Introduction to

UHF CIRCUITS AND COMPONENTS

By MILTON S. KIVER

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PREFACE

Ever since its inception prior to World War I, electronic communication has steadily advanced into higher and higher frequencies. With the years the pace of frequency increase has accelerated until now communication activities range all the way to 10,000 mc and beyond.

In view of their extensive application, it behooves those who follow the electronic field, either for a livelihood or as a hobby, to understand the operation of ultra-high frequency circuits and components. It is the purpose of this book to point out the underlying equality of all radio, whatever the frequency. The concepts of ultra-high frequency circuits are presented as logical outgrowths of the more familiar low-frequency equipment. With what the reader already knows as a guide, the reasons for modifications become evident and fall more naturally in place.

At various points throughout the book, explanations are presented with more of an eye toward easier comprehension than mathematical rigor. For that, no excuse is offered. However, at no time are the basic principles ever consciously distorted. In keeping with the character of the book, they are merely simplified. There are many excellent theoretical treatises available, and the more inquisitive reader is directed to them.

The book is divided into 12 chapters. At the outset, Chapter 1, the reader is introduced to the higher frequencies by way of the changes that must be made in familiar tuning circuits to adapt them to the higher frequencies. Detailed treatment of specific components then follow in order, with transmission lines in Chapter 2, waveguides in Chapter 3, and cavity resonators in Chapter 4. By this time the reader is ready to consider various methods of generating the higher frequencies, and the next four chapters, 5 through 8, deal with this aspect of high-frequency communication. In Chapter 9, UHF antennas are discussed, both for reception and transmission. Applications discussed range from frequencies below 100 mc to those above 10,000 mc. UHF measurements constitute the subject of Chapter 10, and here again the step-by-step approach is employed in order that each modification may be fully understood.

The final two chapters are concerned with UHF receiving systems. The departure here from conventional low-frequency practice is not as marked as it is in transmission, but differences do exist and these are carefully underscored.

Illustrations are used liberally throughout the text and for many of these the author is indebted to various technical journals and equipment manufacturers. Special acknowledgment is due to the Institute of Radio Engineers, *Radio and Television News Magazine,* Radio Corporation of America, *Bell System Technical Journal,* the General Radio Company, Sylvania Electric Company, Andrew Corp., Technicraft Laboratories, Sperry Gyroscope Co., Inc., and Standard Coil Products, Inc. Every one of these organizations cooperated splendidly and, by their assistance, lightened the task of writing this book.

M. S. K.

November, 1954
Highland Park, Illinois

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Chapter 1

INTRODUCTION TO THE HIGHER FREQUENCIES

Historically, the period from 1940 to 1945 will always be known as the years of World War II, but to those in the field of communications these years will also signify the period during which tremendous advances were made in utilizing the frequencies between 100 and 10,000 mc for transmission and reception purposes. Techniques were evolved in these five years which enabled television and frequency modulation broadcasting to appear on an extensive commercial scale immediately after the war. Since the frequency spectrum below 50 mc was already well occupied by existing A–M services, the only frequencies which could be alloted to these newer broadcasting media were in the very-high-frequency band (30–300 mc), the ultra-high-frequency band (300–3000 mc), and the super-high-frequency band (3000–30,000 mc). At the moment, the major portion of television and all of F–M broadcasting are concentrated in the very-high-frequency band. However, the lower portion of the ultra-high-frequency band has recently been opened to television and, in time, will carry the bulk of such programming.

The Effect of Increasing Frequency. In order to demonstrate what happens to ordinary radio apparatus when the operating frequency is raised, take a common oscillator and attempt to increase its output frequency. The relationship between frequency and coils and capacitors is given by the formula

$$F = \frac{1}{2\pi\sqrt{LC}}$$

where L is the inductance in henries,

C is the capacitance in farads.

In order to have the frequency F increase, either L or C or both must decrease in value. This means using fewer turns for the coil and fewer plates for the tuning capacitor. But there is a limit to this process, and at the end nothing would remain of the capacitor except two small plates, and of the inductance, a turn or two of wire. In Fig. 1–1 there is shown an oscillator using a small two-plate capacitor and a variety of inductances. The lowest frequency is obtained when the 15-turn coil at the extreme right is connected across the capacitor; the highest frequency, when the single-turn coil at the far left is used.

