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CONSIDERATIONS IN THE DESIGN
OF TWO Mc LORAN TRANSMITTERS
INTENDED TO REDUCE SIDE-BANDS
AND PERMIT CYCLE-MACHINE OPERATION

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Preliminary Pages a-b
Numbered Pages 9
Plates 7

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TABLE OF CONTENTS

	<u>PAGE NO.</u>
ABSTRACT	b
STATEMENT OF PROBLEM	1
INTRODUCTION.	1
A GRID MODULATED CRYSTAL OSCILLATOR - POWER AMPLIFIER (COPA) LORAN TRANSMITTER	2
THE RADIO FREQUENCY MULTIPLIER.	2
THE PULSED STAGES	2
SIDE-BAND REDUCTION DATA.	4
HARMONIC REDUCTION METHOD AND DATA	5
SIDE-BAND REDUCTION BY MEANS OF FILTERS.	6
PULSE SHAPING BY MODULATION.	7
ADVANTAGES OF A CRYSTAL OSCILLATOR - POWER AMPLIFIER (COPA) LORAN TRANSMITTER	7
CONCLUSIONS	8
REFERENCES	8
PLATE 1 Block Diagram of Grid Modulated Loran Transmitter	
PLATE 2 Block Diagram of Radio Frequency Multiplier for a Crystal Oscillator - Power Amplifier Loran Transmitter	
PLATE 3 Radio Frequency Multiplier (Schematic)	
PLATE 4 Pulsed Stages (Schematic)	
PLATE 5 Waveforms Observed in Experimental Copa Loran Transmitter	
PLATE 6 Amplitudes of Side-Bands Generated by Experimental Crystal Oscillator - Power Amplifier Loran Transmitter.	
PLATE 7 Response Curve of Ser. No. C-379 National HRO Receiver Employed in the Measurement of Frequency Components of Loran Pulses	

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ABSTRACT

Loran transmitters currently in service are of pulsed oscillator type. They suffer from pulse and frequency instability. Their signals occupy large bands in the spectrum with consequent inter-channel interference in addition to interfering with the operation of other services. Greater accuracy in Loran systems may be obtained by matching individual r-f cycles, the first prerequisite of which is rigid control of the radio frequency and phase of the transmitter output. Since present Loran transmitters are not compatible with the requirements for reduction of side-band radiation and cycle-matching techniques, an investigation was conducted to ascertain the possibilities in the design of new Loran transmitters. A simple method of deriving the radio frequency from the Loran Timer's crystal oscillator has been evolved, thus permitting the use of cycle-matching techniques and insuring excellent frequency stability. Side-bands may be minimized by controlling the shape of the pulse. This report describes the techniques employed and the results obtained with an experimental grid-modulated crystal-oscillator power-amplifier transmitter.

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STATEMENT OF PROBLEM

1. Reference (1) requested the Laboratory to devise a means for reducing the side-band radiation from Loran transmitters. The method of attack was to be determined by the Laboratory. It became apparent that cycle-matching as developed for LF Loran results in improved accuracy and a reduction in the effects of noise. Consequently, reference (2) requested the Laboratory to determine the feasibility of incorporating cycle-matching in standard 2 mc. Loran systems. Enclosure (A) of reference (2) states that "the overall results which this and associated NRL problems should provide are: (a) Design suggestions for a MOPA type of transmitter with restricted band radiation, capable of utilizing the timer oscillator as a source of stabilized frequency; (b) Means for deriving the transmitter frequencies from the timer oscillator". This report covers the results of the work on this project by the Transmitter Section of the Ship-Shore Radio Division.

INTRODUCTION

2. Loran transmitters currently in service are of the pulsed oscillator type. They suffer from pulse and frequency instability. Their signals occupy large bands in the spectrum. The fundamental design of these transmitters does not permit the application of cycle-matching techniques in the synchronization of slave stations. Consequently, the most modern Loran transmitter, the Model TDP-1, is not regarded as an ultimate design in Loran transmitters. Cycle-matching and side-band reduction both entail stabilization of the transmitter frequency and control of the pulse shape. The transmitter frequency may be stabilized by deriving its carrier frequency from the Loran timer's crystal oscillator. Side-bands may be minimized by controlling or modulating the shape of the pulse. Reference (5) contained four proposals for new types of Loran transmitters. After a conference with representatives of the United States Coast Guard and Code 935 of the Bureau of Ships, it appeared that the second proposal of reference (5) was the most practical one to meet service needs. Reference (6) contained brief circuit design suggestions and a description of a crystal oscillator-power amplifier type of transmitter which derives its carrier frequency from the Loran timer's crystal oscillator.

3. The side-band reduction problem was attacked by two methods: (1) An attempt was made to build filters which would attenuate the undesirable side-band spectra. (2) Rectangular radio-frequency pulses were fed to a power amplifier stage where they were shaped or modulated, thus reducing side-bands.

4. The transmitter described in the following paragraphs is the culmination of the experiences gleaned in working on the project. A complete description is provided for a radio-frequency multiplier which permits the derivation of various carrier-frequencies from the Loran timer crystal oscillator. A simple system of generating and modulating radio-frequency pulses is described. Data on the side-band and harmonic spectra due to transmitted pulses are also presented.

