

SUPPLEMENT

TO

THE POST OFFICE ELECTRICAL ENGINEERS JOURNAL

Vol XXVII

January 1935

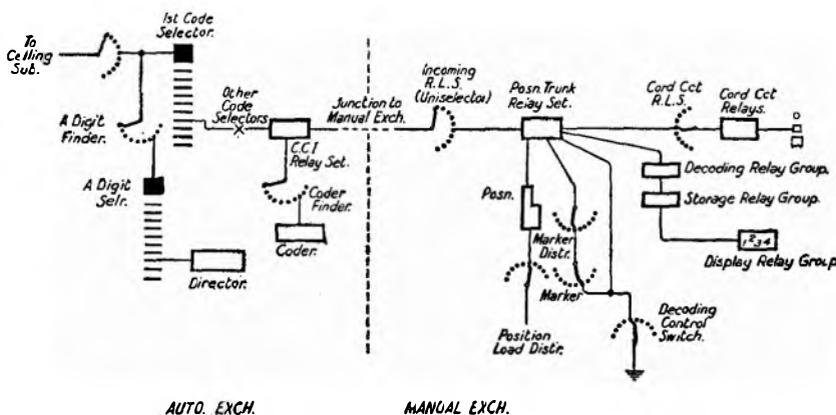
No 4

CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS, 1934

TELEPHONY, FINAL; SECTION I, AUTOMATIC TELEPHONY

Q. 11. In the case of a call from an automatic exchange to a manual exchange, the coder registers the called subscriber's number as received from the director. Indicate by means of a sketch the items of equipment concerned in the subsequent progress of the call up to the stage at which the called subscriber answers, and mention the principal duty of each item. (40).

A. 11. The items of equipment concerned in the subsequent progress of the call are shown in the sketch.



The Cord Circuit Relays control the application of ringing current and its subsequent tripping, the connexion of the called subscriber to the calling subscriber, and the supervisory signals required for the subsequent clear down.

Q. 12. A relay of R ohms resistance and L henrys inductance is connected in series with a variable resistance to a battery of constant voltage. With a standard adjustment of the relay it is found that it will just operate when the series resistance is

The Incoming R.L.S. hunts for and seizes a free position trunk relay set.

The Position Load Distributor ensures the cyclic distribution of incoming calls over the suite of positions, and ensures that calls shall be routed to a position which is free to deal with them.

The Marker Distributor brings the markers forming part of the position equipment into use in cyclic order.

The Marker hunts for and marks a seized position trunk relay set in readiness for the subsequent decoding operation.

The Decoding Control Switch ensures that the decoding relay group is connected to each incoming call in the order in which the calls arrived at the position.

The Decoding Relay Group receives the battery pulses from the coder at the automatic exchange and converts them into their numerical equivalent, at the same time passing the number into the storage relay group.

The Storage Relay Group is operated by the decoding relay group and retains the call until the display relay group is ready to receive it.

The Display Relay Group is operated by the storage relay group and controls the illuminated display given to the operator.

The Cord Circuit R.L.S. is a unselector and hunts for the position trunk relay set from which the call connected over the cord circuit was displayed.

S ohms. If the operating lag of the relay when it is connected directly across the battery is t seconds, show how the formula

$$t = \frac{L}{R} \log_e \left(1 + \frac{R}{S} \right)$$

may be established from Helmholtz' Law. (40).

A. 12. If the voltage of the battery is E , then the operate current $i = \frac{E}{R + S}$

From Helmholtz' Law,

$$i = \frac{E}{R + S} = \frac{E}{R} \left(1 - e^{-\frac{Rt}{L}} \right)$$

$$\therefore \frac{R}{R + S} = 1 - \frac{1}{e^{\frac{Rt}{L}}}$$

$$\frac{1}{e^{\frac{Rt}{L}}} = 1 - \frac{R}{R + S} = \frac{S}{R + S}$$

$$\therefore e^{\frac{Rt}{L}} = \frac{R + S}{S} = 1 + \frac{R}{S}$$

$$\therefore \frac{Rt}{L} = \log_e \left(1 + \frac{R}{S} \right)$$

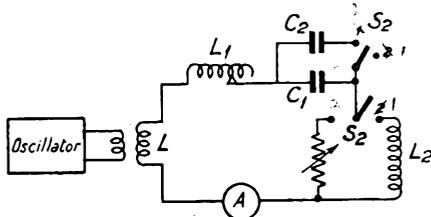
whence $t = \frac{L}{R} \log_e \left(1 + \frac{R}{S} \right)$.

RADIO COMMUNICATION. INTERMEDIATE. QUESTIONS AND ANSWERS.

By A. C. WARREN, B.Sc., A.M.I.E.E.

Q. 1. Describe any method whereby the high frequency resistance of an inductance coil can be accurately measured. Mention any precautions necessary to avoid errors.

A. 1. The high frequency resistance of a coil can be conveniently measured by the substitution method, as shown in the diagram, in which a condenser C_2 and variable resistance are substituted for, and adjusted to equal, the reactance and resistance respectively of the coil under test.



A variable radio frequency oscillator is loosely coupled to a resonant circuit consisting of a tuning coil L_1 , a tuning condenser C_1 , the coil under test L_2 , and a thermo milliammeter A. Switches S_1 and S_2 are inserted to enable the condenser C_2 to be switched in parallel with C_1 and the variable resistance to be substituted for L_2 .

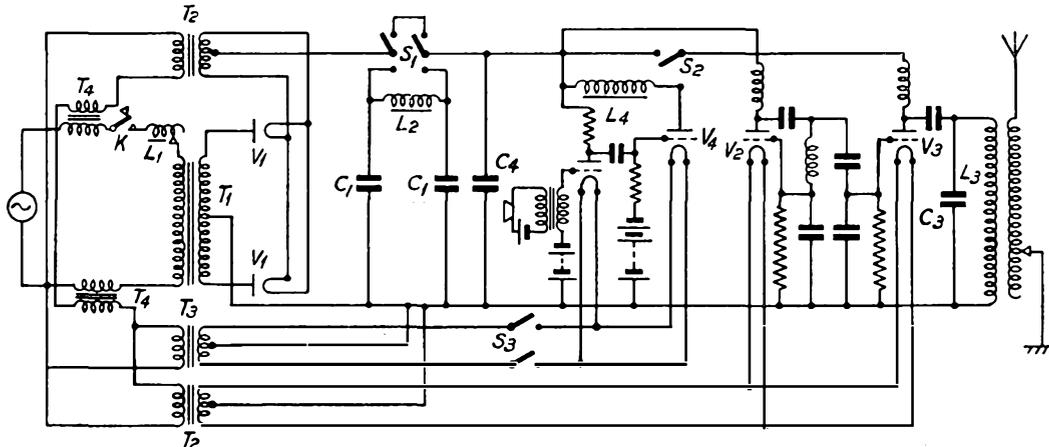
The oscillator is set to the desired frequency and, with the switches in position 1, the circuit is tuned accurately to resonance by means of C_1 and the reading of A noted. With the switches in position 2, the circuit is then retuned by means of C_2 and the variable resistance is adjusted until the reading of A is the same as before. The resistance of the coil is given by the value of this resistance.

In order to avoid errors it is essential that—

- (1) The coupling between the oscillator and the test circuit shall be loose.
- (2) There shall be no direct coupling between oscillator and the coil under test, i.e., the oscillator and the coupling coil L_2 should be screened. The absence of direct coupling can be checked by reversing the connexions of L_1 or L_2 and checking the measurements.
- (3) The sensitivity of tuning C_1 and C_2 should be of the same order, vernier condensers being employed if necessary.
- (4) C_2 should be comprized of high quality mica or air condensers and the variable resistance should be designed as a non-inductive resistance of negligible self-capacity and its radio-frequency resistance should preferably be equal to its D.C. resistance.
- (5) The resistance of L_1 , L_2 , and A should preferably be low compared with the resistance of the coil under test.

Q. 2. Show a circuit diagram and give a description of a ship's transmitter of about $1\frac{1}{2}$ kilowatts input suitable for C.W., I.C.W., and telephony. Include in the diagram the switches necessary to make these changes.

A. 2. A $1\frac{1}{2}$ kw. ship's transmitter suitable for I.C.W., C.W., and telephony is shown in the following diagram. It consists



of a motor alternator furnishing an output of $1\frac{1}{2}$ kw. at 200-250 v and 300-500 cycles/second feeding a full wave thermionic rectifier (output 5000-7000 volts) via the transmitting key K and the power adjustment choke L_1 . Separate transformers tapped off the alternator feed the rectifier modulator and oscillator filaments.

Smoothing for C.W. working is provided by the choke L_2 and condensers C_1 which are cut out by the switch S_1 for I.C.W. The oscillator circuit comprizes the master oscillator valve V_2 , the main amplifying valve V_3 being fed from the oscillatory circuit of V_2 . V_3 is a valve of 300-500 watts dissipation working into the primary circuit L_3C_3 which is coupled to the aerial.

Anode modulation or choke control is employed, the modulator circuit comprising the modulating choke L_4 , modulator valve V_4 , again of 300-500 watts dissipation, which is fed from the submodulator stage with V_5 as submodulator.

For telephony, switch S_1 in the C.W. position and switches S_2 and S_3 are thrown so as to bring the modulator into circuit.

The H.F. bypass condenser C_4 of .001 - .01 μ F is fitted to provide a low impedance path for H.F. when employing I.C.W.; its smoothing effect is negligible.

In such transmitters, owing to the poor regulation of the alternator, it is usual to fit compensating transformers T_4 in the supply to the filament transformers. This transformer is so arranged that an e.m.f. is induced in series with the filament supply to compensate for the drop in alternator voltage when the key is depressed. In this way the valve filaments are maintained at uniform brilliancy.

