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A SURVEY OF TUNED CIRCUITS FOR THE
300 TO 3000 MC FREQUENCY RANGE

By F. C. Isely

- Report R-2984 -

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SHIP-SHORE RADIO DIVISION - RECEIVER SECTION

26 September 1946

A SURVEY OF TUNED CIRCUITS FOR THE
300 TO 3000 MC FREQUENCY RANGE

By F. C. Isely

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* * *

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ABSTRACT

A survey of possible circuits for use in the 300 to 3000 Mc frequency range is given. Advantages and disadvantages of these circuits, which are either well known or recently developed at this Laboratory, are compared, in order to have a starting point for an intensive research program on the development of circuits to be used in Naval Communication Receivers. Abstracts dealing with the mathematical and technical considerations of the circuits are included.

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INTRODUCTION

1. There has been comparatively little development and exploitation, up to the present time, of wide frequency coverage circuits for use in the frequency range at 300 Mc of 3000 Mc. Such wide frequency coverage circuits as are available do not give results comparable to those obtained at the low frequencies. This lack affects not only communication receivers but also intercept equipment for countermeasures and direction-finding applications. A survey of the various known circuits would appear to be of value before undertaking an intensive research program in this difficult part of the radio spectrum. Recent engineering development has pushed the frequency range of standard naval communication receivers up to 400 Mc, though the top 100 Mc is difficult; and has produced receivers for a few narrow bands of frequencies above 3000 Mc. However, the range from 300 to 3000 Mc has been comparatively neglected because of the exigencies of war and of the technical difficulties involved in the region of transition from lumped circuits to those of the concentric line and cavity type.

2. The present survey is intended principally for the benefit of scientists at the Naval Research Laboratory in order that they may more readily compare the advantages and disadvantages of the various circuits, before undertaking any post-war development along this line. It is desired also to exchange information in this field with other laboratories. The circuits presented herein do not necessarily include all those known by other agencies; it is also possible that difficulties encountered here in developing some of these circuits may have been solved or approached in a different manner at other laboratories.

PRELIMINARY CONSIDERATIONS

3. Before embarking upon a detailed discussion of circuits, it is advisable to point out several general factors which must be borne in mind when considering UHF circuits. A group at the Laboratory, represented by the author, is interested in communication receivers; consequently the considerations of circuits is generally aimed at the wide frequency coverage (at least two to one) suitable for preselector work. Preselectors are considered as including the signal circuits, the oscillator, and the mixer circuits of a radio receiver. Vacuum tubes are associated with these circuits and the limited rate of tube development is to a great extent a "bottleneck" in preselector research. If possible, it is desirable to provide at least three signal circuits with one stage of r-f amplification. The acorn type of tube is not suitable for wide-range work above 300 or 400 Mc. An exception to this is the new 6F4 Type acorn tube (triode) which may operate up to about 1000 Mc, (1400 Mc natural period of resonant frequency) but the grid contacts are not located advantageously for use in most circuits. Some of the "door-knob" tubes such as types 368A and 703A, have resonant frequencies above 1500 Mc, but are rather large in size and are not applicable above 1000 Mc in wide-frequency-range preselectors. The light-house tube type 2C40 is usable above 3000 Mc; but its base is too large for many circuits and it will not oscillate with a single tuned circuit (wide range) much above

1000 Mc. The new type (triode) A2302 tube made by Radio Corporation of America and still in the experimental stage, is a step in the right direction; it will amplify at frequencies up to about 2000 Mc and oscillate to about 3000 Mc, but again 1000 Mc is about the limit of oscillation with a single tuned circuit. It is understood that a new version, the A2302A tube should have better gain with more stability. Information on the General Electric Company L8 tetrode tube indicates a good amplifier to 3000 Mc, although it is still in the development stage and, being of the lighthouse type, will be bulky. The Klystron type of tube must also be considered: it is understood that a new design will allow operation down to 1000 Mc. These latter tubes require, of course, a voltage control as well as control of the resonant circuit which may be no more difficult than the control of two tuned circuits. In the analysis of tube behavior, the noise factor must always be considered along with the gain to determine whether it is worth while to include an r-f amplifier stage.

4. Another important factor to consider is that of sliding or rotating contacts. At the present time the naval service does not approve the use of sliding contacts in high-frequency circuits because of the noise produced in such a contact. As far as is known, very little work has been done to produce a noise-free long-wearing contact. In default of a solution of this problem, split-stator circuits have generally been used. (Recently, in concentric lines, the S type choke has been a solution). If a good sliding contact system could be developed, many circuits would be available in smaller size and weight and certain complexities could be eliminated. Work on this phase of the circuit problem is under consideration.

5. The application of trimming adjustments is also an important factor. If a circuit is to be ganged for use over a specific frequency range, it is essential to be able readily and independently to adjust both the top and bottom resonant frequencies. This may be done, as in lower frequencies, by adjusting a trimming capacity and a trimming inductance; at higher frequencies a change in length of the line or of some other circuit parameter may be found suitable.

6. A fourth consideration is that of measurements. It is very valuable in r-f circuit work to know the impedances as well as the "Q". In the 300 to 3000 Mc range very little reliable equipment is available except perhaps for spot frequencies. The need is for reliable and stable oscillators, vacuum tube voltmeters and impedance measuring devices to measure up to several thousand ohms. Calculations are valuable, but in most circuits this is not very satisfactory, so that it is quite desirable to be able to make reliable measurements.

CONVENTIONAL COILS AND CAPACITORS

7. Low frequency practice with coils and capacitors has an upper frequency range of perhaps 400 Mc. Much difficulty is encountered however in reaching this frequency with a two to one coverage, 200 Mc is a more satisfactory upper limit for this type of circuit. The difficulty is due to the distributed inductance in the capacitors. Reference 1 gives a good explanation of

this behavior. This reference also gives a very good picture of the coaxial line, butterfly, semi-butterfly and cylindrical circuits. Table I is a condensation of the pertinent points of the various circuits and should be referred to as well. The conventional type of circuit then, since 200 to 400 Mc is its upper limit, need not be considered as suitable for the r-f region under review.

COAXIAL LINE

8. The coaxial line is one of the older circuits for UHF work and has many advantages to offer. It is completely shielded, is symmetrical and has high Q's and impedances. The lighthouse type tube is well adapted to this circuit as is the RCA A2302 tube. Wide ranges may be covered and if different modes of operation are used in the circuits, continuous oscillations may be achieved without harmonics and spurious responses. In some cases a shielded two-wire line may be used, but in general the coaxial line is superior. There are difficulties, however, with this line. It is very bulky, and with the trend toward smaller size and weight it is not entirely satisfactory; actually, for frequencies below say 1500 Mc, it is satisfactory for special purposes only. Ganging of circuits is difficult and the use of sliding contacts necessary unless elaborate machining is resorted to for making S type chokes, Reference 3. It is possible to load a fixed length of coaxial line with a variable capacitor. However, if the frequency range is large, difficulty may be encountered with spurious effects which result in loss of frequency control by the line.

CAVITIES

9. The cavity-resonator-type circuits have been used extensively above 3000 Mc, but for the lower frequencies it is believed that they are too large to be satisfactory in most Naval equipment applications.

BUTTERFLY CIRCUIT

10. This circuit, developed by the General Radio Company and extensively used during the war, is well discussed in Reference 1. Some circuits have been designed to operate at frequencies as high as 3000 Mc, but it is believed that 1000 Mc is near the practicable upper limit, Plate I. The circuit exploits simultaneous variation of inductance and capacity, although for straight-line-frequency applications, a large change in inductance cannot be obtained. The circuit is axially symmetrical and has yielded frequency ranges of five to one. The Q of this circuit is normally in the order of several hundred and the resonant impedance around 8000 to 10000 ohms. The door-knob type of tube is most satisfactory in this application, since the connections are well distributed with reference to the circuit. The circuit requires precision machine work in construction and is not easily ganged. The useable tuning rotation is 90°. One of the greatest difficulties of this circuit lies in the spurious responses which are frequently present. The General Radio Company has done a great deal of work on this phase of the circuit and have been able in certain cases, to eliminate some of the troubles, but care must be used in working with these circuits to assure the suppression of undesirable resonance phenomena.

11. Most circuits have many possible variations. One of the variations in the butterfly is the cylindrical butterfly, reference 4. According to the inventor, it has many advantages over the original circuit.

SEMI-BUTTERFLY CIRCUIT

12. This circuit is also a product of the General Radio Company, though it was independently developed at this Laboratory, Plate I. It is not symmetrical and is not useful at frequencies higher than about 700 Mc, but it has some advantages over the other circuit. The Laboratory design can utilize standard variable capacitor manufacturing methods and it appears to have fewer spurious effects. Reference 2 gives details on the use of the circuit in several models of preselector heads that were being developed at the close of the war. Ganging of three circuits was accomplished and the addition of a fourth circuit would probably not be difficult. The use of both acorn and lighthouse tubes was found possible.

