accomplished automatically.

In switch position a - a the circuit operates from 3-15, and must oscillate in the fundamental mode only; i.e., if a 3 mc crystal is plugged in the circuit must not operate at 9 mc. This is accomplished as follows:



OSCILLATOR AND ASSOCIATED CIRCUITRY

FIGURE I

T_3 and T_4 are 2N123 transistors which act only as switches. T_2 is a 2N247 transistor and amplifies the AC control signal from the emitter of T_1. It should be noted that the output of this circuit is rectified to provide DC control signals for switches T_3 and T_4.

The 100 KΩ resistor and 1 μf capacitor (C_1) combination at the base of T_3 and collector of T_4 is significant. If this capacitor is allowed to charge to -25 V it will turn T_3 'on'. If, however, a DC signal is applied to the base of T_4 it will turn T_4 'on' which in turn will short circuit the 1 μf capacitor and keep T_3 'off'.

If T_3 is off the 100Ω - 1 μh combination is connected to T_1, whereas if T_3 is on, the .02 μf capacitor is grounded thus providing an AC bypass for the 100Ω - 1 μh series path. With the 100Ω - 1 μh path in the oscillator circuit the range of oscillation is from 3-7 mc. If this network is short circuited the range of oscillation is from 7-15 mc.

The sequence of operation in the 3-7 mc band is as follows:

(a) A 3 mc crystal is plugged in.

(b) The 1 μf capacitor starts charging with a long time constant. Before T_3 can be turned 'on' the oscillator oscillates at 3 mc.

(c) It can not oscillate at 9 mc because the 100Ω - 1 μh combination is still in the circuit, because T_3 is still off.

(d) As soon as oscillations occur T_4 is shorted thus discharging C_1 (1 μf capacitor) and ensuring that T_3 remains off.

The sequence of operation for 7-15 mc is as follows:

(a) A 9 mc crystal is plugged in.

(b) The circuit can not oscillate until T_3 is shorted so that the 100 Ω - 1 μh combination is bypassed. This will occur when C_1 is charged.

(c) C_1 will remain charged since under this condition there is no signal at the emitter of T_1 and thus there is no DC signal available for application to T_4.

The transistor T_5 is short circuited from 3-7 mc and introduces a low pass filter later in the system. This serves to reduce distortion since the cutoff frequency is set at about 8 mc. In the 15-30 mc band the oscillator circuit must ensure oscillation only on the 3rd overtone of the crystal. Thus if a 6 mc crystal is plugged in, the circuit should oscillate at 18 mc rather than 6 mc. In this case switch S_1 is in position b. It should be noted that the 100Ω - 1 μh conbination is short circuited. Furthermore it should be pointed out that there will be a DC signal at point B (base of T_6) from 15-18 mc thus short circuiting the 24 μμf capacitor in the collector of T_1. The tank circuit in the collector consequently consists of the 2 μh inductor of the 50 μμf capacitor. This provides a lower frequency cutoff of about 13 mc which is adequate to ensure proper operation. However, this low cutoff frequency results in marginal operation at 30 mc so that it is necessary to add the 24 μμf capacitor in series with the 50 μμf. This raises the cutoff frequency to about 18 mc and results in an appreciable increase in output at 30 mc.

The circuit operation in the 15-30 mc range is quite straightforward and may be summarized as follows.

With a 5 mc crystal (fundamental frequency) the circuit will oscillate at 15 mc and a signal will be returned to point B, short circuiting the 24 μμf capacitor.

With a 7 mc crystal the circuit will oscillate at 21 mc, but no DC signal will be returned to point B since the AC has been filtered. Thus the tank is comprised of 50 μμf in series with 24 μμf.