A GRID MODULATED CRYSTAL OSCILLATOR - POWER AMPLIFIER (COPA) LORAN TRANSMITTER

5. Plate 1 is a block diagram of the proposed type of COPA Loran transmitter. A radio frequency multiplier generates a frequency of half the carrier frequency from the 100 kc Loran Timer oscillator. This continuous wave output is then applied to a pulsed doubler which generates a rectangular excitation wave at the carrier frequency. A series of IPA stages increase the power level prior to driving the grid modulated power amplifier stage. The power amplifier is modulated by a cosine wave derived from the same source which triggered the excitation wave.

THE RADIO-FREQUENCY MULTIPLIER

6. Plate 2 is a block diagram of the radio-frequency multiplier which is required to generate a frequency of one-half the carrier frequency from the 100 kc timer oscillator voltage. Two of these radio-frequency multipliers are required for double pulse operation as diagrammed in Plate 1. The 100 kc signal from the timer oscillator is multiplied by a factor of nine before the signal is injected into a converter. Reference to Plate 2 will clarify the method by which the various frequencies are combined in the converter to permit operating the COPA transmitter on either 1750, 1800, 1850, 1900, or 1950 kc. With the use of the 20, 25, and 33 1/3 cps repetition rates, this frequency allocation would provide for the operation of 120 pairs of Loran stations without operating more than one pair on the same radio-frequency at the same repetition rate.

7. Plate 3 is a schematic diagram of a radio-frequency multiplier. Tubes V1 and V2 operate as triplers thereby driving grid number 1 of the converter, V3, with a 900 kc signal. Switch S1 selects the appropriate beat frequency which together with the tuning of the circuit L3C3 determines the converter output frequency. The intermediate amplifier, V4, smooths the amplitude modulations resulting from the beating action of the converter. Constant amplitude waves at one-half the transmitter output frequency are delivered to the pulse exciter. Tube V5 is a locked divider generating a 25 kc signal which is doubled and tripled by V6 and V7, respectively. Dividing is accomplished in tube V5 by driving grid number 1 with a 100 kc signal while grid number 3 is being driven by a 75 kc signal, the plate circuit being tuned to the beat frequency of 25 kc. Tripler V7 multiplies this 25 kc signal to 75 kc for application to grid number 3 of divider tube V5.

THE PULSED STAGES

8. Plate 4 is a schematic diagram of the pulsed stages of an experimental COPA transmitter. Tubes V8 and V9 act as pulsed "push-push" doublers with grid circuit L9C9 tuned to one-half the carrier frequency. The plate circuit L10C10 is tuned to the carrier frequency. This stage is biased beyond cut-off until the positive keyer pulse at "C" drives the tubes to saturation resulting in the rectangular radio-frequency excitation pulse shown in Plate 5 (B).

This excitation pulse has a base length of 75 microseconds and a rise time of 2 microseconds. The doubler keying pulse recorded in Plate 5 (C) has a base length of 65 microseconds. A second pulsed doubler is required for double pulse operation. Under these conditions both pulse doublers should employ the common plate tuning circuit, L10C10, so that both pulses would encounter similar tuned circuits. The plates and screens of a second pulsed doubler may be connected at the point "B" in Plate 4. Radio-frequency pulses are generated in the last doubler stage in order to minimize radiations on the carrier frequency between pulses. It is necessary to employ careful shielding and isolation of the pulsed doubler and radio-frequency multipliers in order to minimize radiations which might interfere with signals received between pulses by the timer receiver.

9. The schematic drawing of an experimental grid-modulated power-amplifier stage is shown in Plate 4. A high power transmitter similar to the one diagrammed in Plate 1 would employ three IPA stages. These stages have not been employed in the experimental transmitter in the interest of simplicity. However, Loran transmitters with three pulsed stages have been successfully constructed at the Laboratory. In designing IPA stages for a grid-modulated Loran transmitter it is imperative that the rise time of the pulse in each stage be kept as fast as possible in order to minimize the time delay introduced from the time the first IPA stage is excited until the last IPA stage delivers a pulse. Since IPA stages were not employed in the experimental transmitter being described, the rectangular excitation pulse from the pulsed doubler is coupled directly to the power amplifier grid circuit. The power amplifier is biased beyond cut-off prior to the arrival of the radio-frequency excitation pulse "B" and the modulation waveform "E". Plate 5 (B) is a photograph of the excitation pulse while Plate 5 (E) shows the modulation waveform. The modulated power-amplifier stage generates a pulse similar to the one recorded in Plate 5 (A).