VARIABLE-CHARACTERISTIC-IMPEDANCE CONTROL

13. With a loaded concentric line, it is possible to vary the frequency by changing the characteristic impedance. This can be seen by examination of the formula for the resonant length of a loaded, quarter-wave line $l = \frac{\lambda}{2\pi} \tan\left(\frac{\pi Z_0}{Z_0'}\right)$. If the line is kept constant in length, any variation in Z_0' causes a variation in frequency, however a large change in Z_0' is necessary for even a small change in f . The General Radio Company's coaxial Butterfly is of this type of circuit. At this Laboratory a circuit has been built up in which the center conductor could be varied in position to vary Z_0' and at the same time vary the loading capacity. This gave a two-to-one variation of frequency, but contained a rotating contact. The variation of the loading capacity brings in possible spurious responses as mentioned before.

CYLINDRICAL CIRCUITS

14. This circuit consists of two concentric cylinders, each slit lengthwise, Plate I. With the two slots lined up, the highest frequency is obtained; while the inner cylinder is turned 180° to give the lowest frequency. A two-to-one frequency coverage can be obtained and with proper shaping a straight line frequency curve is easily possible. This circuit is well adapted to the 6F4 tube. Difficulty may be had in getting satisfactory bearing arrangements for the inner cylinder, but it is feasible and ganging should be possible.

SELBY CIRCUIT

15. This circuit, developed by Eugene Selby of the Radio Corporation of America, is essentially a three-quarter wave length line circuit with a series capacitors placed at a point a quarter-wave length, at the higher frequency, from the shorted end. The operation of this circuit can roughly be considered as follows: if the capacitance is zero, then the line is three quarters wave length long, while if the capacitance is infinite, the line is one-quarter wave length long. The actual operation and calculations are shown in Appendix 1. From the above considerations, a three-to-one coverage is theoretically

possible, but no capacitor will cover this range so that a one and a half to one coverage is about the limit. It is possible to add another half wave length of line at the top of the circuit and a capacitor at this point and theoretically cover five to one, but again an actual coverage of between two and three to one is the limit. It is possible with this circuit, at frequencies up to about 400 Mc, to use the circuit as a two wire line and gang two commercial capacitors together with a common shaft for a double type circuit, the center part of the line being simulated by a small length of coiled wire, thus producing a circuit without sliding contacts. The frequency limitation of this circuit is again the distributed inductance in the capacitor.

16. The previous circuits are either well known or those that have recently been discussed in published articles. The circuits discussed below have been developed at this Laboratory. Due to war work, these circuits have not been investigated or developed to any great extent until recently and even now are in the early stages of evolution. Several of these circuits require sliding or rotating contacts, but are mentioned as possibilities for further development.

THE INDUCTIVE SHUNT LINE

17. This line is similar to that of Selby but utilizes a variable inductive shunt at a point up one half wave length of the highest frequency from the shorted end. At zero inductance the line is three quarters wave length long whereas, at infinite inductance, it is one quarter wave length long. Again more than one section with an increased number of variable inductances may be used as in the Selby circuit. The difficulty is, of course, that no known variable inductance as normally considered is suitable for use. A type of inductance that may be suitable for this will be considered later. The advantage of this line, if a suitable inductance were available, is the fact that chokes in the tube leads could possibly be eliminated. Appendix 2.

DISTRIBUTED CAPACITY LINE

18. This line is the outgrowth of the commercial variable condenser. Its action at VHF was originally predicted by Ronald King, but was at a latter date, independently discovered experimentally at this Laboratory. If a variable capacitor is shorted at one end, it can be considered as a short-circuited line, the shaft being one line and the stator supports the other. As the rotor is turned, frequency calibration curves may be plotted for the quarter, three quarter, five quarter, etc., modes. Appendix 3. This is, of course, also true if the capacitor is unshorted; it can be seen in the split stator type as well, though spurious responses will be present due to the oscillation modes induced by coupling between rotor and each stator. This latter defect can be eliminated by using an insulated shaft with individual insulated rotor plates. This circuit has been used with some success as a wave trap. The concentric line can be modified by this type of circuit. Plate 2. An oscillator of this type has been built using a lighthouse tube that operates from about 400 Mc to 1100 Mc. The advantage of this type of line is that the tuning is by rotation and not by change of length. Variable feed back is necessary for oscillation over this frequency range. The losses

of this type of line will be greater than in the normal line due to concentration of currents over a portion of the line. With any line it must always be borne in mind that there is a possibility of operation in various modes.

DISTRIBUTED INDUCTANCE LINE

19. This line is similar to that of the Distributed Capacity Line except that the inductance is varied instead, Appendix 3. In the present form it is either a two-wire line or concentric line with rotating contacts. Plate 3. The rotor is made of a slit cylinder, with the slits perpendicular to the axis and going over three quarters of the way through. The stator is a narrow plate with a concave cylindrical surface into which the rotor is placed; the closer the spacing the greater the frequency change. When the two solid portions are adjacent, the inductance is low and frequency highest. On rotating the cylinder 180° the solid portions being further away the inductance is greater and at the same time, due to the fringe effect, the capacity is approximately the same so the frequency is lower. A frequency change of over two to one is easily obtainable with a rotor to stator spacing of twenty mils and a rotor diameter of one-half inch. Larger diameters will give greater frequency coverage. For a concentric line, the outer cylinder is slotted in a way similar to the inner one. The impedance and Q of this type of line is low, which may limit its usefulness. Again operation in different modes is possible. This type of line may be combined with the distributed capacity line to give a circuit with much greater frequency coverage. Plate 3 shows a line of this type with a coverage of five to one.

MODIFIED SELBY AND INDUCTIVE SHUNT LINE

20. A transmission line between one quarter and one half wave length long and shorted at one end is capacitive while if it is open it is inductive. Similarly a line between one half and three quarters is inductive if shorted and capacitive if open. Thus a line may be substituted for the capacity of the Selby Circuit and the inductance in the inductive shunt line. No advantage is secured with an ordinary sliding contact concentric line for this purpose, except that it should be possible to cover the complete theoretical three-to-one range. The change of length needed is greater than for an ordinary line. In order to eliminate this bulkiness, either of the distributed constants types of line can be used. This type of circuit is still in a very early experimental stage where its possible value is not predictable and where the difficulties are numerous, Appendix 4.

CONCLUSIONS

21. The circuits discussed here are those which have come to the attention of or been developed by a small group at this Laboratory. There are undoubtedly many variations of these circuits and probably many other types besides. No one circuit will be ideal for all problems in the 300 to 3000 Mc range. All of the circuits discussed have their limitations, but it is hoped that this survey may bring to light other circuits or start a train of thoughts along these or new avenues that will produce better circuits. Criticism of the ideas here given would be welcomed and it is hoped that suggestions of other circuits and methods for utilizing this part of the radio frequency spectrum will be forthcoming.

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 4. Everett, Frederick C., Tuned Circuits for the U.H.F. and S.H.F. Bands. Communications Vol. 16, pp-19-21, June 1946.
 5. U.S. Patent Application 515905 of Dec. 28, 1943 by Eugene Selby
- Original data recorded in NRL Log Book 4192.

ACKNOWLEDGEMENT

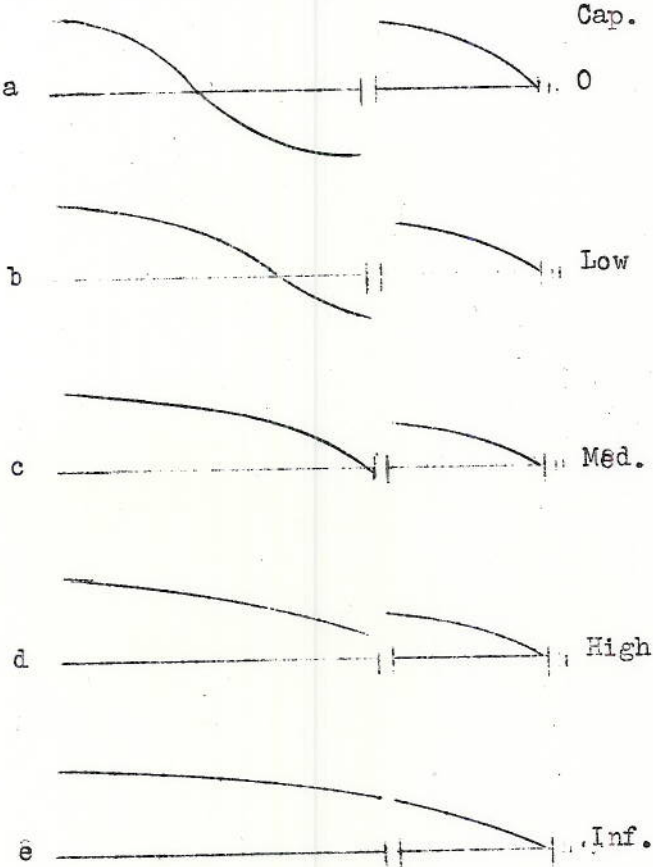
The author wishes to express his appreciation to Mr. T. McL. Davis and Dr. L. T. Bourland for their encouragement on the study of the original circuits here presented.

