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IN THIS ISSUE

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This article is the second part of the "Semiconductors and Transistors" article which appeared in the May issue of Radiotronics.

In this part five additional experiments are described in which, with the aid of semiconductor devices, an investigation may be made of the properties of inductors and capacitors, and of techniques such as modulation, transmission and reception which find everyday application in electronic communications.

FURTHER EXPERIMENTS IN ELECTRONICS

H. R. WILSHIRE

Experiment No. 10
Characteristics of Inductance

(a) **Reactance.** This property of an inductance is given by:

$$X_L = 2\pi fL, \qquad (1)$$

where X_L is the inductive reactance in ohms,
f is the operating frequency in c/s,
L is the inductance in henries.

Aim. To show the change in X_L produced by varying the operating frequency f.

Equipment. Transistor oscillator unit tunable over range of approximately 330 to 850 Kc/s (see Fig. 21), and cathode ray oscilloscope.

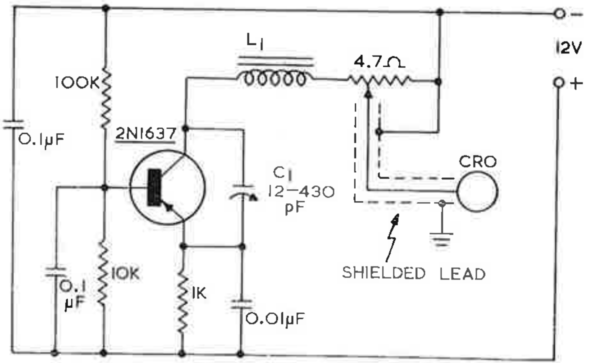
Method. Connect the equipment as shown in Fig. 21.

The circuit of the oscillator maintains an approximately constant voltage swing across L_1 as the frequency is varied by C_1. Under these conditions a change in reactance will be indicated by a change in current through L_1. Since current = voltage/reactance and the voltage is constant, the current will vary inversely as the reactance, i.e., a decrease in X_L will cause an increase in current.

In this experiment the current in L_1 causes a voltage drop in the 4.7-ohm resistor and this is indicated by the c.r.o.

If the frequency of the oscillator is varied a change in the current through L_1 and hence a change in the reactance of X_L (refer Equation 1) will be indicated by a variation in the height of the pattern on the c.r.o.

Note. Set the horizontal time base of the c.r.o. to a frequency of approximately 1000 c/s or a speed of 100 μs/cm. and the sensitivity of the vertical amplifier to 100 mV/cm.



R.F. OSCILLATOR

FIG. 21

Connect the c.r.o. to the 4.7-ohm resistor with a short length of shielded wire and connect the shield of the wire to the —12 volt end of the 4.7-ohm resistor with as short a lead as possible.

The d.c. power supply **must** be operated in the "floating" condition, i.e., with no connection between either side and "earth". To reduce the effects of induced "hum" it may be necessary to connect the shield of the input lead of the c.r.o. to "earth". This may be achieved automatically by the mains earth of the c.r.o. In other cases a separate wire between the c.r.o. and a suitable earth such as a waterpipe may be required.

(b) **"Back" E.M.F. of Self Induction.**

Aim. To indicate the generation of the "back" or induced e.m.f. across an inductance when the current through the inductance is interrupted.

Equipment. Iron-cored inductance (primary of soldering iron transformer), neon lamp, 12 volt d.c. power supply.

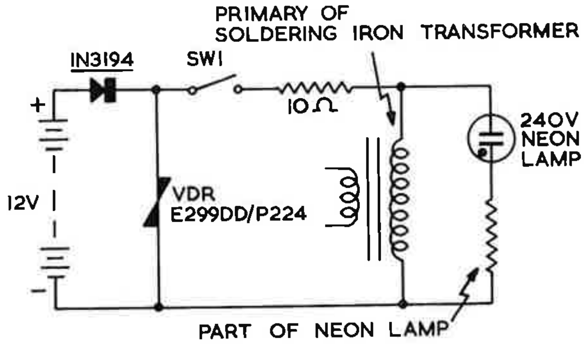


FIG. 22

Method. Connect as shown in Fig. 22.

Close SW1 and after a short period open to interrupt the d.c. from the power supply. The induced back e.m.f. will now cause the neon to flash, indicating that its magnitude is greater than the ionizing voltage of the neon (100-160 volts).

Note. The voltage dependent resistor VDR and the 1N3194 diode are provided to protect the power supply from damage due to the high induced e.m.f.

Since the induced voltage across the transformer primary may be very high for a short interval of time a spark may occur across the switch as it opens. A part of the high voltage may then appear across the 12V power supply and cause damage.

The diode is connected in the direction of forward conduction to enable the current to be built up in the inductance and it therefore operates in the "reverse" or high-resistance direction for the induced voltage.

Experiment No. 11
Characteristics of Capacitance

(a) **Reactance.** Capacitative reactance is given by:

$$X_C = \frac{1}{2\pi fC} \qquad (2)$$

where X_C is reactance in ohms,
f is operating frequency in c/s,
C is capacitance in farads.

Aim. To show the change in X_C produced by varying the operating frequency f.

Equipment. Transistor oscillator unit as used in Experiment 10, capacitance C_2 (100pF) and cathode ray oscilloscope.

Method. Connect equipment as shown in Fig. 23.

The 100K-ohm resistor will maintain a constant current through the capacitor C_2 and the height of the pattern on the c.r.o., will be proportional to the reactance X_C. Since X_C is proportional to 1/f, the height of the pattern on the c.r.o. i.e., the voltage across C_2, will vary inversely with f.

Note. Set the horizontal time base of the c.r.o. to a frequency of approximately 1000c/s or a speed of 100 μs/cm. and the sensitivity of the vertical amplifier to approximately 100 mV/cm.

(b) **Stored Charge and Time Constant.**

Aim. To demonstrate the storage of an electric charge in a capacitor and the time constant of a circuit containing a capacitor and a resistor.

Equipment. Neon lamp, 200 volt d.c. power supply and three capacitors -24 μF 300V, 50 μF 300V and 100 μF 300V (made from 2 × 50 μF 300V units).

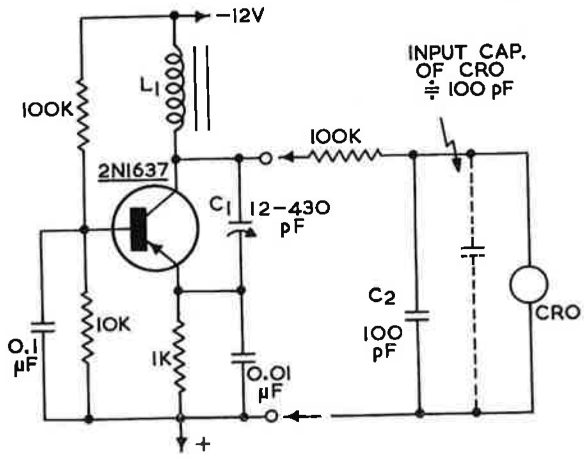


FIG. 23

Method. Connect as shown in Fig. 24.

Charge one of the capacitors to 200V by connecting through SW2 to the d.c. power supply. Then operate SW2 to connect the capacitor across the neon lamp. Note the time t during which the neon is ionized. Repeat for each of the capacitors and compare the times.

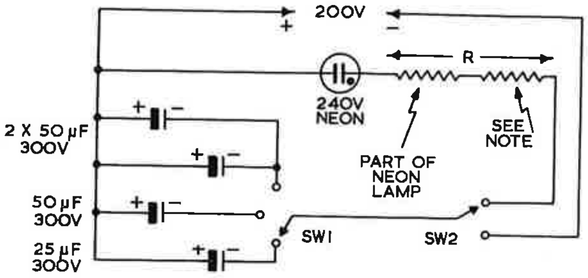


FIG. 24

Note. A normal 240V neon lamp is supplied with a series resistor (approximately 33K-ohm) fitted internally in the base. The resistor is necessary to limit to a safe value the current that can flow after the neon ionizes. An added resistor may have to be wired in series with the lamp to provide a suitable compromise between time constant and brightness.

Time constant T is defined as the time required for the capacitor to discharge to a specific percentage (1/e = 36.8%) of its initial value and is proportional to the product of capacitance and resistance, i.e., T proportional to CR. Therefore for a fixed resistance, the time to discharge the capacitance is proportional to its value C.

The magnitude of the stored charge is indicated by the time during which the neon lamp is ionized, since during this time current is flowing and hence energy is being dissipated in the resistance of the circuit.

WARNING. The energy available from the 200-volt supply or any of the charged capacitors could be dangerous and this equipment **must** be handled with sufficient care to avoid electric shock by contact with any part of the body.

Experiment No. 12
Modulation of R.F. Carrier Wave

Aim. To demonstrate the amplitude modulation of an r.f. carrier wave by an a.f. signal.

