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Model TCS Equipment Keying Tests

by

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NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

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NAVAL RESEARCH LABORATORY
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Report of

MODEL TCS EQUIPMENT KEYING TESTS

by

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ABSTRACT

Tests have been made to determine the effect on clipping of individual relay characteristics, primary supply voltage variation, crystal characteristics, multiple band operation, and oscillator circuit characteristics, in the Model TCS transmitters. The relays were found to be causing a major part of the clipping when the transmitter is performing acceptably, and some improvement is considered possible. A minor modification of the crystal oscillator circuit did not result in less clipping due to oscillator lag.

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AUTHORIZATION

1. The tests described in this report were authorized by reference (a). Other relevant data are contained in references (b) and (c).

References: (a) BuShips ltr. Serial No. 1319(925B) of 28 March 1944 to NRL.
(b) Specification XA 8877D.
(c) Collins Radio Co. ltr. of 1 Sept. 1944 to NRL via Rinsmat.
(d) NRL ltr. S67/52(380-GA) of 17 April 1944 to BuShips.

OBJECT OF INVESTIGATION

2. Reference (a) requested this Laboratory to investigate the factors entering into the clipping of telegraphically keyed signals with a view toward modification of equipments, so as to minimize keyed wave clipping to an extent consistent with service requirements.

INTRODUCTION

3. In tests of quartz crystal units intended for use with Model TCS Series Equipments certain assumptions were made concerning the Model TCS transmitter in which the tests were made; namely, (a) that the two keying relays, K102 and K103, operate simultaneously, although with a certain common time delay; (b) that additional time is required for the oscillations of the crystal to build up to a maximum value; and (c) that radiation from the transmitter ceases practically immediately when the key is raised. A greater or less portion of each telegraphically keyed "dot" is thus lost and the fractional part missing has been referred to as the "clipping".

4. Limited tests have been made to determine the maximum clipping that may be permitted if telegraphically keyed signals are to be readable, under conditions of no atmospheric disturbances. Such limited tests indicated that the clipping should not exceed approximately 75 per cent at a keying speed of 30 words per minute. The lengths of perfect and clipped dots at this keying speed, and the general shape of the upper half of the resulting dot envelope, are shown on sheet 11D of reference (b). It will be observed that this general shape of the dot envelope is not that considered most desirable. It is preferred that the dot begin more abruptly but end slightly less so, and that the clipping be much less. In so far as the maximum height of the actual dot envelope is attained only slowly, the term "clipping" is not as apt in the case of crystal operation as in the case of master oscillator (MO) operation.

DOT-POWER CONSIDERATIONS

5. If a transmitter emits a succession of perfectly rectangular

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dots, separated a distance equal to the dot length, and if the naive assumption is made that an otherwise continuous wave is merely interrupted, it is evident that the average power radiated is half that for the c-w emission. If then, because of some relay operating lag, the transmitter emits perfectly rectangular dots but shorter than the dot separation ("clipped" dots), the average power radiated is still less. If the average power radiated in the unclipped dots is taken as a reference level, then the fractional loss of power due to clipping has the same numerical value as the expression for the clipping. The maximum instantaneous field intensity for these clipped dots at a distant point is still the same as for c-w emission, and the radiation should be detected by a suitable receiver.

6. If a transmitter emits a succession of imperfect dots a certain loss of power will result. However, it may be assumed that during a portion (at least 25 per cent at a keying speed of 30 words per minute) of each dot the amplitude of the carrier attains a maximum value (the same value as for c-w emission), and that a distant receiver will respond. The readability of signals is dependent upon departure of dot shape (and dash shape) from an ideal shape, on clipping, and on keying speed; and might thus be considered to be only secondarily dependent upon the area enclosed by the dot envelope. The fractional power loss resulting with the imperfect dots may be expressed as

$$1 - \left(\int_{t_i}^{t_f} [e(t)]^2 dt \Big/ E^2 (t_f - t_i) \right) \quad \text{where } E \geq e(t) \geq 0,$$

$e(t)$ being the instantaneous value of the carrier amplitude. It may be seen that for other than rectangular dots, such as are obtained with the Model TCS Equipment, the power loss does not bear a simple relationship to the clipping, and is not simply related to the area enclosed by the dot envelope.

EXPERIMENTAL ARRANGEMENT

7. Three Model TCS Equipments were available for study of keying characteristics: Model TCS-5, Serial No. 623; Model TCS-8, Advance Production Model; and Model TCS-12, Serial No. 229. Three types of power supplies were used: the 409M-5 rectifier type unit; the 413C motor-generator type unit; and the 416T-4 dynamotor type unit. The transmitters were keyed by a special, commutator-type, keyer developed as part of a Keying Analyzer. The keyer both keys the transmitter to produce a succession of correctly spaced dots at any speed up to 130 words per minute, and also provides a corresponding succession of rectangular pulses. These pulses are used to show by oscillographic comparison with other pulses such factors as relay lag.

8. The three transmitters, operating on different frequencies and

[redacted]

into dummy loads, were simultaneously keyed. Several receivers, appropriately tuned and connected to small probe antennas, were located in a shielded room. Their outputs (on BFO operation), the keyer comparison signal, and a 1000-cycle reference signal were applied to the elements of a Westinghouse type PA string oscillograph.

9. Trigger devices were connected to the circuits of the two keying relays, K102 and K103, of the Model TCS-5 transmitter so as to respond at the instant of operation of these relays. The output pulses of these devices, the receiver output, the keyer comparison signal, and a 1000-cycle reference signal were applied to the elements of the string oscillograph. Keying speed, primary supply voltage, and transmitter orientation were varied.

10. The output pulses of the trigger devices, the receiver output, and the keyer comparison signal were observed simultaneously on the cathode ray oscilloscope screen by means of three electronic switches. Two signals were applied to each of two electronic switches, and the output of each switch was applied to the third, the output of which was applied in turn to the oscilloscope. The type of transmitter operation (crystal or MO), crystal construction, frequency band, transmitter orientation, and keying speed were varied.

11. An accelerometer Indicator Unit was connected to two relays of different types to indicate any opening of relay contacts under vibration and shock. The unit employs Thyratron tubes which "fire" when the input circuits are opened momentarily and cause indicator lamps to light.

RESULTS OF TESTS

12. General Characteristics. The three transmitters were keyed simultaneously, as described in paragraph 6. The Model TCS-5 transmitter was powered by the 413C motor-generator type supply; the Model TCS-8 transmitter, by the 409M-5 rectifier type supply; and the Model TCS-12 transmitter, by the 416T-4 dynamotor type supply.

(a) Plate 1 shows the oscillograms of receiver outputs (on BFO operation) when the Model TCS-5 transmitter was operated on a 1600 kc Telicon crystal, when the Model TCS-8 transmitter was operated on 2400 kc on MO, and when the Model TCS-12 transmitter was operated on 2000 kc on MO, all three transmitters being keyed simultaneously at 30 words per minute. The smaller amplitude of the trace for the Model TCS-12 transmitter is due only to failure to obtain a more favorable adjustment of receiver output level, and is not due to low transmitter output. The trace marked "Keyed Input" is that of the keyer comparison signal previously described. In general, it may be seen that a delay occurs in the beginning and ending of the dots emitted by the transmitters. In the case of the trace for the Model TCS-8 transmitter it is assumed that the self oscillator (MO) starts oscillating without delay as soon as the keying relays operate, so that the delay at the beginning of the dots is due to relay lag. In this trace the delay amounts to about 16 milliseconds, or slightly longer than that given in reference (b). The large delay is expected because of the use of the 409M-5 rectifier type power supply. The dot does not end until 3 milliseconds after the key is released. In this instance the effective clipping may be considered to be 31 per cent. In the case of the trace for the Model TCS-12 transmitter a larger relay lag occurs. In the case of the Model TCS-5 transmitter the delay at the beginning of the dots is, in this trace, about 19 milliseconds; but this delay must be due both to relay operating time and to any crystal oscillator lag. The 413C motor-generator type of power supply has been found to make better performance (less clipping) possible than the other types of power supplies. The delay in ending the dots is about 5 milliseconds. The effective overall clipping here is 34 per cent.

(b) Plate 2 shows the oscillograms of receiver outputs when the transmitters were operating on Collins crystals of frequencies near 1600 kc. In the case of the Model TCS-8 transmitter the trace does not show typical behavior. The delay times shown are 25 and 4 milliseconds, and the clipping is 50 per cent. The trace for the Model TCS-12 transmitter shows best the expected behavior. Here the amplitude of oscillation of the crystal may be supposed to have increased gradually to the maximum value. Some delay in ending the dots is evident. In this case the clipping is nearly the maximum permissible. The trace for the Model TCS-5 transmitter shows a similar behavior, but the general performance is poorer.

(c) Plate 3 shows oscillograms for the Model TCS-5 transmitter operating on 2050 kc on MO, when keyed at a rate corresponding to 8 words per minute. In these traces the delay in beginning the dots is about 23 milliseconds. This should be relay operating time, but is somewhat larger than that observed on Plate 1. It may be further observed in the traces for the Model RAO receivers and for the simple diode detector response that breaks occur at the very beginning of the dot (within about the first millisecond) probably due to erratic relay contact. The dot ends about 11 milliseconds after the key is raised. The effective overall clipping here is only about 8 per cent. It may be noted that an anomaly also appears near the end of the dot, where the output of the transmitter is slightly diminished during the last 8 milliseconds.

(d) Plate 4 shows oscillograms for the Model TCS-5 transmitter operating on a 1600 kc Telicon crystal, when keyed at 30 words per minute. This Telicon crystal shows little delay in starting; the characteristic gradual increase in oscillation amplitude shown on Plate 2 is not evident here, but instead there is some indication of relay break at the beginning of the dot. The delay in beginning the dots is about 18 milliseconds. There is also the reduced transmitter output during the last 8 milliseconds. The magnitude of the apparent reduction is expected to vary with receiver characteristics and receiver adjustment, since the output of the second detector

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in a superheterodyne receiver on BFO operation depends on the relative strengths of the BFO oscillation and the i-f oscillation. The delay in finally ending the dots is 10 milliseconds, but the value of the effective overall clipping might be judged from the trace for the Model NC-200 receiver to be 40 per cent, or from the trace for the Model RAO-3 receiver to be 20 per cent.

13. <u>Individual Relay Characteristics</u>. Plate 5 shows oscillograms of the receiver output from the Model TCS-5 transmitter and of the operating times of the two keying relays, K102 and K103, of this transmitter. The Antenna Relay, K102, serves to key the plate circuit of the P-A stage and to transfer the antenna from the receiver to the transmitter. The Send-Receive Relay, K103, serves to key the plate circuits of the oscillator and buffer-doubler stages and to make the receiver inoperative. The relays are physically identical, and are simultaneously energized. However, the two relays are mounted differently in the transmitter; both are mounted with their base plane vertical, but K102 has the axis of rotation of its armature horizontal while K103 has it vertical. The difference in orientation results in some difference in operating time. At the time of these tests the transmitter had been in intermittent use for approximately a year. Relay contacts had been somewhat pitted, and one unused contact on K102 had become loose. Before this test the contacts were cleaned and the loose contact was secured.

(a) Under the conditions of the test relay K102 operated approximately 17 milliseconds after the key was pressed. About 2 milliseconds later, relay K103 operated. Breaks in relay contact are evident in the trace for the relay K102. They cause a reaction on the plate supply circuit portion of the other relay by coupling through the spark suppressor circuit. The delay of the 1600 kc Telicon crystal in starting to oscillate after operation of relay K103 appears to be less than one millisecond. Approximately one millisecond after the key was raised the relay K103 released, removing the plate potential from the oscillator and buffer-doubler stages. Approximately 6 milliseconds after the key was raised the relay K102 released, removing the plate potential from the P-A stage and disconnecting the antenna. Emission from the transmitter ceases after release of the relay K102, and does appear to be of diminished intensity during the last 5 milliseconds of the dots. Here the clipping of the relay K103 is 41 per cent, while that of the relay K102 is 28 per cent. The experimental agreement with the results described in paragraph 12(a) is sufficiently good. The spare relay included with the Model TCS-5 Equipment is shown to have about 31 per cent clipping, and to have somewhat worse contact breaks. This relay was operated in parallel with K102 and K103.

(b) The orientation of the two relays is changed by standing the transmitter on end. Plate 6 shows relay operating times for this case at a keying speed near 40 words per minute (instead of 30 words per minute as the plate is marked). Analysis of the traces from this plate does not show con-

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clusive results. Additional data will be presented in paragraph 15 of this report.

