Supplement

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The answers to the examination papers which are given in this Supplement are not claimed to be thoroughly exhaustive and complete. They are, however, accurate so far as they go and are such as might be given within the time allowed by any student capable of securing high marks in the examinations

VII.—RADIO-COMMUNICATION, GRADE I; QUESTIONS AND ANSWERS

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

Q. 1. What is meant by the terms self-induction and reactance? Two coils have self-inductance of 5 henries and 10 henries respectively. What will be their reactance at a frequency of 50 cycles per second when connected (a) in series, (b) in parallel?

A. 1. If a current is passed through a coil, a magnetic flux is set up which links to some extent with the coil itself. Any change in this current and flux sets up an e.m.f. in such a direction as to oppose the change of flux. This is known as the back e.m.f. of self induction and the coil is said to possess inductance.

The practical unit is the henry which is the inductance of a coil in which a back e.m.f. of 1 volt is set up when the current is changed at the rate of 1 ampere per second.

If an alternating e.m.f. (v) is applied across an inductance

$$V = L\frac{di}{dt} \text{ or } i = \frac{1}{L}\int v \sin \omega t \, dt .$$

$$= \frac{V}{\omega L} \sin (\omega t - 90^\circ)$$

ωL is known as the reactance of the inductance.

(*a*) The inductance of two coils L_1 and L_2 connected in series is $L = L_1 + L_2$

$L_1 = 5H.$ and $L_2 = 10H.$

$\therefore L = 15H$ and $\omega L = 2\pi \times 50 \times 15 = \underline{4710}$ ohms.

(*b*) The inductance of two coils L_1 and L_2 connected in parallel is $L = \dfrac{L_1 L_2}{L_1 + L_2}$

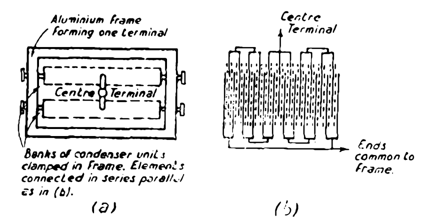
$\therefore L = \dfrac{50}{15} = 3{\cdot}33H.$

$\omega L = 2\pi \times 50 \times 3{\cdot}33 = \underline{1045}$ ohms.

Q. 2. Describe the construction of a fixed condenser suitable for high voltage and high frequency. A condenser of 2 microfarads capacity is charged to a potential difference of 1,000 volts. What is the amount of energy stored in the condenser? If this charged condenser is connected in parallel with an uncharged condenser of 3 microfarads capacity, what will be the potential difference and the total energy stored after connexion? Explain the reason for any difference in the energy stored in the two cases.

A. 2. High voltage, high frequency fixed condensers may be constructed with air, oil or mica as a dielectric. For small capacities, say up to 0.001 μF, air may be used and for condensers up to say 0.02 μF oil or mica. Above this value, oil condensers are too bulky and mica is used almost exclusively.

A mica condenser is constructed of ruby mica which gives a power factor of .0002-.0003, *i.e.*, the power to be dissipated in the condenser is .02 to .03 per cent. of the K.V.A. input. Although this is a very small figure, mica being a very good heat insulator, the condenser must be built up in small sections, each plate is say 2″ × 3″. A typical method of construction is shown in the sketch (*a*), a large number of units, each consisting of a number of sheets of copper foil interleaved with sheets of mica as in sketch (*b*), are connected in series parallel to make up the required capacity. The frame may be used as one terminal and the centre of the condenser as the other as indicated. The whole is immersed in high-grade insulating oil in a sealed tank to ensure good cooling. The amount of copper in the condenser is determined by the current and the number of units in series is determined by the voltage; thus, the size of the condenser increases more or less proportional to the K.V.A.



The energy stored in a condenser is $\frac{1}{2}$ CV^2

$$= \tfrac{1}{2}\, 2 \times 10^{-6} \times 10 = 1 \text{ joule}$$

If this stored condenser is connected in parallel with an unstored condenser, the quantity of electricity in the stored condenser will be distributed between the two condensers until they are charged to the same voltage.

Thus $C_1V_1 = (C_1 + C_2)\,V_2$ or $V_2 = \dfrac{2}{5} \times 1000 = 400$ V.

Thus in the example the total energy stored will be

$\frac{1}{2}(C_1 + C_2)\,V_2^2 = \frac{1}{2} \times 5 \times 10^{-6} \times 16 \times 10^4 = 0.4$ joules.

On connecting the two condensers in parallel a damped oscillatory discharge will be set up and energy to the extent of 0.6 joules will be dissipated in the resistance of the condensers.

Q. 3. A condenser of 2 microfarads, a resistance of 50 ohms and an inductance of 6 henries are connected in series. What current will flow when an E.M.F. of 200 volts R.M.S. at 50 periods per second is applied to the circuit?

A. 3.

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

$$= \frac{200}{\sqrt{50^2 + \left(2\pi \times 50 \times 6 - \frac{10^6}{2\pi \times 50 \times 2}\right)^2}}$$

$$= \frac{200}{\sqrt{50^2 + (1885 - 1592)^2}} = \frac{200}{297}.$$

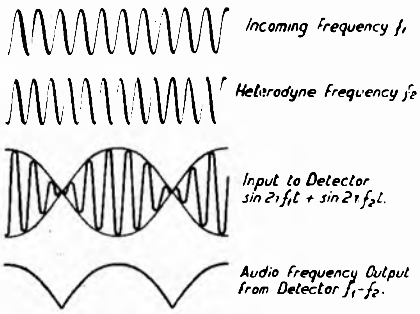
$= 0.694$ amperes.

Q. 4. What are meant by damped waves, continuous waves and interrupted continuous waves? Why is a detector necessary in order to obtain audible indication in a telephone of high frequency oscillations? Is a simple detector sufficient in order to obtain audible indications of continuous waves? If not, state what additional apparatus is necessary and the reasons for its use.

