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Seventh Bimonthly Report on
The RT-21 Transmitter Program

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I. Purpose

See Bimonthly Report No. 1.

II. Abstract

This report describes work which has been carried out in an attempt to increase the output power of the transmitter itself while at the same time decreasing the circuit complexity. Recent work on the automatic impedance matching unit is also described.

Using 2N1337 Pacific Semiconductor transistors an output of 2.5 watts has been obtained from the transmitter at frequencies up to 30 mc. The circuit used to achieve this result is described as well as the associated control circuitry. Construction of the variable elements of the automatic matching unit has been completed. The motors, gears and variable reactances have been assembled and the entire unit tested. With the servo loop completed, including sensors, modulators, amplifiers, motors, torque multipliers and variable reactances, successful operation of the system has been achieved at a number of frequencies, using signals supplied by a generator. However, at the low end of the range, (around 3 mc) instability is experienced. Steps are being taken to overcome this difficulty.

III. Factual Data

1. Automatic Transmitter

(i) Introduction

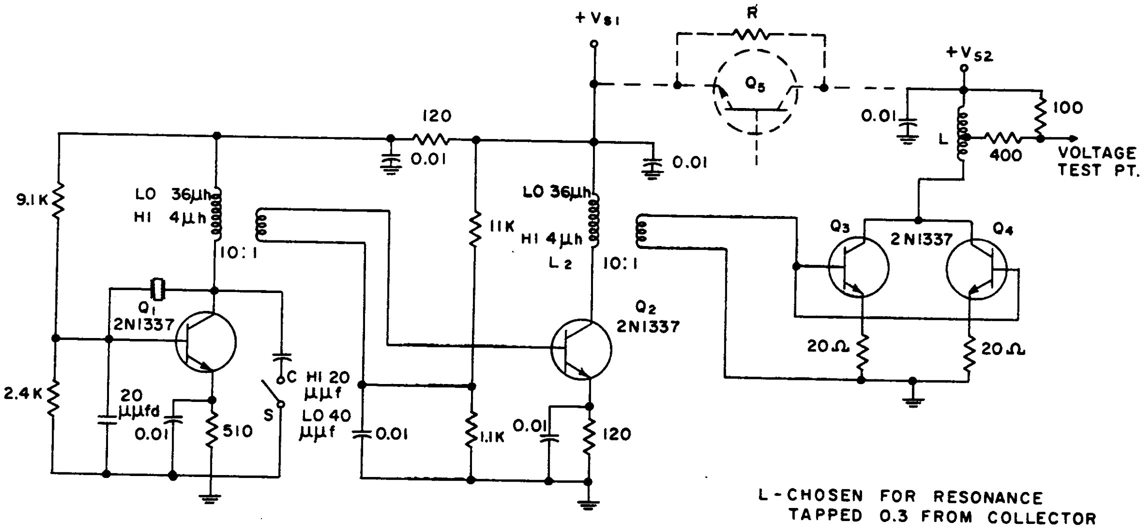
During the past reporting period work has been performed in an effort to produce substantial power output from high frequency transistors which are now becoming available from industry sources. Encouraging results have been obtained with type 2N1337 transistors supplied by Pacific

Semiconductors. Two of these units connected in parallel have produced 2.5 watts output at 30 mc. Since power gain at this level is low, moderately high power driving stages are necessary. Some work was performed in an effort to increase the power level of the crystal oscillator so as to minimize the number of driver stages required. The experimental work included the construction and testing of high and low band crystal oscillators, driver stages, and power output stages.

(ii) Experimental

Two test circuits were constructed to develop 2.5 watts crystal controlled r-f power. One circuit was designed to operate in the low frequency band of 3 to 15 mc and the other in the high frequency band of 15 to 30 mc. It was recognized that a 2 position band switch could have been employed in a single circuit to select the desired band, but to simplify the experimental construction work individual low and high band test circuits were employed. Figure 1, which shows the basic circuit configuration of the units, indicates the component values used for their respective bands. Transistor Q_1 serves as a crystal controlled oscillator which feeds the driver stage Q_2, and Q_2 in turn drives the output stage composed of parallel connected transistors Q_3, Q_4 and a tapped tank coil L. Series connected 100 and 400 ohm resistors serve as a 500 ohm load and provide a low impedance test point for voltage measurements.