14. Effect of Primary Supply Voltage. It may be expected that the rapidity of operation of the relays should be affected by the value of the voltage applied to the relay solenoids. Accordingly, tests were made to determine the effect of increasing by 10 per cent the primary input voltage to the type 413C motor-generator set supplying power to the Model TCS-5 transmitter when the latter is operating on the 1600 kc Telicon crystal, and of decreasing the voltage to 10 per cent.

(a) Plate 7 shows the effect of a voltage 10 per cent above the rated value of 24 volts, at a keying speed of 30 words per minute. Here the delay in operation of the relay K102 is about 12 milliseconds, or about 70 per cent of that occurring at rated input voltage. The delay in releasing is practically unaffected. The effective overall clipping might thus be expected to be appreciably diminished.

(b) Plate 8 shows the effect of a voltage 10 per cent below the rated value at nearly the same keying speed (actually just slightly higher). In this case the delay in operation of the relay K102 is about 23 milliseconds, or about 135 per cent of that occurring at rated voltage. The delay in releasing is again not shown to be affected. The effective overall clipping is markedly increased.

(c) At a much higher keying speed the effect of high supply voltage is strikingly shown. Plate 9 shows the performance obtained at 60 words per minute at rated voltage. For some dots neither relay operated. The spare relay from the Model TCS-5 equipment performed better. Of the output from the Model TCS-8 transmitter the clipping was only about 31 percent. Plate 10 shows the performance obtained at the same speed when the supply voltage is 10 per cent higher than the rated value. Here the delay in operation of the relay K102 is only about 19 milliseconds, but breaks occur during the following 2 to 4 milliseconds. These breaks cause undesirable breaks in the transmitter emission, as may be seen in the case of the trace for the Model TCS-8 transmitter. It is evident from these tests that to secure the best possible performance from the Model TCS transmitters the primary supply voltage should be at least equal to the rated voltage, and might be slightly higher; but excessive voltage causes bad relay contact breaks. These breaks may cause key clicks.

15. Orientation Effect. When C-R oscillograms were made of the receiver output, the relay operating pulses, and the keyer comparison dots, the effect of relay orientation was more strikingly shown. On these plates the "Keying Relay" is K103 while the "Antenna Relay" is K102.

(a) Plate 11 shows an abnormal effect obtained prior to the partial reconditioning mentioned in paragraph 11. The Model TCS-5 transmitter was

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operating on MO. In general the beginning of the output dot corresponded to the instant of operation of the relay K103, while the end of the output dot corresponded to the instant of release of the relay K102. When the transmitter was tipped over on its right end, the order in which the relays responded on pressing the key was reversed, and the clipping of relay K102 was excessively large.

(b) Plate 20 shows more normal behavior after the loose relay contact on K102 was secured in place. The Model TCS-5 transmitter was operating on the 1911.25 kc Collins crystal. The rectified r-f output of the transmitter, shown by the top trace in each photograph on this plate, provides a better representation of the transmitter overall performance than does the receiver output. In most instances there is evidence of some transient effect on the output dot probably due to power supply regulation characteristics. The effect lasts as long as 20 milliseconds. Emission from the transmitter ceases after release of the relay K102, but is of diminished intensity after the release of the relay K103. Such behavior has been shown on Plate 4. It is expected that oscillations in the oscillator and buffer-doubler stages should decay more or less rapidly after K103 releases, and that the P-A stage should supply reduced power to the antenna or dummy load for a short time or until K102 releases. Table 1 presents approximate relay acting times and clipping measurements taken from Plate 20. It should be observed that since the height of the dot envelope during the last few milliseconds of the dot is less than 75 per cent of the maximum height, the values of overall clipping given in Table 1 do not take into account this trailing portion of the dot. In general, the clipping of relay K102 is appreciably less than that of K103, under the conditions of the test. When the transmitter was tipped over on its right end, rotating relay K103 in its vertical base plane until the armature rotation axis was horizontal, some consistent improvement in the performance of relay K103 resulted.* The orientation of relay K102 is the preferred orientation for this type of relay. If both relays, K102 and K103, in the Model TCS transmitter were mounted similarly to relay K102, the overall clipping should be the least, consistent with optimum dot shape. However, the crowding of component parts in the Model TCS equipment does not readily permit a change in the mounting of relay K103.

16. Plate 21 shows additional evidence that the main development of the transmitter output dot corresponds closely in time to the operation and release of relay K103. The trailing end portions of the output dots, of diminished intensity, are not evident on this plate; no final break in the transmitter emission subsequent to the release of relay K103 occurs here - the emission merely decays to zero.

17. <u>Crystal Characteristics</u>. The 1600 kc Telicon crystal and the 1911.25 kc Collins crystal are relatively active crystals, having no appreciable delay in the start of oscillations when keyed. When less active crystals are employed in the Model TCS transmitters a larger overall clipping

[redacted]

results due both to relay lag and to crystal oscillation starting time. In general, crystal units employing electrodes plated on the crystal faces have given less delay in starting to oscillate; and of crystal units employing plate electrodes with small fixed air gaps, those much less than one inch square usually exhibit appreciable delay in starting to oscillate. Plates 12, 13, and 14 show oscillograms of the dot envelope shape at 20, 30, and 40 words per minute, respectively, for ten experimental 2090 kc American Jewels crystals. The quartz plates in these units are approximately three-quarters inches square. The dot envelope shape on MO operation at the same frequency and keying speed is also shown on each plate as photograph Number 11. In some instances, as in the case of crystal No. 3 on Plate 12, a multiple trace appears. The additional trace is believed to result primarily from erratic relay action; the relay lag varies slightly, in a chance manner, from dot to dot, and each photograph represents the superposition of three or more dots. The variation in relay lag may also be detected on Plate 5. Plates 12, 13, and 14 show no trailing end portions of the output dot. In general, such trailing end portions have not been observed in the case of less active crystals. Table 2 presents clipping data from these three plates. At 40 words per minute the dot formation is very poor. In addition to the clipping values, the fraction of the dot area missing is tabulated. There is shown to be some correlation between this fraction and clipping. However, this fraction is not regarded as a primary measure of the readability of telegraphically keyed signals or as such a measure of power output as to determine the maximum instantaneous field intensity at a distance.

18. <u>Upper Band Operation</u>. On Bands 2 and 3 doubling and quadrupling of the oscillator frequency occurs by multiplication in the buffer-doubler stage and in the plate circuit of the oscillator stage. The number of tuned circuits ganged for single dial frequency control varies from one for Band 1 crystal operation to three for Band 3 MO operation. The P-A plate circuit is tuned independently. The correctness of the tuning depends in large measure on the accuracy of calibration of the main tuning dial and on the alignment of the circuits so controlled. Plates 15, 16, and 17 show oscillograms of the dot envelope shape for operation on the three bands under conditions of uncertain control of such factors as primary supply voltage. On these plates "Fundamental" means no frequency multiplication, while "Second Harmonic" means that the output frequency is double the oscillator frequency. Table 3 is intended to show the effect only of switching operation from one frequency band to another without disturbing any other adjustment. No dependence can be placed upon absolute values. Certain unexpected results are indicated, such as the clipping values in one instance of 33, 82, and 66 per cent for the three bands. These differences are not attributed merely to large experimental error or to erratic relay action, but are believed to be related to difficulties with tuning circuit alignment. The original alignment of the transmitter had not been disturbed. Sufficient study has not been made of this effect to permit further analysis; however, it is believed that maintenance of the transmitting equipment should include attention to the possibility of misalignment as well as attention to

[redacted]

relay condition.

19. Relay Types. The Models TCS-5 and TCS-8 transmitters on which these tests were made use Leach relays (Collins No. 407N86A). The Model TCS-12 transmitter uses a Guardian relay (Collins No. 410N23), which has a somewhat heavier, counterweighted armature. The Guardian spare relay provided with this equipment bears the same number and is similar except for still greater armature mass. Another Model TCS-12 transmitter (Serial No. 2831) has been observed to use an Aemco relay for K102 and a Guardian relay for K103. Some comparison has been made of the characteristics of the Leach and Guardian relays.

(a) Plate 18 shows operating times of the spare relays furnished with the Models TCS-5 and TCS-12 equipments when both were mounted similarly to the relay K102 and both were energized from the same battery source. The Guardian relay (TCS-12 spare) is seen to have a consistently greater delay in operating when the key is pressed, the delay being of the order of 20 milliseconds for the Guardian relay and 14 milliseconds for the Leach relay under the conditions of the test. The delay in releasing when the key is raised is not greatly different. The shorter operating time for the Leach relay (than the values given earlier in this report) is attributed to the use of a different energizing source.

(b) Plate 19 presents additional information showing principally an improvement in the performance of the Guardian relay obtained on removing the counterweight. The top trace in each photograph is for the relay K102 in the Model TCS-12 transmitter when the latter was operated on the type 416T power unit, while the second trace is for the spare Leach relay when it was operated in parallel with the relays in the Model TCS-5 transmitter powered by the type 413C unit. Since the two relays compared were energized by different sources of power, the data have been interpreted with caution. Furthermore, in the "Relays Mounted Horizontally" cases the Leach relay was actually oriented similarly to K103, but the Model TCS-12 transmitter was merely tipped over on its right end so that the Guardian relay was then supported with its base plane horizontal. In the case of the bottom row of photographs, it is probable that the primary input voltage applied to the power supplies was slightly higher than for the other series of photographs, resulting in somewhat less clipping. In general, the clipping of the Guardian relay was halved when the counterweight was removed, and became then about two-thirds as great as the clipping of the Leach relay. As before, the delay in releasing of the relays when the key is raised does not differ appreciably.

20. Effect of Vibration and Shock. It is understood (reference (c)) that the function of the counterweight is to dynamically balance the armature of the relay so as to eliminate chattering of the contacts under vibration. To determine if the removal of the counterweight resulted in faulty performance of the relay under such vibration or shock as might be experienced on shipboard, certain tests were made.

[redacted]

(a) The Leach and Guardian spare relays were mounted on a test table and subjected to vibration at frequencies up to 1900 cycles per minute for four hours. The solenoids of the relays were not energized, and an accelerometer Indicator Unit was arranged to show any momentary breaking of the normally closed contacts due to vibration of the armature. No contact breaks were indicated for either relay, with or without the counterweight. No disadvantage is therefore known to result in this application from the elimination of the counterweight.

(b) The same relays were subjected to shock under a variety of conditions. A total of 100 shocks of 250 g intensity was imparted. Contact breaks always occurred for such shocks, regardless of direction of the shock or whether the solenoids were energized. For shocks of about 12 g intensity the Guardian relay was unaffected, but the Leach relay, unenergized gave contact breaks when the direction of acceleration was normal to the base plane of the relay. Shocks of about 18 g intensity caused contact breaks in the Guardian relay with the counterweight, but did not cause contact breaks when the counterweight was removed. Thus, although the relays are not resistant to shock, the elimination of the counterweight causes no additional difficulty, but does permit better performance in keying.

21. <u>Variation of Capacitance of C122.</u> Reference (a) requested that the effect of varying the "feed back condenser" C122 in the crystal oscillator circuit be observed. This condenser has a capacitance of 50 μμfd. Although increasing the capacitance might be supposed to increase the feedback and thus improve the response of the circuit when keyed, it may also be expected to cause a larger capacitive loading on the crystal and even prevent the circuit from oscillating, especially if a small size crystal is being used. Plate 22 shows the effect of increasing C122 from 50 to 75 uufd when a 2090 kc American Jewels (three quarter inch) crystal is used. The clipping is increased at every keying speed. The capacitance was also decreased to 25 μμfd, in which case no appreciable reduction in clipping occurred. For this crystal, crystal voltages and currents were measured for the three capacitance values, and are presented here;

C122 (μμfd)	Voltage (Volts)	Current (Ma)
25	9.1	14
50	13.1	12
75	12.1	23

The crystal voltage in this case is a maximum for the 50 μμfd. It is believed on the basis of these tests that no advantage is gained by changing the value of C122. Previous experiments (reference (d)) showed no sensible improvement in circuit performance when the inductance of choke L109 was varied. It is concluded from the information available that little opportunity is afforded to improve the circuit by minor modification.

[redacted]

CONCLUSIONS

22. From these tests the following conclusions are drawn:

(a) The crystal oscillator circuit used in the Model TCS transmitter is of such a type that a superior crystal unit must be used if oscillations are to be generated without sensible delay when the keying relay operates. If a delay occurs, the resulting characteristic dot envelope shape is very different from that giving optimum signal readability.