Q. 3. Give a diagram of the circuit of a rectifier of alternating currents for high tension supply to a radio receiver.

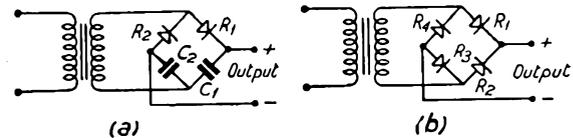
How can a rectifier be used

- (a) as a voltage doubler,
- (b) as a full wave rectifier,

when a centre tapped transformer is not available?

A. 3. Either of the arrangements shown in the following diagrams may be employed as a rectifier for H.T. supply to a radio receiver.

Diagram (a) shows a transformer without a centre tapping employed as a voltage doubler. During one half-cycle the



rectifier R_1 will pass current, the condenser C_1 being charged in a positive direction. During the second half-cycle the rectifier R_2 will pass current and condenser C_2 will become charged. Each condenser thus provides one half of the output voltage, i.e., the circuit behaves as a voltage doubler.

This circuit is, in effect, a full wave rectifier since current is taken from the transformer during each half-cycle.

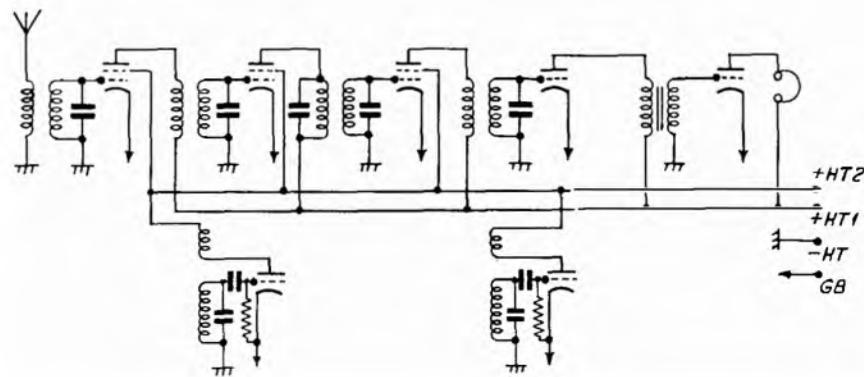
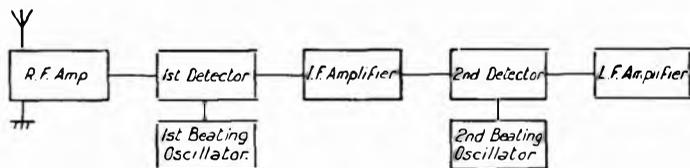
A further full wave rectifier is shown in diagram (b). During one half-cycle, current passes from the transformer through the rectifier R_1 into the condenser, the circuit being completed via the rectifier R_2 back to the transformer. During the other half-cycle, current passes through the rectifiers R_2 and R_4 .

Q. 4. Describe the principle of operation of a supersonic heterodyne receiver. Give a circuit diagram suitable for the reception of C.W. telegraphy or telephony.

A. 4. In a simple heterodyne receiver, the input is amplified at radio frequency and is then heterodyned by an oscillation of such a frequency that the resultant beat note on detection is of audio frequency. The difficulties of obtaining sufficient radio frequency amplification at high frequencies led to the development of the supersonic heterodyne receiver, in which the radio input of frequency f_1 is heterodyned by a frequency f_2 such that on detection the resultant frequency ($f_1 - f_2$) is supersonic, i.e., of radio frequency. The heterodyne oscillator is adjusted so that $f_1 - f_2$, known as the intermediate frequency, is constant, usually 30,000-110,000 cycles. The output after detection can thus be amplified at the intermediate frequency, heterodyned a second time if C.W. reception is involved, detected, and amplified at audio frequency. A block schematic diagram of a super heterodyne receiver is shown below.

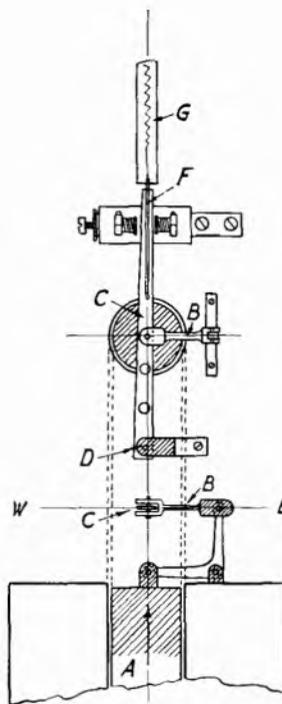
It will be seen that the receiver consists essentially of (1) a radio frequency amplifier; (2) a first beating or heterodyne oscillator; (3) a first detector; (4) an intermediate frequency amplifier; (5) a second beating oscillation for C.W. reception; (6) a second detector and L.F. amplifier.

A wiring diagram of a superheterodyne receiver suitable for the reception of C.W. telegraphy or telephony is shown below. For the reception of telephony the filament and H.T. of the second beating oscillator would be switched off.

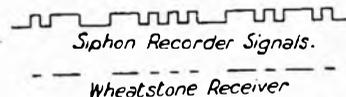


Q. 5. Give a sketch of a siphon recorder and describe how it works. How do the recorded signals differ from those delivered by a Wheatstone receiver? Why are the siphon recorder signals to be preferred for radio reception?

A. 5. A sketch of the siphon recorder is shown below. It consists essentially of a moving coil relay and tape recording mechanism. The D.C. impulse, the output of the receiver, is fed to the moving coil A which is suspended between the pole pieces formed by the magnet system. This coil travels in an upward or downward direction and through the link mechanism communicates an E-W movement to the arm B coupled to the pen arm C. The pen arm which is pivoted about the point D thus vibrates between stops in accordance with the signals. Ink is fed from the ink well to the pen through a flexible siphon tube F, the signals being recorded on a tape G which passes



SKETCH (i).



SKETCH (ii).

more accurately, as variation in amplitude shows the prevailing radio conditions and cause of mutilation.

Q. 6. Explain with a schematic diagram the working of a simple type of radio telephone link between two land line networks. Can such a system be worked on the same wave-length in both directions? What are the limitations of such a system?

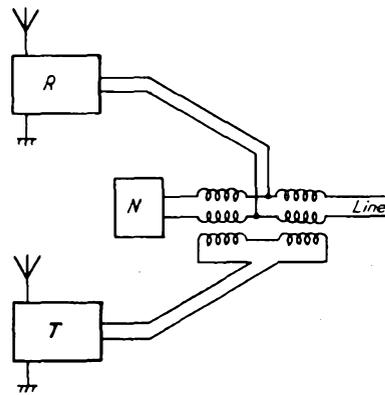
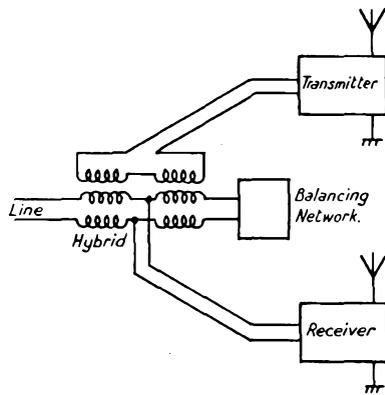
A. 6. A simple method of connexion of a radio telephone link with a land line is shown in the block schematic diagram.

The radio telephone link is essentially a four-wire circuit whilst the land line network consists of two-wire circuits.

The two networks must be combined in such a way that speech transmitted along the "go" circuit passes to the distant land line and no part of it is returned via the return circuit to the sending end. The simplest method of combining the circuits is the hybrid transformer as shown. Speech from the subscriber passes round the loop consisting of the line, the hybrid transformer and the balancing network in such a manner that voltages are set up across the transmitting or "go" line and speech passes out to the transmitter.

Speech from the radio receiver is applied across the hybrid as shown such that the current splits equally, one half passing into the balancing network and one half into the line. If the coils L_1 and L_2 are equal and their coupling to the transmitting leg is identical, there will be no resultant e.m.f. induced into the transmitting leg due to received speech.

In order that the current shall split equally, the balancing



network must be equal to the impedance of the two-wire line at all frequencies. Since telephone lines vary and are frequently incorrectly terminated, this condition becomes impossible to meet. Thus the degree of balance obtained at the hybrid termination is imperfect, the attenuation of received speech in the transmitting leg being perhaps only 6-10 db.

The radio path is a variable one and its attenuation may vary from instant to instant; thus, if the circuit is adjusted so that the output at the receiving end is equal to the input at the transmitting end, a sudden decrease in the attenuation of the radio path will cause the circuit to sing.

This circuit can only be employed, therefore, provided that the attenuation of the radio path is practically constant, *i.e.*, if the radio link is a short one.

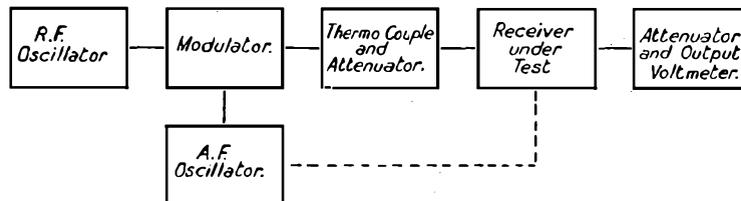
It has the further disadvantage that

- (1) If one radio receiving circuit is noisy, the unbalance in the hybrid will cause noise to be radiated by the transmitter at that end of the circuit only slightly attenuated and will penalize reception at the distant end.
- (2) If one wire line is noisy, its noise will be transmitted and will be received at the distant end. Owing to lack of balance at the hybrid, it will then penalize transmission from the distant end.

