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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

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OTTAWA

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SUMMARY

This report describes briefly, in schematic form, the design and performance of a stable three-tube C.W. transmitter. A neutralized 300 Mc. amplifier, using a type 5894A (9903) tube, is made to oscillate by means of plate-to-grid feed-back through a high-Q quarter-wave co-axial filter. Long-term stabilities of 1 part in 10^5 or better are obtained. A 5894A buffer-amplifier stage on 300 Mc. drives a 4X150G doubler stage to 40 watts output on 600 Mc. The doubler stage may be plate-and-screen modulated for voice transmissions.

INTRODUCTION

For communication purposes in the U.H.F. band (e.g., 400 to 800 Mc.) the long-term carrier stability is often required to be at least 1 part in 10^4 and preferably 1 part in 10^5. This is usually accomplished by means of a low-power quartz crystal oscillating at a frequency in the region 10 to 50 Mc. A chain of frequency multipliers and power amplifiers is needed to increase both the frequency and power to the desired output values. A self-excited master oscillator operating at the carrier frequency, or a convenient sub-multiple of it, obviates the need for long multiplying chains, and the oscillator tube may work at a power level more comparable to the final output. However, conventional high-frequency oscillators, using tank circuits of the parallel-line or co-axial line types, leave much to be desired by way of short-term stability, and their long-term stabilities are only marginal. This is because of the loading effect of the tube elements on the tank circuits.

Co-axial and parallel-line resonant circuits in the V.H.F. and U.H.F. regions can be designed to have unloaded Q's of several thousand, that is, of the order of the average commercial H.F. quartz crystal. They have often been used as the frequency-controlling element in the grid of a conventional triode or pentode oscillator circuit where the feed-back occurs through the plate-to-grid capacity of the tube. By tapping down toward the ground level of the inner conductor of a quarter-wave co-axial tank, for example, the loading of the tube grid on the tank can be reduced considerably, while at the same time enough grid excitation is retained to sustain oscillations. At frequencies above 200 Mc., and with high-Q tanks several inches in diameter, the grid lead to the centre conductor becomes a substantial fraction of a wavelength and the circuit behaves poorly.

The type 5894A tetrode, which is a Phillips tube made in the U.S.A. by Amperex and formerly designated type 9903, is probably the best 50-watt double tetrode available for use in the 200-400 Mc. region. It has a single cathode for both sections and the grids and plates are internally cross-neutralized for use in push-pull amplifier circuits. The neutralization is so effective that the tube cannot be made to oscillate at 300 Mc. without deliberately coupling the output to the input. It would therefore be unsatisfactory in a conventional high-Q grid tank circuit as described in the previous paragraph, apart from the grid connection difficulty. However, if the circuit is set up as a tuned-grid tuned-plate neutralized amplifier and a feed-back loop provided from plate to grid through a high-Q resonant filter, very stable oscillations may be obtained. A typical filter is shown in Fig. 1. The stability is dependent chiefly on the Q of the filter and is relatively independent of the Q's or the tuning of the grid and plate tanks, which in this case serve only as tuned loads for the tube, with the added facility that they can change the feed-back phase over a moderate range for optimum operation.