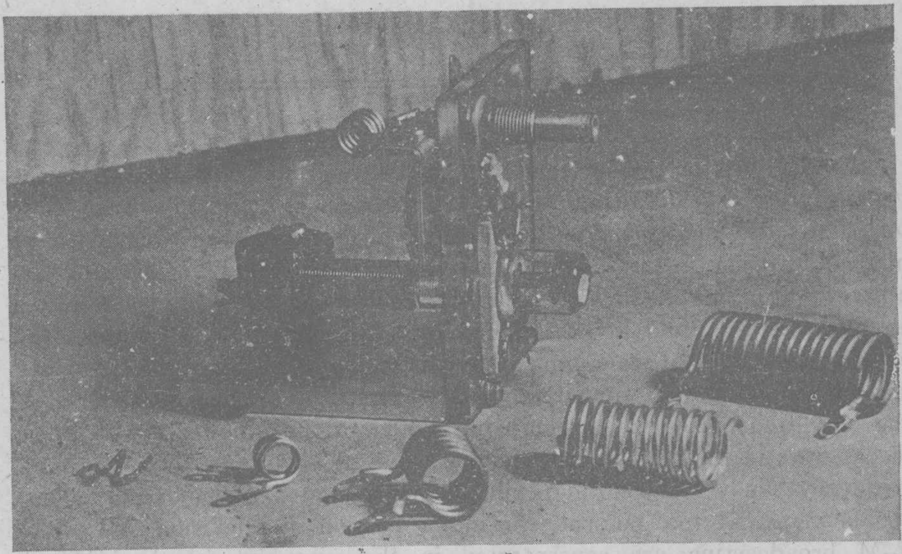

FIG. 1.1. An oscillator using a small two-plate capacitor and a variety of inductances to cover a wide range of frequencies. (*Courtesy Radio News*)

Throughout this book frequent reference will be made to frequency and wavelength, and the reader should be familiar with the relationship between them. Frequency is related to wavelength by the expression

$$\lambda \text{ (wavelength)} = \frac{300{,}000{,}000}{f \text{ (frequency)}}$$

where λ is given in meters,

f is given in cycles per second.

This formula possesses a variety of forms, all of them equivalent, provided that the proper units are used for wavelength and frequency. Thus, if frequency is expressed in megacycles instead of in cycles, the foregoing formula becomes:

$$\lambda \text{ (meters)} = \frac{300}{f \text{ (mc)}}$$

Again, if λ is desired in feet instead of meters, we have

$$\lambda \text{ (feet)} = \frac{984}{f \text{ (mc)}}$$

because there are 3.2802 feet in one meter. Finally, at the very high frequencies it is more convenient to express wavelength in centimeters and frequency in megacycles. The expression for this is:

$$\lambda \text{ (cm)} = \frac{30{,}000}{f \text{ (mc)}}$$

Other combinations of units are possible, but the foregoing are the ones most frequently used.

The metal and glass tubes that the radio man ordinarily encounters in his everyday work with A–M receivers may appear to be small in comparison to the tubes used in the sets of the early 1930s, but if any one of these

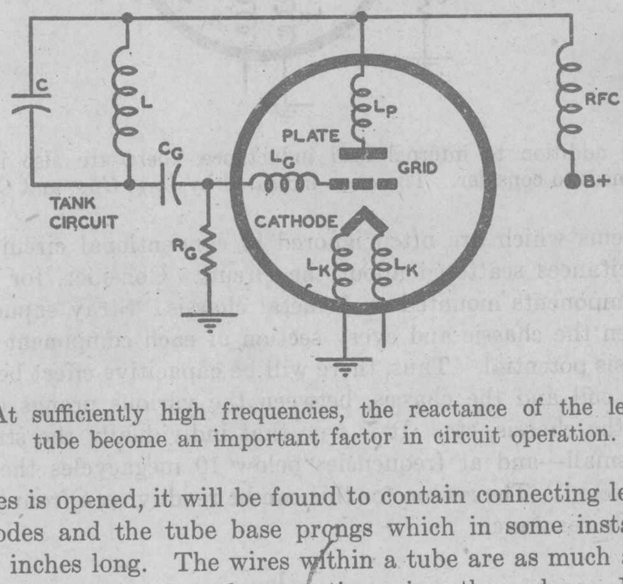

FIG. 1.2. At sufficiently high frequencies, the reactance of the leads within a tube become an important factor in circuit operation.

newer tubes is opened, it will be found to contain connecting leads between the electrodes and the tube base prongs which in some instances are as much as 2 inches long. The wires within a tube are as much a part of the circuit wiring as the external connecting wires themselves. Hence, if we are to indicate properly all of the wiring in a circuit, we must include the leads within the tube. This has been done in Fig. 1–2.

