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Final and Tenth Bimonthly Report on the Automatic Transmitter Program

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I Purpose

In the First Bimonthly Report the purpose of this program was stated. At that time, since the program constituted an effort to advance the state of the art,a considerable portion of that which was written was, necessarily, of a speculative nature. It is worthwhile, at the conclusion of the program, to compare the actual course of the program with the projected program as outlined in the First Bimonthly Report.

The first and second paragraphs of the original "Purpose" remain perfectly valid. The third paragraph refers to the two approaches, solid state and mechanical, which were to be taken in order to realize the automatic tuning and impedance matching functions. Both approaches were studied and the resultant transmitter incorporates a combination of the two methods, a mechanical servo system being used for the impedance matching function for reasons discussed in the body of this report. Advances in the transistor art, which it was hoped would result in the availability of an RF output power of 10 watts over the 3-30 mc range, did not take place sufficiently rapidly for inclusion in the present transmitter. Semiconductor device development did not, however, form part of the present program.

II Abstract

This report, in addition to describing the complete transmitter, gives an outline of the design history showing the reasons for the various decisions which were made in arriving at the final version. The material is broken into two parts, one being concerned with the transmitter itself while the second covers the automatic impedance matching portion of the equipment. Complete circuit diagrams are included as well as a set of operating instructions.

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The equipment delivered at the conclusion of this program consists of two units, one case containing the transmitter and antenna matching unit with appropriate built in power supplies to operate from a 12 volt DC source. The second case houses an auxiliary power supply permitting operation from a large range of AC line voltages with frequencies of 50 to 60 cycles per second. A feature of this auxiliary supply is an indicator system which permits the operator to adjust the unit to the correct line voltage setting without having to know what the line voltage is.

The program was originally divided into three phases. This report is the final report marking the conclusion of the second phase. The first phase was concerned with the electrical design of the equipment to meet the original specifications to the extent permitted by the state of the art. The second phase covered the construction of the equipment in deliverable form but without attempting the ultimate in miniaturization by packing components with the maximum density. The third phase, for which no negotiations have yet taken place, would cover packaging the equipment in as small a physical volume as possible - preferably a package measuring 3" x 6" x $1^{1}/2$" as opposed to the present case which measures approximately $4^{11}/16$" x $9^{1}/4$" x $2^{1}/2$".

III Factual Data

1 The Transmitter

(i) Introduction

The specifications call for a transistorized transmitter covering the 3-30 mc frequency spectrum with an output power of 10 watts. The transmitter should be designed for CW operation either from an internal key or by means of an external automatic keyer. Other than setting a band switch and plugging in an appropriate crystal, the operator should not be required to make any tuning adjustments. Below 15 mc operation is on the fundamental crystal frequency while from 15-30 mc the third overtone mode is used. While under normal circumstances the transmitter will be crystal controlled, provision is required for the connection of an external VFO.

(ii) Automatic Tuning

As was reported in earlier Bimonthly Reports several approaches were tried in an attempt to perform the automatic tuning function. Of the electrically variable tuning devices available, variable capacitors were felt to be more desirable than variable inductors since with the latter it is customary to supply a current to the device for as long as the particular value of inductance is required. This necessitates a constant power drain and is not compatible with the design objective of high efficiency. With variable capacitances, it is customary to maintain a voltage across the device in order to obtain the required value of capacitance. However, the device is usually of extremely high resistance so that there is virtually no power required.

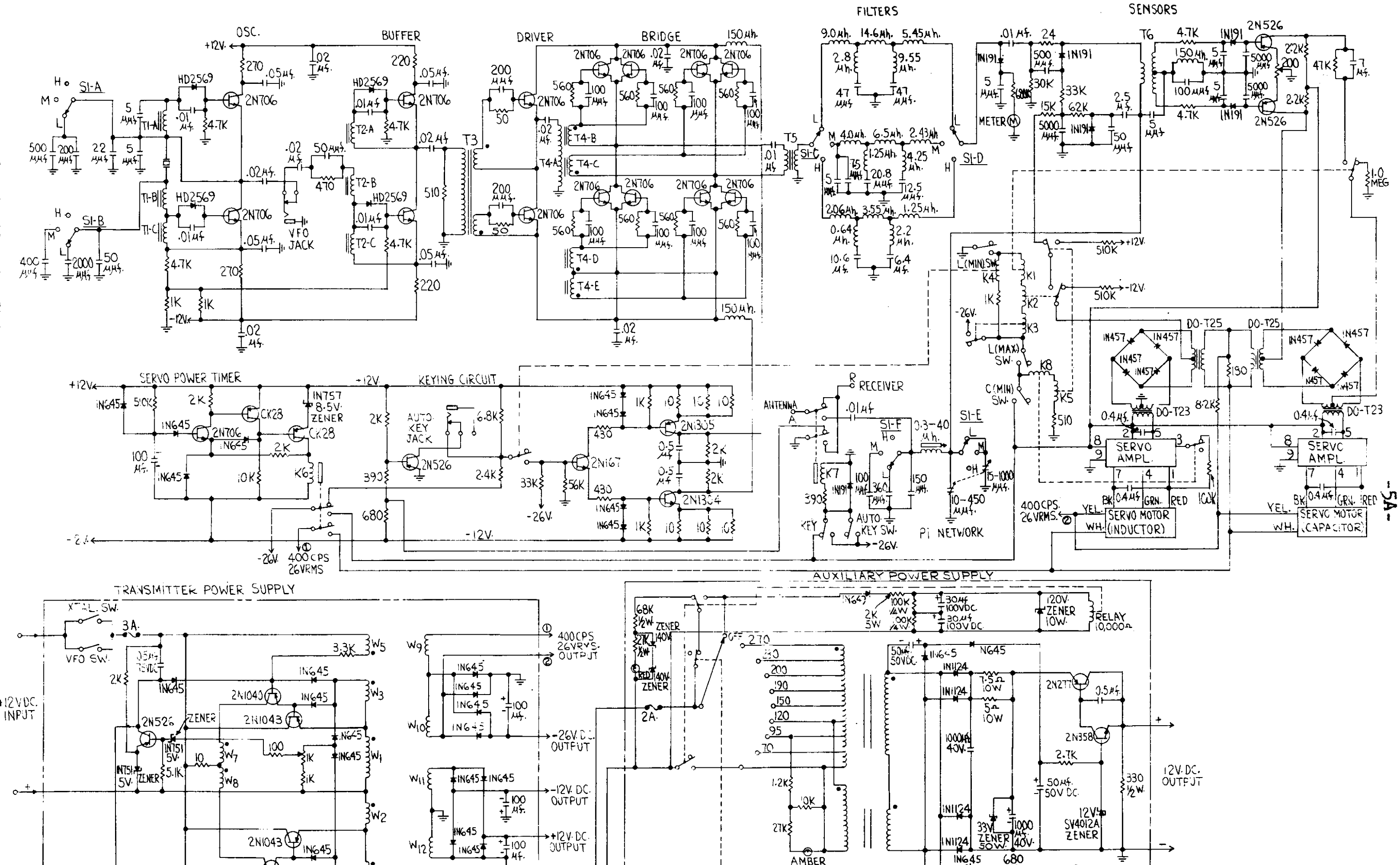
Two types of electrically variable capacitor appeared to be potentially useful to this project. One was the "Varicap" type of capacitor consisting, essentially, of a back biased diode. The second capacitor makes use of a ceramic dielectric, the dielectric constant of which is a function of the applied voltage. Some experiments were made on this type of capacitor but at the present state of materials development it did not offer any advantages over the back biased diode type and introduced the disadvantage of quite high bias potentials. This approach was consequently dropped.

Considerable effort was put into the "Varicap" approach. This led to encouraging results but necessitated automatic band switching since it was, naturally, not possible to cover the required tuning range with one set of voltage variable capacitor diodes. A successful automatic band switching circuit was designed which permitted operation in the following manner. After insertion of the crystal the DC voltage on a "Varicap" type device was swept from zero to a high value, limited by the maximum permissible inverse voltage which could be applied to the diode. The capacitance was consequently changed from a high value to a low value. Since the "Varicap" was in parallel with a coil, the parallel resonant frequency of the resultant tank circuit was swept from a low frequency (3 mc) to a high frequency. The oscillator was designed so that it would not oscillate unless the tank circuit was tuned to the crystal frequency. If, during the sweeping action, the resonant frequency of the tank circuit coincided with the crystal frequency, oscillation commenced. A portion of the oscillator output was rectified and used to stop the sweeping action so that the tank circuit remained tuned to the appropriate frequency.