B. Amplifier Stages

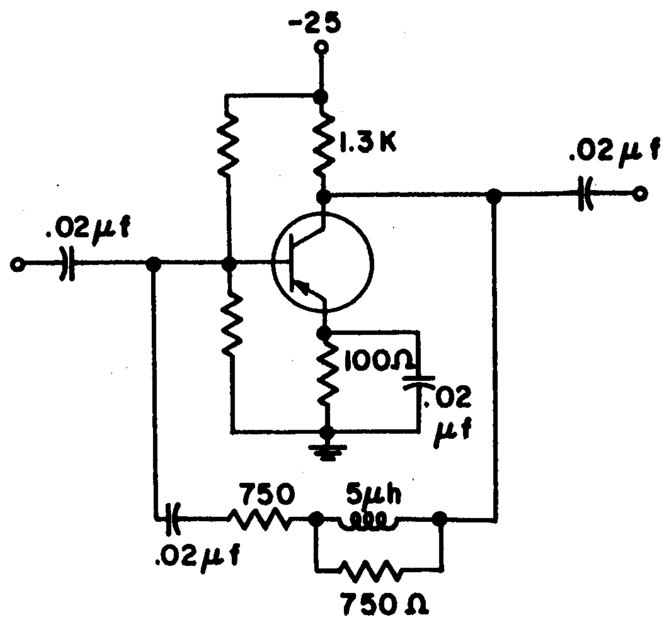
The oscillator signal is at a relatively low level and must be amplified. The exact amount of amplification required depends to a large extent on the capabilities of the output transistors. However it is clear that several low level, Class A, linear amplifiers will be needed. These can be broad-band covering the region from 3-30 mc. The transistor found most advantageous in this application is the 2N509. A typical low level amplifier stage is shown in Figure 2.

The operation of this stage is extremely simple. The feedback network from the collector to the base shapes the frequency response such that the gain rises slightly as the frequency increases. The output impedance of this stage is quite low, making the cascading of several stages relatively simple.

It should be noted, however, that linear operation of this circuit is only possible for low signal levels (about 1 V rms with a 100 Ω load).

Since a final output swing of about 30 V rms is required it becomes clear that a driver stage for the output is essential. Because of the extreme harmonic distortion specification, a push pull driver is necessary. A pair of 2N509 transistors appears adequate for this application although all tests of the final stages have not yet been completed. It may prove necessary to use a higher power transistor in the driver application.

The output stage will also be push-pull in order to derive maximum output. Several "pulse-transformers" have been tried in the push-pull stages and broad-band operation from 3-30 mc appears to be feasible. However up to



LOW LEVEL PREAMPLIFIER
FIGURE 2

the time of writing it has not been possible to use a transformer in the output of the final amplifier stage because of the power level. Two approaches are being taken to solve this problem:

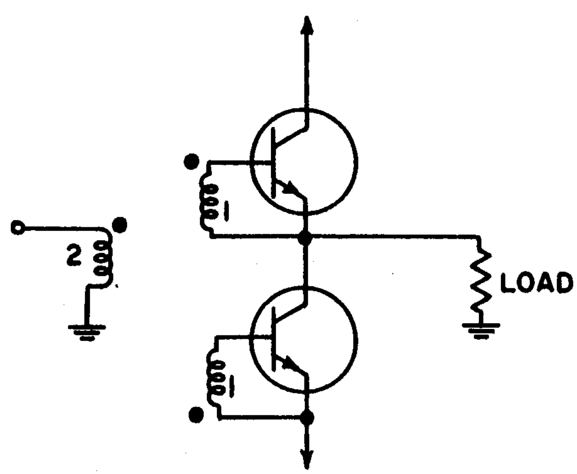
(i) Evaluation of new transformers supplied by Aladdin Electronics which may be able to cover the range in two bands.

(ii) The output circuit shown in Figure 3 circumvents the need for an output transformer.

This circuit has been tested extensively and shows a great deal of promise. However it is necessary to tune out the output capacitance in order to meet power level and distortion requirements.

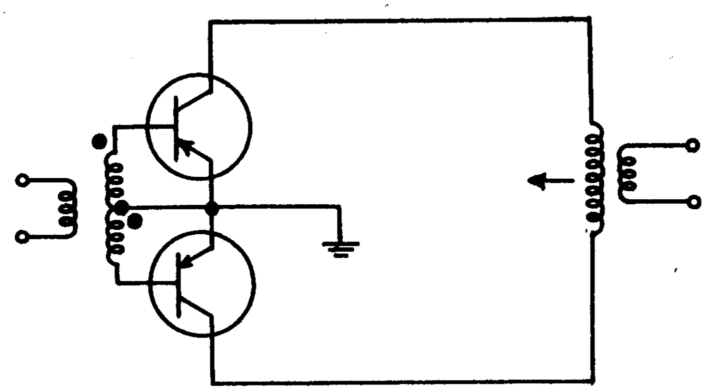
The input transformer has a 2:1:1 turns ratio to provide a better impedance match for the driver stage. The driver can consist of an identical circuit, or a conventional class B stage as shown in Figure 4. An advantage of this circuit compared with that shown in Figure 3 is that both halves of the input transformer are at AC ground potential, thus reducing shunt capacitance problems. However both circuits perform well.

