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SHIP-SHORE RADIO DIVISION - SEARCH RADAR SECTION

23 July 1945

DECLASSIFIED by NRL Contract Declassification Team
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PERFORMANCE TEST OF CXFA TRANSMITTER AND 527 VACUUM TUBE

By R. A. Herring, Jr.

- Report R-2586 -

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Preliminary Pages ... a-c
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Plates 12

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23 July 1945

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By R. A. Herring, Jr.

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ABSTRACT

This report is a broad summary of tests conducted at the Naval Research Laboratory between July 1943 and September 1944 on the CXFA/X5000 transmitter and on the type 527 vacuum tube used in the oscillator of this transmitter. The tests were made under NRL problem S423T-C. The transmitter, built by the Eitel McCullough Co., was a prototype of that subsequently incorporated in the SK-1M radar, manufactured by the General Electric Co. for the U.S. Marine Corps. The object of the tests was two-fold: To determine the behavior, primarily the life expectancy, of the 527 tube, and to ascertain and correct any faults in, and otherwise improve, the transmitter. During the first eight months of the tests, approximately, the 527 was still under development. Samples of several evolutionary stages including the final model of the tube were life tested. These tests, together with their results, are described for each developmental model tested. Life in general was satisfactory. An improved keying circuit was developed and incorporated. Some simplifying modifications of the high frequency grid tuning circuits were tested, but were not feasible. Extensive tests were made in an attempt to improve the frequency characteristic of the oscillator, in which the power output and efficiency fell off rapidly at the higher frequency end of the operating band, but no improvement was found possible. It was concluded that the behavior was a characteristic of the 527 tube itself and not of the circuit. Tests were made of the transmitter performance when operating with a pulse length some three to four times normal (in connection with work on another radar using the 527 tube with such a long pulse). The relevant characteristics of the oscillator were substantially the same with the normal and the longer pulse.

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INTRODUCTION.

1. The CXFA transmitter was tested at the Naval Research Laboratory from 26 July 1943 to 16 Sept. 1944. The object of the tests was a determination of the behavior, primarily the life expectancy, of the type 527 vacuum tube under conditions of proposed military radar service, in the SK-1M marine radar, given below. Certain secondary tests were also performed in the course of the work in order to obtain necessary information about the tubes and circuits used. The CXFA was a very basic prototype of the SK-1M transmitter. It was built by the Eitel-McCullough Co., Inc., and known also according to their designation as the X-5000. This report is a not-too-detailed summary of the project. During the period of the tests, close contact was maintained with representatives of the Bureau of Ships and of the various manufacturers concerned by means of letters, interim reports and personal contacts.

1-1. The work done on these tests was authorized by NRL problem S423T-C. Letters concerning this authorization are listed as references (1) and (2) in the complete list of REFERENCES pertinent to this report, which appears after the text.

1-2. The type 527 tube is a medium mu triode of 300 w plate dissipation designed for pulsed operation up to a nominal frequency of 200 Mc, and its mechanical design adapts it readily to a ring type multitube circuit, in which all anodes are at ground potential for radio frequency voltages. The tube is shown in the photograph of Plate 1. The single plate connector on the side is so placed for connection to a block common to all tube plates, in the center of the ring, and the two pairs of grid connectors on each side of the tube provide low inductance connectors convenient for completion of the ring. The tube has a thoriated tungsten filament requiring 5.5 v at 120-150 a and is capable of a minimum emission of 100 a at 2500 v. The filament terminals are brought out in a concentric arrangement in which the outer conductor forms the mounting base of the tube, which can mount in stiff spring fingers on a concentric filament line outer conductor, the inner conductor being engaged by similar springs on the line inner conductor.

1-3. Proposed operational specifications for the SK-1M radar using four type 527 tubes, which determined the life test conditions for the subject test, were as follows: frequency 185-225 Mc, pulse length 5 microseconds, repetition rate 180 pps (with provision for the use of 60 pps), plate supply voltage 18 kv or less and a nominal output of 1 megawatt pulse power, which required, at the given duty cycle, an average power output of 900 w. The oscillator was to use grid circuit modulation, the pulse being shaped and timed by an artificial line; at the start of the CXFA tests, the method of controlling repetition rate had not been fully decided upon.

1-4. The CXFA equipment consisted of an oscillator together with necessary power supplies, control equipment, and output load apparatus.

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1-4-1. The CXFA oscillator, shown in Plates 2 through 5, was housed in an aluminum box with removable side panels, having viewing windows at tube level. It differed from the SK-1M oscillator as later produced, in two major respects: the size of the CXFA in cross section was appreciably larger than that of the SK-1M, and it had shorting and coupling bars on the tuning frames which had to be internally and individually adjusted, whereas the SK-1M uses gear driven grid and filament tuning mechanisms, ganged and brought out to the front panel. The SK-1M oscillator is therefore considerably more crowded than was the CXFA, leading to greater possibilities of trouble from corona and flashover, and to possible differences in tuning adjustments and grid and filament tuning tracking because of the extra apparatus in close proximity to the high frequency circuits. The CXFA oscillator used a four tube ring circuit, all the anodes being connected by a block at the center of the ring, to which the high voltage plate supply was brought in from above, and which was at r-f ground potential. This unit can be seen in Plate 4. The grid and filament circuits were tuned. The grid circuits seen at close hand in Plate 5, consisted of four two-conductor frames, alternately placed with the tubes around the ring, with the grids of each of the two tubes on either side of a given frame being connected to the frame conductor nearest the tube, by means of spring contacts contained in a channel mounted on the conductor rod. These grid frames were symmetrical vertically about the grid connectors, i.e., had short-circuited tuned sections equal in length both above and below the grid connectors. These sections were short-circuited at the ends and had movable sliding shorting bars for tuning, between the ends and the grid connectors. The grid return, carrying d-c and pulse modulation frequency currents, was made to the end-bar on one of the frames, and thence to the other tubes by means of the grid ring circuit. The filament heating circuit for each tube was a concentric line connecting by stiff spring fingers to the concentric filament terminals of the tube. All outer and all inner conductors of these lines were connected respectively at their bottom extremities to two flat plates (one of which was the bottom of the oscillator box) separated by dielectric, which formed a by-pass capacity. The two sides of the filament power circuit were connected to these plates. The radio-frequency filament and output circuits can be clearly seen in Plate 3. For tuning, a movable shorting plate was used near the bottom of the four filament line outer conductors. Two opposite lines were connected by a tie-bar just below the tubes, and the other pair of opposite lines were connected further down by a movable tie-bar, from which the output power was taken. The output transmission line was brought in through the center of the bottom of the oscillator box, the outer conductor terminating about five inches inside the box, and the inner conductor extending up between the filament lines and joining the output coupling bar described just above.

1-4-2. Two air cooling supplies for the oscillator were provided. They are shown in Plates 1 and 6. One blower furnished the main cooling stream into the lower back of the oscillator box. This stream travelled upward past the tubes and out through the viewing windows and the top (which was customarily left open in operation, although a top with ventilating holes was originally furnished for the box). A second and somewhat higher

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pressure blower furnished air up the center of each filament line. This air emerged against the glass of the tube base and seal off and escaped through holes provided in the tube filament outer conductor terminal, between the contact fingers of the mount. This blower also supplied a stream, which escaped at the plate connector block for cooling of the plate seals, down through the tube carrying the plate supply voltage.

1-4-3. The input power supplies and control circuits were housed in a cabinet (Plates 1 and 6) separate from the oscillator box. The power supplies were in the first and second decks of the cabinet, from the bottom. A high voltage transformer rated at 22 kv and 150 ma, four tube bridge rectifier using type 100-R tubes, and filter consisting of a 2500 ohm resistor and $\frac{1}{2}$ microfarad condenser furnished the plate power. The filaments were heated by a transformer rated at 6 v and 600 a. Both plate and filament voltages were variac controlled in the primary circuits of their supply transformers. The grid modulation circuit, on the third deck, was of the self-quenching type using control of the discharge timing of the quench capacitor for repetition rate control. A six-section, 50 ohm, 5 microsecond artificial line was used to form the pulse, and discharge timing was controlled by a variable discharge resistance, type 304-T discharge tube and a driving transformer for this tube which could be fed either from the 60 cycle line supply or from a 180 cycle audio oscillator-amplifier. By using the resistance alone to discharge the artificial line, variable time-constant-controlled repetition rates were available, or by using the keying tube with the line or audio oscillator controlling frequency, synchronized rates of 60 and 180 pps respectively could be had. Control relays at the top of the cabinet, were arranged for overload protection of the plate supply (with provision for locking off after a certain number of "tripouts" within a predetermined interval), and for shut down in case of water failure to the dummy load.

1-4-4. The output load equipment consisted of a pair of matching stubs at the oscillator output point, a slotted line, and a water-cooled dummy load with another pair of matching stubs. Standard three-inch concentric air-dielectric line was used throughout. Part of this equipment can be seen in Plate 1.

PRELIMINARY TESTS

2. The CXFA equipment was set up and put in operation at the Naval Research Laboratory on 26 July 1943. Prior to the start of and during the early stages of the life tests, several preliminary tests were performed on the apparatus to check conditions and to obtain necessary information. The type 527 tube, for about the first eight months of the CXFA tests, was still in the advanced developmental stage, and the particular version known as the X-47 was used in the oscillator during the preliminary tests, unless otherwise noted.

2-1. A measurement was made of the operating pulse length of the transmitter. No accurate method was available for working with the r-f output pulse, so the duration of the grid current pulse was measured.

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Since grid current of any appreciable magnitude is drawn only during oscillation in a transmitter of this type, the duration of the grid current pulse corresponds very closely to that of the output pulse. The measurement was made using a calibrated servoscope. The pulse was found to be the rated five microseconds in duration within the accuracy of measurement.

2-2. The two synchronized repetition rates of 60 and 180 pps obtained by using the keying tube, driven respectively from the 60 cycle line voltage and from the 180 cycle audio oscillator provided, were checked by beating them against the output of an audio oscillator. They were found to be accurate.

2-3. The output duty cycle was measured, using a duty cyclometer, with both repetition rates. It was found to be 0.03% at 60 pps and 0.09% at 180 pps, consistent with the measured pulse length and repetition frequency.

2-4. A comparison was made between performance of the transmitter with the load applied at the end of the 50 ohm output transmission line adjusted to 50 ohms pure resistance, and with this load mismatched to produce a two-to-one voltage standing wave ratio in the transmission line. The oscillator could be correctly loaded by means of its tuning stubs in each case, and no significant difference in power output was found.