(b) Relay lag causes a large part of the overall clipping in any case. This relay lag occurs both at the beginning and end of the dots and is different for the two relays because of differing orientations with respect to gravity. Representative values for this delay for Leach relays are 17 and 5 milliseconds at the beginning and end, respectively, for K102, and 20 and 2 milliseconds for K103. The overall clipping for Leach relays should be less when both are oriented similarly to K102. For such an arrangement, the clipping might well be less than 30 per cent at 30 words per minute on MO or with superior crystal units.

(c) Changes in the primary power supply voltage affect markedly the delay times of the relays at the beginning of the dot, a change of 10 per cent in voltage resulting in a change of 30 per cent in operating time. The importance of maintaining the voltage at the rated value is evident.

(d) The Guardian counterweighted relays are slower acting than the Leach relays, thus causing greater clipping. However, if the counterweight is omitted, the performance of the relay surpasses that of the Leach relay. An overall clipping of the order of 20 per cent at 30 words per minute might be realized on MO in such cases.

(e) The relays are affected by shocks of low intensity, but little difference is observed if the counterweights on the Guardian relays are removed. No vibration effect was observed. Hence, it is believed that removal of the counterweights will be decidedly beneficial altogether.

(f) Consideration is being given to a possible arrangement of relay K103 intended to provide the minimum clipping possible for the relay types in use.

Distribution:
BuShips (10)

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TABLE 1

RELAY DELAY TIMES AND CLIPPING (FROM PLATE 20)
MODEL TCS-5 TRANSMITTER - 1911.25 KC COLLINS CRYSTAL

Keying Rate (w.p.m.)	Delay Time (Milliseconds) Operation K103	Delay Time (Milliseconds) Operation K102	Delay Time (Milliseconds) Release K103	Delay Time (Milliseconds) Release K102	Clipping (Per Cent) Relay K103	Clipping (Per Cent) Relay K102	Clipping (Per Cent) Overall
Transmitter in Normal Position							
20	22	18	2	6	32	19	29
25					31	21	32
30	22	16	3	13	45	7	44
35					45	11	40
40	19	13	2	11	52	7	46
45					50	36	47
50					54	17	54
20 MO					25	15	24
30 MO	19	15	2	11	40	9	35
40 MO					50	11	45
Transmitter on Right End							
20	16	14	2	5	23	14	25
25					29	18	28
30	19	14	4	6	38	19	32
35					42	19	37
40	13	11	2	6	38	16	39
45					53	23	48
50					79	38	76
20 MO					24	18	22
30 MO	17	13	3	6	33	17	32
40 MO					44	17	42

[redacted].

TABLE 2

CLIPPING OF EXPERIMENTAL AMERICAN JEWELS CRYSTALS
IN MODEL TCS-5 TRANSMITTER

Crystal Serial No.	Overall Dot Clipping (%) 20 w.p.m.	30 w.p.m.	40 w.p.m.	Fraction of Dot Area Missing (%) 20 w.p.m.	30 w.p.m.	40 w.p.m.
1	52	87		47	83	93
2	62	66	85	55	69	83
3	64	87		61	82	97
4	50	91		47	89	96
5	52	71		48	75	87
6	47	84		45	83	94
7	61	82		56	83	97
8	46	69	72-91	43	71	73
9	45	83		43	82	95
10	42	81		42	79	94
MO	27	52	59	36	55	62

[redacted]

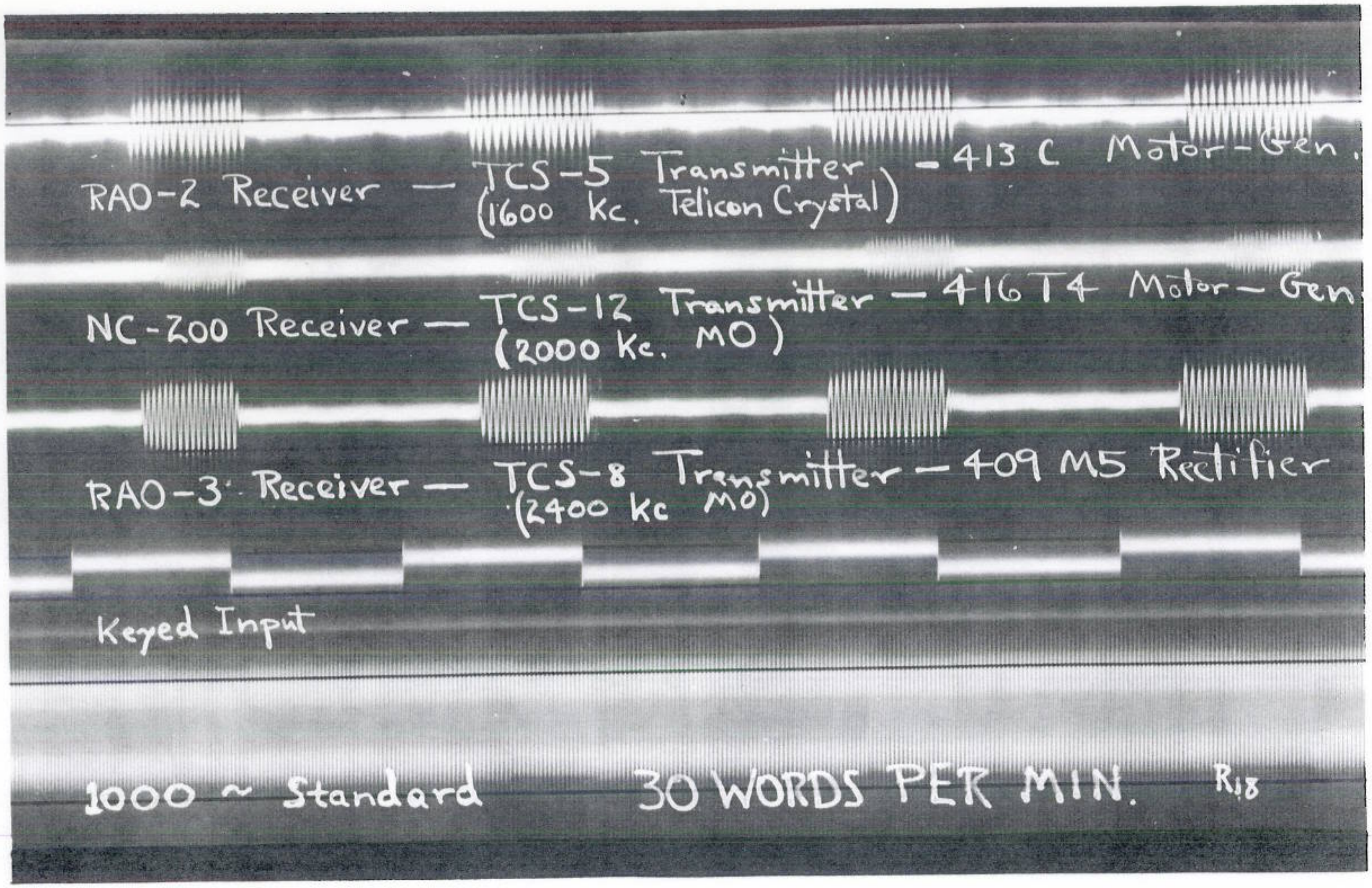
TABLE 3

OPERATION ON BANDS 1, 2, 3
MODEL TCS-5 TRANSMITTER - CRYSTAL RESEARCH LABORATORY CRYSTALS

Band	Overall Clipping (Per Cent)			
	20 w.p.m.	30 w.p.m.	40 w.p.m.	40 w.p.m. MO
		Crystal Serial No. NS-102		
1	22	32	33	49
2	45	61	82	32
3	56	57	66	91
		Crystal Serial No. NS-104		
1	29		37	33
2	37	41	32	26
3	37	45	34	26
		Crystal Serial No. NS-105		
1	23	32	39	31
2	27	37	39	48
3	24	39	34	40

[redacted]

Three Transmitters Keyed Simultaneously



DECLASSIFIED

PLATE I

Three Transmitters Keyed Simultaneously--Crystal Operation

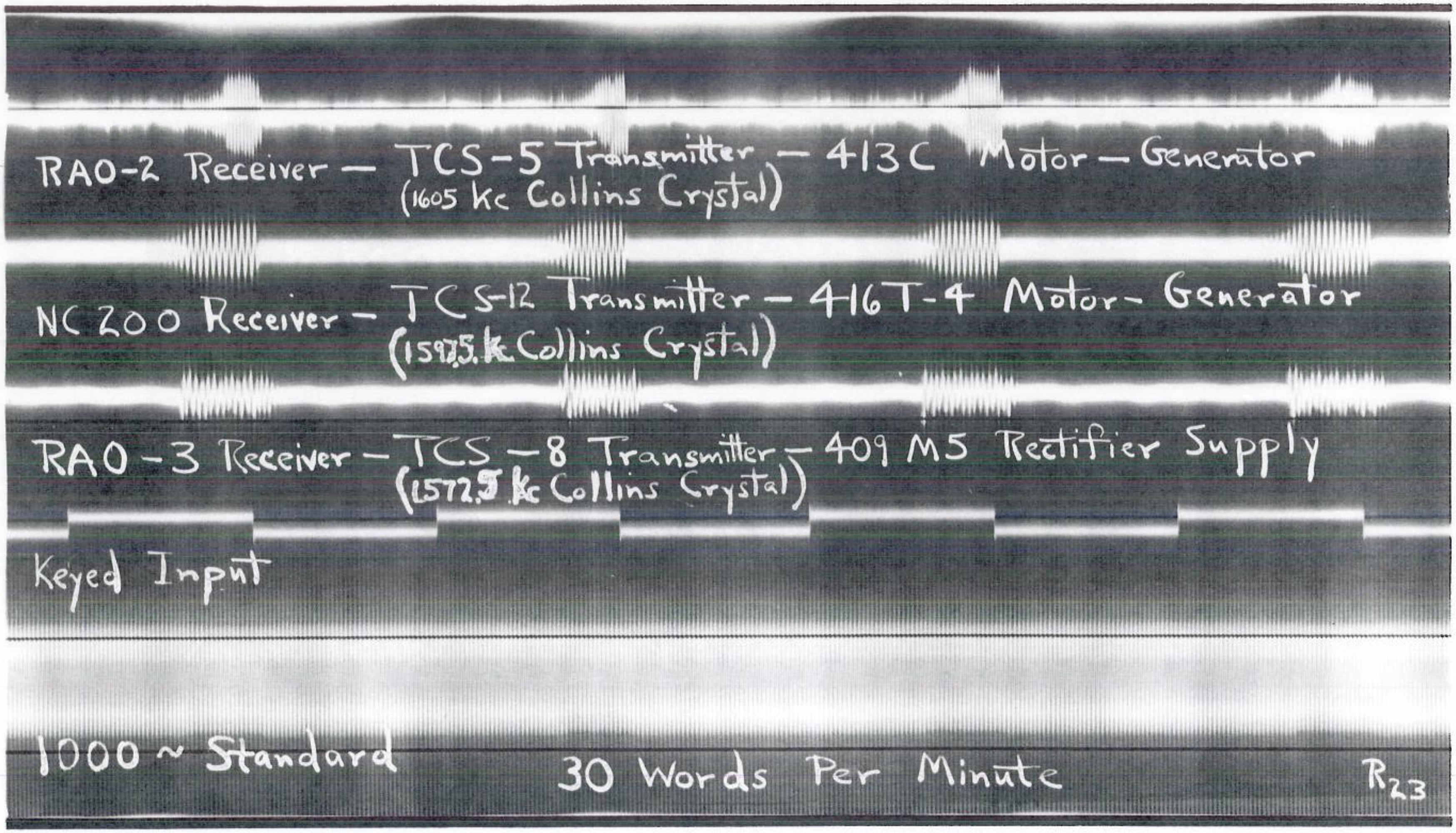
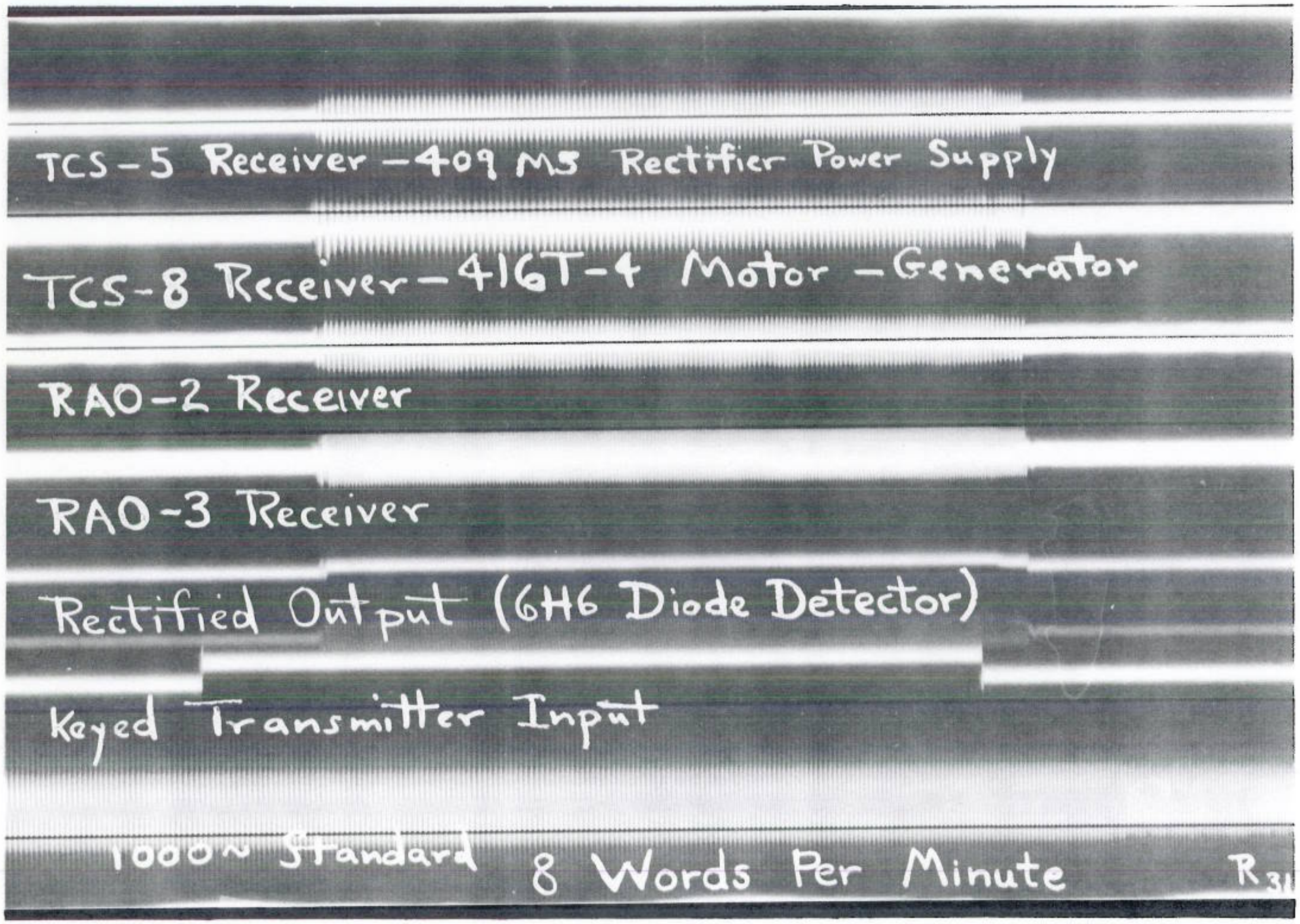