A. 4. *Damped Waves.* If a charged condenser is included in an oscillatory circuit, a damped oscillatory discharge will take place. Damped waves are those in which this process is repeated at an audio frequency rate.

Continuous Waves are alternating current of constant amplitude at radio frequencies.

Interrupted Continuous Waves are continuous waves interrupted at an audio frequency rate.



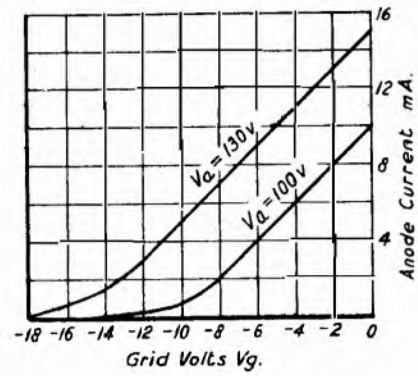
A simple detector is insufficient to obtain audible indications of a continuous wave. The ear is unable to detect vibrations of frequencies exceeding about 20,000 periods per second whereas radio communication is effected at considerably higher frequencies. To render a continuous wave f_1, audible, therefore, it must be (*a*) heterodyned by a radio frequency wave f_2 such that $f_1 - f_2$ is an audio frequency and (*b*) detected.

The heterodyning is performed by an oscillator included in the receiver; in fact, one of the amplifying stages may be used as this oscillator. The effect of heterodyning and detection is illustrated in the sketch.

Q. 5. The following readings were taken on a three electrode valve. Plot the characteristic grid voltage anode current curves and determine the internal impedance at zero grid voltage, the amplification factor and mutual conductance.

Grid Voltage.	*Anode current in milliamperes.* (*a*) *With 130 volts H.T.*	*Anode current in milliamperes.* (*b*) *With 100 volts H.T.*
0	15	10
− 2	13	8
− 4	11	6
− 6	9	4
− 8	7	2
− 12	3	0.4
− 14	1.5	0.1
− 16	0.7	—
− 18	0.2	—

A. 5.



$$\text{Internal Impedance} = \frac{\partial V_a}{\partial I_a} \text{ with } V_g \text{ constant} = \frac{30}{5} \times 10^3$$
$$= 6{,}000 \text{ ohms.}$$

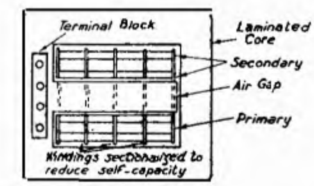
$$\text{Mutual Conductance} = \frac{\partial I_a}{\partial V_g} \text{ with } V_a \text{ constant} = \frac{2}{2} = 1 \text{ mA per volt.}$$

$$\text{Amplification Factor} = \frac{\partial V_a}{\partial V_g} \text{ with } I_a \text{ constant} = \frac{30}{5} = 6.$$

Q. 6. Describe the construction of an iron-cored transformer suitable for use in an audio-frequency amplifier.

The output valve in a receiver is coupled to a loud-speaker through a transformer. The impedance of the loud-speaker is 15 ohms and it is desired that the primary winding of the transformer should present a load of 7,500 ohms to the valve. What should be the winding ratio of the transformer?

A. 6. A typical iron-cored transformer is illustrated in the sketch; for the sake of simplicity the case is omitted. A transformer in an audio-frequency amplifier has to carry a direct current through its windings and therefore the iron circuit must be designed so that the iron is not saturated by this current, otherwise the impedance of the windings to the audio frequencies will be seriously reduced and, in addition, amplitude distortion is likely to occur. For this reason the core is constructed with a small air gap. The laminations may be of high permeability material such as Mu metal and are only 2-5 mils in thickness to cut down hysteresis and eddy current losses. The primary and secondary windings are sectionalized and arranged as in the sketch so as to reduce their self capacity between windings. The transformation ratio is proportional to the turns on the windings and to the square root of the impedances.



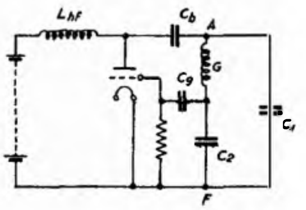
Sectional Elevation of Transformer.

$$\text{Transformation ratio} = \frac{V_2}{V_1} = \sqrt{\frac{Z_2}{Z_1}} = \sqrt{\frac{15}{7500}} = 0.045.$$

i.e., the Transformer has a step down ratio of 22.3.

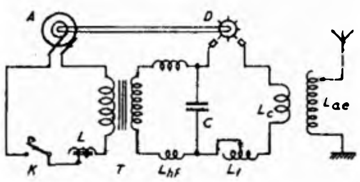
Q. 7. Show by means of a diagram how a three electrode valve can be used to generate oscillations. Show in the diagram means whereby the direct current anode potentials and grid bias potentials are excluded from the high frequency circuits.

A. 7. A simple diagram of a valve as a generator of oscillations is shown in the sketch. The circuit will oscillate provided that the voltage reacted back on to the grid is approximately 180° out of phase with the anode voltage and provided that this voltage exceeds a critical value. This phase relationship is accomplished in the circuit shown as the voltage between F and G must be 180° out of phase with that between G and A. The d.c. potentials are excluded from the oscillatory circuits by the use of the blocking condensers C_g and C_b. The high frequency choke $L_{h.f.}$ is necessary in order to prevent the short-circuiting of the oscillatory circuit by the anode D.C. Supply.



Q. 8. Give a diagram and description of a spark transmitter of about $1\frac{1}{2}$ kW input. What determines the power input to a spark transmitter? Show how it is possible to change the wave-length of such a transmitter without changing the power input.