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APPENDIX I

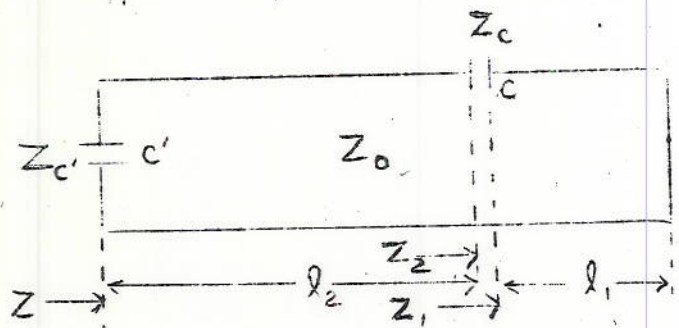
THE SELBY CIRCUIT

1. The pictorial operation of the Selby circuit can be seen in the following diagrams. The portion from the grounded end to the capacitor is 1/4 wave length and from capacitor to the upper end, 1/2 wave length of highest frequency. At zero cap the voltage distribution is as at a, giving the highest frequency. The capacitor can be thought of as taking up some portion of 1/2 wave length of the line. In the case a, this is zero. In the other cases where C is increasingly greater, this portion is greater until in case e, it is a whole 1/2 wave length. The capacitor also has opposite voltage potentials on it's two sides, but the voltages do not necessarily have to be on the opposite side of the ground or arbitrarily chosen zero potential point. Thus one can go from the 3/4 to 1/4 wave length without going through the 1/2 wave length mode.



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2. A calculation of the capacity for various frequency for a given line of this type can be made by obtaining a formulae from transmission line methods. Plate 4.



$$Z_1 = Z_0 j \tan \frac{2\pi l_1}{\lambda} \quad Z_2 = Z_1 + Z_c = Z_0 j \tan \frac{2\pi l_1}{\lambda} - j \frac{5.3 \lambda}{C}$$

$$Z = Z_0 \frac{Z_R + j Z_0 \tan \frac{2\pi l_2}{\lambda}}{Z_0 + j Z_R \tan \frac{2\pi l_2}{\lambda}} \quad Z_{c'} = \frac{5.3 \lambda}{C}$$

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$$j \frac{5.3 \lambda}{c'} = Z_0 \frac{Z_0 j \tan \frac{2\pi l_1}{\lambda} - j \frac{5.3 \lambda}{c'} + j Z_0 \tan \frac{2\pi l_2}{\lambda}}{Z_0 + j (Z_0 j \tan \frac{2\pi l_1}{\lambda} - j \frac{5.3 \lambda}{c'}) \tan \frac{2\pi l_2}{\lambda}}$$

$$\begin{aligned} \frac{5.3 \lambda}{c'} Z_0 - \frac{5.3 \lambda}{c'} Z_0 \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} + \frac{5.3 \lambda}{c'} \frac{5.3 \lambda}{c'} \tan \frac{2\pi l_2}{\lambda} \\ = Z_0^2 \tan \frac{2\pi l_1}{\lambda} + Z_0 \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{c'} \end{aligned}$$

$$\begin{aligned} \frac{5.3 \lambda}{c'} \left(\frac{5.3 \lambda}{c'} \tan \frac{2\pi l_2}{\lambda} + 1 \right) \\ = Z_0^2 \tan \frac{2\pi l_1}{\lambda} + Z_0 \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{c'} Z_0 + \frac{5.3 \lambda}{c'} Z_0 \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} \end{aligned}$$

$$\frac{5.3 \lambda}{c'} = Z_0 \frac{Z_0 \tan \frac{2\pi l_1}{\lambda} + \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{c'} + \frac{5.3 \lambda}{c'} \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda}}{\frac{5.3 \lambda}{c'} \tan \frac{2\pi l_2}{\lambda} + 1}$$

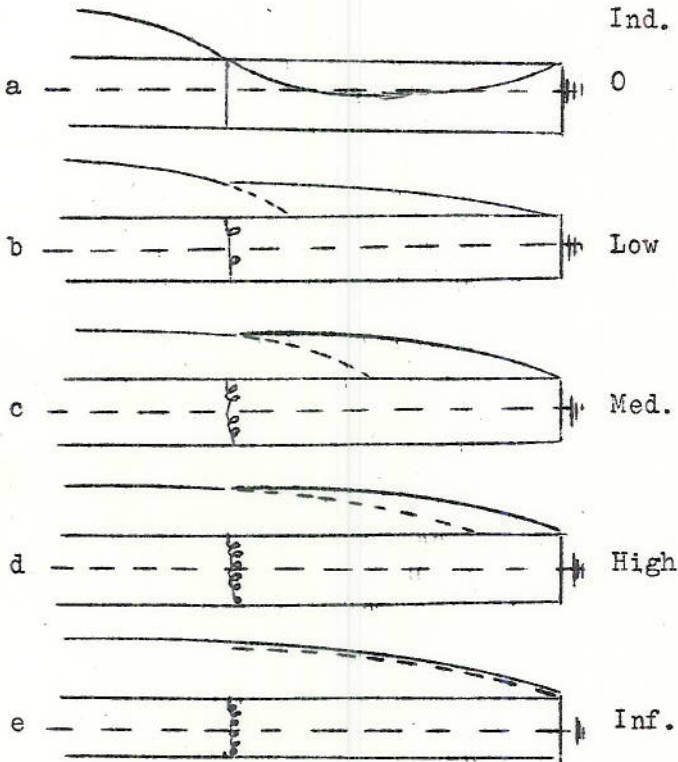
$$\frac{c}{5.3 \lambda} = \frac{1}{Z_0} \frac{\frac{5.3 \lambda}{c'} \tan \frac{2\pi l_2}{\lambda} + 1}{Z_0 \tan \frac{2\pi l_1}{\lambda} + \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{c'} + \frac{5.3 \lambda}{c'} \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda}}$$

$$C = \frac{5.3 \lambda}{Z_0} \frac{\frac{5.3 \lambda}{c'} \tan \frac{2\pi l_2}{\lambda} + 1}{Z_0 \tan \frac{2\pi l_1}{\lambda} + \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{c'} \left(1 - \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} \right)}$$

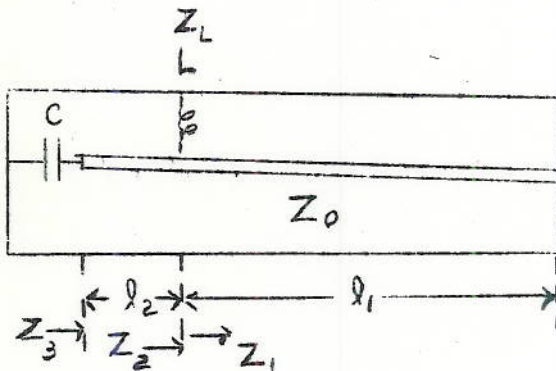
APPENDIX 2

THE INDUCTIVE SHUNT LINE

1. This line is somewhat similar to that of Selby, there being a discontinuity in the voltage curve at the point at which the inductance is attached to the line. Considering a two wire line, a plane of zero voltage may be drawn through the middle and



passing through the mid-point of the inductance. The inductance on one side of this line will contain a portion of 1/4 wave length, which is shown in the diagrams as dotted. Thus in a the inductance contains zero wave length, while at e a 1/4 wave length or nearly so. In C, where the lower line is 1/4 wave length, the inductive load, reduces the voltage at the junction so that the maximum voltage is still at the end of the line. As in the Selby circuit, transmission line theory can be used to develop. A formulae for calculation of the necessary inductance for tuning the line. An accompanying graph illustrates this for a range of 333 1/3 Mc to 1000 Mc. The 500 Mc point is indeterminate, but may be calculated, by assuming the grounded end on S of the line as of infinite impedance at the junction with the inductance. Plate 5,



$$Z_L = j2\pi fL = j \frac{kL}{\lambda} \text{ where } k = 18.85 \times 10^{10} \text{ if } L \text{ in } \mu\text{ch.}$$

$$Z_C = -j \frac{1}{2\pi f C} = -j \frac{5.3 \lambda}{C} \quad \text{if } C \text{ in } \mu\text{mF}$$

