ELECTRICAL INTERFERENCE TO RADIO BROADCAST RECEPTION

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ABSTRACT. The paper relates to studies of electrical interference to radio broadcast reception on short and medium wave-lengths from typical Indian sources like d. c. ceiling fan, d. c. pumping installation, d. c. operated refrigerator, d. c. operated electric tool, etc. After discussing the nature of r. *f*. interference signal, different methods of measurements employed elsewhere as well as the authors' method were considered in details.

The r. f. interference voltage input to the receiver (resulting from the normally polarized electric component of the direct radiation field of the source as well as that of radiation field of any wiring along which energy may have been conducted) has been measured at a typical distance on wave-lengths from 10 to 550 metres for different sources. The effect of speed regulation of ceiling fans has been studied.

Studies have been made on the state of polarization of r. f. ground wave interference signals. The ratio of abnormally polarized to normally polarised component has been measured on various wave-lengths for different sources, and its variation with speed in case of ceiling fans has been observed.

Studies have been made on the propagation of r. f. interference signal in typical surroundings. An attempt has been made to verify the view-point that the interference signal is propagated from the source to the receiving point in typical conditions both (*a*) as radiated ground wave and (*b*) as wave conducted simultaneously by the electrical wiring to the vicinity of the receiving equipment whence it may be radiated to be picked up by the same. Horizontal polar diagrams have been shown.

Studies have been made as to the frequency components in the audio-frequency band resulting from r. f. interference signal from different sources and the distribution of power in the band. The effect of speed variation of ceiling fans has also been observed in this connection.

The equivalent normally polarized and abnormally polarized components of the electrical field intensity (in mv/m) of the interference on different metre-bands at typical distance have been obtained for various sources. The ratio of broadcast signal strength to total noise strength has been estimated in a few cases.

1. INTRODUCTION

Electrical Interference to radio broadcast reception is direct consequence of electrification for domestic, industrial, traction and other utilization purposes.

Direct-current equipments and systems are much greater offenders than alternating-current ones. Ceiling and table fans, pumping installations, refrigerators, vacuum cleaners, lifts, high-voltage transmission systems, converting plants, tramways, trolley-buses, automobile and aircraft systems, neon signs and electro-medical apparatus are known to have sources of interference associated with them.

The usual locations of interference source in some of the electrical machines and systems are (*a*) commutators in d.c. fan motors; (*b*) commutators, switches, contactors, etc., in large d. c. pumping installations; (*c*) commutators, switches and relay circuits in d. c. operated refrigerators; (*d*) high-voltage switchgears, contactors, mercury-arc rectifiers, etc., in power systems; (*e*) spark plugs, magnetos and electric horns in automobiles; and (*f*) collectors, brake-magnet coils, etc, in tramway systems.

Investigations on electrical interference from traction systems,[8] tıolley buses,[11] high-voltage transmission lines,[1] electro-medical equipments,[11] automobiles and air-crafts,[1] have been undertaken by various bodies and solo workers in Great Britain, the United States and on the Continent. The methods of suppression and the legistations, [2,3,5,9] relating to them have also received adequate attention.

The conditions are much different in India and other tropical countries which, though much less industrially developed, need fans, pumps and refrigerators as household necessities. The direct-current supply systems still hold the field in majority of town areas in these regions. The chief interfering sources are therefore located in d. c. operated domestic equipments like fans, pumps and refrigerators out of which the d. c. fans may be called the worst type of offenders. Also it is evident that in majority of cases the sources of interference are situated either within the very premises of radio listener or in premises adjacent to his.

With the rapid expansion of radio broadcasting (specially of the short-wave type) in India during last five years, the demand for study of electrical interference on various wave-lengths from typical sources found here has considerably increased. The present paper has been an attempt to meet with the same and to obtain data suitable for broadcast designers.

2. NATURE OF R.F. INTERFERENCE SIGNAL

The interference signal can be considered to be made up of signal components at various frequencies arising out of any variation in the electrical condition of circuit or circuits associated with the interference source under consideration. The more abrupt the variation in the condition, the higher will be the frequencies of the interference signal components. The frequencies of the signal components will vary with different types of electrical equipment as well as with speed and other conditions at which they are worked.

Difference has also been found to exist between similarly designed equipments of the same type but of different makes and even between individual equipments of same design and same make. Moreover, the type of maintenance applied to equipment makes lot of difference to the interference caused by it. A badly maintained equipment causes much severe interference than a well-maintained one of the same design and make.

The analysis of the audio output (in Section 7) as well as the observation of oscillograph patterns (in Section 5) indicate that the interference signal spectrum for fans, pumping installation and refrigerator is more or less continuous.

Taking the specific case of commutator of a d. c. motor it will be noted that deviation from linear commutation takes place due to 'reactance voltage' (*i.e.*, self-induced e. m. f. in the coil due to change of current in it). This results in sparking between the brush and the receding commutator segment whose duration is prolonged due to self-induction. During this small duration of sparking, the circuit conditions undergo rapid change. A steady spark condition giving a limited number of frequency components is rapidly being altered to unsteady spark conditions giving rise to larger number of frequency components more or less as in a continuous spectrum. The greater the speed of the motor, the greater becomes the reactance voltage and consequently the greater the liability for sparking.

