GENERATION, AMPLIFICATION, AND MODULATION OF VERY-HIGH FREQUENCIES

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STUDY SCHEDULE NO. 45

For each study step, read the assigned pages first at your usual speed, then re-read slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each step in this same way.

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GENERATION, AMPLIFICATION, AND MODULATION OF VERY-HIGH FREQUENCIES

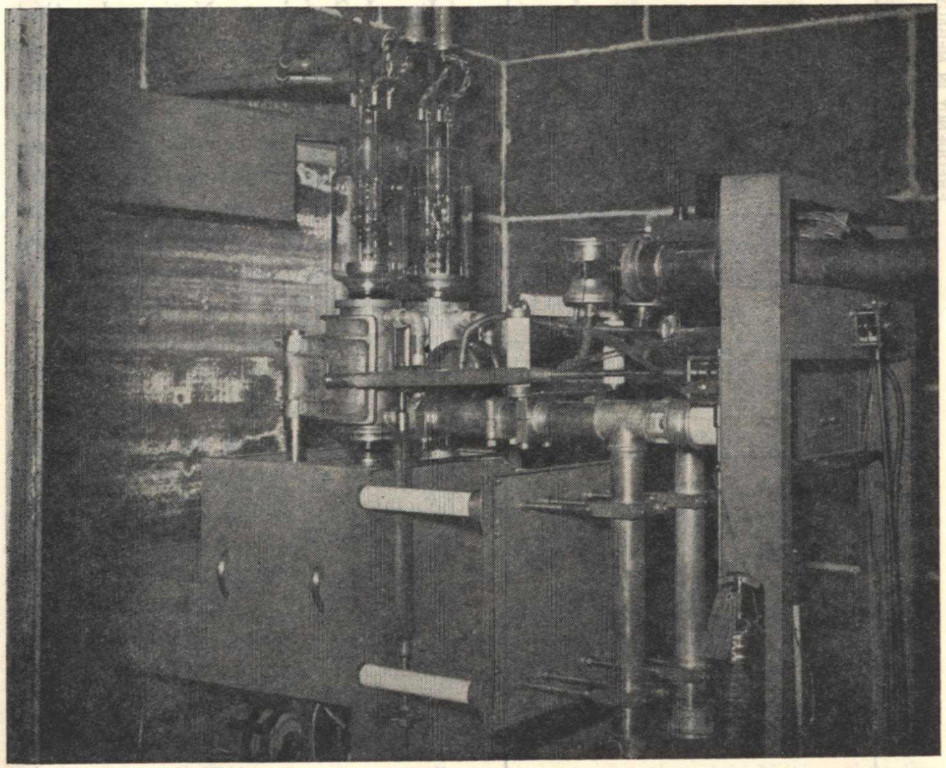
V.H.F. Services and Problems

THE RANGE of radio frequencies from 30 megacycles to 300 megacycles is called the *very-high-frequency* band, commonly abbreviated v.h.f. We have made it the subject of a separate lesson because the techniques of generating, amplifying, and modulating signals in this band of frequencies are quite often different from the techniques used below 30 mc.

V.H.F. RADIO SERVICES

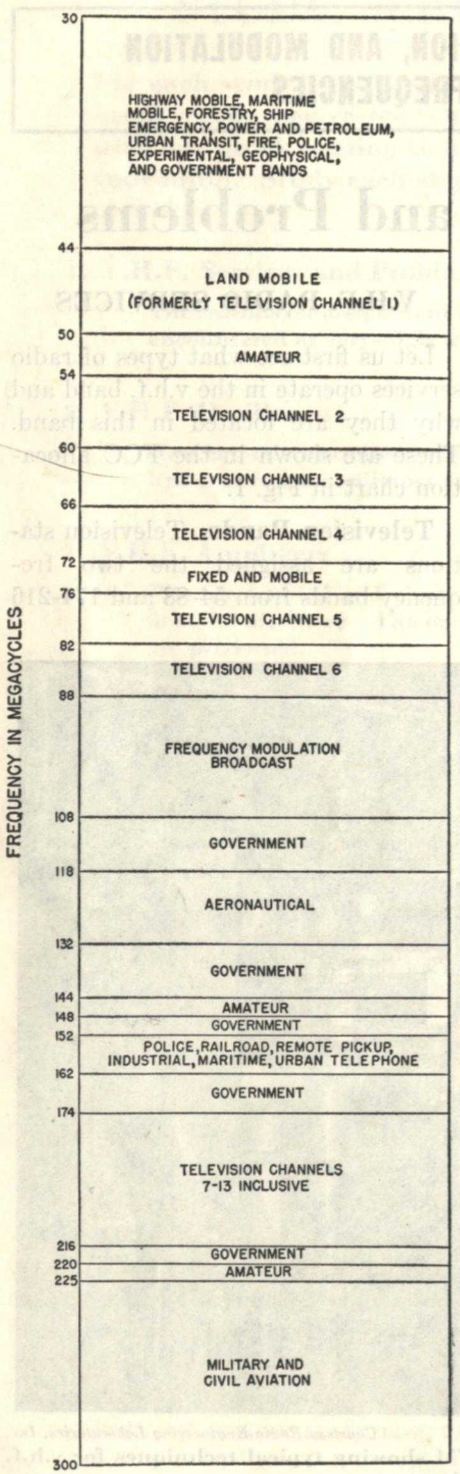
Let us first see what types of radio services operate in the v.h.f. band and why they are located in this band. These are shown in the FCC allocation chart in Fig. 1.

Television Bands. Television stations are assigned the two frequency bands from 54-88 and 174-216



Courtesy Radio Engineering Laboratories, Inc.

The 50 kw. amplifier of f.m. station WMFM showing typical techniques for v.h.f. operation.



mc. because only at these frequencies is it possible to design r.f. amplifiers to accommodate the wide band width of this service. Remember that a television channel is 6 megacycles wide—about 6 times the width of the entire standard broadcast band. It is good engineering practice not to permit the modulation band width of radio transmitters to exceed 10 per cent of the carrier frequency if ordinary LC filters are used in r.f. amplifiers. Following this rule makes radio transmitters and receivers easier to build and operate. We see, therefore, that carrier frequencies of 60 mc. or higher are desirable for television, even though some stations operate in channels where the carrier frequency is less than this.

Local Services. Notice also that the v.h.f. band includes many services that are local in coverage—for example, f.m. broadcast, urban transit, fire, police, urban telephone, railroad, broadcast and press relay, and taxicab services. As a general rule, radio waves above 30 mc. are not reflected back to earth from the Kennelly-Heaviside layer. For this reason, a station in the v.h.f. band can serve only the local area that is reached by ground waves. Thus, frequency assignments for these services can be duplicated in many places throughout the country without interference between stations.

Another reason that standard f.m. broadcast stations are assigned to the v.h.f. band is to accommodate a large number of station channels. Since

FIG. 1. This is the FCC frequency allocation for the very high frequency band, 30 to 300 mc. It contains two bands for television, one band for f.m. broadcast, and three bands for commercial point-to-point fixed and mobile services.

f.m. station channels are 200 kc. apart, there could be, for example, but five in the standard broadcast band. In the 88-108 mc. band, however, the 20-mc. range permits 100 channel assignments. This, with the limited coverage of v.h.f. signals, permits the simultaneous operation of a large number of f.m. broadcast stations in various sections of the country.

V.H.F. PROBLEMS

As we start our study of the v.h.f. band, let us first briefly study the problems that are encountered on this band. We will meet these problems again and again as we study v.h.f. oscillators, amplifiers, and modulators.

Lead Inductance and Distributed Capacitance Limit the Upper Frequency. As the resonant frequency of a circuit is increased, the value of the inductance and capacitance must be decreased. Above about 30 mc., the values of L and C become very small. The tube elements and tube leads of a vacuum tube form small capacitors and also have some inductance. Although this stray inductance and stray capacitance are small in comparison with the L and C of the resonant circuit at frequencies below 30 mc., they cannot be ignored above that frequency, because they may be a large part of the L and C needed for resonance. To operate at very-high frequenices, therefore, it is necessary to use tubes in which interelectrode capacitance and lead inductance are small. Such tubes have small elements and short, direct leads.

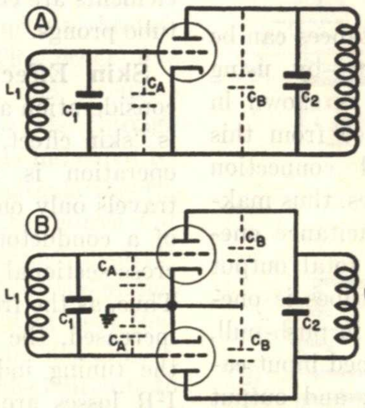


FIG. 2. In A the input and output capacitances of a tube shunt the input and output tuning circuits. In B push-pull operation of tubes halves these shunting capacitances and permits operation at higher frequencies for given values of L_1C_1 and L_2C_2.

Reducing the tube element size reduces the power-dissipating ability of the tube. This is one reason why it is difficult to obtain large amounts of power at very-high frequencies.

Let us study the effect of the interelectrode capacitances of a tube on the design of v.h.f. tuning circuits.

In Fig. 2A, we see the basic triode tuned amplifier circuit. (The d.c. circuits are not shown.) Notice that the input capacitance of the tube C_A, which is a combination of C_{gp} and C_{gk}, shunts the input tuning condenser C_1. The tuned circuit L_1 and C_1 plus C_A therefore tunes to a lower frequency than would L_1 and C_1 by themselves. The output capacitance of the tube C_B is in parallel with C_2, affecting the frequency of resonance of the output circuit in a similar manner. In the 807, the beam power amplifier used in the low power stages of many commercial transmitters, C_A is 11 mmfd., and C_B is 7 mmfd. These are comparable to the actual capacitor values used in tuning the circuit at these frequencies.