If, during the sweeping action, the tank circuit had not passed through the correct frequency by the time the "Varicap" voltage reached its maximum value, a threshold was crossed which resulted in the operation of a switching circuit. This circuit changed the setting of some transistor RF switches resulting in a smaller portion of the inductance being included in the tank circuit. The sweeping voltage across the "Varicap" was reduced to zero and the sweep restarted. This process of sweeping the capacitor value and changing taps on the coil continued until the correct frequency was reached. It was consequently possible to cover the required frequency range, the only decision required of the operator being to set a bandswitch to either the 3-15 mc or the 15-30 mc position. This was necessary since the specifications call for the use of fundamental crystal control only as high as 15 mc, the 5-10 mc crystals being used over again as third overtone units to cover the 15-30 mc range. The bandswitch indicated to the equipment whether fundamental or third overtone operation was required.

This approach was eventually dropped for two reasons. Although it was possible to track the tuning of the driver stage with that of the oscillator, using the same control circuitry, as the power level of the RF increased from one stage to the next, the effective capacitance change obtainable from the "Varicaps" became smaller and smaller. This difficulty arose from the necessity of keeping the diode reverse biased over the whole cycle despite a large RF swing. As a result of the small tuning range it would have been necessary to use an unreasonable number of coil taps in order to operate over the 3-30 mc spectrum. Furthermore, on a different program, which was being carried out concurrently, very encouraging results were being obtained with broadbanding techniques.

The transmitter, in its final form is broadbanded throughout, resulting in a very significant reduction in the number of components with the attendant advantages of increased reliability and reduced size requirements and power drain. The broadbanding process has necessitated the use of special high frequency ferrite torroidal transformers. As may be seen from the circuit diagram, Figure 1, the whole RF circuitry is of a balanced nature with two transistors in the oscillator, two buffer transistors, two driver transistors


OSC.
BUFFER
DRIVER
BRIDGE
FILTERS
SENSORS
S1-A
S1-B
S1-C
S1-D
S1-E
S1-F
HD2569
2N706
VFO JACK
T1-A
T1-B
T1-C
T2-A
T2-B
T2-C
T3
T4-A
T4-B
T4-C
T4-D
T4-E
T5
T6
2N526
1N191
METER
1.0 MEG
510K
+12V.
-12V.
-26V.
L(MIN) SW.
L(MAX) SW.
C(MIN) SW.
K1
K2
K3
K4
K5
K7
K8
DO-T25
DO-T23
1N457
SERVO AMPL.
SERVO MOTOR (INDUCTOR)
SERVO MOTOR (CAPACITOR)
400 CPS. 26VRMS.
YEL.
WH.
BK
GRN.
RED
SERVO POWER TIMER
KEYING CIRCUIT
IN757 8.5V. ZENER
CK28
K6
AUTO-KEY JACK
2N167
2N1305
2N1304
ANTENNA
RECEIVER
KEY
AUTO KEY SW.
PI NETWORK
TRANSMITTER POWER SUPPLY
XTAL. SW.
VFO SW.
3A.
12V DC. INPUT
2N1040
2N1043
IN751 5V. ZENER
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
400 CPS 26 VRMS. OUTPUT
-26V DC. OUTPUT
-12V DC. OUTPUT
+12V DC. OUTPUT
AUXILIARY POWER SUPPLY
RELAY 10,000Ω
120V. ZENER 10W.
140V. ZENER
2A.
OFF
AMBER
110 VAC. 60~
IN1124
2N277
2N358
33V. ZENER 50W.
12V. SV4012A ZENER
27V. ZENER 10W
RELAY 1600Ω
12V. DC. OUTPUT

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and eight output transistors arranged in a bridge configuration.

(iii) Final Arrangement of Transmitter Circuitry

The oscillator, while essentially broadband in design, employs one of three different capacitors across the transformer in the feedback path according to the band in which it is desired to transmit. The broad tuning effect of these capacitors ensures that the crystal cannot operate in the incorrect mode for the particular band switch position. The output of the oscillator is coupled to the buffer stage through a transformer. The input of this transformer is tuned in a broadband manner as the band switch shunts the transformer input with one of two different capacitors. The output of the buffer is then transformer coupled to the driver stage which is similarly coupled to the output bridge circuit. The driver and bridge transistors are operated as switches rather than linear amplifiers. This method of operation has several advantages including the following.

(a) Because the transistors are either turned on or turned off, the power dissipated in them is kept to a minimum, resulting in very high efficiency and relatively high RF power output for the power rating of the transistors.

(b) Equalization problems are reduced in severity since it is only necessary to provide sufficient drive at all frequencies to ensure that the transistors are driven from cut-off to saturation. The output power is then determined by the value of the load resistor and the power supply voltage rather than the gain of the transistor.

(c) Since the output waveform is a square wave, it contains only the fundamental and odd harmonics. By dividing the 3-30 mc range into three bands it is possible to design an appropriate fixed low pass filter for each band, which, when placed between the output of the transmitter and the input of

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the automatic impedance matching network, will attenuate the odd harmonics sufficiently to ensure proper operation of the matching circuitry. When the matching network has adjusted itself, it provides further filtering action so that the amplitude of the harmonics reaching the antenna is greatly attenuated.

Physically the driver and output stage transistors are located in recesses in an aluminum block which is, in turn, bolted to the bottom of the aluminum case. Consequently the whole of the case is used as a heat sink, giving adequate cooling for the transistors. In order to provide electrical insulation of the transistor cases from the heat sink, the recesses in the aluminum block are larger than the transistors. To provide good thermal conduction, however, the space between the transistors and the aluminum is filled with silicon oil. Leakage of the oil is prevented by seating the transistors on small rubber "O" rings.

(iv) Auxiliary Circuitry

As will be seen from the description of the automatic impedance matching circuitry, it is essential that anytime the operator changes frequency, the equipment be allowed to go through a certain sequence of self adjustment. In order to relieve the operator of remembering the sequence to be followed, a switch is associated with a plunger on the crystal socket. Withdrawing the crystal from the socket opens the switch in the main power line turning off the whole transmitter. Inserting a new crystal reconnects the power and the impedance matching circuitry automatically goes through a preposition procedure.

The specifications also call for the provision of a means whereby an external VFO can be connected in place of the crystal oscillator. A jack is provided on the front panel for this purpose. Associated with the VFO jack is a switch which performs the same function as the plunger operated switch associated with the crystal socket. It should be stated that, when operating from a VFO rather than a crystal, it is necessary to disconnect the VFO from the transmitter while changing the frequency, reconnecting it after the frequency change has been made.

A second jack is provided on the front panel which permits connection of an automatic keyer in place of the manual key which is built into the side of the case. The manual key is arranged so that it can be pulled out and locked in the "on" position. However, the transmitter operation during the tuning cycle is independent of the key position. During this period the small blue light on the front panel is "on". The blue light turns "off" to indicate that the initial adjustment procedure has been completed. The operator may then commence sending. In the interests of high efficiency, when the blue light turns "off", power is also automatically disconnected from the antenna matching servo system, advantage being taken of the memory function inherent in a motor.

In order to provide facilities for "break in" operation, a relay is included in the antenna circuit. This relay connects the transmitting antenna to the transmitter only when the key is down or the automatic keyer is connected to the transmitter in place of the manual key. When the key is up, the transmitting antenna is disconnected from the transmitter and could be connected to an associated receiver via the terminal block on the top of the case. When automatic keying is being used, the antenna relay does not operate since break in operation is not required, the transmitting antenna being permanently connected to the transmitter.

(v) The Keying Circuit

The keying of the transmitter is accomplished by keying (via switching transistors) the DC power leads to the RF bridge and driver circuit. During the tuning cycle, these RF stages are automatically keyed "off" during the prepositioning of the impedance matching unit and are automatically keyed "on" during the remainder of the tuning cycle. This feature eliminates unnecessary transmission during the initial portion of the tuning cycle. When the tuning cycle has been completed, the keying of the RF signal is no longer automatically controlled, and keying may be performed with the manual key or the automatic key.

