Radiotronics

Number 129 JANUARY — FEBRUARY 1948

WELDING VALVE ELEMENTS TO STEM SUPPORTS AND INSPECTING COMPLETED MOUNTS AT THE RADIOTRON VALVE WORKS, ASHFIELD, N.S.W.

RADIOTRONICS

Number 129 **JANUARY — FEBRUARY** **1948**

IN THIS ISSUE

Technical Editor
F. Langford-Smith, B.Sc., B.E.

Radiotronics is issued six times a year and now forms part of "Radiotron Technical Service" for which the annual inclusive mailing fee is 7/6d.

All communications, subscriptions and change of address notices should be directed to the Valve Company — except in New Zealand, where correspondence should be addressed to the National Electrical and Engineering Company Limited, 286-288 Wakefield Street, Wellington.

Published by the Wireless Press
for
Amalgamated Wireless Valve
Company Pty. Ltd.
47 York Street, Sydney, N.S.W.

Radiotronics is printed in Australia by the
Cloister Press (D. & W. Short),
Redfern, N.S.W.

Our cover shows an operator and inspector completing the assembly of Radiotron valve mounts. The operator, farthest from camera, is welding component parts to a radio valve stem by means of a 1 KVA electric welder. Very special care is needed to ensure that the weld of very small parts is of correct strength and thickness. The completed mounts are passed to the inspector who carefully scrutinises the welded components, using a magnifying glass where necessary. Spaces of only a minute fraction of an inch are also checked for correct distance between diode plates and cathode. These operations are carried out with every Radiotron valve manufactured at the Valve Works — Ashfield.

"PRACTICAL ANALYSIS OF ULTRA HIGH FREQUENCY TRANSMISSION LINES. RESONANT SECTIONS. RESONANT CAVITIES. WAVE GUIDES."

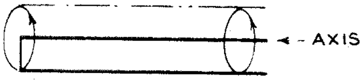
by J. R. MEAGHER and H. J. MARKLEY

This is the first of two articles dealing, in a simplified manner, with u-h-f transmission lines, etc., and is published through the courtesy of the R.C.A. Service Company, copyright proprietor. The first article deals with transmission lines and resonant sections, and the second article will cover resonant cavities and wave guides.

Transmission Lines

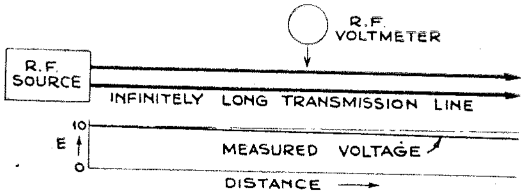
A transmission line is a means of transferring r-f energy from a source to a load in an efficient manner.

For simplicity, most of the illustrations in this booklet show parallel-wire transmission lines, but the information also applies to coaxial lines. The similarity between a section of parallel-wire line and a coaxial section may be seen by rotating a parallel-wire section about one wire so the outer arm forms a cylinder as shown.

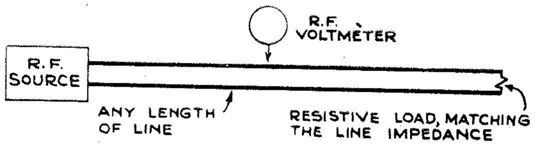


The r-f voltmeter, referred to in the text, usually consists of an r-f rectifier and meter which indicates the rectified peak amplitude of the r-f voltage at any point along the line.

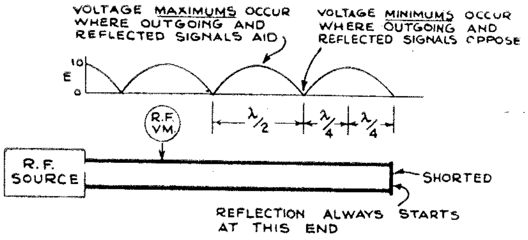
Standing Waves on Lines



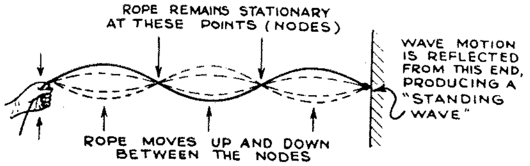
In this illustration, an r-f source is feeding r-f energy into a transmission line. If the line is infinitely long, the signal never reaches the end, and therefore cannot be reflected, so there are no "standing waves." The r-f voltage measured along the line gradually decreases due to losses in the line.



If the line is *terminated* in a resistive load that matches the line impedance (also termed "surge" or "characteristic" impedance), the outgoing signal is completely absorbed by the load. As a result, there are no reflections and no standing waves, and the voltage is essentially the same at all points along the line.



If the load is not resistive and matched to the line impedance, it reflects signal back into the line. *The combination of the outgoing and reflected signal produces a standing wave on the line.*



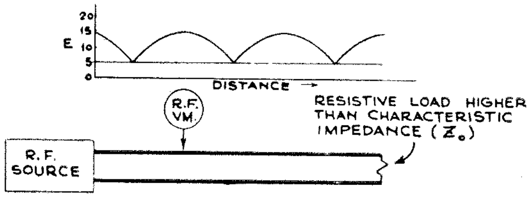
This analogy shows standing waves produced by wave motion and reflection on a rope. A similar analogy can be made to standing waves of sound along a pipe.

Standing Wave Ratio

$$\text{The standing-wave ratio} = \frac{\text{Minimum Voltage}}{\text{Maximum Voltage}}$$

This ratio indicates the ratio of mismatch of the load impedance.

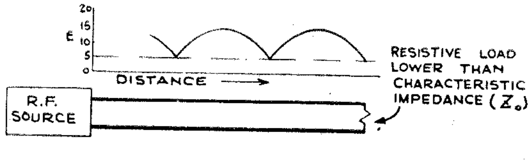
In the example shown below, the voltage at minimum's is 5, and the voltage at maximum's is 15.



The ratio is $\frac{5}{15}$ or 1 to 3.

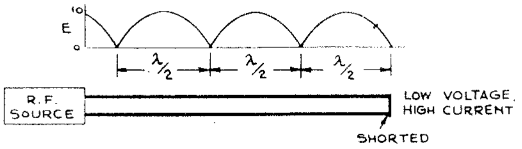
Hence, the load impedance is either 3 times larger than the line impedance, or one-third of the line impedance. (In the foregoing example, the voltage at the load is maximum, so the load impedance is higher than the line impedance.)

If the load has an appreciable reactive component the standing-wave ratio is only a rough indication of the impedance mismatch. This can be seen from the curves in the appendix.

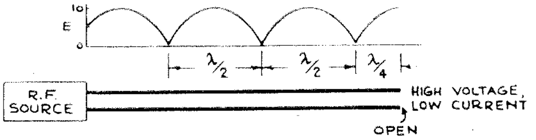


In the example shown above, the voltage at the load is minimum, so the load impedance is lower than the line impedance.

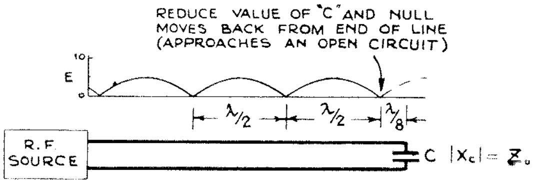
Position of Voltage Minimums and Maximums

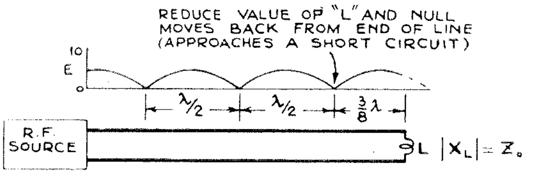


If the end of the line is shorted, the voltage at the short is low and the current is high. The first voltage minimum occurs a half-wave back from the end of the line.



If the end of the line is open, the voltage at the end is high, and the current is low. The first voltage minimum occurs a quarter-wave back from the end of the line.





For loads containing reactance, the standing-wave will be shifted, depending on the nature of the load.

Often it is desirable to speak of electrical degrees rather than fractions of a wave-length:

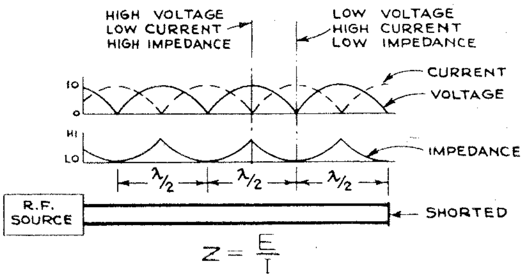
$\frac{1}{8}\lambda = 45°$
$\frac{1}{4}\lambda = 90°$
$\frac{3}{8}\lambda = 135°$
$\frac{1}{2}\lambda = 180°$
$\frac{5}{8}\lambda = 225°$
$\frac{3}{4}\lambda = 270°$
$\frac{7}{8}\lambda = 315°$
$\lambda = 360°$

Impedance at Different Points Along the Line

The impedance at any point along the line is determined by the ratio of voltage to current at that point: If the voltage is high, the current at the same point is low, and therefore the impedance at that point is high.

If the line has low losses, and no energy is absorbed by the termination, the low-impedance points are equivalent to short-circuits, and the high-impedance points are equivalent to open circuits. If there is energy loss in the line or termination, the impedance tends to become more uniform along the line. *When the load matches the line, the impedance becomes uniform along the line, and is equal to the "characteristic" impedance.*

It should be noted that an open circuit, a short-circuit or a pure reactance at the end of the line will not absorb power. Standing-waves will therefore exist with such loads.



Summary—Effect of Line Termination

(1) If a line *of any length* is correctly terminated with a resistive load that matches the line impedance, there are no reflections, and no standing-waves.

(2) If a line is not correctly terminated, the signal is reflected back from the load and this results in standing-waves.

(3) The value and nature of the load determines the *ratio* of voltage at maximum and minimum points along the line, and also the *position* of these maximum and minimum points.

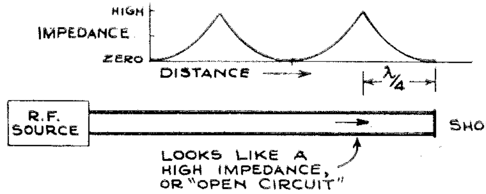
In most applications where a line is used to connect a signal source to a load (for instance, to connect a transmitter to an antenna) it is generally desirable to make the load match the line. *If the load is not matched, the length of the line becomes critical,* and incorrect length may affect the power output and frequency of the source. *When the load is matched to the line, the length of the line is not critical.* ("Matching" means that the load must be resistive and equal to the line impedance.)