$$Z_1 = j Z_0 \tan \frac{2\pi l_1}{\lambda} \quad Z_2 = \frac{Z_1 Z_L}{Z_1 + Z_L}$$

$$Z_2 = \frac{-Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda}}{j \frac{K_L}{\lambda} + j Z_0 \tan \frac{2\pi l_1}{\lambda}} = j \frac{Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda}}{\frac{K_L}{\lambda} + Z_0 \tan \frac{2\pi l_1}{\lambda}}$$

$$j \frac{5.3 \lambda}{C} = Z_3 = Z_0 \frac{j \frac{Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda}}{\frac{K_L}{\lambda} + Z_0 \tan \frac{2\pi l_1}{\lambda}} + j Z_0 \tan \frac{2\pi l_2}{\lambda}}{Z_0 + j j \frac{Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda}}{\frac{K_L}{\lambda} + Z_0 \tan \frac{2\pi l_1}{\lambda}} \tan \frac{2\pi l_2}{\lambda}}$$

$$\frac{5.3 \lambda}{C} = Z_0 \frac{\frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda} + (\frac{K_L}{\lambda} + Z_0 \tan \frac{2\pi l_1}{\lambda}) \tan \frac{2\pi l_2}{\lambda}}{\frac{K_L}{\lambda} + Z_0 \tan \frac{2\pi l_1}{\lambda} - \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda}}$$

$$\begin{aligned} \frac{5.3 \lambda}{C} \frac{K_L}{\lambda} + \frac{5.3 \lambda}{C} Z_0 \tan \frac{2\pi l_1}{\lambda} - \frac{5.3 \lambda}{C} \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} \\ = Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_1}{\lambda} + Z_0 \frac{K_L}{\lambda} \tan \frac{2\pi l_2}{\lambda} + Z_0^2 \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} \end{aligned}$$

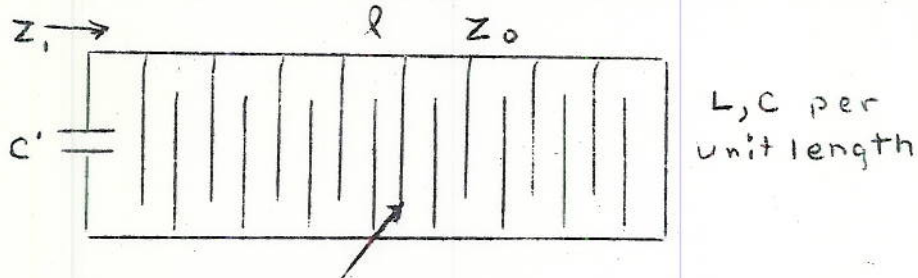
$$\begin{aligned} L \left(\frac{5.3 K}{C} - \frac{5.3 K}{C} \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 K}{\lambda} \tan \frac{2\pi l_1}{\lambda} - \frac{Z_0 K}{\lambda} \tan \frac{2\pi l_2}{\lambda} \right) \\ = Z_0^2 \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{C} Z_0 \tan \frac{2\pi l_1}{\lambda} \end{aligned}$$

$$L = \frac{Z_0 \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda} - \frac{5.3 \lambda}{C} \tan \frac{2\pi l_1}{\lambda}}{\frac{5.3 K}{C} (1 - \tan \frac{2\pi l_1}{\lambda} \tan \frac{2\pi l_2}{\lambda}) - \frac{Z_0 K}{\lambda} (\tan \frac{2\pi l_1}{\lambda} + \tan \frac{2\pi l_2}{\lambda})}$$

APPENDIX 3

THE DISTRIBUTED CONSTANTS LINE

1. This is a line in which either the distributed capacity or distributed inductance is varied or also where both are varied in the same way. Normally if the spacing or size of a line is varied, the distributed capacity and distributed inductance will both vary but in the opposite direction with the resultant resonant frequency remaining constant. A commercial variable condenser can be considered as a line, where the rotor shaft is one side of the line and the stator supports the other. On rotating the plates, the inductance remains practically constant while the capacity discretely distributed throughout the whole length varies. If it were possible to vary the distributed inductance with the capacity constant, the same result would be obtained.



This line, as in the normal transmission line, has modes of operation of $1/4$, $3/4$, $5/4$ etc. or $1/2$, $2/2$, $3/2$ etc. depending on whether it is shorted or open. The operation of this line was originally predicted by King in 1937 I.

2. In a transmission line $v = 1/\sqrt{LC}$ and $f\lambda = v$ so $f = \frac{1}{\lambda\sqrt{LC}}$ where λ is fixed depending on the mode of operation. The variable is now L or C and f (also v) instead of T and f . It is possible to calculate the length of such a line for a given frequency from transmission line theory.

$$Z_1 = Z_0 j \tan \beta l, \quad Z_0 = \sqrt{\frac{L}{C}}, \quad \beta = 2\pi f \sqrt{LC}$$

$$Z_{C'} = -j(1/2\pi f C') \quad \text{and} \quad Z_1 + Z_{C'} = 0$$

$$\text{then } \frac{1}{2\pi f C'} = \sqrt{\frac{L}{C}} \tan 2\pi f l \sqrt{LC}$$

$$\text{or } \tan 2\pi f l \sqrt{LC} = \frac{1}{2\pi f C'} \sqrt{\frac{L}{C}}$$

$$\text{the length } l = \left(\frac{1}{2\pi f \sqrt{LC}} \right) \left(\tan^{-1} \frac{1}{2\pi f C' \sqrt{\frac{L}{C}}} \right)$$

$$\text{for higher modes } l = \frac{1}{2\pi f \sqrt{LC}} \left(\tan^{-1} \frac{1}{2\pi f C' \sqrt{\frac{L}{C}}} + n\pi \right) \quad n=0, 1, 2 \text{ etc.}$$

1. King, Dr. R. B. Phil. Mag. Vol. 25, PP 339-363 Feb 1938.

~~SECRET~~

Plate 6 shows the operation of such a line as a wave trap utilizing the even modes. The condenser line is shorted at one end, resulting in a short at the other end when at resonance. Plate 7 shows that the spacing of the discretely lumped capacity is not critical but that the resonance curves continue in approximately the same manner. Plate 8 is the frequency curve of such an oscillator circuit using a split stator arrangement. 300 Mc is about the limit of oscillation using commercial variable condensers. Using a concentric line of this type an oscillator operating from about 400 to 1300 Mc has been built. Plate 2. It appears quite probable that some spurious responses in normal lumped constant circuits and in the butterfly circuit may come from this type of operation for the capacity from one stator to the rotor is at least twice as great as from stator to stator. Plate 9 shows the results from experimental work while Plate 10 is calculated for a possible split stator condenser.

3. While investigating this type of coaxial line it was found that considerable capacity change could be secured even though the center stators were removed. This is due to the fringe effect, for which calculations are very difficult. A rough calculation can be made by assuming a perpendicular plate to be substituted for the rotor plates, at the periphery of rotation.



← assumed plate along this edge

This is true if the plate spacing is fairly close.

4. It is possible to have variable distributed inductive line due to this fringe effect. Plate 3. As can be seen this line is formed of a saw toothed cylinder and a concave stator. Plate 11 shows the results of the varying spacing of the rotor slit. There is a certain amount of inductive effect along the teeth, depending on their thickness and on the spacing between but most of the current is carried along the solid portion. This particular line is 10 cm long and should resonate at 750 Mc ($\frac{1}{4}\lambda$ mode). Actually this resonant frequency, with solid portions closely spaced, is about 625 Mc. The reduction is due mostly to the fringe capacity of rotor to stator. The curves show that the capacity is about constant until the tooth to slot portion is in the ratio of one to four. The frequency range is also greatest in this case indicating the least inductive effect along the slotted portion. With the solid portions adjacent and 35 mil spacing, the capacity as calculated is .994 $\mu\text{uf/cm}$ and measured as 1.3 $\mu\text{uf/cm}$. The inductance as calculated from strip line theory (not completely applicable) is 960 $\mu\text{uh/cm}$. Since the resonant frequency is 84% of normal, there must be a capacity effect from the rest of rotor. The capacity varies in a transmission line inversely as the square of the frequency or velocity so in this case it is 1.42 times the previously calculated value or 1.41 $\mu\text{uf/cm}$ (measured 1.3 $\mu\text{uf/cm}$). With the rotor 180° from the previous position the frequency is 330 Mc (1/16" teeth 1/16" slot). The inductance varies inversely as the square of the frequency so should be 3500 $\mu\text{uh/cm}$, while the calculations from strip line theory give 6400 $\mu\text{uh/cm}$. In other words the inductance along the teeth has reduced the effective inductance to about 55% of the calculated value. These values are all approximate for the calculations are difficult to make.