A. 8. The circuit diagram of a $1\frac{1}{2}$ kW. spark set is shown in the sketch. A is an alternator giving the required output at 300-500 periods per second directly coupled to the disc discharger D. The alternator is connected through the key K, the power adjustment choke L to the step up transformer T. The oscillatory circuit is connected across the secondary of this transformer through H.F. chokes $L_{h.f.}$ The primary and aerial circuits are tuned by L_1 and L_{ae}, and the aerial coupling adjusted on L_c. The disc discharger consists of a metal disc with spokes arranged so that two rotating spokes come opposite two fixed spokes simultaneously. The number of spokes on the discharger is such that the fully charged condenser breaks down the gap between the fixed and rotary spokes every half cycle of the alternator wave.



The power taken by the set is $\frac{1}{2}$ $CV^2 \times 2f$ watts, *i.e.*, it depends on the alternator frequency (f), the capacity C, and the voltage V to which the condenser is charged at the instant the gap breaks down, *i.e.*, it is dependent on the length of gap between the rotary spokes and the fixed spokes.

The wave-length can therefore be changed and the power maintained constant provided C remains constant, *i.e.*, provided all tuning is carried out on L_1.

Q. 9. An aerial tunes to 450 metres with an inductance of 100 microhenries in series and tunes to 600 metres with an inductance of 200 microhenries in series. What is the capacity and inductance of the aerial?

A. 9. Let L_0 and C_0 be the capacity and inductance of the aerial, and L_1 and L_2 the added inductances when L and C are in μH and μF respectively. Then

$$\lambda_1 = 1885\sqrt{C_0(L_0 + L_1)} \text{ metres}$$

$$\lambda_2 = 1885\sqrt{C_0(L_0 + L_2)} \text{ metres.}$$

$$\therefore \frac{L_0 + L_1}{L_0 + L_2} = \frac{\lambda_1^2}{\lambda_2^2}$$

$$\text{or } L_0 = \frac{L_2\dfrac{\lambda_1^2}{\lambda_2^2} - L_1}{1 - \dfrac{\lambda_1^2}{\lambda_2^2}}$$

$L_1 = 100\ \mu$H. $\lambda_1 = 450$ metres.

$L_2 = 200\ \mu$H. $\lambda_2 = 600$ metres.

$$\therefore L_0 = \frac{200 \times \frac{9}{16} - 100}{1 - \frac{9}{16}} = \underline{28.5}\ \mu\text{H.}$$

$$\text{and } C_0 = \frac{\lambda_1^2}{1885^2(L_0 + L_1)} = \frac{450^2}{1885^2 \times 128.5}$$

$$= 0.000443\ \mu\text{F}$$

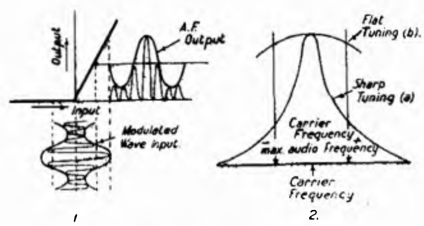
$$\text{or } \underline{443\ \mu\mu\text{F}}.$$

Q. 10. Explain the action of a radio receiver when used to convert radio-telephony signals into speech signals. How does the sharpness of tuning of the receiver affect the quality of the speech output?

A. 10. A radio receiver consists essentially of

(1) An aerial circuit with or without a series of coupled circuits.
(2) A radio-frequency amplifier.
(3) A detector.
(4) An audio-frequency amplifier.

An e.m.f. is induced in the aerial from a large number of stations, but by the use of one or a series of tuned circuits, the wanted station is selected and applied to the grid of the first valve. For efficient detection a voltage of at least 0.1 volts is desirable and therefore if the voltage on the first grid is smaller than this, radio frequency amplifying stages are essential. Radio telephony signals are, in effect, a modulated wave, *i.e.*, a wave the amplitude of which varies proportional to the speech. The envelope of this wave is the same on either side of the zero line and thus, in order to render it audible, one half of the wave must be cut off. This operation is performed by the detector. This process is illustrated in sketch 1. Thereafter the audio frequency may be amplified if desired for application to a loud-speaker.



A modulated wave may be analysed into a carrier and two sidebands, *i.e.*, the signal is spread over a band of frequencies of width equal to twice the maximum audio frequency used. If the sharpness of tuning is such that the bandwidth of the chain of tuned circuits is less than the width of the band of radiated frequencies, the upper audio frequencies will be attenuated as in sketch (2*a*). The sharpness of tuning must be only such that it permits the passage of all frequencies contained in the modulated wave sketch (2*b*).

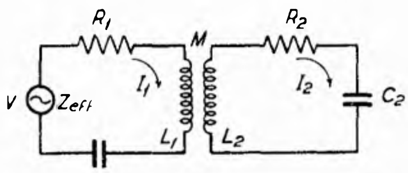
VIII.—RADIO-COMMUNICATION, FINAL EXAMINATION: QUESTIONS AND ANSWERS

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

Q. 1. Two circuits, each consisting of an inductance of 160 microhenries, a resistance of 10 ohms and a condenser of 0.001 microfarad, are coupled by a mutual inductance between the inductances of 2 microhenries.

If an E.M.F. of 100 volts R.M.S. at 400,000 cycles per second is applied in series with one circuit, what will be the currents in the circuits?