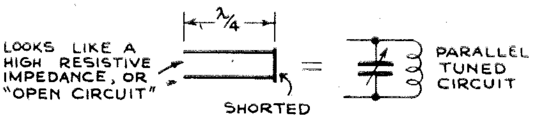
Resonant Sections

Quarter-wave and half-wave sections and their action as tuned circuits will now be considered. This action will be explained on the basis of change in impedance produced by standing waves along an opened or shorted line.

When sections of line are used as tuned circuits, their action depends on the existence of reflections and standing-waves to produce the effect of high-impedance and low-impedance tuned circuits. Therefore, sections of lines, when used as tuned circuits or transformers are either effectively shorted or opened at the end to produce the maximum standing-wave ratio and the highest or lowest possible input impedance, as desired in the application.

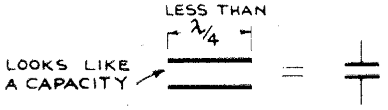
Quarter-Wave Shorted Section



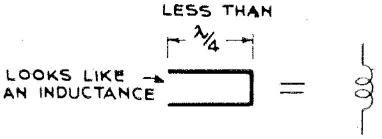


The quarter-wave shorted section at the end of the line looks like a high-impedance to the input signal, and being tuned, it is resistive. The equivalent conventional circuit is a parallel-tuned circuit, for it also has high resistive impedance at the resonant frequency.

The action of a quarter-wave section may also be explained as follows:

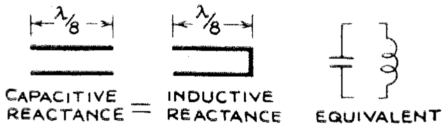


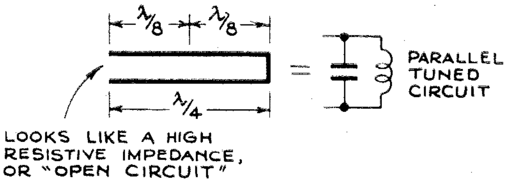
A section of line open at each end and less than a quarter-wave long acts like a *capacity.*



A section of line shorted at one end and less than a quarter-wave long acts like an *inductance.*

The capacitive reactance of a section of line one-eighth wave-long, open at the ends, is equal to the inductive reactance of a section of line one-eighth wave long, shorted at one end: The values of these reactances are equal to the "characteristic" impedance. (The "characteristic" or "surge" impedance depends on the size and spacing of the conductors.)

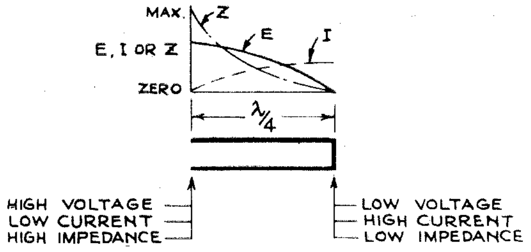




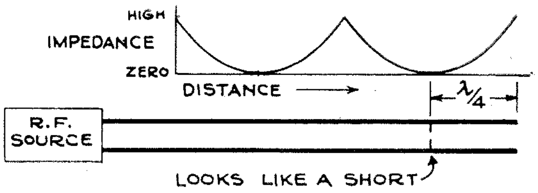
If the two sections are combined, the result is a resonant circuit that has high-resistive impedance, like a parallel-tuned circuit.

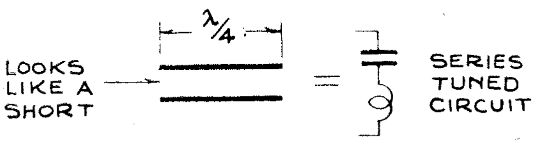
(This example is given because it is simple to visualize. Naturally, any two sections that add in length to equal one-quarter-wave electrically will have equal reactance and will produce the same result.)

The voltage, current, and impedance relations for a quarter-wave section are shown below:



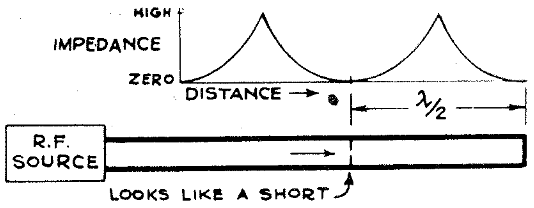
Quarter-Wave Open Section

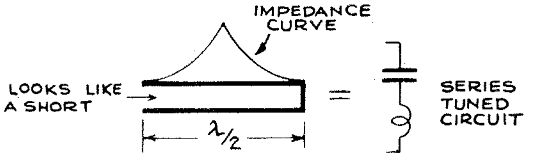




The quarter-wave section at the end of the line has very low input impedance, and, being tuned, it is resistive. It is equivalent to a conventional series-tuned circuit.

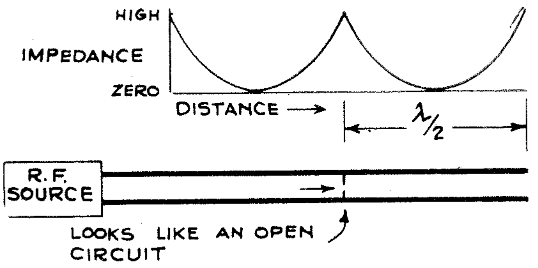
Half-Wave Shorted Section

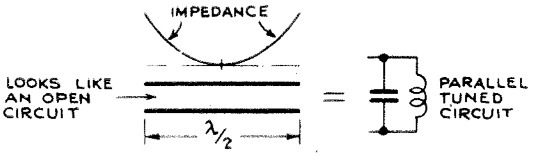




The half-wave shorted section at the end of the line also has low resistive input impedance. It corresponds to a series-tuned circuit.

Half-Wave Open Section





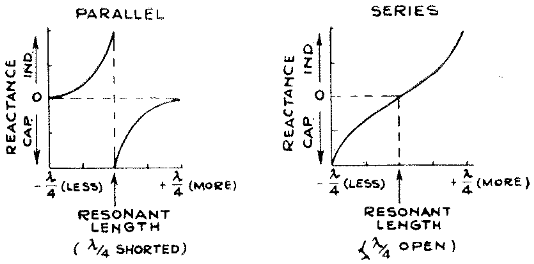
The half-wave open section at the end of the line has high input impedance. This section corresponds to a parallel-tuned circuit.

Tuning Characteristics of Resonant Sections

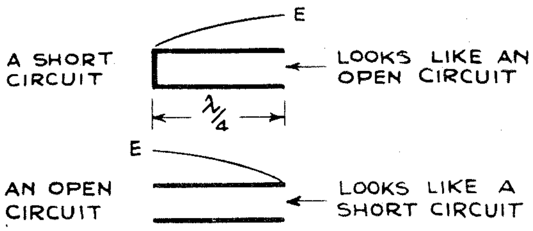
We have seen the four principal resonant sections:

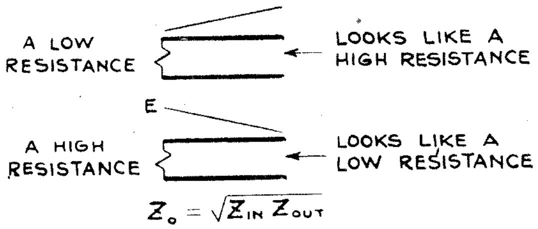
1. Quarter-wave, shorted } Equivalent to a parallel-tuned circuit
2. Half-wave, open }
3. Quarter-wave, open } Equivalent to a series-tuned circuit
4. Half-wave, shorted }

If a section of line is tuned above or below the resonant input frequency (by making the line shorter or longer) the effect is the same as in a conventional tuned circuit. The section will no longer look resistive. Either capacitive or inductive reactance will predominate. This is shown further in the tables on page 7 and in the graphs at right.



Quarter-Wave Line "Inverts" the Load



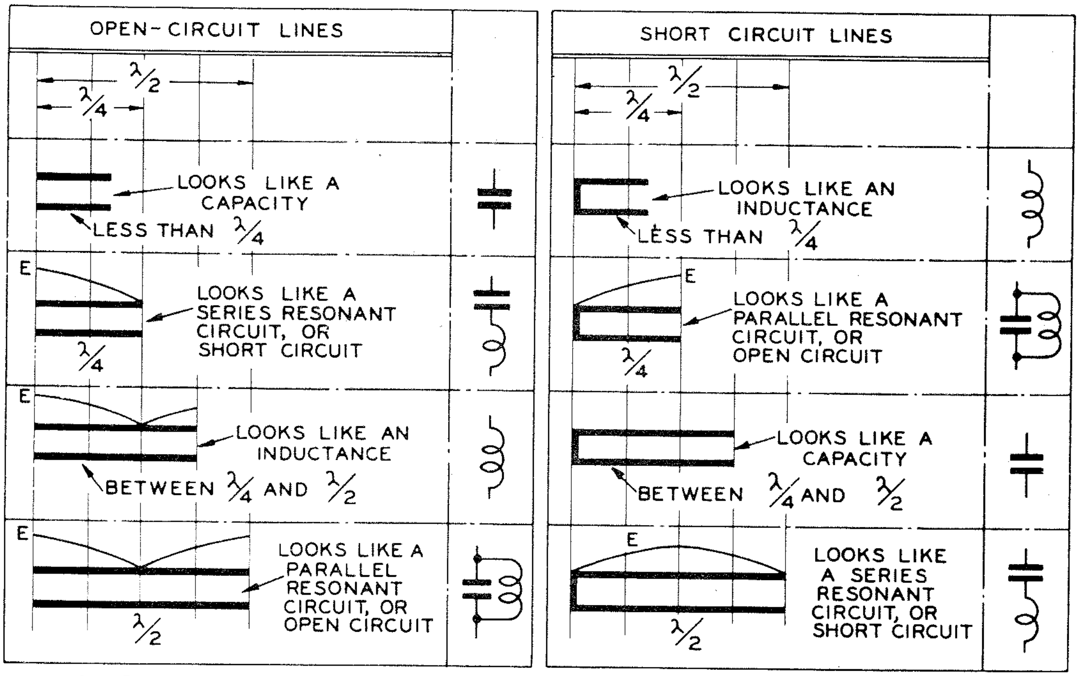


A quarter-wave line "inverts" the load as seen by source.