These shunting capacitances can be reduced—halved, in fact—by using two tubes in push-pull as shown in Fig. 2B. As you can see from this diagram, the push-pull connection puts the two C_A's in series, thus making the total input capacitance one-half C_A. Similarly, the total output capacitance of the two tubes is one-half C_B. Two 807 tubes in push-pull, for example, have combined input capacitances of 5.5 mmfd. and output capacitances of 3.5 mmfd. Because of this reduction in tube capacitance, the tuned circuits can resonate at higher frequencies in a push-pull circuit than they can in single-ended operation.

V.H.F. Operation Increases Losses. For efficient, stable operation, the Q of the tuned circuit of an oscillator or amplifier must be high. There are, however, several factors in a v.h.f. circuit that can lower the Q of the tuned circuit, causing instability and inefficiency, unless special precautions are taken. Let us investigate them.

Insulation Losses. Bakelite is a good insulator at standard broadcast frequencies but not at very-high frequencies. There can, therefore, be considerable losses in a bakelite tube base or socket in the v.h.f. band. This is avoided by using tubes with low-loss ceramic bases or tubes in which the leads from the tube elements are brought out directly from the glass envelope and the base is dispensed with altogether. The sockets for these tubes are made of some low-loss ceramic or plastic material. In some cases, no socket is used and the circuit elements are connected directly to the tube prongs.

Skin Effect. Another important consideration at very-high frequencies is "skin effect." As the frequency of operation is increased, r.f. energy travels only on the thin outside layer of a conductor, so that the effective cross-sectional area is greatly reduced. Thus, as the frequency of operation is increased, the effective resistance of the tuning inductance increases, the I^2R losses are increased, and the Q of the circuit is lowered. To minimize this effect, low-loss tuning elements consisting of sections of resonant transmission lines (coaxial lines, two-wire open lines, or flat plate lines) are used. We will study these shortly.

I^2R losses occur not only in the tuned circuit but also in the tube and the leads to it as well. For example, let us consider Fig. 3. In A, the amount of capacitance necessary for resonance is 500 mmfd. and the output capacitance C_2 of the tube (stray wiring capacitance plus C_{pk} of the tube) is 10 mmfd. Thus the tuning condenser C_1 must be 490 mmfd. Now if the current in the tank circuit is 10 amperes, the current through C_1 is 9.8 amp. and through C_2 is only 0.2 amp. As indicated by the heavy lines, most of the tank current flows through C_1 and L_1, and, since these elements can be designed to have low losses, the circuit efficiency can be quite high.

However, a considerably different action occurs at higher frequencies (see Fig. 3B).

At very-high frequencies, for example, the capacitance necessary for resonance may be only 20 mmfd. Assuming the same value for C_2 and assuming that the tank current is the same, we find that C_1 is only 10 mmfd. and that the current through it is only 5 amp. The other five amperes of r.f. current now circulate through C_2—in other words, through the tube and its leads, as indicated by the heavy lines. The circulating r.f. current through the tube causes I^2R losses in the tube leads and elements that lower the efficiency of the circuit and increase the amount of heat that must be dissipated by the tube. Short, direct leads from the tuned circuits to the tube and in the tube itself must be used to minmize this effect.

Radiation Losses. At low radio frequencies, the size of the circuit elements and the length of the r.f. leads are small in comparison with one wavelength of the r.f. At very-high frequencies, however, the lead lengths may be an appreciable part of a wavelength. For example, at 300 mc. a lead need be only 10 inches in length to be a quarter-wavelength long. Because of this, v.h.f. circuit elements radiate r.f. energy; this lowers the Q of the circuit. We will soon take up various methods that are used to minimize the r.f. radiation from resonant v.h.f. tuning elements.

Transit Time Losses. At low r.f. frequencies, transit time—the time necessary for the electron stream to travel from the space charge to the plate—is negligible. At very-high frequencies, however, this time is no longer negligible. Transit times causes the grid circuit to be effectively shunted by a resistance, thus lowering the Q of the circuit connected to it.

Fig. 4A shows a simple triode amplifier circuit with the plate-to-grid

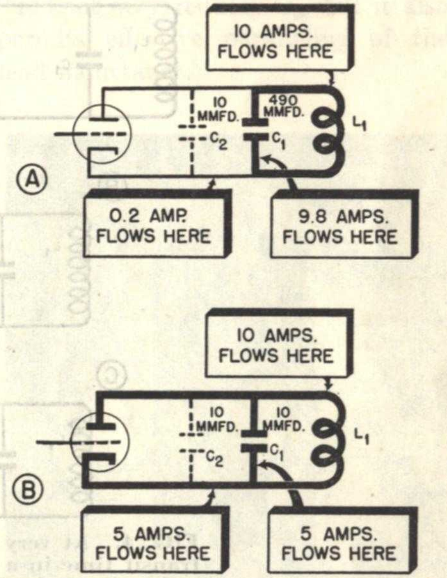


FIG. 3. In a radio circuit where the tuning capacitance is much larger than the output capacitance of the tube, most of the tank current flows in L_1 and C_1, as shown by the heavy lines, and very little flows through the tube. However, in a v.h.f. circuit where the tuning capacitance is very small, a large part of the tank current flows through the tube and its leads. This causes increased I^2R losses in the tube and its leads, lowering the efficiency of the circuit.

and grid-to-cathode capacitances C_{pg} and C_{gk} indicated. When the load is resistive and the transit time is small compared to one cycle of the input, the plate current is in phase with the grid voltage and the input tuning condenser C_1 is effectively shunted by a condenser that we can represent as C_A in Fig. 4B.

At frequencies at which the electron transit time through the tube is not negligible, however, the plate current of the tube lags behind the grid voltage of the tube. This causes the current flow through C_{pg} to lag likewise, so that C_{pg} is *effectively* a condenser shunted by a small resistor.*

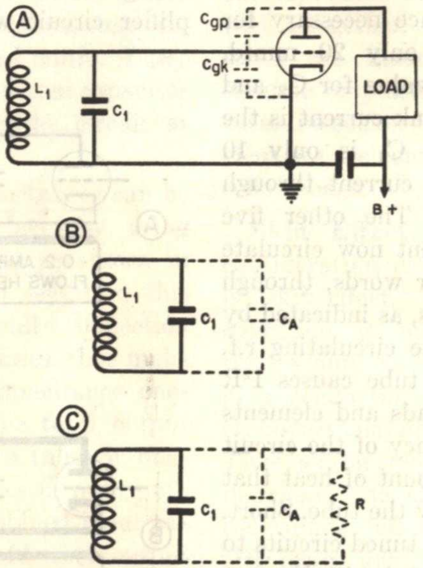
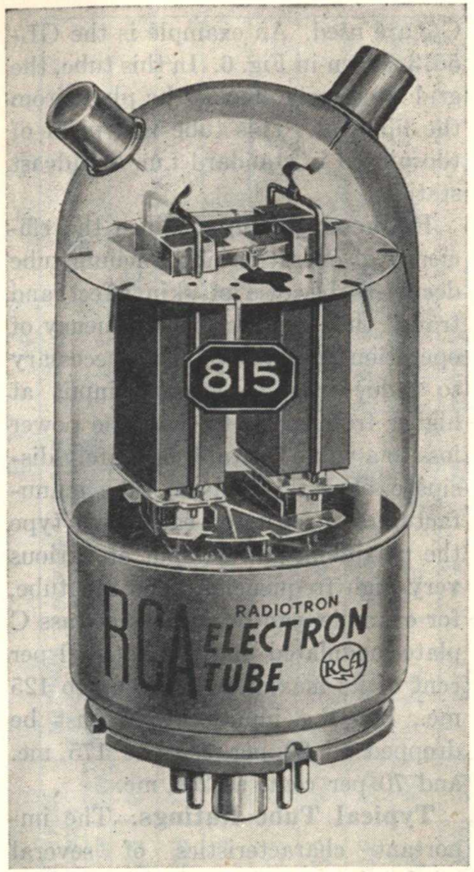


FIG. 4. At very high frequencies, the transit time in a tube causes the input to be effectively shunted by a resistor as shown in C. This lowers the input resistance of the tube, causes more losses in it, and lowers the efficiency of operation.

The equivalent input circuit of a tube at very-high frequencies, therefore, is as shown in Fig. 4C. As you can see, the effect of the transit time is to shunt the grid input circuit with a resistance R, thus lowering the grid input resistance.

As the frequency of operation increases and the plate current lags more and more behind the grid voltage because of electron transit time, the effective value of R decreases. This further reduces the input resistance of the tube. For example, the input resistance of a 6J7 tube at 5 megacycles with a pure resistance plate load is practically infinite; at 30 mc., however, it drops to 20,000 ohms, and at 100 mc. it is about 1,500 ohms. Tubes with small, closely spaced elements have relatively short transit times and correspondingly large input resistance at high frequencies. For instance, the 954, an "acorn" type tri-

* Remember that when an a.c. voltage is applied across a condenser, the current through the condenser is 90° ahead of the voltage. However, when a resistor is connected across the condenser, the current flow is *less* than 90° ahead of the voltage. Thus, for a condenser and a resistor in parallel, the current flow *lags* behind the current that would flow if there were no resistor across the condenser. When the current flow through a condenser lags because of electron transit time, the effect is the same as if a resistor were in parallel with the condenser.



Courtesy RCA

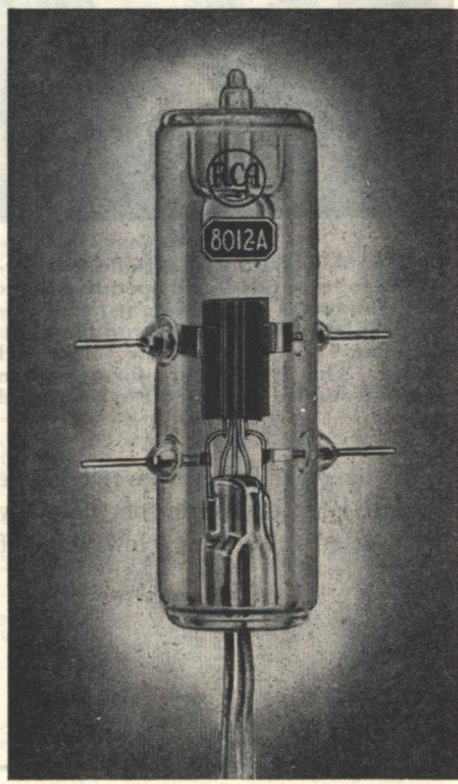
FIG. 5A. The 815 v.h.f. tube showing how it is built to minimize interelement capacitance. In this dual-beam power tube, the two plate leads come through the glass envelope, and the grid leads are in the base.

ode tube, has an input resistance of about 20,000 ohms at 100 mc.