Circuit operation is straightforward. Insertion of a crystal may or may not produce oscillations depending upon the state of switch S and the magnitude of V_{S1} which initially is set at a low value. Supply voltage V_{S1} is gradually increased until oscillation begins, and switch S, which



L-CHOSEN FOR RESONANCE
TAPPED 0.3 FROM COLLECTOR

V_{S1}- + 20 TO + 60 V

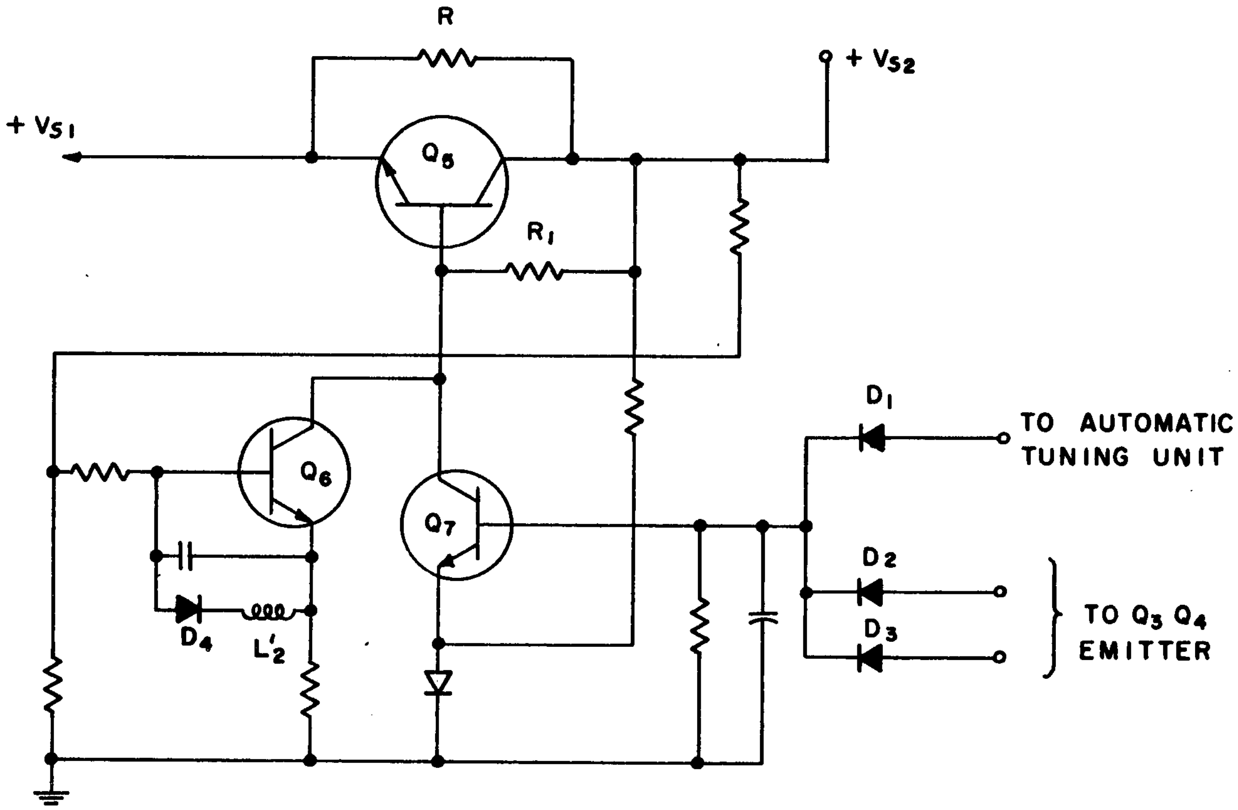
V_{S2}- + 60 V

TEST CIRCUIT FOR PRODUCING 2.5 WATTS OF R-F POWER IN A 500 OHM LOAD

FIGURE 1

would normally be a transistor in the automatic transistor, is set in the position which provides maximum oscillator output. An additional increase in V_{S1} is applied, if necessary, to increase the Q_2 amplifier stage signal power level to a value sufficient to drive the output stage to full power output. The power stage drive condition may be conveniently monitored by observing the dc potential developed across the 20 ohm resistors connected to the Q_3, Q_4 emitter terminals. Inductance L is tuned to resonate at the operating frequency. The design is arranged so that the coupling networks L_1 and L_2 are broadband and fixed tuned. The variable inductance L may be provided by the automatic impedance matching unit. Switch S serves to couple the fixed capacitor C into or out of the oscillator tank circuit and so subdivides each frequency band into low and high ranges. The ambiguity of whether oscillations occur at the fundamental crystal mode or at higher modes is removed by setting the switch in the position which yields the highest oscillator output. A transistor flip-flop and an oscillator output detector may perform the switch function or alternately the oscillator tuning circuitry indicated in Figure 1 of the Sixth Bi-monthly Report may be adapted for use with the oscillator.