APPENDIX 4

THE MODIFIED SELBY AND INDUCTIVE SHUNT LINE

1. The Selby circuit requires a variable capacity and the Inductive Shunt Line requires a variable inductance for tuning. This variable capacity or inductance can be obtained from a transmission line of the proper type. For example a shorted $1/4$ wave length line has zero capacity, which is the value needed for the highest frequency of the Selby circuit; if this line is made longer, it will increase from the $1/4$ wave length to the $1/2$ wave length, at which point, the line is of infinite capacity or will tune the Selby circuit to one third of the top frequency. If the line is lengthened still more, going from the $1/2$ wave length position toward $3/4$ wave length an inductance is added in place of a capacity and a still lower frequency will be reached. This type of line can, of course, get very long and unfortunately other modes are possible which cause difficulty in smooth tuning. This can be seen in the accompanying graph, Plate 12, where oscillations take place in the 0 to $1/4$ wave length inductive mode, rather than in the $1/4$ to $1/2$ wave length capacitive mode that is desired. The distributed constants line may be used to eliminate the large length, though the moding is still possible. Elimination of the moding can be avoided by the use of double tuned circuits, as seen in the graph Plate 13; using the $1/4$ to $1/2$ wave length mode in combination with the $3/4$ to $3/2$ wave length modes. Another difficulty with the distributed constants line is the large change in L or C required as can be seen in table 2.

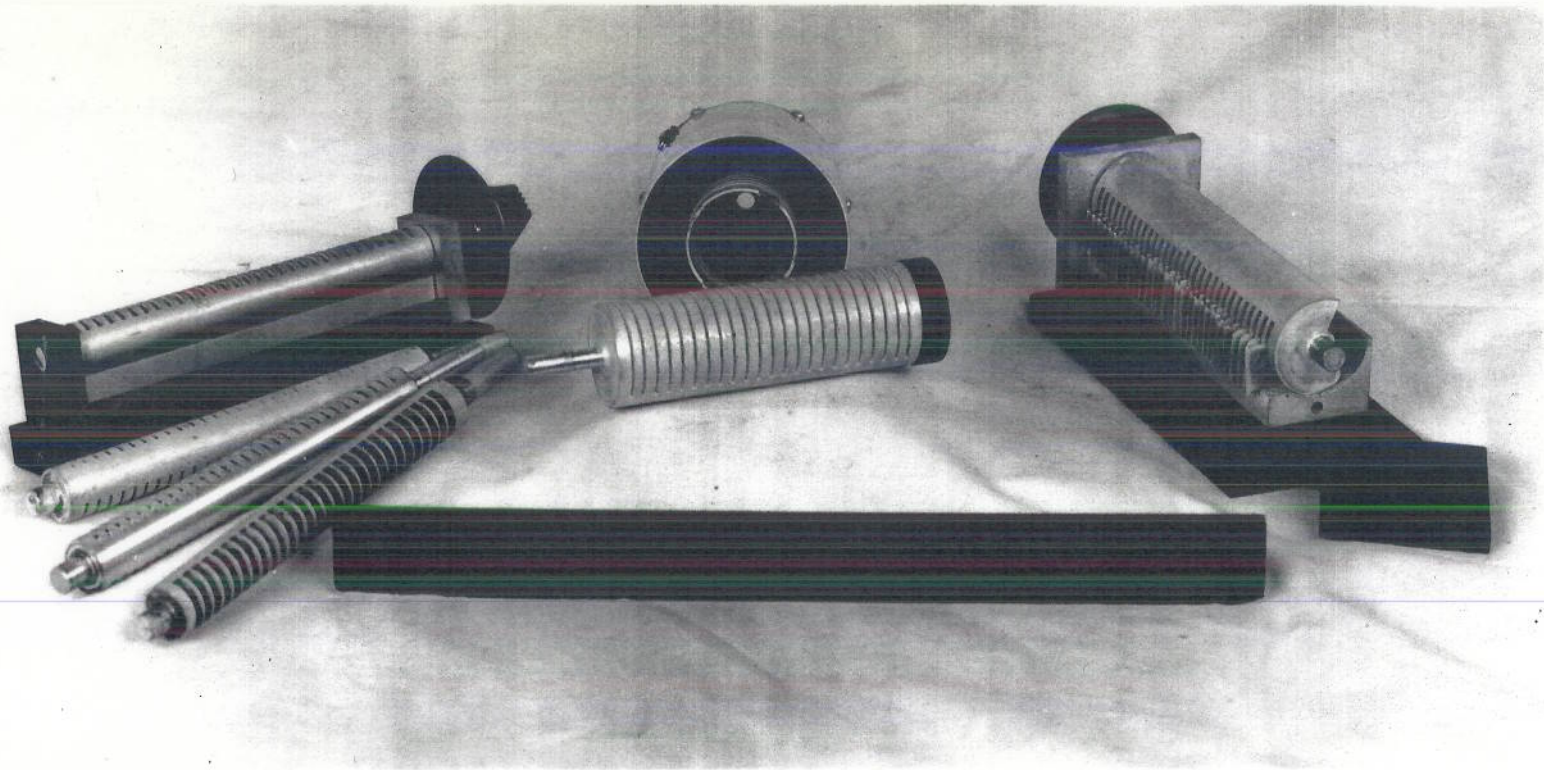
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TABLE I

SUMMARY OF CIRCUITS FOR THE 300 -3000 Mc rf RANGE

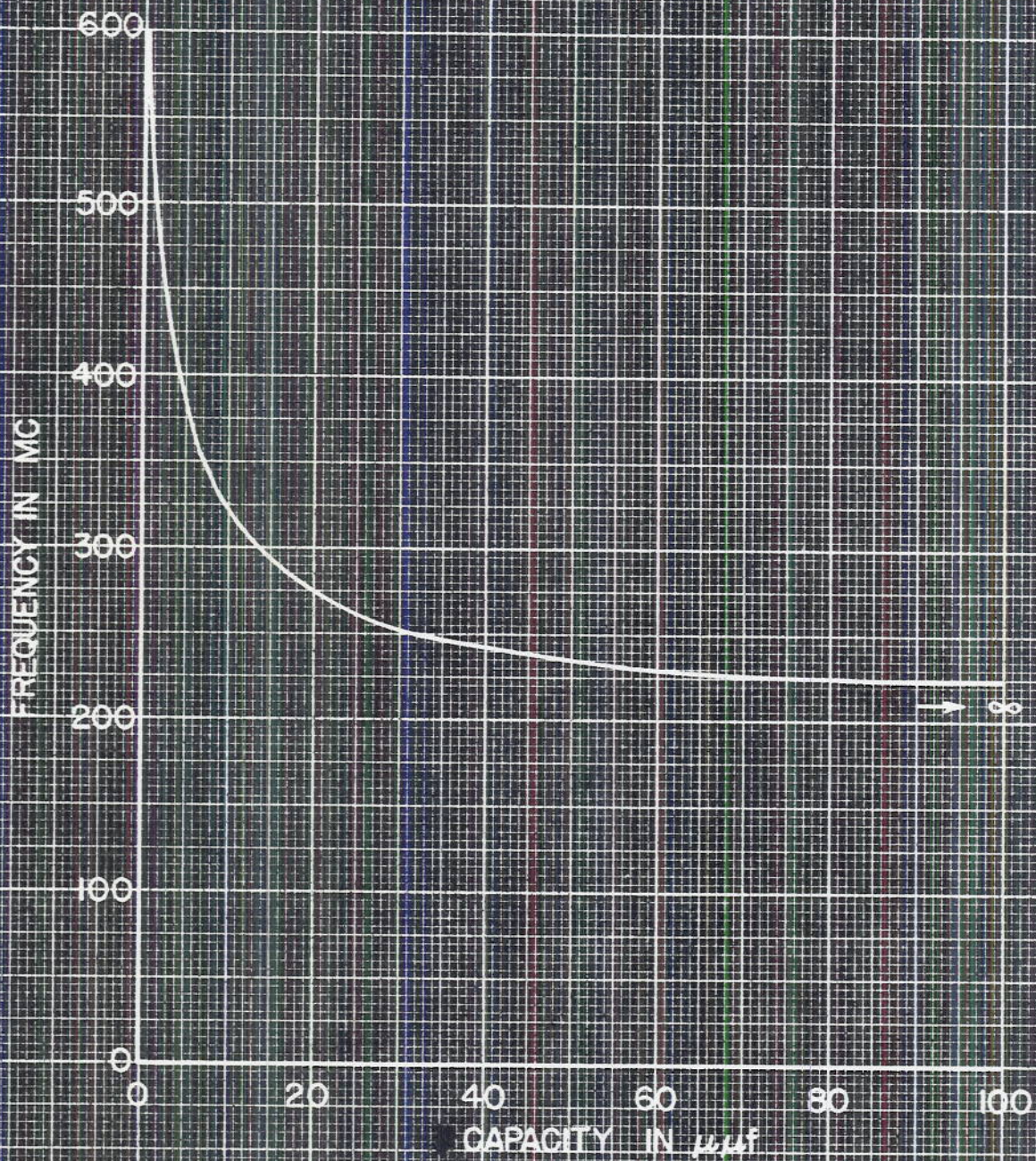
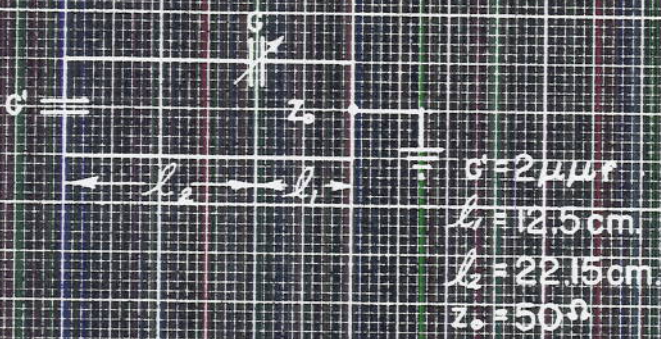
CIRCUIT	FREQ. LIMITS MC	TUBES USED	ADVANTAGES	DISADVANTAGES
Coil and Capacitor	400	955 954 958 956 6F4 Minature types	Ganging not too difficult. Easy to manufacture. 270° rotation possible.	Inductance appears in Condenser. Chokes required.
Butterfly (G.R.)	100 -1000 (3000)	955, 958, 6F4 WE 316A, 368A 703A	Symmetrical circuit. Large freq. coverage (5-1) L and C both change.	Spurious modes. Tube Mounting difficult. High degree of machining required. Ganging difficult. Only 90° effective rotation. Chokes required.
Semi Butterfly (G.R.) (NRL)	100 -700	955, 958, 6F4 954, 956 WE 316A, 368A 703A 2040	Standard Mfg. Technique. L and C both change. 180° rotation. Tube mounting not too difficult. Ganging not too difficult. No spurious modes. No ceramic shafts or rods.	Non Symmetrical. Chokes required.