The amplifier has not been completed at the time of writing although the various components have been tested rather extensively. It now appears that the final configuration will consist of a preamplifier comprised of several common emitter feedback stages. These will be followed by a push-pull driver and finally a push-pull output stage. The amplifier will be broad-band except for the output stage which should have a tuned circuit at the collector. As described elsewhere, it appears that this tuning can be conveniently accomplished by the automatic antenna matching network. The power output will be about 1 watt from 3-30 mc.



PUSH PULL OUTPUT STAGE

FIGURE 3



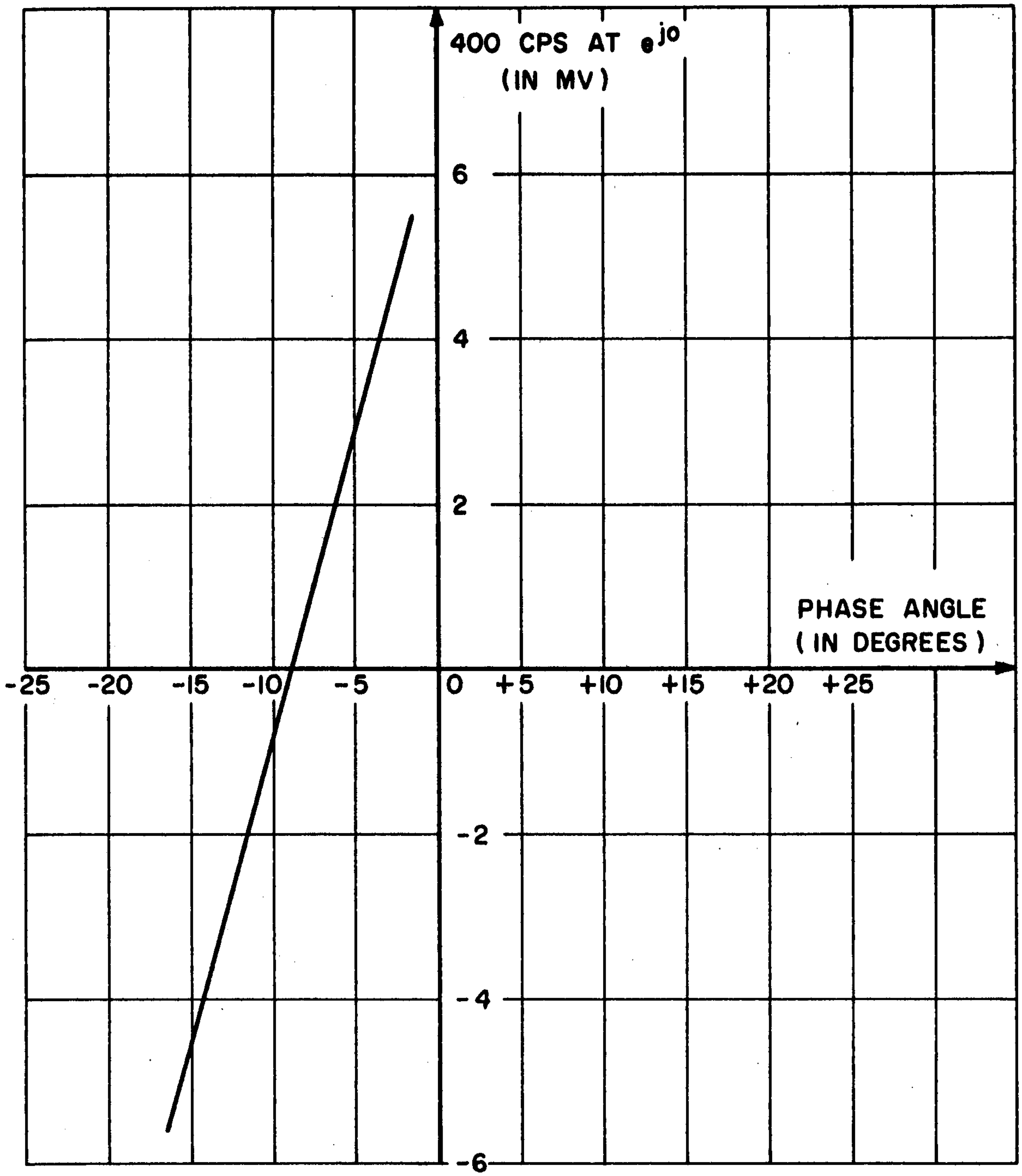
CONVENTIONAL CLASS B. STAGE
FIGURE 4

It may prove desirable to include in the amplifier a simple AGC in order to compensate for variations in oscillator output. This AGC would also accomplish gain equalization with respect to frequency and thus eliminate the need for carefully designed shaping networks.