The schematic diagram of the keying circuit is shown in Figure 1. The plus and minus DC for the RF power stages are routed through the 2N1304 and 2N1305 transistors, which are turned on and off by the 2N167 transistor. During the prepositioning of the impedance matching unit, the relay K_4 is deactivated and the 2N167 is held "off" by the 56 KΩ - 33 KΩ voltage divider. When prepositioning has been completed, the relay K_4 closes and the 2N167 is now held "on" by the bias current flowing through the 6.8 KΩ resistor to the 12 volt supply. (The servo timer relay K_6 is energized, thus disconnecting one end of the 2.4 KΩ resistor.) When the tuning cycle has been completed, the servo timer relay is deactivated, and the 2N167 is now held "off" by the 6.8 KΩ - 2.4 KΩ voltage divider. The 2N167 may now be turned on either by providing a ground in the automatic key circuit or by pressing the manual key.

The circuit is also arranged so that the antenna terminal is automatically connected to the transmitter (and the receiver terminal is grounded) during the tuning cycle. Once the tuning cycle has been completed, the antenna is connected to the receiver when the key is in the "up" position unless an automatic keyer is being used.

2 The Automatic Impedance Matching Unit

(i) Introduction

The requirements of the program are that automatic features be provided which enable the transmitter to be matched, over the 3-30 mc range, into any antenna impedance falling within the area shown in Figure 9 of the Fourth Bimonthly Report, which is roughly bounded by the limits of 25 to 1300 ohms resistive and ± j 1000 ohms reactive. Two main problems presented themselves. One was that of designing a network which was capable of handling this extremely large range of transformation and which was at the same time capable of being reduced to practice with realizable components. The other major problem was that of how to control such a network automatically.

Considerations of the automatic control requirements indicated that a matching network with only two variables would be, in the interests of small size and relative simplicity, the most desirable. This conclusion placed further difficulties on the design of the matching network with realizable components.

(ii) Considered Approaches

Since a self adjusting system was required, it was necessary to determine the source of appropriate signals which would indicate when a matched condition existed. A matched condition can be detected by sensing the phase and magnitude of the RF signal being fed to the antenna. When the RF current and voltage are in phase, the reactive portion of the antenna impedance must have been tuned out. Similarly, if the voltage across the transformed antenna resistance is equal to that across the generator or, in this case, desired minimum load resistance, the two resistances must be equal. When both these conditions are satisfied, the transmitter will be matched to the antenna.

By sensing the phase and magnitude of the RF fed to the antenna, two control voltages may be derived, which may be used to control directly two elements in the matching network. More complicated schemes can be devised which result in the derivation of a third control signal. Although such schemes would substantially ease the matching network design problems, they were not adopted on this program in the interests of small physical size.

Considering a transformation network with two variable elements a configuration was eventually determined which had feasible, if not readily available, maximum to minimum ratios for its elements.

It was necessary to run a large number of calculations to determine the insertion loss of such a network under various load and frequency conditions and to compare these losses with those which would be experienced if no attempt had been made to match in the first place. Under certain circumstances, due to the finite Q of the components of the matching network, particularly the inductance, the insertion loss can be quite high.

It was stated that both a mechanical and an electrical approach would be studied to determine the most satisfactory method of controlling the transfer characteristics of the matching network. This was done and although from an electronic engineer's standpoint a choice would tend to be prejudiced in favor of an all electronic system, a basically mechanical approach was finally adopted. The reasons for this choice were as follows. Electronically variable reactances generally depend upon a control signal acting on a non-linear characteristic which, to the controlled signal, appears linear or essentially so. A well known example of this type of operation is a "Varicap" type of diode in a tuned circuit where the capacitance of the diode is set by a DC voltage, which is necessarily large compared with the signal voltage impressed on the tuned circuit. Similarly with the saturable reactor type of variable inductance where the magnetic properties of the core are controlled by a large field so that the inductance of the signal winding may be varied. For proper operation, the field due to the signal winding has to be small compared with that of the control winding.

Although it was not possible, due to the state of the transistor art, to obtain an output of 10 watts, the signal level fed to the antenna is still high. Consequently the control signals necessary to vary the reactive elements which form the antenna matching network would have to be very high. This is undesirable from an overall power efficiency standpoint. Furthermore components capable of handling high control power tend to be physically large which is in conflict with the requirement for small size.

A second serious objection to electrically variable reactances is the necessity, in most cases, of keeping the control signal on for as long as it is desired that the component exhibit a particular reactance - in other words for the duration of a transmission. From a power efficiency standpoint, this is highly undesirable.

Even if these disadvantages are temporarily overlooked, with presently known techniques it did not appear that an all electronic system would offer any assistance in obtaining small physical size and would lead to a very high degree of circuit complexity.

The mechanical system which has been adopted offers the advantage that after the necessary self adjustment process has been completed, the power can automatically be removed from the servo system since the motors provide the necessary memory function. In addition the system is relatively simple and non-linearity problems referred to do not occur, the variable reactances being of the conventional type. With the small motors which are currently available, the physical dimensions are not prohibitively large. On the other hand, the torque supplied by the smallest standard servo motors currently available is more than adequate to turn the variable reactances. A worthwhile area for future development would, consequently, be in the development of smaller servo motors. Torque multipliers of standard design are also over designed for this application, something resembling a watch mechanism being more desirable.

(iii) Final Version of Impedance Matching Circuitry

Of the several impedance transforming networks investigated, the pi network (shown in Figure 1) was best suited for operation under the constraints discussed in the preceding section. The impedance matching within the transmitter consists of the transformation of a large range of antenna impedances into a 500 ohm resistive impedance. The selection of a 500 ohm impedance level represents a compromise between the impedance level which leads to the most easily realized network components and the impedance level which can be most conveniently coupled to the RF output stages. The impedance transformation network components could be more easily realized with an impedance level considerably greater than 500 ohms, but the problem of coupling to the RF output stages could be handled more satisfactorily if the impedance level were considerably less than 500 ohms. Since the RF bridge transistors are operated as switches, high output powers can be obtained by switching a large voltage across a low impedance. The available output power is limited, however, because of the voltage, current and power dissipation ratings of the transistors. As a result of these considerations, the impedance level loading the RF bridge was set at 80 ohms by the design of a suitable output transformer.

The pi is automatically tuned by utilizing two signals from an impedance sensor (shown in Figure 1). The operation of the impedance sensor is described in the Third Bimonthly Report. In brief, two DC signals are obtained from the impedance sensor. The polarity of one indicates the phase of the impedance terminating the sensor, while the polarity of the other indicates the relative magnitude of the terminating impedance. Zero signal from both circuits indicates a purely resistive termination which has the desired magnitude (500 ohms). It should be noted that the presence of harmonics in the RF signal results in improper operation of the impedance sensor. (This occurs because the input impedance of the pi is different for each frequency component. The sensor outputs then consist of a mixture of the signals due to each frequency component.) The effect of harmonics is made negligible by inserting low pass filters(1) between the RF output bridge and the input to the pi. The filters used in each of the three frequency bands are also shown in Figure 1.

The variable components in the pi are coupled to 400 cps servo motors (Norden-Ketay 008E2C) by 100:1 speed reducers (Pic U1-7). Ring modulators are used to convert the DC signals from the impedance sensor into 400 cps signals. The signal amplification necessary to drive the servo motors is achieved by Norden-Ketay servo amplifiers (TS4-4-200A).