TUBES FOR VERY-HIGH FREQUENCIES

As you can see, vacuum tubes for v.h.f. operation must be specially designed to produce a minimum of r.f. and transit time losses.

First, v.h.f. tubes must be constructed with leads that are as short and direct as possible to reduce the lead inductance and interelectrode and distributed capacitance. For example, in some tubes leads are brought out through the glass envelope. In the 815, a dual beam power amplifier shown in Fig. 5A, the two plate connections are at the top of the glass envelope and the grid leads are brought out at the socket. This minimizes the plate-to-grid capacitance. In the 8012 tube illustrated in Fig. 5B and in the 8025 tube (quite similar to the 8012), there are two connections to each plate and grid. This not only reduces C_{pg} but it also permits effective paralleling of the lead inductance.



Courtesy RCA

FIG. 5B. The 8012 triode v.h.f. tube has four connections on the glass envelope, two to the plate and two to the grid. This minimizes interelectrode capacitance and lead inductance. It also makes the tube usable with high Q balanced double transmission line tank circuits.

Courtesy General Electric Co.

FIG. 6. A GL5513 v.h.f. triode tube designed for grounded-grid operation. The grid, the metal connection at the top, is a shield between the plate and filament, reducing C_{pk} to a very low value, 0.11 mmfd. This is necessary for operation in the grounded grid circuit to be studied soon.

In the grounded-grid circuit, to be studied later in this lesson, uniquely constructed tubes with a low value of C_{pk} are used. An example is the GL-5513 shown in Fig. 6. In this tube, the grid effectively shields the plate from the filament. This tube is typical of those used in standard f.m. broadcast stations.

Reduced Ratings. Since the efficiency of operation of a vacuum tube decreases because of skin effect and transit time losses as the frequency of operation is increased, it is necessary to reduce the d.c. power input at higher frequencies to limit the power loss to a value the tube can safely dissipate. For this reason, tube manufacturers specify for each tube type the maximum power input at various very-high frequencies. The 815 tube, for example, can be used as a class C plate-modulated amplifier at 100 per cent of its maximum value up to 125 mc., but the input power must be dropped to 80 per cent at 175 mc. and 70 per cent. at 200 mc.

Typical Tube Ratings. The important characteristics of several v.h.f. tubes are shown in Fig. 7. Notice particularly the low interelectrode capacitances of these tubes. The column headed "MAXIMUM FREQUENCY" shows the maximum frequencies at which 100% of the rated power input is permissible.

TUBE	PLATE DISSIPATION (WATTS)	FILAMENT VOLTS	FILAMENT AMPS.	MAXIMUM PLATE VOLTAGE	INTERELECTRODE CAPACITANCES C_{GK}	C_{GP}	C_{PK}	MAXIMUM FREQUENCY (MEGACYCLES)	DRIVING POWER (WATTS)	CARRIER POWER (WATTS)	TUBE TYPE
2C34	10	6.3	0.8	300	3.4	2.4	0.5	250	1.8	16	DUAL TRIODE
HY75	15	6.3	2.5	450	1.6	3.8	0.6	60	—	21	TRIODE
35T	50	5	4	2000	4.1	1.8	0.3	100	13	200	TRIODE
2E30	10	6.0	0.7	250	10	0.5	4.5	160	0.07	7.5	PENTODE
807	25	6.3	0.9	600	11	0.2	7.0	60	0.4	40	BEAM POWER
815	25	6.3	1.6	500	13	0.2	8.5	125	0.13	56	BEAM POWER
829	40	6.3	2.25	500	14.5	0.1	7.0	200	0.7	83	DUAL BEAM POWER
4-125A	125	5.0	6.2	3000	10.3	0.03	3.0	120	2.5	375	TETRODE
8025	30	6.3	1.92	1000	2.7	2.8	0.35	500	1.6	35	TRIODE
8012	40	6.3	2.0	1000	2.7	2.7	0.35	500	1.6	35	TRIODE
7C24	5KW	12.6	29	5000	19	16	0.45	110	710	4.45KW	GROUNDED-GRID TRIODE
9C25	17.5 KW	6	285	11500	58	40	0.9	30	3.75KW	32.5KW	"
GL 5518	4 KW	6.3	250	7500	28.5	20	0.55	110	—	6.4 KW	"
GL 5513	1.2 KW	6.3	32	4000	21.1	8.7	.11	220	125	2 KW	"
WL 473	25 KW	6	60	3000	17	15	0.6	60	330	3.25KW	"
8D21	6 KW	4.2	135	6000	24	0.15	6	216	—	—	TELEVISION DUAL TETRODE

FIG. 7 CHARACTERISTICS OF SEVERAL TUBES USED IN V.H.F. CIRCUITS

V.H.F. Oscillators

Ordinary tubes and lumped circuit elements will work quite satisfactorily in v.h.f. oscillators operating from 30 to about 60 megacycles, and low interelectrode-capacitance tubes built especially for very-high-frequency operation will perform satisfactorily to about 120 megacycles. As soon as we go much beyond 120 megacycles, however, we find that the lumped parameters (L and C) used at lower frequencies are no longer effective. Parallel lines and coaxial lines must be used for the tank circuits of oscillators and amplifiers operating at these high frequencies.

Because there are so many services in the v.h.f. band, the FCC sets strict frequency stability requirements for most stations in the band. Only crystal control is sufficiently precise to meet these requirements. Line-controlled oscillators are permissible only in amateur service and in a few low-powered services.

CRYSTAL-CONTROLLED OSCILLATORS

Crystal-controlled v.h.f. carriers are produced by using a comparatively low-frequency crystal oscillator whose output is multiplied by frequency multiplier stages until the desired final frequency is reached. Generally a small receiver-type tube, such as a 6AG7 or a 7C5, is used in the crystal oscillator stage. These tubes are inexpensive, easily obtained, and take so little driving power that the crystals used may be very small and inexpensive.

Incidentally, it was once thought that crystals, to be accurate, had to be cut so that the finished crystal surface was at least one inch by one inch. However, it has been found that the crystal size is unimportant as long as small tubes are used for oscillators so that the crystal activity is small. Crystals one-half inch by one-half inch in area, or smaller, are now commonly used.

Small crystals are a distinct advantage in very-high-frequency work, because the decrease in the size of the crystal holder and the decrease in the internal stresses within the crystal permit the use of crystals whose frequency of operation is higher than was previously possible. Today, reliable, inexpensive, and stable crystals are available that permit operation of crystal oscillators at fundamental frequencies up to about 10 megacycles, making the doubling and tripling up to the final frequency a fairly simple operation.

As a matter of fact, some crystals are available that can go up to 54 mc. in fundamental frequency. However, they are generally fragile, expensive, and not as stable as lower frequency crystals. They are not yet, therefore, in general use.

In Fig. 8 is shown the schematic of a high harmonic output crystal oscillator, using a 6V6, that will give excellent output up to the ninth harmonic and has been used up to the eleventh. In this circuit, L_1C_1 is tuned below the crystal frequency and L_2C_2 is tuned to the desired harmonic frequency. With a 10-megacycle crystal, this circuit can give an output on the order of 100 megacycles in the plate circuit. The power output on the

higher harmonics, however, is very low and may be insufficient to drive anything but a 6AG7 or another 6V6. It may even be necessary to add r.f. amplifier stages to obtain enough power to drive the next stage. It is, however, more generally the practice to choose a lower harmonic and use frequency multiplier stages rather than to attempt to obtain the very-high frequencies directly from the crystal oscillator.

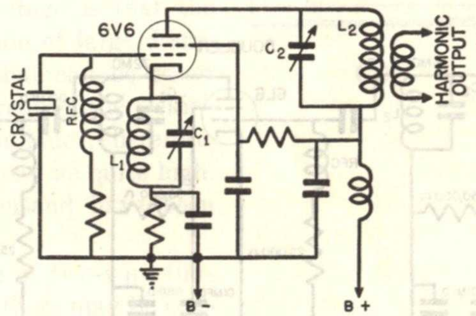


FIG. 8. The basic schematic of a high-harmonic output crystal oscillator used as the master oscillator in many v.h.f. transmitters. L_1C_1 is tuned to a frequency lower than the crystal, and L_2C_2 is tuned to the harmonic desired. The power output at high harmonics is very low so that it is generally limited to the fourth harmonic of the crystal frequency.

FREQUENCY MULTIPLIERS

Before we go into the uses of frequency multipliers, let us study the characteristics of this type of circuit at very-high frequencies.

No Neutralization. One characteristic that is of particular importance at very-high frequencies is that there is no need for neutralization. For the energy fed through the plate-to-grid capacitance of a tube to cause oscillations, the output tank circuit must be inductive, meaning that it must be tuned to a slightly lower frequency than the input circuit. In a frequency multiplier circuit, the output is tuned to a much higher frequency than the input, making it so capacitive that there can be no oscillation.

R.F. Drive and Efficiency. When an r.f. amplifier circuit is used as a frequency multiplier, the r.f. driving power on the grid must be increased and the efficiency of the circuit is greatly reduced. To see why, remember that to obtain a high harmonic output from an r.f. amplifier, the tube must conduct for only a very small portion of the grid cycle; to produce this effect, the bias must be increased to at least twice and preferably three times the normal class C bias. When the tube is biased in this manner, the r.f. drive required is several times normal. Furthermore, since energy is supplied to the plate tank circuit only on every other cycle (in a frequency doubler, for example), the plate efficiency is also low.