10. Plate 4 also contains circuit drawings of the keying and modulating circuits. The heart of the pulse generating circuit is the thyatron, V12, and its associated artificial line. The artificial line in the plate circuit of the thyatron is charged to 800 volts through a 50000-ohm resistor during the "off" period. When the thyatron is triggered through the pulse input transformer, T1, the thyatron effectively acts as a switch in terminating the artificial line across the 100 ohm resistor in the cathode of the thyatron. Thus a positive pulse of voltage appears at the cathode of the thyatron as the artificial line is discharged and the thyatron extinguishes itself. The line is recharged during the "off" period between pulses. Plate 5 (E) shows the waveform generated by the thyatron. The slope of the leading or lagging edges of the pulse may be reduced by adding low values of resistance in series with the first or last condenser in the artificial line. A half of tube V11 is employed as a pulse squaring amplifier, the output of which is shown in Plate 5 (D). The other half of tube V11 is employed as a pulse inverter in order to produce the pulsed doubler keying waveform shown in Plate 5 (C). Reference to Plate 1 shows that two of these pulse generator circuits and a diode mixer are required for double pulse operation. The pulse forming thyatron,

V12, in Plate 4 is suitable for generating waveforms in grid modulating high-power Loran transmitters, since the JAN Type 4C35 thyratron may be employed to generate several kilovolts of pulse potential.

SIDE-BAND REDUCTION DATA

11. Pulse transmission spectra consist of a carrier and an infinite set of upper and lower frequency sidebands. For a given pulse repetition rate the number of significant side-bands and the effective band-width increase as the pulse length is shortened. At a given pulse repetition rate the number of significant side-bands and the effective band-width also increase when the rise and decay time of the pulse are shortened. It is permissible to think of the shape of the pulse as a function of the amplitude vs. frequency distribution of the radio-frequency components. As observed by the Loran navigator, the steepness of the leading edge of the pulse is in part due to the shape of the transmitted pulse and in part due to the shaping by the receiver-indicator. Figure 35 of reference (4) shows how narrowing the receiver band-width widens the observed pulse shape and reduces the steepness of the pulse. The overall problem, therefore involves both the transmitter and the receiver characteristics. From the receiver standpoint, it is desirable to restrict the band-width as much as possible in order to minimize the effects of noise and interference, and yet to keep the band sufficiently wide so as not to reduce the pulse slope sufficiently to impair the measurement accuracy. From the transmitter standpoint, it is desirable to restrict the frequency of the radiated components in order to avoid interference with other Loran channels and other services, while at same time transmitting a pulse which meets the demands of the Loran service.

12. After considering the numerous variables involved, the Bureau of Ships established a specification on desirable transmitter pulse shape in Par. 5 of reference (8). Paragraph 3-30 of reference (7) established specification limits on the amplitude vs. frequency distribution of radio-frequency components due to the transmitted pulses. These specifications state that the pulse width at half amplitude shall be within the limits of 38 and 42 microseconds. The pulse rise time to 90% amplitude shall not exceed 25 microseconds. Maximum width of the pulses at 10% amplitude shall not exceed 60 microseconds. The energy in the spectrum due to the transmitted pulses shall be down 10 db at ± 25 kc, 35 db at ± 50 kc, and 75 db at ± 100 kc.

13. The experimental transmitter described in previous paragraphs was adjusted to emit a pulse similar to the one recorded in Plate 5 (A). Its shape meets the specification requirements in par 5 of reference (8) since the pulse length at half amplitude was 41 microseconds, the rise time to 90% amplitude was 25 microseconds, the length at 10% amplitude was 60 microseconds, and the base length was 66 microseconds. Plate 6 contains a curve of the amplitude vs. frequency distribution of energy due to the transmitted pulses. It should be noted that the side-band energy is down approximately 38 db at ± 25 kc, 52 db at ± 50 kc, and 57 db at ± 100 kc. According to data recorded for similar measurements by the Bell Telephone Labora-

tories in reference (3), existing Loran transmitters generate sidebands down approximately 10 db at ± 25 kc, 22 db at ± 50 kc, and 35 db at ± 100 kc. The Interservice Laboratory of the National Bureau of Standards has recorded approximately similar data in Fig. 16 of reference (4). Approximately similar data have also been recorded at this laboratory by adjusting experimental transmitters to simulate the usual Loran pulse.

14. The general method of measurement was similar to that employed by the Bell Telephone Laboratories and the Interservice Radio Laboratory, both of whom employed National HRO receivers in probing the spectrum. Plate 7 contains the frequency response curve of Ser. No. C-379 National HRO receiver employed in determining the sideband data recorded in Plate 6. Pulse signals for probing by the receiver were derived from a capacitor type of divider connected across the dummy load resistor at point "A" in Plate 4. A fifty-foot length of 52-ohm coaxial cable served as one side of the capacitor divider in addition to conducting the sampling signal to the probing receiver. The indicator of a DAS-2 Loran receiver was connected to the output of the probing receiver in order to present the output visually as a means of adjusting the gain. Signals from a Model 605B General Radio Oscillator were then substituted for the transmitter signal as a means of determining the relative signal input potentials. The nodal points of the curve in Plate 6 represent points of maximum and minimum energy as determined by the probing receiver.