2-5. The spectrum of the transmitted signal was examined, using a pulse transmission spectrometer, with the oscillator operating on 198 Mc at a repetition rate of 60 pps. The width of the main envelope (between the first two minima) at half-voltage was 230 kc. For a perfect rectangular pulse of 5 microseconds duration, repeated 60 times per second, the corresponding theoretical width is 240 kc. The minor spectral envelopes of the CXFA signal were somewhat asymmetrical about the center frequency. From these data it is to be concluded that the signal bandwidth was satisfactory and that there was not a great deal of frequency modulation.

2-6. The regulation of the plate power supply was noted, for a change from normal operating full load to no load on the supply. The regulation at 60 pps was 16.3% and at 180 pps, 35.2%, of the full load voltage. This information was obtained for the use of the manufacturer of the SK-1M.

2-7. A run was made of oscillator frequency as the plate supply voltage was varied. The oscillator was operated at about 205 Mc, at 60 pps, and the supply voltage was varied in steps from about 7 kv to about 20 kv, the frequency being observed at each step. The resulting curve is shown in Plate 7. The average frequency increase per kilovolt increase in plate voltage was about 85 kc. The curve had a steep portion between about 7 and 10 kv, over which the average increase was about 200 kc per kilovolt increase, while from 10 to 16 kv the average increase was only about 35 kc per kilovolt.

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2-8. The oscillator plate voltage was varied in steps from about 7 kv to about 20 kv, and the power output and efficiency were recorded at each step. Tubes of the X-91 developmental version were used for this test, and the oscillator was operated on about 225 Mc, at 60 pps, using the "flywheel" keyer to be described below. The results of the test are shown in Plate 8. The curve of power rose at a slightly greater rate than the square of the voltage (due probably to the slight increase in efficiency - or to accidental errors), showing that the tubes had adequate emission. The low efficiency was due to the relatively high frequency used. This point will be discussed in more detail later.

LIFE TESTS OF TYPE 527 TUBE

3. Life tests of the type 527 tube were carried on from 29 July 1943 to 16 Sept. 1944. The tube was carried through many developmental stages or versions by the manufacturer, several of which were life tested at this laboratory. During the period of test, the life runs were very frequently interrupted to allow other tests and changes in the equipment. In this report, the life test periods, conditions, and results will be given in chronological sequency, with notations made as to the nature of other tests or changes at the times they took place. These separate experiments will then be described in detail as to methods and results in a later section of this report.

3-1. Life tests were begun on 29 July 1943. From this date to 18 December 1943, the tubes on test were the X-47 version of the 527. A repetition rate of 60 pps was used except during certain tests other than life runs as noted below, and the pulse length was 5 microseconds. During the life runs the plate supply voltage was kept at 18 kv; for some other tests it was reduced to prevent exceeding the rated plate dissipation.

3-1-1. After the start of life runs, it was found that the oscillator timing went out of step with its intended repetition frequency control (this is referred to hereafter as "out-of-synch" operation) quite easily at times of the day when the line voltage changed due to load changes, i.e., especially early in the morning and in the evenings. The consequent improper grid voltage wave shape developed plate hot spots and ultimately holes in the plates and glass envelopes. Accordingly, a twenty-four hour day watch was instituted on the equipment about 7 August. The transmitter was operated at about 200 Mc. Pulse power output was approximately 1000 kw and the plate efficiency was approximately 40%. Of the tubes installed in the circuit and failing prior to the continuous watch, discounting mechanical breakage by the operator, one tube failed at 95 hours life due to a punctured plate and envelope, and another was removed at 141 hours while still good, but near the end of its life, having several plate holes and visible signs of trouble in its glass. Three other tubes installed before the start of the watch and failing later had average lives of 283 hours. One of these showed high grid emission; the other two would not allow the oscillator to key properly but the exact trouble was not determined.

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3-1-2. In the case of tubes started after institution of the continuous watch, life improved, with a few exceptions. A batch of seven tubes had an average life of 297 hours. Two of these had lives of only 66 and 35 hours, and the average life of the other five tubes was 396 hours. Both of the short-lived tubes failed due to loss of grid cut-off ability; of the other five, one became gassy, one developed grid emission, one developed plate holes and a punctured envelope, one developed a slight crack in the top of its envelope, and the last would not pulse properly due to undetermined trouble. Two other tubes, both having a life of 12 hours, are not included in this summary: one of these had a very poor grid voltage - plate current cut-off characteristic when new, and the other failed due to a punctured envelope caused suddenly by out-of-synch operation during a test. During the period covered in this paragraph, a number of tests besides the life runs were conducted on the equipment. Data on oscillator performance with various standing wave ratios in the output transmission line were obtained. Several oscillator loading stub runs were made, of varying duration, to adjust the oscillator tuning for best power output and efficiency when the frequency was changed or when new tubes were installed, etc. Tests were made to determine the effect of unbalancing the normally symmetrical grid tuning frames, that is, of making one short-circuited section of each frame considerably longer than the other, while still keeping the combination adjusted to give the same operating frequency.

3-1-3. Between 5 October and 18 December 1943, when the X-47 version of the tube was superceded, tube life was extremely poor, partially due to the conduction of other tests on keyer circuits which quite ofteh subjected the tubes to conditions of improper pulsing. One tube was removed from the circuit at a life of 253 hours, still good, but with plate holes, so that all of the oscillator tubes would be in good condition for the keyer tests to be described. Excluding mechanical breakage by the operator, the average life of a lot of six tubes was 22 hours. Four of these tubes became gassy (one showing poor grid cut-off characteristics in addition), one developed an internal grid-cathode short circuit, and the last cracked a grid terminal seal. Four other tubes were removed from the oscillator to allow insertion of tubes of the next version received, the X-91, while still operating properly on 18 December. At the time of removal, the average life of these four tubes was 91 hours. Two of these tubes had been used for part of the keyer tests, the other two had not. It was during this period from 5 October to 18 December that much experimental work was done, using the transmitter, on the keying or repetition rate control circuit that was incorporated in the SK-1M transmitter, known as a "flywheel" circuit. In adjusting this control to proper operation, the oscillator tubes were necessarily frequently subjected to multiple pulsing, which undoubtedly contributed to the abnormal shortening of life observed in the batch of six tubes discussed. Of the two tubes which never failed though used for the flywheel tests, one was installed only after the tests were virtually completed and the circuit well adjusted, but the other simply appears to have been a more than usually rugged tube - it had been operated 128 hours when removed.

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In addition to the keyer work, tests were also made during this period of modified grid tuning lines, in which the grid connectors, instead of being mounted in channels fastened to the transmission line conductors, were contained in channels milled into the conductors themselves. The operating frequency during this period was varied across the entire band, in conjunction with the tests other than of life.

3-2. On 18 December 1943, the X-91 version of the 527 was installed in the oscillator, and tested until 5 January 1944. None of the accumulated hours during this period were on pure life runs. Further flywheel repetition rate control tests were made. A test of power output and efficiency as a function of plate voltage was conducted. Several mechanical breakdowns caused loss of time. Only four tubes were used, the life of which at the time they were removed (while still in good condition) was about 25 hours.

3-3. On 5 January 1944, tubes of the X-97 version were put on test, and run until 18 February. They were operated at 180 pps using the flywheel repetition rate control, except for a brief check using the original keying circuit to obtain a comparison of efficiencies, and at a pulse length of 5 microseconds. The frequency was varied from 200 to 220 Mc. Efficiency varied from about 46% to 35%, and power output from about 1000 kw to 600 kw at 18 kv plate supply voltage. Several tuning control runs were necessarily made to adjust for output and efficiency. An antenna duplexer contemplated for use in the SK-1M equipment was installed in the output transmission line for a life test of its spark gaps. Several mechanical and electrical breakdowns in the water-cooled load and in the plate supply transformer caused loss of time. Poor regulation of power line voltage made it necessary to install separate supply lines for the plate and filament supplies from a distribution panel. Tube life was poor. A total of nine failures gave an average life of 70 hours. Four of these were from grid emission, three from cracked grid seals, one from a punctured envelope due to a plate hot spot, and one from an undetermined cause leading to failure to key properly, in which the tube had a somewhat low plate/grid voltage cut-off ratio after failure, which may have been the cause. Three tubes remaining in operating condition at the conclusion of tests on the X-97 version had been operated an average of 91 hours. They were not tested further since the next tubes received were of a later variety, furnishing no fourth tube for a matched set. The tubes of the X-97 variety had when new a cut-off ratio considerably higher than had the X-47's and X-91's (in the neighborhood of 30 or above as against about 20 for the earlier tubes), and a higher ratio was retained in the tubes subsequent to the X-97's. The increase of this ratio may have been obtained by placing the grid closer to the filament. This would cause the grid operating temperature to be higher. The marked increase in the number of failures due to grid emission and to cracked grid seals with this version is perhaps significant as indicating a rise in grid operating temperature. If this is true, the temperature rise may have been connected with the increase in cut-off ratio. It is, of course, entirely possible that the increased amplification factor was obtained by a decrease in grid mesh spacing or a combination of the two methods. Which scheme was used is not known.

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3-4. Tests were begun on the X-114 version of the type 527 tube on 24 February and continued until 11 March. The flywheel was used except for one very short period. Keying was at 180 pps with a pulse length of 5 usec. Because of the nature of the failures obtained with the X-97 version, it appeared necessary to reduce the operating temperature of the tube structure. The efficiency could be brought up only by reducing the operating frequency, and accordingly this was reduced from about 210 Mc to approximately 190 Mc. At this point an output of approximately 1000 kw was obtained at a plate efficiency of greater than 45%. A check was made of the performance of the equipment using the original keyer and no difference was found in the efficiency or power output as compared to those obtained using the flywheel. The check was made because the Eitel-McCullough Co., using a duplicate of the transmitter under test at this laboratory except for the use of the discharge tube instead of a flywheel circuit, had been obtaining considerably higher efficiency. The respective operating frequencies only, however, were found to account for the difference. Of six tubes tested during this period, three tubes failed, one at 8 hours because of a cracked envelope, the second at 70 hours, its plate/grid voltage cut-off ratio having fallen, and the third at 147 hours with a cracked grid seal. Two of the remaining good tubes had been operated 147 hours, and the third 69 hours.