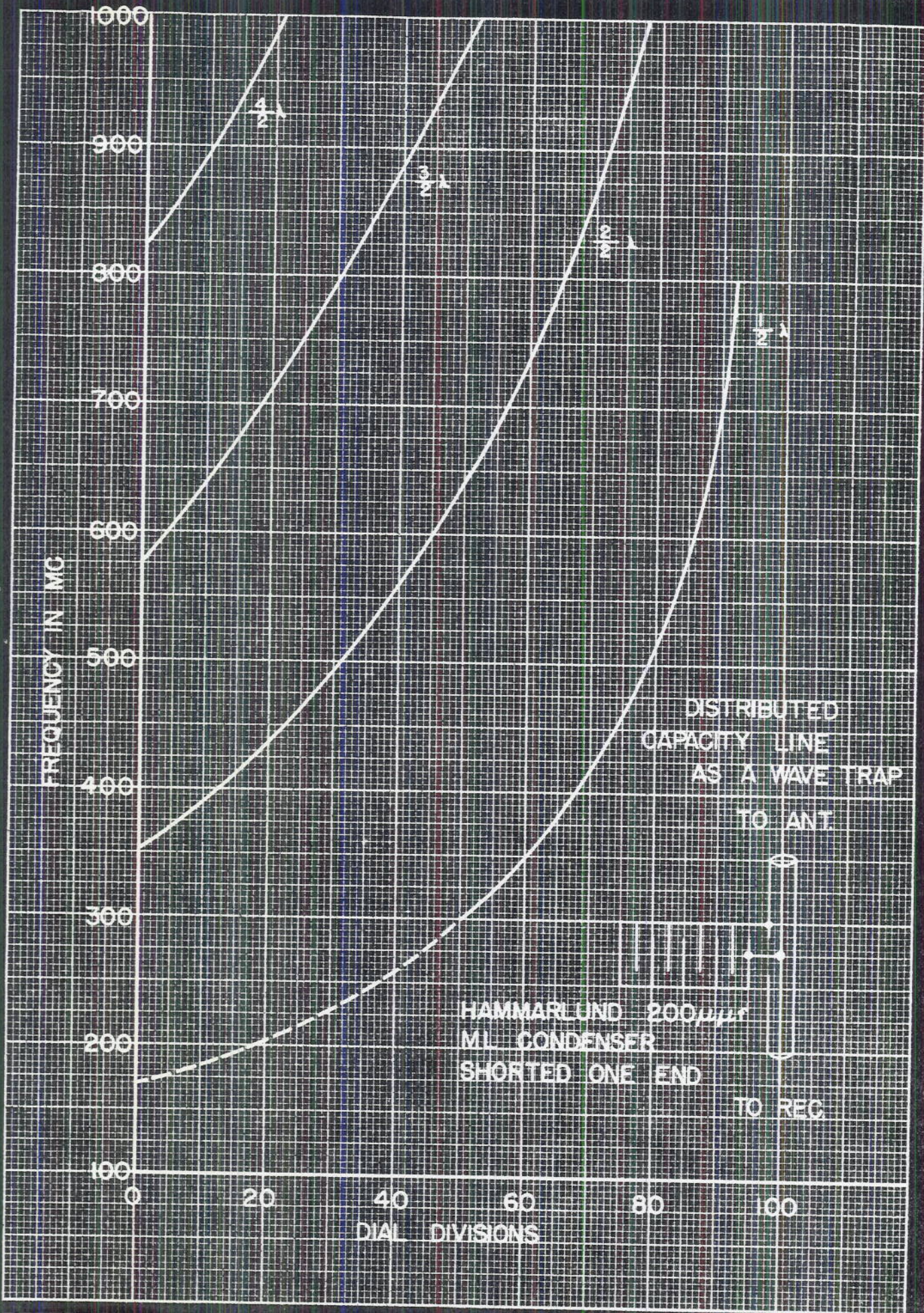
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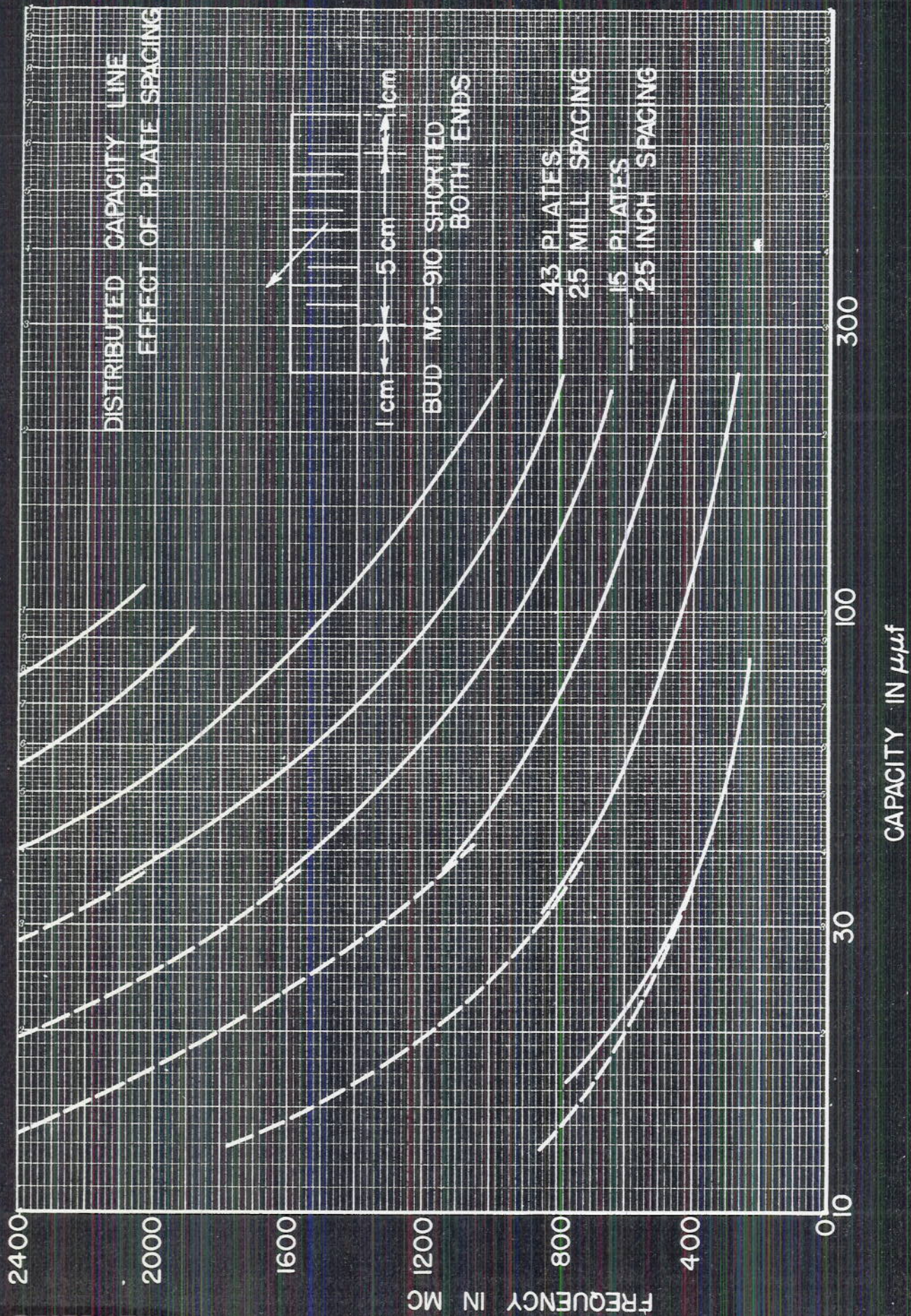