The automatic adjustment of V_{S1} during transmitter tuneup may be performed by a voltage control transistor, shown dotted in Figure 1, connected between terminals V_{S1} and V_{S2}. Figure 2 illustrates a method for performing the desired control. The voltage V_{S1} is determined in part by the current flow through resistor R and transistor Q_5. A minimum value of V_{S1} will result if Q_5 is nonconducting, and a maximum value, nearly equal to V_{S2}, will result if Q_5 is fully conducting. Any intermediate value may be obtained



L_2 = WINDING ON Q_2 OUTPUT COIL L_2

AUTOMATIC VOLTAGE CONTROL CIRCUITRY

FIGURE 2

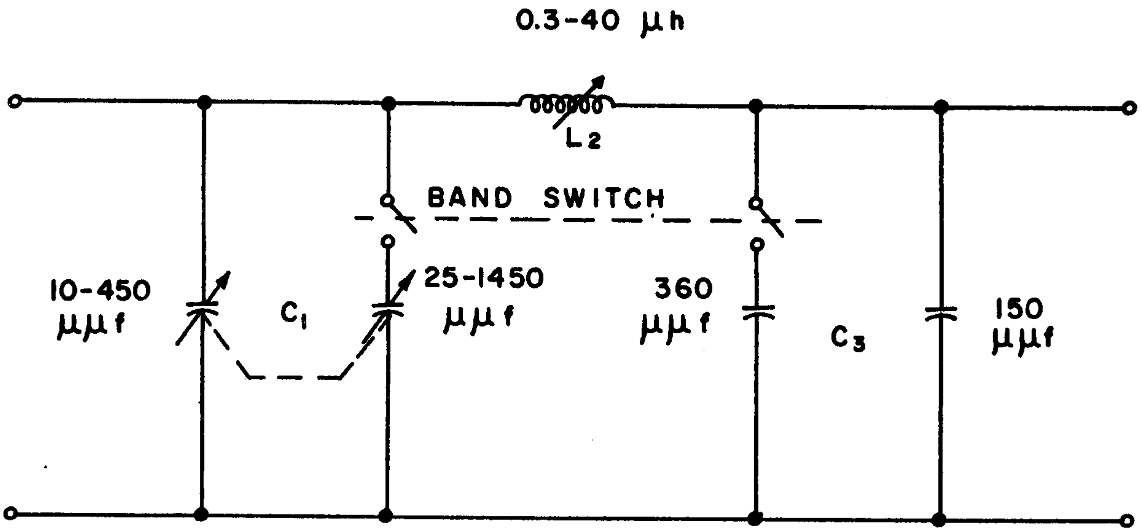
by appropriate control of the conduction of Q_5. The degree of conduction of Q_5 is determined by the base current available from resistor R_1. If Q_6 and Q_7 are nonconducting, then the full current from R_1 is applied to the Q_5 base and full conduction of Q_5 results. On the other hand if Q_6 or Q_7 conduct, the base current of Q_5 is reduced, and consequently, the voltage V_{S1} is reduced. The circuit is arranged so that initially, without crystal oscillator output, Q_6 is conducting and V_{S1} is at its minimum value due to nonconduction of Q_5. When a crystal is inserted, oscillations begin and the L_2' D_4 detector circuit produces a dc potential which reverse biases the base emitter of Q_6 causing Q_6 to become nonconducting. The voltage V_{S1} can rise provided Q_7 is not conducting. The conducting condition of Q_7 is determined by dc signals from the automatic tuning unit, and the emitters of Q_3 and Q_4. The automatic tuning unit provides a positive dc signal whenever the unit is in an untuned condition. This is fed to the base of Q_7 via the diode D_1. Thus, Q_7 conducts and maintains the V_{S1} voltage at a low value whenever the automatic impedance matching unit is not tuned. This prevents excessive output stage r-f drive during the tuneup period which might otherwise result in damage to the output transistors Q_3 and Q_4. Once the tuning unit has attained a tuned condition the positive potential at D_1 disappears, and Q_7 conduction decreases. The resulting rise in V_{S1} increases the driving signal fed to the output transistors Q_3 and Q_4, and this produces a rise in dc potential at their respective emitters. When the emitter potentials have risen to a value sufficient to cause conduction in D_2 and D_3, Q_7 becomes conducting again, thus preventing a further increase in V_{S1}. The drive signal to Q_3 and Q_4 accordingly stops rising, and the r-f output is stabilized at its designed maximum value.