The manner in which the components of the pi may be driven to achieve a resistive input is described in the Fourth Bimonthly Report. In brief, the phase error signal is used to drive the input capacitor, while the magnitude error signal is used to drive the inductor. The manner in which the system produces a purely resistive input impedance is as follows. The operation of the system requires that the inductor be at its maximum position and the capacitor be at its minimum position when the tuning cycle begins. This is accomplished automatically by means of relays which, when unactuated, apply signals which cause the inductor to increase and the capacitor to decrease. When both components reach the proper positions, limit switches are closed thereby causing the relays to be actuated. The tuning cycle now begins. The output of the phase detector tends to drive the capacitor to the position which cancels any phase angle associated with the input impedance. The output of the magnitude detector tends to drive the inductor to the position which produces the proper value of input resistance, provided that the capacitor is able to leave its minimum position and achieve

(1) "Symmetrical Two-Section Filters" by Pawsey, IRE Trans. Circuit Theory, Mar. 1960.

a zero phase condition. In the event the capacitor is held at its minimum position, a signal is applied to the inductor which causes it to decrease until the capacitor leaves its minimum position. The tuning cycle is completed as the phase and magnitude error signals drive the capacitor and inductor to their proper positions. In order to maintain servo system stability throughout the frequency range and under all load conditions, it is necessary to reduce the speed of the coil as the tuned position is approached. This is accomplished by inserting a feedback resistor (via relay K_8) in the servo amplifier controlling the coil. In order to keep the tuning time as short as practical, the circuit is arranged so that the coil runs at full speed during the component prepositioning time interval and also as long as the capacitor is held at its minimum position.

3 The Power Supply

(i) Introduction

The specifications call for a DC input to the transmitter of 12 volts ± 1.5 volts. The power supply incorporated within the transmitter, as distinct from the auxiliary power supply, described in Section 4 of this Report, is called upon to provide DC voltages of ± 12 volts and -26 volts as well as a 400 cycles supply for the servo motors and modulators. The unit, consequently, consists of a relatively conventional DC to DC converter operating at a 400 cycle rate with appropriate voltage regulation.

(ii) Specific Circuitry

The circuitry of the transmitter power supply is shown in Figure 1. Output power is provided at plus and minus 12 VDC, minus 26 VDC and 26 VRMS at 400 cps. A sinusoidal 400 cps oscillator and amplifier to provide servo motor power was eliminated by designing the DC-DC converter to run at 400 cps. The square wave produced by the converter contains a fundamental frequency component plus odd harmonics, but the harmonic content is not large enough to impair the operation of the servo motors.

The operation of the converter is summarized as follows: The current from the 12 VDC power service is alternately switched through windings W_1 and W_2 by the two pairs of 2N1040 and 2N1043 transistors. The base drive is provided by W_5 and W_6. Additional "turn on" drive is provided by W_7 and W_8. The transistors are turned off by W_3 and W_4. The regulation is achieved by using a 2N526 in conjunction with two 5 volt zener diodes. When the primary voltage rises, increased base drive is applied to the regulating transistor, which in turn shunts some of the base drive away from the switching transistors. This increases the voltage drop across the switching transistors and hence reduces the voltage impressed on the primary winding. It should be noted that the regulation employed in the primary side regulates the voltage applied to the primary. A consequence of this is that the frequency of the converter is also regulated, since the frequency is very nearly proportional to the voltage applied to the primary winding. Since the converter frequency is also the servo power frequency, it is necessary that this also be regulated.

(iii) Time Delay Circuit

In order to conserve operating power, the servo power is turned off after the tuning cycle has been completed. This is accomplished by routing the minus 26 VDC and 26 VRMS servo power through relay contacts which open after the transmitter tuning has been completed. The circuit controlling the relay is shown in Figure 1. The relay remains energized until the

100 µf capacitor has been charged to the voltage level (approximately 15.5 volts) at which time the 2N706 turns on. The regenerative action of the circuit then rapidly deactivates the relay. The circuit time constant has been selected to allow the servo power to remain connected for $1^1/4$ minutes.

4 Auxiliary Power Supply

(i) Introduction

As a companion unit to the transmitter, the specifications call for an auxiliary power supply capable of converting from a wide range of AC line voltages to the 12 volts DC required by the transmitter. Specifically, line voltages ranging from 70 to 270 with frequencies of 50 to 60 cycles can be accommodated. Provision is made so that the operator may adjust the equipment to the correct line voltage without having to know what the actual line voltage is. Regulation is provided so that even if the line voltage falls between specific tap voltages, a constant output of 12 volts will be obtained.

(ii) Specific Circuitry

The schematic diagram of the auxiliary power supply is shown in Figure 1. An AC line voltage selector switch enables the operator to select one of the following positions: Off, 270, 230, 200, 190, 150, 120, 95, 70. The lighting of an amber light indicates that sufficient AC voltage has been applied, while the lighting of a red light indicates excessive voltage has been applied. In order to operate the equipment it is always necessary for the operator to set the switch initially to the OFF position. Should the operator connect power to the unit with the switch in any other position, since the latching relay would remain unoperated, no damage can occur.

As the switch is rotated to successively lower voltage positions, the amber light will be turned on when the proper tap position is reached. If the switch is rotated beyond this point, the red warning light will be turned on and the primary disconnected from the AC line. The arrow under the red light indicates to the operator that he should return the switch to the OFF position in order to reconnect the AC line to the transformer primary.

A special transformer was designed to provide the desired voltage taps. However, it was found that adequate regulation and filtering could be most conveniently achieved by using this tapped transformer in conjunction with an additional transformer. A parallel connection is used on the primary windings, and a series connection is used in the secondary circuit. A redesign of the tapped transformer would eliminate any need for an additional transformer; but, since this would cause a postponement of the delivery date, the redesign was not undertaken at this time.

Since the AC power supply is required to deliver $2^1/2$ amps at 12 VDC under full load, the problem of ripple is most easily handled by employing a transistorized regulator in the output circuit. This scheme has the added advantage that the AC power supply can operate over the continuous 70 to 270 volt range rather than only at discrete points.

IV Conclusions

Photographs of the transmitter and auxiliary power supply are shown in Figures 2 to 6. The results of this program may be summarized as follows. It is practical to construct a small transistorized transmitter which is

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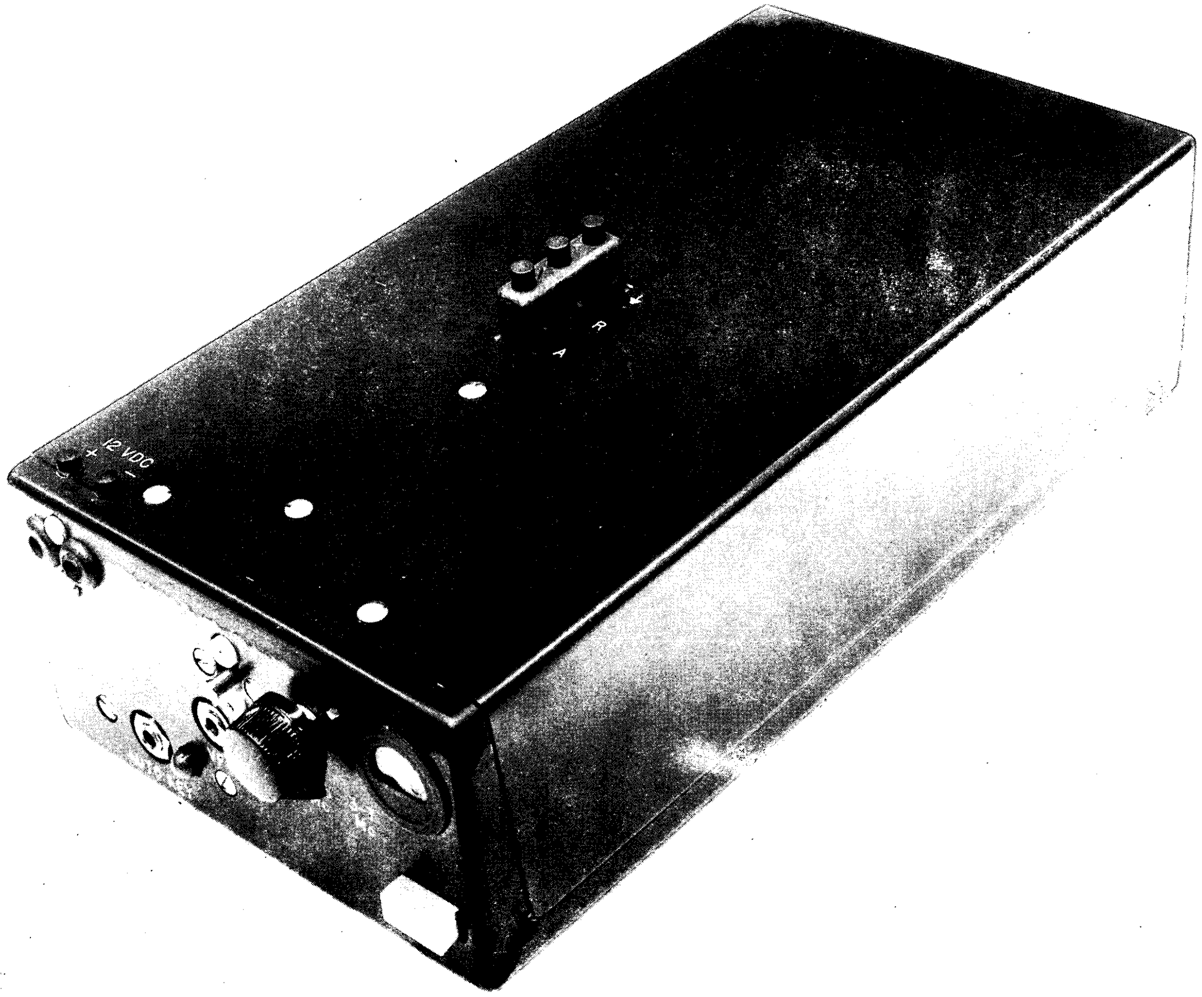