Equipment. Audio frequency oscillator unit of Experiment No. 8, radio frequency oscillator of Experiment No. 10 and c.r.o.

Method. Connect as shown in Fig. 25.

In this experiment the audio frequency oscillator of Experiment 8 is used as the modulator for the r.f. oscillator of Experiment 10. An isolating stage, the emitter follower, is used between the two oscillators.

Observe on the c.r.o., connected across the 9-turn winding L_{1C}, the amplitude-modulated wave. The depth of modulation may be varied by adjusting the potentiometer in the a.f. oscillator circuit.

Note. Adjust the horizontal time base of the c.r.o. to a frequency of 100-400 c/s or a speed of 1 ms/cm., and the sensitivity of the vertical amplifier to 100 mV/cm.

Experiment No. 13
Transmission and Reception of Radio Waves

Aim. To transmit an electromagnetic wave and demonstrate its reception over a short distance.

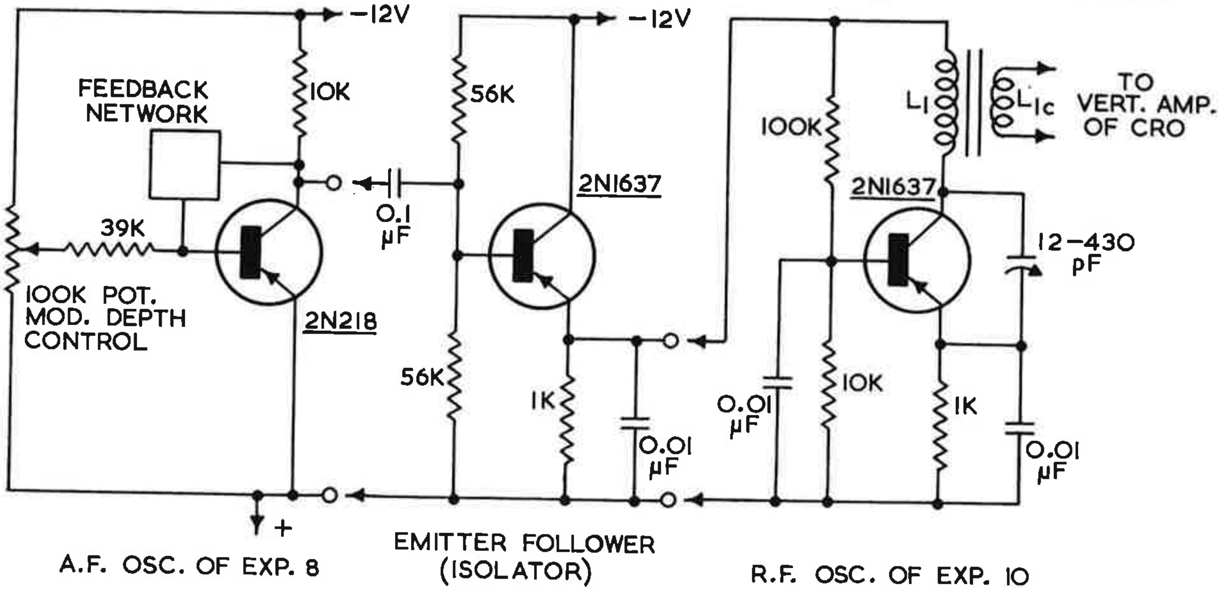


FIG. 25

Equipment. R.F. oscillator of Experiment No. 10, a receiver using a transistor detector and a 50µA meter.

Method. Connect as shown in Fig. 26.

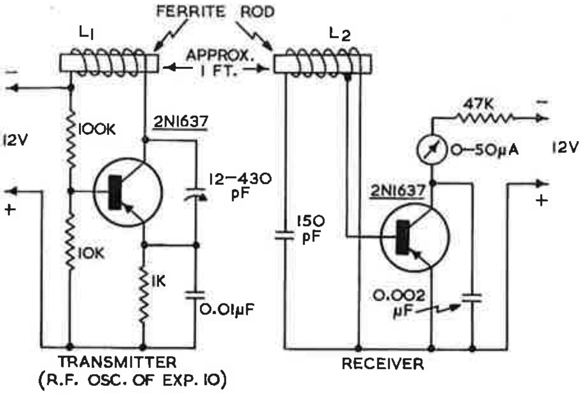


FIG. 26

Tune the transmitter by means of the variable capacitor over its frequency range while observing the 50µA meter of the receiver. When both are tuned to the same frequency the r.f. signal picked up by the ferrite rod and coil of the receiver will be rectified and amplified by the transistor and will be indicated as a direct current through the 50µA meter.

Note. A wave emanating from a radiator has two parts—near the transmitter there is an "induction" component which decreases very rapidly with distance and further away there is the "radiation" component. Each of these components of the wave is made up of a magnetic and an electrostatic field which are at right angles to one another and to the direction of propagation. In the case of this experiment, where the spacing between the transmitter and receiver is very small, the magnetic field of the induction component is predominant and is mainly responsible for the transfer of the r.f. signal from the transmitter to the receiver loop antenna.

Experiment No. 14
Resonance

Aim. To demonstrate the effects of resonance in a circuit containing inductance and capacitance.

Equipment. R.F. oscillator of Experiment No. 10 with an added coupling winding, the inductance L_2 of Experiment No. 13, a capacitance C_2 and the c.r.o.

Method. Connect as shown in Fig. 27. ($C_2 =$ 150pF.)

Tune the r.f. oscillator until its frequency equals the resonant frequency of L_2 and C_2. Since at resonance the current through the series circuit is a maximum this condition will be indicated by the development of maximum voltage across the capacitor C_2.

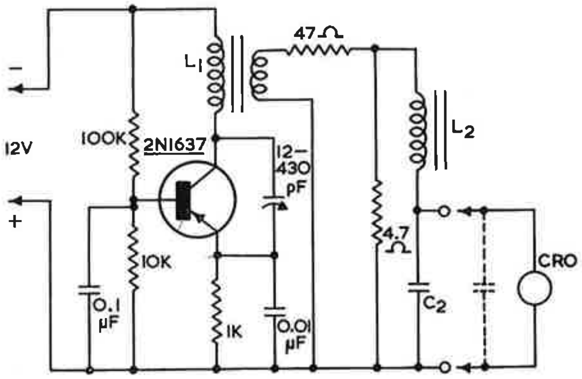
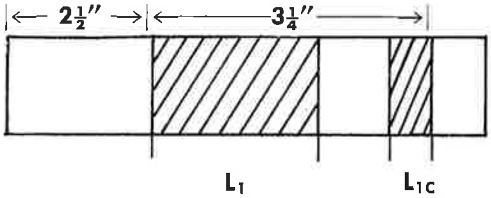


FIG. 27

Appendix

Special units required for Experiments 10 to 14.

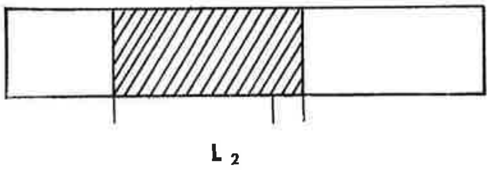
Inductance L_1 (Oscillator Coil)



Ferrite rod
8" x ½" Diam.

L_1—58 turns of 20/44 Litz closewound.
L_{1C}—9 turns of 22 SWG insulated hook-up wire closewound.

Inductance L_2 (Aerial Coil)



Ferrite rod
8" x ½" Diam.

L_2—58 turns of 20/44 Litz closewound tap at 20 turns.

Iron Cored Inductance
Primary of 240V to 6V soldering iron transformer.

Neon Lamp
240V pilot lamp (with limiting resistor).

List of parts required for Experiments 10-14 inclusive:

Semiconductors.

Qty.	Item
2	2N1637
1	1N3194

Resistors.

Qty.	Item	
1	4.7 Ω	½ W
1	10 Ω	1 W
1	47 Ω	½ W
2	1000 Ω	½ W
1	10 kΩ	½ W
1	47 kΩ	½ W
2	56 kΩ	½ W
2	100 kΩ	½ W

1—Voltage Dependent Resistor Type E299DD/P224.

Capacitors.

Qty.	Item	
1	100 pF	
1	150 pF	
1	0.002 μF	25 V
2	0.01 μF	25 V
3	0.1 μF	25 V
1	24 μF	300 V
3	50 μF	300 V

1—Variable Capacitor 12-430 pF.

Wire.

Qty.	Item
17 ft.	20/44 Litz
1.5 ft.	22 SWG C.E.

Miscellaneous.

