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HARMONIC RADIATION FROM THE TYPE TUI TRANSMITTER

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by
Samuel E. Taggart
H. F. Keary
Arthur E. Frederick

Electronics Division

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CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT
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INTRODUCTION

This report describes an investigation of spurious and harmonic radiation from a Type TUI control tower transmitter. The investigation was made at the request of the Office of Federal Airways.

Harmonics developed and emitted by the Type TUI transmitter may be attributed to the mechanical construction and assembly of the radio-frequency (r-f) compartments and to the poor electrical design of the r-f circuits. Apparently not much attention was given to isolation of the r-f circuits from power-supply components and circuit wiring in this transmitter.

A reduction of most of the spurious radiation, within the frequency band from 88 to 160 megacycles (Mc), at distances of several hundred feet from the transmitter was possible by making certain modifications to the multiplier stages and to the antenna coupling circuit and by improving bonding of the transmitter cabinet to the back cover and front panels.

The results obtained when a mode type of crystal oscillator with a multiplier stage and a low-powered amplifier stage were substituted for the crystal oscillator with the multiplier stages originally used are also shown.

Considerable r-f leakage emanates from the transmitter cabinet and is due principally to mechanical construction and assembly of the r-f compartments. It is believed that redesign of these compartments would be necessary to reduce the leakage to a negligible value. The present layout and crowded condition of the exciter compartment make it difficult to effect any real improvement in harmonic suppression, although the use of an open-ended stub inserted in the cable feeding the antenna reduced the second harmonic to a low value after an r-f feed-through bushing was properly installed in the transmitter cabinet. The stub was one-quarter wavelength at the second harmonic frequency.

EQUIPMENT

Two Type TUI transmitters, Serial Nos. 26 and 227, were furnished for the tests. These transmitters usually work into a Type CA-1350 antenna for communications between aircraft and control towers. A Type CA-1350 antenna was available at the Center, and both transmitters were tested in turn with this type of radiator.

The frequency of the crystal furnished was 4929.17 kc. This was multiplied 24 times through the various r-f stages in the transmitter to obtain an output frequency of 118.3 Mc. The frequency of the crystal used in the overtone oscillator tests was 59.150 Mc. The mode of the crystal was not specified by the manufacturer. The frequency was doubled in the second section of a 12AT7 oscillator-doubler stage and amplified by a Type 2E26 tube. Fig. 1 is a block diagram of the r-f portion of an unmodified Type TUI transmitter. Fig. 2 shows in similar fashion the same portion of the transmitter after it was modified to permit use of the overtone oscillator.

A Stoddart field intensity meter was employed to indicate the magnitude of the spurious radiation relative to the main carrier frequency. Field strength measurements of harmonic radiation were obtained over the frequency band from 88 to 240 Mc.

HARMONIC FIELD STRENGTH MEASUREMENTS

During the initial tests of the unmodified transmitters, strongest harmonic radiations within the band measured at a distance of 800 feet were observed at frequencies of 157.7, 113.37, 123.23, 128.16, and 138.46 Mc. A strong second harmonic of the carrier frequency (236.6 Mc) was in evidence, and one of lesser intensity at 197.132 Mc. Both transmitters exhibited the same harmonic radiation characteristics.

Transmitter No. 227 was modified to provide inductive coupling between the doubler plate circuit and the tripler input circuit. The tripler input circuit was resonated to the output frequency of the doubler plate circuit. The lead connections between coil and tuning capacitors and r-f by-pass condensers in the quadrupler and doubler stages were shortened to permit the use of one variable tuning capacitor in each plate circuit instead of two in series as originally used.

During the course of early measurements of harmonic radiations, it was noted that several harmonic frequencies (namely, 128.16, 138.016, 152.804, and 157.7 Mc, and harmonic frequencies within the band from 88 to 104 Mc) were nearly coincident with frequencies assigned to other services, and all of these harmonic frequencies could be a possible source of interference up to distances of several thousand feet under favorable receiving conditions.