The input impedance in the above cases can be determined as follows:

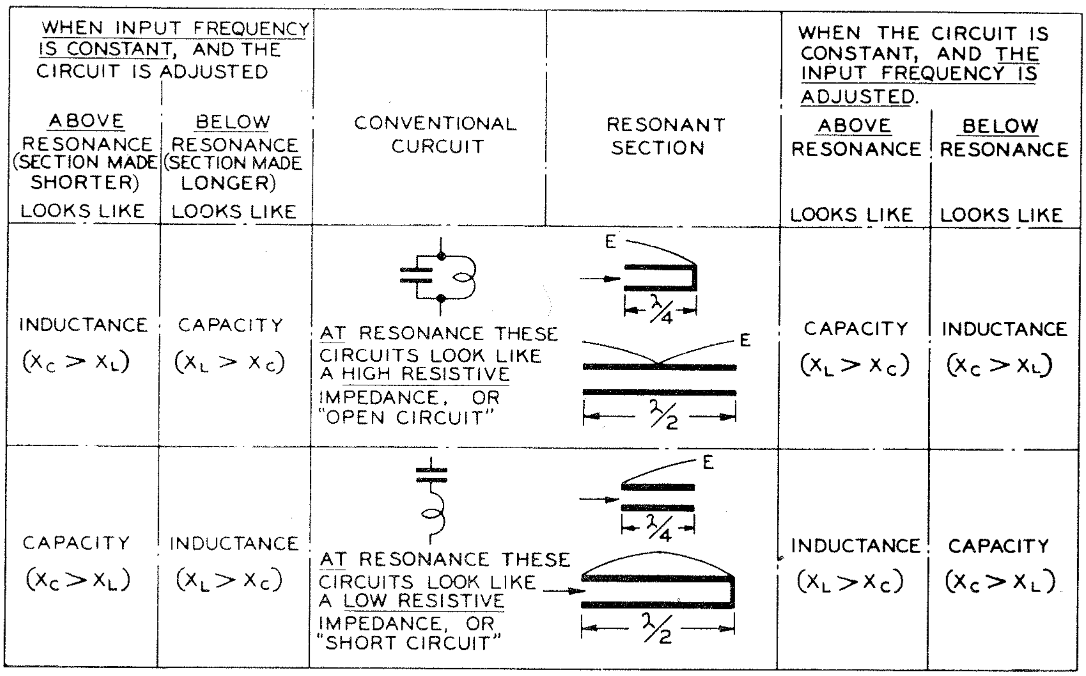
$$\text{Input impedance} = \frac{(\text{Line impedance})^2}{\text{Load impedance}}$$

Characteristics of Line Sections



CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED.

Tuning Characteristics of Resonant Sections and Conventional Circuits



WHEN INPUT FREQUENCY IS CONSTANT, AND THE CIRCUIT IS ADJUSTED		CONVENTIONAL CURCUIT	RESONANT SECTION	WHEN THE CIRCUIT IS CONSTANT, AND THE INPUT FREQUENCY IS ADJUSTED.	
ABOVE RESONANCE (SECTION MADE SHORTER) LOOKS LIKE	BELOW RESONANCE (SECTION MADE LONGER) LOOKS LIKE			ABOVE RESONANCE LOOKS LIKE	BELOW RESONANCE LOOKS LIKE
INDUCTANCE $(X_C > X_L)$	CAPACITY $(X_L > X_C)$	AT RESONANCE THESE CIRCUITS LOOK LIKE A HIGH RESISTIVE IMPEDANCE, OR "OPEN CIRCUIT"		CAPACITY $(X_L > X_C)$	INDUCTANCE $(X_C > X_L)$
CAPACITY $(X_C > X_L)$	INDUCTANCE $(X_L > X_C)$	AT RESONANCE THESE CIRCUITS LOOK LIKE A LOW RESISTIVE IMPEDANCE, OR "SHORT CIRCUIT"		INDUCTANCE $(X_L > X_C)$	CAPACITY $(X_C > X_L)$

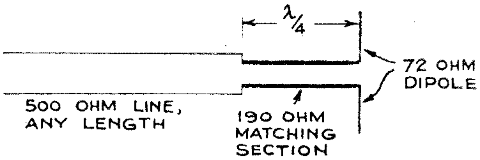
TUNED LINE CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED

QUARTER-WAVE MATCHING SECTION

The "inverting" property of a quarter-wave section can be put to practical use when it is necessary to match a line of one impedance to a load of a different impedance. To do this, the section must have an impedance calculated as follows:

$$Z_{\text{MATCHING SECTION}} = \sqrt{Z_{\text{LINE}} \times Z_{\text{LOAD}}}$$

For example: A 500-ohm line can be matched to a 72-ohm dipole through a quarter-wave section of 190 ohms.



The *line* looks into a load of

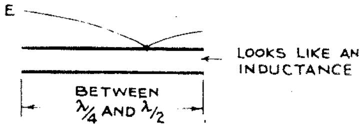
$$\frac{(\text{Z of matching section})^2}{\text{Z of load}} \text{ or 500 ohms.}$$

The *antenna* looks into a source of

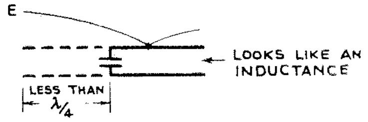
$$\frac{(\text{Z of matching section})^2}{\text{Z of line}} \text{ or 72 ohms.}$$

"INVERSION" OF CAPACITY AND INDUCTANCE

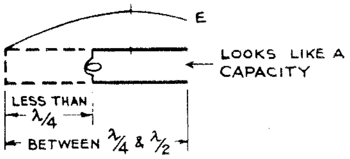
Inversion of capacity and inductance can be explained as follows:



An open section of line between one-quarter and one-half wave long looks like an inductance to the source.

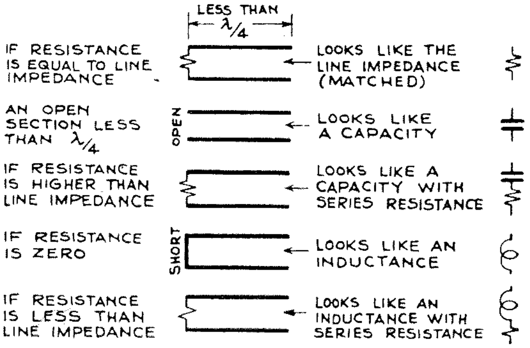


If a part (less than one-quarter wave) is replaced by a capacity (an open section less than one-quarter wave looks like a capacity), the section still looks like an inductance to the source.

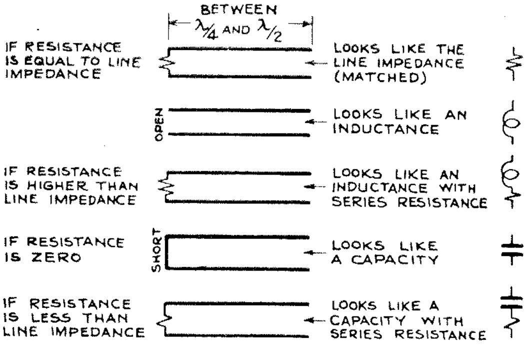


A shorted section between one-quarter and one-half wave looks like a capacity. If part (less than one-quarter wave) of the shorted end is replaced by an inductance, the section will still look like a capacity to the source.

SECTIONS LESS THAN QUARTER-WAVE

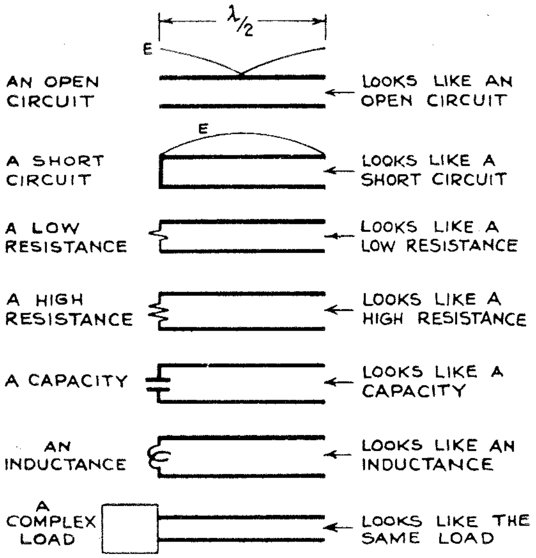


SECTIONS BETWEEN ONE-QUARTER AND ONE-HALF WAVE



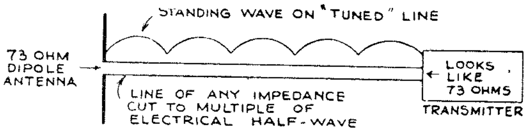
HALF-WAVE LINE "REPEATS" THE LOAD

A half-wave line acts as a "double inverter" and hence will "repeat" whatever appears on the far end:



A line that is any multiple of one-half wave has the same characteristics.

The action of a half-wave section, or a line cut to a multiple of a half-wave, is used extensively in practical applications. For example, if a dipole antenna with an impedance of 73 ohms is to be coupled to the output of a transmitter, through an open-wire line (spaced pair) with a characteristic impedance of several hundred ohms, the line can be cut to a multiple of an electrical half wave.



The transmitter will look into a load of 73 ohms, regardless of the impedance of the line.

"Tuning Out" the Reactance of a Load

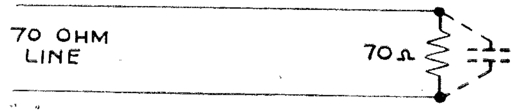
One of the important applications of tuned-line sections is to "tune out" the effects of residual capacitive or inductive reactance in a load, so the load will look like a pure resistance.

For example, assume that a 70-ohm resistor is used to terminate a 70-ohm line. If this line, with its resistor termination is connected to a slotted line and checked for match over a wide range of frequencies, it will be found that at some frequency the termination looks resistive. This is the resonant frequency of the resistor. Above and below this frequency the resistor has capacitive or inductive reactance and no longer matches the line. In other words, the resistor is not a "pure resistance" at most frequencies.