3-5. On 20 March, tests were begun on the X-122 and X-125 versions of the tube. Additional air jets had been installed for increased cooling of the tube grid seals, because of the large number of failures from cracked seals experienced in the two previous batches of tubes. A lengthy tuning run was made to determine the optimum power output and efficiency of the tubes and oscillator throughout the intended operating band of the SK-1M radar. Following this, considerable time was spent in investigating the possibility of tuning the oscillator for best output and efficiency without the use of an output power indicator, that is, by means of the indications of the grid and plate current meters alone. These two tests occupied the entire month of April, and accounted for failure of three of the tubes. Operation was then suspended because of lack of tubes until 12 May, when life tests were started using mixed sets of old tubes and those of the final 527 type which had been received. A new cooling system, employing an exhaust fan, replaced the former main blower air supply, without change in the high pressure system used for cooling the tube base seals through the filament lines, and a modified plate connector block and support, having the former type of plate-seal cooling from the high pressure system, was installed, before the resumption of operations. The temporary grid seal cooling jets were removed at the same time. The Eitel-McCullough Co. had made extensive tests to determine the cooling air requirements for the tubes, and had arrived at the quantity requirement as well as the fact that the air stream should be supplied by an exhaust rather than a blower system, to obtain most even air distribution and maximum cooling for a given fan capacity. In the new system the cooling air entered the top of the oscillator box through an orifice plate, passed downward over the tubes, and was removed by the exhaust fan at the bottom rear of the box. The modified plate connector unit removed a source of deflection of incoming air introduced by the original one. The

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fan, orifice plate and plate connector assembly were supplied by the Eitel-Mc Cullough Co. The resumption of life test was made at 198 Mc, 900-1000 kw pulse power output, and 40-45% efficiency. The last of the lot of X-122 and X-125 tubes failed 27 May. Of the three tubes failing during the preliminary tests, the lives were 29, 113 and 130 hours, and the causes of failure an intermittent grid-filament short circuit, and two decreased cut-off ratios, respectively. Of the three tubes life tested, the lives were 56, 212 and 267 hours, and the failures were due respectively to two cases of gas and one of grid emission. It is to be noted that no tubes were lost due to seal breakage during this period.

3-6. The final version of the type 527 tube was put on test 12 May, after the installation of the new exhaust cooling system.

3-6-1. After preliminary tuning, mixed sets of the final tubes and remaining X-122 and X-125 types were life tested at 198 Mc, 900-1000 kw pulse output, 40-45% plate efficiency, 5 usec pulse length, and 180 pps, flywheel controlled, until 4 June, during which time 204 hours of operation were accumulated. None of the new tubes failed during this life run, although one failure, a cracked plate seal at 19 hours life, had occurred during the preliminary tuning.

3-6-2. A number of tests other than life runs were made on the equipment between 4 June and 30 August. The poor frequency characteristic of power output and efficiency of the CXFA was a subject of great concern. As a result of the tests made by this laboratory, the tube manufacturer and others, it appeared fairly certain that the characteristic was a fault of the tube itself, and not of the CXFA circuit, but since there was still a slight doubt remaining, experimental changes were made in the output coupling circuit of the CXFA oscillator to check one possibility, that the drooping characteristic was due to inability to load the tube properly at the higher frequencies. Other tests were made with a pulse length of 18 microseconds, in connection with work being done on the SR radar, using the same type tube. Further tests were made on the flywheel repetition rate synchronizer, to determine the dependence of repetition rate on oscillator loading, plate supply voltage, and the value of discharge resistance used across the pulse forming network. Both the flywheel normally used and one from an SK-1M equipment, which was by now coming into production, were used. During this period, discounting accidental breakage, there were three failures. All of these had been on life test during the period covered in the preceding paragraph, and had lasted over 200 hours. (The fourth tube from the life test was broken accidentally at 250 hours.) The average life was 242 hours. One failure was due to grid emission, one to a decreased cut-off ratio, and one to an undetermined cause.

3-6-3. On 30 August the life test was resumed at 192 Mc, 1000 kw pulse power output, 42-44% plate efficiency, 5 microseconds pulse length and 180 pps, and was continued until 16 September, the date of conclusion of work on the CXFA project. Four failures occurred. One of these, at 6

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hours, was a cracked plate seal. After this event, the oscillator tube mounting connectors were found to be out of alignment, placing undue stress on the seals, and were realigned. The other three tubes all exceeded 200 hours in life, the average being 253 hours. All three had been used in the miscellaneous tests between 4 June and 30 August. The failures were due to an internal grid-filament short-circuit, grid emission, and an undetermined cause, in the three cases. Of the three good tubes remaining in the oscillator after the last failure, the oldest had been operated 237 hours, and the others 91 and 78 hours.

ADDITIONAL TESTS AND CHANGES IN THE EQUIPMENT.

4. In addition to the preliminary and tube life tests, the CXFA equipment was subjected to a number of other tests, and was changed in some respects, with a view to improving the performance and tube life of the CXFA itself and of the SK-1M.

Changes in Synchronizing Circuit

4-1. During the first few months of the test, when the discharge tube keying circuit originally incorporated in the equipment was used, considerable trouble was experienced with erratic pulsing due to loss of synchronization with the discharge tube timing wave, which occurred with changing line voltage at times of daily load changes, and to a lesser extent with variations in plate voltage and changing conditions in the tubes during life. When properly synchronized, the circuit carried the oscillator grid voltage sharply from beyond cut-off through the level at which oscillation started. Upon loss of timing, however, it was possible for the grid voltage to remain in the region between cut-off and oscillation levels for relatively long periods. Under this condition the plate current drawn by a tube focused through certain regions of the grid structure, heating the plate locally. In turn the grid in the vicinity of the plate hot spot was damaged by the temperature, so that subsequently, even under correct operating conditions, plate current focusing took place. Thus, even if the tube would operate in the oscillator after the damage to its grid, the ultimate result was plate holes and finally a punctured envelope.

4-1-1. A "flywheel" pulse repetition rate control circuit was designed by this laboratory to replace the original CXFA vacuum tube keying circuit. Such a circuit is an L-C resonant circuit which is placed in series with the oscillator grid return. It is excited by the grid current pulse during each period of oscillation, and its subsidence voltage wave is superimposed on the normal exponential decay of the pulse forming network capacity, which is resistance discharged, by the series connection. The exponential curve alone has a relatively low slope as it crosses the cut-off bias level and, if it is used alone, plate current flows for an appreciable time before the oscillation bias level is reached, the oscillator efficiency is reduced and there is a tendency toward current focusing and hot spotting. Furthermore, the low slope of the grid wave allows the repetition frequency to vary widely with changes in loading and in plate

[redacted]

voltage. The addition of the sine wave, properly phased and proportional in amplitude, steepens the slope of the total grid voltage wave in the critical region, which increases the oscillator efficiency and stabilizes the repetition frequency. The design of the circuit involves the proper choice of the flywheel inductance, capacity and the pulse forming network discharge resistance, so that pulsing occurs at the desired rate, with a steep grid voltage wave and with the proper fraction of sinusoidal component.

4-1-2. If the resistance discharge were used alone, there would be no question of loss of synchronization - there is nothing with which the oscillator can get out of step - but with the addition of the flywheel the necessity for synchronization arises, i.e., the exponential decay time must be roughly adjusted to proper timing with the flywheel. With correct adjustment, the oscillator pulse will occur at approximately zero phase of the sine wave - the steepest part - when it is going in a positive direction. There is a sudden slip in phase as the flywheel condenser is charged by the oscillator grid current, and the succeeding sine wave will then go from its start at a negative maximum through a positive and another negative peak, before the next pulse occurs at about zero phase. If the network discharge time is not correct relative to the flywheel period, keying may occur and the flywheel be excited in such a phase that the normal energy relations are radically changed, the correct repeating transient will not be set up, and the circuit behavior may take a variety of forms. It may reach no steady state at all, or it may settle into a condition in which there is a regularly repeating cycle comprising several transients, each of which is different in grid wave form and in pulse spacing. Worse yet from the standpoint of the tubes, the semi-static condition will probably arise in which the grid voltage hangs between cut-off and oscillation for relatively long lengths of time, causing plate hot spotting. For example, if the network discharge time is too long, keying will not occur until a second positive peak is reached by the sine wave after the preceding pulse, a point where the grid wave slope is very low, or, if too short, on the first peak, where the same is true. There is, however, a fairly wide range of adjustment of resistance for proper operation, over which the slope is high and the pulsing frequency is well stabilized. Furthermore, the circuit is largely self-compensating under varying operating conditions. If the grid current changes for any reason, such as a change in plate voltage or in loading, both the exponential and the sinusoid vary in amplitude proportionally. In the case of plate voltage changes, where the cut-off bias level also changes almost proportionally, the compensation is virtually perfect. With large changes in loading, however, since the cut-off level will remain fixed, it is possible for non-synchronous operation to occur, so provision for variation of the network discharge resistance must be made for use in tuning. Also, though changes in line voltage, insofar as they change the plate voltage, do not affect synchronization, they can have a pronounced effect through variation of filament voltage. If the oscillator tubes are operated near the limit of emission, a small percentage decrease in filament power can change the bias swing a great deal, and since the cut-off level will not change greatly for small plate voltage variations,

[redacted]

out-of-step operation can easily occur. The repetition frequency is, of course, somewhat a function of the discharge resistance, since the sinusoidal component is of finite slope and amplitude.

4-1-3. The flywheel circuit was compared with the original tube keying arrangement and with pure resistance discharge as to oscillator efficiency. Both the tube keyer and the flywheel were designed for a grid voltage wave of approximately the same steepness, so that they would be expected to give the same efficiency. The tubes being used at the time were of the X-47 type, and the oscillator was operated on about 195 Mc with a pulse length of 5 microseconds. The results of the test were as follows: At a repetition frequency of 60 pps, the oscillator average plate efficiency was: (a) with the vacuum tube keyer 39.3%, (b) with the flywheel 38.9% and (c) with resistance discharge 34.2%. At 180 pps the efficiency under these respective conditions was: (a) 43%, (b) 42.5% and (c) 38.4%. These are averages of several results. With all three types of keying the oscillator power output was the same, as would be expected since these keyers are simply triggers. Both the tube and the flywheel control circuits are seen to have produced substantially the same efficiency. Their values in turn are very much better than those obtained with the low slope grid wave of the resistance discharge method. The efficiency is better in all cases at the 180 pps rate than at 60 pps, since at the higher rate the slope of the grid wave (even with the exponential variation) is much higher than it is at the lower rate. The efficiency of the oscillator using the flywheel was checked against that with the original keyer in use, during tests of several of the other versions of the tube, and the two circuits were found to be equivalent in this respect.