Qty.	Item
1	Pilot Lamp 240 V Neon
2	Ferrite Rod 8″ x ½″

FERRITE ISOLATORS AND CIRCULATORS

B. J. Simpson

This note is intended to answer queries that have come in from readers who are interested in microwaves, or at least have been reading up the subject, and have seen references to ferrite isolators and circulators. Whilst the names themselves give some clue as to the nature of these components, they do not of course explain how these devices work. In fact, it is probably true to say that search into rather heavy amounts of literature might be necessary to unearth a simple explanation such as the casually-interested reader would require.

In order to lay a proper foundation, some restatement of well-known facts may be necessary. We know of course that ferrous materials are those made of or containing iron, and iron is one of a number of materials which can be classified three ways, according to their magnetic properties, or, to put it more precisely, according to their permeability.

Permeability μ is the ratio between magnetic induction B and the field strength H, being generally expressed in the form $B = \mu H$. There is more than a superficial similarity between this expression and Ohms Law, and between the respective parts of μ and R, μ being equivalent to conductivity (1/R) in electrical circuits. Permeability in air is unity. In paramagnetic or "partially magnetic" materials, the permeability will be something greater than unity, in ferromagnetic materials the permeability will be high or very high, whilst in diamagnetic materials the permeability figure will be less than unity. The simpler ferromagnetic materials also have low resistivity.

The use of soft iron and various proprietary formulations in "iron-cored" transformers and chokes is well known. When thought was given to using the same materials in radio frequency inductors, however, it was possible to deduce from Maxwell's equations that this type of material would be unsuitable due to its low resistivity. Measurement will bear this out.

We are also familiar with the so-called "dust-cores" used in high frequency inductors, wherein an attempt was made to remove the disadvantage of soft-iron formulations in high frequency work by making the core of numerous small particles of iron suspended and held in a neutral carrying medium, such as certain clays, and wherein the iron particles were separated from each other. These devices are now probably entirely replaced by ferrites, of one type or another, exhibiting superior properties.

Ferrite materials have high permeability coupled with high resistivity, perhaps 10^{12} times that of soft iron; they are manufactured compounds rather than basic elements. The basic formula of a ferrite is $MeO.Fe_2O_3$, Me being a divalent metallic ion, that is, a charged atom capable of combining with two atoms of hydrogen or their equivalent. The most usual metals used for the metallic ion are manganese, nickel and magnesium, although several others have been used.

The unique character of all ferromagnetic materials, soft iron, ferrites and the like, is the high degree of coupling or exchange forces that exists between the magnetic moments of neighbouring electrons, magnetic moment being defined as the ratio of the torque or turning force exerted on a magnet or magnetic material to the magnetising force of the magnetic field in which it is situated. The electrons responsible for the high magnetic moments associated with ferrites are not in the conduction band of the material as they are in soft iron, but are at a lower energy level; this explains why the resistivity of ferrites is so high.

The coupling or exchange forces between adjacent electrons in a ferrite can be reduced by the application of thermal energy, so that the properties of ferrites are temperature-sensitive. The temperature at which neighbouring electron spins or couplings are completely decoupled is called the Curie temperature, above which temperature the ferrite material ceases to behave as a ferromagnetic material and becomes paramagnetic. For ferrites used in microwave work, typical Curie temperatures would be in the range 100-300°C.

Without going into great detail on the operation of ferrites, which would in any case be out of place in this short note, some of the interesting properties of ferrites must be stipulated to assist the understanding of material which is to follow. It is possible, for example, to apply a dc magnetic field to ferrite material. This produces a torque acting on all the electrons in the material, causing precession of the axes on which the individual electrons are spinning, precession taking place about the axis of the applied field. The torque is as one would suppose, dependent on the magnetic moment and the strength of the applied field. The case stated is the loss-less case; where losses are involved, the precessional motion spirals into alignment with the axis of the applied field.

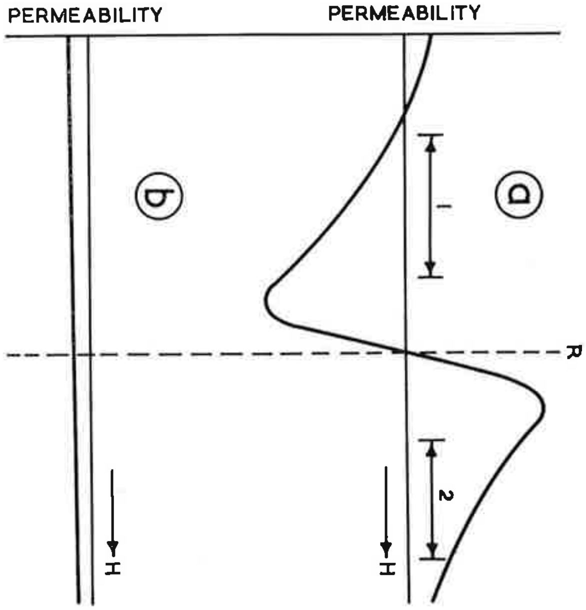


FIG. 1

The next significant property or set of properties concerns the effect of applying an alternating magnetic field to the ferrite material in the plane perpendicular to the direction of the dc bias field. Mathematical analysis, which can be found in the literature of the art, reveals (a) that a magnetization vector may be produced in a given direction not only by a field applied in that direction, but also by a field applied perpendicular to that direction: (b) that the component of magnetization produced by the perpendicularly-applied field is in time quadrature with respect to the applied field: (c) that propagation in a ferrite media may be non-reciprocal; and finally (d) that a resonance condition may be set up by a suitable choice of the applied dc field in relation to the frequency.

Losses occur at resonance due to the coupling of energy to the precessing electrons, and are affected to a lesser degree by imperfections in the material. It is therefore usual to use the ferrite material either above or below the resonant point. There is a further high-loss region in the area of low-strength fields, which is also avoided in practice. Ferrite materials have been developed for use at frequencies as low as 100 Mc.

The propagation constant in ferrite material is a function, for a given material at a given frequency, of the applied magnetic field H. Of interest in the present context is the propagation of circularly-polarised waves in a ferrite material where the component of the magnetic field in one direction is equal to but 90° out of phase with the component at right angles to it.

Fig. 1 shows plots of the permeability of a ferrite material (a) for clockwise-polarized waves propagating in the direction of the dc bias field and (b) counterclockwise-waves. The discriminator-like curve of (a) in Fig. 1 shows the resonant point, denoted R. The probable choice of operating regions, mentioned above, is indicated by the areas numbered 1 and 2 below and above the resonant point.

FERRITE ISOLATORS

An isolator in this context is a device which will pass a propagated wave in one direction with little or no loss, but which will offer high attenuation to a wave travelling in the opposite direction. In simpler terms, it is similar to a mechanical one-way valve. Such a device can be used, for example, for preventing reflections which occur in a waveguide due to mismatching from travelling back along the guide to the wave source.

Faraday Rotation Isolator

The Faraday rotation isolator was the first ferrite circulator to be widely used. It is illustrated in Fig. 2, where it is seen to consist of rectangular waveguide input and output ports, with transitions to an intermediate section of circular waveguide. The axes of the rectangular input and output sections are arranged at a 45° angle. The circular waveguide section contains a ferrite rod, at either side of which is positioned a resistive or lossy card. The card at the input end is positioned in a plane normal to the E-fields in the input waveguide section, whilst the card at the output end is similarly positioned with respect to the output waveguide section. It will be seen that because the input and output waveguide sections are at a 45° angle, so are the two resistive cards.

It should perhaps be mentioned before going further that the resistive cards are one of a number of attenuating devices used with waveguides. They will usually consist of a sheet of comparatively thin insulating material with a resistive material deposited thereon, similar to the sprayed resistance tracks of composition potentiometers, or they may be cut from sheets of material formed of a compound which includes a resistive material.

The resistive card offers little or no attenuation to a wave when the plane of the card is normal to the plane of the E-fields of the propagated wave, and offers maximum attenuation when the plane of the card and the plane of the E-field are parallel. Whilst this gives rise to the possibility of a variable attenuator by rotating the card about the longitudinal axis of the waveguide, this is not usually done, the preferred method being to arrange the card plane parallel to the E-fields plane and then control the penetration of the card into the waveguide.

However, after that short digression to colour the picture, let us return to the isolator. A dc magnetic field is applied in the direction H to bias the ferrite rod. Permeability of the ferrite rod for clockwise-polarised waves is different from that for anticlockwise-polarised waves. This means that the polarization of a linearly-polarised wave, which consists of the sum of oppositely-rotating circularly-polarized waves, will rotate as it travels through the ferrite rod in the direction of propagation.