The system described thus far is relatively insensitive to temperature variations: the greatest problem will be encountered in the allowable power level of the output stage.

2. Automatic Impedance Matching

The accuracy with which the servo system produces a 500 ohm input impedance depends on the sensitivity of the servos. Since the magnitude of the error signals is determined by the RF output power level, the drop of this level by an order of magnitude with respect to that originally anticipated has necessitated further work on the sensing circuitry. It appears that by modifying the transformer in the phase detector an output of sufficiently high level can be achieved. Further improvement is also obtained by the optimum transformation of impedance level between the sensing circuitry and the ring modulator. Work is currently in progress to evaluate the operation of miniature transformers having various transformation ratios. Since the miniature transformers have characteristics which differ considerably from those predicted by "ideal" transformer theory, the desired transformation ratio is being determined experimentally. A plot of 400 cps output from the ring modulator as a function of phase angle at 3 mc is shown in Figure 5. (Further modifications may improve this characteristic.) It is expected that an input to the servo amplifier of about 3.5 mv will activate the servo motor. This signal level is obtained when the phase angle error is about 14 degrees,



PLOT SHOWING 400 CPS OUTPUT VOLTAGE FROM THE RING MODULATOR AS A FUNCTION OF PHASE ANGLE AT 3 MC

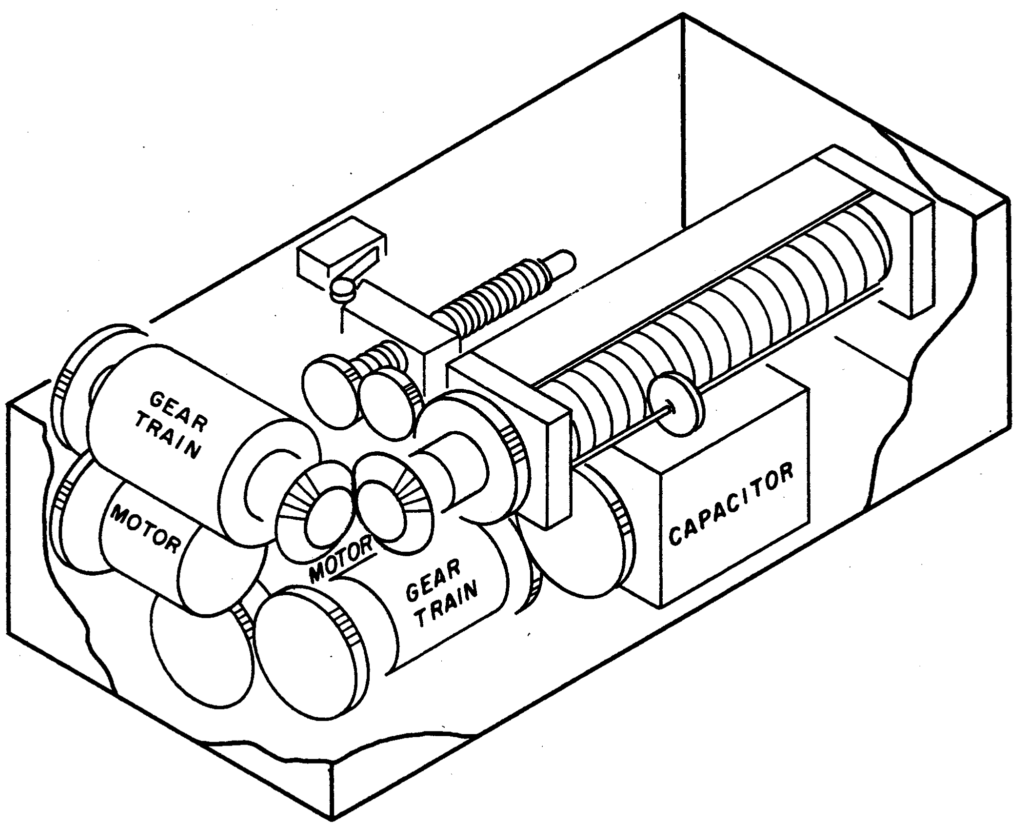
FIGURE 5

which represents a negligible mismatch loss (a 20 degree phase angle represents only a 2 1/2% mismatch loss).