4-1-4. Observations were also made of the relative stability of keying using the two keyers. The flywheel allowed stable keying over a very much wider range of voltages and tube conditions than did the discharge tube. Stability data taken using the production tube, on repetition rate vs. oscillator loading, plate supply voltage and network discharge resistance are shown on Plates 9 and 10. The oscillator at the time was operating with a 5 microsecond pulse on a frequency of about 190 Mc. It is seen that the repetition frequency was affected greatly only by the value of discharge resistance. By keeping this value in the range where keying occurs at a steep part of the grid voltage wave (the upper portions of the rate vs. resistance curve of Plate 10), the repetition rate is well stabilized and is affected very little by loading and voltage changes. In the curve of rate vs. resistance of Plate 10, the rapid rate of change at the higher resistance values is caused by the fact that the pulse is occurring well above zero phase on the sine wave component, where the slope is low. Raising the resistance somewhat more would lead to keying on the second sine wave peak,,and unstable operation. In the region of the fairly flat top, keying is occurring in the steep portion of the sinusoidal component. Going to too low a value of resistance would cause the pulse to occur at the first peak of the wave, with instability. It is seen that quite a wide range is available for proper operation. The data on variation of rate with other factors were taken with a value of resistance in an only moderately flat region of the rate-resistance curve, yet the stability with variation of these other factors is quite good.

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Tests on High Frequency Grid Tuning Circuits

4-2. The original CXFA grid frames were constructed of aluminum tubing, to which were attached exterior channels which contained the grid connector springs. Fixed shorting bars at the top and bottom of each of the frames were used to mount the frames on stand-off insulators, and two sliding shorting bars were provided on each frame for tuning, which were normally spaced equidistantly along the frame from the center of the tube grid structure. Two modifications of this assembly were tested in attempts to simplify construction and tuning.

4-2-1. While testing both the X-47 and the production versions of the 527, the sliding shorting bars on each frame were displaced from their normally symmetrical setting, so that one tuning section on each frame was longer than the other, to simulate conditions that would obtain if only one shorting bar were to be varied in the process of tuning. No significant difference was found in either power output or efficiency from the normal values with balanced frames.

4-2-2. A set of grid frames consisting of solid rods having the connector springs mounted in channels milled into the rods were tested using the X-47 tubes. Because of the physical dimensions of the oscillator, the rods of this design were closer together than those of the original frames, and the consequent lower surge impedance required a greater length of frame for a given frequency. The oscillator efficiency, when using these tuning frames, was 5 to 10% lower than when using the original frames, and the power output was from 90 to 95% of that available using the original frames. Eitel McCullough Inc., in similar tests, found that the channel frames gave an efficiency about 7% lower than normal, and a power output of only 83% of normal, in a transmitter identical with the CXFA/X-5000.

Tests in Regard to Improvement of Frequency vs. Power and Efficiency Characteristic of Oscillator

4-3. A test was made of power output and efficiency over the frequency range from 190 to 225 Mc (the specified operating band of the SK-1M radar). Tubes of the X-122 and X-125 series were used, with a pulse length of 5 microseconds and a repetition frequency of 180 pps. The test was conducted at a plate supply voltage of about 15 kv, to reduce plate dissipation at low efficiency settings while tuning, and power outputs at 18 kv were calculated, assuming power proportional to the square of the voltage. (The tubes had been found to have adequate emission; also a few points on the 18 kv curve were checked experimentally and found to be correct.) In obtaining the data, tuning was for maximum efficiency. The maximum possible power output was always obtained from the oscillator with slightly different tuning adjustments from those giving best efficiency, but the differences in both power and efficiency at the two settings were very slight. Hence the power obtained was substantially the best possible from the oscillator. The results of the test are shown on the curves of Plate 11. It is seen that both the power and

[redacted]

efficiency of the oscillator fell off quite rapidly above 205 Mc. This was very disturbing in view of probable frequent operation of the SK-1M above this frequency. A number of changes were made in the output coupling circuit of the oscillator in an endeavor to improve the frequency characteristic.

4-3-1. In the output coupling scheme, three-inch transmission line entered the bottom center of the oscillator box; originally the outer conductor terminated about five inches inside the box, and the $1\frac{1}{4}$ inch inner conductor was extended up and connected to the output coupling bar on the filament lines at a point several inches higher. The following schemes were incorporated and tested over the frequency band in succession: (a) three-quarter inch diameter pipe replaced the regular $1\frac{1}{4}$ inch inner conductor between the coupling bar and the first stub junction, about six inches below the oscillator box; (b) The 3/4 inch conductor was shortened to a point even with the top of the outer conductor of the transmission line just inside the box; (c) The inner conductor was enlarged to a two-inch diameter between the coupling bar and the top of the outer conductor; (d) The inner conductor was returned to its original diameter, and the outer conductor was extended up into the oscillator to the level of the coupling bar and attached to the two free opposite filament lines at this level. No change was found in the frequency characteristic of the oscillator as a result of any of the modifications, and the output coupling circuit was returned to its original condition.

4-3-2. The data obtained in these tests, together with those found by Eitel McCullough, by General Electric Co. working with the SK-1M, and by the Westinghouse Electric and Manufacturing Co. in connection with the SR radar, lead to the conclusion that the poor frequency characteristic is an inherent fault of the type 527 tube, rather than of the circuit used.

Tests with Long Pulse Length.

4-4. To obtain verifying information in connection with work done by the Westinghouse Electric and Manufacturing Co. on the SR radar, using the type 527 tube with a 20 microsecond pulse among others, the CXFA pulse length was increased to 18 microseconds (the repetition frequency being reduced to 60 pps), and using the production 527's, a run was made of power output and efficiency vs. frequency. The resulting curves are shown on Plate 12. There was no appreciable difference in pulse power output or in efficiency using the 5 and the 18 microsecond pulse length, nor in the variation with frequency of these quantities obtained at the two pulse lengths.

Change in Cooling System

4-5. Considerable trouble was experienced in excessive cracking of grid seals when tests on the X-97 and X-114 tube varieties were made. The main air blower (at the bottom of the rear panel of the oscillator cabinet) was not forcing sufficient air past the tubes, and too much turbulence was being introduced to evenly cool all terminals. To remedy this condition, before tests of the X-122's and X-125's, four air directors

[redacted]

or jets were constructed and so installed as to direct air downward across the grid seals of all tubes. These were fed from high pressure air lines. This method of cooling was satisfactory, no seal cracks occurring among the X-122's and X-125's, but was mechanically cumbersome. Eitel McCullough, as the result of extensive tests of cooling requirements of the tubes, found that a uniform air velocity of 600 ft./min. past the tube blanks was necessary, and that this requirement should be furnished by an exhaust rather than a blower system to insure the greatest stream velocity uniformity. They then furnished this laboratory with an adequate exhaust fan, motor, and orifice plate for mounting in the top of the oscillator cabinet, the fan being installed in the rear panel in place of the original blower. The orifice plate, besides providing better air direction, also constricted the air intake opening to simulate space requirements in the SK-1M production oscillator. This new cooling system was installed just before tests on the production type 527 were instituted. The number of tube failures from cracked seals was satisfactorily low after its installation.

<u>Tuning Procedure</u>

4-6. The correlation between plate and grid current trends and output power and efficiency was investigated. It was found that tuning by means of the stubs for a maximum ratio of plate to grid currents gave an output and efficiency very close to the maximum possible. By slight readjustments of the stubs it was possible to increase the power output by about 10%, and to add two or three percent to the efficiency. These gains would not significantly affect the performance of a radar equipment, and in service operation of the equipment could not be realized unless some sort of power output indicator were provided. It would be expected that this method of tuning would hold for other oscillators of the same type using the same tubes, such as the SK-1M.

[redacted]

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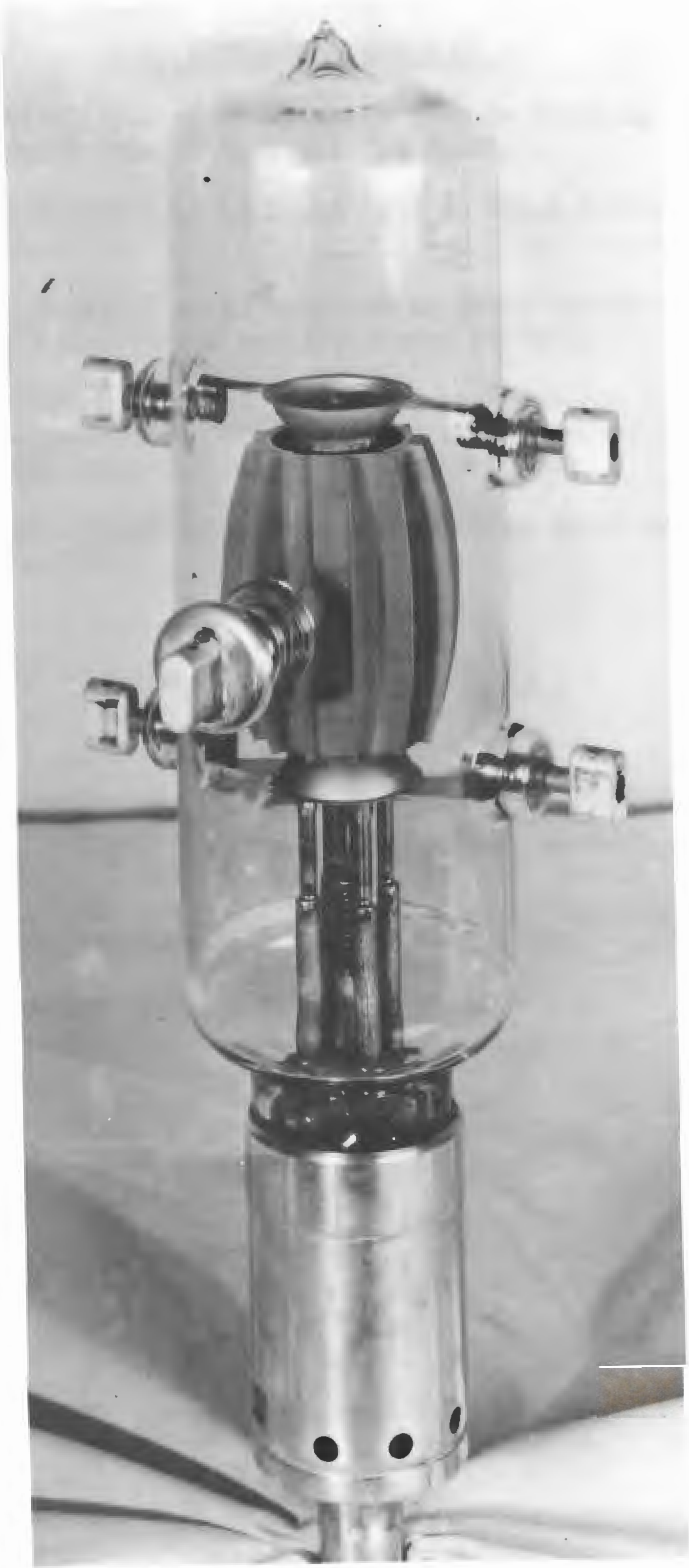
[redacted]