HARMONIC REDUCTION METHOD AND DATA

15. Harmonics from Loran transmitters are of sufficient strength to interfere with other services. This condition will become increasingly serious as the peak power output of Loran transmitters is increased. Experiments in harmonic reduction were conducted with the experimental grid modulated transmitter. A series circuit resonant to the harmonic frequency was connected across the dummy load resistor, between point "A" and ground in Plate 4. The following data were recorded when a pulse similar to the one shown in Plate 5 (A) was transmitted:

Harmonic	Frequency (Kcs)	Relative Output Unfiltered (DB)	Relative Output Filtered (DB)
0/	1850	0	0
2	3700	-37.0	-45.5
3	5550	-38.0	-45.0
4	7400	-41.0	-49.0
5	9250	-43.0	-50.5
6	11100	-47.5	-56.5
7	12950	-63.5	-74.0
8	14800	-73.0	--

No changes in pulse amplitude or shape due to tuning of the series resonant circuit could be observed on a Servoscope connected across the dummy load resistor. When the filter was tuned to the eighth

harmonic, the signal was just barely noticeable above the noise level. It should be remembered that the data recorded above are not an indication of the harmonic radiation which may be anticipated from actual Loran transmitters since push-pull final amplifiers might be expected to reduce even harmonics. The antenna coupling unit and the antenna are frequency selective devices. The experimental transmitter has a single-ended power amplifier stage. The data and experimental results show that harmonics due to Loran transmitters may be reduced by employing simple series resonant circuits, without distorting the pulse shape or complicating transmitter tuning procedures.

SIDE-BAND REDUCTION BY MEANS OF FILTERS

16. The problem of pulse shaping to reduce side-bands was originally attacked from the aspect of filtering undesirable components. Design calculations for a conventional pass-band filter with the desired characteristics showed the impracticability of this scheme for Loran transmitters, considering the high peak potentials and currents which would be encountered in high-power transmitters. These filters also reflect a variable impedance with frequency as observed by the power amplifier stage. Vestigial side-band filters similar to those employed in television transmitters were then investigated. This general type of filter, described on page 301 of Volume V of the RCA Review, actually dissipates most of the energy in the undesired side-band. Lumped constants were employed instead of the coaxial stubs encountered in television transmitters. An attempt was also made to filter both side-bands instead of one as is required in television practice. The input impedance of an experimental double side-band vestigial filter, suitably terminated, remained reasonably constant at ± 150 kc of the carrier frequency. However, the insertion loss was approximately 6 db. Under steady-state conditions, the attenuation at ± 100 kc was approximately 27 db. Under pulsed conditions, a rectangular pulse was converted to a type approximating the exponential rise-exponential decay with little improvement in side-band reduction as compared to present transmitters. "Ringing" on the trailing edge of the pulse was also in evidence. This type of filter requires precise control of the constants, entailing close tolerances in manufacture and operation. Different filters would have to be designed for each channel frequency. It also appeared that voltages which would be encountered in high-power transmitters would render this type of filter impractical, even if further development could have improved its characteristics.

17. The effect of shaping rectangular pulses by passing them through a Loran receiver is well known. The tuned circuits discriminate against various components in the side-bands depending on the selectivity of the receiver. An attempt was made to construct a series of three transformers for insertion between the transmitter and the antenna. These circuits proved to be difficult to tune since tuning one of them varied the characteristics of the others. It must be remembered that in receivers the tubes act as decoupling devices between the various tuned transformer circuits. No appreciable improvements in side-band reduction were effected by this method.

PULSE SHAPING BY MODULATION

18. After reaching the conclusion that pulse-shaping by means of filters was impractical for application to Loran transmitters, greater consideration was given to pulse shaping by actual modulation of some stage in the transmitter. Pulse shaping could actually be performed by keying the pulsed doubler with a suitable waveform. However, this would necessitate the use of linear amplifiers in all subsequent stages of high-power Loran transmitters. Linear amplifiers are more difficult to adjust and have lower efficiency than do Class C amplifiers. Another possibility would be plate modulation or keying of the final amplifier. It is believed that plate keying might be accomplished successfully by employing a modulator tube and pulse transformer under single pulse conditions. However, the design of pulse transformers is quite dependent upon repetition rate. Under double pulse conditions in Loran transmitters the repetition rate approaches infinity as the cross-over point is approached. Consequently, it would be necessary to employ separate pulse transformers in connection with diode mixers. The diode mixers would have to be capable of peak emissions equal to the power amplifier tubes, rendering this method somewhat impractical. Absorption modulation was attempted and it was found possible to generate cosine shaped output pulses rather easily. However, it was not found possible to modulate to the degree necessary to generate the desired cosine-squared waveform.

19. Grid-bias modulation of the power amplifier stage seems to be the most reasonable approach to pulse shaping by modulation in order to avoid the use of a number of linear amplifiers. A comparatively small tube is capable of controlling transmitters of considerable power. In this system the plate voltage is essentially constant and the power output during the pulse is obtained by increasing the plate current during the pulse.

ADVANTAGES OF A CRYSTAL OSCILLATOR - POWER AMPLIFIER (COPA) LORAN TRANSMITTER

20. (a) The COPA transmitter facilitates the application of cycle-matching techniques to 2 mc operation.
- (b) The COPA transmitter minimizes the possibility of off-frequency operation and locks the master and slave stations on precisely the same frequency as long as synchronization is maintained.
- (c) The COPA transmitter is potentially capable of providing excellent frequency and pulse stability under variable conditions of temperature, humidity, and line voltage. The transmitter frequency stability is determined by the timer crystal oscillator, which is an extremely stable device.
- (d) The COPA transmitter minimizes the possibility of frequency shift during the pulse, thereby reducing the side-band radiations. The pulsed oscillator currently employed in Loran Transmitters derives its plate potential from a capacitor in which the potential decreases by as much as 20 per cent during the pulse. This

condition is conducive to frequency shift in oscillators. Phase and frequency modulation complicate the side-band frequency spectra.