Practically, these facts mean that we must use a tube of much higher power output for a doubler or tripler than would be required in a straight amplifier to get a given amount of power out. Also, the size of the tube required to drive a doubler or tripler must be increased.

Reflected Load. The effect of the reflected load back from the plate into the grid circuit is not as great in most frequency-multiplying circuits as it is in a straight amplifier. Because of the high grid bias and consequent small angle of grid conduction in a doubler or tripler circuit, the input grid impedance is quite high.

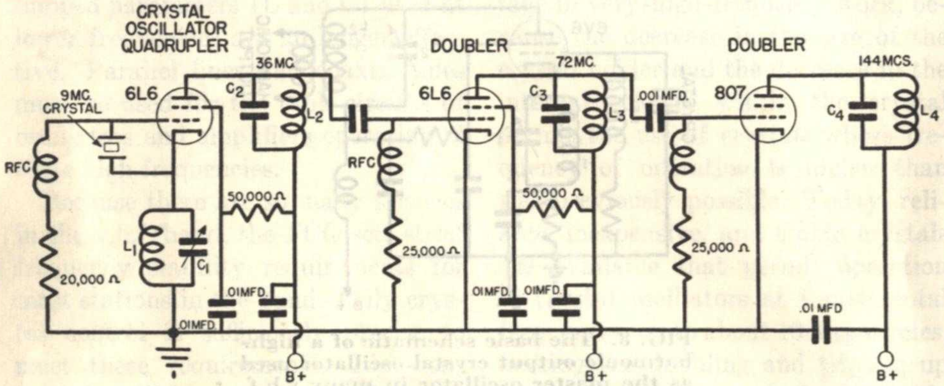


FIG. 9. This is a basic crystal-controlled driver for obtaining a 144-mc. output from a 9-mc. crystal. The first stage is a crystal oscillator quadrupler with a 36-mc. output; two doubler stages are used to raise the output frequency to 144 mc.

PRACTICAL V.H.F. DRIVER

Fig. 9 shows the schematic of a practical v.h.f. crystal-controlled driver with a 144 mc. output that can be used to operate a v.h.f. power amplifier. Although this particular circuit is used by amateurs, it is the basic circuit used by manufacturers of communication equipment for the 152-162 mc. band. The first stage is a crystal oscillator-quadrupler that permits 36 mc. to be obtained from a 9-mc. crystal. The next two stages are frequency doublers used to obtain a 144-mc. output.

Notice that the circuit is straightforward in design and uses conventional tuned circuits.

LINE-CONTROLLED OSCILLATORS

As the frequency of operation increases (especially beyond about 120 mc.), the decreasing size of L and C necessary for resonance makes it more and more difficult to build a high-Q tuned circuit capable of handling high r.f. power efficiency. Fortunately, however, sections of resonant transmission lines can be used for tuning elements at very-high frequencies.

A transmission line one-quarter wavelength long behaves like a parallel resonant circuit. As a matter of fact, as shown in Fig. 10A, such a line can be used in a conventional oscillator circuit in place of a parallel resonant tuned circuit. Notice that, as shown in Fig. 10B, the equivalent circuit is an ultra-audion oscillator.

In this circuit, a section of a parallel two-wire transmission line is shown as the tuning element. As we will see shortly, however, other types of transmission lines can be used.

One advantage of transmission line tuning elements is that the elements, even at very-high frequencies, are large enough to be convenient to handle. For example, a quarter-wave line at 120 mc. is about two feet long. As a matter of fact, these tuning elements are sometimes referred to as "long lines."

The second advantage is that the elements can be made of large diameter metal tubing that can be silver or gold-plated to reduce the "skin-effect" losses to a minimum; therefore, the Q of the circuit can be quite high. (Q's of several thousand have been obtained.)

One disadvantage of two-wire tuning elements is that there may be considerable radiation of energy from the line because of its physical size. This can be minimized by placing the wires close together. The practical limit to this is that arc-over may occur at the high-impedance end of the line on r.f. peaks if the wires are too close together.

Another example of a v.h.f. oscillator using lines for the tuning elements is given in Fig. 11. A twin tetrode tube, the 815, is used. Notice that resonant lines are used for both the plate and grid circuits of this tuned-grid, tuned-plate oscillator; in actual circuits, these grid and plate lines are at right angles to each other to prevent magnetic coupling between them.

In this particular circuit, the plate-to-grid capacitance of the 815 is so small that a slight additional capacitance is necessary for feedback. This may be obtained by running a wire from the plate to the vicinity of the grid line.

Tuning Resonant Lines. Resonant lines are tuned by varying the electrical length of the line. One way of doing this is to physically shorten the line, as for example in Fig. 11, by moving a shorting bar along the line. Care must be taken when using this latter method to prevent the unused portion of the line from absorbing energy and thereby affecting the efficiency of operation.

A resonant line can also be tuned

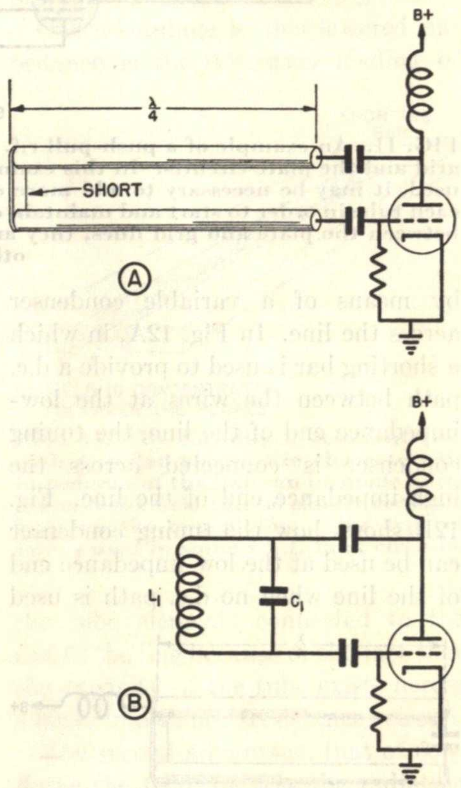


FIG. 10 At very-high frequencies the tuned circuits of oscillators and amplifiers can be replaced by resonant transmission lines. In this case, a quarter-wave line is used to replace the tank circuit in an ultra-audion circuit. Because these lines are physically large, even at very-high frequencies, they are frequently referred to as "long lines."

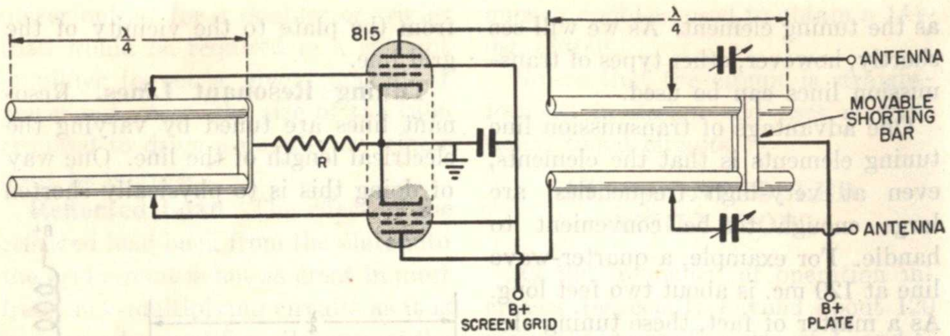


FIG. 11. An example of a push-pull r.f. oscillator using parallel lines for both the grid and the plate circuits. In this example, when an 815 dual beam power tube is used, it may be necessary to add more capacitance between the plate and grid of each tube in order to start and maintain oscillations. To prevent magnetic coupling between the plate and grid lines, they are generally placed at right angles to each other.

by means of a variable condenser across the line. In Fig. 12A, in which a shorting bar is used to provide a d.c. path between the wires at the low-impedance end of the line, the tuning condenser is connected across the high-impedance end of the line. Fig. 12B shows how the tuning condenser can be used at the low-impedance end of the line when no d.c. path is used

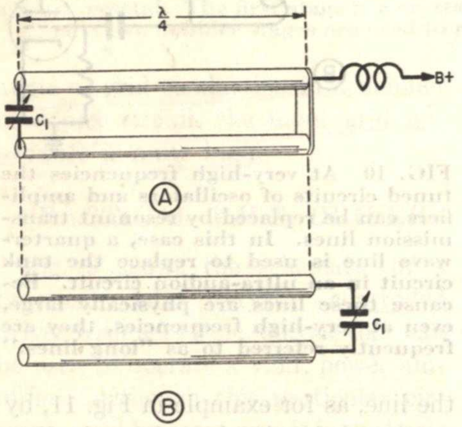


FIG. 12. The resonant frequency of a long-lines tank circuit can be varied by a variable condenser across the line. When there must be a d.c. path from one line to another, the tuning scheme in A can be used where the condenser is across the high impedance end of the line. When no d.c. path is desired the tuning condenser can be used as the low r.f. end of the line as illustrated in B.

between lines. Increasing the tuning capacitance decreases the frequency of operation.

Generally, the line is adjusted to approximately the proper physical length for the desired frequency of operation, and the tuning condenser is used as a fine control to obtain the exact frequency.

COAXIAL LINE OSCILLATORS

The principal advantage of using a section of coaxial line in a line-controlled oscillator is that because the electromagnetic field is almost completely enclosed, the line is non-radiating. This fact eliminates the radiation loss that tends to reduce the Q of the circuit when open lines are used.

The coaxial line-controlled oscillator circuit of Fig. 13 has been used as the basic circuit for a considerable number of very-high frequency transmitters and for high-frequency diathermy equipment. It has good stability because of the high Q of the grid circuit. The r.f. is easily coupled from the circuit either inductively or capacitively. Capacitive feedback to main-

tain oscillations is supplied mostly by the grid-plate capacity of the tube. Slight additional capacity may be added between the plate and grid connections if necessary.

