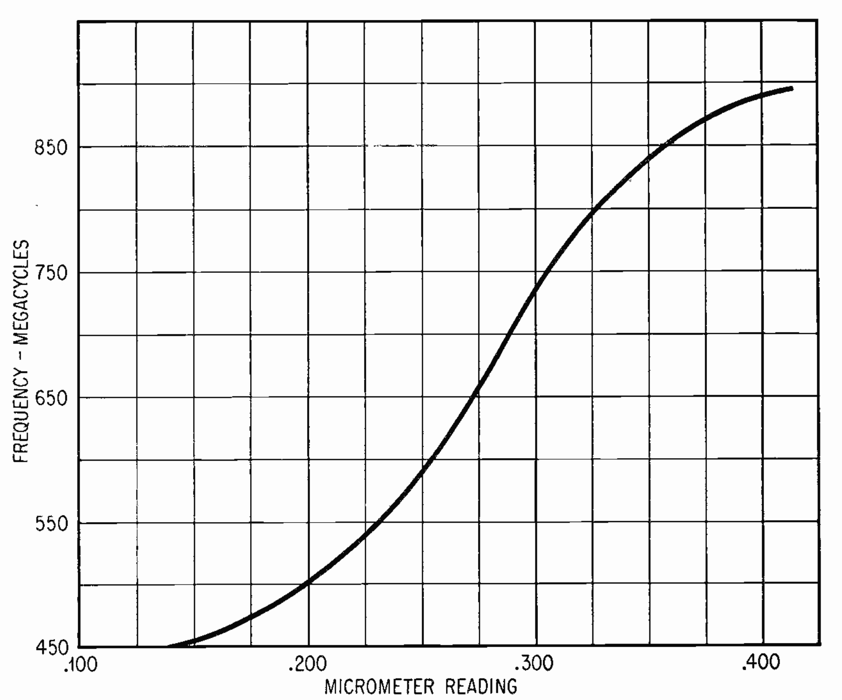


TYPICAL OSCILLATOR CALIBRATION

FIG. 10

while the solder is still molten. The spacing between the wires should be ⅜″ except at the tuner end where they spread to ½″.

The capacitative tuner for the grid-dip oscillator is made by soldering small semi-cylinderical plates to the ends of the grid and plate line. The one on the plate line becomes the stator of the tuning capacitor, while the one on the grid wire acts as a wiper against the rotor. The rotor consists of a short cylinder of brass tubing which is driven longitudinally to engage the stator sections by a micrometer head drive mounted on the handle tube. The micrometer head, which may be of the dime-store variety, provides a precisely readable calibrated drive which can be manipulated smoothly with the thumb of the hand holding the meter.

The details of the capacitor tuner are shown in Fig. 9. Since the builder will probably have to utilize whatever micrometer head is readily available, and the exact duplication of this detail is not necessary, dimensions determined by the drive used will be left to the builder to determine. The micrometer head is mounted on the side of the handle tube at the angular position shown in Fig. 7a. This is accomplished with a brass block, as shown in Fig. 9, which is drilled with a hole of the proper size to fit the stationary barrel of the micrometer and fitted with a set-screw to lock it in place. The bottom of the block is filed to the proper contour to fit the handle tube and is "sweated" in place.

The tuner rotor, made from brass tube stock ¼″ i. d., 5/16″ o. d., and ⅜″ long, is pressed onto a ¼″ polystyrene shaft. This "poly" shaft, in turn, is coupled to the micrometer shaft by means of a rigid shaft coupler. The coupler must fit will enough to make the rotor run true when the micrometer drive is revolved. If the micrometer shaft used is not of the proper diameter to fit a standard coupler, one should be lathe turned.

The stationary tuner plates are made from ⅜″ o. d. brass tube stock sawed lengthwise to form semi-cylinders ⅛″ long. These are soldered to the ends of the grid-plate lines concentrically so that the rotor cylinder will move smoothly through them. The semi-cylinders are ⅛″ apart. They can be best aligned by soldering them in place while the rotor is engaged providing all parts are pretinned to prevent the heat of soldering from softening the polystyrene shaft. After the plates are soldered in place, the spacing of the line is adjusted so that the grid plate makes a smooth wiping contact on the rotor, while the semi cylinder on the plate line is carefully spaced only a few thousandths of an inch from the rotor cylinder. This adjustment is critical if the full UHF TV range is to be spanned. Air insulation is used between the stator and rotor if the latter has no "wobble" so that close spacing can be maintained without shorting. If not, a thin sheet of a high quality dielectric should be cemented to the inside surface of the plate cylinder. A piece of "pliofilm" of the kind used by grocers for vegetable bags was found to have sufficiently low losses for this purpose. Cellophane was found excessively lossy.