FIGURE 2

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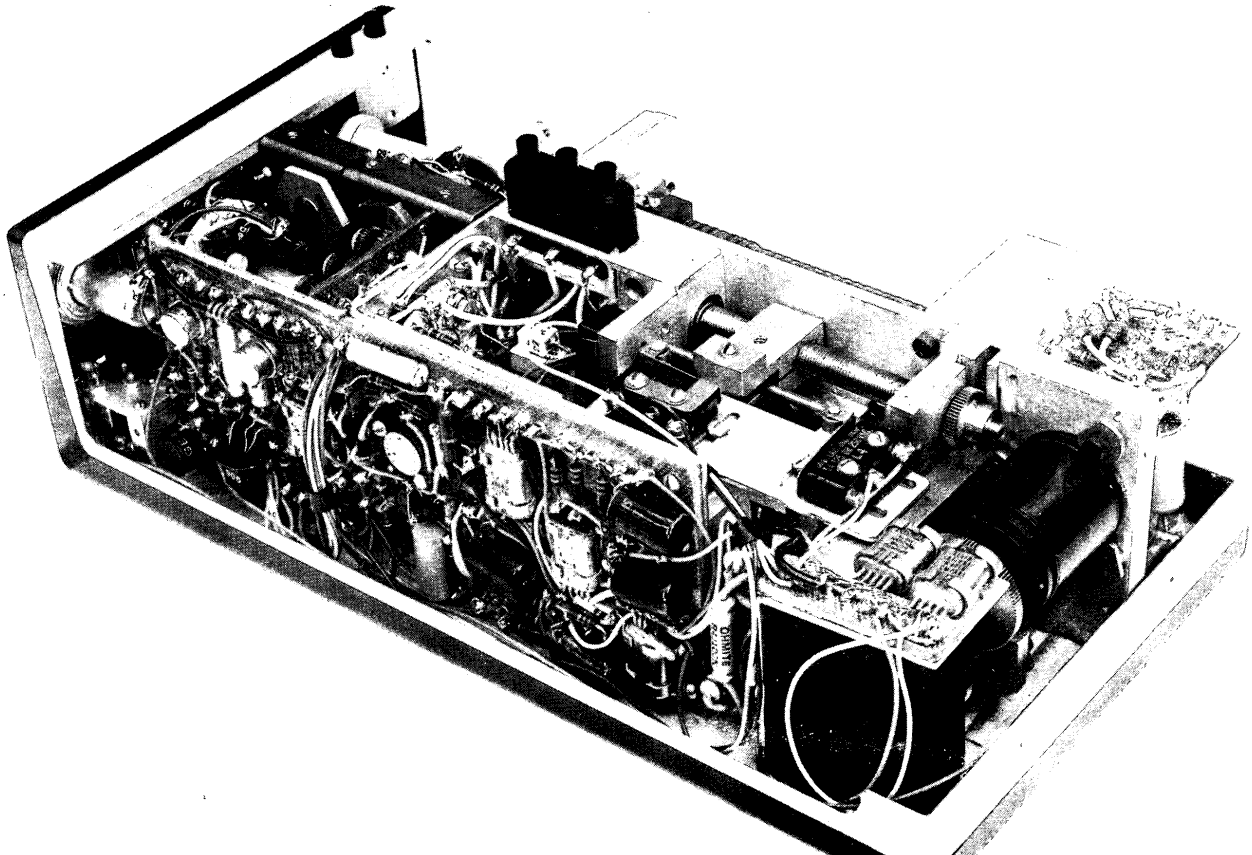