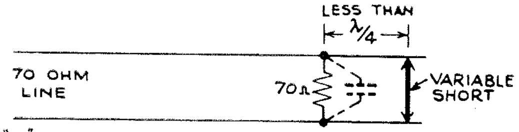
At the required operating frequency, the resistor may look like a resistance with shunt capacity as shown in "A." If an inductive section of line is connected to the termination as shown in "B," it may be adjusted to resonate with the capacity, to look like a parallel-tuned circuit.

The line, therefore, instead of seeing a resistance with shunt capacity, now sees a resistance with a shunt parallel-tuned circuit, as shown in "C."

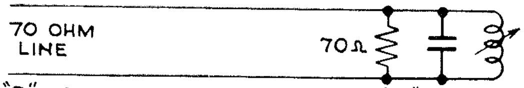
The parallel-tuned circuit looks like a high resistive impedance as shown in "D," and, therefore, has little effect on the total resistance. If the combined resistance is correct, the line will be "matched."



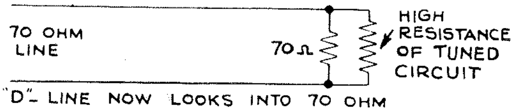
"A"- RESISTOR WITH RESIDUAL CAPACITIVE REACTANCE.



"B"- INDUCTIVE SECTION ADDED AND RESONATED WITH CAPACITY TO THE INPUT FREQUENCY.



"C"- EQUIVALENT CIRCUIT OF "B"

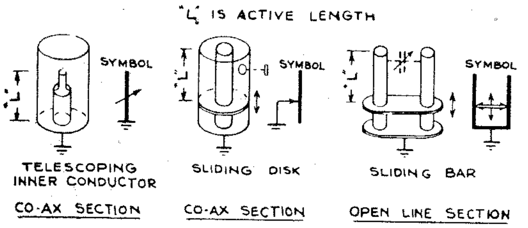


"D"- LINE NOW LOOKS INTO 70 OHM SHUNTED BY HIGH RESISTANCE.

Tuned-Line Sections—Types of Construction

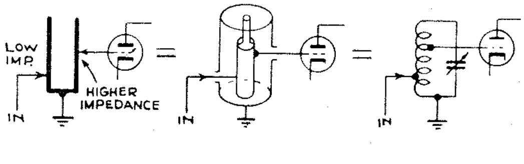
The characteristics of tuned lines are used to good advantage in UHF equipments. Quarter-wave and half-wave sections are used as parallel- and series-tuned circuits, as step-up and step-down transformers, as impedance and phase inverters, and even as insulators. Such sections of line take the place of conventional tuned circuits which become too small and inefficient at ultra-high frequencies. The tuned-line sections are made in both co-axial form, and in open-line type, from metal tubes and rods; generally silver-plated to reduce r-f losses. Some representative types of construction are sketched at left. Methods of adjustment to resonate the sections are indicated.

Some sections are cut short, and resonated with an adjustable capacitor (indicated by dotted lines) instead of being resonated with a sliding disc or bar.



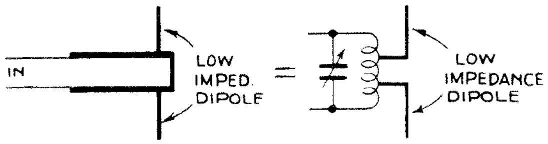
Quarter-Wave Sections as Transformers

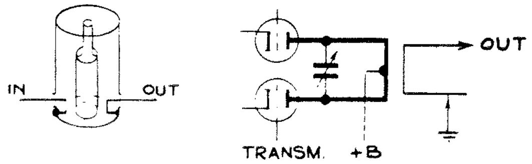
A quarter-wave section (co-ax or "open-line" type) shorted at the end, may be used as a step-up transformer, similar to a parallel-tuned auto-transformer. When a resonant section is "loaded" with reactance, for example, connected to the grid of a tube, the section must be readjusted to obtain electrical resonance).



A quarter-wave shorted section may be used as a step-down transformer.

Inductive coupling to tuned sections is sometimes done as shown in the following two different examples:





Co-Ax Arms on Tuned Sections

In push-pull UHF circuits, lengths of co-ax are frequently used to form the arms of one-quarter or one-half wave shorted sections. This is done for several reasons, including:

(1) The inner conductors may be used to carry d-c and a-c supply voltages, or low-frequency signals, to the tube elements.

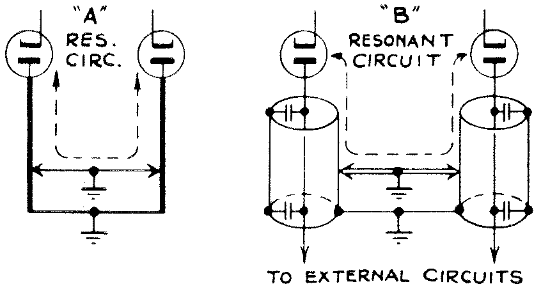
(2) The outer conductors can be grounded.

(3) A sliding bar on the outer conductors can be used to adjust the electrical lengths of the section mentioned in (1) above.

In such applications, capacitors are used at the end of the co-ax to place the inner and outer conductors at the same r-f voltage.

An example of co-ax arms forming tuned sections is shown in the illustration.

"A" is the quarter-wave shorted section required for input tuning. But it is necessary to take the diode currents to external circuits, and (for constructional reasons) the arms of the section must be grounded. "B" shows how "A" is rearranged to do this. *The co-ax lines do not act as tuned sections by themselves, but form the arms of the quarter-wave shorted section shown in "A."*



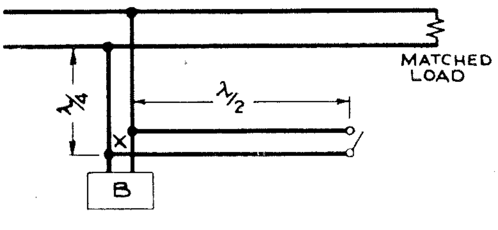
Miscellaneous Application of Tuned Sections

Tuned sections are put to many uses in addition to that of replacing conventional tuned circuits.

Some miscellaneous uses are described to indicate several of the many applications.

(1) Use of Sections in Switching Circuits

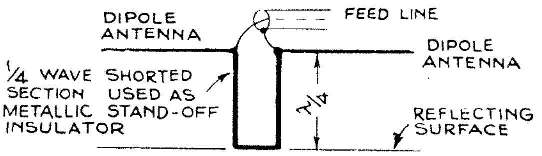
In some equipments it is necessary at times to prevent signals from "A" getting to "B." This is accomplished by shorting the end of the one-half wave section. By virtue of the action of one-half wave sections, this short appears as a short across "B" input line at "X." The one-quarter-wave line, being thus shorted at "X," looks like a high impedance to the signal from "A."



When it is desired to leave signals through to "B," the switch is opened at the end of the one-half-wave line. At "X," the one-half-wave resonant line now looks like an open circuit. With no short at "X," the one-quarter-wave section is simply an ordinary part of the line, and signals can pass to "B."

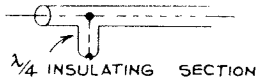
(2) Quarter-Wave Shorted Section Used as an Insulator

(a) A quarter-wave shorted section looks like a high resistive impedance. This fact is utilized in some antenna systems by employing one-quarter-wave shorted sections as metallic stand-off insulators to support and space a dipole antenna one-quarter wave from a reflecting surface, as shown below:

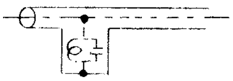


The quarter-wave section looks like a high impedance to the antenna feed line. (The feed line can be run inside one arm of the quarter-wave section.)

(b) Another example of a quarter-wave "insulator" is shown below, together with an analogy of a conventional parallel-tuned circuit.



λ/4 INSULATING SECTION ACTS LIKE A HIGH Z SHUNT ACROSS THE LOW IMPEDANCE LINE.

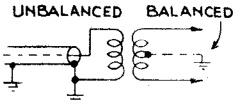


EQUIVALENT CIRCUIT

(3) Line Balance Converter (Bazooka)

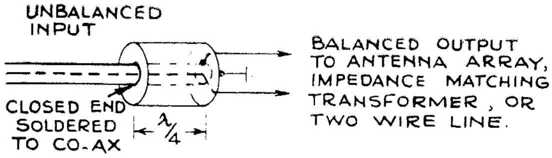
In some applications, it is necessary to change from a co-axial transmission line (unbalanced, since outer conductor is grounded) to a balanced transmission line or load (both conductors approximately the same impedance above ground).

A "bazooka" is used for this purpose. The action is shown in the sketches, and may be explained as follows:



PRINCIPLE OF CONVERTER

BAZOOKA FORMS SHORTED QUARTER WAVE SECTION PLACING "A" AT HIGH Z TO GROUND.



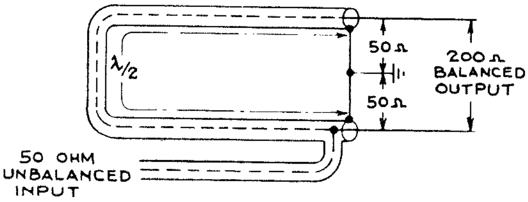
1. The quarter-wave shorted section effectively removes the r-f ground from the end of the outer conductor of the co-axial line.

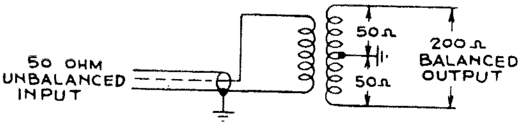
2. Both the inner and outer conductors of the co-axial line are now at a relatively high impedance above ground, and effectively balanced to ground.

3. The bazooka may be used in reverse manner to feed from a balanced circuit to an unbalanced circuit.

(4) Half-Wave Phase and Impedance Converter

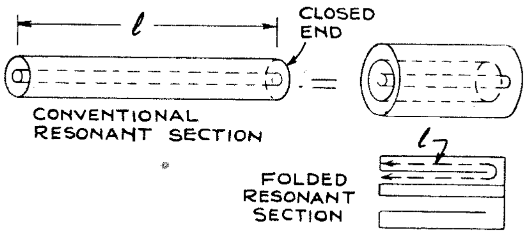
The following arrangement is used in some applications. The action may be reversed, to feed from high-impedance balanced input to low-impedance unbalanced output.





(5) "Folded" Resonant Section

At relatively low frequencies, the physical length of a resonant section may be too long for convenient use, and a "folded" section may be used. The effective length of the folded section is indicated by the dotted line. More than one "fold" may be used for further reduction of the physical length.