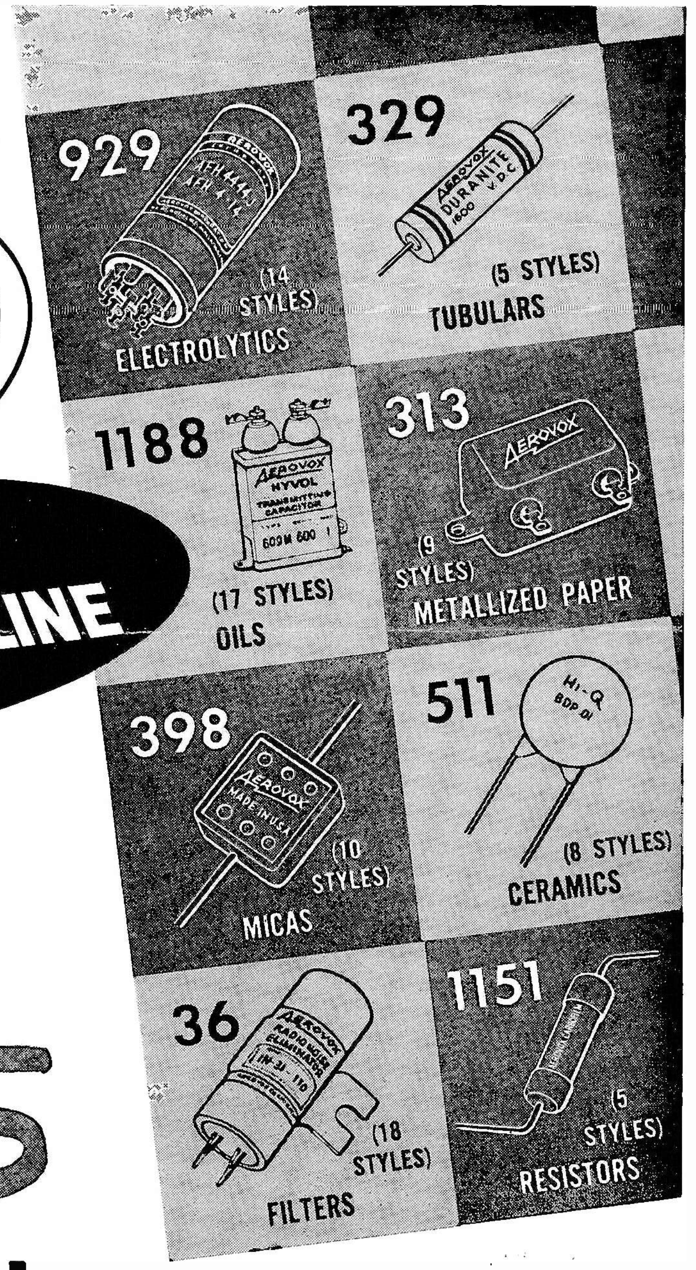
The length of the polystyrene rod is adjusted to allow the rotor to be moved from a position where its end is flush with the far side of the grid wiper cylinder (high frequency end of tuning range), to a position where it is fully engaged with both cylinders and its end is flush with the far side of the plate cylinder (low frequency position). If good alignment and close tuner spacing is maintained, the resulting tuning characteristic will be similar to Fig. 10. The finished meter should be calibrated against a frequency standard such as a *Lecher* line. The absorption frequency meter described in Part 1 of this series is an ideal tool for use in adjusting the tuning range of the grid-dip oscillator. After adjustment, the oscillator must be handled carefully to prevent disturbing the calibration.

Using the Grid Dip Meter

The use of the experimental grid-dip meter for UHF is identical to that of the low frequency versions. The plate voltage on the 6AF4 tube is adjusted (R2) until the grid meter indicates that the tube is oscillating and drawing between ¼ and ¾ milliamperes grid current. (The corresponding plate current must not exceed 16 milliamperes). The bent portion of the grid-plate line is then brought close to the circuit of unknown frequency and the micrometer tuner is run through its range. There will be a sharp dip in grid current at the frequency of the circuit being measured. A little practice with a resonant circuit of known frequency will acquaint the user with the position for optimum coupling.

Needless to say, the grid-dip oscillator can also be used for a calibrated test oscillator, a rough "Q" meter, and many of the other uses which have been found for the versatile grid-dip oscillator at lower frequencies.

Reference: Aerovox Research Worker, June 1940, "Use of L-C Checker for R-F Measurements."



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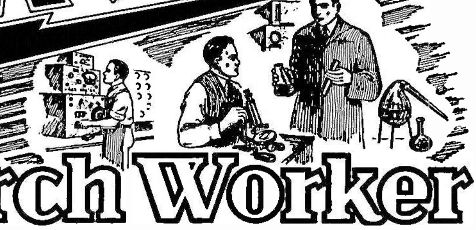

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UHF Instrumentation

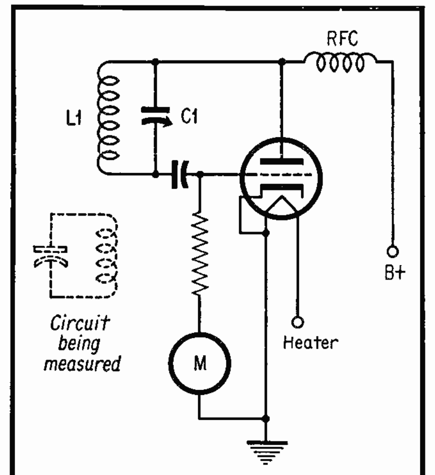
Part 2: A UHF Grid-Dip Oscillator

By the Engineering Department, Aerovox Corporation

THE AEROVOX RESEARCH WORKER for July, 1952 discussed the need for simple, economical measuring instruments for use by the experimenter, service technician, and amateur working in the rapidly expanding ultra-high frequency region. This need is even more imperative since the lifting of UHF television construction bans in January of this year and the subsequent appearance of new stations scattered throughout the *seventy* new UHF channels.