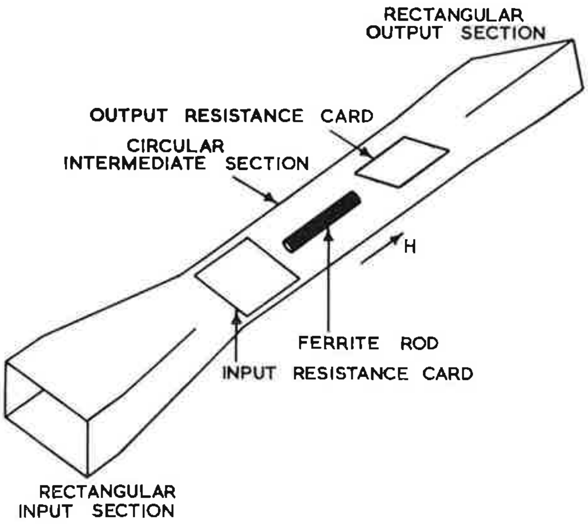


FIG. 2

This occurs because the velocity of propagation of electromagnetic waves is inversely proportional to the square root of the permeability of the medium in which the wave is being propagated, in this case the ferrite rod. It follows from what has gone before that the velocity of propagation for clockwise-polarized waves travelling through the ferrite will be slower than for counterclockwise waves.

When the two waves leave the ferrite rod, they combine to form a linearly polarized wave similar to that which entered the ferrite rod, but having its direction of polarization at a different angle from that of the entrant wave. In the present case, where a rotation of 45° is required and the mechanical features are arranged to suit, the dc field is adjusted to such a value that the difference in permeability for the two waves, and therefore their different velocities of propagation, are such that the required rotation of 45° is realised through the ferrite rod.

When the isolator is correctly adjusted, the input and output resistive cards offer no attenuaion as they are normal to the planes of the E-fields at their respective points. It is now necessary to consider what happens to a reflected wave entering the output end of the circulator. The reflected wave will pass the output card with zero attenuation, as the E-fields of the reflected wave at this point lie in the same plane as the E-fields of the outgoing wave.

The reflected wave is now propagated through the ferrite rod, which rotates the axis of polarization by an additional 45° (45° outgoing plus 45° returning = 90°). This means that the input resistive card is in the same plane as the E-fields of the reflected wave at that point, and heavy attenuation of the reflected wave will occur. The device is thus seen to function in the required manner.

Resonance Absorption Isolator

Although the Faraday rotation isolator was early in the field, the resonance absorption isolator is by far the more popular in general use. They are in general smaller and cheaper, and have good power-handling capability in relation to size. Many varieties are extent, but they are all founded on the same basic plan.

An isolator of this type is shown in Fig. 3. The isolator consists of a length of rectangular waveguide containing a ferrite slab positioned as

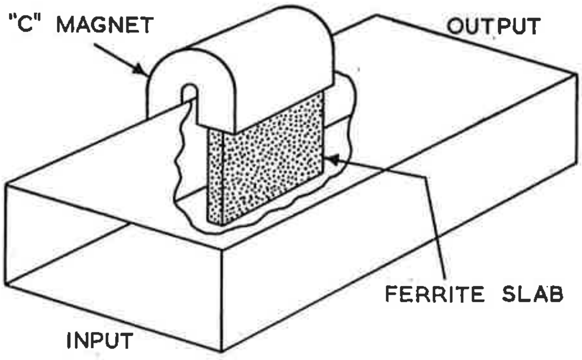


FIG. 3

shown, one quarter of the distance across the waveguide from one narrow side to the other. An external magnet is positioned to apply a transverse dc magnetic field to the ferrite as a bias field.

The dominant propagation mode in a rectangular waveguide is the TE_{10} mode. The H or magnetic fields in this mode are transverse at the centre of the waveguide and longitudinal at the sides of the waveguide. (See Fig. 4.) If we consider the position chosen for the ferrite slab, and then visualise a wave propagated down the waveguide, the direction of the H-fields is first of all, say, transverse, then longitudinal, then transverse in the opposite direction, longitudinal, and so on. The H-fields therefore appear to be circularly-polarized, and rotating about an axis at the selected quarter-way point. The same condition occurs at the three-quarter-way point, but here the wave appears to rotate in opposite sense.

It will now be seen, from the information just given, and a comparison of Figs. 3 and 4, that at the quarter-way position, for a wave propagated in the waveguide in the direction shown, the H-waves appear to be circularly-polarized in a counter-clockwise direction, whilst at the three-quarter-way position they appear to be circularly-polarized in a clockwise direction. For propagation in the opposite direction, it will be clear that the senses of polarization at the two positions will be reversed.

If now a ferrite body is placed at either of the two positions mentioned and is biased to resonance by the external magnet the device will absorb waves travelling in one direction, whilst allowing free passage to waves travelling in the opposite direction. This is the basic isolator requirement.

It has been assumed for simplicity that the magnet is a "C"-type permanent magnet, but an electromagnet would provide perhaps more easily the facility for biasing the ferrite to resonance. Typical performance of this popular type of isolator is 30 db isolation with an insertion loss of 0.5 db over a 10% bandwidth.

FERRITE CIRCULATORS

Circulators are devices which allow one to couple a number of lines or waveguides, usually but not necessarily four, in such a way that each port will couple energy only to one of the other three and not to the remaining two. In this way, with a four-port circulator, four predetermined coupling paths are set up. These devices have many uses, such as coupling two units together without mutual interaction, and so on. They come in a number of forms.

Faraday Rotation Circulator

Just as the Faraday rotation isolator was the first of its kind to receive widespread use, so in the case of circulators, the Faraday rotation circulator was early in the field. This is not entirely surprising, as there is a strong basic similarity between them. Reference to Fig. 5 shows the basic construction.

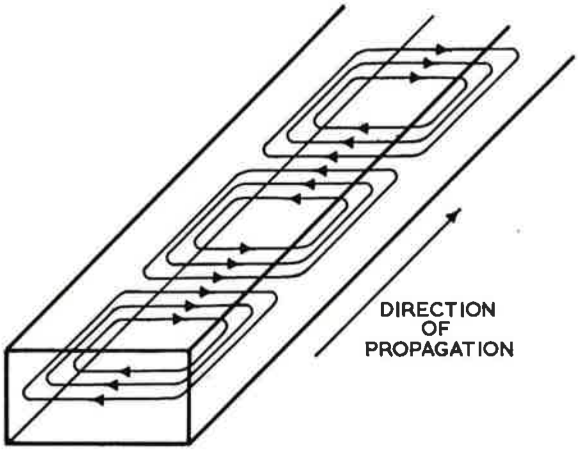


FIG. 4

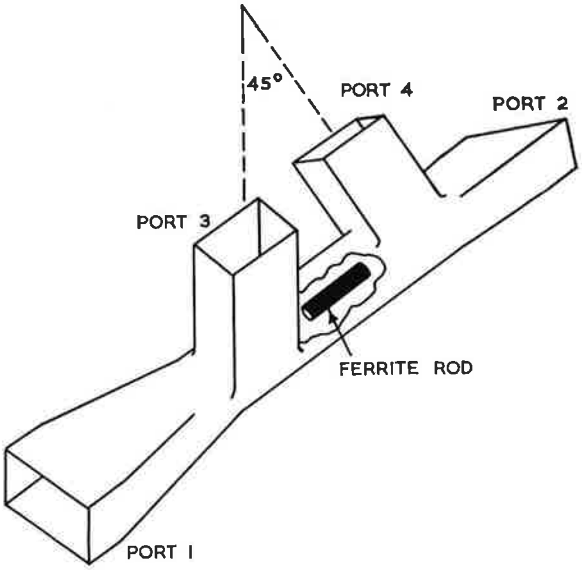


FIG. 5

It will be seen from the diagram that the main body of the circulator consists of two rectangular waveguide sections ending in ports 1 and 2, joined by an intermediate section of circular wave-guide. A ferrite rod is positioned at the centre of the circular section. At each end of the circular section are two rectangular waveguide branches designated ports 3 and 4. These two additional branches are respectively normal to the plane of the major dimension of waveguide ports 1 and 2.

The ferrite rod is magnetically biased to produce a 45° rotation as before, and the axes of ports 1 and 2 form a 45° angle. Waves entering port 1 pass through the ferrite section, where they are rotated by 45°, and leave the circulator at port 2. There is no coupling of energy from port 1 to either port 3 or port 4, because when the wave passes these points, the polarization of the E-field is at right angles to the propagating mode at both ports.