Notice in this circuit that the grid is coupled inductively from the hollow inside conductor. Condenser C_1 is used for fine tuning of the oscillator. An ordinary lumped L and C tuned circuit is used in the plate circuit so that the r.f. power can be coupled out of the circuit easily.

A coaxial line, incidentally, can be tuned by means of a shorting plug that makes contact with both the outer conductor and the center conductor. Generally, however, this method does

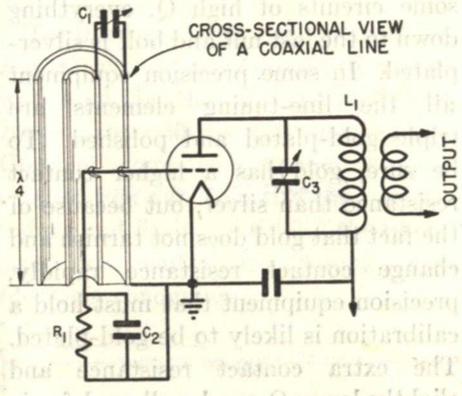


FIG. 13. A basic oscillator circuit using a coaxial line as the resonant grid circuit. Note that a lumped-constants (L and C) circuit is used in the plate circuit. Because of the high Q of the grid lines this circuit is very stable.

not permit wide control of frequency, because it also affects the coupling to the circuit.

FLAT PLATE LINES

One designer of v.h.f. circuits uses the "flat plate" line shown in Fig. 14 for the tuning elements.

Two important characteristics of this type of line are: first, since the distributed inductance of a strap lead is lower than that of a round lead, this line can be constructed to have a low characteristic impedance; and second, most of the electromagnetic field is confined between the two plates.

One advantage of this lowered impedance is the decreased loading of

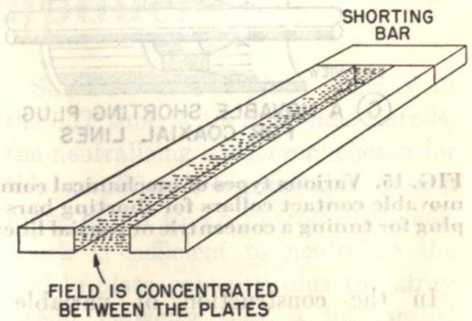


FIG. 14. By forming a resonant line with two flat plates, the characteristic impedance of the line can be made quite low and the field can be closely confined between the two plates. This type of line is used in some v.h.f. tank circuits.

the tube elements connected to the end of the line because of the fact that the capacity of the tube exists across a lower impedance (resistance) circuit.

The second advantage, that of confining the field, reduces the radiation losses so that the Q of the circuit is kept high. The chief disadvantage of the flat plate line is the difficulty in coupling energy out of it.

CONSTRUCTION OF RESONANT LINE ELEMENTS

Resonant transmission line tuning elements are frequently made of large-diameter metal pipes, for which reason they are frequently referred to as "plumbing." Let us learn something about the general problems encountered in the construction of these lines.

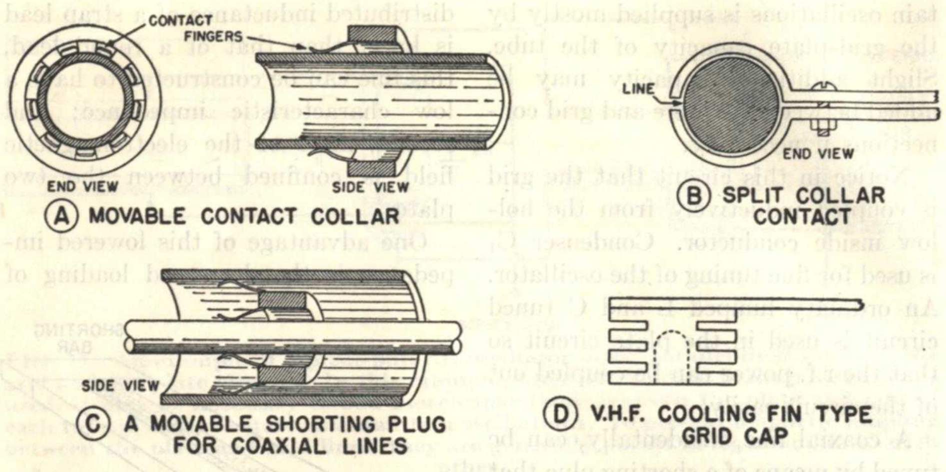


FIG. 15. Various types of mechanical connections used in v.h.f. circuits, A and B are movable contact collars for shorting bars on r.f. lines. C shows a movable shorting plug for tuning a concentric or coaxial line; D shows a v.h.f. grid cap with cooling fins.

In the construction of variable transmission line tuning elements, the movable contacts and the connections to the tubes are apt to give the most trouble. Fig. 15 shows various types of movable contacts and a special grid cap. Most manufacturers plate the copper or brass tubing used for the parallel line element with several layers of silver. Silver has, as you know, a very low contact resistance, and, in some circuits of high Q, everything down to the last nut and bolt is silver-plated. In some precision equipment all the line-tuning elements are triple gold-plated and polished. To be sure, gold has a higher contact resistance than silver, but because of the fact that gold does not tarnish and change contact resistance rapidly, precision equipment that must hold a calibration is likely to be gold-plated. The extra contact resistance and slightly lower Q can be allowed for in most cases. The cost of either silver or gold plating is very small compared to the total cost of the apparatus.

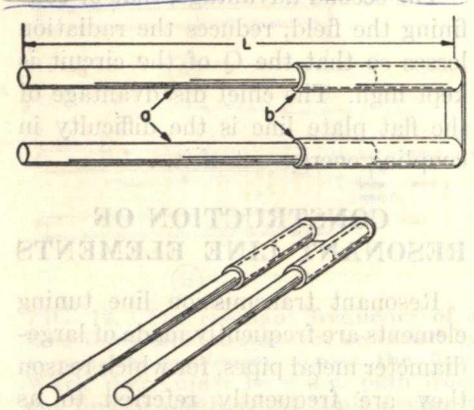


FIG. 16. By "tromboning" a transmission line tuning element, a variable length line is obtained with no exposed, unused line to absorb energy and reduce the efficiency of the circuit.

Designers of very-high-frequency apparatus use "tromboning" (fitting one section of the line inside the other as shown in Fig. 16) to give a variable line with no dead weight or unused line to dissipate energy.

The length L of the line is varied by moving the rods (a) into or out of the hollow sections (b). Because of the difficulty in maintaining an even contact between a and b, this tromboning is generally used in circuits in which a and b do not touch but capacitive coupling is used to make the line electrically complete. This means that this type of line cannot be used if the line must provide a d.c. path. The trombone line is used mostly for antenna coupling circuits, or in link coupling circuits using parallel lines where the coupling is to be varied.

V.H.F. Amplifiers

In the frequency range from 30 to 120 megacycles, conventional r.f. amplifier circuits and lumped L and C tuning elements can be used. It is important, however, for all the precautions already mentioned to be carefully observed.

To illustrate this, let us consider Fig. 17, which is the circuit of a 300-watt amplifier that will operate in the range from 30 to 120 megacycles. Complete component details are given so that you can compare the various values and fix in your mind the likely sizes for neutralizing tuning, and blocking condensers.

Since the grid-to-plate capacity in the 35T tube is 1.9 micromicrofarads, the neutralizing condensers chosen for this amplifier are adjustable over a range of 1.5 to 4.5 micromicrofarads, which is sufficient to neutralize the grid-to-plate capacity plus the stray circuit capacity that is in parallel with it.

Because of the extremely small interelectrode capacitance of the 35T's, the values of L and C for all tuned circuits are reasonable, even at 120 megacycles.

The excitation required for this amplifier could be furnished by an oscil-

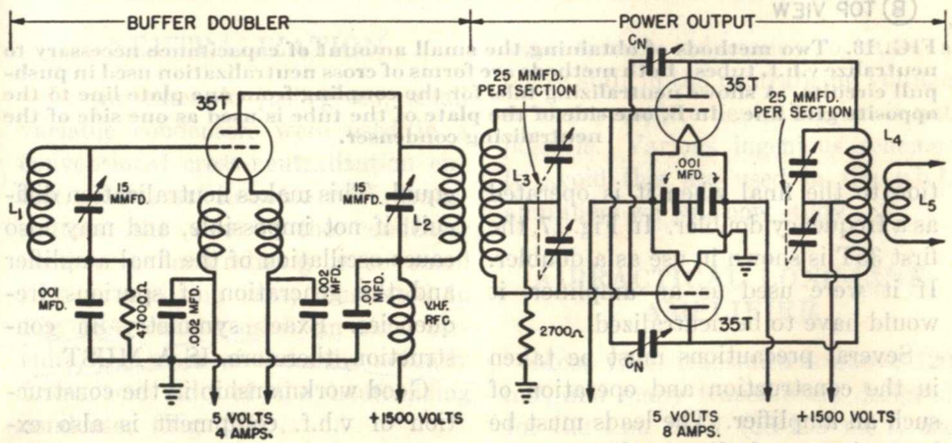


FIG. 17. The basic schematic diagram of a 300-watt 30-120 mc., r.f. amplifier. This circuit is conventional and values of various components are shown. The inductances L_1 through L_5 will depend on the frequency to be amplified. CN are 1.5 to 4.5 mmfd. variable condensers.

lator-buffer combination capable of supplying about 15 watts—the combination of Fig. 9 would be more than adequate. At the lower frequencies, the driver stage would be operated at the same frequency as the final amplifier and would thus be acting as a straight driver or intermediate power amplifier. This driver stage is also capable of supplying sufficient excita-

placement of parts in the push-pull circuits must be symmetrical.