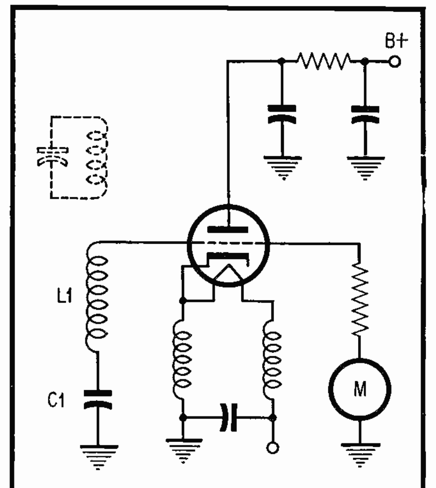
CORRECTION: Figure 3 of the March 1953 issue inadvertently illustrated a 6C4 as Pentode. The correct symbol should have illustrated a Triode with only one control grid.

The UHF absorption frequency meter described in the above mentioned issue fulfills the first need for an instrument to determine the frequency of a *signal source* operating in the vicinity of the new channels (470-890 mc.). Thus, the tuning range of the local oscillator of a UHF television converter could be measured and adjusted. Another need, however, which is not satisfied by the absorption meter, is that of determining the resonant frequency of *passive* circuits which are not generators of energy. Such an instrument permits measurement of the frequency of resonance of UHF con-



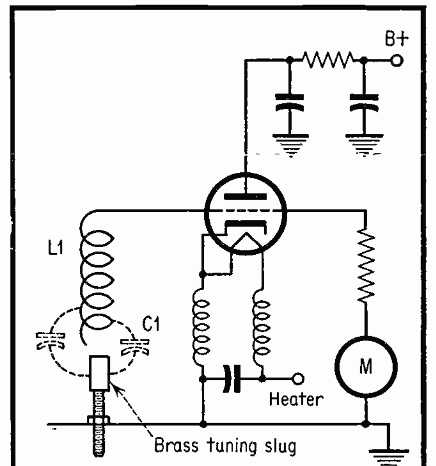
SIMPLE GRID-DIP OSCILLATOR CIRCUIT

FIG.1



SERIES-TUNED UHF OSCILLATOR

FIG.2



SLUG-TUNED SERIES-RESONANT UHF CIRCUIT

FIG.3

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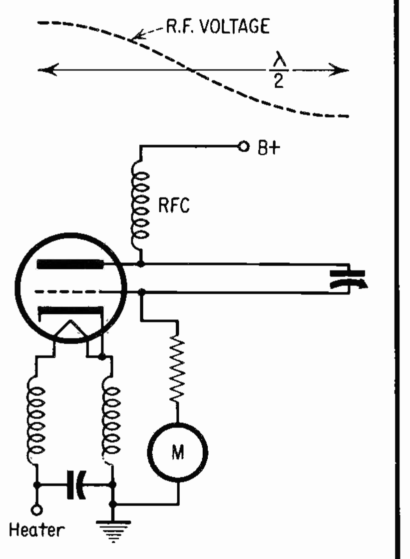


HALF-WAVE LINE
UHF OSCILLATOR CIRCUIT
FIG.4

verter preselectors, mixers, wave-traps, and oscillator or amplifier "tanks" with all power removed. This need can be fulfilled by a UHF adaptation of the popular grid-dip oscillator. The design and construction of an experimental instrument of this kind is the subject of this issue.

Theory of Operation

Anyone who has used the grid-dip meter at low frequencies is well acquainted with the versatility of this instrument. Amateurs, service technicians, and laboratory personnel have been quick to adapt it to many uses. It should be an equally valuable tool in the new UHF region. To understand the special design requirements of the UHF grid-dip meter, however, it would be well to review the operating principles of this device.

Basically, the grid-dip meter is a simple self-excited oscillator capable of continuous tuning over the range of frequencies of interest and provided with a metering arrangement in the grid circuit to measure grid excitation. These conditions are met by the simple *ultra-audion* circuit of Fig. 1. In this circuit the grid and plate of the vacuum tube are connected to opposite ends of the resonant circuit L1, C1. In this way, part of the energy in the resonant circuit is fed back to the grid in the correct phase to maintain oscillations. This r.f. feed-back swings the grid positive, so that the grid draws current. The meter (M) reads the rectified grid current, which is a measure of the r.f. energy in the "tank" circuit.

Now, if the resonant circuit of an oscillator of this type is brought close to another circuit which is tuned to the same frequency, some of the r.f. energy in the oscillating tank circuit will be absorbed. The result is a sharp decrease, or "dip", in the rectified grid current. This happens since the removal of some of the oscillator energy reduces the amount of feed-back drive available to the grid. The plate current undergoes an increase at the same time due to the increased oscillator loading. The grid dip is sharper, however, since a cumulative effect occurs; a decrease in the r.f. energy in the tank, caused by absorption, results in less feed-back drive on the grid, which decreases the output and, hence, reduces the grid drive still further. Therefore, a sensitive indication of resonance in a nearby circuit is provided. If the grid-dip oscillator is calibrated in terms of frequency or wavelength, the frequency or wavelength of the circuit being measured is then known by the point at which absorption takes place. The accuracy is maximum when the coupling between the grid-dip meter and the circuit of unknown frequency is the least which will produce a readable "dip".

UHF Design Considerations

Although the design of a grid-dip oscillator for low frequency usage is a relatively straightforward undertaking, producing one for use in the new UHF TV channels is considerably more difficult. This is partially because, as stated before in these pages, the new channels lie in the "transition" portion of the radio-frequency spectrum where the frequency is "too low for cavity circuits and too high for coil and condenser circuits". It is difficult also because of the special requirements of a grid-dip oscillator which must:

(a) Oscillate smoothly over at least the frequency range extending from 470 to 890 megacycles.