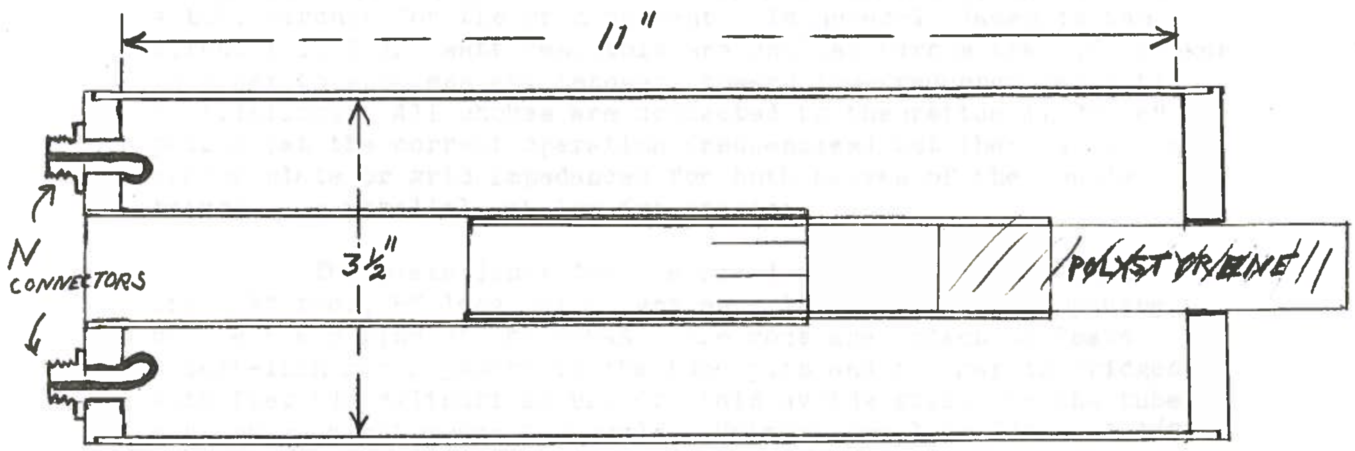

Fig. 1 High-Q Quarter-wave Filter

CIRCUIT DETAILS

Fig. 2 is the schematic outline of the three-tube transmitter. The oscillator and buffer stages are contained in compartments side by side on the same chassis. The tube sockets are mounted in partitions in these compartments, thus separating the grid and plate circuits. The 4X150G doubler stage is in a separate unit, with the 300 Mc. half-wave flat strip grid line located under the chassis and the 600 Mc. half-wave co-axial plate tank above the chassis.

The high-Q quarter-wave feed-back tank is shown in more detail in Fig. 1. The sizes of the coupling loops, or their orientations, may be adjusted for minimum coupling consistent with maintenance of oscillations. The couplings to the grid and plate tanks of the oscillator may also be adjusted for the same purpose.

In Fig. 2, the grid lines of the oscillator and buffer stages are two 1/8" rods, about four inches long and spaced 1". The split-stator tuning condensers are double-spaced receiving types, about 15 mmfd per section, connected across the lines about 1 1/2" from the socket pins. The rotors are left floating. The voltage minimum on these half-wave lines occurs just at the socket pins, therefore the grid coupling loops, which are about 1" in diameter, are located between the line elements adjacent to the sockets. Small chokes attached to the grid pins provide a D.C. circuit for the grid current. In several places in the circuits 10 K 1/2 watt resistors are shunted across the r.f. chokes in order to suppress any tendency toward low-frequency parasitic oscillations. All chokes are connected to theoretically "cold" points (at the correct operating frequencies) but they can act as common plate or grid impedances for both halves of the double tetrodes in parallel, at low frequencies.

The plate lines for the oscillator and buffer stages are 1/4" rods, 8" long, with centres 9/16" apart -- the spacing of the plate pins of the 5894A. The rods are broken to leave a half-inch gap adjacent to the tube pins and the gap is bridged with flexible cylindrical braid: this avoids stress on the tube pins which might crack the seals. Hairpin coupling loops, 1 1/2" long and 1/2" wide, are coupled to the plate tanks, one on either side in the case of the oscillator tank. The tanks are tuned by conventional sliding bars.