TRANSMITTER X-5000

DESIGNED & CONSTRUCTED BY

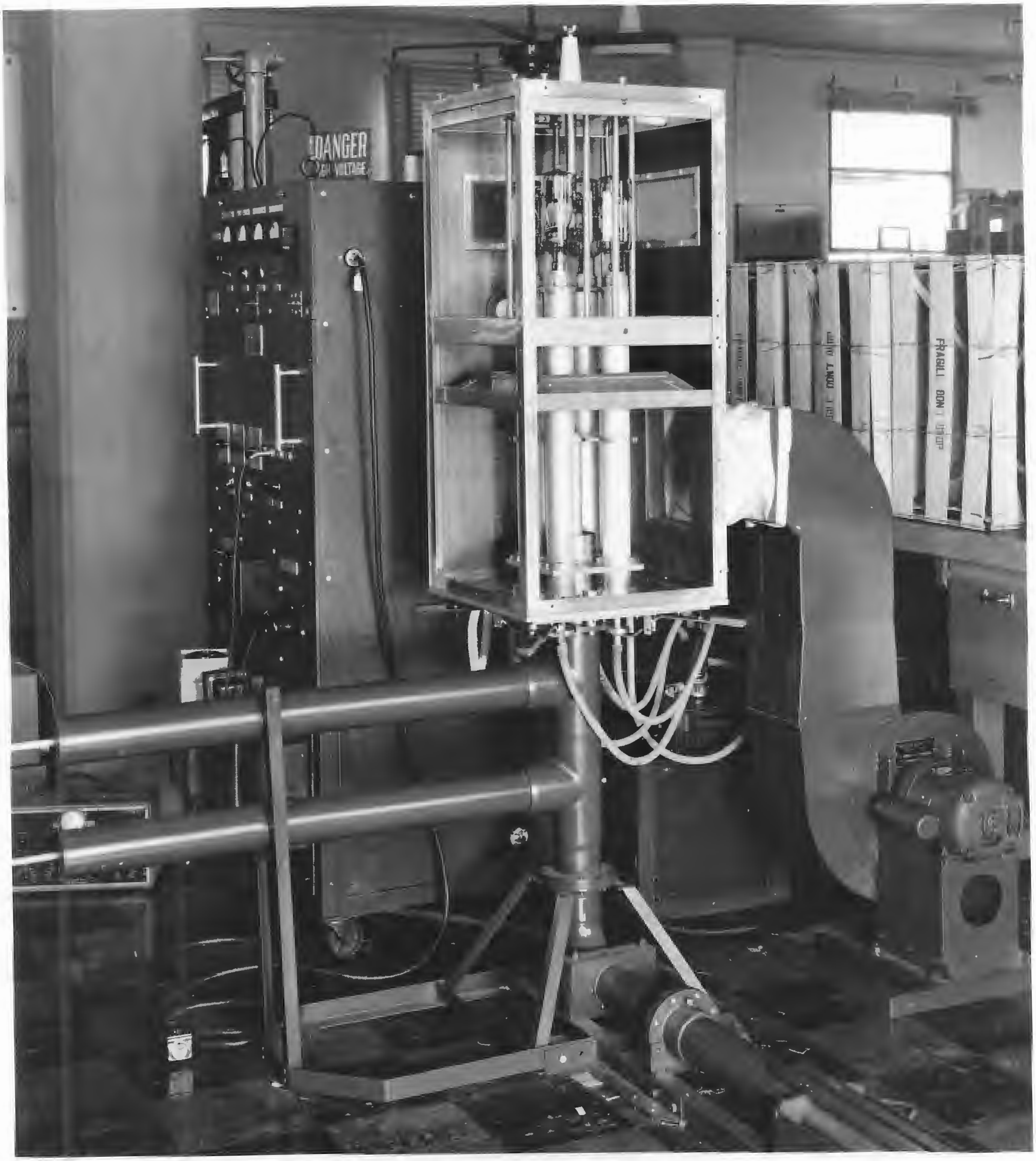
EITEL - McCULLOUGH CO.
SAN BRUNO, CALIFORNIA.

AUGUST 2, 1943 AT NRL

DECLASSIFIED

PLATE I

[redacted]



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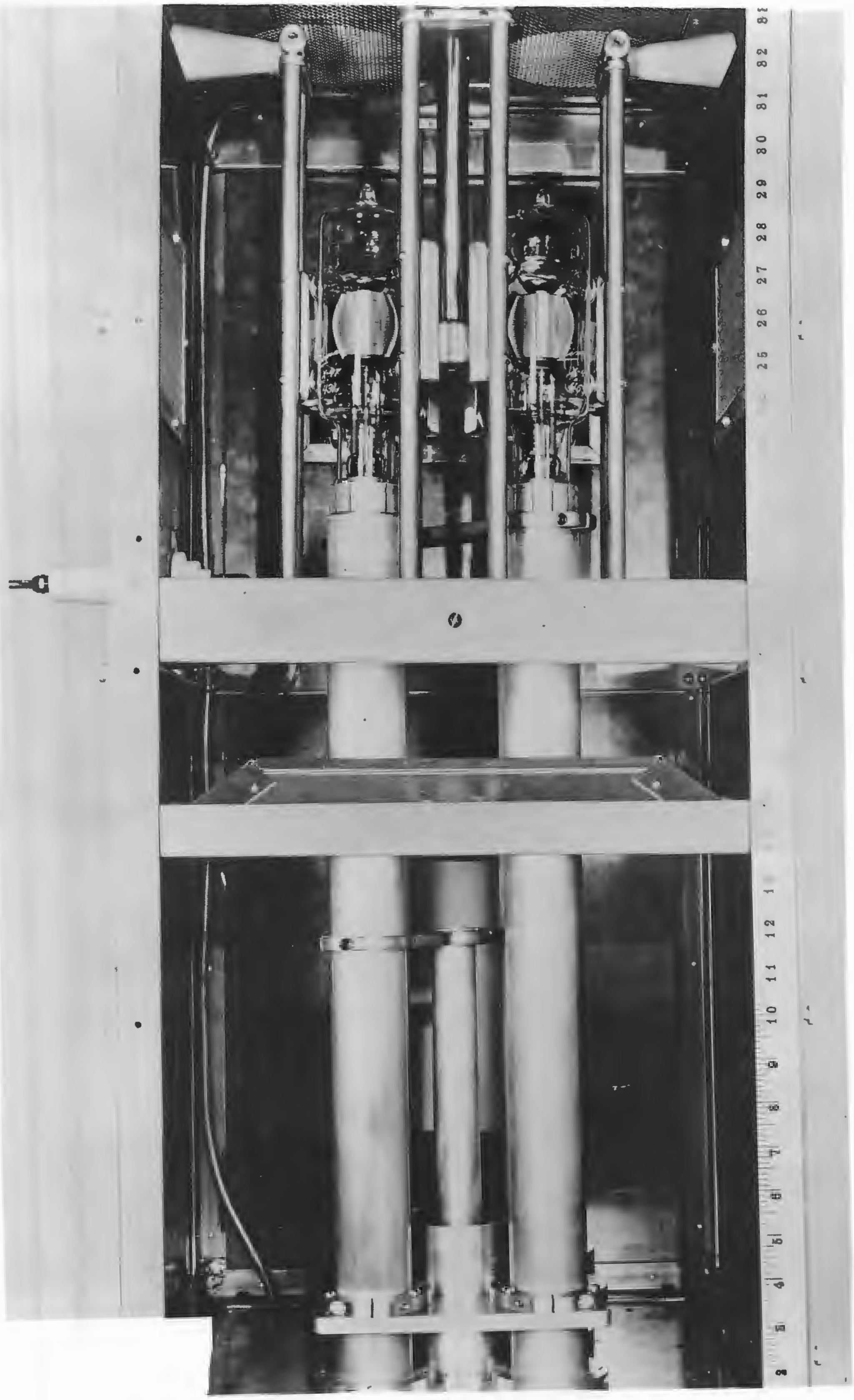

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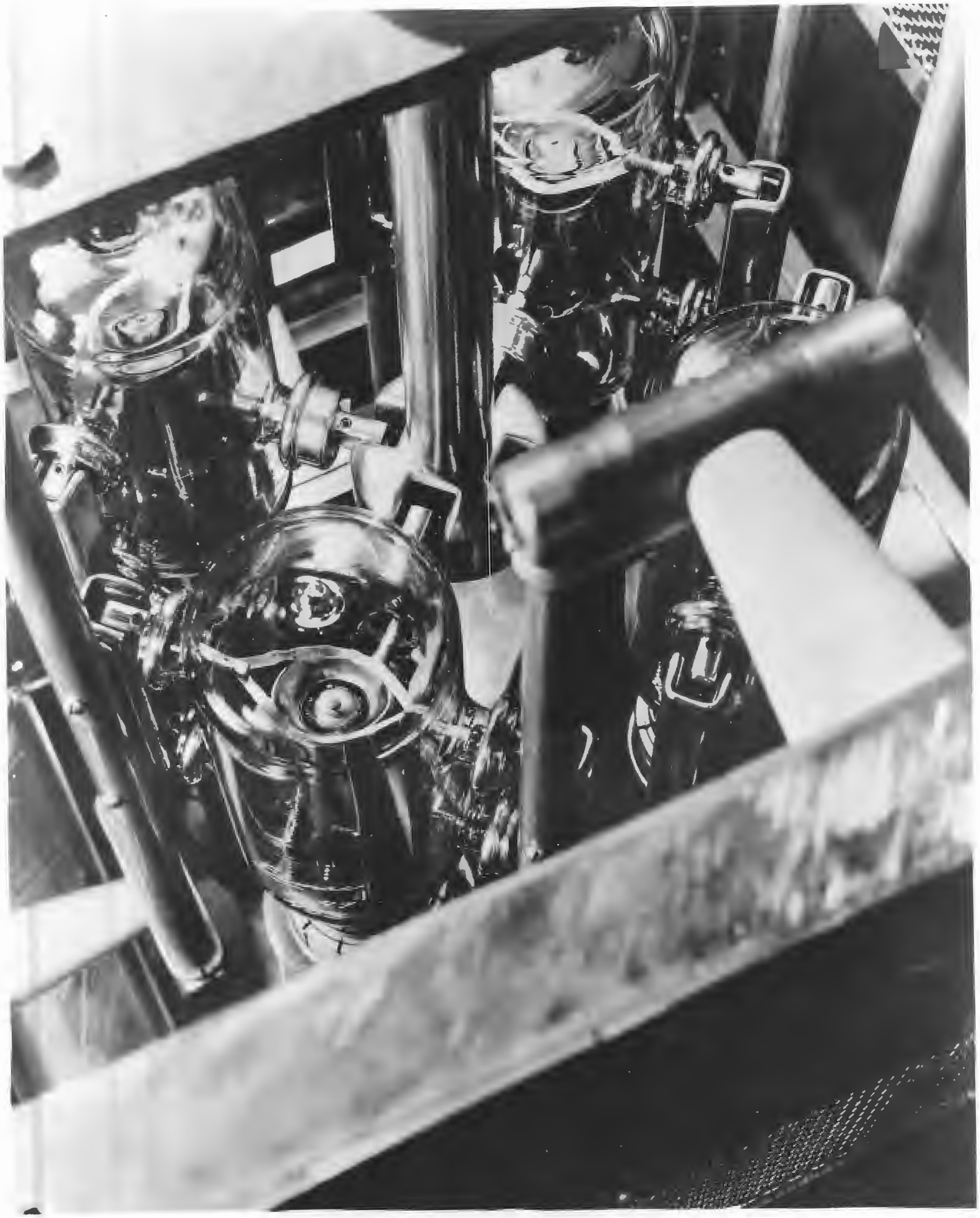
AUGUST 2, 1943 AT NRL