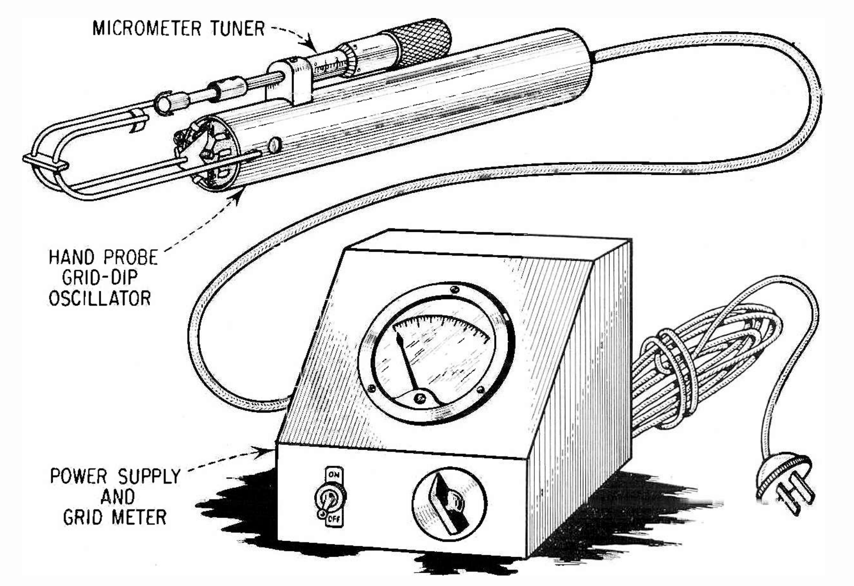
(b) Have sufficient stability to prevent frequency "pulling" by the circuit being measured.

(c) Have a compact form factor suitable for hand probing in limited space.

(d) Have a resonant circuit configuration which affords easy inductive coupling to external circuits.

(e) Be easy to construct with a minimum of machine work.

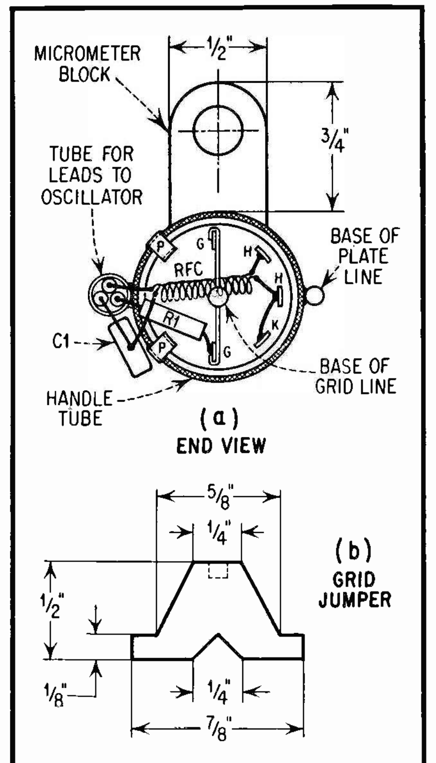
The best place to look for a type of self-excited oscillator to fulfill these requirements is among those which have been developed for UHF television local oscillators. Unfortunately, the field is limited to a few types, since many manufacturers have utilized the harmonics of oscillators operating at lower frequencies. The UHF tuner circuits which have proven successful for fundamental frequency operation are the butterfly, the semi-butterfly, the split-ring, the series tuned circuits, and various forms of transmission line tuned oscillators. The first three of these were illustrated and discussed in Part 1 of this series. We will now consider the applicability of these various kinds to the grid-dip application problem at hand.



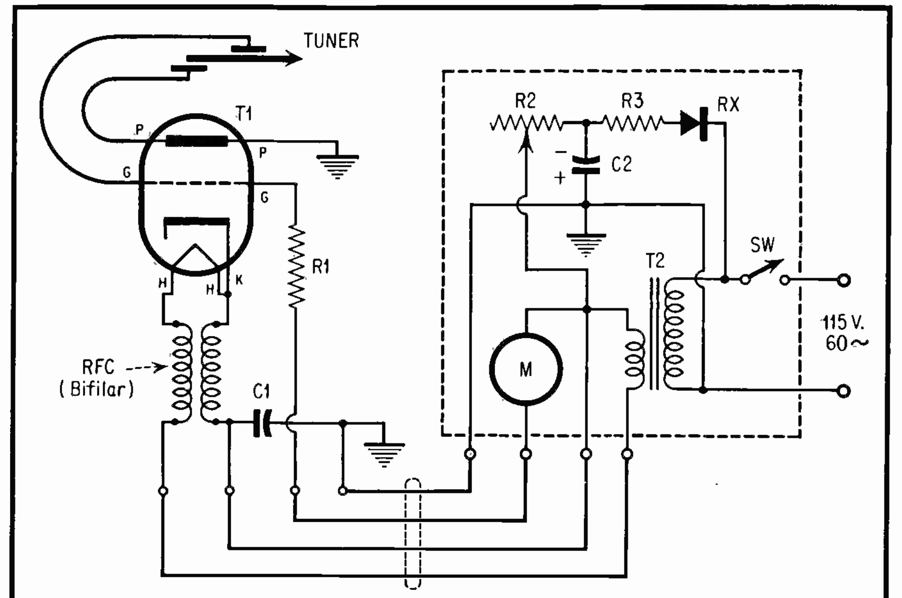
COMPLETED GRID-DIP METER FOR UHF TV
FIG.5

The split-ring, or split-cylinder tuner, now widely used in TV converters could be used for grid-dip oscillator purposes although its form-factor is not ideal in its usual form. For a hand-held oscillator it would be somewhat bulky and difficult to conveniently tune. Experimental split-ring oscillators were tried using this kind of tuner modified as in the absorption frequency meter described in Part 1. It was hoped that the entire oscillator could be constructed within the tubular handle which forms the basis of the split-cylinder tuner. A grid-dip oscillator having an ideal form factor would result. However, it was found that the addition of the tube interelectrode capacitance to the resonator circuit lowered the upper frequency attainable. To compensate for this effect, a smaller diameter cylinder would have to be used, precluding the possibility of enclosing the tube and other oscillator parts within the handle.