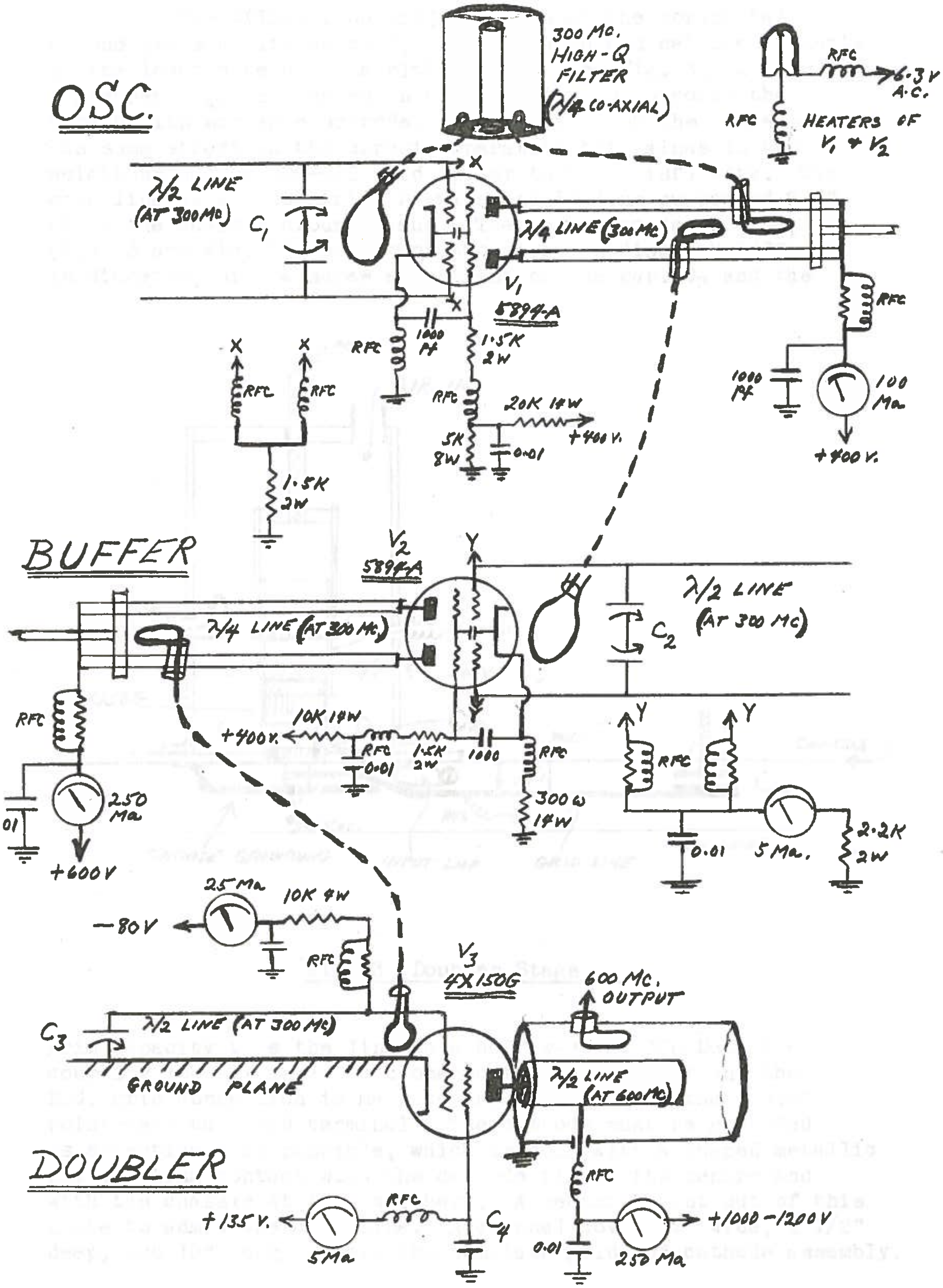

Fig. 2 Schematic Diagram

The 4X150G tube projects through the horizontal ground plane of its chassis, with the grid and cathode elements on the lower side and the plate above. See Fig. 3. A ring condenser, C_4, is mounted on the chassis and supports the tube by its screen electrode. The capacity of the condenser has some effect on the circuit operation but values in the neighbourhood of 200-400 mmfd appear to be satisfactory. The grid line is a flat strip, 2" wide and 6" long supported 3/4" above the chassis ground plane. The tuning condenser, C_3, (Fig. 2 and Fig. 3) consists of two circular discs, 2 1/2" in diameter, with a screw adjustment of the gap. C_3 and the