If both transmitters are worked on the same wave-length the field set up at the receiver by the local transmitter will be very much higher than that set up by the distant transmitter. Since the radio receiver is adjusted to receive the distant station, the receiver output will far exceed the speech input to the local transmitter; thus, the circuit will "sing" round the circuit comprised of the hybrid, the local transmitter and receiver, *i.e.*, this system is unsuitable for operation on the same wave-length in both directions.

Q. 7. Explain how an attenuator can be used in connexion with a radio frequency oscillator and an audio frequency oscillator for measuring the amplification, selectivity and fidelity of broadcast receivers.

A. 7. A suitable method for measuring the amplification, selectivity and fidelity of a broadcast receiver is shown in the following block diagram.



The apparatus consists of,

- (1) A radio frequency oscillator capable of fine adjustment over the range of broadcast frequencies.
- (2) A variable audio frequency oscillator of constant or adjustable output.

(3) A modulator stage.

(4) A thermocouple or voltmeter and calibrated attenuator for measuring the output from (1), (2) and (3).

(5) The receiver under test.

(6) An output voltmeter.

The amplification of the receiver may be measured in separate stages, *i.e.*, the gain of the R.F. stages, the efficiency of the detector and the gain of the A.F. stages; or it may be measured in terms of the A.F. output when an R.F. input modulated to a specified percentage modulation is applied to the input.

The first method only is described.

A modulated R.F. input is applied first to the grid of the detector and the output of the A.F. stages measured. This input is then applied to the input of the receiver and the attenuator adjusted until the output of the A.F. stages is the same as before. The attenuation inserted in the attenuator is equal to the gain of the R.F. stages.

The gain of the A.F. stages is obtained by applying a fixed A.F. input to the grid of the first A.F. valve, the A.F. output being connected to the voltmeter through the attenuator. The input is then measured and the attenuator adjusted until the reading on the output voltmeter is the same as the input. The attenuator setting is then equal to the gain of the A.F. stages.

The efficiency of the detector can be determined by applying a known modulated R.F. voltage to the input of the detector and measuring the output of the detector or A.F. stages.

In the case of a superheterodyne receiver it is preferable to adopt the second method.

The selectivity of the receiver may be measured by applying an R.F. voltage modulated to a fixed percentage, tuning the receiver accurately to this input and measuring the A.F. output, the attenuator being inserted immediately in front of the output voltmeter. Leaving the receiver untouched, the R.F. input is then varied over a range of radio frequencies, the output being noted for each setting. A curve of A.F. output against R.F. input can then be plotted.

The fidelity of the receiver can be measured by applying a modulated R.F. input of constant amplitude to the receiver which is accurately tuned and measuring the A.F. output, the

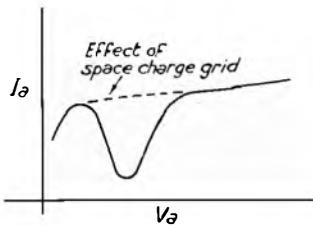
attenuator being fitted in front of the output voltmeter. The modulation is fixed and the modulating frequency varied over the full A.F. range, the output being measured for each frequency. A curve is then plotted of A.F. output against frequency

Q. 8. What is a pentode? Explain the functions performed by the various electrodes. Give a typical anode current grid voltage characteristic for a pentode.

A. 8. A pentode is a five-electrode valve consisting of an anode, a filament, and three grids, the control grid, screen grid and space charge grid respectively.

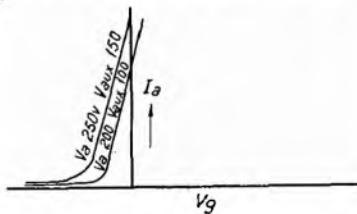
The grid nearest to the filament is known as the control grid. The input is applied to this electrode which serves to control the anode current and hence the alternating voltage set up across the output circuit which is connected in series with the anode.

A positive potential of about half the anode voltage is applied to the screen grid which is inserted to neutralize the inter-electrode capacity between the control grid and anode. The introduction of this electrode materially increases the anode A.C. resistance of the valve and at the same time introduces a kink in the anode current-anode voltage curve, as illustrated in sketch (i), due to secondary emission of electrons from the anode



SKETCH (i).

when the screen grid is positive to the anode. This kink reduces the length of the anode current anode voltage curve which can be used. The insertion of a fifth electrode connected to the cathode between the screen grid and anode overcomes this defect since electrons which are shot off from the anode will be repelled by this grid and driven back on to the anode. The resultant effect on the characteristic is indicated by the dotted line. Sketch (ii) shows a typical anode current grid voltage curve.



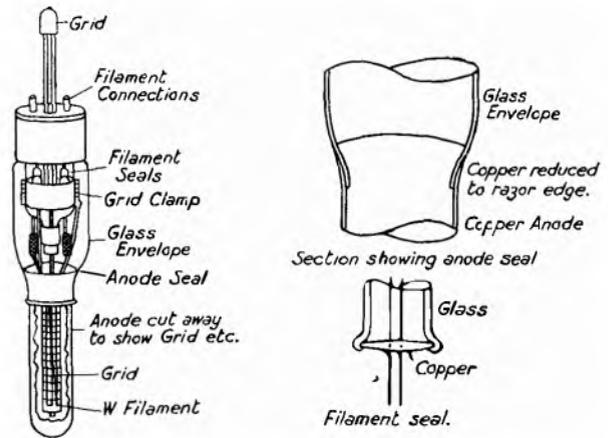
SKETCH (ii).

Q. 9. Draw in section a cooled anode three-electrode transmitting valve and explain how the connexion between the metal anode and the glass portion is effected. What materials are used for the anode of such valves and what fluids are used for cooling?

A. 9. A section of a cooled anode valve is shown in the sketch. The anode is normally constructed of copper or chrome iron. Water cooling is usually employed, but in some short wave transmitters oil cooling is used.

Various methods are employed for effecting the seals between the metal and glass depending upon the metal used. Those employed for making seals with copper are shown in sketches (i) and (ii). Sketch (i) shows an anode seal; the anode is flared and is reduced in thickness to a razor edge. The glass envelope and copper anode are heated together and the glass pressed into uniform contact with the anode. Union or wetting of the glass and metal is effected through a thin film of copper borate which is formed on the anode by chemical action. In spite of the unequal coefficients of expansion of the glass and metal a perfectly air-tight seal is effected.

A typical filament or grid seal is illustrated in sketch (ii). In this case, the glass tube is thickened to form a bead seal round the metal disc through which the connexions are taken.



SKETCH (i).

SKETCH (ii).

Q. 10. Explain why some types of electrical machinery are liable to produce interference with radio reception. How is such interference transmitted? Indicate any method or methods of suppressing interference from small direct current motors.

A. 10. When the current in a circuit is suddenly made or broken, transients are set up which give rise to damped radio frequency oscillations in the circuit, or between the circuit and earth. If that circuit is connected to the electric mains, those oscillations will be propagated along the mains. Thus when a lamp is switched on or off in a house lighting system a "plop" is heard in an adjacent radio receiver.

In the case of a motor or generator fitted with a commutator sudden changes of current occur during commutation and then such motor or generator will set up radio frequency oscillations which, due to the continuous process of commutation, are heard as a harsh note in a radio receiver.

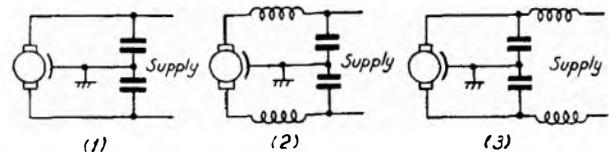
This disturbance may be transmitted to an adjacent radio receiving aerial—

- By direct radiation from the machine and adjacent wiring.
- By propagation along the electric mains, usually between both conductors in parallel and earth, and reradiation from the house wiring at the receiving point.
- By induction from the machine and adjacent wiring, or from the mains if overhead, into other overhead wires such as telephone or tramway wires from which it will be radiated.

Three methods of eliminating interference from small direct current motors are shown below.

In method (1) two non-inductive condensers are connected in series across the armature of the machine and the centre point is connected to its frame and thence to earth. The capacity of the condensers should be from 0.01 μ F to 2 μ F.

In methods (2) and (3), two high frequency chokes of 200-1000 μ H are connected in series with the machine and the condensers connected on the machine or supply side respectively. Method (2) should be employed when the impedance of the supply mains is low, whilst method (3) is used when the effective impedance of the machine is low.



In general, however, with small electric motors, condensers alone provide sufficient suppression except where the leads to the condensers and to earth have to be made long.

RADIO COMMUNICATION : FINAL. QUESTIONS AND ANSWERS.

By A. C. WARREN, B.Sc., A.M.I.E.E.

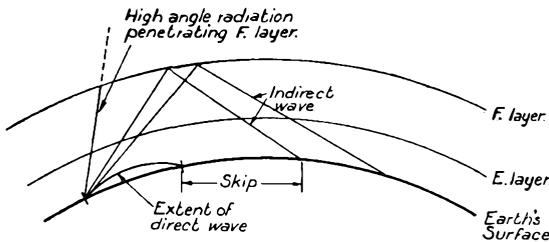
Q. 1. What is the part played by the Heavside layer in the propagation of short waves? Why is it necessary, in short wave communication over long distances, to use longer waves during the night than during the day?

A. 1. The Heavside layer consists of two ionized regions known as the E and F layers, the heights of which are approximately 90 and 250 k.m. respectively above the earth. The radiation from a long wave aerial is mainly horizontal and is reflected from or refracted through the E layer, thus enabling the wave to follow the curvature of the earth.

On short waves, however, aerials and arrays can be constructed so that the large proportion of the radiation is at an angle to the horizontal. It is thus found that the transmission from a short wave aerial follows two paths.