Waves entering port 2 pass port 4 and after rotation through 45° in the ferrite exit via port 3, being now correctly polarized to propagate to port 3. Energy does not propagate to port 1 because this port is now at right angles to the propagating mode. In the same way it can be shown that waves entering port 3 will go to port 4 and that waves entering port 4 will go to port 1. The directions in which energy can travel in this device can therefore be summed up as follows:—

In 1, Out 2
In 2, Out 3
In 3, Out 4
In 4, Out 1

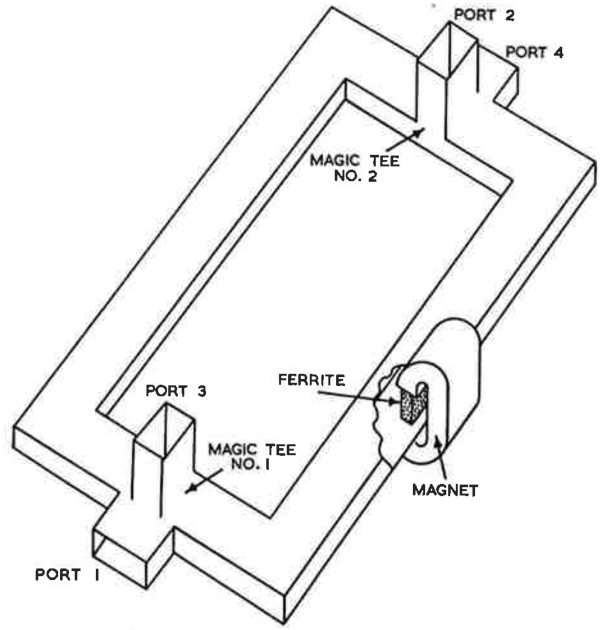


FIG. 6

The circulator is thus seen as an aggregate of four one-way switches, as it were. Obvious uses for such a device, for example duplexing aerials to transmitters and receivers, will readily occur. Typical performance for a circulator of this type is 25 db isolation to uncoupled ports with 0.5 db insertion loss to the coupled port over a 10% bandwidth.

Differential Phase Shift Circulator

This type of circulator is essentially a balanced bridge system, into one arm of which is introduced a non-reciprocal ferrite phase shifter. The general arrangement is shown in Fig. 6. It consists of two "magic tee" formations back to back, with each pair of colinear arms connected by U-shaped lengths of rectangular waveguide. The two colinear ports are designated ports 1 and 2, whilst the two right-angle ports are designated ports 3 and 4. In one arm of the arrangement is placed a ferrite body, at the plane of circularly-polarized H-fields.

The strength of the magnetic field is adjusted so that the ferrite produces a phase shift of 180° more for waves travelling in one direction than the other, that is, a relative difference of 180°. This is done by adjusting H to some value above or below resonance. (See Fig. 1.)

With the ferrite biased to produce a differential phase difference of 180°, the operation of the circulator can now be considered. Waves entering port 1 split in magnitude and propagate into the two colinear arms of the first "magic tee" leading to the second "magic tee." The wave which travels through the right-hand arm of the bridge is retarded by 180° more than that which travels through the left-hand arm, due to the presence of the biased ferrite body. When these two waves reach the second "magic tee," they are 180° out of phase and therefore propagate to port 2, the difference arm of the tee.

Waves entering port 2 split in magnitude and propagate out of the two colinear arms of the second "magic tee." However, their relative phase at this point is 180° due to the characteristics of the "magic tee." As the wave in the right-hand arm is not changed in phase when passing through the ferrite body, due to the non-reciprocal nature of the ferrite utilisation, the two waves arrive at the first "magic tee" still 180° out of phase, and therefore pass into the difference arm of the tee and out at port 3. In the same way it can be shown that waves which enter port 3 propagate to port 4, and that waves entering port 4 propagate to port 1.

It will be seen that the characteristics of this type of circulator are similar to those of the previously described type, but the differential phase shift circulator is capable of handling higher powers.

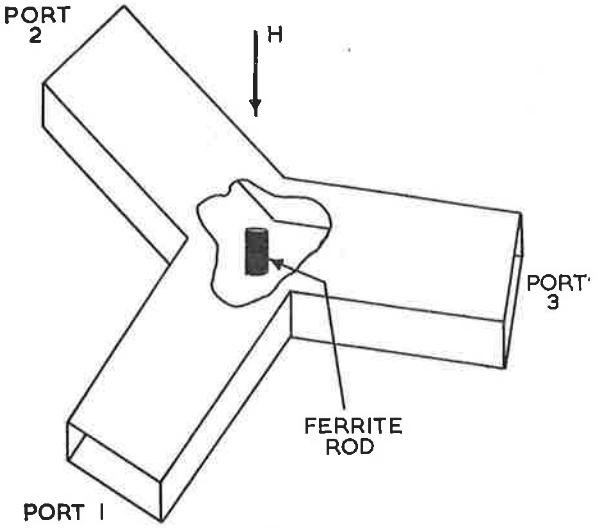


FIG. 7

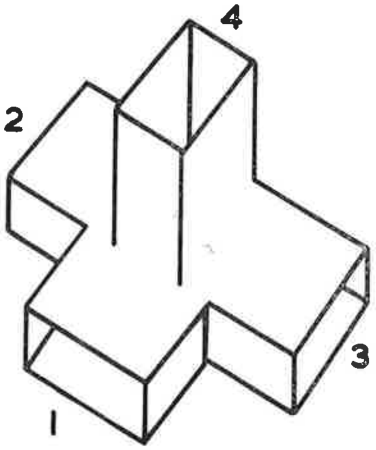


FIG. 8

Birefringent Ferrite Circulator

The birefringent ferrite circulator is the most popular type in use today. It is basically cheaper and simpler than the other two types described. It is a three-port circulator, and the general arrangement is shown in Fig. 7. It may be constructed of waveguide or strip transmission line, but for our purpose we will consider the waveguide case. Three rectangular waveguides form a "Y" junction. At the centre of the junction, a ferrite post is placed in the waveguide normal to the larger waveguide face. An external magnet is used to produce a tranverse biasing magnetic field.

The wavefront propagating in a transversely-magnetised ferrite body rotates about the axis of the magnetising field. This phenomenon is known as birefringence, hence the name of the circulator. The dc bias is adjusted to produce 60° of bending, resulting in propagation from port 1 to port 2, port 2 to port 3, and port 3 to port 1. This is assuming a completely symmetrical arrangement. It would be possible to produce similar devices for specific applications, either with more than three ports, or with special features. This type of circulator can be made with very low insertion losses of the order of 0.1 db or so and with isolation better than 30 db. It is however a lower-power device.

"Magic Tee"

The so-called "magic tee" is a hybrid junction, which is a junction with four branches, so arranged as to render these branches conjugate in pairs. This common form of hybrid junction known as a "magic tee" is a combination of an E-plane T-junction and an H-plane T-junction, as shown in Fig. 8. In the diagram, arms 1, 2, 3 form the H-plane T, and arms 2, 3, 4 form the E-plane T.

The operation of this hybrid is very simple. An input at 1 divides to 2 and 3, but not to 4. An input at 4 divides to 2 and 3 but not to 1. Inputs from 2 and 3 which arrive at the junction in phase go to 1 and not to 4, inputs which arrive at the junction in antiphase go to 4 and not 1. This may help those who have not previously met this arrangement.

ERRATUM

In the Semiconductors and Transistors article which was published in the May issue two lines were omitted from the note paragraph of experiment 4 which appeared on Page 92. The correct copy is:

Note: The curve relates collector and base currents and hence current gain for the measured collector-to-emitter voltage. In this experiment the two silicon diodes (1N3194) supply a source of low voltage for the collector which is reasonably independent of the current drain. (Refer to Experiment No. 2 for the curve relating voltage drop and current for diodes of this type, and check the value of V_{CE} measured in this experiment with that expected from the 1N3194 characteristic for two diodes in series.)

RADIO PROPAGATION

AND THE AMATEUR RADIO OPERATOR

By Howard G. Jones, Jr., W3MBW*

RCA Electronic Components and Devices

In the following article, the author reviews the subject of radio propagation as it applies to the amateur operator. The data should aid the amateur in understanding how his signals reach their destination, whether by skywave or groundwave propagation, and help him to use his frequencies more efficiently, and thereby communicate more effectively.

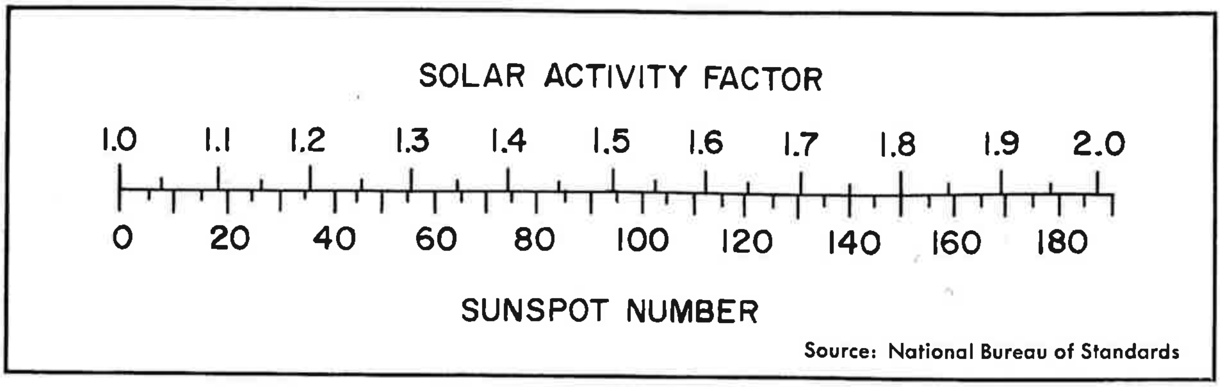
Long-range transmission in the amateur bands below 30 megacycles is dependent primarily upon the skywave mode of radio-wave propagation. This mode of propagation is made possible by five ionospheric regions, collectively called the *ionosphere,* which are found at distances from 50 to 350 kilometers (about 31 to 217 miles) above the earth. It is important to visualise the structure of the ionosphere to understand more fully the mechanism by which the ham operator's signals reach their destination in the skywave mode. Some knowledge of the response of the ionospheric regions to different frequencies; of their signal-absorption characteristics; and of unusual transmission effects attributed to them is also essential if effective use is to be made of skywave propagation.