FIGURE 3

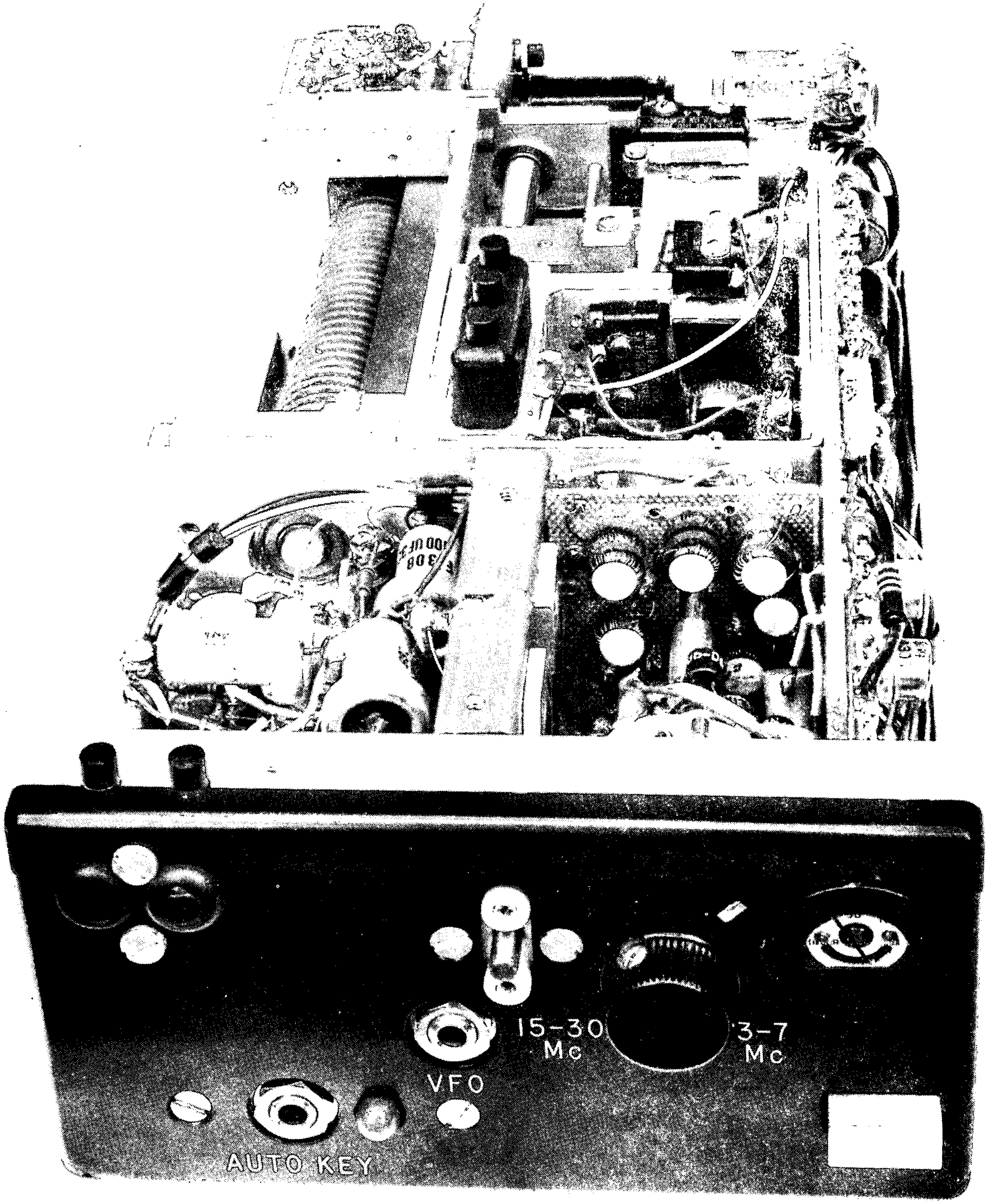

FIGURE 4

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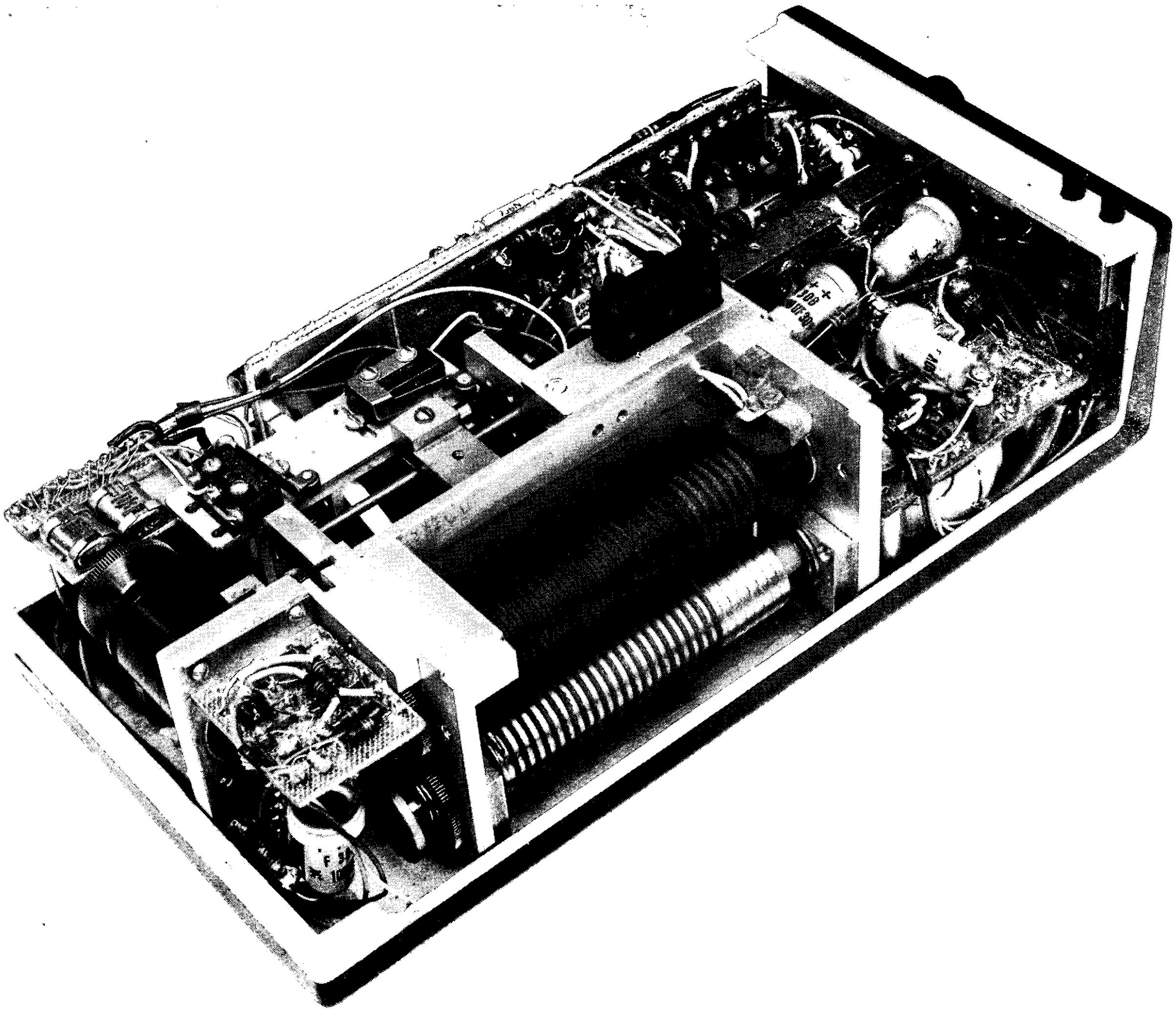

FIGURE 5

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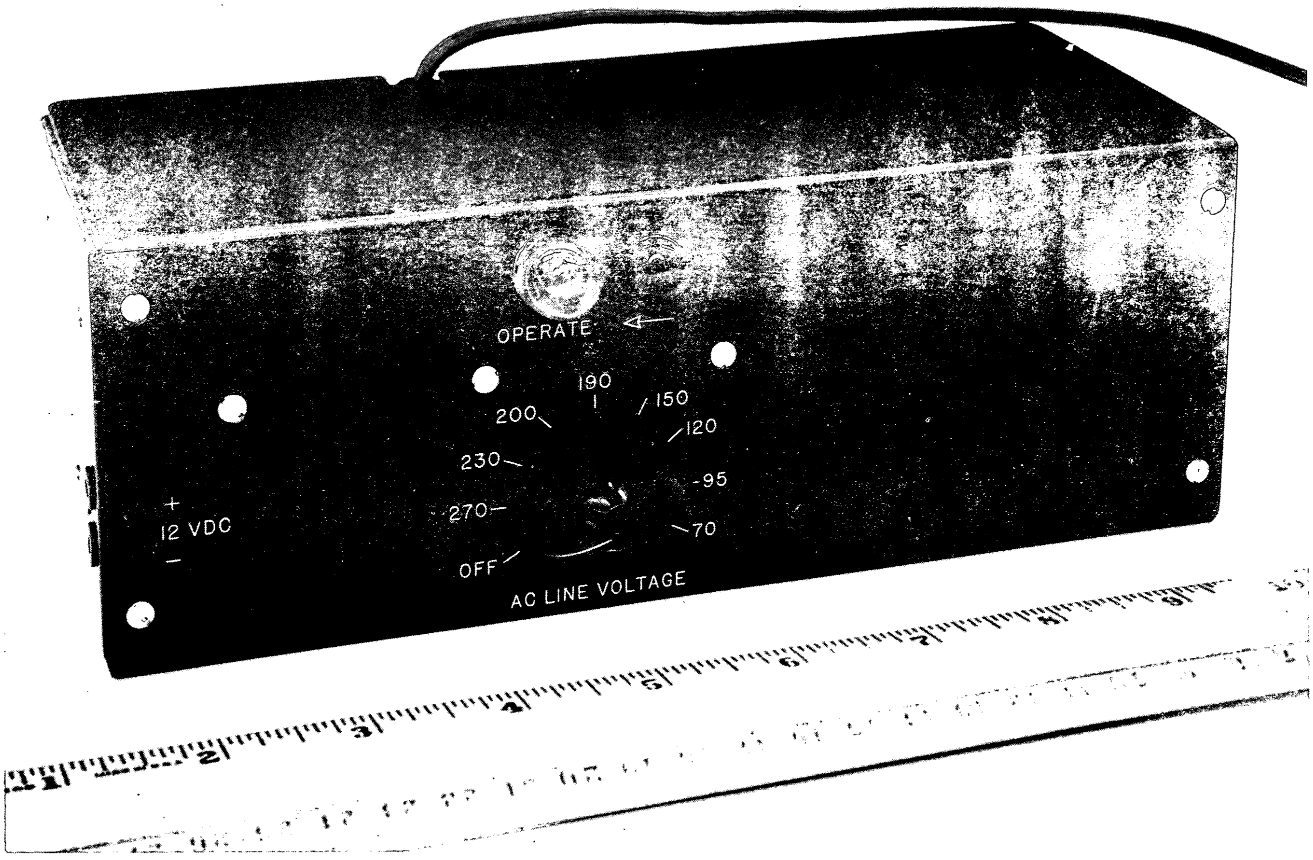
OPERATE
190
150
200
120
230
-95
270
70
OFF
+
12 VDC
−
AC LINE VOLTAGE

FIGURE 6

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capable of operation over a 10:1 range in frequency, into a very wide range of antenna impedances without requiring the operator to make complicated adjustments of any sort. It had been hoped that the transistor art would have advanced sufficiently rapidly during the course of this program to permit a full output of 10 watts. Unfortunately this was not the case. In this connection, it was agreed to waive the environmental temperature specifications since the effect they would have had on the present design would have been to require a derating of the output transistors. The output power would, consequently, have had to be further reduced. If the output power becomes too low, not only is the transmitter less useful as a piece of equipment but design of the sensing circuitry becomes difficult due to the very high sensitivity required. It did not appear to be worthwhile designing extremely high sensitivity sensing circuits since, as soon as suitable output transistors become available, these circuits would not be necessary.