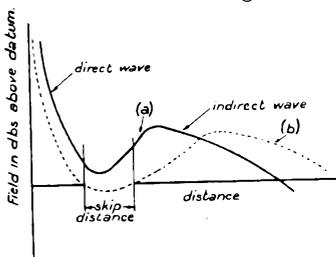
- (a) The direct path or low angle ray.
- (b) The indirect wave or high angle radiation which penetrates the E layer, travels unattenuated in the ionized region between the E and F layers, and is reflected or refracted from the F layer. If, however, the radiation is practically vertical, it may penetrate both the E and F layers and be entirely lost.

These effects are shown in sketch (i). The variation of field

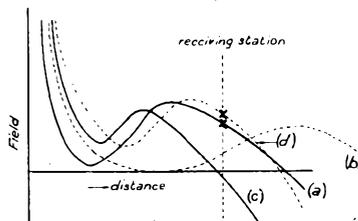


SKETCH (i).

strength with distance from the transmitting station is shown in sketch (ii). At short distances from the transmitting station the direct wave and at long distances the indirect wave only is received. There is, in addition, an intermediate region known as the skip distance where both direct and indirect rays are weak.



SKETCH (ii).



- (a) 20 metres daylight.
- (b) 20 " night.
- (c) 60 " daylight.
- (d) 60 " night.

Curve showing 20 metres daylight & 60 metres night, both good at a given range.

SKETCH (iii).

At night their height increases, the attenuation of the direct ray decreases, and the skip distance shifts outwards from the transmitter, i.e., the distance at which the

indirect ray is first received increases. Thus using 20 metres good reception may be obtained at a given distance during daylight whereas at night the receiving point will fall within the skip distance. By increasing the wave-length to 40 or 60 metres good reception will be obtained. This effect is illustrated in sketch (iii).

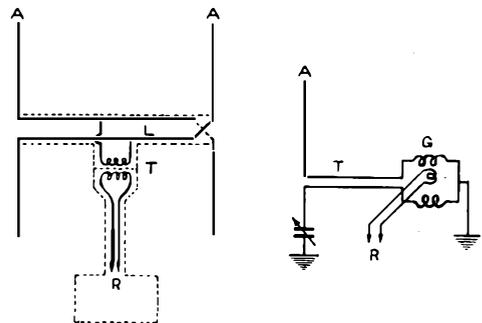
Q. 2. What is the cause of night errors in rotating loop and Bellini-Tosi direction finders? Explain clearly how the Adcock aerial tends to obviate such errors. Give diagrams of the aerials and associated circuits for:—

- (a) Rotating Adcock system.
- (b) Fixed Adcock system.

A. 2. Direction finders which employ loop aerials give accurate bearings only when receiving vertically polarized waves, i.e., when horizontal polarization due to indirect waves is absent. On long and medium waves the indirect wave is strongest at night and hence the errors due to downcoming horizontally polarized waves is greatest.

These errors can be avoided by using the Adcock system which consists of spaced vertical aerials (two or four) as shown in the sketches. The vertical aerials pick up only the vertically polarized waves and if these waves are combined through horizontal members which are so arranged that their pick-up is negligible the errors are eliminated.

(a) **Rotating Adcock System.** A suitable arrangement for a rotating Adcock system is shown in sketch (i). It consists of two spaced vertical aerials A which are broken at their centres and combined through a screened transmission line L and coupled to the receiver R via the transformer T. In order to ensure perfect screening and the absence of horizontal pick up, the leads to the receiver must also be screened.



SKETCH (i).

SKETCH (ii).

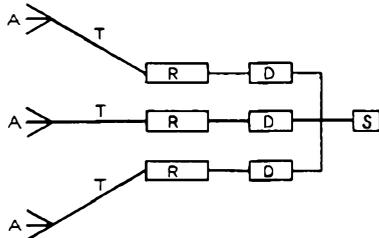
(b) **Fixed Adcock System.** A fixed Adcock system consists of four aerials spaced in the form of a square. Each aerial is led into goniometer coils G on a horizontal transmission line T. A double wire line is used, each aerial being earthed at its base, through a balancing condenser, sketch (ii). The line is then balanced so that its pick up is negligible. The four aerials are connected to separate coils in the goniometer, opposite aerials being associated. The goniometer is similar to that in a standard Bellini Tosi system.

Q. 3. Explain what is meant by diversity reception. Indicate by means of a circuit diagram how radio-telegraph reception on this system is carried out in practice.

A. 3. Short wave transmission suffers from severe fading due to the fact that the waves picked up at the receiving aerial may have travelled along paths of different length, this difference in length being one half wave-length or more. At the receiving point, therefore, components of the wave which have travelled by different parts may nullify each other. The path lengths are, however, changing continuously and so the field at one point may be low at a given moment, whilst the field a short distance away may be high and vice versa. If therefore the

e.m.f.'s in a number of aerials or arrays placed some distance apart are combined, their vector sum will be reasonably constant. The system of reception employing such an arrangement is known as diversity reception. Two or three aerials or arrays are normally employed and are spaced 500-1500 feet apart.

A schematic diagram of the method in which reception is carried out is shown below. Three aerials or arrays A are



coupled to three separate receivers R through transmission lines T. These receivers are normal short wave heterodyne receivers. The low frequency output of each receiver is passed to a detector D and the outputs are combined through a low pass filter and D.C. amplifier S. The output of the D.C. amplifier may be utilized to operate a Wheatstone receiver or relay. An incoming signal on any one aerial results in an A.F. output from its receiver. This output is rectified and the D.C. component passes through the filter, is amplified, and is sufficient to operate the telegraph relay. Each aerial will contribute its output and the rectified D.C. component of each must be additive. The effects of fading are therefore overcome. It will be observed that the practical system overcomes any defects of combining the three aerials at radio frequency.

Q. 4. What is meant by the characteristic impedance of a transmission line? Give the general expression for the characteristic impedance of a line in terms of series resistance, series inductance, shunt conductance, and shunt capacitance. How can this expression be simplified for currents of high frequency and what is approximately the phase of the characteristic impedance at high frequencies?

A. 4. The impedance of a transmission line of infinite length is defined as the characteristic impedance. Thus if a line of finite length is terminated at the receiving end by an impedance equal to the characteristic impedance, the impedance of the line as viewed from the sending end will be equal to the characteristic impedance. It may be defined as the impedance which is the vector ratio of the applied e.m.f. to the steady state current on the line when the line is terminated by that impedance.

The characteristic impedance Z_0 is given by

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where R, L, G, and C are the resistance, inductance, conductance, and capacitance per unit length respectively.

At radio frequencies $\omega = 2\pi f$ is high, but R and G do not vary considerably from their low frequency values; thus, in general, R and G may be neglected in comparison with $j\omega L$ and $j\omega C$ whence we see that $Z = \sqrt{\frac{L}{C}}$ which is resistive, i.e., of zero phase angle.

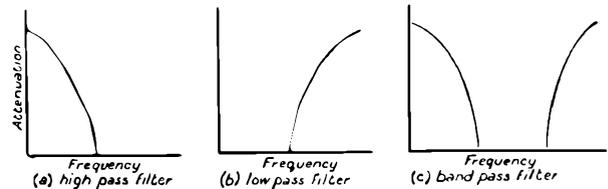
Q. 5. What is a wave filter? Give typical characteristic curves indicating the attenuation in respect to frequency in the case of high pass, low pass and band pass filters. How does the ratio of series impedance Z_1 to shunt impedance Z_2 in a filter determine its attenuation in respect to frequency?

A. 5. A wave filter may be defined as a network which has a low or negligible loss over a band of frequencies and high loss at all other frequencies. Typical characteristics of high pass, low pass and band pass filters are shown in curves (a), (b) and (c)

The propagation constant P of a filter is given by $P = A + jB = Z \sinh^{-1} \frac{1}{2} \sqrt{\frac{Z_1}{Z_2}}$ where Z_1 and Z_2 are the series and shunt impedances. It can be proved that:—

- (1) If $\frac{Z_1}{Z_2}$ is positive then the filter will attenuate.
- (2) If $\frac{Z_1}{Z_2}$ is negative and is less than four in absolute magnitude the filter will not attenuate.

i.e., the pass range of the filter is those frequencies for which the ratio $\frac{Z_1}{Z_2}$ is negative and is less than four.



Q. 6. What are the reasons for the use of piezo-electric crystals for frequency control? What precautions are necessary if the best results are to be obtained? What, approximately, are the highest frequencies for which quartz crystals can be manufactured and used? How can frequencies above this limit be controlled?

A. 6. In order to maintain constancy of frequency in a valve transmitter, it is desirable to control the frequency of the output stage. This can be achieved (a) by the use of a master oscillator; (b) by means of a tuning fork controlled oscillator; (c) by means of a piezo-electric crystal controlled oscillator. The last has the advantages (a) that the frequency constancy obtainable thereby is considerably better than that obtainable with a master oscillator, and (b) crystals can be ground so as to control directly on frequencies up to 3-10 megacycles per second.

The following precautions are necessary if best results are to be obtained:—

- (a) The crystal should be ground to work on a frequency of 3-5 megacycles per second.
- (b) It should be cut from the crystal in such a manner as to have a minimum temperature coefficient.
- (c) The crystal should be selected so as to be free from multiple frequencies of vibration.
- (d) The crystal and the complete oscillator circuit should be mounted in a temperature controlled oven.
- (e) All supplies to the crystal oscillator should be maintained constant.
- (f) The load on the oscillator should be constant, i.e., it should be independent of the output of the main stages of the transmitter. For this reason the output is fed through a buffer or separator stage which is very lightly loaded.