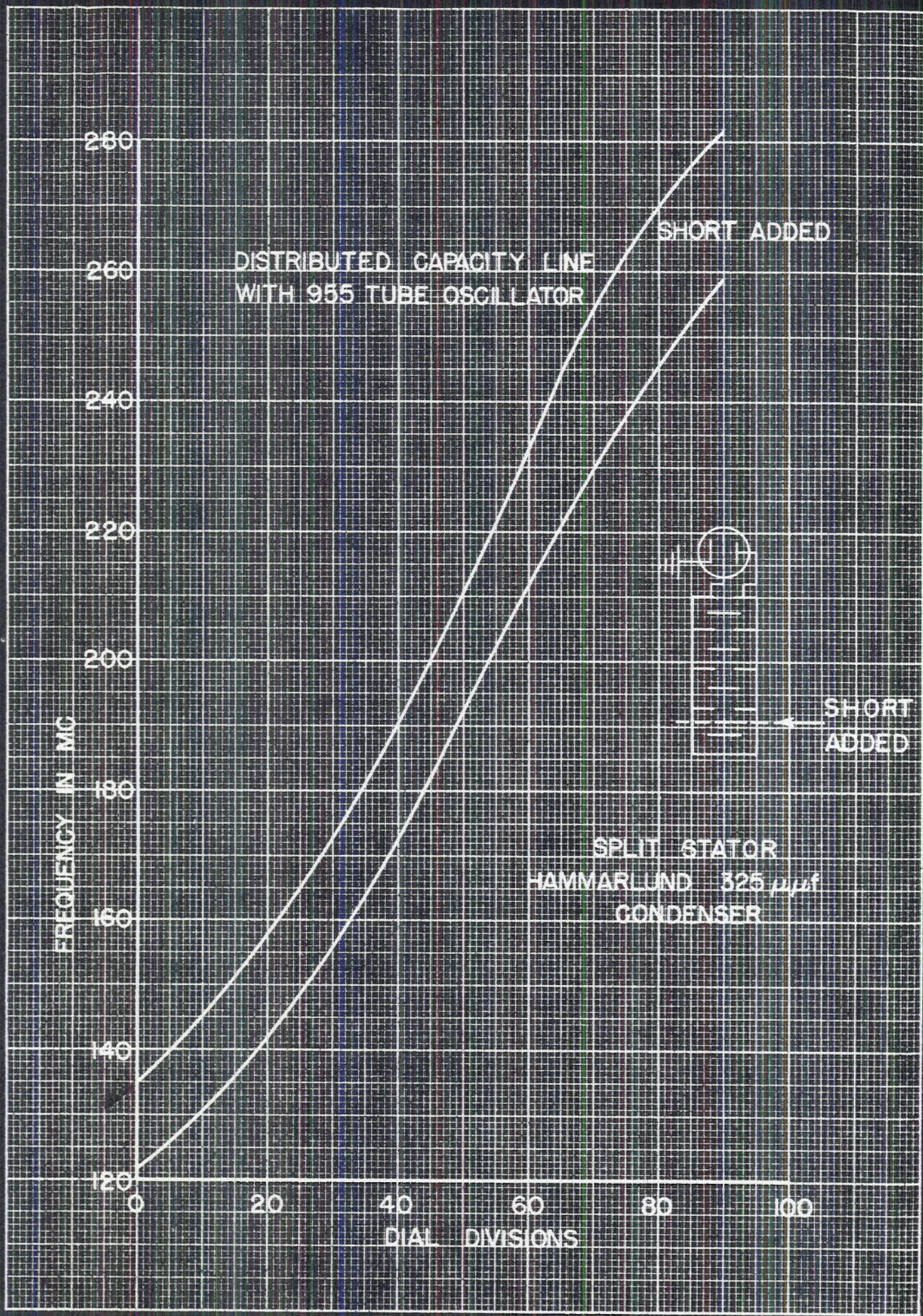
TWO WIRE AND CONCENTRIC DISTRIBUTED INDUCTANCE LINE
AND COMBINED CAPACITY AND INDUCTANCE LINE