Further tests were conducted in the vicinity of the transmitter. The field strength meter dipole was oriented to limit the maximum input to the instrument to approximately 100,000 μv when the separation between the transmitter antenna and the receiver dipole was approximately 45 feet.

The relative strength of harmonic radiations and carrier levels for the several distances from the transmitter are listed in Table I. Also shown in Table I are the conditions obtained when the TUI transmitter was terminated in a 52-ohm dummy load. The transmitter cabinet was found to be hot when the dummy load was used, and a considerable field of r-f near the transmitter was observed even though all shields and panels were in place and securely fastened. The radiation from the cabinet seemed to be strongest in the vicinity of the front panels associated with the power amplifier (PA) and exciter chassis.

The individual r-f stages were investigated, starting with the PA stage and working back toward the quadrupler stage. Table II shows the relative harmonic fields and carrier strength for the PA and tripler stages, and it also shows the harmonic fields from the plate circuits of the quadrupler and doubler stages.

Table III shows the results of attempts to minimize the harmonic content of the first and second multiplier stages. The crystal circuit was adjusted to function as an electron-coupled oscillator, and the plate circuit of the crystal stage was tuned to twice the crystal frequency. The driving power to the quadrupler grid (acting as a doubler) was decreased until near zero grid current was indicated on the grid meter. Under these conditions, sufficient driving power was available to succeeding stages to produce normal power output from the transmitter. The driving power to the second doubler grid could not be decreased to any great extent without a reduction in output power from the transmitter.

The tube sockets of the crystal stage and first and second doubler stages were isolated from the chassis to minimize the distributed capacity and losses in the circuits and to provide a better tuning range for the variable tank condensers. No decrease in harmonic radiation was apparent as a result of this modification.

The harmonic fields that radiated from the unloaded transmitter were erratic and unstable; and since some harmonic frequencies were practically coincident with assigned frequencies of local stations, considerable annoyance and delay were encountered in obtaining reasonably accurate measurements. Sometimes a change in circuit components in the transmitter would require a different orientation of the field meter dipole for maximum pick-up of some harmonic fields.

TABLE I

HARMONIC RADIATIONS OF A TYPE TUI TRANSMITTER

Frequency	CA-1350 Antenna Load				52-Ohm Load	
	Distance 800 Feet		Distance 45 Feet		Distance 12 Feet	
(megacycles)	Modified (μv)	Unmodified (μv)	Modified (μv)	Unmodified (μv)	Modified (μv)	Unmodified (μv)
157.7	0	6	5	50	88	500
152.804	0	1	0.8	9	2	12
147.874	0	0	0	1 3	1	12
142.945	0	0.2	0	4	1	7.5
138 016	1.5	1.5	10 5	12	12	27
133 087	0	0.5	0.5	0.8	0.9	3
128 16	0	1.8	1.4	20	0.8	80
123.23	0	3	0.75	55	0.3	52
118 3	10,000	10,000	100,000+	100,000+	25,000	14,000
113.37	0	5.5	8	20	2.7	77
108.441	0	0.5	0.7	10	0.5	120
103.512	0	0	0.2	0.4	0.5	120
98.583	0	0	0.2	5.5	1.4	100
93.654	0	0	0	0		
88.725	0	0	0	0		
236.6	28	123	230	630	750	

TABLE II

HARMONIC RADIATIONS OF AN UNMODIFIED TYPE TUI TRANSMITTER, SERIAL NO. 26
WITH RECEIVER DIPOLE LOCATED FOUR FEET FROM TRANSMITTER

Frequency	PA Chassis Removed From Cabinet			PA Stage
	Quadrupler Stage	Doubler Stage	Tripler Stage	Unloaded
(megacycles)	(microvolts)	(microvolts)	(microvolts)	(microvolts)
157.7	14	15	150	470
152.804	1	4	2.5	12
147.874	30	35	10	35
142.945	12	15	8	0.5
138.016	55	120	50	25
133.087	8	22	9	5
128.16	24	43	25	13
123.23	5	14	20	2
118 3	30	50	10,000	6,500
113.87	5	3	15	5
108.441	8	3	37	42
103.512	3	1		Not measured
98.583	35	25	18	Not measured
93.654	2	0	1	Not measured
88.725	1	3.5	1	Not measured
236.6				