A. 1.



$$Z_{eff} = R_1 + \frac{\omega^2 M^2}{|Z_2|^2} + j\left(X_1 - \frac{\omega^2 M^2}{|Z_2|^2} X_2\right).$$

where $|Z_2|$ = numerical value of the impedance of the secondary circuit.

$$\omega = 2\pi \times 4 \times 10^5 = 2.512 \times 10^6.$$

$$\omega^2 M^2 = (2.512 \times 10^6 \times 2 \times 10^{-6})^2 = 25.4.$$

$$X_1 = X_2 = \omega L_1 - \frac{1}{\omega C_1}$$

$$= 1.6 \times 10^{-4} \times 2.512 \times 10^6 - \frac{10^9}{2.512 \times 10^6}$$

$$= 401 - 398 = 3 \text{ ohms.}$$

$$\therefore |Z_2|^2 = 10^2 + 3^2 = 109.$$

$$Z_{eff} = 10 + \frac{25.4 \times 10}{109} + j\left(3 - \frac{25.4}{109} \times 3\right).$$

$$= 12.33 + j2.3.$$

$$\therefore I_1 = \frac{V}{Z_{eff}} = \frac{100}{\sqrt{12.33^2 + 2.3^2}} = \underline{8\text{A.}}$$

$$I_2 = \frac{\omega M I_1}{Z_2} = \frac{5.04 \times 8}{10.4} = \underline{3.88\text{A.}}$$

Q. 2. A condenser of 0.01 microfarad is charged to a D.C. potential and connected across an inductance of 1,000 microhenries having a resistance of 15 ohms. What time will elapse after connexion before the amplitude of the oscillatory current has decreased to 1 per cent. of its initial amplitude?

A. 2. The amplitude of the oscillation will decay in accordance with $e^{-\frac{R}{2L}t}$.

$$\therefore e^{-\frac{R}{2L}t} = 0.01.$$

$$\text{or } \frac{R}{2L} t = \log_e 100 = 4.606$$

$$\therefore t = \frac{2 \times 10^{-3} \times 4.606}{15} = \underline{6.14 \times 10^{-4}} \text{ seconds.}$$

Q. 3. In an audio-frequency amplifier the valve has an amplification factor of 40 and an internal impedance of 40,000 ohms. It is coupled to a succeeding stage by a transformer of 1 to 3.5 ratio having a primary inductance of 40 henries and a primary resistance of 500 ohms. The secondary load is of infinite impedance. What will be the amplification for frequencies of 40, 100, 1,000 and 10,000 cycles per second, if the primary of the transformer resonates at 10,000 cycles.

A. 3. Since the secondary load is of infinite impedance, the anode circuit may be regarded as consisting of a choke of L = 40H., R = 500 ohms and C = value to resonate at 10,000 cycles/sec. The self capacity may be disregarded at 40, 100 and 1,000 cycles/sec.

$$\text{The amplification } \frac{v_{g2}}{v_{g1}} = T \times \mu \,.\, \frac{\sqrt{R^2 + \omega^2 L^2}}{\sqrt{(\rho + R)^2 + \omega^2 L^2}}$$

where T = transformation ratio.

μ = amplification factor.

ρ = anode a.c. resistance.

(*a*) At 40 cycles.

$$\frac{v_{g2}}{v_{g1}} = 3.5 \times 40 \times \frac{\sqrt{500^2 + (2\pi \times 40 \times 40)^2}}{\sqrt{40500.^2 + 10100^2}}$$

$$= \frac{140 \times 10100}{41700} = \underline{34}$$

(*b*) At 100 cycles.

$$\frac{v_{g2}}{v_{g1}} = 140 \frac{\sqrt{500^2 + 25160^2}}{\sqrt{40500^2 + 25160^2}} = \frac{140 \times 25160}{47650} = \underline{73.7.}$$

(*c*) At 1000 cycles.

$$\frac{v_{g2}}{v_{g1}} = 140 \frac{\sqrt{500^2 + 251600^2}}{\sqrt{40500^2 + 251600^2}} = \frac{140 \times 251600}{254500} = \underline{138}$$

(*d*) At 10,000 cycles.

The effective impedance of the anode circuit is $\frac{\omega^2 L^2}{R}$

$$= \frac{4\pi^2 \times 10^8 \times 16 \times 10^2}{500}$$

$$= 1.26 \times 10.^{10}$$

This is very large compared with ρ

$$\therefore \frac{v_{g2}}{v_{g1}} = \underline{140}$$

Q. 4. If 100 kW. of energy are radiated from an antenna of 100 metres effective height on a wave-length of 5,000 metres, what would be the strength of the electric field in microvolts per metre at a distance of 100 kilometres, assuming that no absorption effects are present?

A. 4. The field strength E at a distant point is given by :—

$$E = 298 \frac{\sqrt{P_r}}{d} \times 10^3 \text{ micro volts/metre.}$$

where P_r = power radiated in kW.

d = distance in kilometres.

$$\therefore E = \frac{298 \times 10}{100} \times 10^3 = 2.98 \times 10^4\ \mu V/m.$$

or $\underline{29.8 \text{ milli volts/metre}}$.

Q. 5. A 1-in. diameter steel wire rope, having a safe working load of 10 tons, supports an antenna between two masts 1,200 ft. apart. If the weight of the rope is 9 lb. per fathom and the maximum load due to the antenna is 2 lb. per foot of span, what must be the initial sag in the rope if the safe working stress is not to be exceeded under a horizontal wind load of 30 lb. per sq. ft. of projected area of the rope?

A. 5. The loads on the cable per foot run are :—

(1) Vertical (*a*) weight $= \frac{9}{6} = 1.5$ lbs.

(*b*) antenna = 2 lbs.

(2) Horizontal wind $= \frac{30}{12} = 2.5$ lbs.

Total effective load = $\sqrt{3.5^2 + 2.5^2} = 4.3$ lbs./ft. run.

The sag is given by $d = \dfrac{\omega l^2}{8H}$.

where ω = load/ft. run.

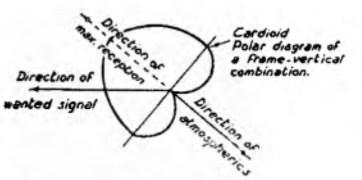
l = length in feet.

H = safe working load.