2. Automatic Impedance Matching

During the past reporting period the mechanical assembly of the variable inductor, variable capacitor and the associated gear trains and motors has been virtually completed. A modification of the variable inductor has been found to give improved electrical performance. Instead of using a rotating wheel to tap a portion of the total inductance, the modified inductor incorporates a brass rod in conjunction with the ferrite rod. The inductance is varied by winding or unwinding turns from the ferrite with the brass rod acting as a "take-up" reel. This method of varying the inductance eliminates the difficulties due to self-resonance of the coil within the frequency band of interest.

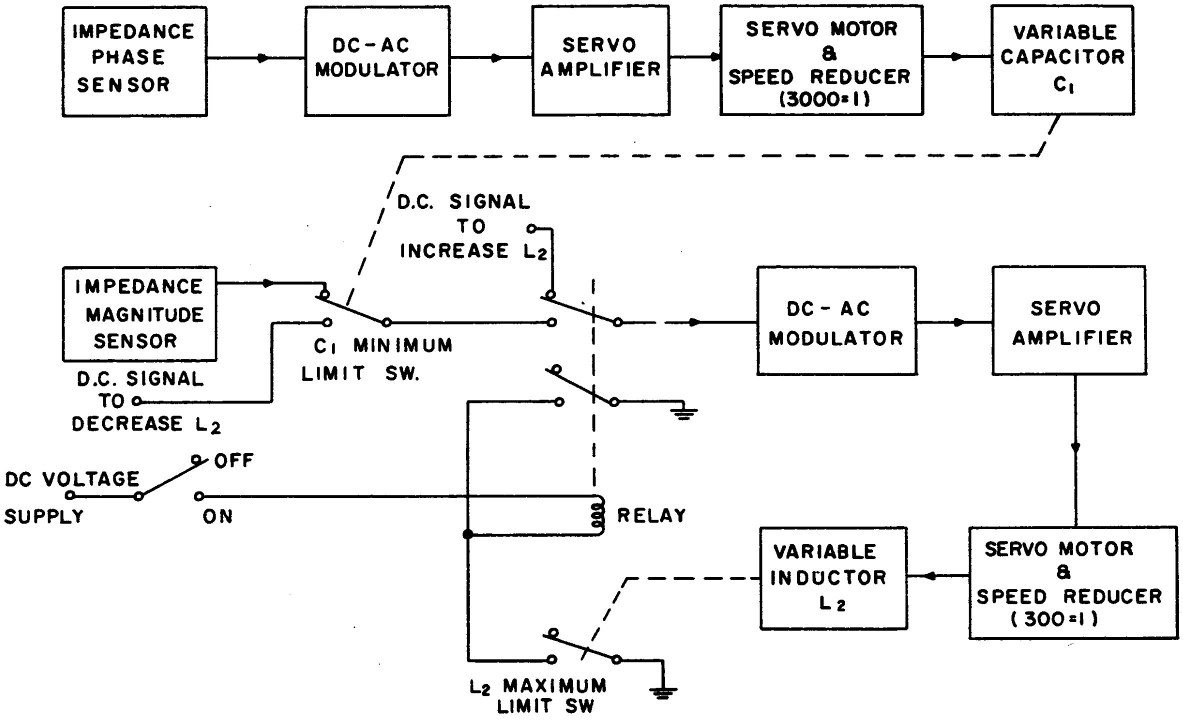
The ranges achieved by the variable capacitor and the variable inductor are shown in Figure 3. The variable capacitor has two taps, thereby allowing a portion of the total capacitance to be removed by the band switch in the 15-30 mc band. The band switch also changes the fixed output capacitor of the pi network.