TABLE III

HARMONIC RADIATIONS OF A MODIFIED TYPE TUI TRANSMITTER, SERIAL NO. 227
WITH RECEIVER DIPOLE LOCATED FOUR FEET FROM TRANSMITTER
AND PA CHASSIS REMOVED FROM CABINET

Frequency (megacycles)	Quadrupler Stage Grid Current Near Zero (microvolts)	Doubler Stage With Tripler Stage Inoperative (microvolts)	Tripler Stage (microvolts)
157.7	0	70	32
152.804	0.7	15	Interference
147.874	2	5	16
142.945	1.3	24	22
138.016	0.3	26	16
133.087	0	3	5
128.16	0	0.1	12
123.23	0	3	4.7
118.3	0	18	12,000
113.37	0	7.5	32
108.441	0	1	10
103.512	0	Interference	Interference
98.583	0	Interference	Interference
93.654	Interference	Interference	Interference
88.725	Interference	Interference	Interference

Cleaning the inner surfaces of all front panels, the front and rear surfaces of the cabinet, and inner surfaces of the rear shield to provide metal-to-metal contact between panels, shield, and cabinet provided more stable field conditions but did not reduce local radiation from the cabinet appreciably

Table IV indicates the extent to which the harmonic fields were reduced when the transmitter cabinet was completely enclosed in a metal cage with all stages operating normally under no-output-load and dummy-load conditions. While the metal cage effected some reduction in stray harmonic fields under dummy-load conditions, it was of little practical value when the transmitter antenna was located in the immediate vicinity of receiving equipment.

After completion of the tests outlined above, a few tests were conducted using a mode type of crystal oscillator operating on a frequency of 59.15 Mc.

The combination oscillator and frequency-multiplier shelf in the modified transmitter was removed and replaced by a new one on which the combination of a mode type crystal oscillator, frequency doubler, and r-f amplifier had been installed. The plate tank of the Type 815 frequency tripler originally employed became part of a link circuit used to couple r-f energy from the plate of the Type 2E26 amplifier tube to the grids of the Type 829-B power amplifier.

No changes were made in the transmitter other than those previously mentioned: (1) r-f grounds were made directly to the chassis, (2) the antenna relay was removed and the associated required changes were made, and (3) the outer r-f conductor of the transmission line was well-bonded to the cabinet by means of a feed-through bushing.

When tuning, some pulling of oscillator frequency was noted but no tendency of the oscillator to operate on a lower mode was evident. The pulling of oscillator frequency (less than 10 kc at 118.3 Mc) could probably have been reduced by slight changes in circuitry.[1,2,3] A rough check of the output frequency of the transmitter showed it to be

[1]George H. Lister, "Overtone Crystal Oscillator Design," Electronics, Nov. 1950, p. 88.

[2]Edward P Tilton, "Overtone Crystal Oscillator Circuits," QST, April 1951, p. 56.

[3]F. G. R. Rockstuhl, "A Method of Analysis of Fundamental and Overtone Crystal-Oscillator Circuits," The Proceedings of the Institute of Electrical Engineers, Nov. 1952, p. 377.

TABLE IV

HARMONIC RADIATIONS OF A MODIFIED TYPE TUI TRANSMITTER, SERIAL NO. 227
WITH RECEIVER DIPOLE LOCATED TWELVE FEET FROM TRANSMITTER

Frequency	Transmitter Unloaded		Transmitter Loaded	
	No Cage	Cage	No Cage	Load External to Cage
(megacycles)	(microvolts)	(microvolts)	(microvolts)	(microvolts)
157.7	65	9	190	12
152.804	1.2	2	3	1.75
147.874	0	0.2	1.7	0
142.945	1.25	0.75	1.5	0
138.016	18	1.2	16	12
133.087	2	0	2.2	0.4
128.16	0	0	0.6	0
123.23	0.4	0	1.6	0
118.3	1,100	700	11,000	240
113.37	0.4	0	1	0
108 441	1.25	0.2	1.2	0
103.512	1.0	0	0.3	0
98.583	Interference	0	0.2	0
93.654	Interference	0	Interference	0
88 725	Interference	0	Interference	1.5
236.6	600	9	750	10

approximately 118.38 Mc instead of the desired 118.30 Mc Inasmuch as the object of this investigation was to test the possibility of using a mode type of crystal oscillator to reduce the spurious and harmonic radiation of the Type TUI transmitter, no attempt was made to correct the frequency by modifying the circuits.