Need for Symmetry. At very-high frequencies, variations in lengths of leads or placement of parts in push-pull circuits will cause variations in the inductances and capacitances in the circuit with the result that the drive applied to the two tubes or the power taken from them will be un-

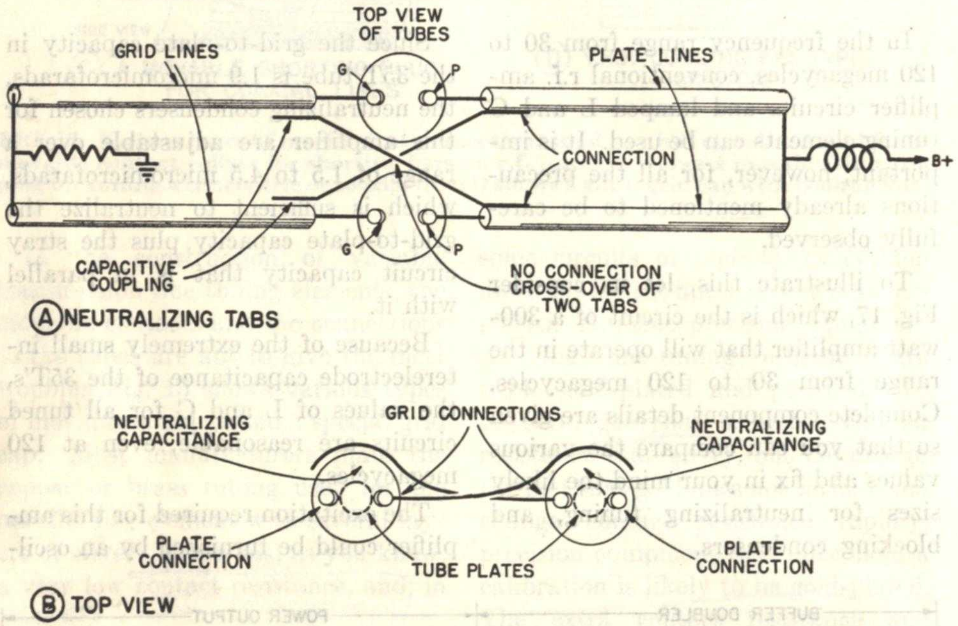


FIG. 18. Two methods of obtaining the small amount of capacitance necessary to neutralize v.h.f. tubes. Both methods are forms of cross neutralization used in push-pull circuits. A shows neutralizing tabs for the coupling from one plate line to the opposite grid line. In B, one side of the plate of the tube is used as one side of the neutralizing condenser.

tion to the final when it is operated as a frequency doubler. In Fig. 17, the first 35T is shown in use as a doubler. If it were used as an amplifier, it would have to be neutralized.

Several precautions must be taken in the construction and operation of such an amplifier. The leads must be kept short and direct. Components must be mounted as close to the tubes as possible. Finally, the wiring and

equal. This makes neutralization difficult, if not impossible, and may also cause oscillation of the final amplifier and the generation of spurious frequencies. Exact symmetry in construction, therefore, IS A MUST.

Good workmanship in the construction of v.h.f. equipment is also extremely important, because only painstaking workmanship makes it possible to use a conventional circuit

like that shown in Fig. 17 at very-high frequencies. Poor mechanical design is more often the cause of failure in v.h.f. work than is poor electrical design; the best electrical design in the world will not function at all at these frequencies if the mechanical construction is not nearly perfect. Soldering must be good, parts must fit snugly, leads must be kept short and direct, strap leads must be used in place of round leads where possible, and all equipment must be kept scrupulously clean.

izing condensers means that the adjustments must be very carefully made. One condition to be avoided in neutralizing a push-pull amplifier is an unbalanced circuit. An unbalanced circuit may seem to be properly neutralized, but when power is applied to the stage, one tube will be loaded more than the other. To make sure a circuit is properly balanced, always check its performance with the power on after you have neutralized it.

At very-high frequencies it often happens that the leads to the tubes

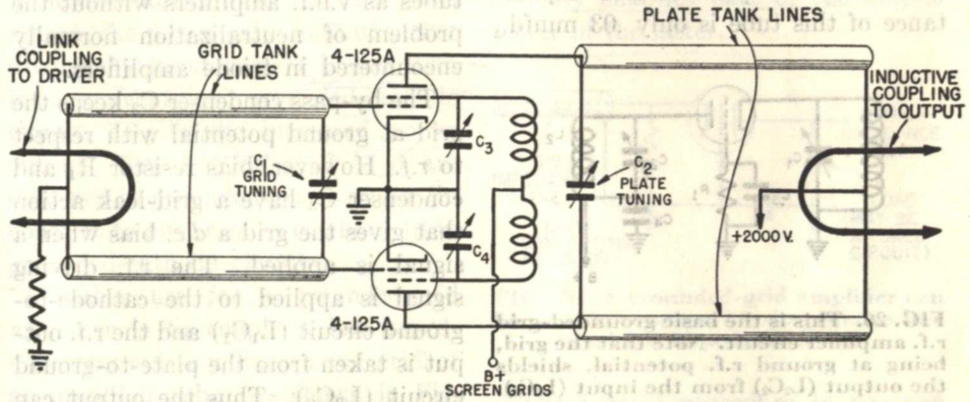


FIG. 19. The final r.f. amplifier of a commercial 250-watt f.m. transmitter. Note that two-wire lines are used for both the grid and the plate tanks. Condensers C_1 and C_2 are used for fine tuning of the grid and plate resonant lines respectively.

NEUTRALIZATION

In the example just given, small variable condensers were used in a conventional cross-neutralization circuit. However, in some v.h.f. transmitters, the size of the condenser needed for neutralizing is so small that neutralizing tabs, illustrated in Fig. 18A, can be used. In other circuits, the plate of the tube actually forms one side of the neutralizing condenser (Fig. 18B).

Although neutralization at very-high frequencies is done in the usual manner, the small size of the neutral-

have enough inductance to cause a phase shift in the neutralizing voltage so that complete neutralization is not possible. Various ingenious schemes to avoid this are used in the v.h.f. amplifiers we will now study.

A PRACTICAL LONG-LINE AMPLIFIER

Most v.h.f. transmitters above 120 mc., and many transmitters designed for the f.m. band (88-108 mc.), use "long lines" for the tuning elements. An example is shown in Fig. 19, which is a simplified schematic of the output stage of a commercial 250-watt f.m. transmitter using two-wire open lines for both plate and grid tuning.

The 4-125A tube used in this circuit is especially designed for v.h.f. operation. Its input capacitance is 10.3 mmfd., so the capacitive load across the grid lines due to the tube is about 5.2 mmfd. The output capacitance of each tube is only 3 mmfd., so the total in this push-pull application is 1.5 mmfd. Variable condensers C_1 and C_2 are used for fine tuning of the plate and grid lines.

Because the plate-to-grid capacitance of this tube is only .03 mmfd.,

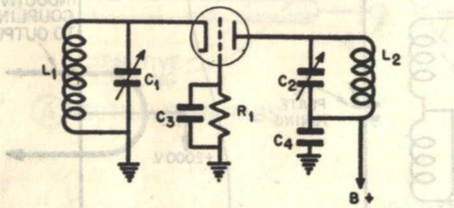


FIG. 20. This is the basic grounded-grid r.f. amplifier circuit. Note that the grid, being at ground r.f. potential, shields the output (L_2C_2) from the input (L_1C_1).

neutralization is generally not necessary. If it is necessary, any of the conventional methods may be used. The method used here is not conventional but works very well. To understand its operation, remember that the plate-to-grid capacitance of a tetrode is minimum only when the screen grid is at r.f. ground potential. At very-high frequencies, however, the inductive reactance of the screen grid leads causes the screen grids to be above r.f. ground. This is avoided in the circuit shown by series resonating this inductance in each tube by means of C_3 and C_4. At resonance, each screen grid is at r.f. ground potential despite the inductance of the screen leads.

GROUNDED-GRID AMPLIFIER

The grounded-grid or "inverted" amplifier is widely used in the amplification of very-high frequencies. Fig. 20 shows the basic grounded-grid amplifier circuit. For convenience, lumped parameters are shown; however, this type of circuit is frequently used with some form of resonant line.

The principal advantage of this circuit is that it permits the use of triode tubes as v.h.f. amplifiers without the problem of neutralization normally encountered in triode amplifiers.

The by-pass condenser C_3 keeps the grid at ground potential with respect to *r.f.* However, bias resistor R_1 and condenser C_3 have a grid-leak action that gives the grid a *d.c.* bias when a signal is applied. The r.f. driving signal is applied to the cathode-to-ground circuit (L_1C_1) and the r.f. output is taken from the plate-to-ground circuit (L_2C_2). Thus the output can be coupled back to the input only through the plate-to-cathode capacitance of the tube. However, since the grid is grounded, it effectively shields the plate from the cathode.

Notice (Fig. 7) that the tubes designed for grounded-grid operation (7C24, 9C25, GL5518, GL5513, and WL473) each have a plate-to-cathode capacitance of less than one micro-microfarad. These small values of C_{pk} mean that neutralization is not necessary in most grounded-grid circuits.

Another important characteristic of the grounded-grid amplifier circuit is that the power output for a given tube is greater than that for the same tube in a grounded-cathode circuit. This extra power, however, does not come from more efficient operation of the amplifier, but must be supplied by the driving source. The reason is that the output is taken from the plate-to-ground circuit, which includes the cathode-to-ground circuit where the driving power is applied. The usual grid circuit losses (including power loss in R_1) are generally smaller than the power supplied to the load from the driver. The normal grid driving power of a grounded-grid amplifier, therefore, is much more than in a grounded-cathode circuit. For this reason, the power gain (output power divided by input power) is less than in a conventional grounded-cathode circuit, despite the increased power output. Power gains of 3 to 5 are obtained in grounded-grid circuits (in contrast to power gains of about 10 in grounded-cathode circuits).

Another use for a grounded-grid amplifier is to couple a low-impedance transmission line to the grid of an amplifier tube. As shown in Fig. 21, the transmission line from some remotely located source is fed into the cathode-to-ground circuit of a grounded grid amplifier. The plate-to-cathode output of this stage can then be coupled into a second stage, which may be another grounded-grid or a normal grounded-cathode stage. This type of circuit is used in booster and satellite stations* as v.h.f. repeat stations.