PLATE 2

Reception of TCS-5 Transmitter Output

Via Diode Detector and Four Receivers

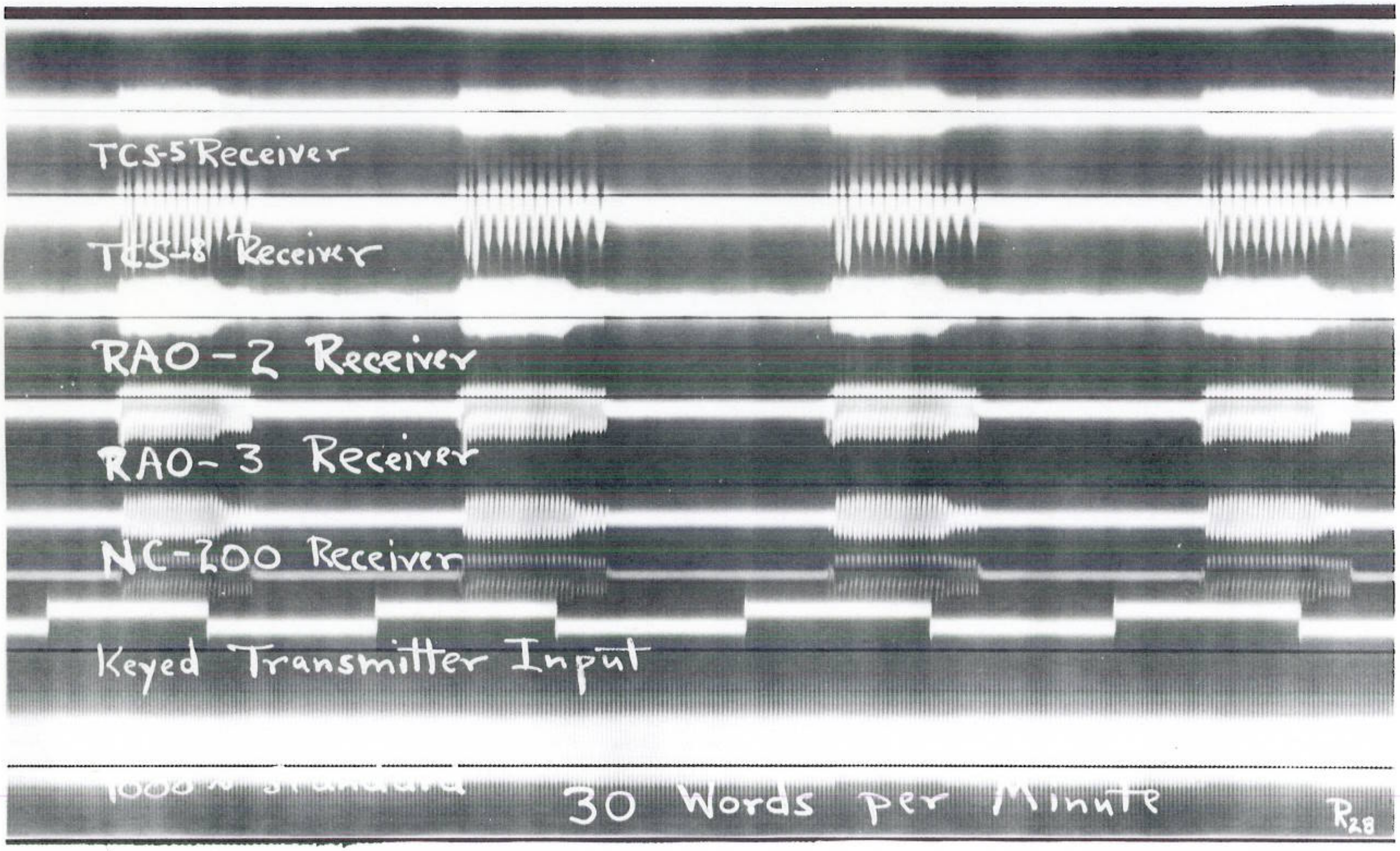


2050 Kc M-O Operation
Transmitter in Normal Position
413C Motor-Generator

DECLASSIFIED

PLATE 3

Reception of TCS-5 Transmitter Output
Via Five Receivers

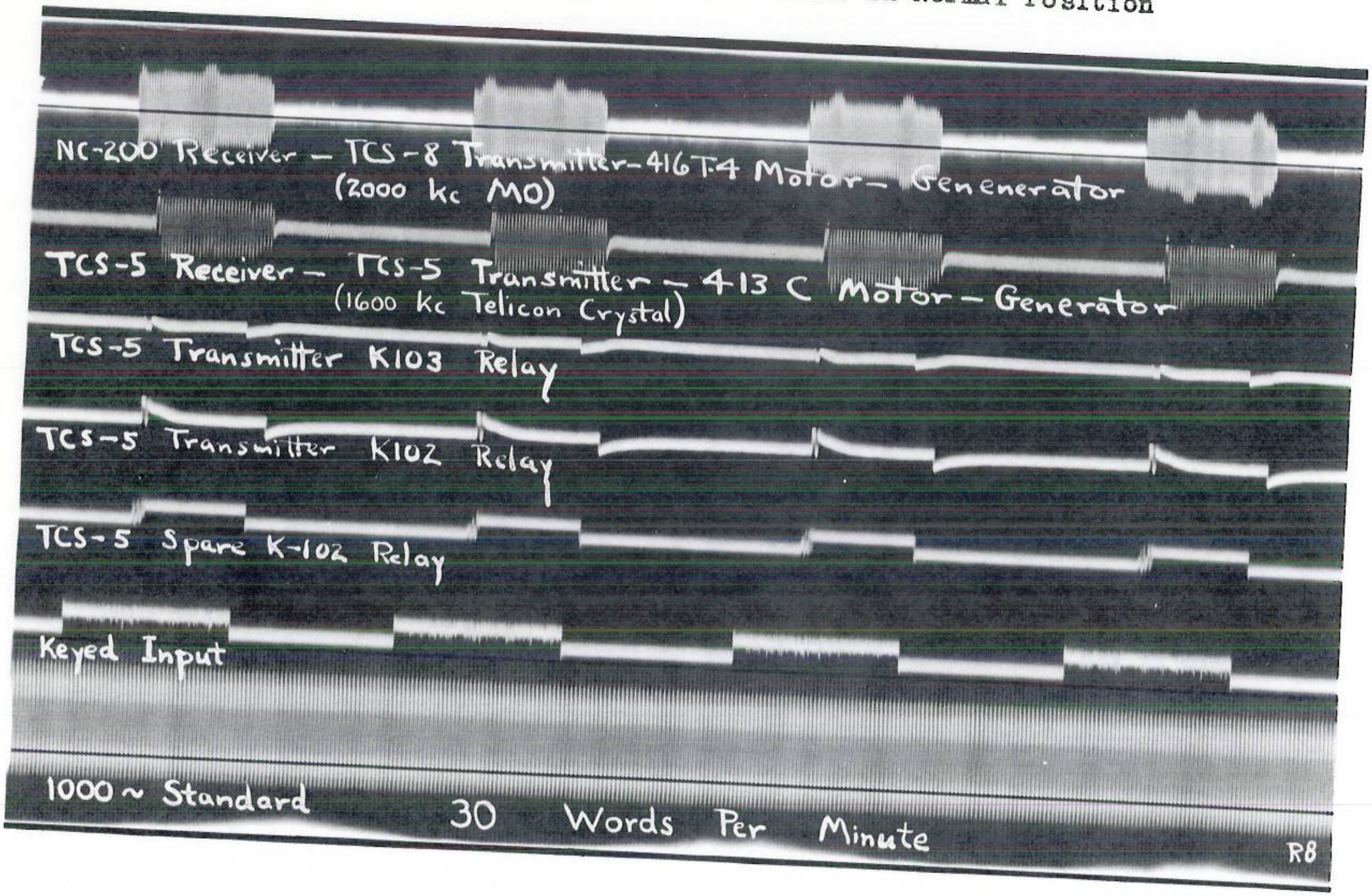


1600 Kc Telicon Crystal Operation
Transmitter in Normal Position
413C Motor-Generator

DECLASSIFIED

Effect of Transmitter Orientation

TCS-5 and TCS-8 Transmitters in Normal Position



DECLASSIFIED

Effect of Transmitter Orientation

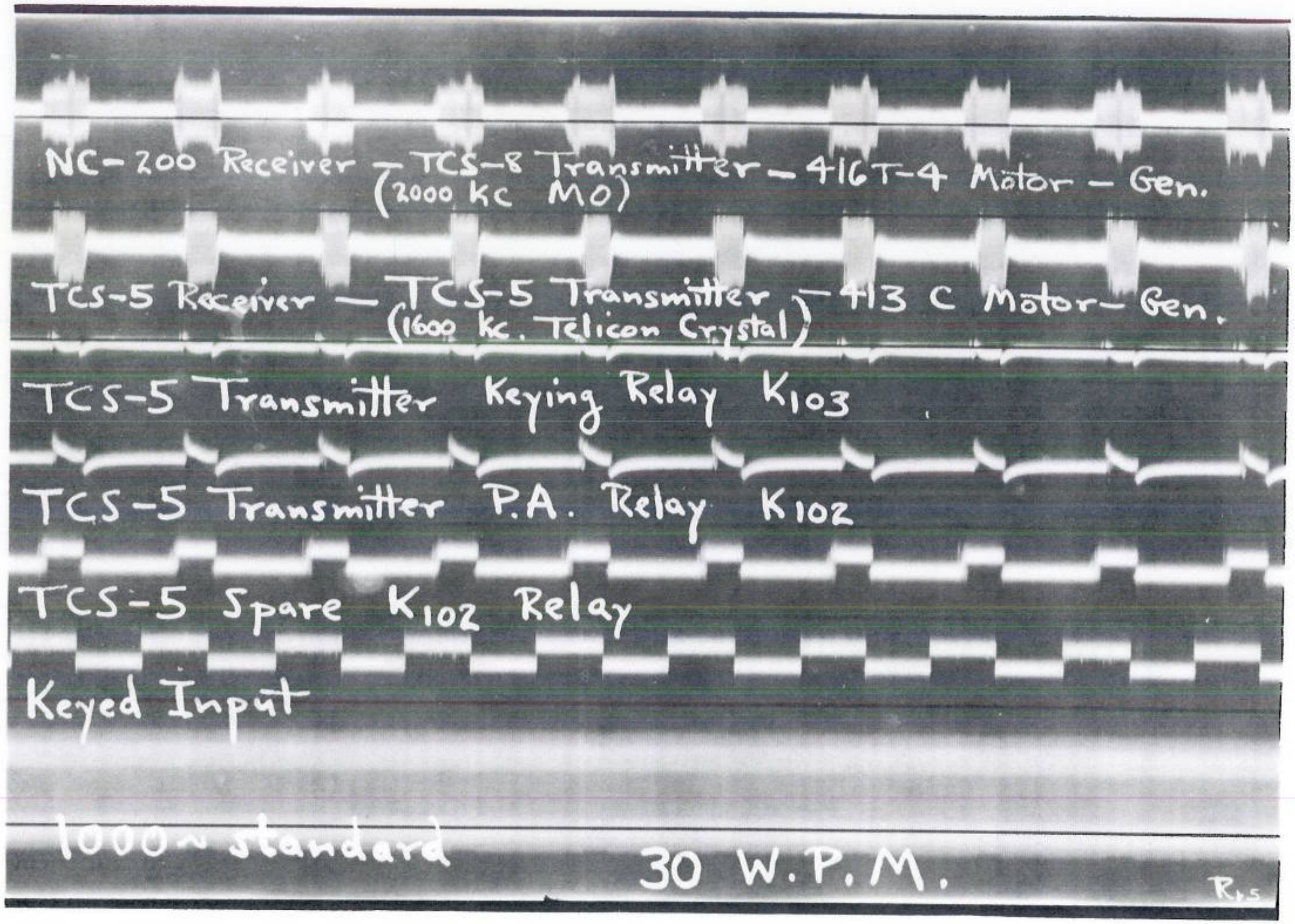
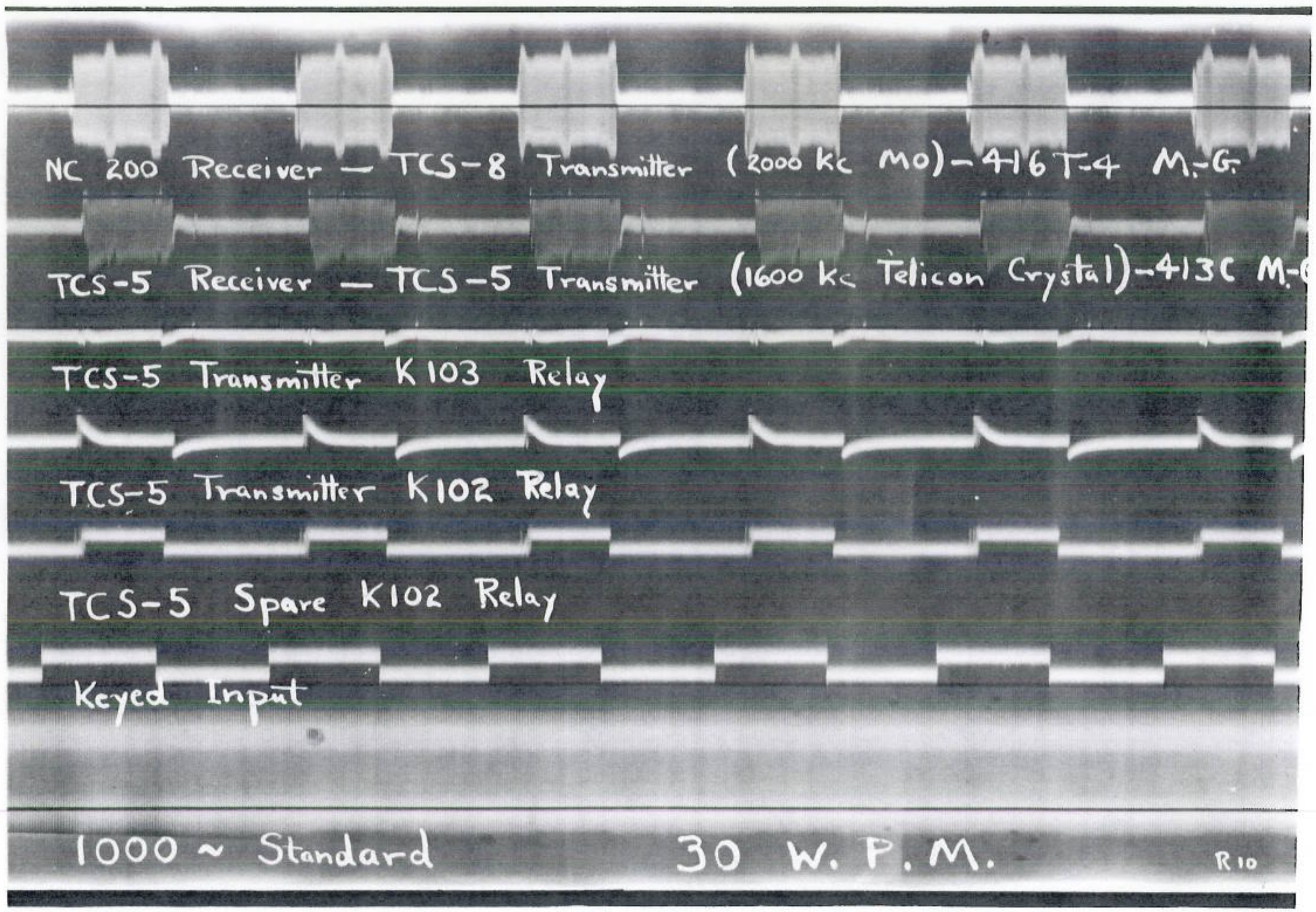