DECLASSIFIED

PLATE 3



TRANSMITTER X-5000

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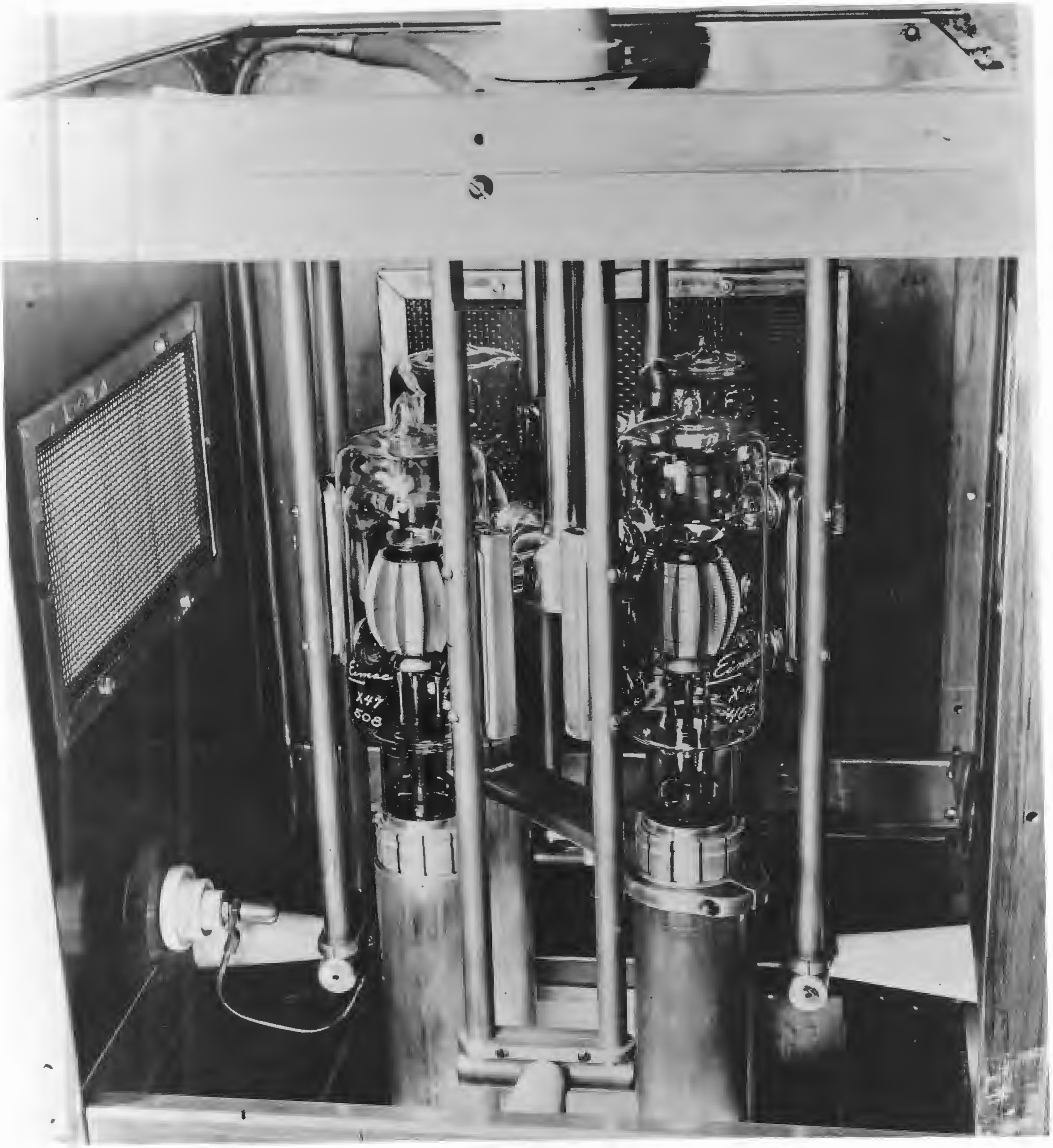
AUGUST 2, 1943 AT NRL

PLATE 4



TRANSMITTER X-5000

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EITEL - McCULLOUGH CO.
SAN BRUNO, CALIFORNIA.

AUGUST 2, 1943 AT NRL

PLATE 5

TRANSMITTER X-5000

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SAN BRUNO, CALIFORNIA.

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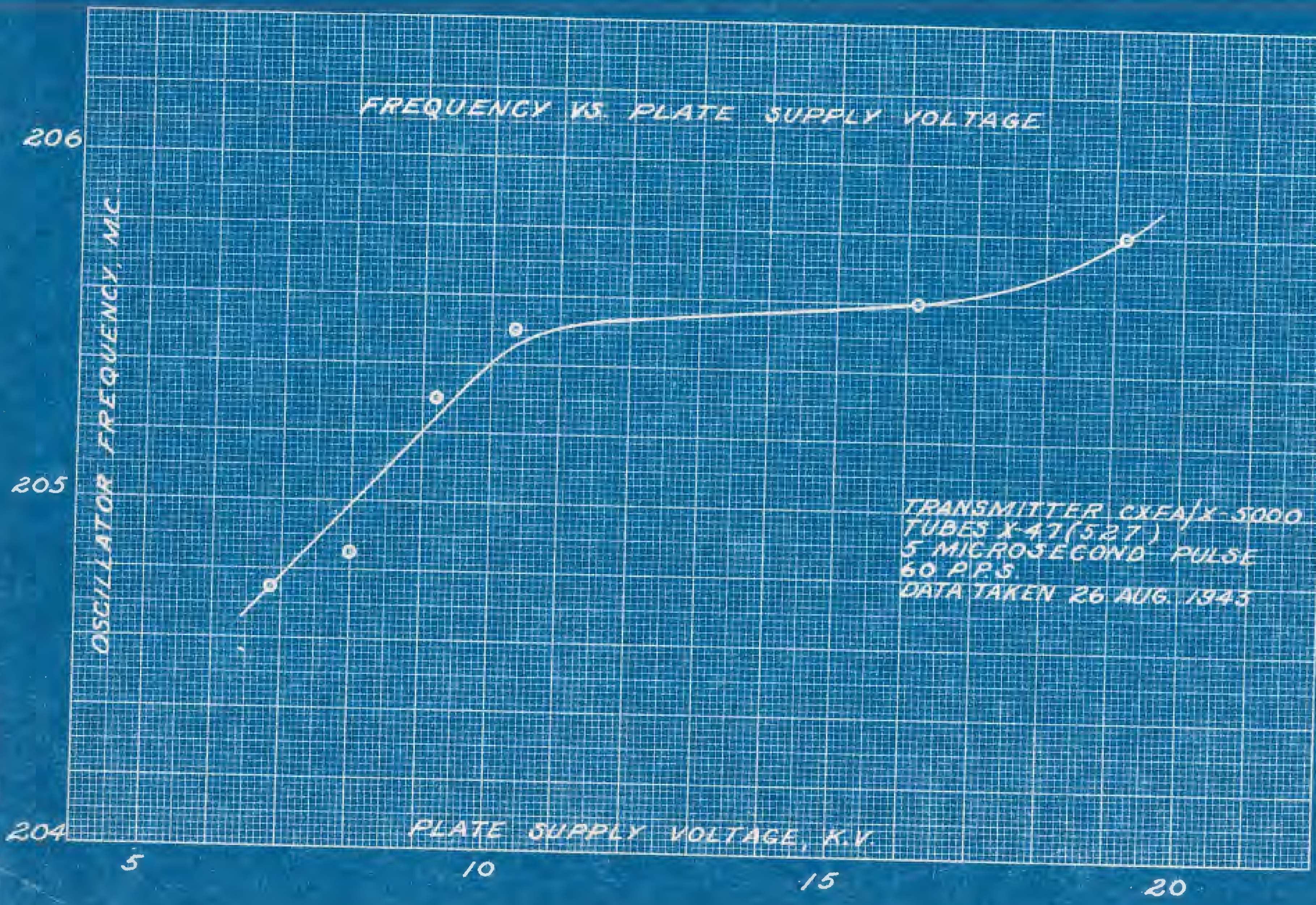

FREQUENCY VS. PLATE SUPPLY VOLTAGE
OSCILLATOR FREQUENCY, MC.
206
205
204
PLATE SUPPLY VOLTAGE, K.V.
5
10
15
20
TRANSMITTER CXFA/X-5000
TUBES X-47 (527)
5 MICROSECOND PULSE
60 P.P.S.
DATA TAKEN 26 AUG. 1943