Several design conclusions were reached during this program. Although automatic tuning can be accomplished using presently available techniques, without resorting to mechanical devices, the circuitry becomes increasingly complex as the power level is increased from stage to stage. On the other hand, recent developments in the ferrite area permit the use of broadband techniques resulting in a very significant simplification in circuitry with consequent savings in physical size and power drain. The automatic impedance matching problem, can, with presently know techniques, best be solved using a mechanical system. This requires the fabrication of special tuning elements providing a very large maximum to minimum ratio. By careful choice of the

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network it is, however, possible to match to the desired range of antenna impedances using physically realizable components. It is important that the Q of the elements in the matching network be made extremely high. Otherwise a situation can exist where, although matching has been achieved, the losses introduced in the matching network can exceed the losses which would have been incurred if no attempt had been made to match, the transmitter being connected directly to the antenna.

In realizing the matching network a variable inductor was constructed having a maximum inductance of 40 µH and a minimum value of 0.3 µH. In order to preserve the high Q which is required, even when the coil is placed in close proximity to the metal case, a ferrite strap was placed adjacent to the coil so that a flux path was provided which is almost entirely in ferrite.

The variable capacitor which was constructed for this program has two sections providing an effective range of 10 to 1450 µµF. The capacitor uses 2 mil thick teflon for insulation between plates. The self lubricating characteristics of teflon help to keep the torque required to turn the capacitor to a minimum.

Due to the various requirements for break in operation, automatic keying, operation from a VFO, etc., the basic transmitter circuitry becomes quite complicated. There are a large number of switching circuits required to prevent malfunctioning of the equipment in the hands of an inexperienced operator. While almost any degree of complexity can be incorporated in an equipment of this type in an effort to make its use as simple as possible from the operator's viewpoint, in an application where small size is of extreme importance as is, presumably, high reliability, a balance has to

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be struck between the desires for the ultimate in operational simplicity and a piece of equipment which is highly reliable, having a minimum of switch contacts. Although the solution to providing reliable switching might be thought to rest in the use of transistor switches, in this type of application this is not really true. The reason for this is that the functions to be performed are of a mechanical interlock nature. The type of switching to be carried out is indicated by the problem of ensuring the operator permits the equipment to go through the correct sequence when he changes frequency. The only aspect of changing frequency which can be relied upon is that one crystal will be removed and replaced by another. Advantage can be taken of this fact by causing the crystal to operate a plunger associated with a pair of contacts which can be used to sense whether or not a crystal is in the socket. A multiplicity of such safeguard circuits can quickly lead to an undesirable number of moving contacts and a piece of equipment that is difficult to service. Strictly speaking it would be possible to perform these functions without moving contacts, for instance the presence of a crystal in the socket could be sensed by the interruption of a light beam aimed at a photo cell or by detecting a change in field caused by the metal of the crystal case. Solutions of this type in this kind of application are not considered to be very practical however.

One precaution which could have been taken relatively easily but which was unfortunately overlooked until too late is in connection with safeguarding the output transistors. As the transmitter stands at present it is possible that insertion of a crystal of higher frequency than that indicated by the bandswitch position, might cause an excessive current through the output

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transistors. It appears that this problem could be overcome by careful choice of the diode and resistors in the 2N1304 and 2N1305 circuitry of the keying circuit.

V Future Plans

This being the final report on the present project, this section will be concerned with a discussion of the areas in which it has become apparent further work is needed.

Obviously, in order to obtain an output of 10 watts over the 3-30 mc frequency range it is necessary that improved transistors be developed. This point is well recognized and there is an industry wide effort already underway to increase the power and frequency capabilities of transistors. What is often not fully appreciated is that while announcements often speak of an X mc Y watt transistor, this does not necessarily mean that it is possible to obtain Y watts from this transistor when operated as an amplifier at X megacycles. A rather careful examination of the detailed specifications is necessary in order to determine the actual capabilities of the device in a specific application.

While this program has demonstrated that the rather severe requirements placed on the impedance matching network can be met using components of a size compatible with portable equipment, considerable work will be necessary before the ultimate volume of 27 cubic inches is attained. The largest single component in the equipment at the present time is the variable inductor. A substantial reduction in this size of this component would have a significant effect on the overall size of the equipment. It is possible that a smaller variable capacitor could be built which would meet the electrical requirements. This component is, however, already quite small and a further size reduction would not result in a very significant reduction in overall transmitter size.

As mentioned in the body of the report, the torque provided by the motors is greater than that which is actually required to perform the assigned functions. The development of smaller motors would pay considerable dividends especially if they could be slow speed, high torque units, permitting the elimination of the present speed reducers. Furthermore, it would be desirable to operate the motors from a higher frequency than 400 cycles since this would permit a reduction in the size of the transformer core used in the DC to DC converter of the power supply.

Although during discussions with the customer it was specifically stated that for "break in" operation it is essential that the antenna relay switch back and forth for each dot and dash which is transmitted, it is recommended that a time delay circuit be included which would hold the relay in the transmit position for the duration of a word or at least a letter. This recommendation is made because the life expectancy of a relay in terms of the number of operations is rather rapidly used up if it is required to open and close for every dot and dash. Furthermore, the transients in the receiver present a serious problem.

For break in operation of the type called for in the specifications it would be desirable to develop a solid state send/receive switch as this would avoid contact life difficulties and permit high speeds of keying. However, it would appear that this switch should be associated with the receiver rather than the transmitter. By including the switch in the receiver, the strength of the transmitter signal appearing in the receiver could be kept much lower than when the switch is associated with the transmitter. This arises because in the latter case, even when the antenna is disconnected from the receiver by the send/receive switch, the receiver still picks up a large signal from the transmitter via the lead connecting the receiver antenna terminal to the send/receive switch.

VI Identification of Key Technical Personnel

See previous Reports.

Appendix

1 Operating Procedure for RT-21 Automatic Transmitter

(i) Connection of DC Power Source

Before connecting the power source, the VFO or crystal should be removed. A source capable of supplying 12 VDC plus or minus 1.5 VDC at 2.5 amp should then be connected in accordance with the polarity markings on the case terminals.

(ii) Tuning Procedure

A. A suitable load should be connected between the antenna terminal (A) and the ground terminal. A suitable load is defined in the modified specifications as one whose impedance lies within the area shown in Figure 7.

B. The band switch should be set to the frequency range which includes the desired operating frequency.

C. Power is applied to the transmitter via a switch which is actuated when either a crystal or VFO jack is inserted. The frequency of the crystal or VFO should be compatible with the frequency range selected on the band switch. When the crystal or VFO is inserted, the tuning cycle is automatically carried out. Neither the position of the hand key nor the state of the automatic keyer has any effect during the tuning cycle. If the automatic key is not inserted, the servo power is automatically turned off at the completion of the tuning