Quartz crystals can be manufactured for frequencies up to 10-20 megacycles per second, but such crystals are very difficult to manufacture and delicate for use. Best results are obtained from crystals ground for frequencies of 3-5 megacycles. Frequencies above this can be obtained by frequency multiplication. The waveform of the crystal oscillator output is distorted in a succeeding stage and the second or third harmonic selected. This process can be repeated if necessary.

Q. 7. Explain what is meant by a single sideband suppressed carrier radio-telephone system. Give a schematic diagram of the apparatus necessary at the transmitter for the production of this type of emission. Mention any advantages of the system for long waves and for short waves.

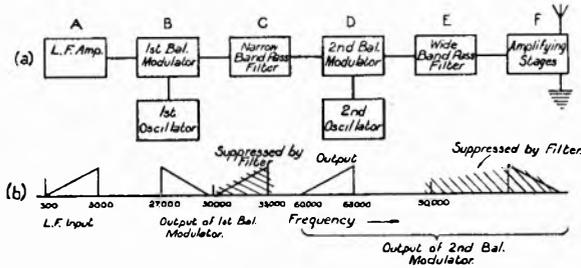
A. 7. A modulated wave I_m may be represented by the equation $I_c \sin \omega_c t (1 + m \cos \omega_m t)$ where I_c is the amplitude of the carrier, $m \times 100$ is the percentage modulation and ω_c and ω_m are 2π times the carrier and modulation frequencies respectively.

This may be expanded as follows:—

$$I_m = I_c \sin \omega_c t (1 + m \cos \omega_m t) \\ = I_c \sin \omega_c t + \frac{m}{2} I_c \sin (\omega_c + \omega_m)t + \frac{m}{2} I_c \sin (\omega_c - \omega_m)t.$$

The first term represents the carrier and the last two terms are known as the upper and lower sidebands respectively. Each of these sidebands contains all the elements of the modulating wave $m \cos \omega_m t$. Thus the suppression of the carrier and one sideband and the transmission of the other sideband alone is sufficient for the transmission of intelligence. Such a system is known as the single sideband suppressed carrier system. A

schematic diagram of a typical transmitter is shown in sketch (a). It consists of:—



- (A) A low frequency amplifier and band pass filter to restrict the speech band to that desired to be transmitted, say, 300-3,000 cycles per second.
- (B) A balanced modulator, the oscillator being fixed at a frequency, say, of 30,000 cycles. The output from this stage will consist of only the two sidebands.
- (C) A band pass filter passing frequencies of 29,700-27,000 cycles only, thereby cutting out one sideband and the residual carrier of the first oscillator.
- (D) A second balanced modulator the frequency of which can be varied over a range of frequencies.
- (E) A second band pass filter which passes one sideband only set up during the second process of modulation and eliminates the residual second oscillator carrier and other sideband.
- (F) Amplifying and output stages of the transmitter.

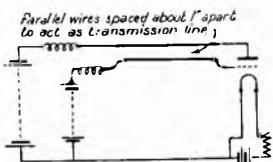
These processes are indicated in sketch (b). The advantages of this system on long waves are—

- (1) Power saving by elimination of the carrier and one sideband.
- (2) Little or no power is consumed in the high power stages of the transmitter except when speech is being transmitted.
- (3) On long waves the ether is very congested and by the elimination of one sideband the band of frequencies occupied by the transmitter is halved.
- (4) The high power circuits are simplified since they can be designed to give a uniform response to a band of frequencies which is only one-half that of a double sideband transmission.
- (5) The system introduces a partial form of privacy, since the carrier has to be reinserted at the correct frequency at the receiving end.

On short waves advantages (1) and (2) still hold, whilst in the present state of the art (5) applies to an increased extent. A further advantage is that distortion due to selective fading which occurs on the double sideband system is reduced and for a given power output the signal noise ratio is improved due to the reduced band width occupied in the ether.

Q. 8. Give a diagram of an electron valve oscillator circuit suitable for the production of oscillations of a wave-length of the order of 50 cm. How can the wave-length of such oscillations be determined?

A. 8. An electron valve oscillator of the Barkhausen type is shown in the following diagram. It consists essentially of a



small valve of a type specially designed for short wave operation. A positive voltage of 100-200 volts is applied to the grid through a small H.F. choke and a small negative potential is applied to the anode through a similar choke. The supply leads to the electrodes are run parallel to act as a transmission line and should preferably be a $\frac{1}{4}$ wave-length or more in length. Electrons shot off from the filament travel with high velocity towards the grid, due to the high positive grid potential, and in consequence some pass through it. They are, however, repelled by the anode and return toward the grid, but before arriving there they may oscillate in the space between it, and the filament and anode two or three times. By adjusting the length of the transmission lines to the frequency of these electron oscillations the output can be usefully employed.

The wave-length of these oscillations can be measured by

utilizing a long transmission line. This serves as a pair of Lecher wires; standing waves are set up on it and if it is bridged by a small lamp, nodes and anti-nodes of voltage can be detected. Successive nodes will be one half wave-length apart and thus a direct measurement of wave-length is obtained.

Q. 9. What are the advantages of automatic gain control when applied to a radio-telephone receiver? How does the time of operation of the control affect the performance of the receiver? Give a diagram of a control system suitable for a high class broadcast receiver. What can be done to avoid excessive noise when tuning between stations?

A. 9. The advantages of automatic volume control in a radio receiver are—

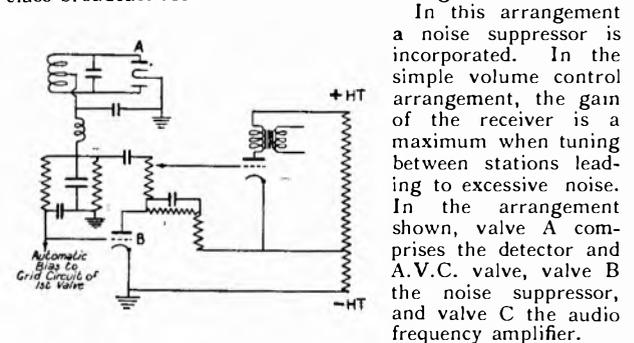
- (1) That the output is maintained sensibly constant when tuning in either strong or weak stations without the necessity of manual adjustment.
- (2) It may be utilized to overcome the effects of fading, particularly in short wave reception.

If the time of operation of the control is long, exceeding say 5 seconds, the control can be utilized to compensate only for variations in average strength of carriers and for long period fading in a given carrier such as occurs in long distance reception of medium wave-lengths at night.

Fading, however, varies in periodicity with wave-length on medium waves; where reception of the indirect ray is concerned, the period may be of seconds or minutes duration. On short waves, rapid fading of periodicity of the order of 1/10th sec. or slow fading of the order of 1-10 secs. may occur and thus it may be advantageous to vary the time of operation of the control device in accordance with the type of fading which prevails.

If the time of operation is made too short, such as 1/50th second, the tendency will be for the control to respond to the received modulation thereby introducing distortion.

A typical diagram of a control system suitable for a high class broadcast receiver is shown in the diagram.



In this arrangement a noise suppressor is incorporated. In the simple volume control arrangement, the gain of the receiver is a maximum when tuning between stations leading to excessive noise. In the arrangement shown, valve A comprises the detector and A.V.C. valve, valve B the noise suppressor, and valve C the audio frequency amplifier.

The grid bias on valve B, which is tapped off the automatic bias voltage, is proportional to the carrier input and a resistance in the anode circuit of valve B is included in the grid circuit of valve C. Thus, when no carrier is applied to the receiver, no automatic bias is applied to valve B which takes current and the voltage drop through the resistance R being applied to valve C cuts off the output from that valve, i.e., noise between stations is suppressed.

When a carrier of predetermined value is applied, valve B is biased to cut off and the bias on valve C is restored to normal by the cessation of anode current through valve B.

Q. 10. An attenuator of T type is required to produce a loss of 10 decibels in a 600-ohm transmission line. Compute the values of the shunt and series resistances.

A. 10. If the series and shunt resistances are R_1 and R_2 respectively, the line impedance R_0 and the ratio of input to output current of the network is n

$$\text{Then } R_1 = R_0 \frac{n-1}{n+1} \text{ and } R_2 = R_0 \left(\frac{2n}{n^2-1} \right).$$

If the loss of attenuation is 10 dbs. $n = 3.162$

$$\text{whence } R_1 = 600 \frac{2.162}{4.162} = 312 \text{ ohms.}$$

$$R_2 = 600 \frac{6.32}{9} = 421 \text{ ohms.}$$

Q. 1. Calculate the current and the voltage drop in a 600-ohm resistance in which the power dissipated is (a) 10 decibels above, and (b) 20 decibels below, one milliwatt.

Compute the ratios of voltages and currents when equal powers are dissipated in 600-ohm and 1,200-ohm resistances. (30 marks).

A.1.

$$EI = \frac{E^2}{R} = \frac{1}{1000} \text{ watts}$$

$$E = \sqrt{\frac{600}{1000}} = \sqrt{0.6} = 0.7746 \text{ volt.}$$

$$I = \frac{0.7746 \times 1000}{600} = 1.291 \text{ mA.}$$

In case (a), $10 = 10 \log_{10} \frac{P_1}{P_2} = 20 \log_{10} \frac{I_1}{I_2}$ or $20 \log_{10} \frac{E_1}{E_2}$

In case (b), $20 = 10 \log_{10} \frac{P_1}{P_2} = 20 \log_{10} \frac{I_1}{I_2}$ or $20 \log_{10} \frac{E_1}{E_2}$

i.e., 10 db. represents a power ratio of 10 and a voltage or current ratio of $\sqrt{10}$; and 20 db. represents a power ratio of 100 and a voltage or current ratio of 10.