Structure of the Ionosphere

The ultraviolet radiation from the sun is believed to supply the energy to ionise the five ionospheric regions. This belief is supported by the significant increase in the ionisation levels that occur during peak of sunspot activity; it is known that the ultraviolet radiation is maximum during such peaks.

The two ionospheric regions nearest the earth, the D and E layers, exist during the daylight hours only. At the relatively low altitudes of these layers, atmospheric particles recombine so rapidly that a constant source of radiation is required to sustain ionisation. The D layer is found from 50 to 90 kilometers above the earth; the E layer, from 90 to 140 kilometers above the earth. Both the height and the ionisation level of the layers vary over different parts of the earth and with the season-to-season changes in the zenith angle of the sun. The ionisation level also changes with the time of the day and reaches a peak at local noon in any given region of the earth. In the E layer, variations in the ionization level are particularly noticeable, and significant changes can be observed from hour to hour.

In the D layer, because of its lower altitude, atmospheric particles are more abundant, and there is a resultant higher incidence of particle



Source: National Bureau of Standards

Figure 1(b): Seasonal-correction factors.

collisions. The signal absorption by this layer is, therefore, greater than that by any of the other atmospheric layers. Particle collisions are also relatively frequent in the E layer, and it too exhibits a comparatively high degree of signal absorption. The E layer, however, reflects zero-incidence radio waves (those directed straight up) far more consistently than does the D layer and is much more useful for communications.

The E_s (or sporatic E) layer is the most unusual and unpredictable of the ionospheric layers. This layer, which can be found at any hour of the day or night in all latitudes, is best visualised as intermittent clouds of ionised particles slightly above the E layer in which the ionisation level may change radically from hour to hour. The source of ionisation of the E_s layer is still somewhat a mystery. According to some hypotheses, the layer is ionised by particle radiation from the sun, rather than by ultraviolet radiation; other hypotheses suggest that the layer is formed by ionised particles trapped in the earth's magnetic field.

In general, the appearance or disappearance of the E_s layer is unpredictable, although in northern latitudes the existence of the layer has been found to be very closely related to the presence of the aurora. Although its effects are unpredictable, the late-evening "short-skips" are often attributed to it, and the E_s layer is very useful for radio communications.

Seasonal Correction Factors

Month	Both Terminals N. Lat	S. Lat	One Terminal N. Lat and Other S. Lat
Jan	0.9	0.7	0.8
Feb	0.9	0.7	0.8
Mar	0.8	0.8	0.8
Apr	0.8	0.8	0.8
May	0.7	0.9	0.8
Jun	0.7	0.9	0.8
Jul	0.7	0.9	0.8
Aug	0.7	0.9	0.8
Sep	0.8	0.8	0.8
Oct	0.8	0.8	0.8
Nov	0.9	0.7	0.8
Dec	0.9	0.7	0.8

Figure 1: Typical solar-activity and seasonal-correction factors. The solar-activity factor (a) must be multiplied by the seasonal-correction factor (b) and the time-of-day factor (see Figure 2) to obtain the absorption-factor K.

The uppermost regions of the ionosphere are the most useful for long-range radio-wave transmission. During the daylight hours, these regions are divided into two separate layers: the F_1 layer at heights of 140 to 250 kilometers and the F_2 layer at heights of 200 to 350 kilometers above the earth. As in all the ionospheric regions, the ionisation levels in the F layers follow the sun. The ionisation reaches a peak just after local noon and declines slowly until sunrise. Because the atmosphere is thin at the altitudes of the F layers, particle collisions (and recombinations) are relatively infrequent; thus, the ionisation of these layers can be sustained throughout the night. Because of the lower collision rate, there is also less absorption as electromagnetic energy is reflected from the F region.

Critical Frequency

The ability of any of the ionospheric layers to reflect radio waves depends not only upon the degree of ionisation of the layer, but also upon the frequency of the radio waves. In measurements to determine the structure and ionisation level of the ionospheric layers, zero-incidence radio waves are often used. In order for any of the ionospheric layers to reflect a radio wave at zero incidence, the frequency of the wave must be below a critical value. This *critical frequency* is that frequency for which 50% of the radio waves will penetrate the layer and 50% will be reflected.

The signals reflected to the earth become weaker as frequencies of zero-incidence radio waves deviate from the critical frequency in either direction. Below the critical frequency, a gradual decline occurs because of increased layer absorption. Above the critical frequency, the decline is much more rapid. With but a small increase, the radio wave will not be reflected at all, but instead will penetrate the layer.

The critical frequency is different for each layer and, in general, increases with the height of the layer. For example, the critical frequency of the F layer is usually higher than that of the E layer. If the frequency of a radio wave exceeds the critical frequency of the E layer, it is therefore possible that the wave will pass through the E layer but will be reflected by the F layer. As the wave passes through the E layer, however, it will be attenuated to some extent.

Maximum-Usable and Optimum-Traffic Frequencies

Closely related to the critical frequency is the *maximum usable frequency* (MUF). The MUF is essentially a measure of the ability of an ionospheric layer to reflect radio waves from one point to another. For any given path, it is the frequency at which 50% of the signal will be reflected and 50% will pass through the layer. Thus, for a zero-incidence wave, the MUF is equal to the critical frequency. For other paths, the MUF will vary with the angle of incidence.

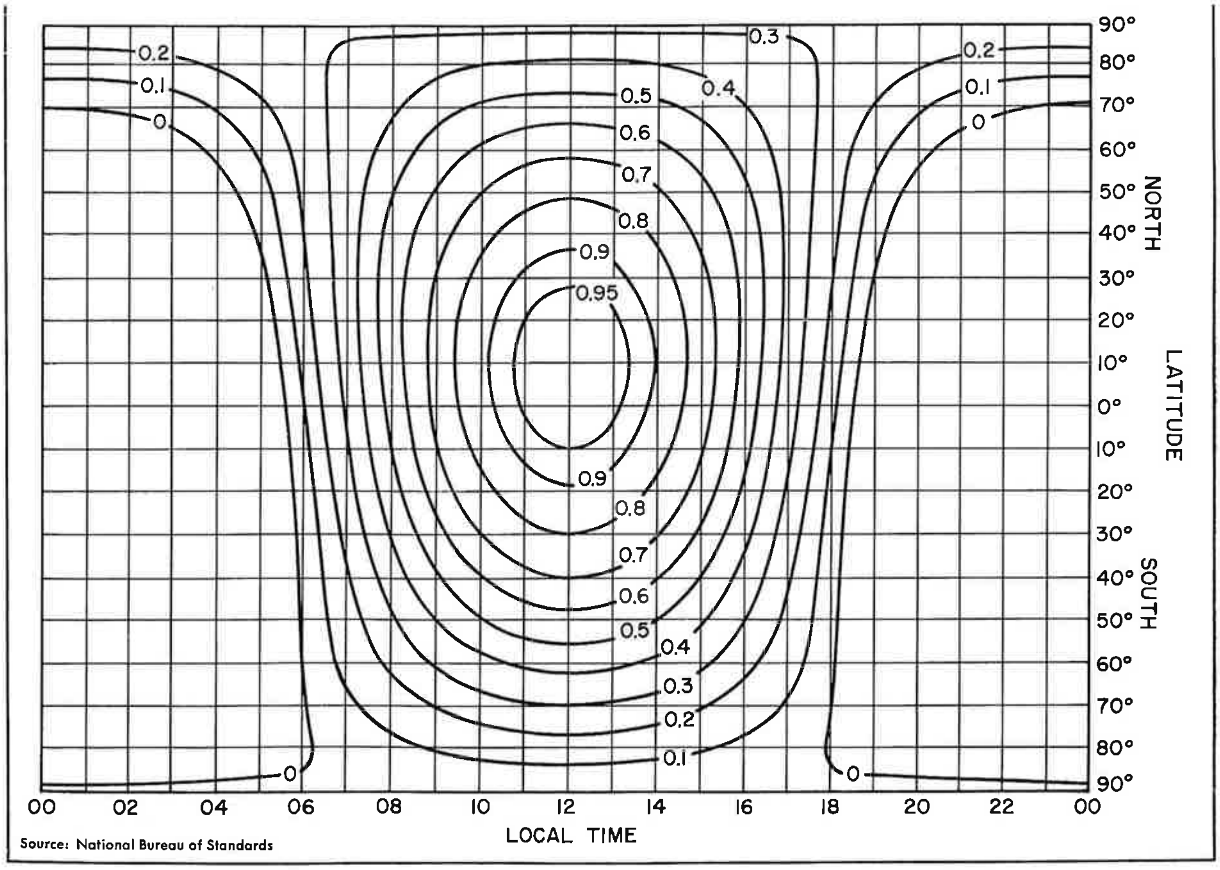
Each month, the National Bureau of Standards predicts the MUF for the E and F_2 layers. Average values for the month are given for zero-incidence waves and for waves reflected between two points 4,000 miles apart. If these two values are known, the operator can interpolate to find the MUF for any communications path in the world. The *frequency optimum for traffic* (FOT) is 85% of the MUF. For a radio wave having a frequency equal to the FOT, 90% of the signal will be reflected and only 10% will pass through the layer.