The butterfly tuners have the disadvantage of being difficult to construct and are somewhat bulky for this frequency range. The semi-butterfly tuner is easier to construct than the full butterfly, but has a poor configuration for our purpose and tunes rapidly with shaft rotation, making reading difficult. Being a single-ended parallel resonant circuit, it too, is considerably foreshortened by the tube capacitance.



SHOWING DETAILS OF
OSCILLATOR CONSTRUCTION
FIG.7



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R2 – 5000 OHM POT., WIREWOUND
R3 – 47 OHM, AEROVOX 1097
C1 – 100 MMFD. MICA, AEROVOX TYPE 1468
C2 – 20 MFD., ELECTROLYTIC, 150 W.V., AEROVOX DANDEE
T1 – 6AF4 TUBE
RFC – SEE TEXT
M – 0-1 MA. METER
RX – 50 MA. SELENIUM RECTIFIER
T2 – 6.3 V., 0.5 AMP. TRANSF.

EXPERIMENTAL UHF GRID-DIP OSCILLATOR CIRCUIT
FIG.6

Series tuned local oscillator circuits, such as that illustrated in Fig. 2, do not easily cover the frequency range required unless a tapped coil is used. Accurate calibration then becomes difficult to maintain. A special form of the series-tuned oscillator, in which the effective length of the coil is changed during tuning by a grounded metal slug which slides inside the coil in such a manner as to move the ground point progressively higher and so reduce the inductance, is shown in Fig. 3. Although it is being used to some extent in UHF local oscillator service, attempts to adapt it to a grid-dip meter were not successful because the required tuning range could not be covered in a structure capable of easy construction.

The oscillator type finally adopted is the half-wave parallel line circuit of Fig. 4. In this arrangement, the more usual shorted quarter-wavelength line is replaced by an open-circuited, half-wavelength line connected between the grid and plate of the oscillator tube. This provides a greater length of line external to the tube than the quarter-wave circuit does, facilitating coupling to the circuit being measured. An oscillator of this kind can be tuned by a variable capacitance located at the end of the grid-plate line. A voltage maximum point exists at this point as well as at the other end where the tube electrodes are connected. This voltage distribution is indicated in Fig. 4 as a dotted line. The zero-voltage point moves along the line during tuning, being in the center when the capacitance of the tuner is equal to the capacities of the tube elements and socket combined. At the high frequency end of the tuning range, the nodal point may be within the tube envelope.

By careful design and construction, the oscillator of Fig. 4 can be made to operate smoothly over the UHF TV range. It requires so few parts that the entire oscillator can be used as a hand probe, held and tuned by one hand. To render the line circuit more compact, the line is folded to form a "U" so that the capacitive tuner is close to the tube. The curved portion of the "U" then serves as an inductive loop to couple the grid-dip meter to the circuit being measured. The tube employed is the 6AF4 miniature now popular in UHF converters. Radio frequency chokes are used in the heater-cathode leads to maintain the entire cathode structure above r.f. ground.

The dip-indicating meter and the power supply required for the oscillator are housed in a separate unit with flexible interconnecting cable. For convenience in the construction of the oscillator, the anode is operated at d.c. ground potential and the cathode at negative 100 volts. For this reason, the power supply is connected for positive-grounded output.

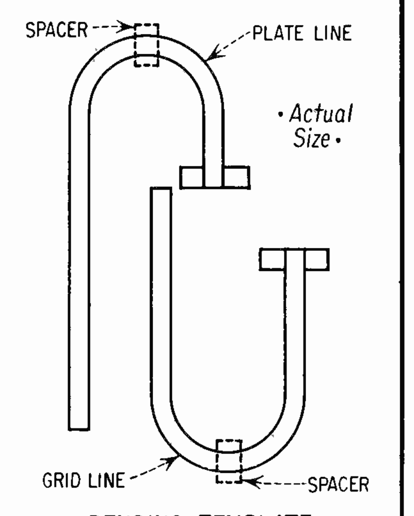
Construction

The completed experimental grid-dip oscillator and supply are shown in Fig. 5 and the corresponding electrical circuit is given in Fig. 6. It must be stated here that, because of the critical nature of UHF circuitry, satisfactory results can only be expected if the details of the oscillator construction are closely followed. Most of the operations involved in making the unit can be performed with hand tools, although several parts should be lathe turned if possible.

The oscillator unit is built in the end of a piece of standard brass tubing ⅞″ o. d. and 5″ long. This tube forms the handle of the grid-dip probe. The 6AF4 oscillator tube mounts *inside* this tube with its socket terminals about flush with the end. A high quality ceramic miniature tube socket of the type having a metal shield base will fit snugly inside the brass tube if the mounting "ears" and small "nubs" designed to engage the shield are filed off. The metal detail through the center of the socket is also removed. To facilitate insertion and removal of the 6AF4, a ¼″ hole is drilled through the wall of the brass tube to coincide with one of the holes in the shield base. This allows the blade of a small screw-driver to be inserted between the tube base and socket to disengage the tube for removal.