PLATE 6

TCS-5 and TCS-8 Transmitters

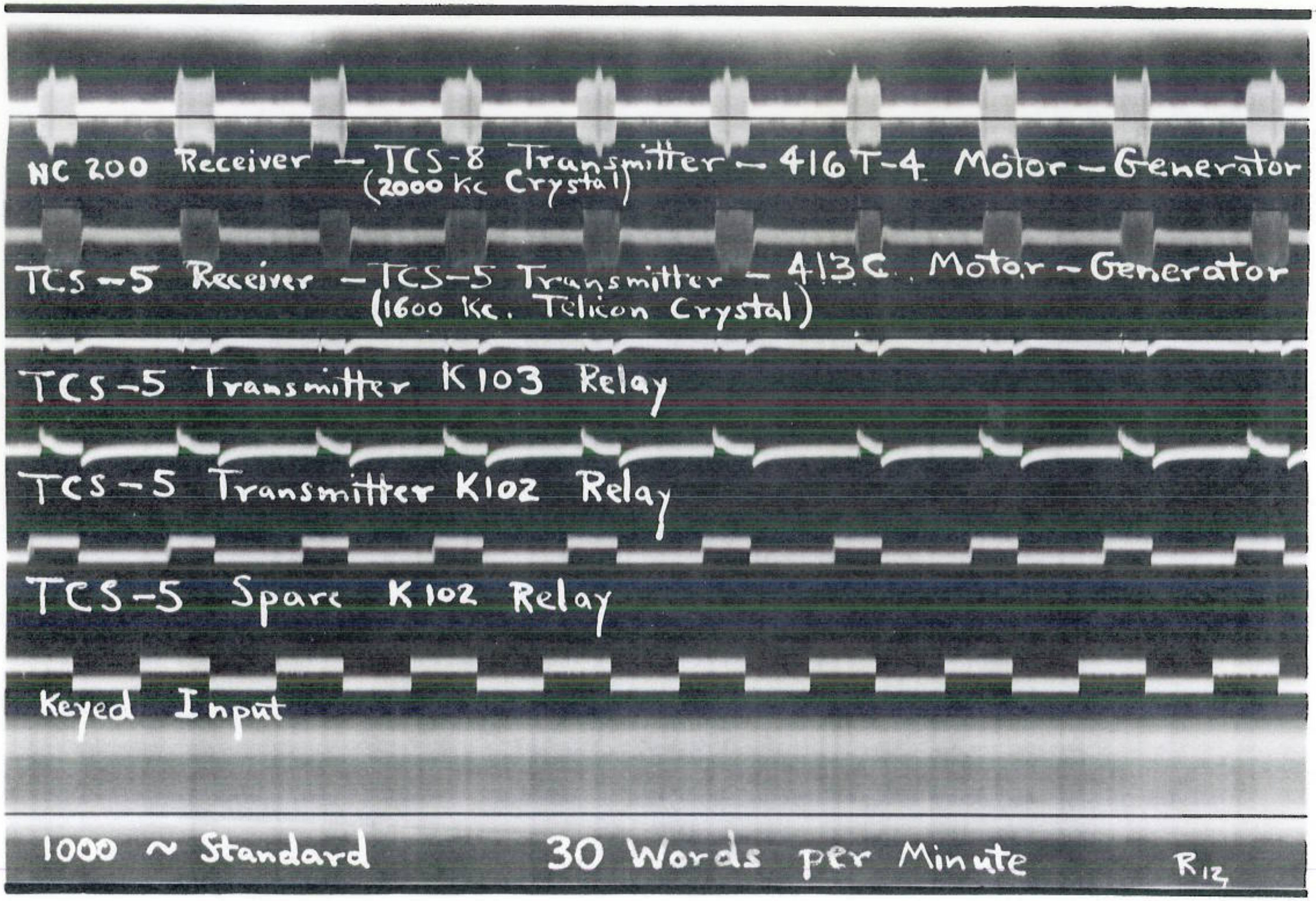
Input Voltage 10% Above Normal



DECLASSIFIED

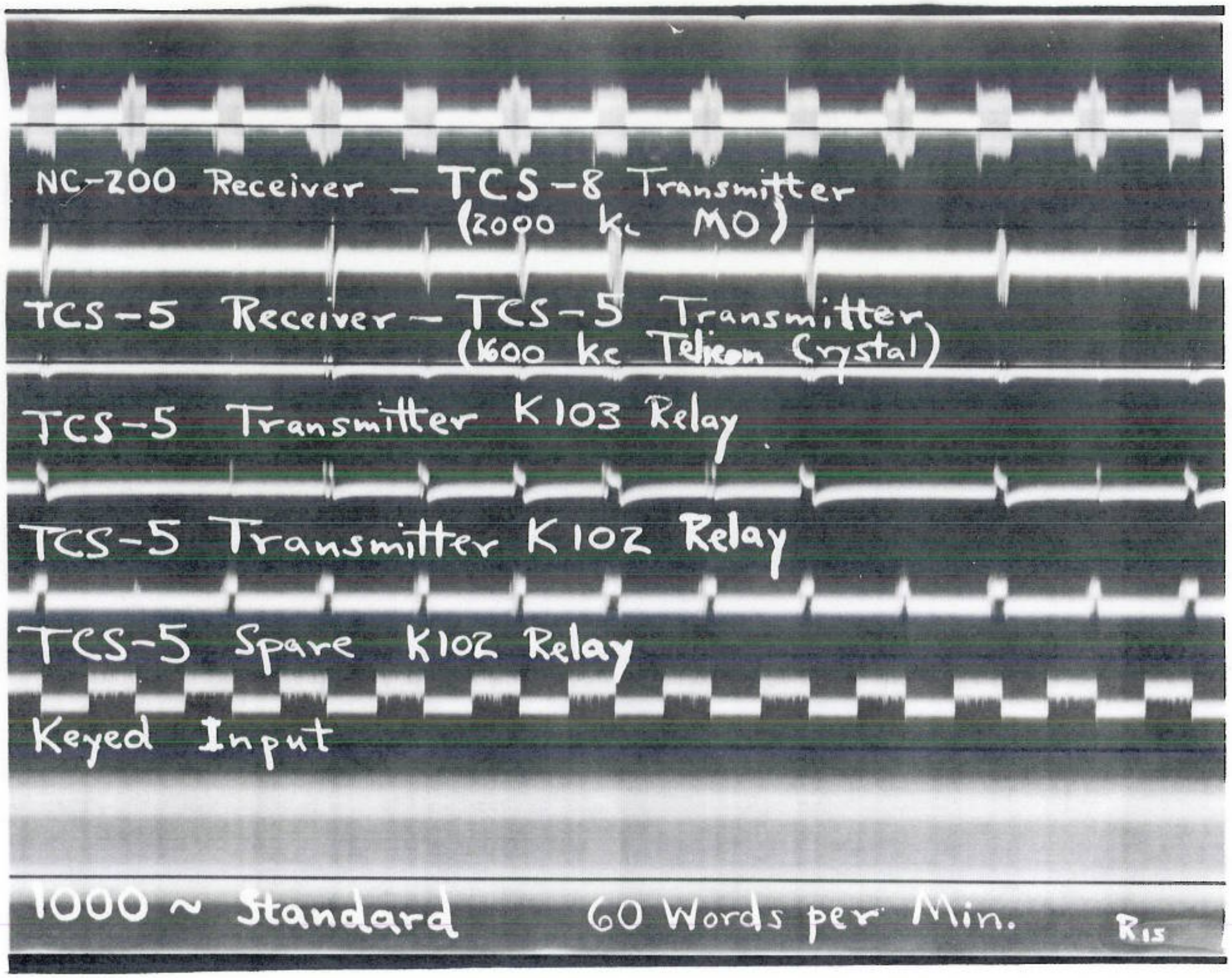
TCS-5 and TCS-8 Transmitters

Input Voltage 10% Below Normal



TCS-5 and TCS-8 Transmitters

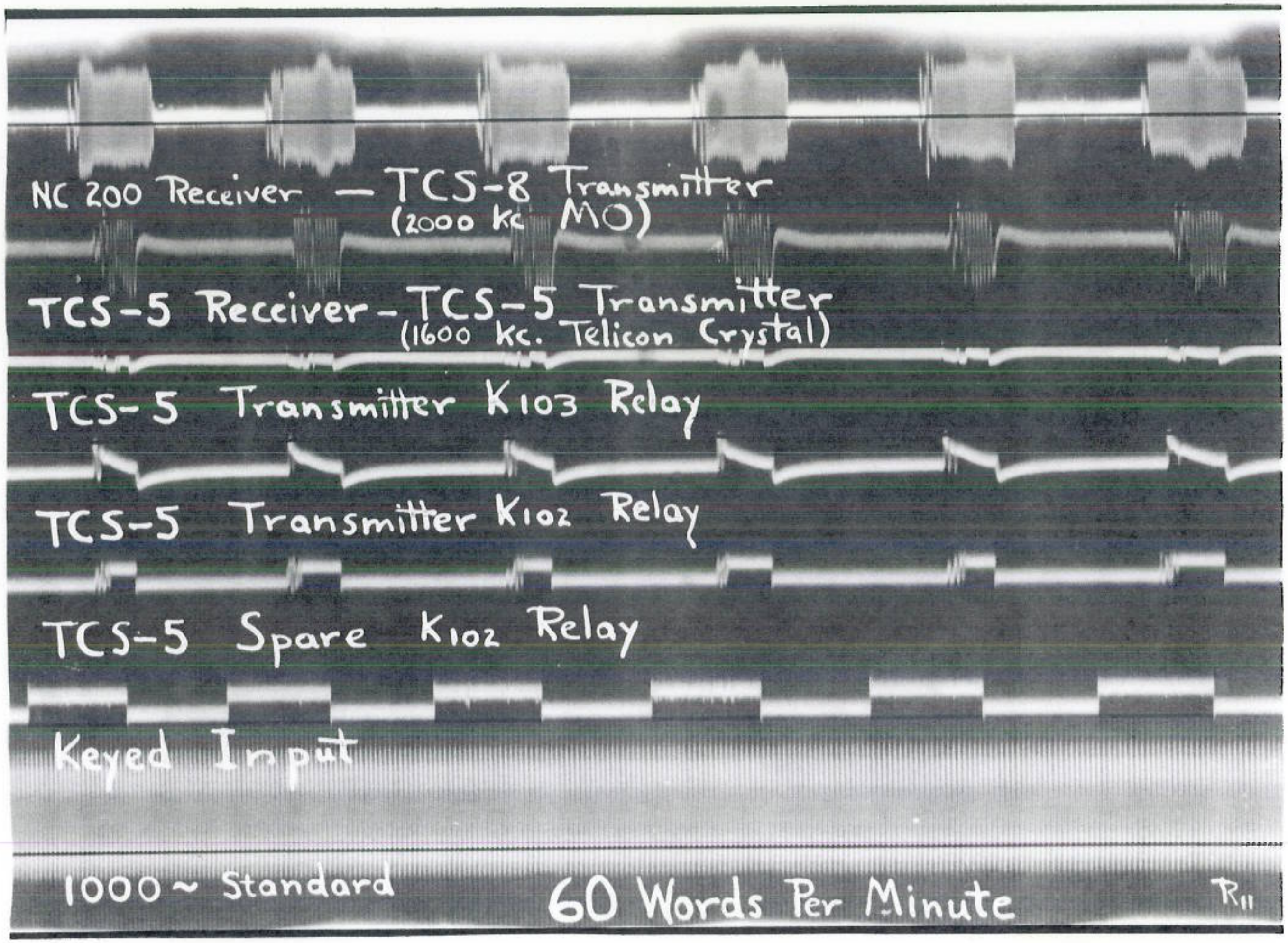
Normal Voltage; 60 W.P.M.



DECLASSIFIED

TCS-5 and TCS-8 Transmitters

10% Overvoltage; 60 W.P.M.

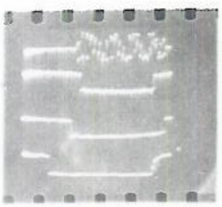


DECLASSIFIED

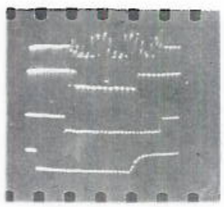
PLATE 10

OPERATION OF TCS-5 TRANSMITTER AND RELAYS AFTER ONE YEAR OF SERVICE

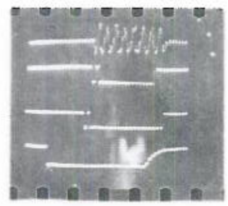
Transmitter in Normal Position



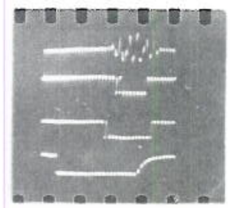
20 W.P.M.



30 W.P.M.

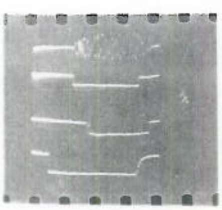


40 W.P.M.

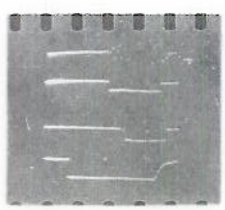


50 W.P.M.

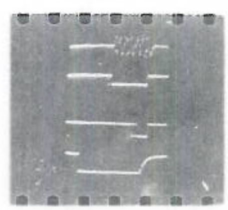
Transmitter on End



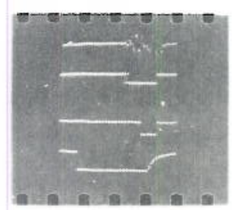
20 W.P.M.



30 W.P.M.



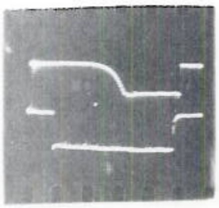
40 W.P.M.



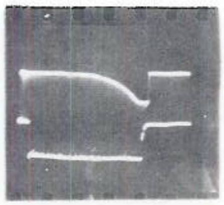
50 W.P.M.

Trace 1 = Receiver BFO Output.
Trace 2 = Keying Relay.
Trace 3 = Antenna Relay.
Trace 4 = Keyed Signal.

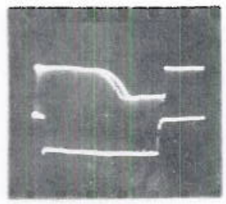
KEYING CHARACTERISTICS OF 2090 KC AMERICAN JEWELS CRYSTALS