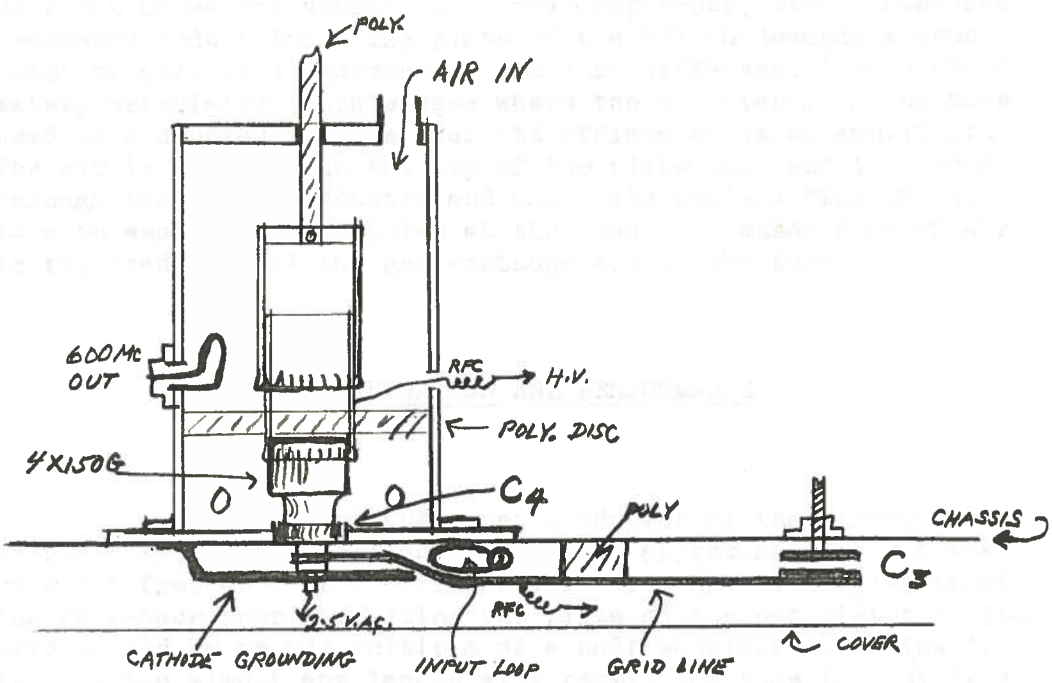

Fig. 3 Doubler Stage

grid capacity tune the line to a half-wave at 300 Mc. The coupling loop is inserted close to the tube socket and the D.C. grid connection is made to the grid line at the "cold" point near the grid terminal. The cathode must be grounded as effectively as possible, which is done with a shaped metallic plate making contact with the cathode pin at its centre and with the chassis at its periphery. A sector is cut out of this plate to admit the grid line. A channel cover, 4" wide, 1 1/2" deep, and 10" long, covers the complete grid and cathode assembly.

The inner conductor of the half-wave (at 600 Mc.) plate line of the 4X150G is in two telescoping sections, tuned by an insulated rod. The D.C. connection to the inner conductor is made at the minimum voltage point. A hairpin loop extracts the 600 Mc. R.F. energy.*

Forced air circulation is unnecessary in the oscillator stage and could be omitted in the buffer stage. However, as the 4X150G does require forced air, it is convenient to divert a part of the air stream to cool the oscillator and buffer tubes, taking care that the flow of air in the oscillator compartment does not cause any vibration of the components, with consequent frequency modulation. The plate of the 4X150G demands a good blast of air, at a recommended pressure differential of 0.6" of water, especially in this case where the efficiency of the tube used as a doubler is less than its efficiency as an amplifier. The air is admitted to the top of the plate tank and is forced through the inner conductor and the plate cooling fins of the tube to escape through holes at the base. A lesser flow of air is required to cool the grid-cathode end of the tube.

OPERATION AND PERFORMANCE

The length of the inner conductor of the high-Q filter is first set to the desired wavelength, approximately. At the resonant frequency of the filter the total electrical length of the feed-back loop connecting the plate of the oscillator to its grid should be an odd multiple of a half-wavelength. Actually, in practice almost any length will permit the tube to oscillate because the plate and grid tanks can be sufficiently detuned to ensure the correct phase relationship. However, the performance is best when the above criterion is approximately met, leaving fine phase adjustment to the tube tanks. The tuning of the grid tank is not at all critical, probably because of its relatively low Q, and the grid condenser may be conveniently used as a vernier to bring the frequency into zero beat with a reference signal.

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* The plate tank of the 4X150G was designed by Mr. E. L. R. Webb and further details should be available in reports to be issued by his section.

The oscillator plate tank should be detuned slightly to one side of its natural resonant frequency; whether higher or lower depends on the initial grid-to-plate phase. If the oscillations are monitored by beating with a reference signal from a temperature-controlled primary crystal standard it will readily be found to which side of resonance the plate tank should be detuned. On the correct side a change in tuning, which would correspond to several megacycles if the high-Q filter were replaced by an aperiodic feed-back loop, causes the beat note to change only a few kilocycles. The "warble", or short-term instability, of the beat note with a harmonic of the 100 kc primary crystal standard is quite small; comparable to the beat between the harmonics of a pair of ordinary commercial quartz oscillators. On the other hand, if the plate tank is detuned to the wrong side the note becomes rough, and the frequency change per unit variation of tuning becomes many times greater. Having determined this once by aural monitoring, the correct side can always be selected over a fairly wide frequency band by observing the oscillator plate milliameter. The plate current is a minimum at plate tank resonance and rises to its non-oscillating value on either side; hence the plate tank is tuned consistently to the inductive or to the capacitive side of resonance as previously determined.