Therefore (a) Current = $1.291 \times 3.162 = 4.09 \text{ mA}$

Voltage = $0.7746 \times 3.162 = 2.45 \text{ V}$

(b) Current = $\frac{1.291}{10} = 0.1291 \text{ mA}$

Voltage = $.07746 \text{ V.}$

In the case of equal powers in 600 ohms and 1200 ohms,

$$E_1 I_1 = E_2 I_2$$

$$\frac{E_1}{E_2} = \frac{I_2}{I_1}$$

that is, one ratio is the reciprocal of the other.

$$\frac{E_1^2}{R_1} = \frac{E_2^2}{R_2}$$

$$\frac{E_1}{E_2} = \sqrt{\frac{R_1}{R_2}} \text{ and } \frac{I_1}{I_2} = \sqrt{\frac{R_2}{R_1}}$$

The voltage across the 1200-ohm resistance will be greater than that across the 600-ohm resistance by the ratio $\sqrt{\frac{1200}{600}}$ or 1.414. Similarly, the current in the 600-ohm resistance will be greater by the ratio of 1.414.

Q. 2. Discuss the dependence of a carrier system upon filters. (30).

A. 2. A carrier system consists essentially of means of transposing voice frequency currents from their normal position in the frequency spectrum to some other position, dependent upon the characteristics of the transmitting channel being used. This higher frequency band contains all the characteristics of the transmitting channel being used. This higher frequency band contains all the characteristics of the normal speech currents and is transmitted along the line. At the distant end, the higher frequency band transmitted is re-transposed to its normal position in the frequency spectrum, and the voice frequency currents resulting are passed forward to the subscriber.

The process of transposition is termed modulation and consists in impressing the characteristics of the voice frequency currents on to a fixed high frequency current termed the carrier. The process of re-transposition is termed de-modulation and consists in extracting from the carrier current the voice frequency characteristics imposed on it at the sending end.

The products resulting from modulation include a component at the carrier frequency, and components having values equal to the sum and difference, respectively, of the carrier and modulating frequencies. Modern carrier systems are of the "suppressed carrier" type, the carrier being re-introduced at the distant end by the demodulator. Further, since both side-bands contain the components of the original speech currents, the transmission of only one of them is required

Low-pass filters are used to separate the voice frequency channel from the carrier channel transmitted over the same physical circuit, whilst band-pass filters are used to permit

transmission only of the required side-band, all other products of modulation being suppressed. High-pass filters are used to prevent the voice frequency currents in the line from affecting the carrier channels. In multi-channel systems, separate frequencies are used for transmitting and receiving; directional filters are therefore inserted in the transmitting and receiving portions to prevent interference between channels.

Q. 3. State the total impedance of a circuit consisting of two parallel branches, one of which has an admittance $Y_1 = g_1 + jb_1$, and the other an admittance $Y_2 = g_2 + jb_2$.

Show that the frequency of an alternating current supplied to a bridge may be determined from the balance of the impedances of two arms, one of which is a resistance and condenser in series, and the other a resistance and condenser in parallel. (30).

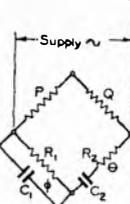
A. 3. The total admittance, in vector notation, of Y_1 and Y_2 in parallel is $Y_1 + Y_2 = (g_1 + jb_1) + (g_2 + jb_2) = (g_1 + g_2) + j(b_1 + b_2)$.

$$Z, \text{ the total impedance} = \frac{1}{Y_1 + Y_2} = \frac{1}{(g_1 + g_2) + j(b_1 + b_2)} = \frac{(g_1 + g_2) - j(b_1 + b_2)}{(g_1 + g_2)^2 + (b_1 + b_2)^2}$$

The impedance of the circuit containing series impedances Z_1 and Z_2 is $Z = (r_1 + jx) + (r_2 + jx_2) = (r_1 + r_2) + j(x_1 + x_2)$

$$\text{The admittance of the circuit, } Y = \frac{1}{Z} = \frac{(r_1 + r_2) - j(x_1 + x_2)}{(r_1 + r_2)^2 + (x_1 + x_2)^2}$$

Where f is the frequency to be determined, let the impedance of the arm containing R_1 and C_1 be $r_1 + jx_1$ and that of the arm containing R_2 and C_2 be $r_2 - jx_2$. Then on balance,



$$P(r_2 + jx_2) = Q(r_1 + jx_1)$$

$$g_1 + jb_1 = \frac{1}{R_1} + j\omega C_1$$

$$\therefore \phi = \tan^{-1} \omega C_1 R_1$$

$$r_2 + jx_2 = R_2 - j \frac{1}{\omega C_2}$$

$$\therefore \theta = \tan^{-1} \frac{1}{\omega C_2 R_2}$$

Let $P = Q$; then on balance, $\phi = \theta$

$$\text{and } \omega = \frac{1}{\sqrt{C_1 R_1 C_2 R_2}}$$

Q. 4. Explain the principles on which transmission testing equipment suitable for measuring line losses and transmission levels is designed. (30).

A. 4. Transmission measuring equipment is usually designed to deliver, at one or more frequencies, a power of 1 milliwatt to a 600-ohm (zero angle) line, and to indicate by reference to 1 mW in 600 ohms the voltage received from line across a 600-ohm terminating resistance. The fundamental requirements of transmission measuring sets are—

(a) The sending and receiving elements should act as 600-ohm terminating impedances on the lines or apparatus tested.

(b) The generated voltage should be independent of the impedance of the line or apparatus tested.

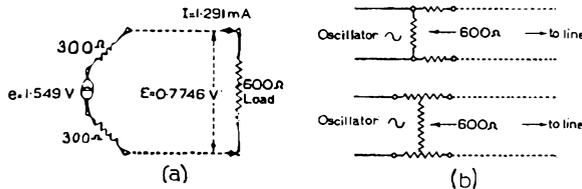
(c) The detector for indicating the transmitted voltage should present a high impedance over the range of frequencies over which the set is required to operate accurately, so that it will not affect the 600-ohm terminating impedance with which it is in parallel, or disturb the impedance and voltage conditions in a line or network with which it is connected for level measurements.

(d) The detector must be efficient over a wide range of voltage values, the range being in the order of -10 (or -20) to -20 (or -30) db. relative to 1 mW in 600 ohms.

(e) The local sending element must be used in association with an accurately known loss for the calibration of the detector.

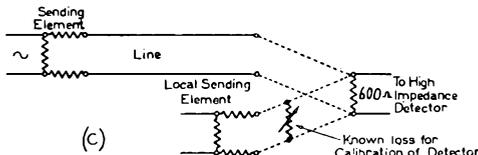
(f) The oscillator output must have an inappreciable harmonic content, or poling changes and errors due to the harmonic may be experienced.

The sending element is therefore required to act as a 600-ohm generator with constant generator voltage, as shown in sketch (a). This condition is realized by employing an L or T



network of pure resistances which will introduce a loss between the terminals connected to the oscillator and those connected to the line (sending terminals) such that the output current to line is only about 2% of the output current from the oscillator, i.e., the network is designed to have an impedance of 600 ohms with high attenuation, say in the order of 20 db. In practice, therefore, the sending element is of the type shown in sketch (b). A milliammeter is usually associated at the inputs to the networks for checking the sent power.

The arrangement of the set for sending power to line, measuring the voltage received across 600 ohms at the distant end, and calibrating the detector are indicated in sketch (c).



If under the calibration conditions, the 600-ohm resistance is disconnected, the voltage, in accordance with transmission theory, will be doubled and the detector will indicate high by 6 db. (approx.). If level measurements are made, the set will only give correct indications of the power passing the point if the line is of 600 ohms impedance and if the level is required in terms of 1 mW in 600 ohms, it is necessary to employ a correction factor in terms of the set and line impedances. In the case of transmission measurements, however, lines, etc., are measured with 600-ohm terminating impedance and the reflection at the sending and receiving ends of the line is not appreciable. The line impedance can be double the set impedance, introducing an error, in sent power, of not more than 0.5 db. Transmission measurements, therefore, are not normally corrected for impedance.

Q. 5. Compute for a frequency of 796 cycles per second the propagation constant, attenuation and phase (wave-length) constants, the velocity of propagation, the wave-length, and the characteristic impedance of a small gauge non-loaded cable circuit having the following constants per mile:—resistance 176 ohms; capacity 0.065 microfarad; inductance and leakage conductance both negligible, (35).

$$A. 5. \quad \gamma = (j\omega CR)^{\frac{1}{2}} = (\omega CR)^{\frac{1}{2}} / 45^\circ$$

$$\beta + ja = \left(\frac{\omega CR}{2}\right)^{\frac{1}{2}} + j\left(\frac{\omega CR}{2}\right)^{\frac{1}{2}}$$

$$\beta = \alpha = \left(\frac{\omega CR}{2}\right)^{\frac{1}{2}}$$

$$V = \frac{\omega}{\alpha}$$

$$\lambda = \frac{V}{f} = \frac{2\pi}{\alpha}$$

$$Z_0 = \left(\frac{R}{\omega C}\right)^{\frac{1}{2}} \sqrt{45^\circ}$$

NOTE: The use of a slide rule is permissible. In the following working with 4-figure logs, the answers are a few per cent. more accurate:—

$$\omega = 2\pi \times 796 = 5000 \text{ radians per second}$$

$$\omega CR = 5000 \times 0.065 \times 10^{-6} \times 176 = 5 \times 0.065 \times 176$$

$$(\omega CR)^{\frac{1}{2}} = 0.2392$$

$$\therefore \gamma = 0.2392 / 45^\circ$$

$$\beta = 0.1691 \text{ népers.}$$

$$\alpha = 0.1691 \text{ radians per mile.}$$

$$V = \frac{5000}{0.1691} = 29560 \text{ miles per second.}$$

$$\lambda = \frac{6.2832}{0.1691} = 37.15 \text{ miles.}$$

$$\left(\frac{R}{\omega C}\right)^{\frac{1}{2}} = \left(\frac{176}{5000 \times .065 \times 10^{-6}}\right)^{\frac{1}{2}}$$

$$= 10^3 \left(\frac{176}{325}\right)^{\frac{1}{2}} = 10^3 \times 0.7358$$

$$Z_0 = 735.8 \text{ ohms } \sqrt{45^\circ}$$

Q. 6. State the overall transmission losses permitted in the individual circuits which may be associated to form the connexion between any two subscribers' telephones, and give a general indication of the type and composition of the lines provided for the various classes of traffic. (35).