IN TCS-5 TRANSMITTER AT 20 WORDS PER MINUTE



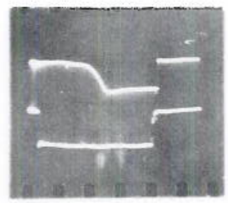
1



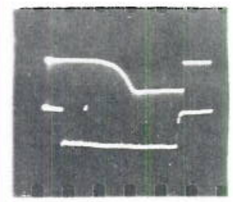
2



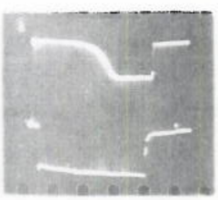
3



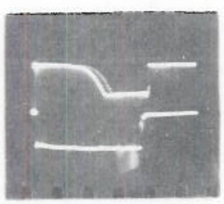
4



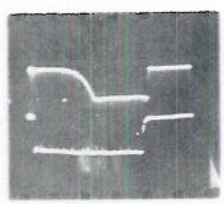
5



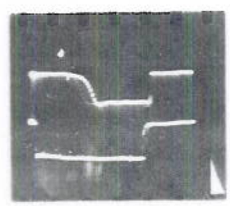
6



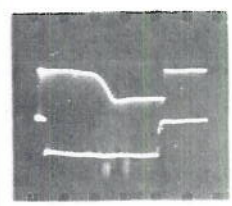
7



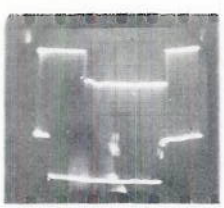
8



9



10

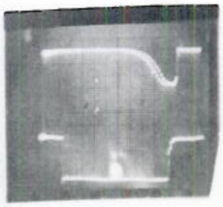


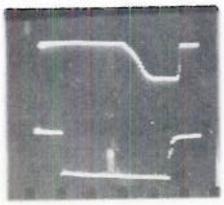
11

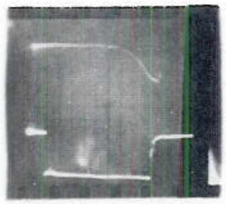
Numerals denote crystal number.
Upper trace = rectified output.
Lower trace = keyed input.

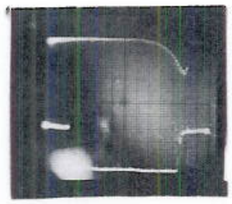
PLATE 12

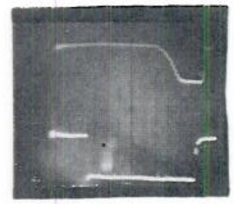
KEYING CHARACTERISTICS OF 2090 KC AMERICAN JEWELS CRYSTALS
IN TCS-5 TRANSMITTER AT 30 WORDS PER MINUTE

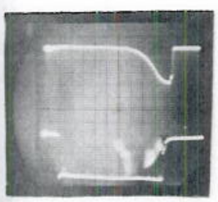

1

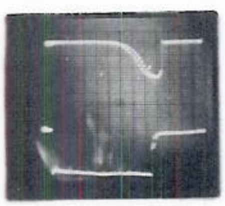

2

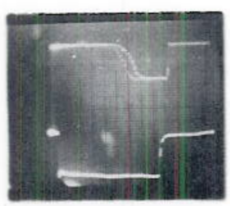

3

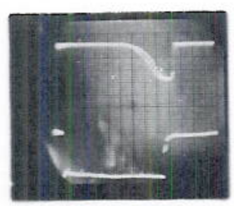

4

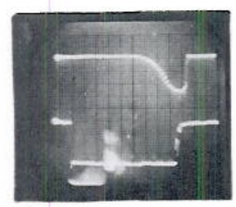

5

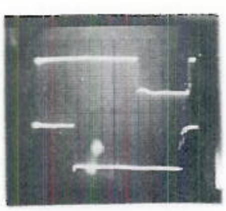

6


7


8


9


10

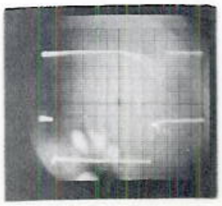

11

Numerals denote crystal number.
Upper trace = rectified output.
Lower trace = keyed input.