Path Absorption

As a radio wave is propagated by an ionised layer, some of the energy in the wave will be dissipated in the layer. This dissipation, called *path absorption,* is directly proportional to an absorption factor, K, which is given by the following equation:

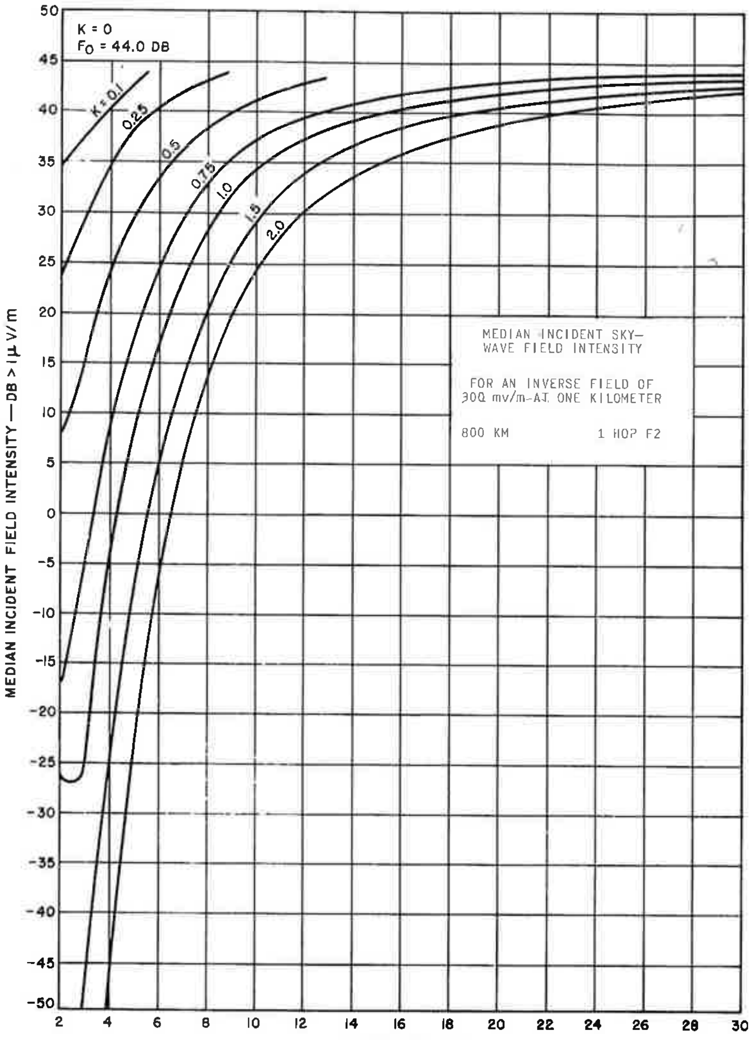
$$K = T \times M \times S$$

where T is a time-of-day correction factor, M corrects for seasonal variations in the ionisation level of the layer, and S is the solar activity correction factor based on the current sunspot number. These factors can be determined from tables and charts



Source: National Bureau of Standards

Figure 2: The chart for the month of April from which the time-of-day factor is obtained. The latter, in turn, is used to determine the absorption-factor K.



Source: National Bureau of Standards

Figure 3: A typical field-intensity graph for incident skywaves. The appropriate absorption-factor K is used to predict the received field strength in μv/meter (microvolts excited per meter of antenna length). The curves show the variations in received field strength for a kilowatt of RF power radiated from a dipole antenna. Corrections are required for different power outputs and antenna gains.

prepared monthly by the National Bureau of Standards. Typical tables of the solar activity factor and corresponding sunspot number and of the seasonal correction factor for both north and south latitudes are shown in Figure 1. A graph such as that shown in Figure 2 is used to determine the time-of-day factor.

If the absorption factor K is properly applied to a "received field strength" graph and the characteristics of the antennas used at the transmitting and receiving stations are taken into account, the ham operator can accurately predict the signal strength that will be received for a radio wave reflected from the ionosphere. Figure 3 shows a typical field-intensity graph for an incident skywave. The effect of different absorption-factor values is also shown.

Propagation Characteristics Of the Ionospheric Layers

The D layer will sometimes reflect radio waves from one point to another; however, reflections at zero incidence are rare. The D-layer path is "lossy" because of the high recombination rates, and, except for short-distance transmissions, is not very useful for radio communications.

The E layer is usable at frequencies higher than the D layer; however, there is some attenuation of the signals as they pass through the D layer both up and down. Because the D layer has higher recombination rates than the E layer, there are usually a few hours each day when the E layer may be used without the D layer presenting serious attenuation problems. These hours occur at sunrise before the D layer ionises fully and at sunset after it has lost some of its ionisation.

The E_s layer exhibits characteristics similar to those of the E layer, except for the sporadic nature of its appearance and disappearance.

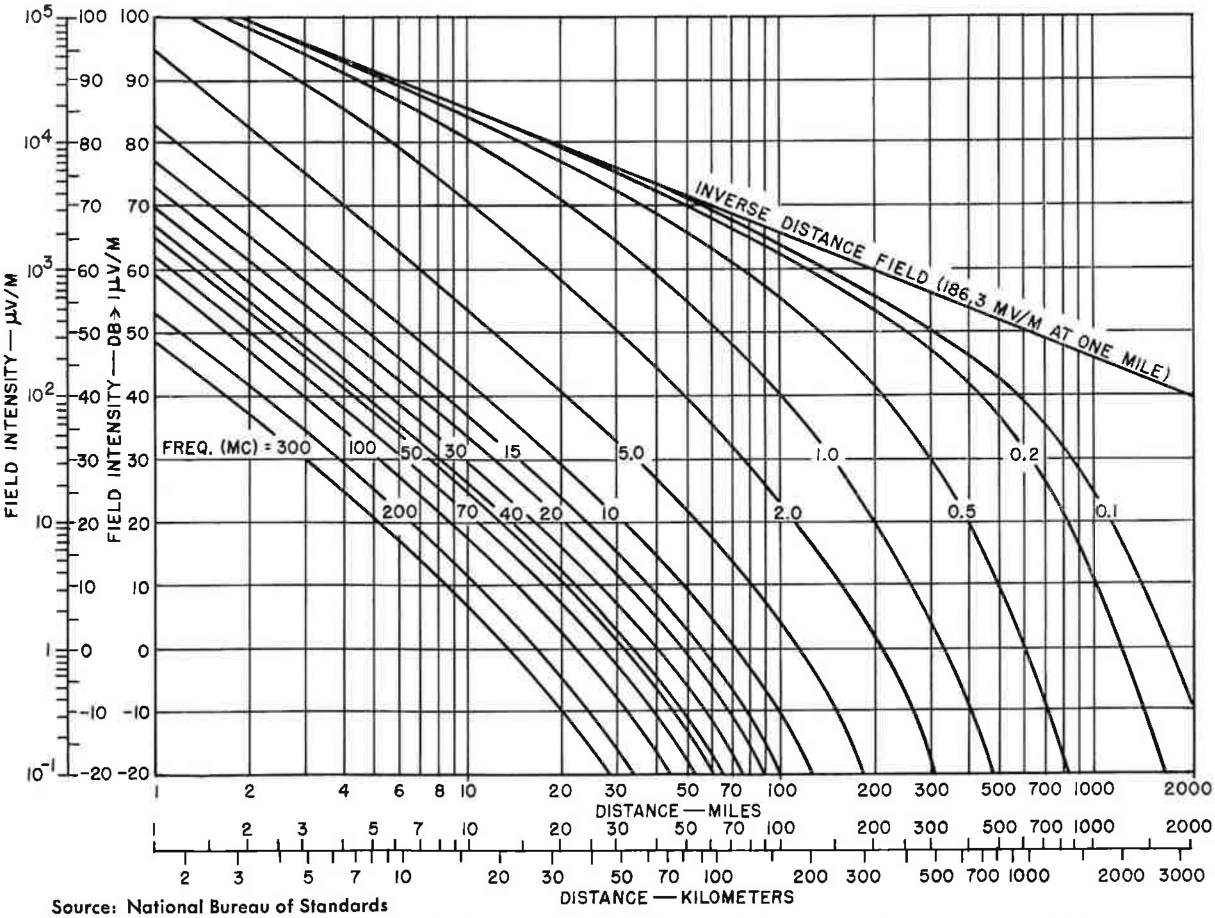
The F_1 and F_2 layers are the "work horses" of communications. These layers are useful both day and night; however, daytime operation is usually "lossy", because of the presence of the D and E layers. At night, long-distance communication paths are possible with very little loss and good dependability.