Tuning a Grounded-Grid Amplifier. When the r.f. driving source is stable—when it is a crystal oscillator with frequency multipliers, for example—tuning of a grounded-grid circuit is done in the conventional manner.

However, when the r.f. source is not stable—when, for example, a line-controlled oscillator is the driver—care must be taken to assure proper operation. Although, in this case, amplifier loading will affect the oscillator frequency even in a conventional grounded-cathode circuit, larger variations occur when a grounded-grid amplifier is used, because the driver actually supplies part of the output power of the latter.

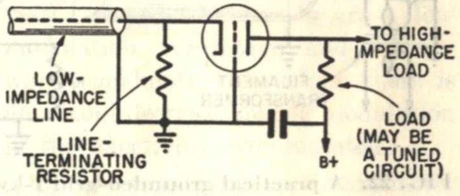


FIG. 21. A grounded-grid amplifier can be used to couple a low-impedance line to a high-impedance circuit.

The normal procedure in practice is to set the frequency of the oscillator with a wave meter or frequency meter. The amplifier grid coupling line is then tuned until the proper grid current for driving the amplifier is reached. The frequency of the oscillator is checked and the oscillator retuned if the frequency has shifted from the desired frequency. The grid circuit of the amplifier is retuned and then plate voltage is applied to the amplifier plates. The plate line is tuned approximately to resonance, the grid is retuned, and the oscillator is checked for frequency once more. The antenna is coupled to the plate of the amplifier and tuned alternately with the amplifier plate lines until the nor-

* A booster or satellite station is used to reinforce the very-high frequency signal in a shadow of a hill where the signal from the original station is unusable, or in the metropolitan area of a large city where the main transmitter is located some distance from the city limits.

mal plate current condition is reached. A complete check is now made of oscillator frequency, amplifier grid current, and antenna output.

As we load the oscillator in tuning the amplifier, the feedback voltage changes. This changes the oscillator grid load and shifts the frequency slightly. If we have sufficient power available from the oscillator to drive the amplifier properly, no permanent

output stage of a commercial f.m. transmitter given in Fig 22.

Notice that the plate and grid tank circuits consist of concentric lines—actually three concentric lines in each case. The r.f. input is fed into the two outside lines of the grid tank. The filament leads act as the third line and, although A is at ground potential, B will be at a high r.f. potential, driving the stage.

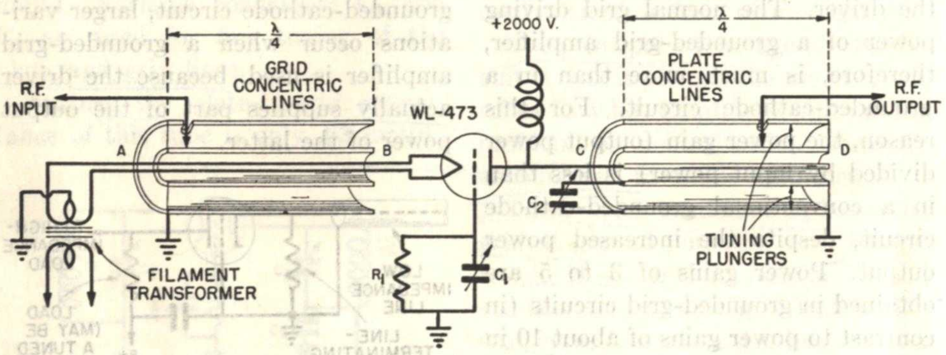


FIG. 22. A practical grounded-grid 1-kw., f.m. amplifier using concentric lines for grid and plate tank circuits.

bad effects occur, and slight retuning of the oscillator is all that is necessary. If, on the other hand, we try to take too much power from the amplifier plate circuit, reflecting an additional load on the amplifier grid that cannot be accepted by the oscillator, then the oscillator output voltage is decreased, excitation to the amplifier decreases, the efficiency decreases, and the tube overheats, and is unstable when modulated.

Commercial Grounded-Grid Amplifier. An example of a practical grounded grid amplifier is the 1-kw.

The d.c. grid bias is developed across R_1. Condenser C_1 is series resonated with any grid lead inductance so that the grid is at r.f. ground potential. This prevents feedback from the output to the input and is effectively the neutralization control.

The plate concentric tank is capacitively shunt fed through center line C-D. The r.f. output is taken from the proper impedance matching point of the center conductor.

Notice that plungers are used for adjusting the frequency of the plate concentric lines. Fine tuning is achieved by varying condenser C_2.

V.H.F. Modulation

Methods used to modulate v.h.f. transmitters do not differ fundamentally from those you have already studied that are used to modulate lower frequency transmitters. However, to amplitude-modulate a v.h.f. transmitter properly, particular care must be taken to assure frequency stability of the carrier and to provide adequate r.f. excitation to the modulated stage.

FREQUENCY STABILITY

To secure maximum power transfer from one stage to another, the stages in many v.h.f. transmitters are coupled together more closely than is customary in lower frequency amplifiers. Modulation of one of the r.f. stages, therefore, is quite likely to be reflected as a varying load back to the master oscillator and cause undesired frequency modulation of it. In a v.h.f. transmitter using a line-controlled oscillator feeding the modulated stage directly, particular care must be taken to minimize frequency instability. If the oscillator is closely coupled to the modulated amplifier, any change in the amplifier load may cause frequency modulation components to be included along with the amplitude modulation products. The signal will then occupy a greater band width than is necessary; generally, this results in an objectionable distortion of the received signal. In television video transmission, f.m. is intolerable, because it produces distortion of the video signal and alters both the shape and the timing of the synchronizing circuits. Both effects cause the picture to be unusable.

It is important, therefore, that the oscillator be lightly coupled to its load so that there will be a minimum of interaction between it and the modulated stage.

EXCITATION

Since r.f. power is difficult to obtain at very-high frequencies, most v.h.f. amplifiers are under-excited rather than over-excited. Many v.h.f. transmitters are operated at too great a carrier power output, with too little r.f. excitation on the grids of the modulated stage. The results are a low modulation percentage and "downward" modulation, in which there is an actual decrease during modulation in the effective power radiated.

Under-excitation in any transmitter may produce unusual effects, such as microphonics in the power amplifier, or "singing" at some parasitic frequency on modulation peaks. These effects are particularly likely to occur at very-high frequencies.

With sufficient driving and with the oscillator well isolated, a very-high-frequency transmitter can be modulated by any of the common methods. Choke or transformer-coupled plate modulation, grid modulation, or cathode modulation may be used. Suppressor grid modulation is not very often used at very-high frequencies, primarily because varying the suppressor voltage will affect the inter-element coupling in the tube and may make neutralization impossible, and also because of the lack of good linearity at any carrier frequency when suppressor modulation is used.

TRANSMISSION-LINE MODULATION

A method of amplitude modulation not common to most of the lower frequency transmitters is shown in Fig. 23. This method, called transmission-line modulation, is especially applicable to very-high-frequency circuits where the length of the transmission lines will not be excessive.

This is a "loss" system of modulation; that is, the modulating tubes do not add any power to the carrier but, instead, merely reduce the amplitude of the carrier in accordance with the modulating signal. The modulating tubes are connected through a quarter-wavelength line to point X, where the output of the final r.f. stage is also applied through a quarter-wavelength line. On negative modulation peaks, the modulator tubes have a high impedance. Because of the impedance-inverting property of a quarter-wave line, this high impedance appears as a short circuit at X. This short circuit, in turn, appears as a high-impedance load at the r.f. output stage, reducing the power to the antenna to a minimum. On the positive peaks of the modulating voltage, the opposite occurs: the modulator tubes have a low impedance that, because it is reflected as a low impedance across the r.f. output stage, causes the r.f. output to increase to a maximum. Thus, the r.f. carrier can be amplitude-modulated by varying the grid voltage on the modulator tubes.

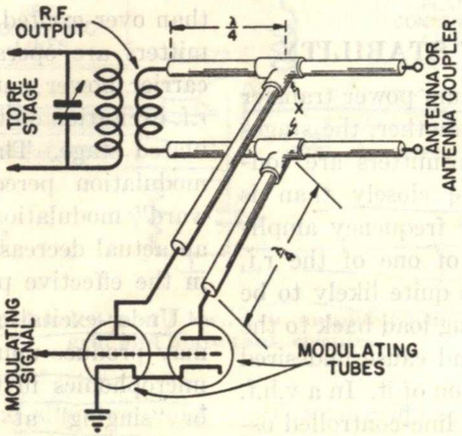


FIG. 23. Transmission-line modulation uses the impedance-inverting properties of two quarter-wave lines to loss-modulate an r.f. carrier.

The circuit is designed so that the proper load impedance for maximum output is obtained only on the positive peaks of the modulating signal. At all other times, the load is higher than the correct value, so that the operating efficiency is decreased; the operating efficiency is about the same as that for grid-bias modulation. This type of modulation is best used in television transmitters because its simplicity permits wide-band modulation.

Like all other very-high frequency circuits, this circuit must be cleanly constructed. Care must be taken to isolate the modulation equipment from high-frequency feedback by using high quality by-pass condensers with the minimum length of lead from condenser to ground. Radio-frequency chokes with low distributed capacity must be used in the plate connections from the modulation equipment to the modulated amplifier. The value of a v.h.f. by-pass condenser is only a few micromicrofarads; a condenser this small may be put across the modulator output without affecting the high modulation frequencies.