$\therefore$ sag $= \dfrac{4.3 \times 1200^2}{8 \times 10 \times 2240} = \underline{34.6 \text{ feet.}}$

Q. 6. What are the methods adopted in practice to reduce the effects of atmospherics and interference in reception (a) in the antenna system, (b) in the receiver?

A. 6. Atmospherics are in the nature of pulses of short duration which shock excite the receiving aerial and receiver on any wave-length to which it is tuned. A receiver normally makes use of one or more tuned circuits and the substitution of these tuned circuits by untuned or mistuned circuits will cause a similar diminution in both wanted signal and atmospheric. Such methods for their reduction are therefore useless. Fortunately, however, atmospherics are directional and come largely from the direction of the tropics. Thus the principle method for their reduction is by the use of directional reception. Directive aerial systems consisting of the simple loop, loop and vertical (cardioid), arrays of loops or loop and vertical combinations or Beverage antennæ may be used. In general, it is possible by correct phasing to arrange for the system to give maximum discrimination against interference from a particular direction whilst giving a useful wanted signal as in the sketch.



Directional Aerial arranged to give maximum discrimination against interference.

In the receiver itself little can be done to reduce atmospherics except by the use of limiting valves by which the atmospheric is limited to a magnitude of the same order as that of the wanted signal. The use of aural reception or undulator recording as opposed to inker recording for telegraphy facilities reading through interference.

Interference from other radio stations may be reduced in exactly the same way as atmospherics, *i.e.*, by directive means in the aerial and in addition by the use of loosely-coupled aerial tuning systems or if telephony is concerned by band-pass aerial filter systems.

Since the interference in this case has a definite wave-length or band of wave-lengths, it can be cut down by the use of a highly-selective receiver, *i.e.*, by the use of tuned high-frequency and tuned low-frequency stages.

The application of tuning and filters to a radio receiver may result in a receiver taking the following form :—

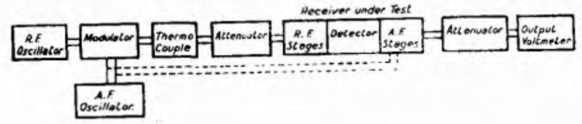
(1) Tuned antenna input circuit.
(2) H.F. Tuned anode amplifying stages.
(3) Detector and Intermediate Frequency Stages.
(4) Intermediate Frequency Band Pass Filter.
(5) 2nd Detector Low Frequency Amplifier and low frequency filter.

The filtration at successive stages will be such as to increase the selectivity progressively without deteriorating the ease and quality of reception.

Q. 7. Describe, with the aid of a schematic diagram, how you would determine (a) the selectivity, (b) the amplification of a radio receiver over a range of frequencies.

State what instruments and apparatus would be necessary to make these tests.

A. 7. A receiver may be used for a high grade commercial telegraph service, commercial or broadcast telephony and hence its bandwidth may vary from a few cycles to many thousands of cycles. This fact has to be allowed for in providing testing apparatus for measuring amplification and selectivity. A suitable arrangement is shown in the sketch.



It consists of :—

(1) A radio-frequency oscillator capable of fine adjustment over the range of wave-lengths concerned.
(2) A variable audio-frequency oscillator of constant or adjustable output.
(3) A modulator stage.
(4) A thermocouple and calibrated attenuator for measuring the output from (1), (2) and (3).
(5) An output attenuator and voltmeter for use with the receiver.

The selectivity of a heterodyne receiver can be measured by setting the radio-frequency oscillator to the midband frequency of the receiver, heterodyning this oscillation to a constant audio-frequency note and measuring the output for a constant r.f. input. The r.f. oscillator and heterodyne oscillator are then varied by the same amount and readings of the output noted. A curve of output against input frequency can then be plotted.

In the case of a telephony receiver, the r.f. oscillator is set to the mid-band frequency and this oscillation is modulated by the audio-frequency oscillator which is varied over a wide range. The output is measured for a constant input and plotted against the audio frequency.

The amplification of a receiver is normally measured by subdividing it into (1) the radio-frequency stages, (2) detector, (3) audio-frequency stages. The amplification or efficiency of these is then measured separately.

In the case of a super heterodyne receiver, it must be further subdivided.

The amplification of the r.f. stages is measured by applying a modulated voltage or r.f. voltage only to the grid of the detector and noting the output. This voltage is then applied to the grid of the first receiver valve through the r.f. attenuator and the attenuator setting for equal output noted. This attenuation represents the gain of the stages.

The same principle can be applied to the measurement of the amplification of the a.f. stages, the a.f. oscillator being applied to the grid of the first a.f. amplifier.

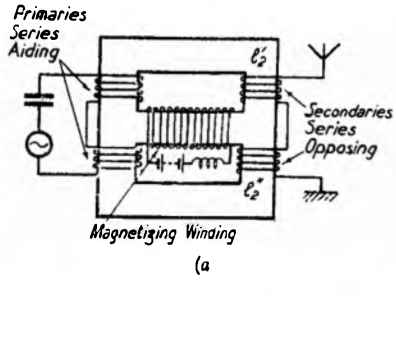
Q. 8. Describe two types of static frequency changer or frequency multiplier used for high frequency transmitters. What are the advantages and disadvantages of such apparatus?

A. 8. Frequency changers are used in radio engineering as

(*a*) Frequency doublers or treblers in association with radio frequency alternators.
(*b*) Harmonic generators in frequency control apparatus in transmitters and measurement work.
(*c*) Modulators and demodulators.

It is proposed to describe briefly changers of the first two types.

(1) *Joly Frequency Doubler.* The circuit arrangement is shown in sketch (1*a*). It consists of a primary and secondary circuit wound over an iron core, each winding being split in two halves, the primaries connected series aiding and the secondary series opposing. A third winding provides D.C. magnetization and brings the normal operating point to the knee of the B-H curve. The primary current, flux and secondary e.m.f. curves are shown in sketch 1(*b*).