A block diagram representation of the impedance matching system is shown in Figure 4. The manner in which this system produces a purely conductive input admittance is as follows: The operation of the system requires that L_2 be at its maximum position when the tuning cycle begins. This is accomplished automatically by means of a relay which, when unactuated, applies a signal which causes L_2 to increase. When L_2 has reached its maximum position, a limit switch then actuates the relay and the tuning cycle begins. The output of the phase detector tends to drive C_1 to the position which cancels any phase angle associated with the input admittance.



IMPEDANCE MATCHING Pi NETWORK

FIGURE 3



BLOCK DIAGRAM OF AUTOMATIC IMPEDANCE MATCHING SYSTEM

FIGURE 4

The output of the magnitude detector tends to drive L_2 to the position which produces the desired input conductance, provided that C_1 was not driven to its minimum position in an attempt to maintain zero phase while L_2 was "prepositioned" to its maximum. When C_1 is driven to its minimum position, a limit switch is actuated. This limit switch applies a signal which causes L_2 to decrease as long as C_1 is at its minimum position. The limit switch is released when C_1 leaves its minimum, and the control of L_2 is returned to the magnitude detector. The tuning cycle is completed as the phase and magnitude error signals drive C_1 and L_2 to their proper positions.

The complete impedance matching system is currently being evaluated in the Laboratory. When driven by an RF generator, satisfactory tuning has been achieved at 15 and 30 mc, but the servo system tends to become unstable as the frequency approaches 3 mc. The following points contribute to the fact that the stability of the system depends upon the transmitter frequency.

(i) The magnitude of the signal derived from the phase sensor is frequency sensitive. This means the speed with which the capacitor responds to a phase angle error is greater at high frequencies than at low frequencies.

(ii) The change in input admittance produced by a specified angular rotation of either the capacitor or inductor shaft is greater at high frequencies than at low frequencies.

The complete significance of these points is not readily apparent since the manner in which the capacitor and the inductor interact is an extremely complicated function of capacitance, inductance, frequency, terminating impedance, and the mechanical parameters of the system.

The Laboratory evaluation of the impedance matching unit indicates that one method of stabilizing the system is to reduce the speed of the coil. The disadvantage of this approach is that the tuning time is lengthened. However, if a suitable method can be devised which causes the coil to be slowed only in the neighborhood of its tuned position, the increase in tuning time will be negligible. Another approach to stabilizing the system would be to synthesize a compensating network to insert into the servo loop. The disadvantage of this method is that, unless the transfer functions of the various components is derived (a task which, if possible at all, would be extremely difficult), the compensation must be done in a "cut and try" manner. No satisfactory compensating network has been devised, but work along this line is being continued. Further work will be directed towards determining the best system by which to achieve system stability.

IV. Conclusions

As far as the transmitter itself is concerned, the circuit shown in Figure 1 has been tested for both low and high band operation. An output of 2.5 watts was obtained at 8 mc in the low band and 30 mc in the high band. An overall efficiency for the transmitter in excess of 60% was achieved at 30 mc. The oscillator and driver stages of both low and high band units provided full driving power over their respective frequency ranges.

Successful operation of the automatic impedance matching unit has been achieved over the majority of the 3-30 mc range. Instability has been observed around 3 mc. The redesigned variable inductance performs well, providing a relatively high Q_1 over the full range without the resonance effects observed in the original design. Similarly, the specially designed variable capacitor has been completed. Assembly was carried out with considerable care in order to keep the necessary torque to a minimum. In the completed servo system, the motors have more than sufficient power to turn the capacitor and variable inductance--so much so that it was felt desirable to construct a slipping clutch in order to avoid damage to the capacitor when it reaches the limit of its travel.

V. Future Plans

Automatic voltage control circuitry such as that indicated in Figure 2 and oscillator switch circuitry will be tested and installed in the experimental units. The automatic antenna tuning unit may then be coupled to the low and high band circuits, and preliminary testing of the interconnected principal components of the transmitter can begin. An effort to obtain improved high power, high frequency transistors suitable for use in the transmitter output stage will continue.

Before connecting the transmitter to the matching network, the instability experienced at the low frequency end of the 3-30 mc range will have to be eliminated. It is to be hoped that this can be done with a minimum of modification. Several remedies suggest themselves and these will be explored in turn, starting with the simplest.

VI. Identification of Key Technical Personnel

The following name should be added to those given in previous reports:

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