As explained in references,[1,2,3] initially establishing the correct frequency of the oscillator is a requirement of the mode type of oscillator. Experience with this and other mode type oscillators of the same kind indicates that the solution lies in proper selection of components and in maintaining certain relations between the inductance, capacity, and coupling of the various circuits. Frequency stability may exceed that of conventional crystal oscillators if due attention is paid to the temperature coefficient of the various components.

Table V indicates the measurements of field strength of the spurious and of the desired signals emitted by the unmodified transmitter and the transmitter modified to use the mode type crystal oscillator. For purpose of more accurate comparison, these measurements were made on the same day. No electrostatic shield on the bottom of the PA chassis was used during any of these tests.

The field-strength reading of 0.75 microvolts at 133 Mc in the modified transmitter was found to be a spurious oscillation originating in the crystal-oscillator plate circuit.

Additional measurements of field strength were made at a distance of 800 feet from the transmitting antenna. These are shown in Table VI.

The signals observed at approximately 151, 153, 163, 202, 208, and 213 Mc are not 59-Mc multiples of the mode type of crystal frequency and their source is unknown. Inasmuch as the 151-, 153-, and 163-Mc signals were also observed while testing the unmodified transmitter, it is possible that they represent beat frequencies between the fundamental or an harmonic of the 118.3-Mc output of the transmitter and some other source of r-f such as a receiver oscillator or another transmitter. In every case the unexplained signal disappeared when the plate voltage of the TUI transmitter was cut off; but this, of course, would be expected if the cause of the signal was either a beat between the 118.3-Mc output of the transmitter and some external r-f source or a spurious signal generated in some part of the modified Type TUI transmitter Additional tests conducted in a shielded room would eliminate any spurious signals caused by beats between the transmitter and an external source.

TABLE V

EVALUATION OF TUI TRANSMITTER WHEN DRIVEN WITH A MODE CRYSTAL OSCILLATOR UNIT

Approximate Frequency (megacycles)	Modified TUI (microvolts)		Unmodified TUI (microvolts)	
89.5	0		28.0	(harmonic)
94.5	0		5.0	(harmonic)
99.0	0		150.0	(harmonic)
104.5	0		25.0	(harmonic)
109.5	0		70.0	(harmonic)
114.0	0		75.0	(harmonic)
118.3	90,000	(fundamental)	60,000.0	(fundamental)
124.0	0		50.0	(harmonic)
128	0		320.0	(harmonic)
130	0		0.5	(source unknown)
133	0.75	(parasitic)	1.25	(source unknown)
134	0		120.0	(harmonic)
139	0		270.0	(harmonic)
144	0		40.0	(harmonic)
148	0		70.0	(harmonic)
151	1	(source unknown)	3.5	(source unknown)
153	0.5	(source unknown)	380.0	(harmonic)
158	0		350.0	(harmonic)
163	3	(source unknown)	30.0	(harmonic)
177.5	10	(harmonic)	Not measured	
198	0		700.0	(harmonic)
202	1.5	(source unknown)	Not measured	
208	1.5	(source unknown)	Not measured	
213	1.0	(source unknown)	Not measured	
236.6	2,000.0	(harmonic)	37,000.0	(harmonic)

NOTE: The dipole used with the field-strength meter was 6 feet above ground. The TUI transmitter operating into CA-1350 transmitting antenna was 25 feet above ground, the receiving dipole was 45 feet horizontal distance from transmitting antenna, and the field-strength meter was 10 feet from TUI transmitter.