Characteristic Line Impedance

The impedance of a line (also termed "surge" or "characteristic" impedance) depends on the dimensions and spacing of the conductors, and the dielectric constant of the insulating material.

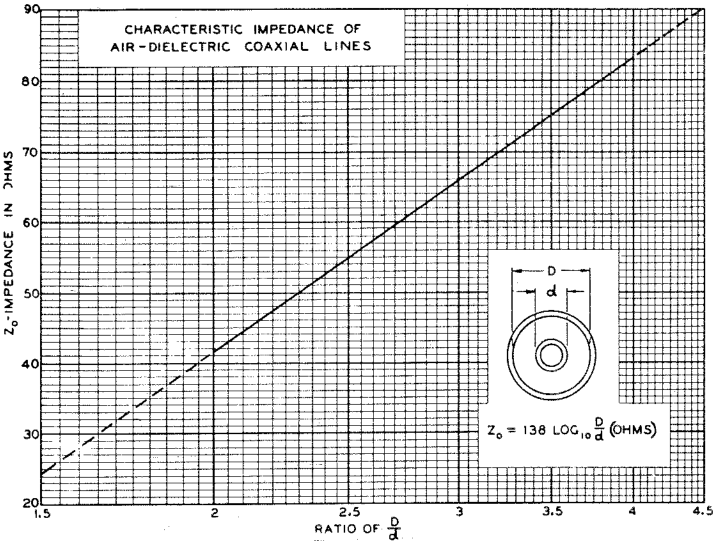
Neglecting Losses—

$$Z_{\text{OHMS}} = \sqrt{\frac{L_{\text{HENRYS}}}{C_{\text{FARADS}}}}$$

In solid dielectric lines (as compared with air dielectric) the impedance is reduced by the factor $\sqrt{1/k}$, where "K" equals the dielectric constant of the insulating material (and has the effect of increasing "C" per unit length in the general formula).

Aircraft Antenna Cable, using solid dielectric is frequently 70 or 50 ohms. Seventy (70)-ohm cable is convenient for use with quarter-wave dipoles and other antennas that have a radiation resistance of 70 ohms. Fifty (50)-ohm cable is used extensively in conjunction with suitable matching on low-impedance array-type antennas.

The two charts on the following page show how the impedance of co-axial and parallel-wire lines varies with the dimensions and spacing of the conductors.

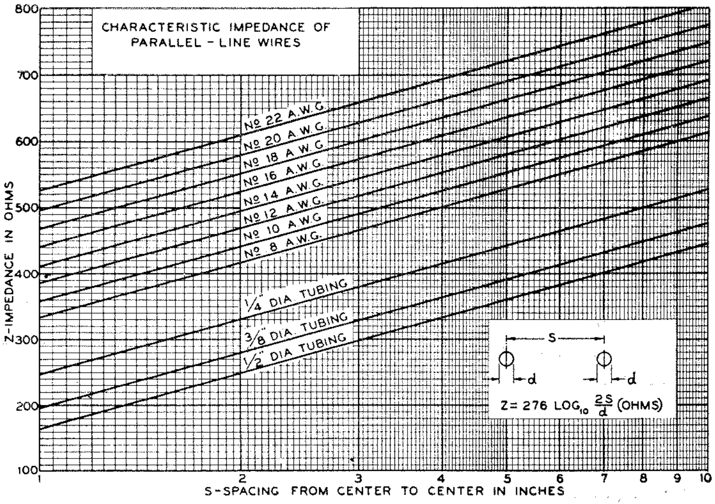


Impedance chart for air-dielectric co-axial lines.

Example: For a 50-ohm line, "D" is 2.3 times larger than "d". For a 70-ohm line, "D" is 3.2 times larger than "d".

Impedance chart for parallel-wire lines.

Example: To obtain a line impedance of 500 ohms, using No. 14 wire, the spacing (S) must be approximately 2 inches.



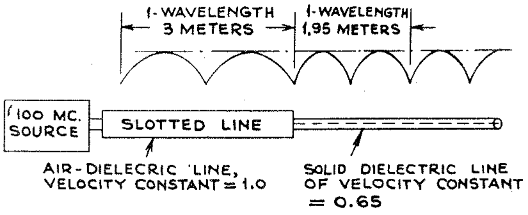
Velocity Constant of Lines

Radio waves travel at a speed of 300 million meters per second in air. The speed is reduced in lines that have spacing insulators or solid dielectric. In a slotted measuring line, with no spacing insulators, the speed is essentially the same as in air.

The speed in solid-dielectric lines of high quality, such as UHF aircraft antenna cable, is about 60-70 per cent of speed in air. Reels of such cable are tagged with the measured velocity constant of a sample cut from the reel.

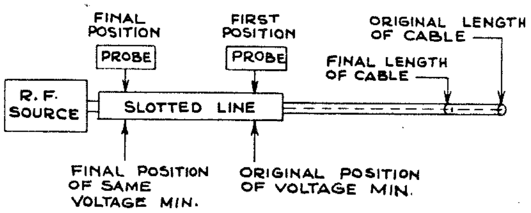
The fact that the velocity is less in the cable than in air means that a wavelength in the cable will be shorter than in air; since the wavelength equals velocity divided by frequency. For example, a wavelength in air at 100 mc. is 3 meters, but in a solid-dielectric cable with a velocity constant of 65 per cent, a wavelength at 100 mc. is only 3 x .65, or 1.95 meters.

The lower velocity in solid-dielectric lines is illustrated below. A 100 mc. signal is fed through a slotted line (air dielectric) and into a solid dielectric line that has a velocity constant of 0.65 (65 per cent of that in air)



A slotted line can be used to check the velocity constant of a co-ax cable.

The equipment is set up as shown:



The end of the cable is left open. Standing waves are therefore set up along the cable and slotted line. The probe is set accurately at the first point of minimum voltage at the cable-side of slotted line. A piece of cable is cut off at the end of the line. This shifts the voltage minimum point to the left, and the probe is reset accurately to the new position of the voltage minimum.

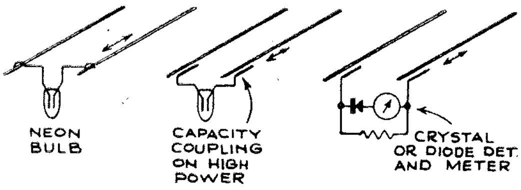
The ratio of the length of the piece of cable cut off to the distance that the probe is moved is the velocity constant of the cable. (In practice, small increments of cable are cut off until nearly the entire length of the slotted line has been traversed by the probe. Each step is plotted, and the slope of the line indicates the velocity constant).

As an example, if the length of cable cut-off is 1 foot, and the probe has been moved 2 feet, the velocity constant is .5, or 50 per cent.

Standing-Wave Indicators for Open-Wire Lines

A small neon bulb may be used to show existence of standing waves on open-wire lines. If the line is correctly terminated (no standing waves) the bulb will have constant brilliance as it is moved along the line.

Better indication can be obtained by using a crystal or diode rectifier and a meter, capacitively coupled to the line as shown.



Slotted Measuring Line

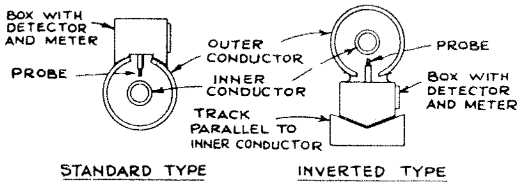
A "slotted line" is a section of co-axial line with a slot along the outer tube to permit loosely coupling an r-f voltmeter probe to the inner conductor.

The slotted line is used to determine:

(1) Ratio of voltages at maximum and minimum voltage points of standing waves along the line.

(2) Position of these points with respect to a "Reference" point.

From this data it is possible to determine the resistive and reactive nature of a load at a specified frequency.



Some Principal Applications Are

(1) To adjust antennas for correct match to a line at a specified frequency.

(2) To determine the resistive and reactive components of a load at a specified frequency, or over a range of frequencies; i. e., impedance and phase angle.

(3) To adjust input systems of receivers, dummy loads, etc., for correct match to a line.

Considerable care is taken in the design and construction of slotted lines to secure:

(1) Uniform impedance throughout the length.

(2) Uniform spacing of the probe in its travel along the inner conductor

(3) Good grounding of the probe box to the outer conductor.

(4) Rigidity of the co-ax assembly, and minimum slop in travel of the voltmeter probe.

The impedance of the slotted line should equal the impedance of the associated co-ax line. Some slotted lines are equipped with two or more mechanically interchangeable inner conductors of different diameters so the impedance can be changed to match the impedance of commonly used co-ax lines (70 and 50 ohms, and some 63 and 40 ohms).

The r-f voltmeter used in conjunction with the slotted line is usually a diode or crystal detector with a current meter and tuned input, capacitively coupled to the inner conductor.

Diode and crystal detectors are insensitive and require a high-output UHF oscillator to excite the line. It is sometimes possible to use the UHF receiver (from an equipment) as an indicator, fitting the input of the receiver with a suitable probe. In this case, owing to the high sensitivity of the receiver, a low-powered UHF generator may be used for the source.

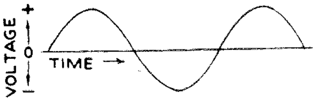
When adjusting antennas, the object in most cases is to "match" the antenna to the line. This is usually done by changing the antenna length and/or the antenna matching stub for *minimum* standing-wave ratio.

For some antennas, and in other applications of the slotted line, it is necessary to determine the resistive and reactive components and phase angle.

This requires checking both the standing-wave ratio and the distance from a minimum (or maximum) voltage point with respect to a "reference" point. This subject is covered in the appendix.

Additional Data on Standing Waves

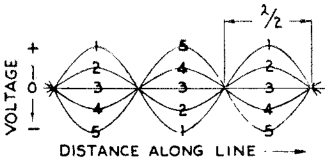
An a-c wave may be drawn as a change in *voltage* during a period of *time*, as shown below.



AC WAVE

A standing wave is not as easy to show, because it involves changes in *voltage* with *time*, and with *distance* along the line.