The wiring from the actual element within the tube to the socket terminals is shown as a small inductance. Thus, L_p is the lead from the plate electrode to the base prong, L_g represents the grid wire, etc. At the frequencies employed for low-frequency audio broadcasting, an extra inch or two of connecting wires will not noticeably affect circuit operation. However, if the frequency at which the circuit is to operate is raised high enough, then this inch or two may possess as much inductance as the tank circuit itself. It will be shown in the chapter on UHF measurements that 3 inches of No. 20 copper wire possess an inductance of 0.075 microhenry. At 100 mc, the impedance of this inductance is 47 ohms; at 1000 mc, it is 470 ohms. Since frequencies in excess of 10,000 mc are being used, the impedance of even an inch of wire must be considered.

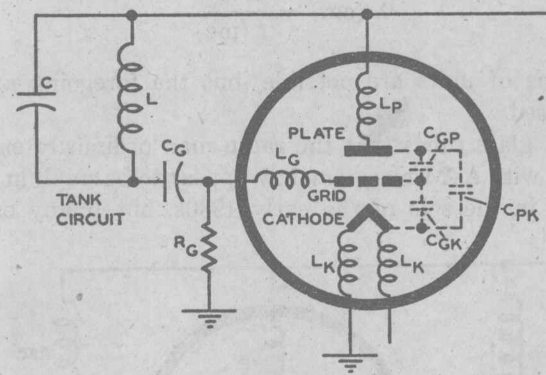

FIG. 1.3. In addition to internal lead inductance, there are also interelectrode capacitances to consider. These are indicated by C_{GK}, C_{PK}, and C_{GP}, above.

Other items which are often ignored in conventional circuitry are the small capacitances scattered about the circuit. Consider, for example, a group of components mounted on a metal chassis. Stray capacitance will exist between the chassis and every section of each component that is not also at chassis potential. Thus, there will be capacitive effect between each turn of the coil and the chassis, between the various prongs of the tube socket and the chassis, etc. It is true that individually the stray capacitances are small—and at frequencies below 10 megacycles their presence may be neglected. The reason for this can be readily seen from the formula for capacitive reactance:

$$X_c = \frac{1}{2\pi fC}$$

Note, as f goes up, X_c goes down. Therefore, the shunting effect of the stray capacitance increases with frequency. However, up to frequencies of 10 mc, with very small stray capacitances, X_c is so large that it can be considered practically an open circuit.

Just as there are capacitances between the various components and the chassis, small capacitances also exist between the various elements within the tube. These are indicated in Fig. 1–3 together with the lead inductances previously shown in Fig. 1–2. Again, at the low frequencies we may disregard them, but above 10 mc, they exert a definite influence on the circuit's operation and must be taken into account.