(e) The COPA transmitter permits modulation of the pulse in order to reduce side-bands.

CONCLUSIONS

21. It is possible to design successful pulsed multistage and multifrequency Loran transmitters which derive their carrier frequency from the crystal oscillator in the Loran timer. This procedure permits the generation of pulsed signals whose radio frequencies are extremely accurate and stable. Phasing controls may be inserted between the crystal oscillator and the radio frequency multiplier thus permitting accurate control of the r-f phase as required in Loran cycle-matching operation. Pulses of excellent stability may be generated.

22. Side-band reduction by means of filters does not appear practical for application to Loran transmitters. However, side-bands may be reduced by shaping the pulse to approach a cosine-squared waveform. This shaping or modulation may be successfully accomplished by grid modulation of the power amplifier stage. An experimental transmitter of this type generated side-bands which were 28 db lower at ± 25 kc, 30 db at ± 50 kc, and 22 db lower at ± 100 kc than side-bands generated by existing Loran transmitters.

23. Harmonics due to Loran transmitters may be reduced approximately 7-10 db by placing a series resonant circuit across the transmitter's output load circuit. Pulse shape is not distorted by this procedure.

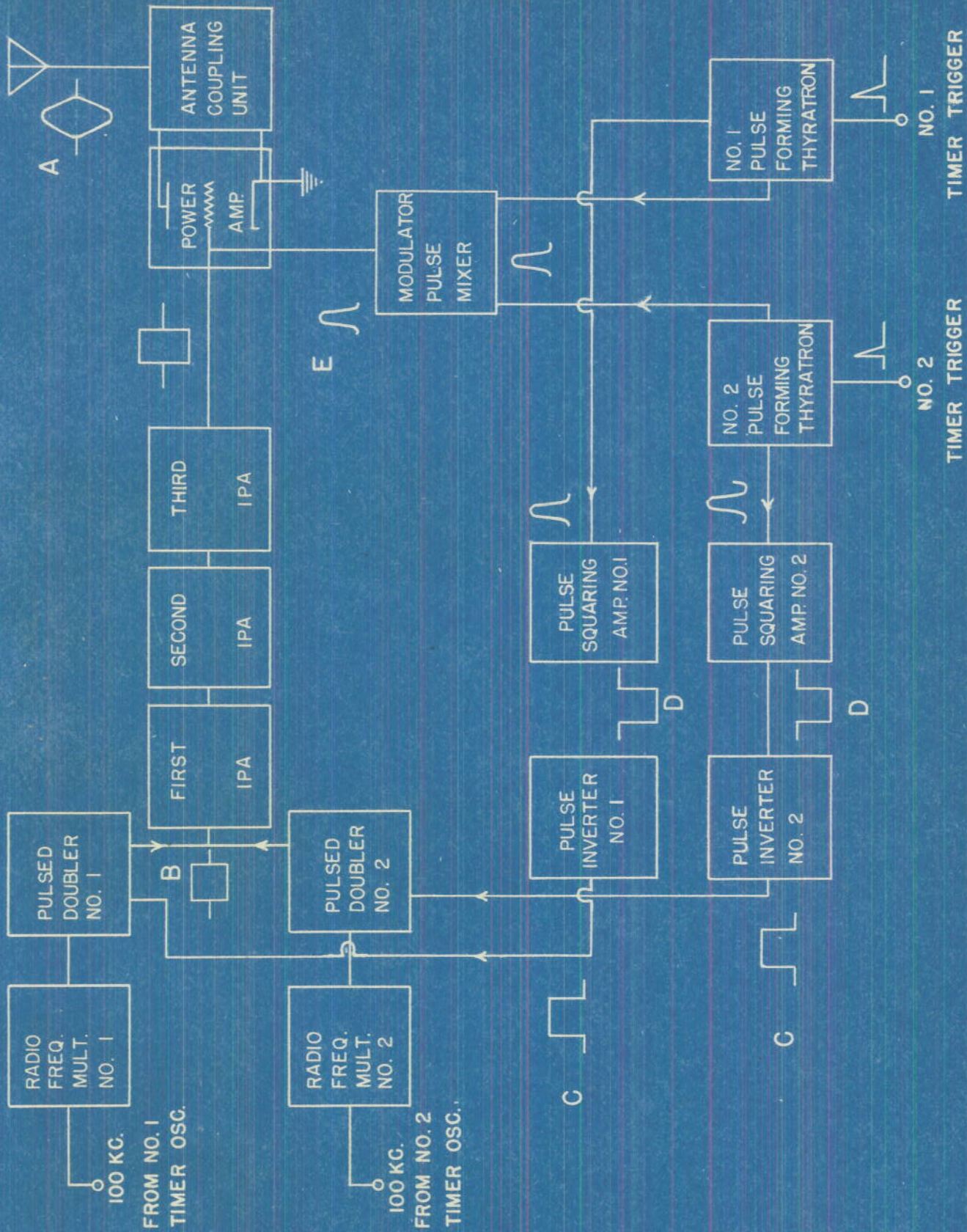
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3. OSRD Report "Interference of Loran Pulse Signals with Radio Telephone and Telegraph Reception" by Bell Telephone Laboratories of 4 March 1943.
4. IRPL Report No. R24 by National Bureau of Standards of 12 October 1945: Relations Between Band Width, Pulse Shape and Usefulness of Pulses in the Loran System.
5. NRL ltr, C-S67-9/10(380-MVH) Ser. No. C-380-492/45 of 18 Sept 1945 to BuShips: Proposals for Loran Transmitters.
6. NRL ltr, C-S67-9/10(380-MVH) Ser. No. C-380-548/45 of 30 October 1945 to BuShips: Proposal for Crystal Oscillator - Power Amplifier Loran Transmitter.