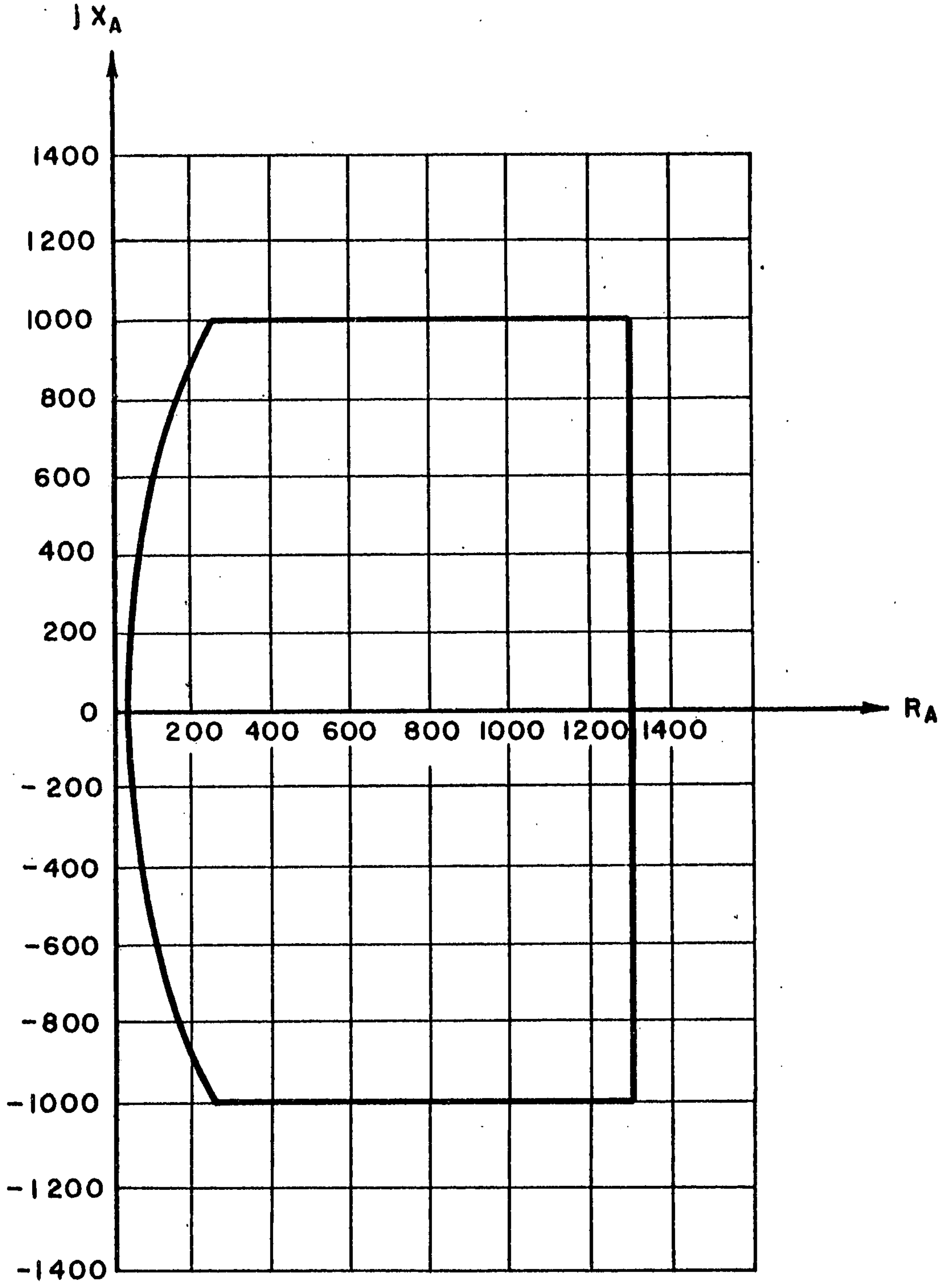

j X_A
1400
1200
1000
800
600
400
200
0
- 200
-400
-600
-800
-1000
-1200
-1400
200
400
600
800
1000
1200
1400
R_A

FIGURE 7

cycle. This is indicated by the turning off of the blue indicator light. If, however, the automatic key jack is inserted, the servo power (and the blue light) are turned off at the completion of the tuning cycle only if the hand key is locked in the "on" position. (The ability to transmit is not affected by whether or not the servo power has been turned off. Only the power drain is affected.)

(iii) Transmitting

At the completion of the tuning cycle the transmitter may be keyed either by the hand key or by the automatic keyer.

2 External Controls

(i) Band Switch

The 3-30 mc frequency range has been divided into the following bands: 3-7 mc; 7-15 mc; and 15-30 mc. The switch should be positioned to the range which includes the desired operating frequency.

(ii) Frequency Source

The transmitter front panel contains a crystal socket and a VFO jack. The VFO should be a constant voltage generator which will apply 6 volts peak-to-peak across an impedance whose magnitude, depending on the frequency, ranges between 50 ohms and 1000 ohms. (A generator such as Tektronix Type 190 Constant Amplitude Signal Generator may be used.)

(iii) Keying

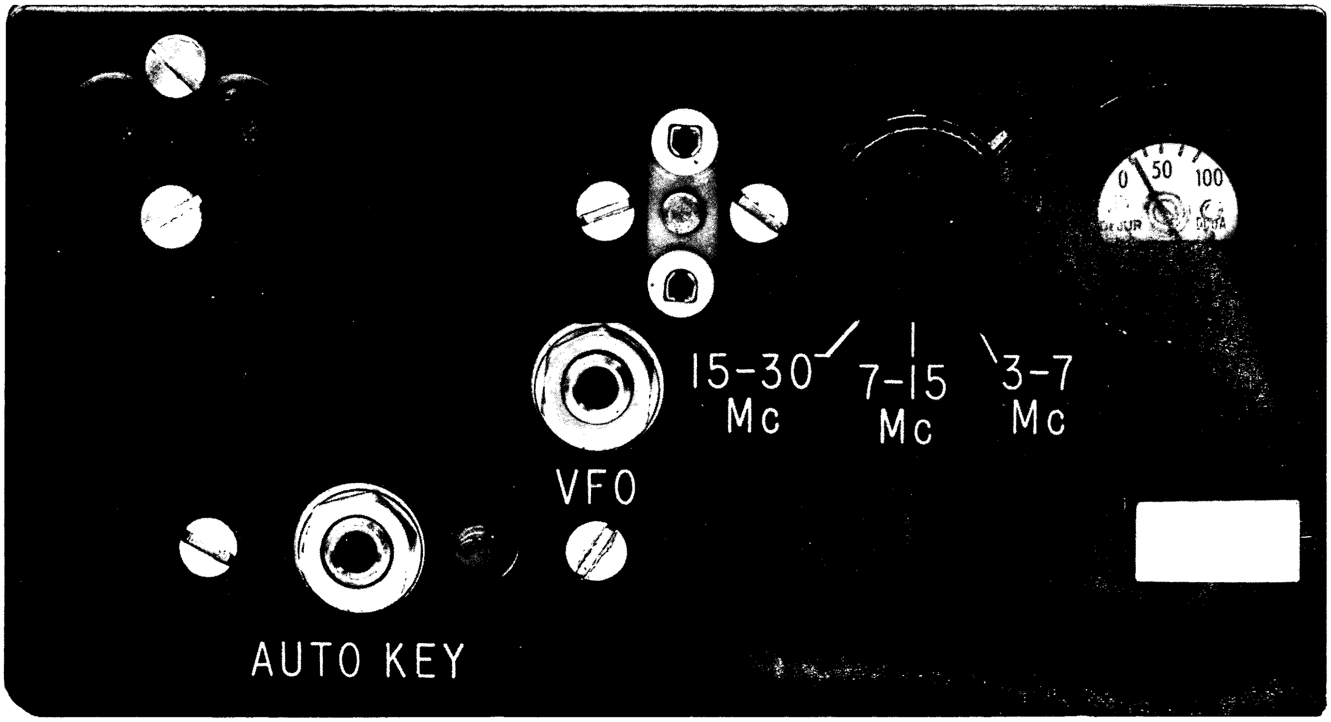
Keying may be accomplished either by a hand key or by an automatic keyer. The hand key is locked off when it is pushed in against the case. When pulled out to the first position, normal keying may be performed. The key may be locked down ("on") by pulling it out to its second position. Automatic keying may be accomplished by inserting the auto-key plug, subject to the following constraints. In the "on" state, a resistance path to ground of no greater than 10 ohms should be presented to the Auto-Key terminals. In the "off" state, bias conditions within the transmitter result in minus 16 volts existing across the Auto-Key terminals. In order to maintain this internal bias, the Auto-Key terminals should be loaded with a grounded resistance no less than 50 kilohms.

(iv) Break In Operation

A relay is included in the transmitter circuitry to allow break-in operation. When transmitting via the hand key, the antenna terminal (A) is connected to the receiver terminal (R) when the key is in the "up" position. In the key "down" position, the antenna is connected to the transmitter RF output. Insertion of the Auto-Key jack results in the connection of the antenna only to the transmitter, since break-in operation is no longer desirable.

(v) RF Meter

The meter on the front panel is an indication of the RF voltage being applied at the input of the matching network. At the completion of the tuning cycle, the meter should be at approximately half scale deflection. A photograph of the front panel is shown in Figure 8.



[redacted]

FIGURE 8

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