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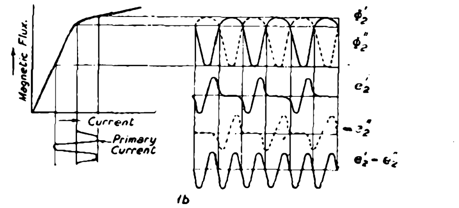
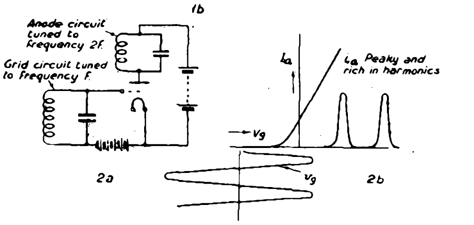




The use of a frequency doubler with an h.f. alternator simplifies the alternator design, but has the disadvantage that the resultant output has a bad waveform and is thus very rich in harmonics.

(2) *Valve Doubler.* In crystal or tuning fork controlled valve transmitters, it is normally necessary to use frequency multipliers. A simple form of multiplier is shown in sketch (2*a* and *b*).

The grid circuit is tuned to the fundamental frequency and the anode circuit to the required harmonic. The valve is biassed below " cut off " on the steady anode current curve and thus impressing an oscillation on the grid, causes a short pulse of anode current to flow. The wave form of this curve is therefore very bad, *i.e.*, it is rich in harmonics and the tuning of the anode circuit to one of these enables it to be selected and amplified. This method is extremely simple, but for harmonics above the third the efficiency is low; for high harmonics careful filtration of side harmonics is necessary. Since only the top of the wave impressed on the grid is " picked off," any ripple on the fundamental will be badly exaggerated in the output. Further slight variations in the amplitude of the fundamental will be considerably exaggerated in the output.

This arrangement has the advantage that it permits the use of a tuning fork or crystal at the best frequency for which this piece of apparatus can be designed.

Q. 9. What methods are adopted in practice to reduce the effects of capacity and inductance in resistances used for high frequency measurements? What is meant by the " time constant " of a resistance?

A. 9. It is essential that resistances used for measurement work on high frequencies should have negligible self capacity and inductance. Fortunately, little current is normally used for this class of work and thus the prime qualification, that of smallness, can be observed.

Such resistances are of two main classes; (*a*) wire, (*b*) carbon compound.

(*a*) *Wire resistances.* By the use of sufficiently fine wire, only a very short length is required for normal work. If the length of a straight wire is such that the inductance is too high, it may be (1) wound inductively on a fine insulating thread or flat strip, (2) wound non-inductively by (*a*) folding the wire in two and winding the doubled wire, (*b*) looping each turn back on itself, (*c*) winding two wires in opposite directions and paralleling the two wires.

The self capacity of such units is normally sufficiently low.

(*b*) *Carbon Compounds.* Carbon compounds, such as carbon-clay, carborundum or graphite, provide useful resistance elements, the specific resistance of which can be varied over very wide ranges. Thus resistances 1/16" diameter × 1" long can be constructed having a resistance from a few ohms to meghoms.

The chief difficulties with such resistances are (1) instability, (2) temperature coefficient, (3) difficulties in making reliable connexions. For frequencies above 3 megacycles, this class of resistance is to be preferred to the wire resistance on account of low self capacity and inductance.

The " time constant " of a resistance is given by $\frac{L}{R}$, CR, or $\frac{2L}{R}$ depending upon whether the resistance has inductance, capacity or inductance and capacity and is the time which would elapse before the current flowing through it fell to 0.368 of its initial value if the supply were removed.

Q. 10(a). State three different methods used in keying valve radio telegraph transmitters, mentioning any advantages or disadvantages.

(b). Give a circuit diagram and a brief description of a master oscillator controlled valve transmitter, working off an A.C. supply, which can be used for radio telephony or radio telegraphy.

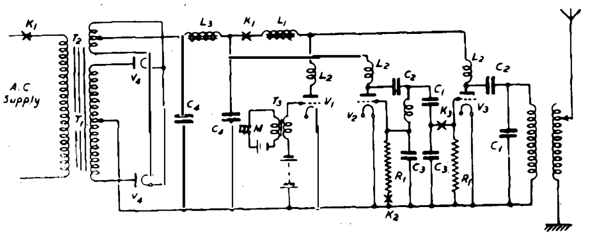
A.10(*a*). A valve transmitter may be keyed by one or more of the following methods:—

(1) Interrupting Main A.C. Supply, and/or H.T.D.C. Supply.
(2) Interrupting the Grid leak.
(3) Interrupting the excitation in a controlled transmitter.

Method (1) is simple and may be used for low power transmitters. As the power is increased, arcing becomes prevalent and magnetic or air blow outs have to be fitted. This system is suitable therefore for low powers up to 1 kW. only.

Method (2), Interruption of the Grid leak, is suitable only in the master oscillator of a controlled transmitter or in the self-oscillator transmitter. In the latter case, it is liable to cause the H.T. D.C. supply to rise considerably if a thermionic rectifier is used. Unless the grid-filament insulation is perfect, " grid ticks " occur during " space " which cause interference.

This method is only recommended for powers up to 1 kW. although in association with (1) it may be used for power up to 5 kW.



Method (3). In a controlled transmitter, the master oscillator or drive normally operates at quite low power and, in consequence, this oscillator may be keyed by one of the above methods or by disconnecting the excitation from the following stage. This method may be used for all powers; care must be taken however to see that the stages beyond the key do not self-oscillate or are not too heavily loaded on space.

The position of these keys is indicated in the answer to 10(*b*).