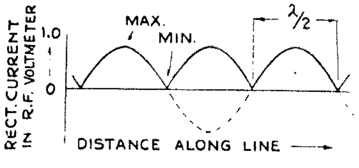
The voltages between node points of a standing wave changes from positive to negative values and back during the time equivalent to one cycle of the r-f source. This r-f change in voltage is roughly indicated by curves 1 to 5 and back in the following sketch.



STANDING WAVE

At some instant, the voltage along the line may be shown by one of these curves. It will be noted that the term "standing" wave can be misinterpreted. In a standing wave the *position* of max. and min. points does stand still, but the voltage changes at the r-f rate.

When an r-f voltmeter is moved along the line, it indicates the relative amplitude of the r-f voltage variation at each point along the line. The rectified r-f current in the meter circuit may be zero at nodes, and increases to a max. when the r-f voltmeter is moved to each voltage max. point. Thus the *measured* standing wave appears as shown below. (This is a sine wave with the negative half-cycles "flopped up.")

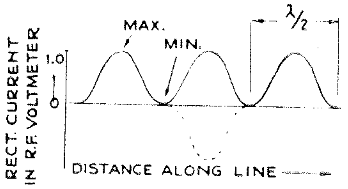


By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the curve is a sine wave.

The standing wave that exists on the line is a sine wave, providing the r-f source is sine wave; that is, a fundamental frequency with no harmonics. For slotted-line measurements, the generator must furnish sine wave output. If harmonics are present, some of the min. points, with the line open or shorted will not be zero.

If the standing wave on the line is sine wave, the *measured* standing wave will be sine wave, providing the r-f voltmeter is *linear.*

If the rectifier in the r-f voltmeter is not linear, the measured standing wave will not be sine wave, but will appear as shown.



By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the standing wave, as measured with a non-linear detector, is far from being a sine wave.

It will be noted that with a non-linear detector, the voltage min. points are not as "sharp" as indicated in the preceding illustration, which shows a standing wave measured with a linear detector.

The graph on page * shows how a non-linear detector introduces distortion in measuring a sine wave standing wave.

This non-linearity causes error in measuring standing wave ratios. In some applications of the slotted line, as for example when adjusting an antenna to "match" the line, this error may be ignored.

In other applications where it is necessary to determine the standing wave ratio accurately, correction can be determined in this way:

1. Plot the standing wave as measured with *the particular detector* at the *desired frequency*, with the line open or shorted, and with the generator output adjusted for exactly full-scale deflection at the max. voltage points.
2. Construct a sine wave (half-cycle) on top of the measured standing wave, with zero and max. points coinciding as shown in the graph on page * The sine wave indicates the current that would flow if the detector were linear.

Assume that a particular load produces a standing wave with a measured ratio of

$$\frac{\text{VOLTAGE MIN.}}{\text{VOLTAGE MAX.}} = \frac{0.21}{0.6} = 0.35$$

Reference to the curve shows that the value of 0.21 on the *measured* curve corresponds to 0.39 on the sine wave curve.

Also the value of 0.6 on the measured curve corresponds to 0.71 on the sine wave curve. The corrected standing wave ratio is therefore

$$\frac{0.39}{0.71} = 0.55 \text{ (instead of 0.35).}$$

---

* The graph will appear in part 2 (Radiotronics 130), page 33.

Use of the 6BA6 and 6BE6 Miniature Tubes in FM Receivers

R.C.A. Application Note AN-121 reprinted by courtesy of Radio Corporation of America.

The expanding requirements of modern receiver design have resulted in the development of several new tubes which may be used to advantage in both FM and standard broadcast bands. Two of these, the 6BA6 and the 6BE6, are new miniature tubes particularly suitable for the rf and converter positions of dual-purpose FM/AM receivers.

Description of the 6BA6

The 6BA6 is a high-frequency pentode in a miniature glass envelope. A sectional view of this tube is given in Fig. 1. Some of the distinguishing features of the tube are noted here. A double-helical heater coil is used to minimize difficulties with hum. A reduction in microphonics is obtained by the inverted pinch-weld which is used in making the cathode assembly. This method of construction is accomplished by drawing an embossing on the cathode against the under side of the mica and pinching the portion of the sleeve above the mica. Because the cathode is free to slide in the bottom mica, it cannot become bowed due to expansion. In order to take maximum advantage of the coated area of the cathode, the control grid is formed to the shape of the cathode. This formed grid permits greater grid-to-cathode spacing for a given transconductance and, consequently, the possibility of grid-to-cathode shorts is reduced. In addition, the combination of a round cathode and a formed grid results in a rugged construction which also helps to reduce microphonics. The lateral wires of the control grid are silver plated in order to minimize variations in sensitivity at low signal levels. The use of copper-alloy side rods for control and screen grids provides maximum heat conduction for these electrodes. Because the plate area is small, the grid-to-plate capacitance, due in part to the internal shielding, is only 0.003 $\mu\mu$f. If an external shield is used, this value is reduced by approximately ten per cent. The total input and output capacitance is only 10.5 $\mu\mu$f. Input loading due to lead inductance is reduced because of the direct-through, short leads afforded by miniature tube construction. Under 250-volt operating conditions, the input resistance of the 6BA6 at 100 megacycles is approximately 1600 ohms and the transconductance is 4400 micromhos.

Description of the 6BE6

The 6BE6 is a single-ended, glass, miniature converter. It is equivalent in most characteristics to the 6SA7 and is similar in electrode arrangement (Fig. 2). In construction, it is similar to the 6BA6 in that it has a formed oscillator (No. 1) grid, an inverted and pinched cathode, copper-alloy side rods, a double-helical heater coil, and short stem leads. The formed grid utilizes the emitting surface of the cathode very efficiently and, therefore, provides a very high oscillator transconductance of 7250 micromhos. Under 250-volt operating conditions, the conversion transconductance is 475 micromhos.

Performance in the Frequency-Modulation Band

At high frequencies, tubes and their associated circuits are essentially inseparable. In order, therefore, to provide reliable and useful measurements, the circuit used must be a representative one. The FM test receiver of Fig. 3 was employed because the mechanical arrangement and choice of component parts are based on contemporary good design practices and because it is representative of practical possibilities.

In this circuit, the converter is followed by an intermediate-frequency amplifier having two 6BA6 stages. The i-f system, which has a bandwidth of approximately 200 kilocycles centred at 10.7 megacycles, is terminated by a square-law, vacuum-tube voltmeter. The voltage gain from the first i-f grid to the voltmeter is 1750. The overall i-f gain, measured from the converter grid, is 18,000. The first i-f transformer is over-coupled in order to obtain a substantially uniform gain throughout the 200-kilocycle band. The second and third transformer are approximately critically coupled.

It is desirable, of course, to obtain performance data both with and without the r-f stage. In either case, the signal is applied to the signal circuit through a 300-ohm resistor. The effects of induced oscillator voltage in the signal circuit, interaction between oscillator and signal circuits, and input loading can be observed with and without the r-f stage. Likewise, the improvement in signal-to-noise ratio, selectivity, and image rejection due to the use of an r-f stage can be ascertained. When the signal is applied (through 300 ohms) to the signal-grid (grid No. 3) circuit of the converter, the measured gain from the terminals of the signal generator to the first i-f grid is 5.5. The equivalent noise is 7 microvolts. For optimum performance, the signal grid is placed $1\frac{1}{2}$ turns from the ground end of a coil of $1\frac{3}{4}$ turns. The antenna connection is made at $1\frac{1}{4}$ turns on the same coil. The image rejection is 26 db.

When the 6BA6 r-f stage is added and the circuit adjustments necessary for stable operation are made, the measured gain from the signal generator to the first i-f grid is 70. The equivalent noise is approximately 5.8 microvolts, or 17 db above the thermal noise of the 300-ohm resistor. Noise-free reception may properly be assumed when the signal is at least three or four times as great as the equivalent noise. The receiver will have satisfactory performance, consequently, when the input signal is 25 microvolts. Addition of the r-f stage increases the image rejection from 26 db to 55 db.

It is natural for the oscillator frequency to undergo a fractional percentage drift during the warm-up

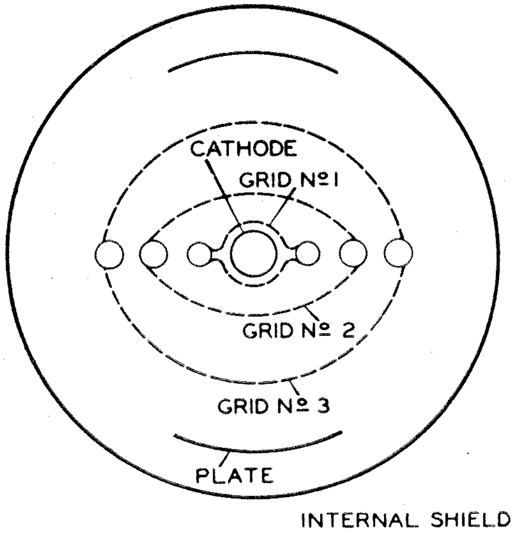


Fig. 1 - RCA-6BA6 Electrode Structure and Arrangement.

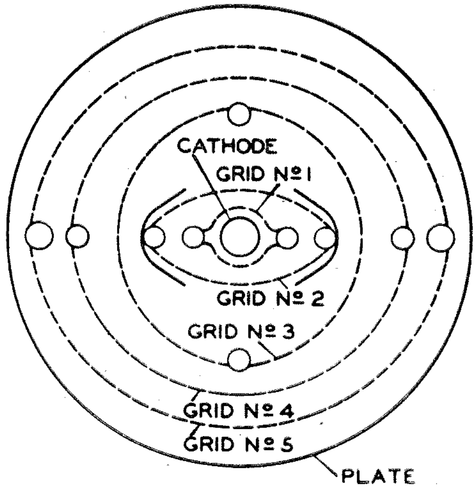
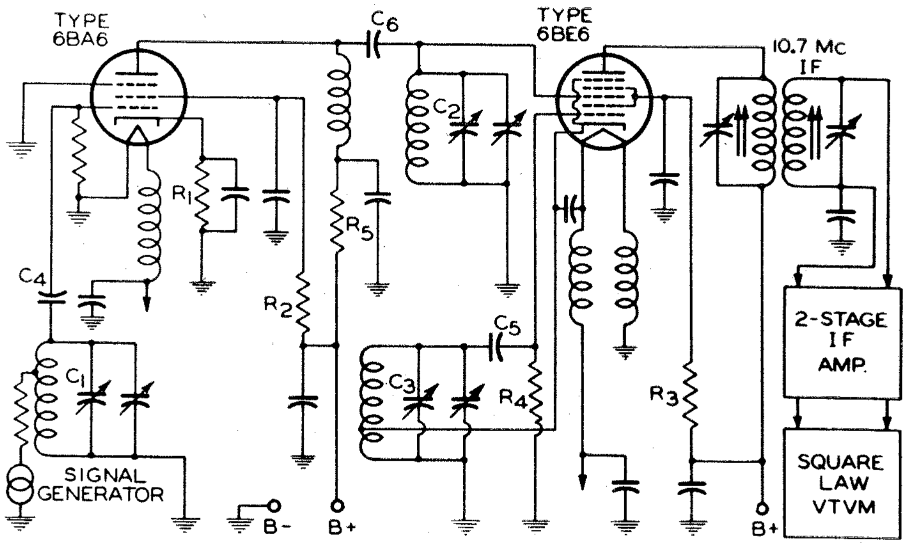


Fig. 2 - RCA-6BE6 Electrode Structure and Arrangement.