TABLE VI

EVALUATION OF TUI TRANSMITTER WHEN DRIVEN WITH A MODE CRYSTAL OSCILLATOR UNIT

Frequency (megacycles)	Modified TUI (microvolts)	Unmodified TUI (microvolts)
118.3	7,500	5,900
236.6	7	60
236.6*	7	18
236.6**	0.7	Not checked

*The quarter-wave stub at 236.6 Mc was inserted in the antenna feed line at the transmitter.

**The length of the transmission line to the antenna was adjusted for maximum reduction of the 236.6 Mc harmonic. The quarter-wave stub at 236.6 Mc was located between the phaser and the transmitter.

NOTE: The TUI into CA-1350 transmitting antenna was 25 feet above ground. The field-strength meter was located 800 feet horizontally from the transmitting antenna. The dipole of the field-strength meter was 6 feet above ground.

CONCLUSIONS AND RECOMMENDATIONS

A. Harmonic radiations from the TUI transmitter are caused by the following

1. Strong harmonic fields from the first and second multiplier stage which employ tubes unsuitable for their present application.
2 Stray coupling between the tripler stage and the second multiplier stage because of proximity of the circuit components, the power-supply wiring, and the meter-switch connections.
3. Excessive coupling between tripler plate circuit and power-amplifier grid circuit.

4. Leakage from the transmitter cabinet due to insufficient bonding between the transmitter cabinet and other surfaces such as the panels of the chassis of the exciter and PA where paint prevents electrical contact.

5. Mechanical discontinuities between the various chassis and their respective panels, and between the panels themselves.

6. Insufficient bonding due to paint between rear surfaces of the cabinet and the rear cover.

7. The presence of r-f currents on the outside of the coaxial transmission line leading to the antenna.

B. The spurious harmonic radiation of the Type TUI transmitter can be reduced but probably not completely eliminated between 85 and 160 Mc by performing the following operations:

1. Modifying the doubler plate circuit and the tripler grid circuit to provide inductive coupling between these stages.

2. Adjusting the center tap on the new tripler grid coil to obtain equal grid r-f voltage on the tripler grids.

3. Providing negative bias of 45 volts plus 12,500 ohms of bias resistor for the tripler grids. (An r-f choke may be used between the center tap on the grid coil and the bias resistor.)

4. Adjusting coupling between the doubler plate coil and tripler grid coil so that grid current is limited to approximately one-half milliampere (ma).

5. Adjusting coupling to the quadrupler stage so that its grid current will be about 0.1 ma.

6. Adjusting coupling to the doubler stage so that its grid current will be between 0.2 and 0.3 ma.

7 Shortening the r-f connecting leads between tuning condensers, coils, and by-pass condensers as much as possible in the quadrupler, doubler, and tripler stages.

8. Connecting all r-f grounds directly to a cleaned surface on the chassis.

9 Installing an electrostatic shield on the bottom of the PA chassis to reduce capacitive coupling between the tripler plate and PA grid circuits.

10. Removing all paint from the back surfaces of the front panels, the inside surface of the rear cover, and the cabinet surfaces where paint prevents direct metal-to-metal contact between these items.

11. Providing a feed-through bushing electrically bonded to the cabinet for r-f output from the transmitter.

C. A mode-type crystal oscillator can also be used to reduce the number of spurious radiations from a transmitter of the TUI type.

D. Reduction of spurious harmonic radiations between 85 and 160 Mc from a Type TUI transmitter operating on 118.3 Mc is simplified when a mode type of crystal oscillator operating on 59.15 Mc is used because:

1 The only harmonic which is present is on the same frequency as the desired output of the transmitter.

2. Cleaning paint from certain areas of the cabinet and panels is not necessary.

3. None of the operations given in items 1 through 6 under the foregoing section B apply to the mode type oscillator.

E. The second harmonic of the carrier frequency can be greatly reduced by installing a stub one-quarter wavelength long at the harmonic frequency in the coaxial cable feeding the antenna. To be most effective, the line should be matched after the stub is installed. The r-f feed-through bushing should be mounted in the cabinet as mentioned above.