The circuit shown consists of a simple Hartley master oscillator followed by one stage of amplification. Modulation for telephony is obtained by the Heising or choke control system; the modulation may be applied to the grid through a speech transformer, as shown, or through a number of stages of low frequency amplification.

For telegraph working the modulator filament is switched off, the aerial coupling is adjusted to give full power output, and the set may be keyed at one or more of the points marked K.

The components are as follows:—

L_1	Speech Choke.
L_2	High frequency chokes.
C_2	Blocking condensers.
C_1	Tuning condenser.
C_3	Grid coupling condenser.
V_1 V_2 V_3 V_4	Modulator, oscillator, amplifier and rectifier valves.
R_1	Grid leaks.
T_3	Speech transformer.
T_1	Main transformer.
T_2	Rectifier filament transformer.
K_1 K_2 K_3	Telegraph keys.

XI.—TELEPHONY, FINAL; SECTION 2, TELEPHONE TRANSMISSION. QUESTIONS AND ANSWERS.

W. S. Procter, A.M.I.E.E.

Q. 1. How would you investigate a complaint of transmission difficulty from extension telephone instruments? What would the overall transmission losses comprise if (a) local battery and (b) common battery telephones were used at the extensions? (30 marks).

A. 1. If the complaint refers to all public exchange calls made from the extension instrument and the transmitter current is fed from the main exchange, the trouble may be due to the high resistance of the exchange and extension lines, or to feeding current losses due to series and/or shunt apparatus in the private branch exchange cord circuit. Similarly if the transmitter current is fed from the private branch exchange cord circuit, the trouble may be due to the resistance of the extension line. If the extension instrument is of the local battery type, the trouble may be caused by the high transmission equivalent of the extension line and, in a C.B. type private branch exchange, of the auxiliary apparatus unit. The difficulty may also be due to a faulty transmitter or receiver.

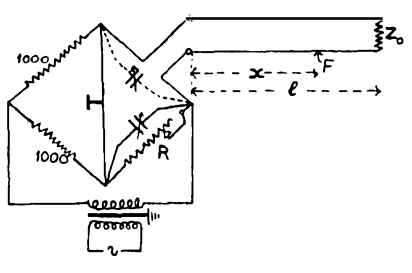
If, however, the transmission difficulty is only experienced on certain long distance calls, then the trouble may be due to the inclusion of low-grade circuits in the chain of connexions. This can be checked by means of a test call from the extension instrument to the distant telephone and observations of the quality of the speech to intermediate points en route.

With a local battery telephone, the overall transmission losses comprise (i) the transmission equivalent of the exchange and extension lines and of the junction and trunk circuits used; (ii) the audio-frequency transmission loss due to the inclusion of series or shunt apparatus in the circuit; and (iii) a fixed allowance for the sending efficiency of the local battery telephone instrument, added to correlate the transmission efficiency with C.B. transmission conditions.

With a C.B. telephone, the overall transmission losses comprise (i) a loss depending upon the value of the direct current fed to the transmitter; (ii) the transmission equivalent of the exchange and extension lines and of the junction and trunk circuits used; and (iii) the audio-frequency transmission loss introduced by the transmission bridges at the main and private branch exchanges, and by any other series or shunt apparatus in circuit.

Q. 2. Describe a method of localising cable faults by means of alternating current bridge measurements. What data is necessary for accurate location of faults by the method described? (30).

A. 2. A diagram of the connexions of an alternating current bridge used in the location of an impedance irregularity is



shown in the sketch. An impedance/frequency test is made on the faulty pair and the bridge resistance readings are plotted against frequency. The distance, x, to the fault is then $\frac{K}{f}$, where f is the mean frequency interval between successive maximum points on the curve and K is an empirical constant. To determine K, the line can be terminated with an impedance other than its characteristic impedance and the bridge resistance readings plotted to determine the resulting mean frequency interval, f_1, between successive maximum points. The constant K is then obtained from $K = lf_1$, where l is the length of the line. Alternatively, for loaded cables K may be taken to be $\frac{1}{2\sqrt{LC}}$ where L is the inductance in henries and C is the capacity in farads, both per mile loop.

The data required for the accurate location of faults by this method are (i) the length of the line, l, for the purpose of determining K; (ii) the impedance/frequency curves under real and artificial fault conditions; and (iii) the normal impedance/frequency curve of the faulty pair.

Q. 3. Describe the steps taken to set up a long 4-wire repeater circuit and state the objects of any measurements of repeater gain, line impedance or transmission equivalent that you consider to be necessary. Explain the causes of variation in transmission equivalent of working circuits. What steps are taken to correct such variations? (30).

A. 3. The inter-station transmission equivalents are measured at 800 p.p.s., the measurements being made in both directions on both go and return lines. The impedances of the go and return lines are measured at 800 p.p.s. from the office side of the transformers, the intermediate repeaters being rendered inoperative by turning their potentiometers to zero, and the termination being closed with 600 or 1,000 ohms according to the impedance of the terminating equipment. If the modulus of the impedance of the line is not within 30 per cent. of the nominal impedance of the equipment, the line transformer is changed for one of more suitable impedance ratio.

The control station prepares a level diagram based upon the inter-station transmission equivalents and the overall transmission equivalent required. The gain at each repeater is estimated and each repeater station sets the repeaters to give the estimated gain. Output level measurements at 800 p.p.s. are then made from the exchange termination to each repeater station in turn. At each repeater station, measurements of output level and repeater gain are made and if the measured value of output level differs from the estimated value by more than ± 1 db., the repeater gain is adjusted.

Equalizers are adjusted so that the required degree of higher frequency equalization as may be necessary is obtained; the overall transmission equivalent of the individual go and return lines should be as uniform as possible from 800 p.p.s. up to 0.7 of the nominal cut-off frequency of the lines. The equalization is checked by a series of output level measurements at different frequencies.