7. BuShips Specification RE 16T13(RE) of 20 October 1944:
Specifications for Loran Radio Transmitting Equipment.

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General Electric Company: Supplementary Design Data No. 1 for
Contract NXsr-90770.

Original data recorded in NRL Log Book 5147



BLOCK DIAGRAM OF GRID MODULATED LORAN TRANSMITTER

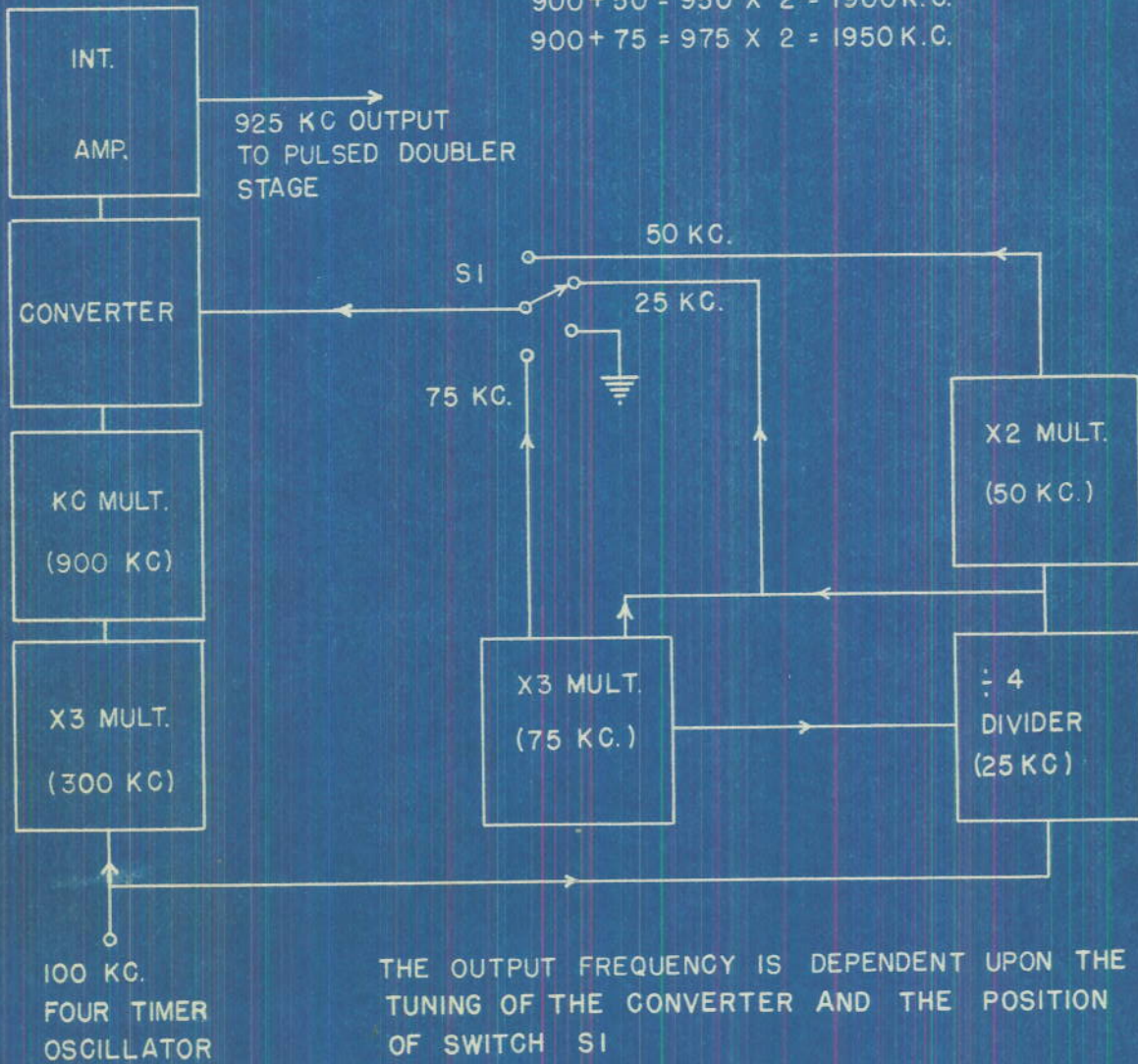
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PLATE I