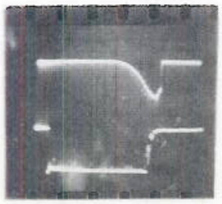
[redacted]

PLATE 13

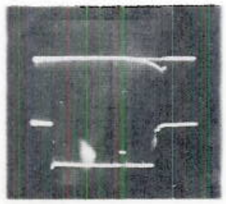
KEYING CHARACTERISTICS OF 2090 KC AMERICAN JEWELS CRYSTALS
IN TCS-5 TRANSMITTER AT 40 WORDS PER MINUTE



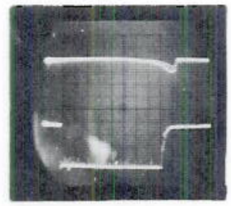
1



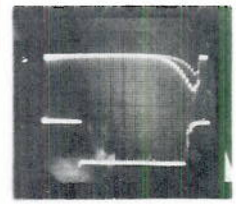
2



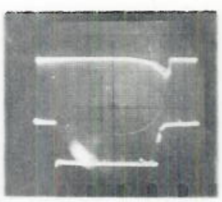
3



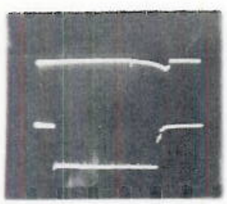
4



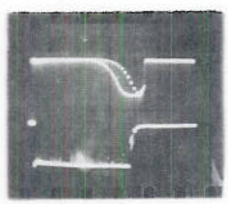
5



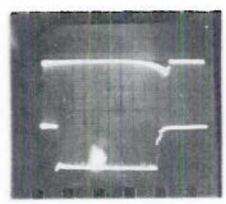
6



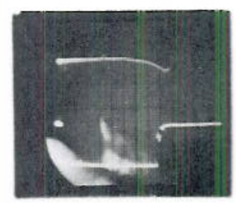
7



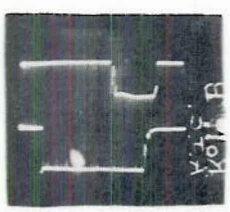
8



9



10



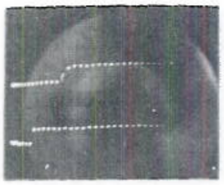
11

Numerals denote crystal number.
Upper trace = rectified output.
Lower trace = keyed input.

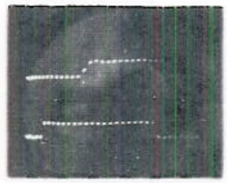
PLATE 14

FUNDAMENTAL AND HARMONIC OPERATION OF TCS-5 TRANSMITTER, CRYSTAL RESEARCH LABORATORIES 2150 KC CRYSTAL NS-102

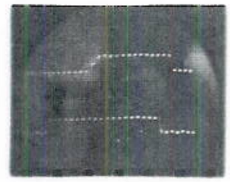
Fundamental



20 W.P.M.

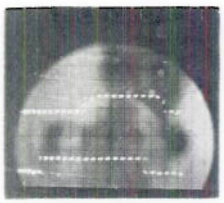


25 W.P.M.

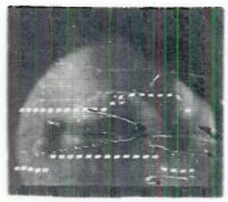


30 W.P.M.

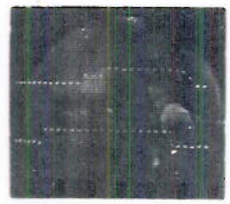
35 W.P.M.



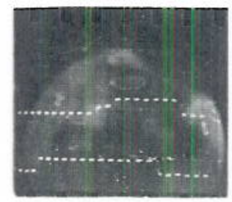
40 W.P.M.



45 W.P.M.

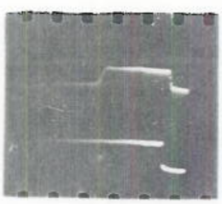


30 W.P.M.
MO

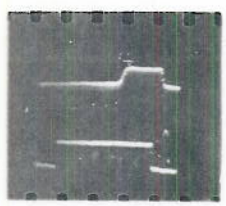


40 W.P.M.
MO

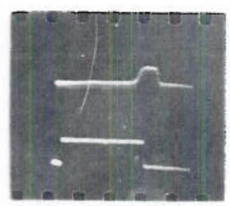
Second Harmonic



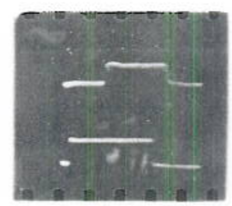
20 W.P.M.



30 W.P.M.

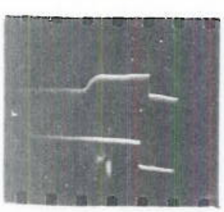


40 W.P.M.



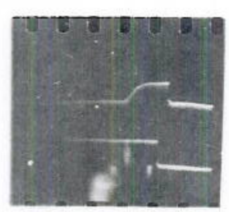
40 W.P.M.
MO

Fourth Harmonic

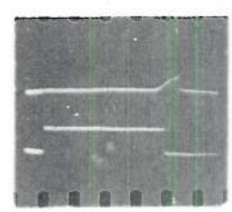


20 W.P.M.

30 W.P.M.



40 W.P.M.



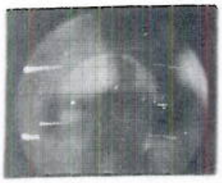
40 W.P.M.
MO

Upper trace = rectified output.
Lower trace = keyed signal.

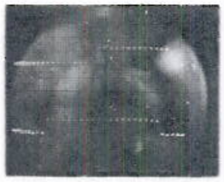
PLATE 15

FUNDAMENTAL AND HARMONIC OPERATION OF TCS-5 TRANSMITTER
CRYSTAL RESEARCH LABORATORIES 2980 KC CRYSTAL NS-104

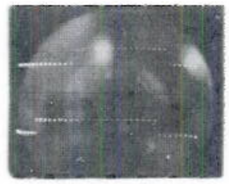
Fundamental



20 W.P.M.



25 W.P.M.



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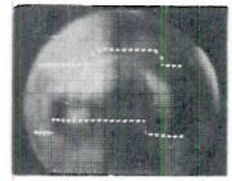

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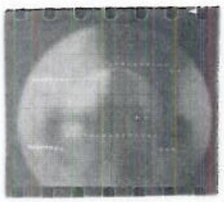

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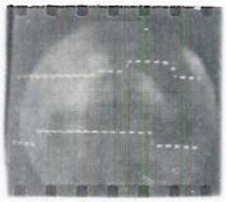

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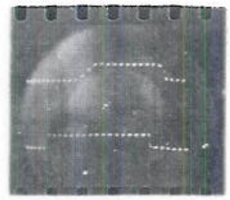
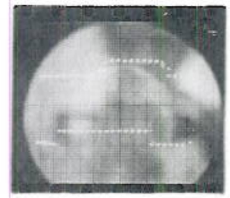
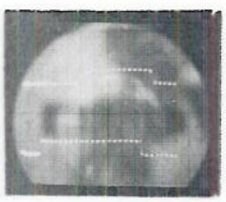


30 W.P.M.
MO

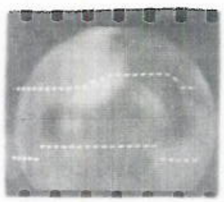


40 W.P.M.
MO

Second Harmonic



20 W.P.M.



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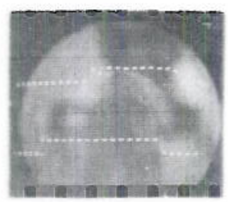

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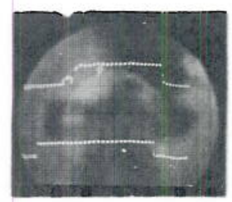
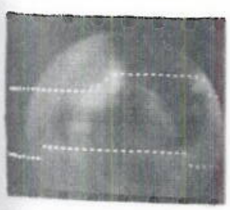


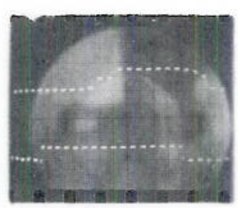
40 W.P.M.
MO

Fourth Harmonic



20 W.P.M.

30 W.P.M.



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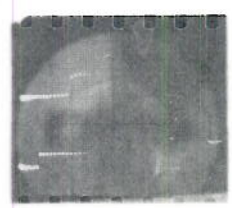


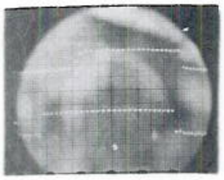
40 W.P.M.
MO

DECLASSIFIED

Upper trace = rectified output.
Lower trace = keyed signal.

FUNDAMENTAL AND HARMONIC OPERATION OF TCS-5 TRANSMITTER
CRYSTAL RESEARCH LABORATORIES 2670 KC CRYSTAL NS-105

Fundamental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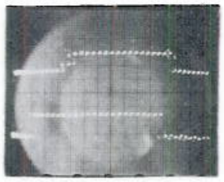
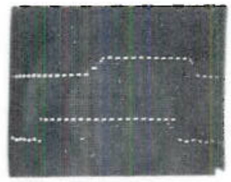

25 W.P.M.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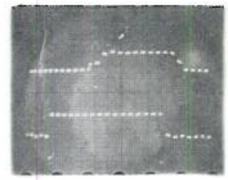
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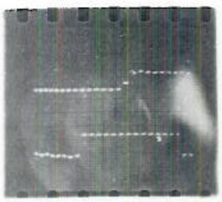
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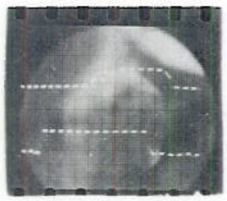
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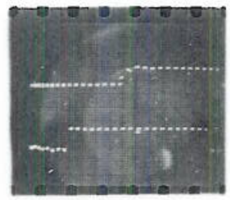
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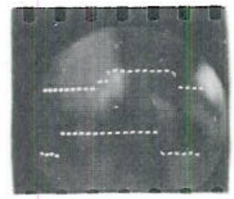
MO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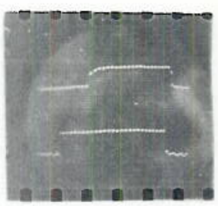
MO

Second Harmonic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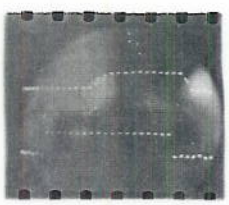
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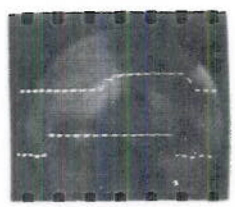
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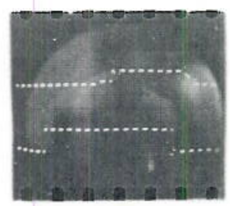
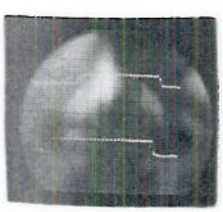
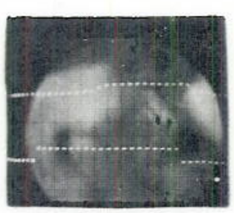

40 W.P.M.
MO

Fourth Harmonic


20 W.P.M.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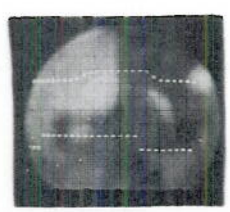
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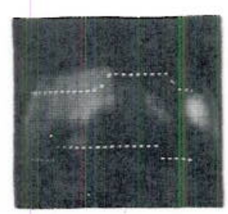

40 W.P.M.
MO

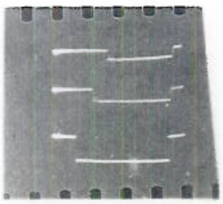
[redacted]

Upper trace = rectified output.
Lower trace = keyed signal.