PLATE 7

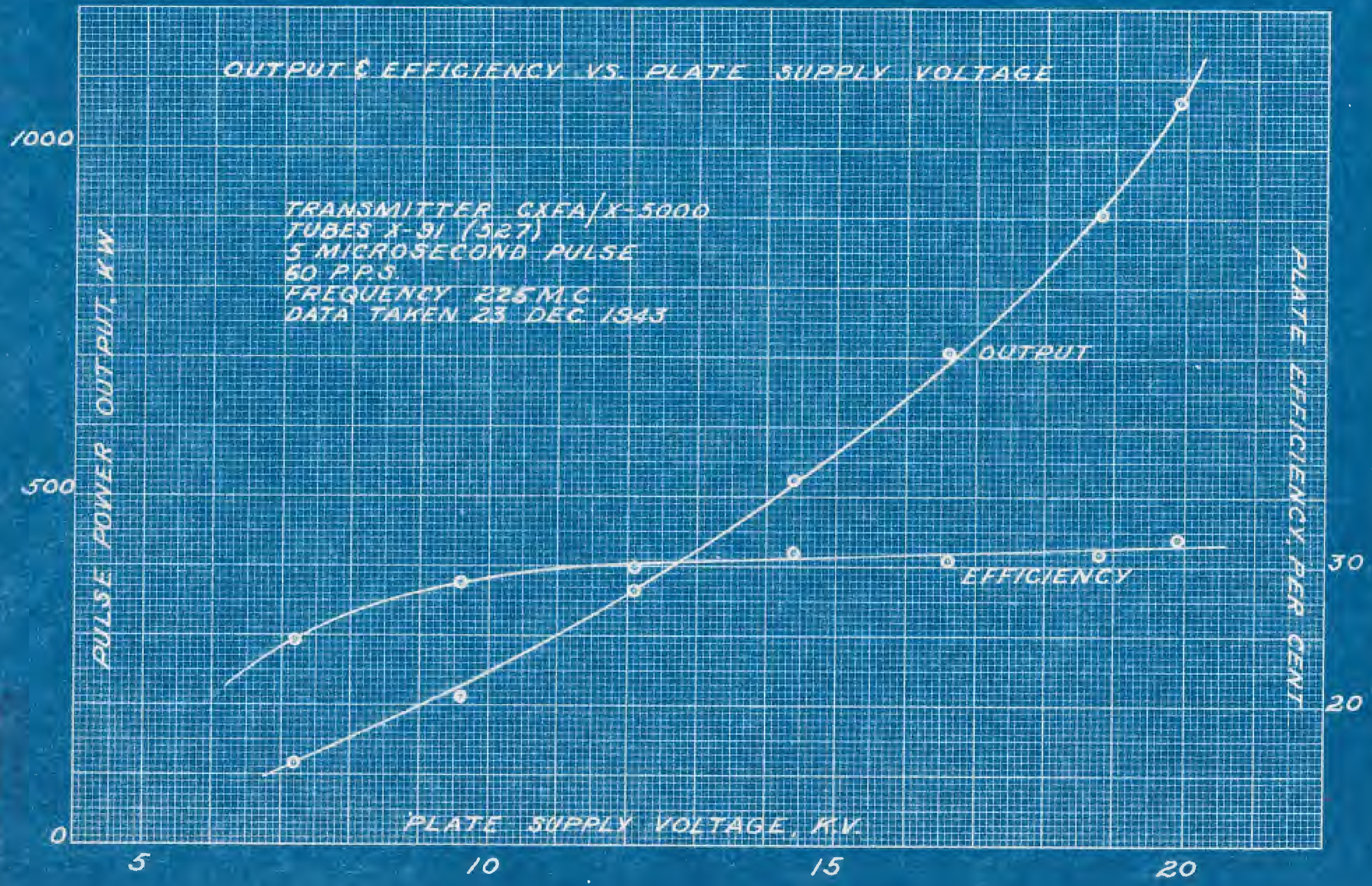
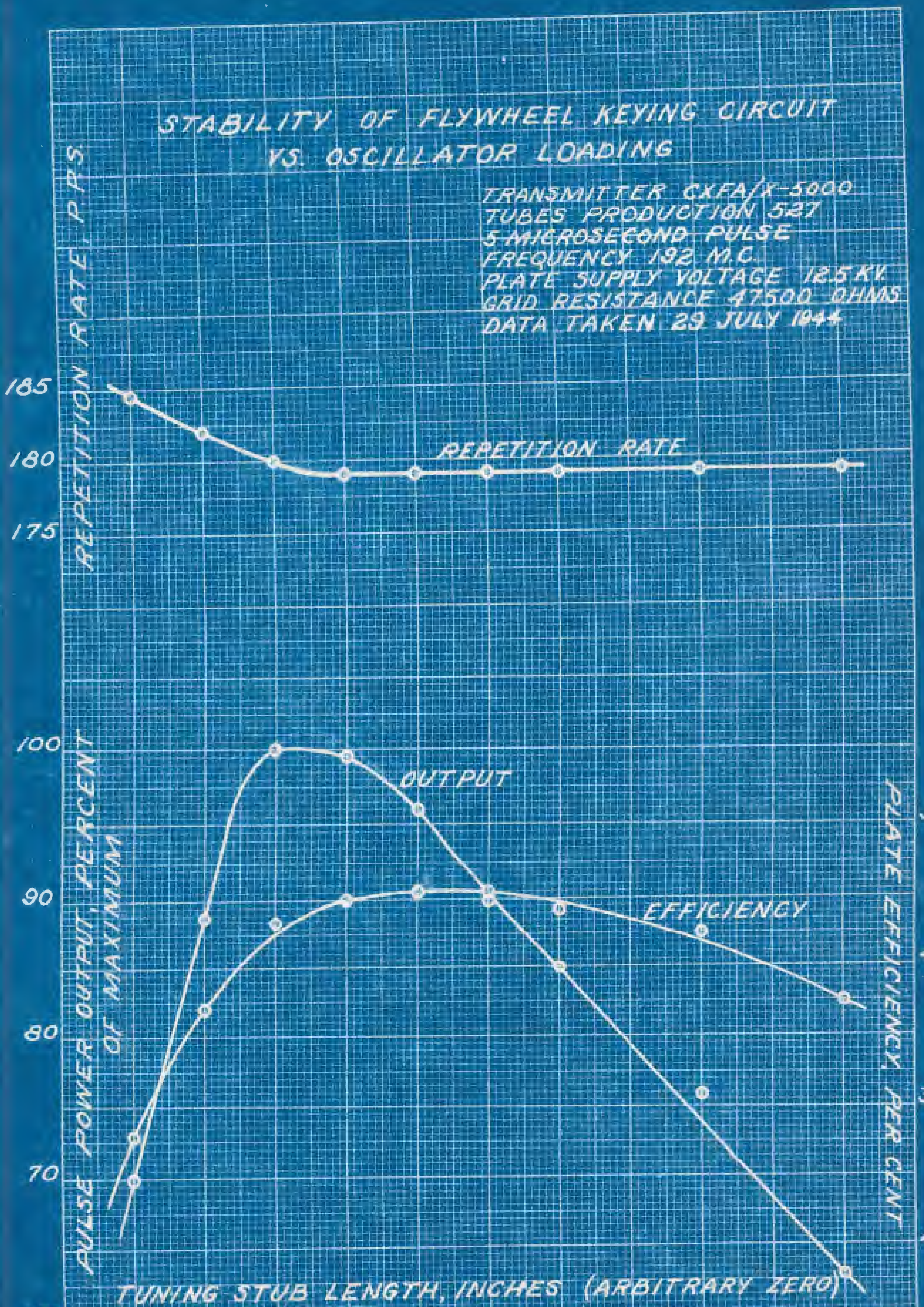

OUTPUT & EFFICIENCY VS. PLATE SUPPLY VOLTAGE
TRANSMITTER CXFA/X-5000
TUBES X-31 (527)
5 MICROSECOND PULSE
60 P.P.S.
FREQUENCY 225 M.C.
DATA TAKEN 23 DEC 1943
OUTPUT
EFFICIENCY
PULSE POWER OUTPUT, K.W.
PLATE EFFICIENCY, PER CENT
PLATE SUPPLY VOLTAGE, K.V.
1000
500
0
5
10
15
20
30
20

PLATE 8


STABILITY OF FLYWHEEL KEYING CIRCUIT
VS. OSCILLATOR LOADING
TRANSMITTER CXFA/X-5000
TUBES PRODUCTION 527
5 MICROSECOND PULSE
FREQUENCY 192 M.C.
PLATE SUPPLY VOLTAGE 12.5 KV.
GRID RESISTANCE 47500 OHMS
DATA TAKEN 29 JULY 1944
REPETITION RATE, PPS
185
180
175
REPETITION RATE
PULSE POWER OUTPUT, PERCENT OF MAXIMUM
100
90
80
70
60
OUTPUT
EFFICIENCY
PLATE EFFICIENCY, PER CENT
50
40
30
20
TUNING STUB LENGTH, INCHES (ARBITRARY ZERO)
13
15
17
19
21
23

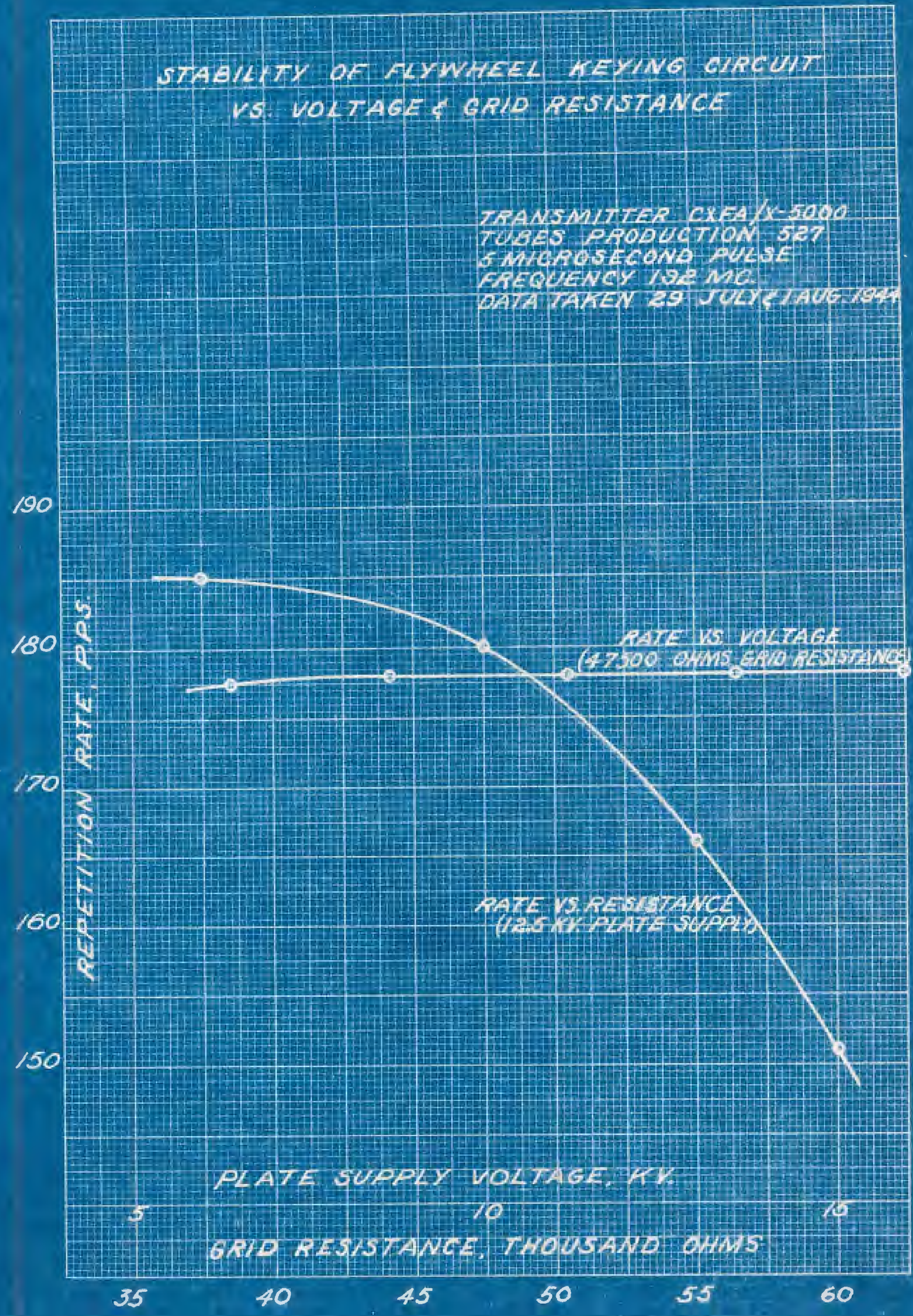

STABILITY OF FLYWHEEL KEYING CIRCUIT
VS. VOLTAGE & GRID RESISTANCE
TRANSMITTER CXFA/X-5000
TUBES PRODUCTION 527
5 MICROSECOND PULSE
FREQUENCY 132 MC.
DATA TAKEN 29 JULY & 1 AUG. 1944
REPETITION RATE, P.P.S.
190
180
170
160
150
RATE VS. VOLTAGE
(47300 OHMS GRID RESISTANCE)
RATE VS. RESISTANCE
(12.5 KV. PLATE SUPPLY)
PLATE SUPPLY VOLTAGE, KV.
5
10
15
GRID RESISTANCE, THOUSAND OHMS
35
40
45
50
55
60