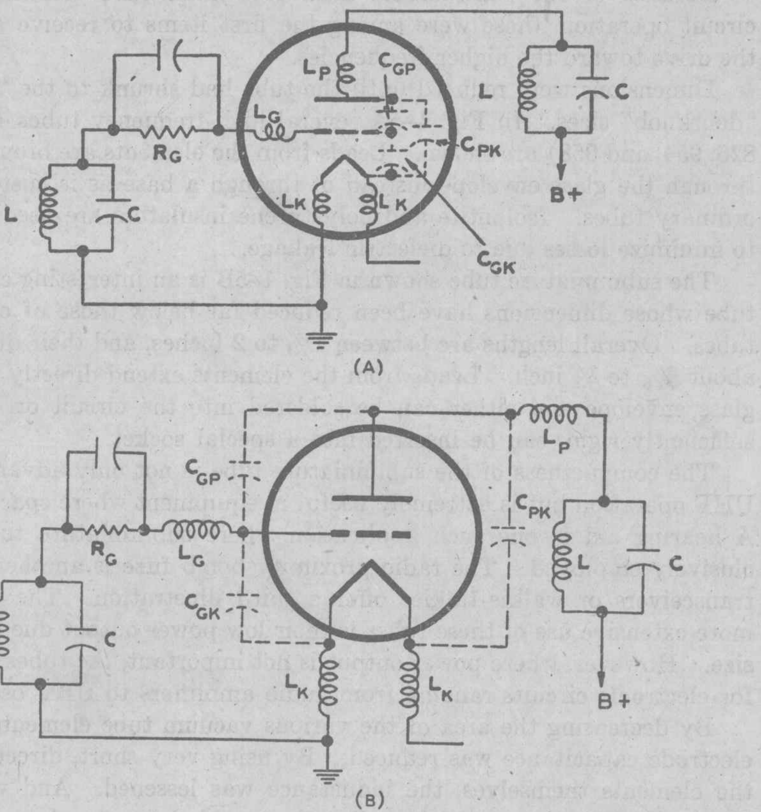

FIG. 1.4. (A) The complete circuit of a tuned-plate, tuned-grid oscillator. (B) The tube inductance and capacitance combined with the external circuit components.

The complete circuit of a tuned-plate, tuned-grid oscillator is shown in Fig. 1–4A. The internal inductances and capacitances of the tube are included in the diagram. In Fig. 1–4B, the internal inductances and capacitances have been moved out of the tube proper and into the circuit. Across the grid tuning circuit we have C_{gk} with C_{gp} and C_{pk} in series. Across the plate tuning circuit we have C_{pk} in parallel with the series arrangement of C_{gp} plus C_{gk}. These capacitances are not constant, but change as the tube warms up, as the plate current varies, and as the tube ages with use. When the circuits are designed to operate at UHF, the internal capacitance of the tube will form an appreciable part of the total circuit capacitance. Thus, with changing internal capacitance, we can expect a drift in frequency and, in general, the circuit will be less stable than when these capacitances form a negligible part of the total capacitance.

Because of the considerable influence which tube elements exert on circuit operation, these were among the first items to receive attention in the drive toward the higher frequencies.

Dimensions were reduced until the tube had shrunk to the "acorn" and "doorknob" sizes. In Fig. 1–5A several high-frequency tubes (9001, 9002, 826, 954, and 958) are shown. Leads from the elements are brought directly through the glass envelope instead of through a base as is customary with ordinary tubes. Isolantite and polystyrene insulators are used throughout to minimize losses due to dielectric leakage.

The subminiature tube shown in Fig. 1–5B is an interesting example of a tube whose dimensions have been reduced far below those of conventional tubes. Overall lengths are between 1½ to 2 inches, and their diameters are about 5⁄16 to ½ inch. Leads from the elements extend directly through the glass envelope and either can be soldered into the circuit or, if they are sufficiently rigid, can be inserted into a special socket.

The compactness of the subminiature tube is not only advantageous for UHF operation but is extremely useful in equipment where space is limited. A hearing aid is one such application where subminiature tubes are exclusively employed. The radio proximity bomb fuze is another, and small transceivers or walkie-talkies offer a third illustration. The only bar to more extensive use of these tubes is their low power output due to restricted size. However, where power output is not important, the tubes can be used for electronic circuits ranging from audio amplifiers to UHF oscillators.

By decreasing the area of the various vacuum tube elements, the interelectrode capacitance was reduced. By using very short, direct leads from the elements themselves, the inductance was lessened. And when it was discovered that the materials ordinarily considered as insulators at the low frequencies became partial conductors at the ultra-highs, newer substances such as polystyrene and isolantite were developed. All in all, considerable research was required to attain the proficiency which we now possess in utilizing the UHF's.

In summary, the requirements for efficient operation of electronic equipment at ultra-high frequencies are:

1. Vacuum tubes must be small.
2. Tuning circuits must have small amounts of inductance and capacitance, yet possess sufficiently high Q values to provide good gain and selectivity.