Fig. 7a illustrates the end-view layout of the oscillator end of the brass tube with the relative positions of the parts and terminals. The two plate terminals of the tube socket are soldered to the inner surface of the handle tube at the nearest points. The grid terminals are tied together by a piece of sheet copper or brass about .015″ thick and cut to the shape indicated in Fig. 7b. The tabs on the end are crimped around the socket terminals and soldered. Crimping provides a firm mechanical attachment which will hold the grid jumper in place even though the solder is re-melted in subsequent soldering operations.

Since the 6AF4 and socket fill the entire diameter of the handle tube, the leads to the oscillator must be run along the outside. For this purpose, a piece of ¼″ o. d. brass or copper tubing is soldered along the length of the large tube at the location shown in Fig. 7a. A strip along the length of each tube is liberally tinned with solder before the two pieces are "sweated" together with a hot iron.



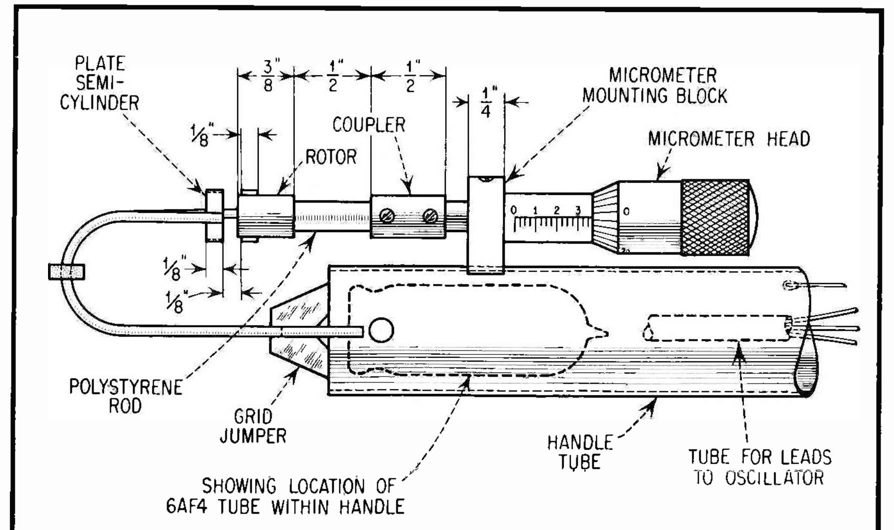
BENDING TEMPLATE
FOR GRID-PLATE LINES
FIG.8

The construction of the r.f. chokes for the heater-cathode circuit of the grid-dip oscillator is critical. If the cathode lead inductance is not the proper value, the oscillator will exhibit "holes" in the tuning range which make its use for determining the frequency of other circuits difficult, since the tuning "holes" also result in dips in grid current. A satisfactory choke system is made by winding both coils simultaneously with No. 22 enameled wire on the shank of a No. 32 twist drill (.116″). This *bifilar* winding is made self-supporting after the removal of the drill by twisting the ends of the wires together for a distance of ¼″ on both ends of the required 12 close-wound double turns. The wound part of the choke is ½″ long and it mounts against the ceramic socket in the space between the two plate terminals and between the two grid terminals.

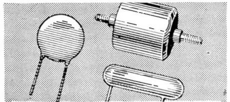
The grid-plate line circuit is made of No. 12 B&S gauge tinned copper.

The plate wire is 3″ long and the grid wire is 2¾″ long. These wires are bent to form a "U" according to the actual-size template given in Fig. 8. The grid line is ¼″ longer at the tuner end of the line and the plate line overlaps ½″ at the tube end; ¼″ of this is soldered to the surface of the handle tube at the location indicated in Fig. 7a. The tube end of the grid line is soldered to the center of the sheet metal jumper made to tie the grid terminals together. A neater connection will result if the grid wire is slotted with a small saw for about ⅛″ so that it will fit around the jumper.

A dielectric spacer is used to maintain the proper spacing between the grid-plate lines. It consists of a ¼″ x ¼″ x ¾″ polystyrene bar drilled on ⅜″ centers with holes just large enough to admit the line wires (No. 38 drill). This spacer may then be fixed firmly at the proper location indicated in Fig. 8 by liberally tinning the wires at that point and sliding the spacer quickly into place



DETAILS OF MICROMETER TUNING SYSTEM
FIG.9



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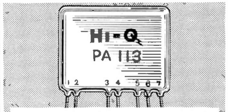

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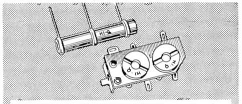

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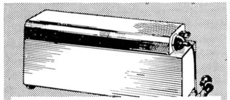

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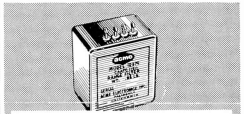

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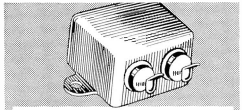

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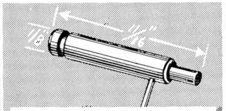

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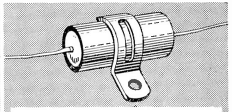

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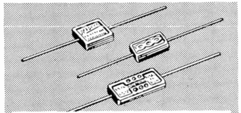