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CONVERTER - X2 MULT - OUTPUT

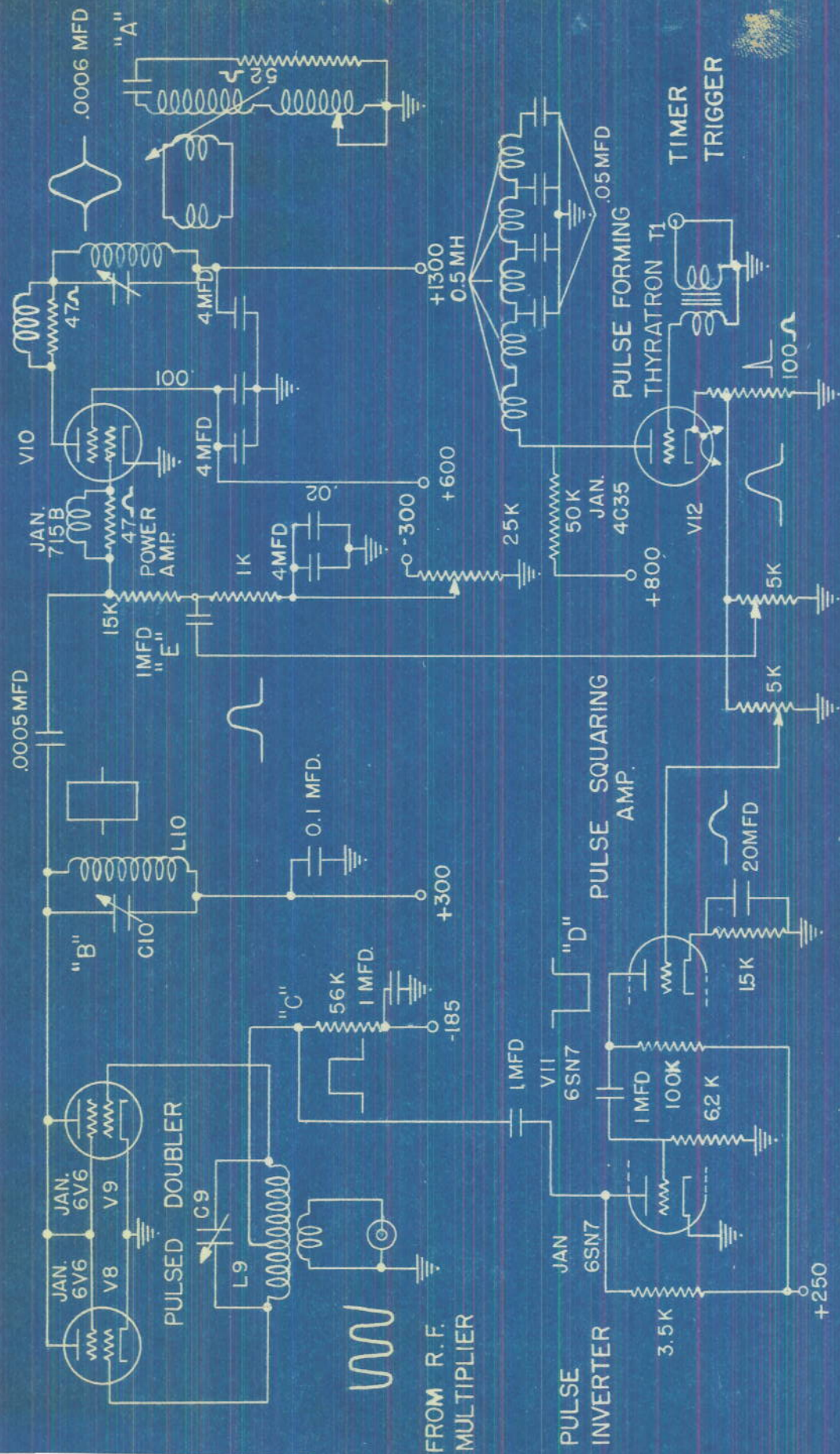
$900 - 25 = 875 \times 2 = 1750 \text{ K.C.}$
 $900 - 0 = 900 \times 2 = 1800 \text{ K.C.}$
 $900 + 25 = 925 \times 2 = 1850 \text{ K.C.}$
 $900 + 50 = 950 \times 2 = 1900 \text{ K.C.}$
 $900 + 75 = 975 \times 2 = 1950 \text{ K.C.}$



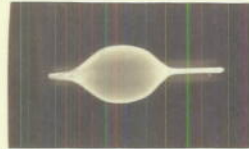
BLOCK DIAGRAM OF RADIO FREQUENCY MULTIPLIER FOR
A CRYSTAL OSCILLATOR - POWER AMPLIFIER LORAN
TRANSMITTER

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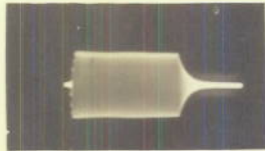
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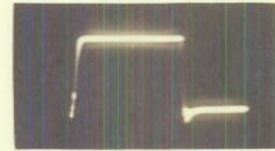
PULSED STAGES