An accurate evaluation of the system sensitivity can not be made until the torque necessary to turn the variable capacitor and inductor has been determined. These elements are being built in the model shop.

A pictorial view of the automatic antenna matching network is shown in Figure 6; the motors, gear boxes, variable coil, and variable capacitor are shown in their approximate positions within the case.

The work in the RF transistor circuitry has indicated that the RF power output can be increased by tuning out the capacity associated with the output stage. It was initially assumed that terminating the output stage in 500 ohms would very nearly yield maximum output power. Since the output capabilities of the transistors are so limited, in order to maximize the output it may be desirable to modify the sensing circuitry so that it will lead to the production of 500 ohm load shunted by an inductance which varies with frequency in a manner which cancels the output capacity of the stage. The manner in which this could be accomplished is as follows: The phase detector nulls when the phase of a reference voltage is the same as that of the line current. Thus, a purely resistive load produces a null if the line voltage is used as the reference voltage. To produce an inductive load, the line current must lag the line voltage, so the reference voltage must also lag the line voltage. This lagging voltage could be obtained by applying the line voltage to a phase shifting network having the desired characteristic. The magnitude detector nulls when the ratio between the magnitude of a small series impedance and the magnitude of the load impedance becomes some fixed



PICTORIAL VIEW
AUTOMATIC ANTENNA MATCHING NETWORK

FIGURE 6

quantity. If the series impedance is a resistor, the magnitude of the load impedance at null is not a function of frequency. If, however, the magnitude of the series impedance varies with frequency, the magnitude of the load impedance also will vary with frequency in a similar manner. It seems reasonable that a phase shifting network and a series impedance which varies with frequency in the desired manner could be synthesized. Further efforts along this line will be made when the characteristics of the RF circuitry have been definitely established.

IV. Conclusions

The transmitter oscillator circuitry is capable of providing an output at the fundamental frequency of crystals when the manual bandswitch is in the 3-15 mc position. In the 15-30 mc range operation is on the third overtone of crystals, the fundamental frequencies of which are between 5 and 10 mc. Within the two ranges set by the manual bandswitch, electronic switching takes place automatically in order to provide the correct frequency at the oscillator output. Preamplifier stages have been constructed but their gain-frequency characteristic has not been finally determined, awaiting settlement of the output stage problem.

It appears that the maximum output which will be available from the transmitter will be approximately 1 watt over the 3-30 mc range. Although as oscillators, transistors would be capable of more impressive performance, considerable difficulty is experienced in driving the units as amplifiers because, at high currents, the gain of the transistor falls off quite sharply.

Some difficulty was anticipated with the antenna matching network sensing circuits due to the low power level available from the transmitter, particularly in the case of the phase sensing circuit. Redesign of the transformer has however increased the sensitivity of this circuit so that it now appears that satisfactory operation can be obtained.

The assembly for the motors, torque multipliers andvariable reactances which form the antenna matching network has been designed as is presently being constructed. The variable capacitor which is used at the input to the π network is being built from parts removed from a commercially available miniaturized variable capacitor.

V. Future Plans

Because of the increased output capability of the special transistors when used as oscillators, the possibility of designing a high power oscillator stage will be investigated. Precautions will be necessary to prevent excessive RF crystal currents.

As soon as the output stage design has been optimized, the RF circuitry will be built in final form. By this time it is anticipated that the matching network and its associated controls will have been built so that the complete system may be tested. With a mechanical servo system, tests made on anything other than that which is intended as the final version are relatively meaningless as friction plays a key role in determining thresholds and unless great pains are taken in the construction of any preliminary versions, the amount of friction present would be excessive.

The building of the matching network calls for completion of the variable capacitor currently under construction. Also required will be the high Q variable inductor which is being built at the present time. Some experimental work remains to be done in order to provide a very high Q even when this coil is in close proximity to the metal case. Ferrite slabs which are currently being pressed, will be placed around the coil in order to provide a low loss flux path.

VI. Identification of Key Technical Personnel

See previous Bimonthly Report.