A. 6. The country is divided into zones, and the zones into groups. Calls between subscribers in different zones normally circulate over lines between the zone centres. Circuits therefore radiate from each zone centre to its group centres, and from group centres to the minor exchanges. Some exchanges are dependent upon the minor exchanges for access to the group centre. Multi-exchange areas are usually group centres. In addition to this system of circuits radiating from traffic centres, a number of exchanges have direct communication with one another. Finally, there are local calls between subscribers on the same exchange.

The transmission standard which will ultimately be realized is a loss not exceeding 15 db. in the chain of connexions between any two subscribers' exchanges. This loss is apportioned as shown in the straight-line diagram, in the case of calls which involve the use of the maximum number of links. When an



exchange has not another exchange dependent upon it for access to the group centre, the loss between M and G may be 4.5 db. Circuits directly connecting group centres will be 3 db. Circuits, radiating from G to exchanges M, for traffic confined entirely to a multi-exchange area, may be 6.5 db.; these are additional to the more efficient circuits which are required for through traffic. Circuits directly connecting minor exchanges and used only for traffic between those exchanges will be 12 db.

The circuits between zone centres will be 4-wire repeated circuits on 20-lb. conductors loaded 120/1.136 and associated with echo suppressors.

Circuits between zone centres and group centres will normally be 10-lb. or 20-lb. 4-wire amplifier circuits. The type of conductor, whether it is non-loaded or loaded 120/1.136, the spacing of amplifier stations, the use of terminal amplifiers, etc., are matters dependent upon the length of the circuits and an economic study in each case. 10-lb. loaded conductors are usually provided when the distance between amplifiers is 14 to 30 miles, and 20-lb. loaded conductors for distances in excess of 30 miles.

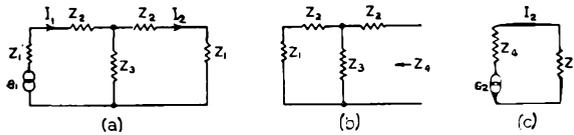
Junctions will normally be provided by 6½, 10, 20, or 40 lb. non-loaded cables, or 10 or 20 lb. cables, loaded 120/1.136, the type being dependent upon the allowable transmission equivalent.

The subscribers' lines are 6½, 10, and in some circumstances, 20 lb. non-loaded cable conductors, or 10 lb. cable conductors associated with 40 lb. bronze or cadmium copper aerial wires. The lines must comply with resistance limits assigned to each exchange area on the basis of realizing a standard grade of transmission from the subscriber's telephone to his local exchange.

Q. 7. State Thévenin's (or Pollard's) theorem. A generator with an internal impedance of 600 ohms, and a generated electromotive force of 1.55 volts, is connected to the input terminals of a T network having 100-ohm series arms and a 1,000-ohm shunt arm. A 600-ohm load is connected to the output terminals. Determine from Thévenin's theorem the equivalent generator which can replace the network and actual generator without changing the current in the load. (35).

A. 7. The current in any impedance Z connected to two terminals of a network, is the same as if Z were directly connected to a generator whose generated voltage is the open-circuited voltage at the terminals in question and whose impedance is the impedance of the network looking back from the terminals, with all generators replaced by impedances equal to the internal impedances of these generators. (Everitt).

To find, by Thévenin's theorem, the generated voltage e_2 and internal impedances Z_4 when $Z_1 = 600\Omega$, $Z_2 = 100\Omega$, and $Z_3 = 1000\Omega$



$$I_1 = \frac{e_1}{Z_1 + Z_2 + \frac{Z_3(Z_1 + Z_2)}{Z_1 + Z_2 + Z_3}}$$

$$I_2 = \frac{I_1 Z_3}{Z_1 + Z_2 + Z_3}$$

$$= \frac{e_1 Z_3}{(Z_1 + Z_2)(Z_1 + Z_2 + Z_3) + Z_3(Z_1 + Z_2)}$$

$$Z_4 = Z_2 + \frac{Z_3(Z_1 + Z_2)}{Z_1 + Z_2 + Z_3} = \text{internal impedance of the equivalent generator.}$$

$$e_2 = I_2(Z_1 + Z_4)$$

$$= \frac{e_1 Z_3 \left[Z_1 + Z_2 + \frac{Z_3(Z_1 + Z_2)}{Z_1 + Z_2 + Z_3} \right]}{(Z_1 + Z_2)(Z_1 + Z_2 + Z_3) + Z_3(Z_1 + Z_2)}$$

$$= \frac{e_1 Z_3}{Z_1 + Z_2 + Z_3}$$

= open circuited voltage of the equivalent generator.

$$\therefore Z_4 = 100 + \frac{1000(100 + 600)}{1700} = 100 + 411.8 = 511.8 \text{ ohms.}$$

$$e_2 = \frac{1.55 \times 1000}{1700} = 0.912 \text{ V.}$$

Q. 8. Give a physical explanation of the increased characteristic impedance and reduced attenuation constant of a line when it is loaded. (35).

A. 8. The general effect of artificially increasing the inductance of circuits by continuous or coil loading is to increase the impedance, reduce the angle of the impedance, and decrease the attenuation. The large negative angle in the case of the impedance of an unloaded cable circuit signifies that the rapidly attenuating voltage along the line will be charging the dielectric, the capacity effect being so much greater than that of the inductance that the energy stored in and released from the magnetic field around the conductors is very small compared with the energy in the electrostatic field between the conductors. For a given applied voltage, there is a high and rapidly attenuating current, and high power dissipation in the conductor resistance; when inductance loads are added, the current will be smaller and the voltage higher, tending to balance the dissipation in conductor and dielectric. The inductance provides for higher magnetic flux and this changing flux in turn generates voltage to sustain the current. This advantage of higher voltage would not be gained if the leakage conductance were appreciable, but in the case of cable circuits leakage conductance is usually negligible. In lines which are electrically short, such as power lines, the impedance of the circuit is largely dependent upon the terminal impedances and transformers are employed to raise the line voltage and lower the line current, so as to reduce the line losses which depend upon the square of the current traversing the line. In telephone lines, however, which are longer electrically, the impedance is substantially independent of the closing impedance, and transformers cannot be employed to effect similar power conversions. The formulæ for Z_0 and β in the case of loaded lines at frequencies where the inductance may be regarded as uniformly distributed, that is, below about 0.6 of the cut off frequency, are

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \text{ ohms} \dots\dots\dots(1)$$

$$\beta = \frac{R}{2} \sqrt{\frac{C}{L}} + \frac{G}{2} \sqrt{\frac{L}{C}} \text{ nepers} \dots\dots\dots(2)$$

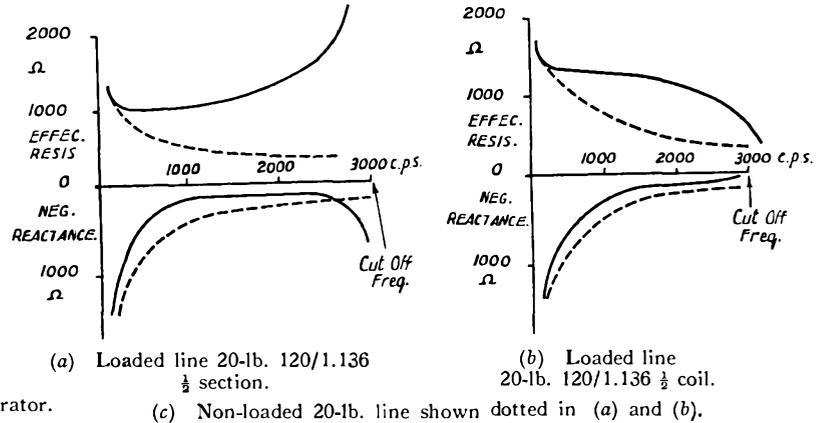
Equation (1) shows that Z_0 is increased when L is made greater, and equation (2) shows that the attenuation per mile would not be reduced appreciably by loading if G be great.

Q. 9. Show by means of curves how, in a typical case, the effective resistance and the reactance vary with frequency for each of the following:—

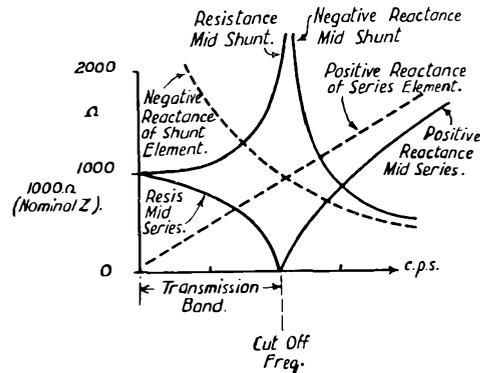
- (a) a coil-loaded cable circuit with the first coil at half section,
- (b) one which begins with a half coil followed by a full section,
- (c) a non-loaded cable circuit,
- (d) a simple low pass filter.