PLATE 10

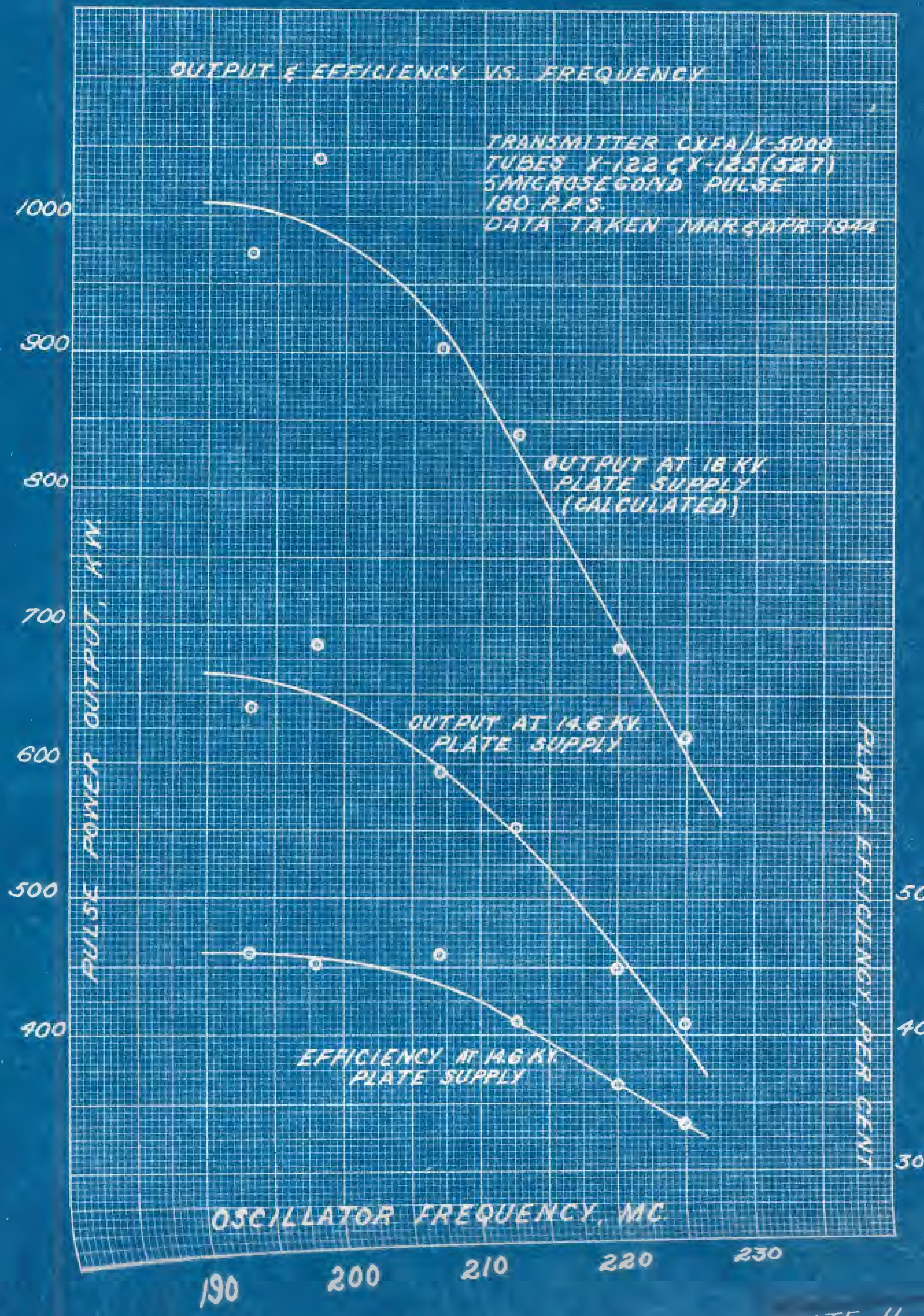

OUTPUT & EFFICIENCY VS. FREQUENCY
TRANSMITTER CXFA/X-5000
TUBES X-122 & X-125(527)
5 MICROSECOND PULSE
180 P.P.S.
DATA TAKEN MAR. & APR. 1944
OUTPUT AT 18 KV. PLATE SUPPLY (CALCULATED)
OUTPUT AT 14.6 KV. PLATE SUPPLY
EFFICIENCY AT 14.6 KV. PLATE SUPPLY
PULSE POWER OUTPUT, K.W.
1000
900
800
700
600
500
400
PLATE EFFICIENCY, PER CENT
50
40
30
OSCILLATOR FREQUENCY, MC.
190
200
210
220
230

PLATE 11

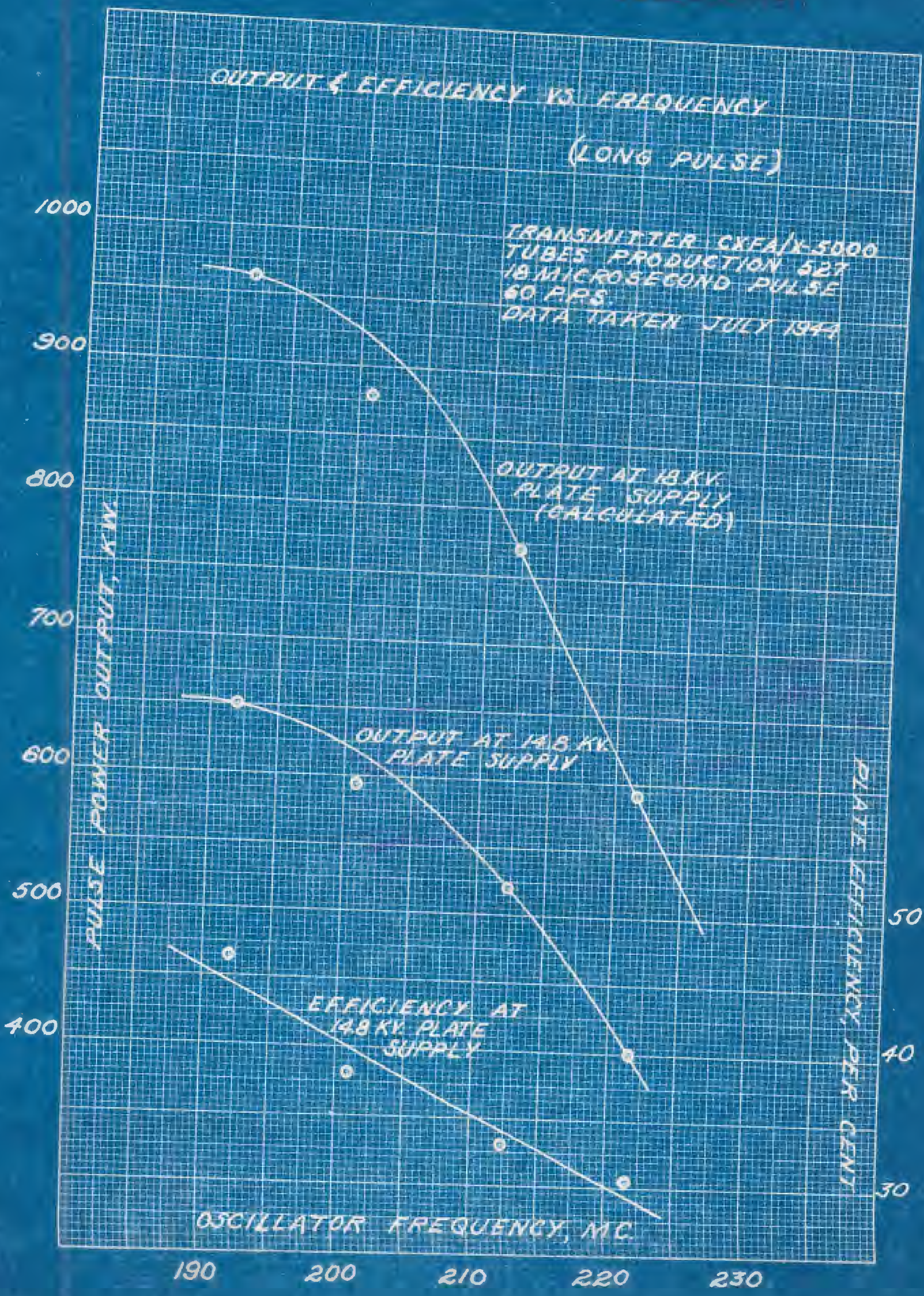

OUTPUT & EFFICIENCY VS. FREQUENCY
(LONG PULSE)
TRANSMITTER CXFA/X-5000
TUBES PRODUCTION 527
18 MICROSECOND PULSE
60 P.P.S.
DATA TAKEN JULY 1944
OUTPUT AT 18 KV. PLATE SUPPLY (CALCULATED)
OUTPUT AT 14.8 KV. PLATE SUPPLY
EFFICIENCY AT 14.8 KV. PLATE SUPPLY
PULSE POWER OUTPUT, K.W.
PLATE EFFICIENCY, PER CENT
OSCILLATOR FREQUENCY, M.C.
1000
900
800
700
600
500
400
50
40
30
190
200
210
220
230

PLATE 12