Various Modes of Radio-Wave Propagation

When an electromagnetic wave is radiated from an antenna, it is generally considered to have the potential for two kinds of communications: groundwave and skywave. Either or both methods may account for successful communications. In some instances, however, a skywave skip is impossible because of the MUF or the time of day.

Groundwave propagation is very dependent upon the type of path over which the signal travels. For convenience, the paths are classified poor, good, and seawater paths, based upon the relative conductivity of the intervening earth. Figure 4 shows typical groundwave field-intensity curves for radiation over "good-earth" paths. There are several generalisations that may be made concerning groundwave transmissions. They are usually limited to electrical line of sight. It therefore stands to reason that an increase in groundwave range may be realised by an increase in the antenna height. In some cases, however, an increase in power is required as well. The sensitivity of the receiver may well be another consideration.

Groundwave propagation is subject to a phenomenon called **shadow loss** caused by the inability of electromagnetic waves to bend around mountains or buildings. In groundwave work it is important to consider the natural and/or man-made obstacles that may introduce shadow loss over any given path.



Source: National Bureau of Standards

Figure 4: Typical groundwave field-intensity curves for 1 kilowatt of RF power radiated from a short vertical antenna at ground level. (A "good-earth" intervening path is assumed).

Aside from the two principal means of propagation (groundwave and skywave), there are a few unusual methods, such as the ones described below:

In the northern latitudes, the aurora have unusual effects on the propagation of radio waves. At the lower frequencies (those below 30 megacycles), the aurora attenuate the signals severely, and this attenuation must be added to that for normal skywave reflection. In the peak auroral-attenuation regions, the auroral-attenuation factor may be as much as 5 orders of magnitude greater than the normal propagational-loss factor K.

The auroras that cause signal drop-out below 30 megacycles are often suitable means of propagation above 30 megacycles. The signals propagated, however, are usually unreadable unless continuous-wave transmission is used, because there is a tendency towards rapid fading and "flutter". Best results are usually obtained by aiming the beam at the auroral display, regardless of the location being received.

As meteors pass through the upper atmosphere, they leave a trail of highly ionised air behind them, which can propagate VHF signals. This technique is virtually useless except perhaps during a meteor shower. Straight CW must be used, because these signals "whistle" and "warble" quite badly.

A technique used more and more by commercial radio links is **troposcatter.** A tendency for radio waves to scatter in the atmosphere is noticeable in the VHF region, but it is most effective and most widely used in the UHF bands. The mechanism of troposcatter allows communications beyond line of sight, with stable signals. The implementation of troposcatter links is complex, however, and requires the use of high-power transmitters and of high-gain antennas.

Tropospheric propagation in the VHF region is principally by means of **tropospheric bending.** At the boundary of air masses of different temperatures and humidities, the refractive index is different from that of either mass. It is therefore possible to communicate along a path (far exceeding line of sight) which falls along this refractive boundary. Signals are sometimes "tunneled" along such boundaries for hundreds of miles.

Recommendations

More effective communications by the ham operator is made possible by the use of the predicted propagation conditions as a guide for scheduling. The author cannot recommend too highly the propagation information offered by the National Bureau of Standards.[1,2] The predictions are based upon experimental data taken at several of the National Bureau of Standards' laboratory sites, and upon the knowledge of the effects of certain cyclic phenomena (sunspots, for example). This information is published three months in advance, and it enables the operator to predict the times, bands, and paths open to him. Or, he may ascertain what time or band would be best to arrange a scheduled contact with another ham. After all, propagation is the basis of all radio communications, both commercial and amateur.

(With acknowledgements to RCA.)

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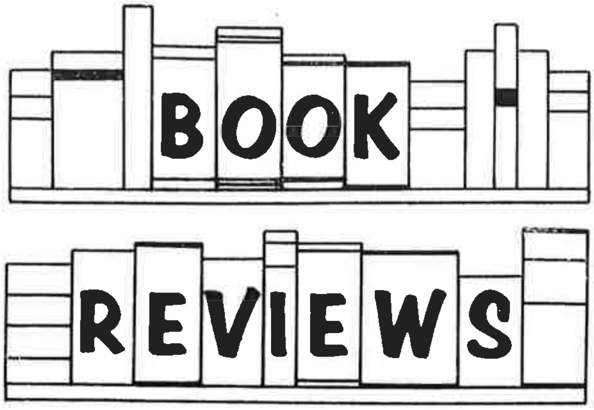

"CIRCUIT THEORY ANALYSIS", J. Mittleman, Iliffe Books Ltd., size 8¾″ x 5½″, 461 pages.

Each chapter if this book contains illustrative examples intended to emphasise the application of circuit theory analysis in practice, whilst exercises at the end of each chapter supplement the text. The object of the book is to help readers solve circuit analysis problems at the final B.Sc. level and examinations of professional bodies. It will however make a useful reference book on the subject.

The argument of the book develops from fundamentals of electron theory, passive and active circuit elements, power and energy, through circuit configurations and their response to time-dependent inputs. A thorough treatment is given of the equations arising from the application of Kirchoff's Laws to circuits. There follows a steady development of analysis techniques through RLC networks, complex frequency analysis and complex multi-loop circuits. Techniques include network graph theory and the important circuit theorems of Thevenin and Norton, delta-star transformations and the reciprocity theorem. A complete chapter devoted to two-part networks is followed by a further chapter on the transformer as a particular case of a two-part network. sinusoidal waveforms is followed by a useful col- A final chapter on the Forrier analysis of non- lection of appendices.

"WORKED EXAMPLES IN ELECTRONICS AND TELECOMMUNICATIONS", B. Holdsworth and Z. Jaworski, Iliffe Books Ltd., size 8¾″ x 5½″.

We have for review volumes 1 and 2 of this work, and there are two further volumes to appear later. Volume 1 is sub-titled "Problems in Electronics" and Volume 2 is sub-titled "Problems in Electronic Theory and Communications". The books have been written specifically to meet the needs of students preparing for final B.Sc. examinations (U.K.) in electronics and electrical engineering, and of those preparing for the qualifying examinations of professional bodies.

Problems are taken from past examination papers of London University and the Institution of Electrical Engineers. Each chapter deals with one main topic and contains a selection of worked examples. All steps are shown in the workings, together with the complete mathematical derivation and analysis required to arrive at the solution. Diagrams, illustrations and graphical solutions are included where necessary.

Efforts have been made throughout to lay stress on areas where difficulties may arise, and alternative approaches and solutions are given where appropriate.

"HIGH INTENSITY ULTRASONICS", B. Brown and J. Goodman, Iliffe Books Ltd., size 8¾″x 5½″, 235 pages.

This book is a comprehensive survey of a rapidly expanding field, and is the first to be devoted entirely to the applications of high-intensity ultrasonics to industrial processes. The first part of the book deals with the principles and properties of ultrasonic waves, whilst the second part covers the various uses to which they may be put.

The discussion turns first of all on the propagation and absorption of waves in liquids and gases, the problems of reflection and refraction, measurements and observations. The important part played by cavitation is recognised by the devotion of a complete chapter to its discussion. Of great practical interest are the descriptions devoted to the methods of generating ultrasonic waves in a medium, characterised by three basic methods. These are mechanical generators, such as sirens and whistles, magnetostrictive transducers and piezoelectric transducers. This discussion is of course supported with the necessary information on power supplies, couplings and control means.

It is not within the scope of this review to list all the possible applications of ultrasonics, but a few may be of interest. Probably the best known application is in the field of cleaning. A less well known field of activity, and a very broad one, is in the homogenisation of manufactured products, of great use and interest to food, textile, cosmetic and pharmaceutical industries. Welding, fatigue testing and ultrasonic machining are among other interesting applications. This would be a useful addition to the bookshelf of anyone working in ultrasonics.


AWV