The coupling of the oscillator plate to the buffer grid should be loosened as much as possible, while providing adequate grid drive for the buffer. Too tight coupling will reduce the frequency stability. Tuning the buffer plate tank reacts very slightly on the oscillator frequency. The output from the buffer stage on 300 Mc. is about 50 watts, as measured through an attenuating cable by a wattmeter employing a small flashlight lamp, photronic cell and meter. More output can be obtained by raising the buffer screen voltage and driving the grid harder, but there is more than ample power to supply the grid losses of the 4X150G.

The output of the 4X150G is sensitive to screen potential. It was found in practice that a fixed screen voltage of 130-140 volts was best. Higher voltages gave reduced output with increased plate current. Table I outlines the voltages and currents read at various points in the system.

TABLE I

Oscillator data

Plate: 400 V. 70 m.a., regulated (100 m.a. not oscillating).

Screen: 60 V. 5 m.a. (approx., varies with tuning).

Grid: grid leak bias (current not measured).

Power output: up to 15 watts on 300 Mc. available but only two or three watts required for next stage.

Buffer data

Plate: 600 V. 170 m.a., regulated.

Screen: 200 V. 20 m.a. (approx., varies with tuning).

Grid: -80 V. 4 m.a. (4 m.a. through 5 K added to -60 V. self-bias).

Power output: 50 watts on 300 Mc., nominal.

Doubler data

Plate: 1200 V. 160 m.a., not regulated.

Screen: 135 V. 3 m.a., regulated (current varies with plate loading).

Grid: -230 V. 15 m.a. (15 m.a. through 10 K, added to -80 V. fixed bias).

Power output: 35 to 45 watts on 600 Mc.

The plate efficiency of the doubler stage is of the order of 20-25%, which seems low but may not be unreasonable for doubler operation at 600 Mc. Higher efficiencies may be obtained using higher grid bias, more drive, and higher plate voltage, but this procedure raises the plate impedance, contrary to the manufacturer's recommendation for the 4X150 type. The same tube used as an amplifier at 600 Mc. might be expected to have efficiencies of the order of 50-60%. A 4X150G amplifier stage added to the three-tube transmitter described here should therefore deliver up to 100 watts, although the experience of others with similar amplifiers suggests that the 4X150 types do not produce in practice more than 60 or 70 watts as 600 Mc. amplifiers. The additional cost, complexity, and chances for failure introduced by the use of an extra 4X150G stage as an amplifier do not appear to be warranted for a power gain of only 3 db.

The 4X150A tetrode is similar in ratings to the 4X150G except that the grid and cathode connections are effectively interchanged. In this circuit the 4X150A might be more satisfactory from the viewpoint of construction of the parallel plate grid line and the cathode grounding technique. The 4X150G was designed for pulse operation and, judging from its construction, it should be somewhat better than the 4X150A at 600 Mc. and higher.

Simultaneous plate and screen modulation of the doubler has proven satisfactory, at a relatively low percentage of modulation. Only ten or fifteen watts of audio power were available for the purpose, and no attempt has been made to push the modulation percentage up to 100%. An increase in grid drive and a reduction in plate voltage would very likely be essential if this were tried.

The three-tube transmitter has run continuously for several weeks without drifting out of audio beat note range, checked at 600 Mc. against a harmonic of the primary crystal standard*. This amounts to a few kilocycles in 600 Mc. or a stability of the order of 1 part in 10^5. However, the variation of the ambient temperature has not been more than about 20°F., and it would probably be necessary to provide crude thermostatic temperature control of the high-Q filter for stability over a very wide temperature range. It was found desirable to regulate the heater voltage of the oscillator tube to avoid slow frequency drift as the line voltage changed. This was done with a small Solar reactance-type 110 V. A.C. regulator. Good short-term stability is largely a matter of building the oscillator circuit components rigidly, and shock-mounting the unit, including the high-Q filter. Examination of the beat-note pattern on an oscilloscope showed a short-term instability, or "warble", of the order of one or two cycles per sec. per sec., provided the oscillator chassis were not jarred. For communication purposes this is very much better than necessary.

Mr. A. Petch constructed the oscillator-buffer chassis, and also parts of the doubler unit, assisted by Messrs. W. Foster and J. D. Stewart.

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* ERA-203 "A Frequency Multiplier from 100 Kc to 50 Mc" by D.W.R. McKinley and J.C. Swail. The frequency range was further extended to 600 Mc. for this purpose.