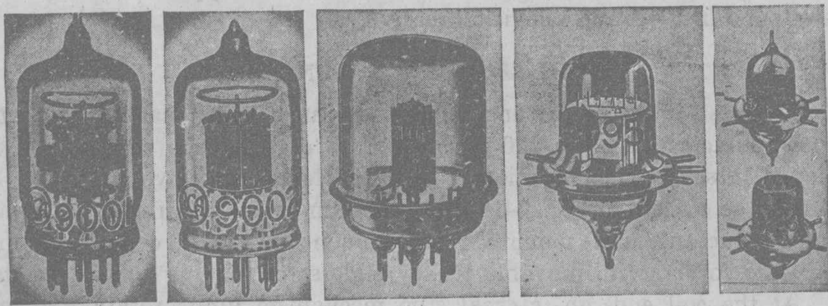

FIG. 1.5A. Number of different tubes that have been designed for ultra-high frequency applications. (*Courtesy RCA*)

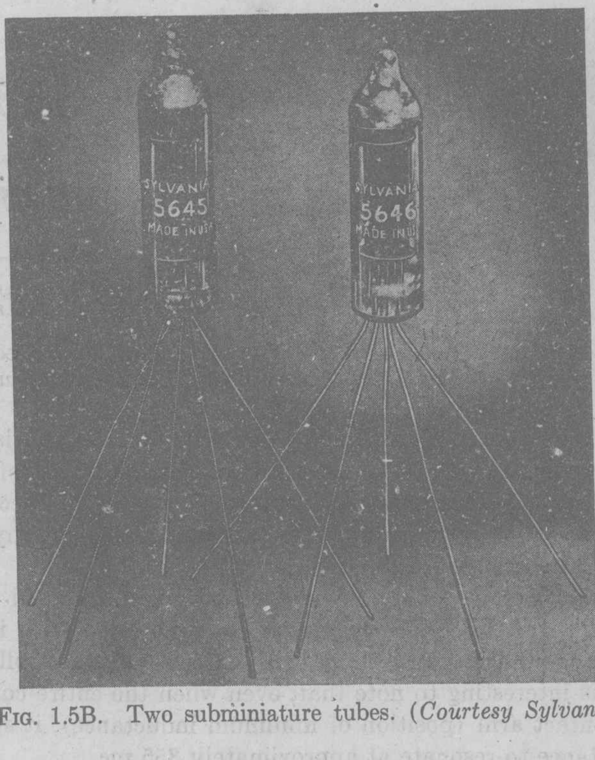

FIG. 1.5B. Two subminiature tubes. (*Courtesy Sylvania*)

3. Insulators must be effective at high frequencies.
4. Wiring between circuit components must be at a minimum.
5. Chassis layout must be carefully planned to minimize stray capacitance.

In the next sections the front-end tuners of receivers operating above 50 mc are explained. They were designed to meet the requirements of these higher frequencies. As a start, let us consider the types of commercial tuners found in F–M and television receivers.

HIGH-FREQUENCY TUNERS

Inductuner. The Inductuner is a wide-range tuner, capable of continuous tuning from 44 to 220 mc. Because of this wide coverage, it is employed in several combination F–M and television receivers.

As can be seen from Fig. 1–6A, the Inductuner consists of three separate variable inductance units mounted on a common shaft. The coils are wound on ceramic forms, with movable trolley sliders for making contact to the coil. At the coil end, an internal stop mechanism limits rotation to ten turns. Each coil is tunable continuously for ten turns producing an inductance variation from approximately 0.02 to 1.0 microhenry. The inductance variation of the Inductuner is in the ratio of 1:50 and is the reason for the wide frequency range. If we compare the inductance of this tuning circuit with the 0.04-microhenry inductance of a straight piece of wire 2 inches long and 0.038 inch in diameter, we can again see why all circuit wiring must be kept as short as possible.

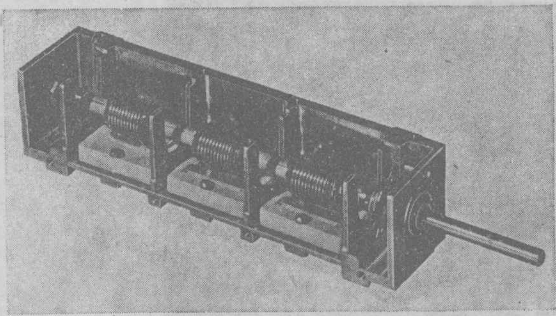

FIG. 1.6A. A continuous tuner used in television and F-M receivers. (*Courtesy P. R. Mallory Co.*)

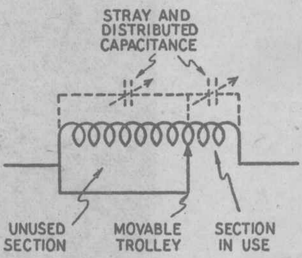

FIG. 1.6B. Electrical circuit of one inductuner winding.