F. The antenna relay should be eliminated and the coaxial cable feeding the antenna terminated as closely as possible to the center conductor of the output coupling loop to improve the efficiency and operation of the output circuit.

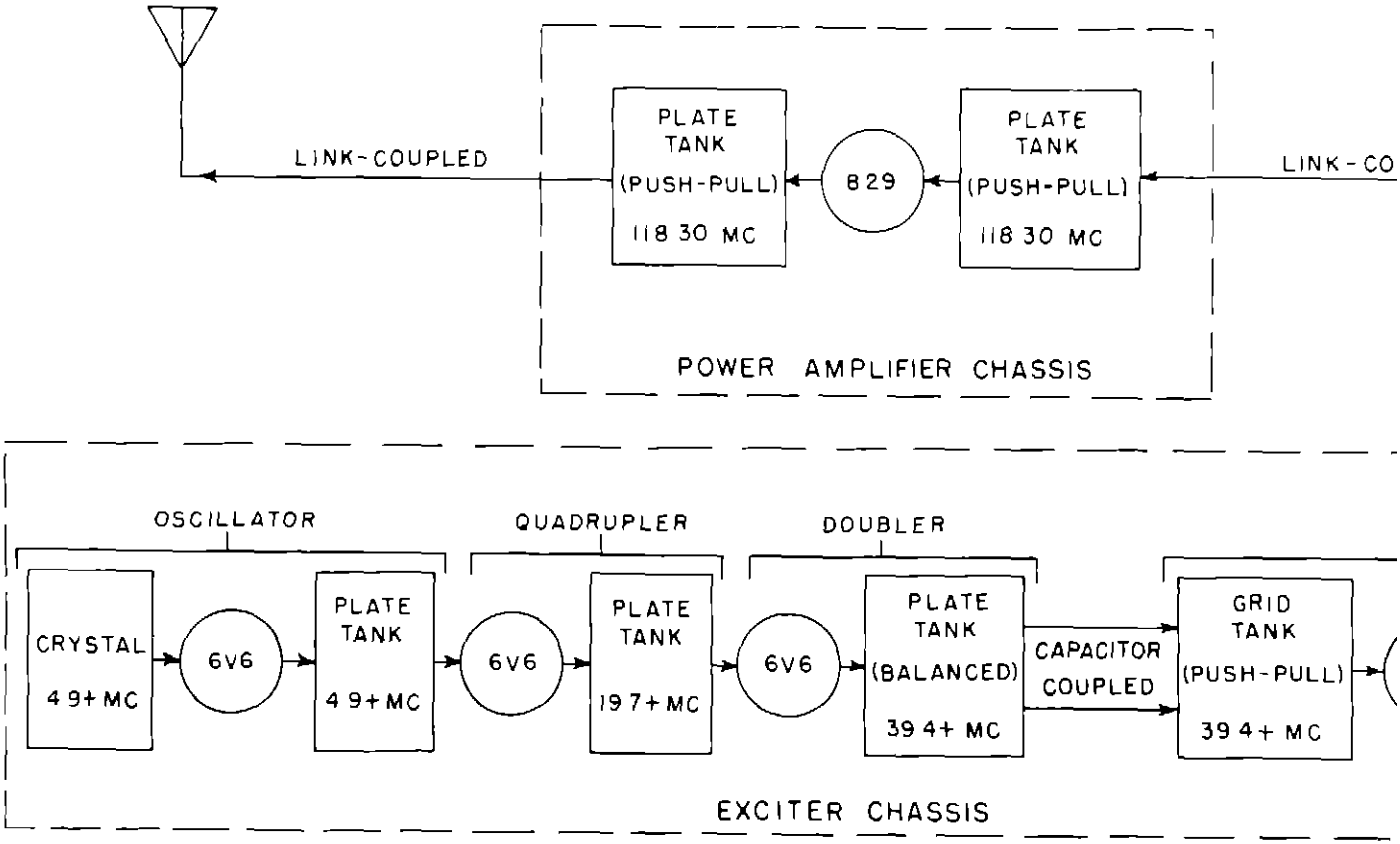

FIG I UNMODIFIED TUI TRANSMITTER

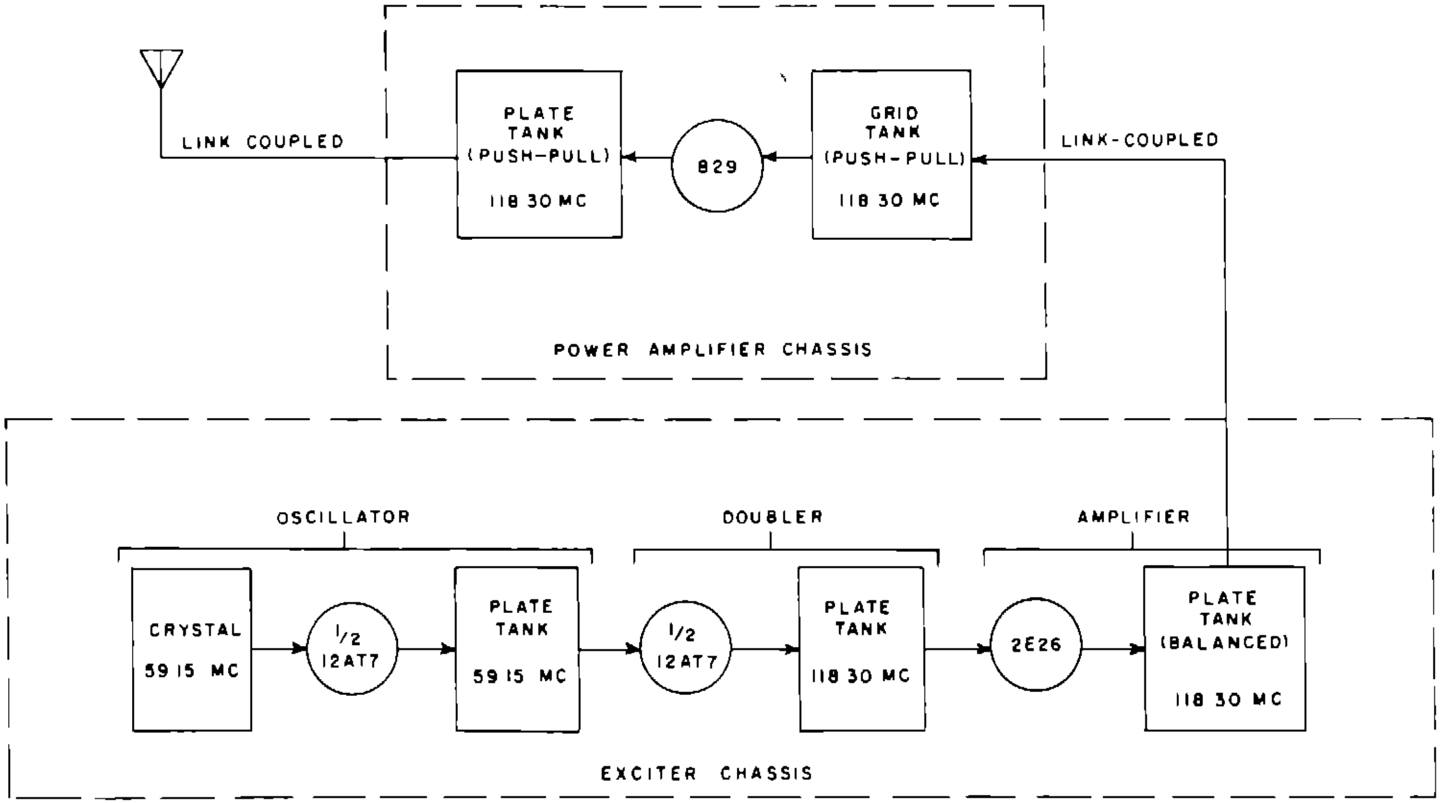

FIG 2 MODIFIED TUI TRANSMITTER