C_1 C_2 C_3 = Ganged Tuning Capacitor 7.5 - 18 μμf
C_4 C_5 = 22 μμf
C_6 = 100 μμf
C_7 = 33 μμf
C_8 to C_{15} = 1000 μμf
C_{16} C_{17} C_{18} = Trimmer Capacitor 1.5 - 7.0 μμf
R_1 = 68 ohms
R_2 = 40000 ohms
R_3 = 22000 ohms
R_4 = 20000 ohms
R_5 = 150 ohms
L_1 L_2 L_3 = 0.1 μh approx. 1-3/4 turns of No. 14 tinned copper wire; coil diameter, 3/4"; spacing between turns, 1/2 coil diam.
L_4 L_5 L_6 L_7 = 26 turns of No. 16 enameled wire close wound on a 3/8" mandrel

Fig. 3 - Typical Self-Excited Converter Circuit for 6BE6 with 6BA6 RF Stage. For Operation at 88 to 108 Megacycles.

period. This drift is due to a slight change in effective capacitance (Δc) of the oscillator LC circuit. As no compensation for this change is provided in the circuit, it is of interest to determine the amount of change (Δc) in oscillator-circuit capacitance as a function of time for the 6BE6 alone. This test was made by placing the cold 6BE6 in operation in the receiver which had already been warmed up. Because a ceramic type of socket was employed, the effect of its temperature change on frequency drift was negligible. As the values of Fig. 4 (Δc versus time) were obtained in this manner, they apply almost wholly to the tube itself.

Method of Circuit Adjustment

The adjustment of pentagrid converter circuits operating at high frequencies is complicated by the fact that there is an appreciable amount of coupling and interaction between the oscillator and signal-grid circuits. In addition, negative admittance across the signal-grid circuit causes appreciable regeneration. Parasitic oscillations, too, may occur when the signal-grid circuit is improperly adjusted. Use of the following procedure, however, will result in correct circuit adjustment with a minimum of difficulty.

1. Connect the signal grid of the converter to ground, adjust the cathode tap of the oscillator for maximum oscillator-grid current, and then vary the oscillator inductance and the size of the fixed capacitance to furnish the desired amounts of frequency variation with the tuning capacitor used.
2. Apply the i-f signal directly to the signal grid of the converter and adjust the first i-f transformer for desired response.
3. Apply the r-f signal directly to the signal grid of the converter and adjust the cathode tap for maximum gain. It should be necessary to move the cathode tap only slightly lower than the previous position for maximum oscillator-grid current. The conversion gain under this condition with an i-f transformer impedance of 12,000 ohms should be approximately six.
4. Place the signal-grid coil back in the circuit by connecting the grid to a tap approximately one turn from the top of the coil. Connect the signal generator through a 300-ohm resistor to a tap on the grid coil of the converter approximately one turn from the bottom. Adjust the values of inductance and fixed capacitance so that tracking is obtained throughout the band. The tuning of the signal-grid circuit of the converter will affect the loading of the oscillator thereby causing a change in oscillator-grid current and converter-plate current. This condition, while complicating the initial circuit adjustment, does not impair the receiver performance because the signal-grid circuit must be considerably detuned before the oscillator is appreciably affected. When the input circuit is properly tuned, the cathode tap may be re-adjusted to provide an oscillator-grid current of approximately 300 microamperes. This adjustment results in a converter-plate current of approximately 3 milliamperes and a screen current of approximately 7 milliamperes. Fig. 5 shows oscillator-grid current, converter-plate current, conversion gain, and equivalent noise as a function of the position of the cathode tap.
5. After the converter has been properly adjusted, apply the signal to the grid of the r-f amplifier and connect the amplifier plate to the top of the signal-grid coil of the converter through the coupling capacitor. A slight additional adjustment of the coil and the trimmer capacitor can now be made in order to obtain proper tracking.
6. Insert the antenna coil and change the values of inductance and fixed capacitance so as to obtain proper tracking. Connect the signal grid of the r-f amplifier to the top of the coil. The signal generator is connected through 300 ohms to the tap.

It must be recognized that the efficiency of the oscillator circuit will affect the oscillator-grid current. This current should not be permitted to drop below 160 microamperes at the nominal supply voltage if operation is to be maintained satisfactorily at low line voltage. Since the inductance of the lead from the cathode tap on the coil to the tube socket accounts for considerable degeneration of the signal, it should be as short as possible. In order to reduce the effects upon the oscillator frequency of the variations in the heater-to-cathode capacitance, it is advisable to operate the heater at r-f cathode potential in the manner indicated in the circuit diagram (Fig. 3). This method of operation considerably reduces microphonic effects, caused by mechanical vibration or acoustic feedback.

Because considerable oscillator voltage is developed at the signal grid when the tube operates at high frequencies, it is necessary to return the signal grid to ground directly and not through the avc system. If appreciable resistance is placed in the signal-grid circuit, the grid current, due to the rectification of oscillator voltage at the signal grid, will develop a voltage across the grid resistance. This voltage will bias the tube and, consequently, reduce the conversion transconductance. No avc voltage, therefore, should be applied to the converter when it is operated in the FM band.

A 3-ohm resistor in series with the signal grid of the converter and connected as closely as possible to the grid terminal may remove parasitic oscillations. The gain, however, may be somewhat reduced. In the circuit used in these investigations, this expedient was not necessary.

Application of the 6BE6 in the Standard Broadcast Band

When the 6BE6 is used in the standard broadcast band, its sensitivity, as a function of the voltage across the oscillator-coil section between ground and cathode (with self-excitation) is given in the curves of Fig. 6. For comparison, a curve for the 6SA7, the metal tube equivalent, is also given. The noise-equivalent resistance calculated for the 6BE6 is of the same order as the circuit impedance obtained in typical broadcast circuits (approximately 100,000

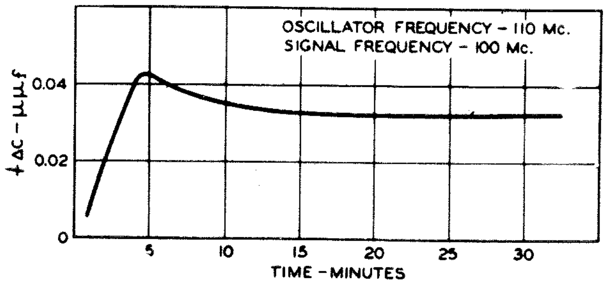
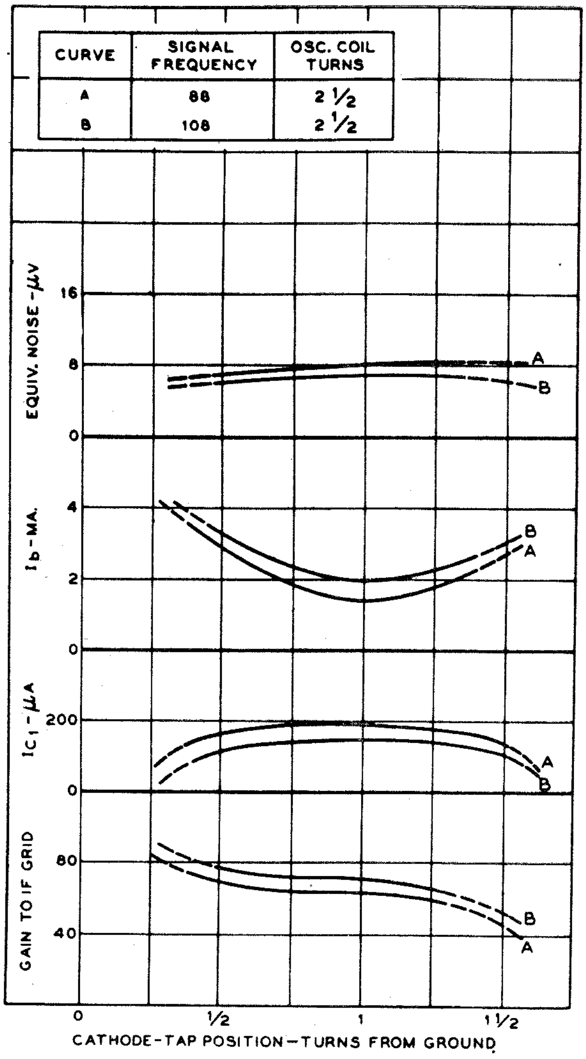
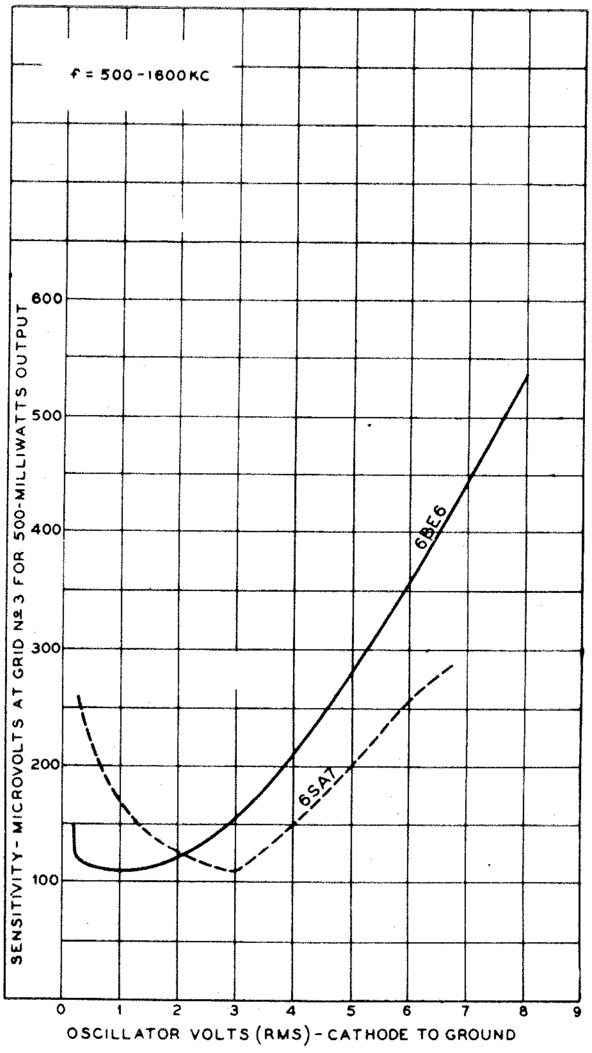


Fig.4 - 6BE6 Warm-up Capacitance Shift in FM Band.