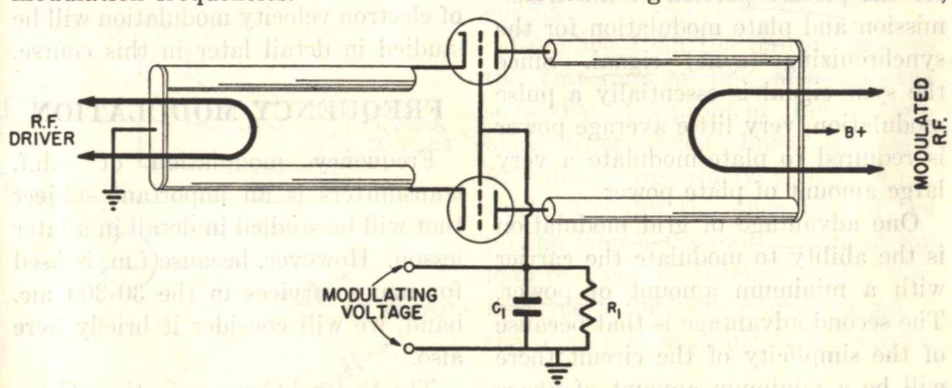


FIG. 24. Grid bias modulation of a grounded-grid amplifier is easily accompli shed The simplicity of the circuit makes it very useful for wide band modulation as in television broadcasting.

AMPLITUDE MODULATION OF A GROUNDED-GRID AMPLIFIER

Modulation of the grounded-grid amplifier offers some special problems. First, the requirement of sufficient driving power for the modulated amplifier is very important in the grounded-grid amplifier because of the fact that some of the driving power reaches the antenna circuit. Thus, modulation of the r.f. output amplifier causes a large variation in power taken from the driving source.

Grid modulation, as shown in Fig. 24, is commonly used in grounded-grid amplifiers. Notice the simplicity of the circuit.

The modulating voltage is applied directly across R_1, the grid bias resistor. The capacitor C_1 is an r.f. by-pass for the carrier frequency. For television transmission, provision may have to be made to prevent this condenser from affecting the higher frequencies of the 4-mc. video modulating signal. However, C_1 will not affect the modulating signal for aural transmission.

When the grid circuit is modulated, the load on the modulated tube varies; this varies the load on the driving stage also. Unless the driving stage has very good regulation, modulation of a grounded-grid amplifier will be reflected back into the preceding stage as a varying load. The preceding buffer stages must be properly designed and operated to prevent this variation from affecting the frequency stability of the master oscillator.

Sometimes both the final r.f. stage and the driver stage are modulated simultaneously so that the driver output will vary in accordance with the varying input power needed to drive the final stage during modulation.

A grounded-grid amplifier can, of course, be modulated by any of the conventional methods of introducing the audio voltage into the grid or plate circuit.

MODULATION OF TELEVISION STATIONS

In television transmitters, the final amplifier, whether it is a grounded-grid or conventional amplifier, is usually grid-modulated. Many transmitters, however, use grid modulation for the picture portion of the transmission and plate modulation for the synchronizing (sync) signal. Since the sync signal is essentially a pulse modulation, very little average power is required to plate-modulate a very large amount of plate power.

One advantage of grid modulation is the ability to modulate the carrier with a minimum amount of power. The second advantage is that because of the simplicity of the circuit there will be a minimum amount of phase distortion of the signal. Phase distortion, as we have said before, is very important in television transmission.

Plate modulation of the video signal is generally not satisfactory because of the high distributed capacities of modulation transformers and modulation chokes and their inability to handle the required power over the entire video-frequency range.

Transmission-line modulation at the higher frequencies has been popular with many experimenters in television transmitters, although most commercial transmitters continue to use grid modulation.

Low-level modulation with class A power amplifiers following, has not received very wide acceptance in television operations, although one large manufacturer has done some very extensive work on this type of transmitter.

Television relay work at frequencies considerably above 300 megacycles has employed many unique modulation methods, such as velocity modulation, which is a modulation system consisting of acceleration and deceleration of the electron stream within a single tube in such a manner that a very complete and faithful modulation envelope is formed. The subject of electron velocity modulation will be studied in detail later in this course.

FREQUENCY MODULATION

Frequency modulation of v.h.f. transmitters is an important subject that will be studied in detail in a later lesson. However, because f.m. is used for many services in the 30-300 mc. band, we will consider it briefly here also.

The Federal Communications Commission insists on a very high degree of carrier stability in f.m. systems. For this reason, only crystal-controlled or crystal-reference transmitters are used. The frequency modulation is generally produced in the low-frequency oscillator. Frequency doubler and tripler stages are then used to bring the carrier to the proper frequency.

This frequency multiplication also increases the frequency deviation. For example, one commercial transmitter uses five tripler and two doubler stages to obtain a multiplication factor of 972. The master oscillator must be operated at 108.33 kc. to produce a carrier of 105.3 mc. A 100 c.p.s. variation in the master oscillator would then appear as a 97.2 kc. frequency swing in the output, which is even more than the 75 kc. deviation used in f.m. broadcast services.

V.H.F. Antenna Coupling

The coupling of a very-high-frequency oscillator or amplifier to an antenna or transmission line offers some rather special problems. First, the physical size of the coupling unit must be small (generally a single loop) because of the short wavelength of v.h.f. energy. Second, the r.f. fields are generally confined to areas where it is difficult to obtain sufficient coupling to a pickup loop.

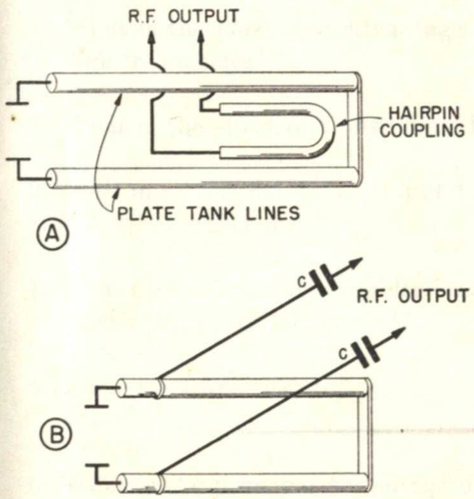


FIG. 25. In A is shown inductive coupling by means of a "hairpin" loop, and, B, capacitive coupling from a "long lines" tank circuit.

Fig. 25 shows various methods of providing this coupling. "Hairpin" inductive coupling is shown in A, and B shows capacitive coupling. Notice that hairpin coupling has been used in many of the v.h.f. circuits we have already studied.

When adjustable coupling is used in a hairpin pickup loop, tromboning sections like those shown in Fig. 16 should be used to prevent the excess portion of the loop from absorbing power and introducing losses in the circuit.

Coupling from the hairpin loop to the transmission line also presents somewhat of a problem. Low-impedance transmission lines, generally 51.5 ohms, are widely used in v.h.f. work. Usually the open end of the pickup loop is the only section of the loop that can be reached easily; this, however, is the high-impedance end of the loop, and coupling the transmission line directly to it would result in a serious mis-match of impedances.

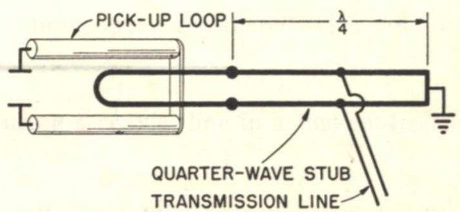


FIG. 26. A shorted quarter-wave stub can be used as shown here to permit coupling of a low-impedance transmission line to the output of an r.f. tank circuit.

This problem can be solved, as shown in Fig. 26, by connecting the open end of a shorted quarter-wave stub to the open end of the pickup loop. Since the open end of the stub is its high-impedance end, a good impedance match is secured between the

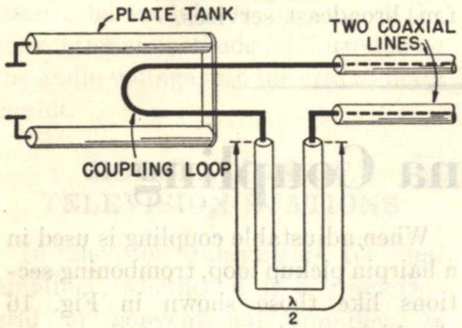


FIG. 27. How a half-wave phasing stub can be used to feed in phase currents to two coaxial transmission lines.

stub and the loop. Then the transmission line can be impedance-matched to the stub by connecting the line to the proper points on the stub; these points can be found by experiment.

Sometimes in multiple antenna arrays the output of a v.h.f. transmitter is fed to two matched lines that must be excited in phase. This is done, as shown in Fig. 27, by adding a half-wave section to one of the two lines. The powers in the two lines are then in phase and equal in amplitude.

Lesson Questions

Be sure to number your Answer Sheet 45RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. What is the particular advantage of operating tubes in push-pull at very-high frequencies?
2. What is the effect of transit time losses on the input resistance of a tube?
3. Why must the d.c. power input to a tube be reduced as the frequency of operation is increased?
4. How many frequency doubler stages are necessary to produce a 160 mc. carrier from a 10 mc. crystal?
5. Why are transmission lines for r.f. tuning generally plated with gold or silver?
6. What is the principal advantage of using a coaxial line in a line-controlled oscillator?
7. What is the advantage of "tromboning" a variable length transmission line tuning element?
8. Draw the basic grounded-grid circuit.
9. Why is it generally unnecessary to neutralize a grounded-grid triode amplifier?
10. How long are the lines used in the transmission-line modulation method?

WASTED TIME

A minute seems such a little thing—something most of us thoughtlessly throw away. But, just as pennies make dollars, so do minutes make hours. Few people realize that ten minutes wasted daily make over sixty hours—more than a work-week—in a year's time.

Study the habits of most successful men and you will find that they made use of odd moments, reading or writing, or *thinking*. Those precious minutes gave them the *extra* weeks, months, and years of time necessary to prepare and to advance themselves.

Now, time spent in healthful recreation is not being wasted. But, how much of your time is spent in idle amusements instead? How much time do you waste "stalling" before starting a task—doing unnecessary or useless things—or doing nothing at all?

Study your actions during the day. Make a list of the things you do. You'll be surprised at the number of five-or-ten-minute intervals you can put to better use, in studying or planning for the future. Be ready for your opportunity when it comes!

J. E. Smith.