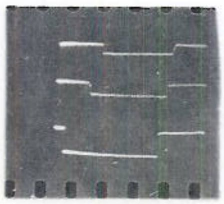
PLATE 17

COMPARISON OF LEACH AND GUARDIAN SPARE PARTS RELAYS

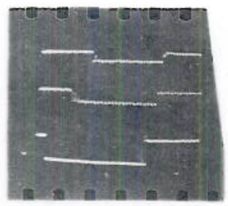
Vertical Position



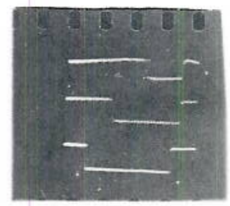
20 W.P.M.



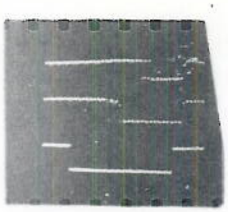
25 W.P.M.



30 W.P.M.



35 W.P.M.



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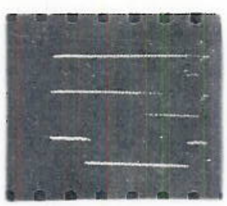
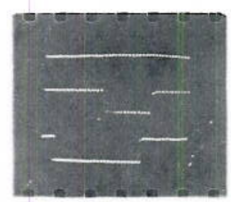


45 W.P.M.

45 W.P.M.



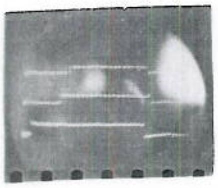
50 W.P.M.

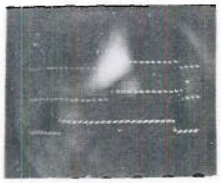
(UNSTABLE)

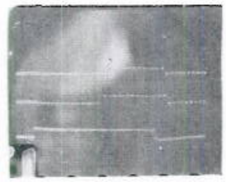
Trace 1 = TCS-12 Spare Relay.
Trace 2 = TCS-5 Spare Relay.
Trace 3 = Keyed Signal.

COMPARISON OF LEACH RELAY AND GUARDIAN LIGHT-WEIGHT RELAY

Relays Mounted Vertically (K-102 Position)

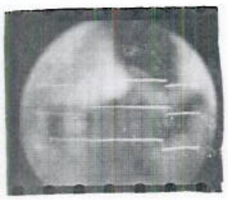

20 W.P.M.


30 W.P.M.


40 W.P.M.


50 W.P.M.

Relays Mounted Horizontally (K-103 Position)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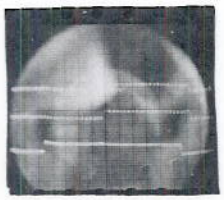
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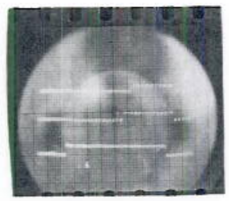
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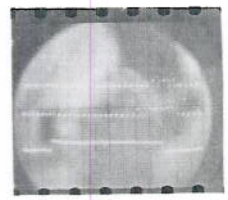
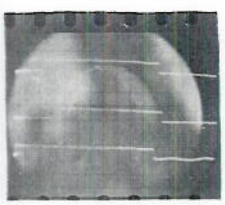

50 W.P.M.

Relays Mounted Vertically (K-102 Position)
Lead Counterweight Removed from TCS-12 Relay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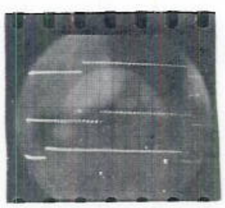
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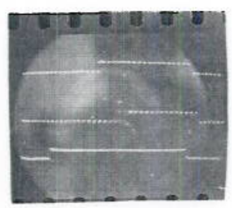
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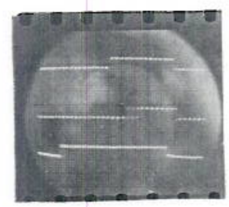
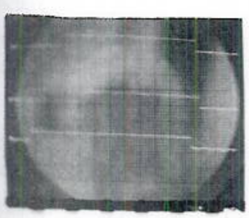
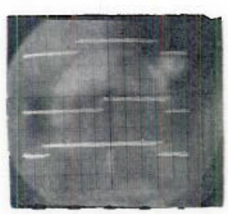

50 W.P.M.

Relays Mounted Horizontally (K-103 Position)
Lead Counterweight Removed from TCS-12 Relay


20 W.P.M.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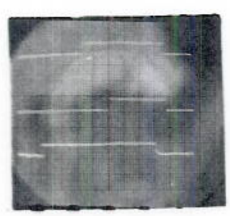
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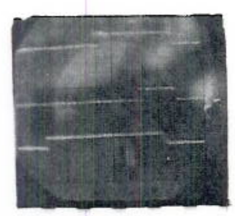
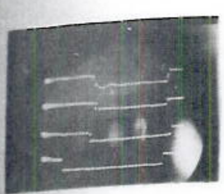

50 W.P.M.

Trace 1 = TCS-12 Relay.
Trace 2 = TCS-5 Relay.
Trace 3 = Keyed Input.

EFFECTS OF OPERATION OF KEYING AND ANTENNA TRANSFER RELAYS ON TCS-5 TRANSMITTER OUTPUT--1911.25 KC COLLINS CRYSTAL

Transmitter in Normal Position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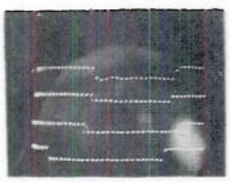
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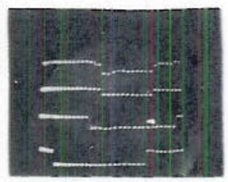
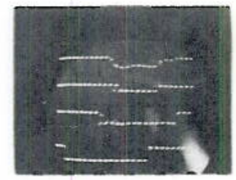

30 W.P.M.


35 W.P.M.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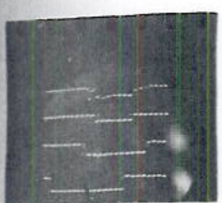
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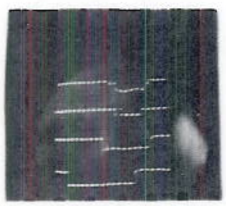
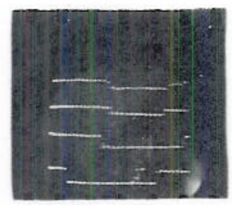
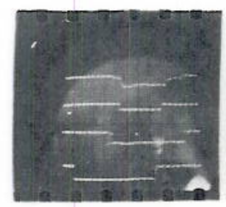
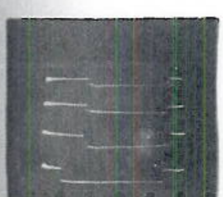

50 W.P.M.


20 W.P.M.
MO


30 W.P.M.
MO


40 W.P.M.
MO

Transmitter on End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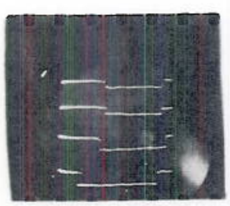
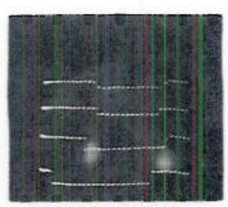

25 W.P.M.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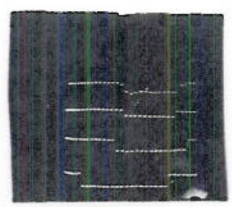
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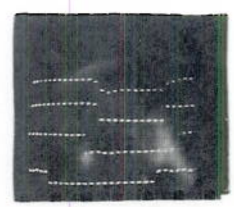
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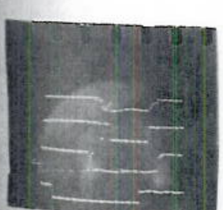
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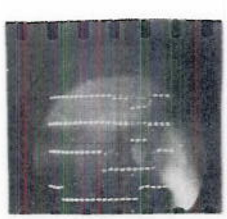
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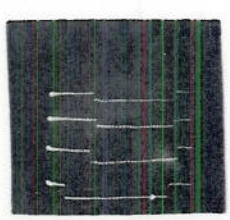
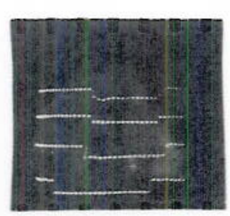
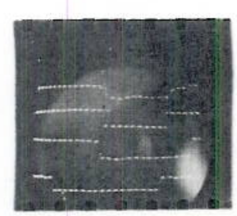
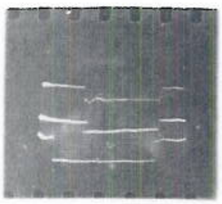

20 W.P.M.
MO


30 W.P.M.
MO


40 W.P.M.
MO

Trace 1 = Rectified 6H6 Output.
Trace 2 = Keying Relay.
Trace 3 = Antenna Transfer Relay.
Trace 4 = Keyed Signal.

DIRECT OSCILLATOR KEYING OF TCS-5 TRANSMITTER--
1911.25 KC COLLINS CRYSTAL; RELAY K102 SHORTED OUT



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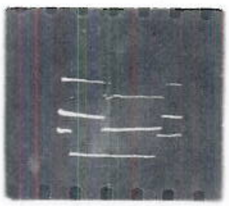

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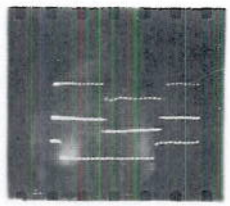

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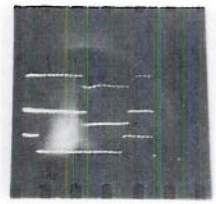
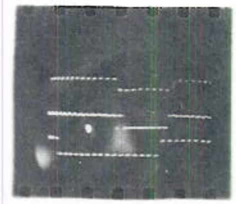
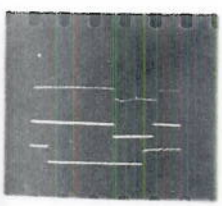


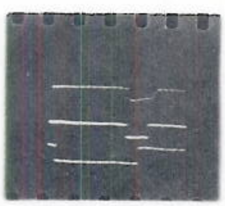
35 W.P.M.



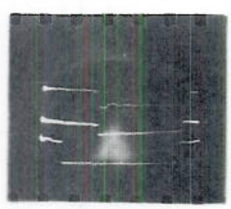
40 W.P.M.



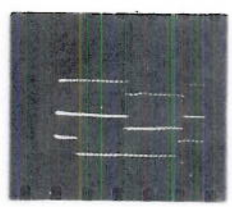
45 W.P.M.



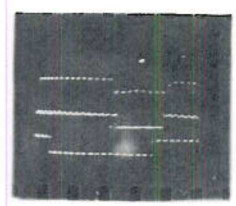
50 W.P.M



20 W.P.M.
MO



30 W.P.M.
MO



40 W.P.M.
MO

Trace 1 = Rectified 6H6 Output.
Trace 2 = Keying Relay.
Trace 3 = Keyed Signal.

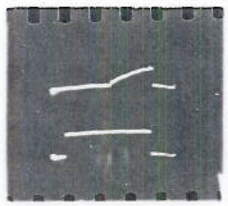
PLATE 21

VARIATION OF COUPLING CAPACITOR C-122 IN TCS-5 TRANSMITTER

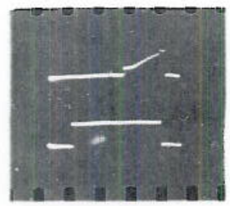
2090 Kc American Jewels Crystal

50 μμf

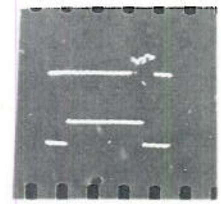
20 W.P.M.



30 W.P.M.

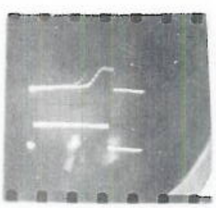


40 W.P.M.

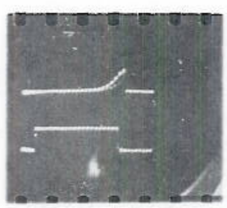


50 W.P.M.

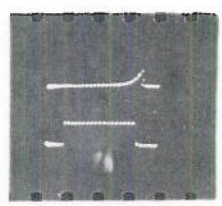
75 μμf



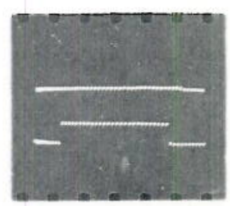
20 W.P.M.



30 W.P.M.



40. W.P.M.



50 W.P.M.

Trace 1 = Rectified Output.
Trace 2 = Keyed Signal.