92CM-6771

Fig.5 - Operation Characteristics of 6BE6 With Change of Cathode-Tap Position in Circuit of Fig.3.



92CM-6772

Fig.6 - Sensitivity of 6BE6 Compared With That of 6SA7.

ohms). Since the increase in circuit noise is only 2 to 3 db, the use of an r-f stage, from the standpoint of noise reduction, is unimportant. In the frequency range of 500 to 1600 kilocycles, the measured equivalent noise side-band input in a typical receiver with an antenna gain of 5 is 3.5 microvolts.

The maintenance of best signal-to-noise ratios with strong signals requires that the gain of the first tube be maintained as high as possible until the signal has become strong enough to override the noise. When the i-f tube is a 6BA6, it is desirable for best signal-to-noise ratios to apply full a.v.c. voltage to the i-f amplifier and approximately 25 per cent. less a.v.c. voltage to the converter.

Application of the 6BE6 in the Short-Wave Bands

The cathode voltage at the low-frequency end of each band should be adjusted to approximately 0.8 volts (RMS). It is likely, however, to rise at the higher frequencies and cause some loss in sensitivity. The use of a 5- or 10-ohm resistor in the oscillator-grid lead may be needed to prevent parasitic oscillations.

New R.C.A. Releases

Radiotron type 6AV6 is a multi-unit miniature valve containing two diodes and a high-mu triode. The diodes are for use in detector and a.v.c. circuits while the triode is for use as a resistance-coupled audio amplifier stage. The triode features a valve of transconductance almost 50 per cent. higher than that for previous similar types, having the same amplification factor of 100.

Radiotron type 7JP4 is a 7″ directly viewed kinescope intended primarily for use in low-cost television receivers, but it is suitable for oscillograph applications. It has a high-efficiency, white fluorescent screen, and utilizes electrostatic focus and electrostatic deflection to provide 4″ x 5½″ pictures.

Radiotron type 12AV6 is identical with the type 6AV6 except that the heater rating is 12.6 volts 0.15 ampere. The rating for the 6AV6 is 6.3 volts 0.13 ampere.

Radiotron type 12AX7 is a small high-mu twin-triode amplifier. Its characteristics are similar to those of the larger types 6SL7-GT and 12SL7-GT, except that it has an amplification factor of 100 instead of 70. It utilizes the small-button noval 9-pin base and a glass bulb slightly larger than that used on the regular miniatures.

Radiotron type 5618 is a new, low drain, filament type, miniature pentode designed primarily for transmitting use in mobile and emergency-communications equipment. It has a maximum plate dissipation of 5 watts, and can be operated with full input to 100 Mc/s.

The 5618 is particularly useful in the doubler and tripler stages of mobile FM transmitters (152 to 162 Mc/s) where compactness and low filament consumption are prime design requirements.

The filament is centre-tapped and permits operation at either 6 or 3 volts, requires less than 1.5 watts, provides a filament voltage operating range of ± 10 per cent., and is ready for operation in less than 1 second after power is turned on.

Radiotron type 5652 is a new twin type vacuum phototube. It is intended for use in those applications, such as facsimile service, now requiring mechanical means for modulating the light input.

The 5652 has very high sensitivity to light sources predominating in blue radiation, and no response to infra-red radiation. It is provided with a non-hygroscopic base to ensure high resistance to surface leakage under high-humidity conditions.

Radiotron type 5653 is a new vacuum phototube intended for light operated relay and other applications where there is always plenty of incident light and where a wider than usual range of luminous sensitivity may be tolerated.

The 5653 has an S-4 response and so is particularly sensitive to blue radiation, but has good response to light from an incandescent lamp.

Types Discontinued by R.C.A.

Type 3AP4 — Kinescope previously used in low priced television receiver.
Type 5BP4 — Kinescope as for 3AP4.
Type 5CP4 — Kinescope as for 3AP4.
Type 5HP4 — Kinescope as for 3AP4.
Type 7CP4 — Kinescope using electrostatic focus and magnetic deflection. It is recommended that type 7DP4 be used in new equipment.
Type 678 — Mercury vapour thyratron replaced by type 5563.
Type 1847 — 2″ iconoscope replaced by type 5527.

Error in Radiotronics 123.

"A Note on Matching by means of T and H Pads"
Page 3 Column 2 Line 6 Should read:
"The total power loss is to be 12 db per section" (Not 4 db as printed).

6AV6, 12AV6

TWIN-DIODE HIGH-MU TRIODES

MINIATURE TYPES TENTATIVE DATA

Radiotron types 6AV6 and 12AV6 are identical except for their heater rating. Each type combines two rf diodes for detector and avc applications with a high-mu triode for audio service as a resistance-coupled amplifier. Since the triode features a relatively high value of transconductance as well as a high mu, it is capable of providing not only exceptionally high voltage gain but also a large voltage to input of the power output stage.

GENERAL DATA

Electrical:

	6AV6	*12AV6*	
Heater, for Unipotential Cathode:			
Voltage (AC or DC)	6.3	12.6	Volts
Current	0.3	0.15	Ampere

Mechanical:

Mounting Position	Any
Maximum Overall Length	2⅛"
Maximum Seated Length	1⅞"
Length from Base Seat to Bulb Top (excluding tip)	1½" ± 3/32"
Maximum Diameter	¾"
Bulb	T-5-1/2
Base	Small-Button Miniature 7-Pin

TRIODE UNIT

Maximum Ratings,

Design-Centre Values:

PLATE VOLTAGE	300 max. Volts
PEAK HEATER—CATHODE VOLTAGE:	
Heater negative with respect to cathode	90 max. Volts
Heater positive with respect to cathode	90 max. Volts

Characteristics:

Plate Voltage	100	250	.. Volts
Grid Voltage	−1	−2	.. Volts
Amplification Factor	100	100	
Plate Resistance	80000	62500	.. Ohms
Transconductance	1250	1600	Micromhos
Plate Current	0.50	1.2	.. Ma

Typical Operation — Resistance-Coupled Amplifier:

See tabulation below.

DIODE UNITS — Two

Maximum Ratings,

Design-Centre Values:

PLATE CURRENT (For each diode) 1.0 max. Ma

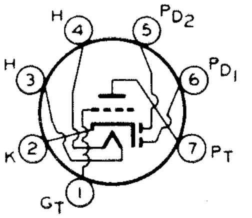
Diode Considerations:

The two diode plates are placed around a cathode, the sleeve of which is common to the triode unit. Each diode plate has its own base pin.

Diode biasing of the triode unit of the 6AV6 and 12AV6 is not suitable.

SOCKET CONNECTIONS

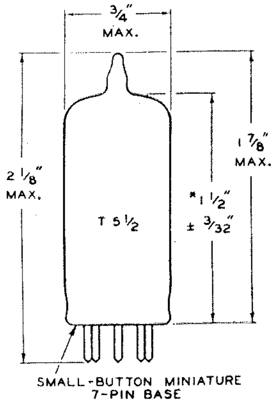
Bottom View



7BT

PIN 1: TRIODE GRID
PIN 2: CATHODE
PIN 3: HEATER
PIN 4: HEATER
PIN 5: DIODE PLATE No. 2
PIN 6: DIODE PLATE No. 1
PIN 7: TRIODE PLATE

DIMENSIONAL OUTLINE



* MEASURED FROM BASE SEAT TO BULB-TOP LINE AS DETERMINED BY RING GAUGE OF 7/16" I.D.

Operating Conditions as Resistance-Coupled Amplifier.

Plate-Supply Voltage		90			180			300		Volts
Plate Load Resistor	0.1	0.22	0.47	0.1	0.22	0.47	0.1	0.22	0.47	Megohm
Grid Resistor (of following stage)	0.22	0.47	1.0	0.22	0.47	1.0	0.22	0.47	1.0	Megohm
Cathode Resistor	4700	7400	13000	2000	3500	6700	1500	2800	5200	Ohms
Cathode Bypass Capacitor●	2.4	1.4	0.8	3.5	2.1	1.1	4.0	2.3	1.3	μf
Blocking Capacitor●	0.013	0.006	0.003	0.013	0.006	0.003	0.013	0.006	0.003	μf
Peak Output Voltage☐	6	9	11	25	34	39	57	69	77	Volts
Voltage Gain	35♯	45♯♯	52‡	47▲	59▲	66▲	52▲	65▲	73▲	

♯ At an output voltage of 2 volts rms.
‡ At an output voltage of 4 volts rms.
♯♯ At an output voltage of 3 volts rms.
▲ At an output voltage of 5 volts rms.

● The cathode bypass capacitors and blocking capacitors have been chosen to give output voltages at 100 cps (f_1) which are equal to 0.8 of the mid-frequency value. For any other value of (f_1), multiply the values of cathode bypass and blocking capacitors by $100/f_1$.

☐ This peak output voltage is obtained across the grid resistor of the following stage at any frequency within the flat region of the output vs frequency curve, and is for the condition where the signal level is adequate to swing the grid of the resistance-coupled amplifier tube itself to the point where its grid starts to draw current.