The movable trolley contact divides each coil into a used and unused section. (See Fig. 1–6B.) Each section has associated with it stray and distributed capacitances, and these will change as the trolley position changes. It is interesting to note that, even when the entire coil is shorted out by the contact arm (position of minimum inductance), it still contains enough inductance to resonate at approximately 355 mc.

The advantage of using a variable coil instead of a variable air capacitor lies in the wider frequency coverage that is possible. A length of wire and its inductance can be reduced to a smaller value than the minimum capacitance of a variable capacitor. Furthermore, as the inductance decreases, the losses reduce proportionately. In fact, it is even possible for the losses to decrease faster than the inductance, giving a rising Q with frequency. This, in turn, produces a desirable rise in gain at the high-frequency end of the band.

The Inductuner shown contains three windings, which permits three circuits to be controlled at one time: the r-f amplifier, the oscillator, and the mixer circuits at the front end of a receiver.

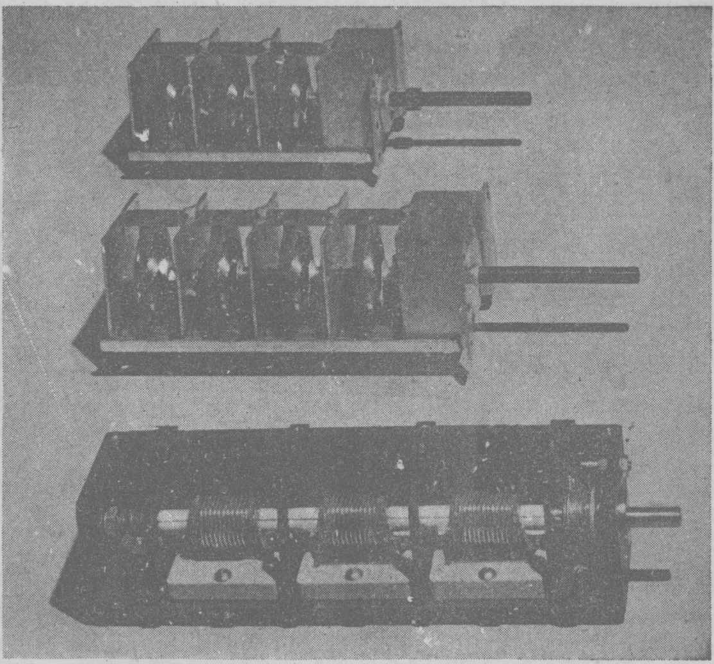

Fig. 1.7. The comparison of the new spiral inductuners (top two) with the older unit (below).

A more recent version of the Inductuner makes use of a spiral type of winding. (See Fig. 1–7.) Operation of this unit is identical to that of the previous Inductuner except that now the contact arm moves around a spiral instead of along a solenoid. The advantages gained are greater compactness, lower cost, and increased mechanical stability. The smaller size permits a fourth winding to be added that can be used at the input to the r-f amplifier.

Permeability Tuning. There are several methods by which the inductance of coils can be varied in order to tune a receiver. The use of the Inductuner is one method. Another approach to the problem is through the use of a powdered-iron core. The position of the core is altered, thereby varying the inductance of the coil. As the iron core is inserted deeper into the center of the coil, the inductance increases. Conversely, as the iron core is withdrawn from the coil, the inductance decreases. This method is known as permeability tuning.

An example of a permeability-tuned coil is shown in Fig. 1-8. Note that a four-strand tinsel wire is used in place of the conventional single-strand wire. The use of four parallel wires is necessary in order to obtain the required inductance change with the small number of turns on the coil. If single-strand wire were employed, the frequency band could not be covered by the maximum movement of the core within the distance allotted to

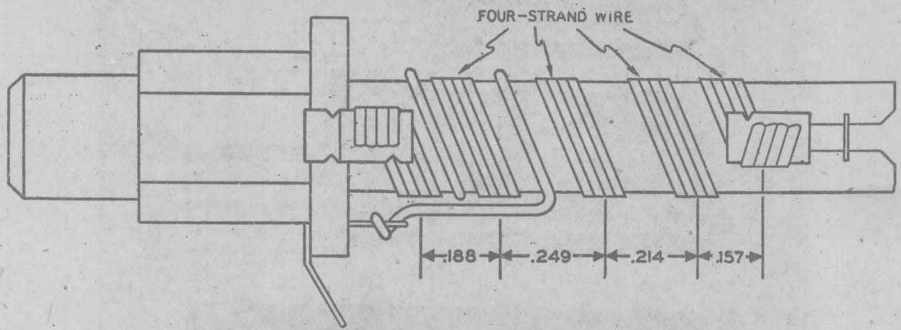

FIG. 1.8. A four-wire permeability-tuned coil. The variable winding pitch produces a linear tuning curve.