(40).

A.9. The curves are given below.



(c) Non-loaded 20-lb. line shown dotted in (a) and (b).



(d) Low pass filter.

Q. 10. Derive expressions for the ratio of voltages and the ratio of currents in the initial and reflected waves at the end of a line where it is terminated first with its characteristic impedance Z_0 , and then with another impedance Z_T .

Describe how the full reflection of an electric wave occurs when a line is (a) open-circuited, and (b) short-circuited. (40).

A. 10. Let E_0 be the open-circuited voltage at the end under consideration. Then, by Thévenin's theorem, where E_{RO} and I_{RO} are the voltage across, and current in, Z_0 and E_{RT} and I_{RT} are the voltage across, and current in, Z_T ,

$$I_{RO} = \frac{E_0}{2Z_0} ; I_{RT} = \frac{E_0}{Z_0 + Z_T}$$

$$I_{RT} - I_{RO} = E_0 \left(\frac{1}{Z_0 + Z_T} - \frac{1}{2Z_0} \right) = \frac{E_0}{2Z_0} \left(\frac{Z_0 - Z_T}{Z_0 + Z_T} \right)$$

$$\frac{I_{RT} - I_{RO}}{I_{RO}} = \frac{Z_0 - Z_T}{Z_0 + Z_T}$$

$$\text{Similarly, } E_{RO} = \frac{E_0}{2} ; E_{RT} = E_0 \left(\frac{Z_T}{Z_0 + Z_T} \right)$$

$$E_{RT} - E_{RO} = -\frac{E_0}{2} + \frac{E_0}{2} \left(\frac{2Z_T}{Z_0 + Z_T} \right)$$

$$= \frac{E_0}{2} \left(\frac{2Z_T - Z_0 - Z_T}{Z_0 + Z_T} \right)$$

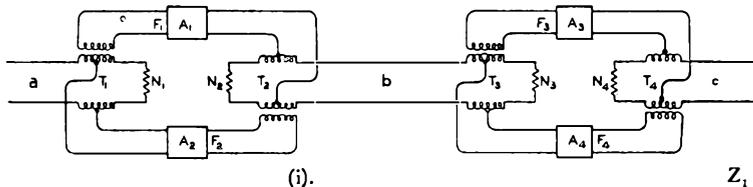
$$= \frac{E_0}{2} \left(\frac{Z_T - Z_0}{Z_0 + Z_T} \right)$$

i.e., $\frac{E \text{ reflected}}{E \text{ initial}} = -\frac{I \text{ reflected}}{I \text{ initial}} = \frac{Z_0 - Z_T}{Z_T - Z_0}$

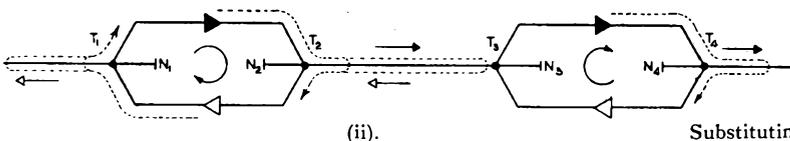
In an infinite uniform line there is no reflection, the ratio of effective (or maximum instantaneous) voltage and current at any point in the line being Z_0 . If the line be open-circuited or short-circuited, the energy normally transmitted at that point, i.e., half in the magnetic field and half in the electric field, cannot be expended or, at telephone frequencies, radiated into space. There must therefore be full reflection of energy in either of those conditions. In the open-circuited case, there can be no current at the immediate end of the line, i.e., the magnetic field collapses, and in the short-circuited case there can be no voltage, i.e., the electric field collapses. The collapsing magnetic field produces a voltage equal to, and of the same sign as, the incident voltage, i.e., the voltage is doubled. Similarly, in the other case the current is doubled. It should be understood that it is the difference between the open-circuited and incident voltages which is re-transmitted, and, similarly, the difference between the short-circuit and incident currents.

Q. 11. Describe how speech currents are transmitted over a 2-wire repeatered circuit. State the impedance relations in the repeater which are necessary for the efficient transfer of power from the valve to the line, for the prevention of reflection of waves arriving from the line, and for the prevention of singing effects. (40).

A. 11. A 2-wire circuit repeatered at two points is shown schematically in sketch (i). The lines a, b, and c are usually

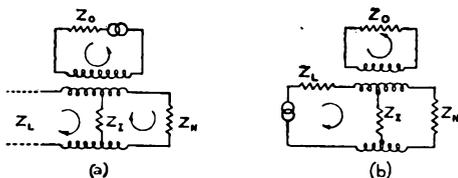


20-lb. or 40-lb. loaded pairs having a cut-off frequency of 2,700-3,400 c.p.s. The impedance of lines a and c, respectively, measured from the repeater termination, is simulated by balancing networks N_1 and N_4 . Each repeater comprises two amplifiers, A_1A_2 or A_3A_4 . The differential transformers, T_1, T_2, T_3 , and T_4 are maintained in a balanced bridge condition by the line and network impedances. Filters are introduced at F_1, F_2, F_3 , and F_4 to prevent the transmission of higher frequencies at which effective balance between line and network is impossible. In sketch (ii), the arrows with triangular heads show the direction of the speech currents amplified by the respective amplifiers. The function of the differential trans-



formers T_1 , etc., is to confine transmission to those paths and prevent the circulation of currents in the paths indicated by the ordinary arrows. Smooth impedance characteristics for the lines, and the correct matching of lines and terminating impedances, are necessary to prevent reflection in paths, some of which are indicated by dotted arrows.

In sketch (iii), (a) and (b), are shown a differential transformer and associated impedances which are Z_L , line; Z_N , net-

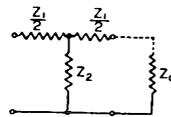


(iii).

work; Z_0 , anode of valve; Z_L , input to amplifier. For effective transmission from valve to line, sketch (a), the transformer must match impedances Z_0 and $Z_L + Z_N$; for the maintenance of equal and opposite output currents in Z_L and Z_N , also sketch (a), $Z_L = Z_N$ and the number of turns on the four series windings must be equal. To prevent terminal reflection, the input impedance viewed from the terminals, sketch (b), must be made equal to Z_L . The impedance of the repeaters is a function of the impedance of the input and output impedances, Z_L and Z_0 , of the amplifier elements and is usually 600 ohms. Line transformers are therefore employed to match the line and repeater impedances.

Q. 12. Derive equations for the propagation constant and the characteristic impedance of a line having uniformly distributed primary constants:— R ohms; L henrys; G mhos; and C farads per mile. (40).

A. 12. At $\omega = 2\pi f$, let the series impedance per unit length be $Z = R + j\omega L$ and the shunt admittance per unit length be $Y = G + j\omega C$. A finite length of line terminated with the characteristic impedance has the transmission characteristics of the same length of line when part of an infinite line. Unit length of line may be represented by a large number of networks, or short sections of line, having localized instead of distributed constants, which collectively have the transmission characteristics of unit length of line. Let each network be of the symmetrical T type, as shown in the sketch. The impedance of the input terminals of one network, when the output terminals are closed with the impedance of all the other networks connected in tandem, i.e., Z_0 , is also Z_0 .



$$Z_0 = \frac{Z_1}{Z_2} + \frac{Z_2 \left(\frac{Z_1}{2} + Z_0 \right)}{Z_2 + \frac{Z_1}{2} + Z_0}$$

$$Z_0 = \sqrt{Z_1 Z_2 + \frac{Z_1^2}{4}} \dots \dots \dots (1)$$

If the number of networks representing unit length of line is n ,

$$Z_1 = \frac{Z}{n}; Z_2 = \frac{n}{Y}; Z_0 = \sqrt{\frac{Z}{Y} + \frac{1}{4} \left(\frac{Z}{n} \right)^2}$$

For this to be true, n must be made great and in the limit

$$Z_0 = \sqrt{\frac{Z}{Y}} = \text{characteristic impedance} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

expressed in terms of the series impedance and shunt admittance per unit length.

The current ratio per network, representing magnitude and phase, is, from (1)

$$\frac{Z_2 + \frac{Z_1}{2} + Z_0}{Z_2} = 1 + \frac{Z_1}{2Z_2} + \sqrt{\frac{Z_1}{Z_2} + \frac{Z_1^2}{4Z_2^2}}$$

$$\therefore \gamma_n \text{ per small section, } \frac{l}{n} = \log_e \left[1 + \frac{Z_1}{2Z_2} \right] + \sqrt{\frac{Z_1}{Z_2} + \left(\frac{Z_1}{2Z_2} \right)^2} \dots \dots \dots (2)$$

Substituting in (2) the proportion of Z and Y respectively,

$$e^{\gamma n} = 1 + \frac{ZY}{2n^2} + \sqrt{\frac{ZY}{n^2} + \left(\frac{ZY}{2n^2} \right)^2}$$

$$= 1 + \frac{ZY}{2n^2} + \frac{1}{n} \sqrt{ZY \left(1 + \frac{ZY}{4n^2} \right)}$$

As n is made great, in the limit,

$$e^{\gamma n} = 1 + \frac{\sqrt{ZY}}{n}$$

$$\log_e (1 + a) = a - \frac{a^2}{2} + \frac{a^3}{3} \dots \dots \dots$$

$$\log_e \left(1 + \frac{\sqrt{ZY}}{n} \right) = \frac{\sqrt{ZY}}{n} - \frac{ZY}{2n^2} + \dots \dots \dots$$

$$\therefore e^{\gamma n} = \frac{\sqrt{ZY}}{n}$$

$$e^{\gamma} = \sqrt{ZY} = \sqrt{(R + j\omega L)(G + j\omega C)}$$