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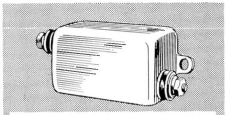

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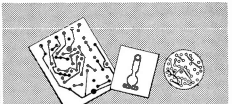

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Millimeter Waves

The New Frontier in Radio

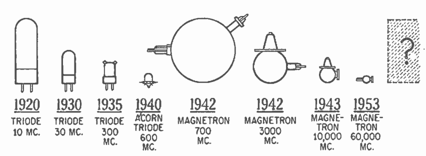
By the Engineering Department, Aerovox Corporation

SINCE the earliest days of radio, the exploration of frequencies higher than those in common use at the time has provided an exciting field of endeavor for the scientist and experimenter with pioneering instincts. Strangely enough, such efforts have almost invariably been ridiculed and condemned to failure by the contemporaries of such "explorers". And, just as unfailingly, the ultimate results have usually proven the skeptics to be wrong and the new portion of the radio frequency spectrum has always turned out to be of extreme value in extending the art of radio communication.

Even before World War I, in the days of spark transmission, the radio amateur fraternity were relegated to the region *"200 meters and down"* because this portion of the spectrum was considered virtually worthless for communication purposes by the professional engineering world. However, when the "hams" demonstrated that trans-oceanic contacts were easily accomplished on the unheard-of wave-length of 100 meters, these same commercial interests flocked to use the new "short waves". Needless to say, this region now contains almost all of the valuable communications channels now in use.

The adventurous experimenters didn't stop at 100 meters, or even 50 meters, however. They pushed the revolutionary new vacuum tube oscillators and receivers all the way down to about 20 meters. Again, this "radio no-mans-land", which had been thought to be worthless, had, in a short time, demonstrated a new phenomonen in communication — long distance signals over a daylight path. This started another rush for new channels, and today these frequencies are highly prized for international broadcasting and communication.

This downward migration, spearheaded by the amateur and experimenter, ground to a halt below 10 meters, where it was found that radio signals were not reflected back to the earth by the ionosphere much of the time, making communications beyond the horizon doubtful. For a long while these line-of-sight VHF frequencies remained unexploited because of these limited propagation



ILLUSTRATING EVOLUTION OF COHERENT OSCILLATORS

FIG. 1

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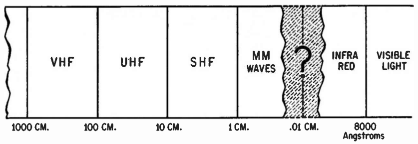
characteristics and the fact that conventional vacuum tubes of that era would not operate efficiently at such elevated frequencies. Transit-time effects, excessive lead inductance, and high losses in the base materials used limited their performance. Little effort was expended in developing improved tubes and circuits since few people had enough vision to see that such short-haul radio might be extremely valuable for local services like police radio, where the line-of-sight characteristic would give freedom from interference by similar services in distant cities.

Here again, however, a few intrepid experimenters, with an eye on the vast reaches of unused megacycles stretching into the VHF region, perservered. They removed the lossy bakelite bases from the available tubes, and developed "long-lines" circuits to minimize the effects of tube element loading. They spent long hours policing unused frequencies looking for someone with whom to communicate. They learned to make multi-element, high-gain antenna arrays compensate for the low powers available from the tubes at hand. Even as late as 1940, a "ham" experimenter engaged in such pursuits was likely to be considered more than slightly demented by his fellow amateurs, who maintained that he was wasting his time with "back-yard" radio when he could communicate across the world by going a few megacycles lower.

In the end, however, these "die-hard" experimenters had pioneered the VHF bands and had laid the groundwork for the techniques now employed in the transmission and reception of television, FM, police radio and many other services. These frequencies now include the most commercially important megacycles in the entire radio frequency spectrum.

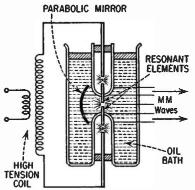
Unquestionably, the most rapid advance in the exploration of the spectrum was made during the period of World War II, when the upper limit of efficient radio frequency generation was extended at least *100 times* in a few short years. The impetus, of course, was the development of radar. At the start of this period, the conventional triode had reached its limit of practicality at about 600 megacycles. From the early "audion" it had been "scaled down" to the size of the familiar acorn tube. This reduction in size was necessary to keep interelectrode capacitances small so that the external circuit would not be reduced to a short between the grid and plate. It was also necessary to space the tube elements extremely close to reduce transit time effects. The result of this size scaling is to greatly reduce the power generating capabilities of the tube, since the small electrodes can only dissipate a small amount of heat.



THE MILLIMETER WAVE SPECTRUM GAP

FIG. 2

The need for a source of powerful centimeter waves for radar led to the development of the microwave magnetron and klystron tubes. These made the extension of the state of the art mentioned above possible because, unlike the triode, their dimensions are comparable to the wavelengths generated. Thus, a magnetron for 600 megacycles was many times larger than a triode for the same frequency and could dissipate proportionally more power. However, as the microwave tubes have been scaled to progressively higher frequencies, the size of their critical elements have decreased accordingly. The result is that the magnetron and klystron have encountered, at around 60,000 megacycles, the same kind of limitations reached by the triode in the thirties. Their size and element tolerances and spacings have become comparable to the acorn tube — and their power handling capabilities not much better.