When an echo suppressor is used, a test of the hang-over is made by conducting a test conversation between the terminal repeater stations and observing that there is no clipping of initial syllables. If the hang-over is too short, the tapped resistances in the suppressor smoothing network are adjusted.

Repeatered circuits are regularly subjected to routine tests of overall transmission equivalent. Any increase is usually found to be due to a defective valve at an intermediate repeater station; the repeaters en route are tested, the defective valve located and changed, and the circuit again placed in service. On the longest circuits, such as London-Glasgow, the repeater gains are periodically adjusted to compensate for variations in conductor resistance due to seasonal variations in temperature.

Q. 4. Give the formulæ for (a) the propagation constant, (b) the attenuation constant, and (c) the wave-length constant of a circuit having uniformly distributed primary constants. Will the formulæ apply to circuits having lumped primary constants? Give the approximate form of the formulæ for the constants (a), (b) and (c) for an unloaded cable circuit having small gauge conductors and for a loaded cable circuit having negligible leakance. Show how the approximate formulæ are derived. (30).

A. 4.

(*a*) $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \beta + j\alpha$

(*b*) $\beta = \sqrt{\tfrac{1}{2}\left\{\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)}+(GR-\omega^2LC)\right\}}$

(*c*) $\alpha = \sqrt{\tfrac{1}{2}\left\{\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)}-(GR-\omega^2LC)\right\}}$

The formulæ do not apply to circuits having lumped primary constants in which case Campbell's formulæ would be applied, although it is usully sufficient to use Mayer's or other approximations. The formulæ do, however, give a rough figure for the secondary constants at 800 p.p.s.

For an unloaded cable circuit having small gauge conductors, L and G may be neglected; then

$$\gamma = \sqrt{jR\omega C} = \sqrt{R\omega C}\,\underline{/90^\circ} = \sqrt{R\omega C}\,\underline{/45^\circ}$$

$$\text{Cos } 45^\circ = \text{Sin } 45^\circ = \sqrt{\tfrac{1}{2}}$$

$$\beta = \sqrt{R\omega C}\cos 45^\circ = \sqrt{\frac{R\omega C}{2}}$$

$$\alpha = \sqrt{R\omega C}\sin 45^\circ = \sqrt{\frac{R\omega C}{2}}$$

In a loaded cable circuit having negligible leakance, the following formulæ are given by making G = O in formulæ (*a*), (*b*) and (*c*) above.

$$\gamma = \sqrt{j\omega C\,(R + j\omega L)}$$

$$\beta = \sqrt{\frac{\omega C}{2}\sqrt{R^2+\omega^2L^2} - \frac{\omega^2LC}{2}}$$

$$\alpha = \sqrt{\frac{\omega C}{2}\sqrt{R^2+\omega^2L^2} + \frac{\omega^2LC}{2}}$$

Q. 5. Give an explanatory diagram of a test set for the measurement of transmission equivalents, repeater gains and transmission levels. Explain, briefly, the theory of the transmission testing set. (35).

A. 5. The typical modern transmission measuring set shown in the sketch is designed to transmit a known power to line and to use the same sending element to calibrate an amplifier-detector for the measurement of power received from line. The sending and receiving elements have an impedance of 600Ω and the loss introduced between the variable-frequency oscillator and the output terminals of the sending element is so great that the sending impedance of 600Ω is constant irrespective of oscillator frequency or output current regulation.

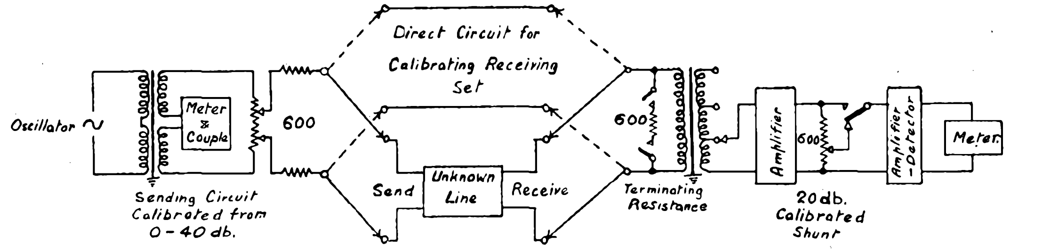
The current in the thermo-ammeter is usually about 40 mA and is kept constant by oscillator output control. With this constant input to the sending element, the transmission measuring set delivers 1 mW to a 600Ω line. If a line of other impedance is connected to the set the power delivered to the line is not appreciably changed, the difference being little more than 0.5 db. if the line impedance is 1200Ω. It is generally assumed, therefore, that the set delivers 1 mW to line and no correction is made for line impedance.

The receiving element comprises an amplifier-detector having a high-impedance input transformer which is tapped, and a continuously variable inter-stage potentiometer calibrated in decibels.

To calibrate the set, 1 mW at the desired testing frequency is transmitted directly from the sending to the receiving element, the input of the latter being shunted with 600Ω to give the correct voltage (0.7746v) at the input terminals. The whole of the inter-stage potentiometer is tapped under this condition and the deflexion on the measuring meter indicates zero db. The primary of the detector valve is adjusted at this stage to give a suitable deflexion on the meter.

When a line is measured, this deflexion is reproduced by introducing loss in the potentiometer if the received voltage exceeds 0.7746v, or, if the received voltage is less than 0.7746v, by stepping up the received voltage at the input transformer by a known amount to permit the reproduction of the deflexion by means of the potentiometer.

For the measurement of levels, the input element is connected to the circuit under test without the 600Ω input shunt. Any departure from the 600Ω impedance condition in the line is more serious in level measurements and corrections become necessary if accuracy is desired. In routine work, however, the test is usually for the purpose of determining changes from previous level measurements and as in that case tests would have been made across the same impedance, the differences between the results would not require correction.



(*To be continued.*)

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