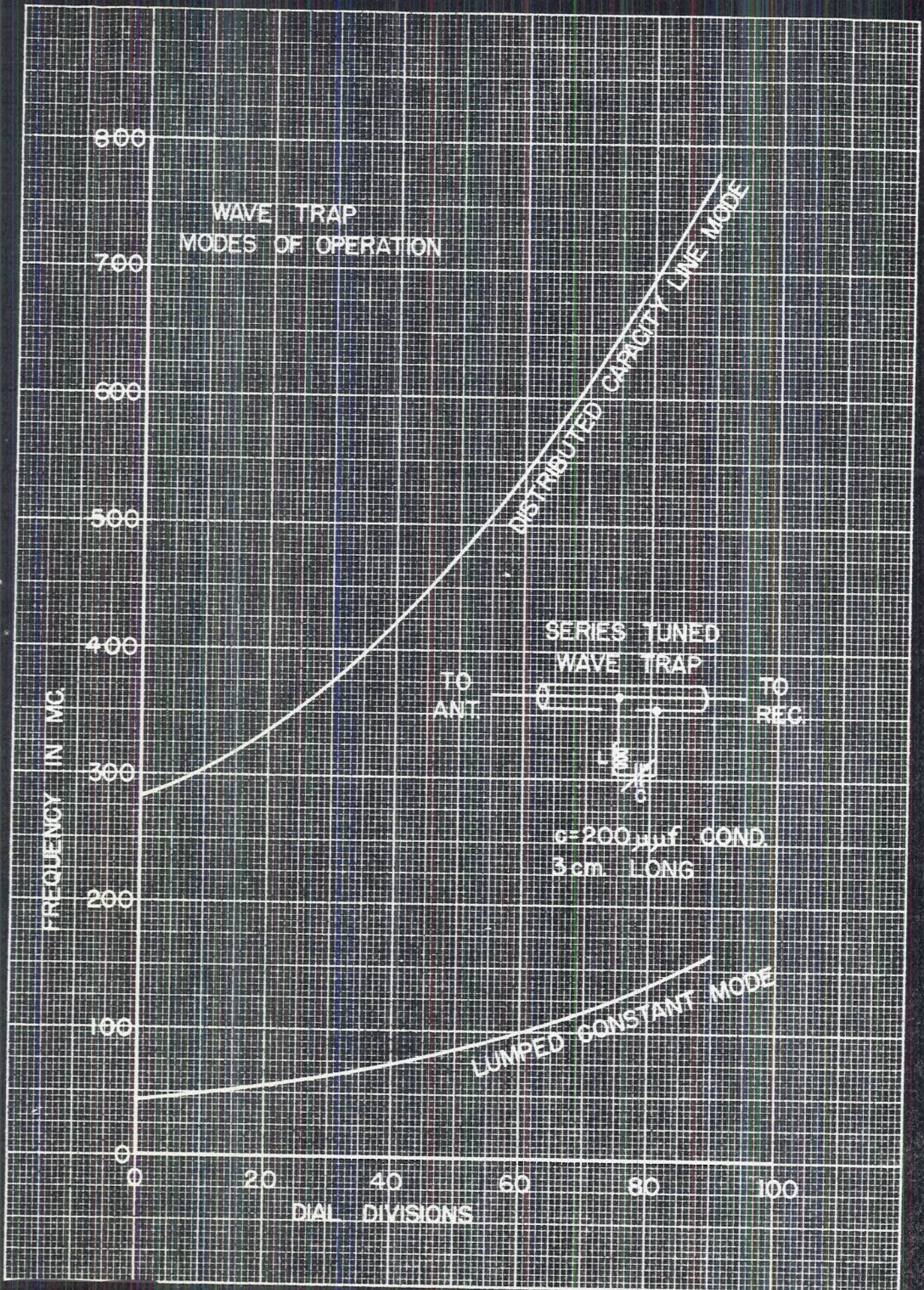
SELBY CIRCUIT











MODES OF OPERATION
SPLIT STATOR TYPE OF CONDENSER

1600

1400

1200

1000

800

600

400

200

0

80

160

CAPACITY IN $\mu\mu\text{f}$ STATOR TO STATOR 10

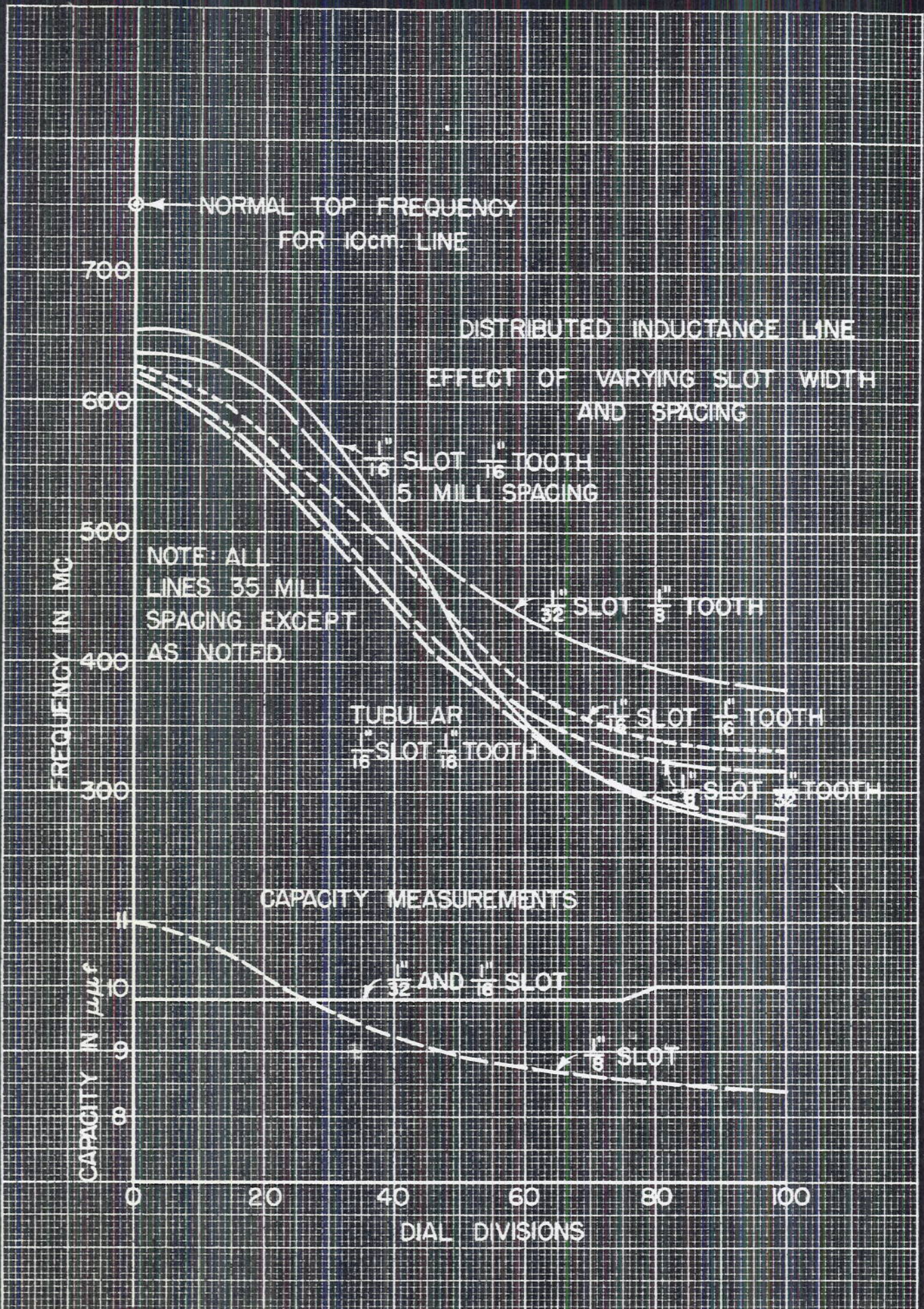
CAPACITY IN $\mu\mu\text{f}$ ROTOR TO ONE STATOR 10

DISTRIBUTED CAPACITY LINE MODE

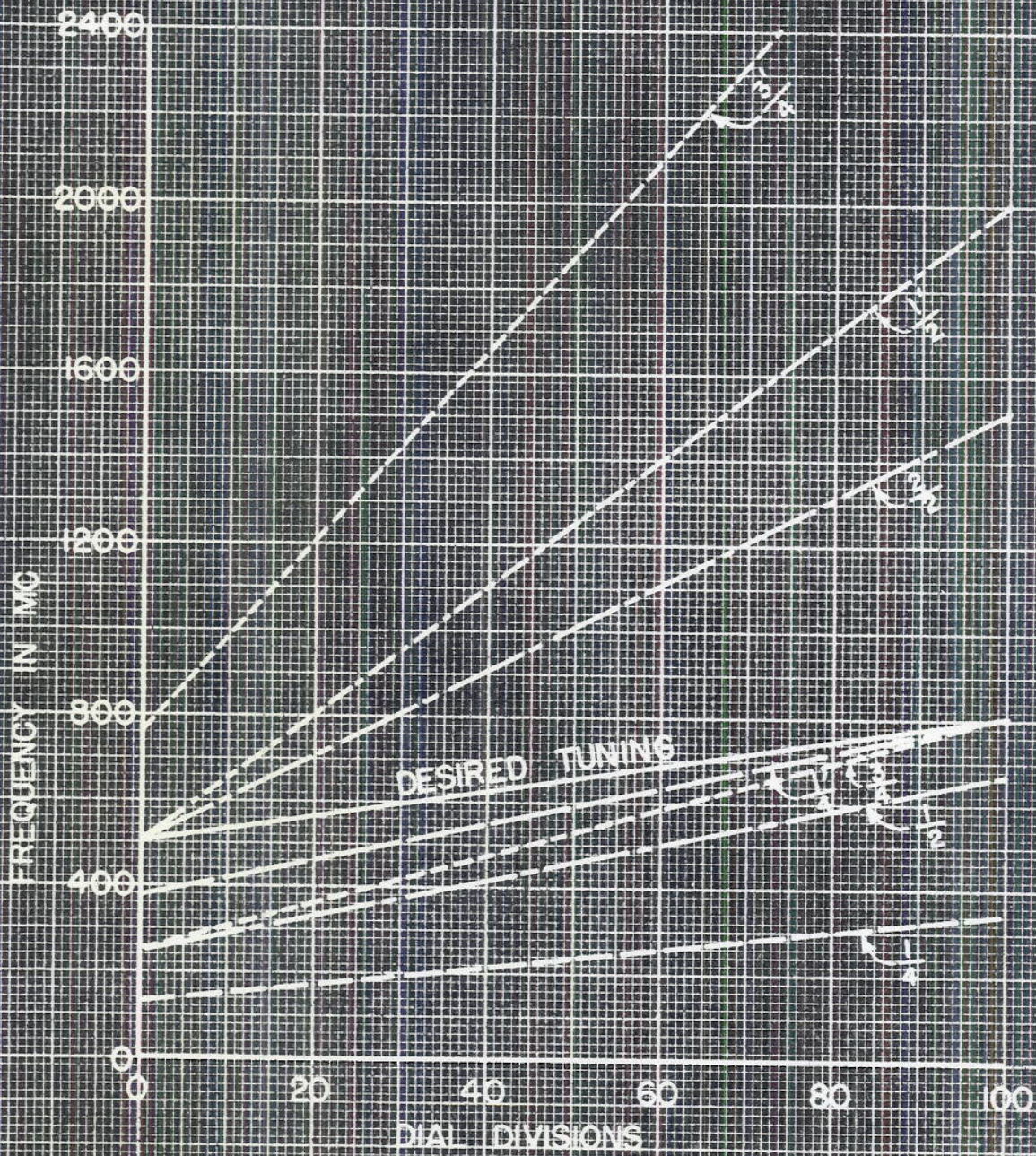
LUMPED CIRCUIT MODE

← POSSIBLE DEAD SPOT
FOR CIRCUIT OSCILLATING
IN LUMPED CIRCUIT MODE

CALCULATIONS MADE FOR 5cm
LENGTH WITH .0012 μh INDUCT-
ANCE FOR LUMPED CIRCUIT AND
.0012 $\mu\text{h}/\text{cm}$ FOR LINE.



SELBY CIRCUIT OR INDUCTIVE SHUNT LINE
DOUBLE TUNED BY TRANSMISSION LINE



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ABSTRACTED