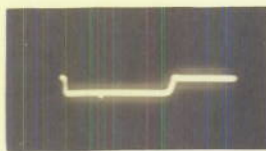
(A) TRANSMITTER OUTPUT
AT DUMMY ANTENNA



(B) PULSED DOUBLER
OUTPUT



(C) PULSED DOUBLER
KEYING WAVE



(D) SQUARING AMP.
OUTPUT



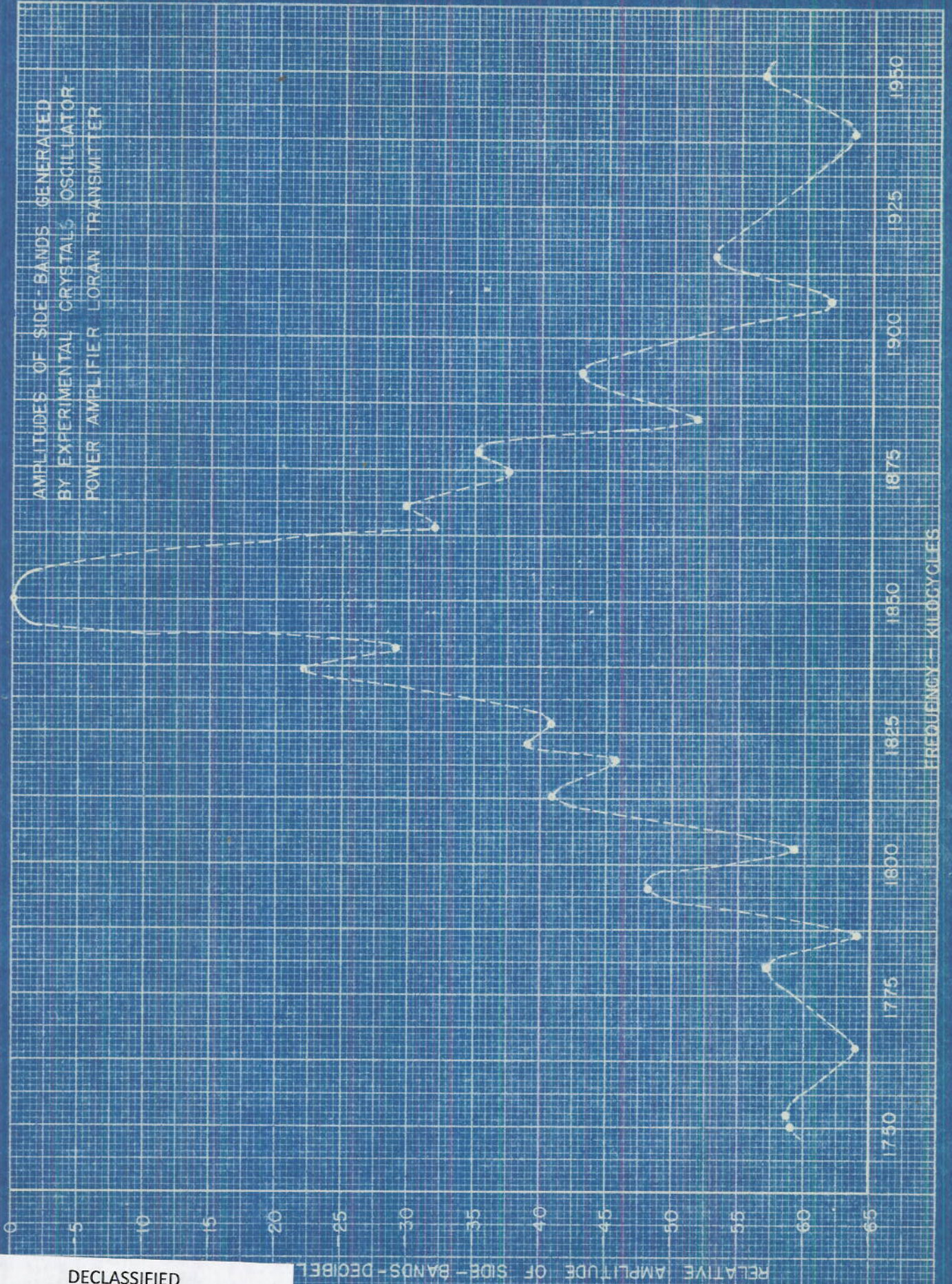
(E) POWER AMP.
MODULATION WAVE

(ALL PHOTOS TAKEN ON 100 μ s SWEEP OF NRL SERVOSCOPE)
WAVEFORMS OBSERVED IN EXPERIMENTAL COPA LORAN TRANSMITTER

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KEUFFEL & ESSER CO., N. Y. NO. 359-11
10 x 10 to the 1/2 inch, 6th lines accented.
Engraving, 7 x 10 in.
MADE IN U. S. A.

AMPLITUDES OF SIDE-BANDS GENERATED
BY EXPERIMENTAL CRYSTALS OSCILLATOR-
POWER AMPLIFIER LORAN TRANSMITTER



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PLATE 6