LEBEDEW'S
MILLIMETER GENERATOR
(1895)

FIG. 4

The evolution of radio frequency generators discussed above is illustrated in Fig. 1, which shows relative size comparisons. It is obvious from this presentation that a new principle is needed to extend the useful limit of generation further into the millimeter wave region. Scientists and physicists interested in spanning the gap which exists between the long infra-red part of the spectrum and the radio frequency portion (See Fig. 2) have long sought this new principle. Figure 1 indicates that a successful generator for the millimeter wavelengths will probably have to be much larger in dimensions, compared with the waves generated, than the magnetron and klystron are. To date, the approaches used in the generation of such extremely short waves have had this property. We will now discuss some of these.

Incoherent Generators

Most of the radio frequency sources, except the early spark transmitters, are *coherent* generators. A coherent generator is one which emits a wave train having a single (or *monochromatic*) frequency of a single and sinusoidally varying phase. An *incoherent* source, on the other hand, is one which emits energy over a band of frequencies consisting of numerous wave trains of various phases and amplitudes. Wave trains of these two types are compared in Fig. 3. Examples of incoherent sources are hot bodies which emit visable light or infra-red waves, and the spark transmitters mentioned above.

The type of generator employed in attempts to span the gap between light waves and radio waves in the past has usually depended upon the background of the researcher. Physicists, trying to extend the long wavelength limits of their light sources for spectroscopy, have pushed into the long infra-red region with incoherent generators, while engineers have scaled coherent oscillators down to a few millimeters from the radio side.

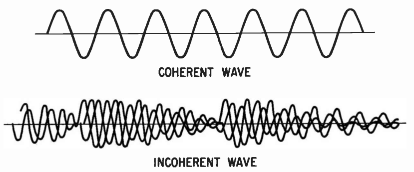
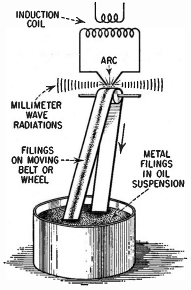


FIG. 3

The first successful millimeter generators were incoherent sources utilizing the spark discharge principle. There were essentially scaled-down versions of the early long-wave spark transmitters, which consisted of a resonant circuit excited by a spark discharge. It will be recalled that a circuit of this kind generates a "damped" wave because the spark *shock-excites* the resonant circuit which then oscillates until the circuit losses cause the oscillator to die out, or *decay*. A good example of a millimeter source using this principle is *Lebedew's* generator, built in 1895. See Fig. 4. In this simple arrangement, a spark discharge produced by a high-tension induction coil is passed through a gap between two resonant elements immersed in an oil bath. A parabolic mirror focusses the oscillatory energy thus produced in the desired direction. The oil bath serves to cool the resonant elements. The wavelength generated is determined by the physical size of the spark-gap elements; incoherent waves as short as .22 millimeter have been generated by this method.



MILLIMETER GENERATOR
OF MASS RADIATOR TYPE

FIG. 5

A similar form of incoherent millimeter wave generator has been known since the early 1920's. This machine, classified as a *mass radiator*, is illustrated in Fig. 5. It consists of a sort of conveyor belt which carries metal filings suspended in oil from a reservoir up through a spark gap where a high-tension spark is passed through them. Here again, the mechanism is similar to that of the old spark transmitter and is closely related to Lebedew's generator, except that the spark is passed through a large number of metallic particles which radiate at the same time. The radiations produced are far from monochromatic because of differing metallic particle sizes and the inherently low "Q" of the radiators. This renders the mass radiator inadequate for the purposes of spectroscopy required by physicists since the large spread in frequency reduces the resolving power of the instrument.

More recent attempts to generate millimeter waves by incoherent means have consisted of impinging charged ball-bearings or atomized mercury droplets on a metal plate, and similar schemes. All such methods suffer from low power generating ability, frequency dispersion, and difficulty in utilizing the energy because it is radiated in all directions.

Coherent Millimeter Generators

To date, the only successful coherent millimeter wave generators are scaled-down versions of the magnetron and klystron. As discussed above, both of these are approaching their ultimate limits a little below 5 millimeters wavelength. Here the efficiency of the magnetron, normally of the order of 50% in the centimeter range, has fallen to only a few percent and that of the klystron is much lower. The powers available are only a few kilowatts pulsed or a few milliwatts continuous wave. The prospects of reaching substantially shorter wavelengths are remote. New principles will have to be evolved.

Many of the new devices which have been proposed for millimeter wave generation are cloaked in military security. Most are so large compared with the wavelength generated and so inefficient as to make practical usage outside of the laboratory highly improbable. One reason for the ponderous size of some of these schemes is the dependence upon "relativistic" electrons, i. e., electrons accelerated to velocities near that of light. Equipment to achieve such velocities is inherently complex and cumbersome.

The question naturally arises as to what possible applications millimeter waves might be put when practically achieved. *To question the ultimate utility of this portion of the spectrum is probably just as fallacious as it was in 1920 to think that all wavelengths below 200 meters are worthless.* If history again repeats, this portion of the radio frequency spectrum should become as important to the art of communication as any which preceeded it.

It is true that waves of this length are difficult to generate, transmission lines to handle them are critical, and high absorption occurs in the atmosphere to make even line-of-sight transmission marginal. However, once the first two of these shortcomings are overcome, the last may even become an advantage. The limitation to very short ranges in the free atmosphere might make highly personalized forms of radio communication possible. Also, because of the small size of the waveguides associated with millimeter waves, long distance communications through evacuated or gas-filled waveguides consisting virtually of "hollow wires" would become possible. Because of the large bandwidths carried by such transmission lines, a single one would be capable of simultaneously carrying thousands of voice communication channels or hundreds of six-megacycle television channels.