it by the tuning dial. To overcome this difficulty, the width of each turn is increased. As the wire width increases, the tuning range is increased. A similar result may be had by winding the coil with parallel wires. This accounts for the four conductors shown in Fig. 1-8.

Application of permeability-tuned coils in a tuner is shown in Fig. 1-9. The antenna, mixer, and oscillator coils are mounted on a bracket fastened to the side of a conventional variable capacitor. The coils cover the F-M band, whereas the variable capacitor tunes over the A-M broadcast and short-wave bands. A cam is mounted on the shaft of the variable capacitor and operates a rocker arm which moves the iron tuning cores in the three high-frequency coils. The unit is very compact, reducing all stray capacitance and inductance to a minimum.

Eddy-current Tuner. Eddy-current tuning is a third method of achieving inductance variation. In this method, nonmagnetic materials, such as copper or brass slugs, are inserted into the core of the coil. Since they are nonmagnetic, inserting them between the turns of a coil lowers the mutual inductance of the coil, with a consequent lowering of coil inductance.

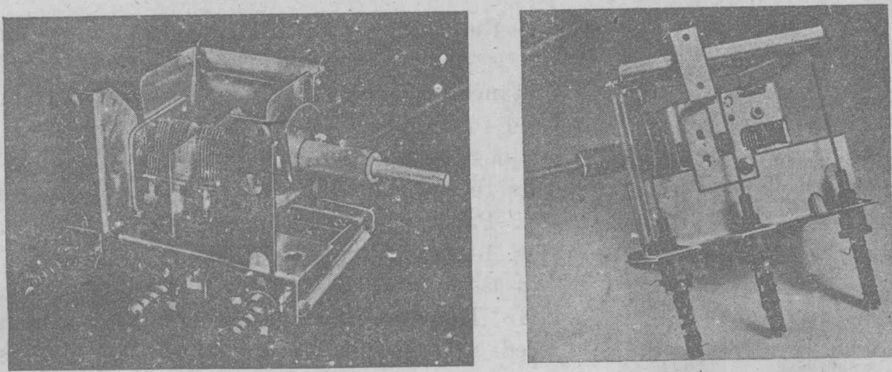

FIG. 1.9. Two views showing how F-M permeability-tuned coils are combined with an A-M variable capacitor in a combination A-M, F-M receiver. (*Courtesy Zenith*)

Furthermore, the slug itself acts as a short-circuited turn, and the current flowing within the slug introduces a loss of power due to heat, which in turn further reduces the inductance of the coil. Hence, the closer the spacing between the slug and the coil, the lower the inductance presented

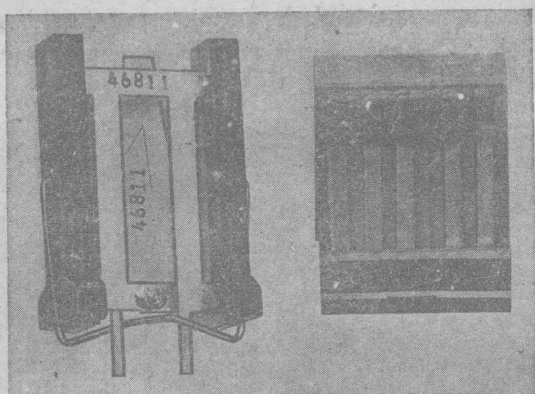

FIG. 1.10. A photograph of the guillotine tuner. Its size can be judged by comparing it with a book of matches. (*Courtesy G.E.*)

to the circuit. Note that this action of the slug is directly opposite to that obtained in permeability tuning.

An eddy-current tuner, developed by General Electric, is shown in Figs. 1–10 and 1–11. Because of its resemblance to the grim French guillotines, it has been nicknamed the "guillotine tuner." The tuner consists of two identical brass frames which form a two-turn inductance when connected at their open ends. To vary the inductance, a brass blade is inserted be-