The electric equipment thus regarded as a source of radio-frequency energy (almost of the continuous spectrum type) radiates wave-components of various frequencies in all direction. The receiver picks up the portion of the radio-frequency interference spectrum lying in the band accepted by it and reproduces it as audio noise in the loud-speaker. It is likely that some radio-frequency energy is simultaneously conducted along the electrical wiring and re-radiated from a point to be also picked up by the same receiving equipment.

The plane of polarization of the radiated ground-wave interference signal from fans, pump and refrigerator has not been found to be vertical as it was observed by workers elsewhere for other electrical equipments. The interference signal is elliptically polarized. Measurement of normally and abnormally polarized components of the electric vector at a receiving point (outside the influence of induction field) has shown that the strength of the latter component is about 70 to 80 per cent of the former component. The ratio between the components has been found to vary with wave-length as well as with speed of the motor incorporated in the equipments.

On tuning a receiver connected to an aerial designed to pick up, say, the vertical component of the electric vector for a modulated broadcast signal of angular carrier frequency 'ω', the voltage input to the receiver due to broadcast signal will be

$$V_s = A(1 + m \cos pt) \cos \omega t \qquad \ldots \quad (1)$$

and that due to the integral of the radio-frequency (vertically or normally polarized) interference spectrum lying in the band accepted by the receiver will in general be

$$V_{RF} = a_0 \cos[\omega t + \theta_0] + a_1 \cos[(\omega + p_1)t + \theta_1] + a_2 \cos[(\omega + p_2)t + \theta_2] + \ldots \quad (2)$$

where $\omega/2\pi$ = broadcast carrier frequency; $p/2\pi$ = modulating frequency; $p_1/2\pi$, $p_2/2\pi$, $p_3/2\pi$...are *frequency differences* between interfering voltage frequencies and carrier frequency; θ_0, θ_1, θ_2,...are phase differences between interfering voltage components and signal voltage; A = carrier amplitude (vertically polarized component), m = modulation factor; a_0, a_1, a_2, are amplitudes of (vertically polarized) interference voltage components.

3. MEASUREMENT OF INTERFERENCE VOLTAGE

If the input to a receiver consists of modulated carrier and interference voltages, say, due to normally polarized (vertically) components represented as follows:

$$V'_{RF} = A(1 + m \cos pt) \cos \omega t + \Sigma a_n \cos[(\omega + p_n)t + \theta_n], \quad \ldots \quad (3)$$

then the audio-frequency output of the receiver (which selects a band of frequencies, rectifies the resultant linearly, rejects all except a certain band of audio frequencies and introduces constant amplification to the frequencies selected) will be given by

$$V' = K' \times [Am \cos pt + \Sigma a_n \cos(p_n t + \theta_n)] \quad \ldots \quad (4)$$

where K′ is a constant. Signal/Noise at the output $= \dfrac{Am}{\Sigma a_n}$. ... (4a)

It will be seen that the interfering voltages appear undisturbed in the output, only their frequencies are changed to the difference between the original r. f. value and the carrier frequency.

If the modulated carrier be regarded to be absent and only the integral of the radio-frequency interference spectrum in equation (2) when it tends to be continuous be the incoming signal, then it can be shewn [11] that the audio-frequency electrical output of the receiver is approximately given by

$$V = k \times \Sigma a_n \cos(p_n t + \theta_n - \phi) \quad \ldots \quad (5)$$

where $\phi = \tan^{-1}[\Sigma \tan(p_k t + \theta_k)]$

and k = a constant.

It will be seen that noise amplitude still remains proportional to Σa_n, but the character of the noise is slightly altered from that of the previous case.

Three distinct methods of measurement [6,7,11] of electrical interference (depending upon the above calculations) have been employed elsewhere. In one method (used by Siemens and Halske), in addition to the interference voltage, a modulated carrier of frequency same as that of the broadcast carrier is introduced to the input of the measuring set and the audio-frequency noise output due to interference is measured by a specially designed peak voltmeter. In another method adopted by the British Post Office and Electrical Research Association, the interference voltage is measured by means of a special valve voltmeter associated with a suitably selective (superheterodyne) amplifier system. In the third method used in U.S.A., the audio-frequency noise output due to interference voltage alone (without introduction of carrier) is measured by a calibrated radio receiver provided with an output voltmeter.

If the characteristic of the measuring equipment be quite linear and the interference has continuous and fairly uniform spectrum, the introduction of carrier does not produce much difference. The same measurements carried out by both first and third methods have yielded results almost agreeing with each other.

The method of measurement developed here is similar to the third method with the important difference that, instead of measuring directly the audio-frequency electrical output, the audio-frequency acoustic output has been measured by a directional microphone connected to an amplifier system.

The loudspeaker as well as the directional microphone-amplifier system have almost uniform response as well as negligible distortion over the audio-band involved. The overall characteristic of the entire measuring equipment (*i.e.*, 'radio-frequency interference input' *vs.* 'audio-frequency noise output of the microphone-amplifier') has been obtained fairly linear.

The advantages of the method are as follows :—

(*a*) The use of acoustic output enables an aural estimation of the intensity and character of the disturbance more or less as they would be in the actual reception to be simultaneously made, and

(*b*) the use of acoustic output is further helpful in distinguishing aurally the 'electrical noise' from the 'atmospheric noise' (which may happen to be picked up) and ensuring measurement of the desired disturbance only at all times in a tropical country (where the atmospheric disturbance is prevalent throughout the year).

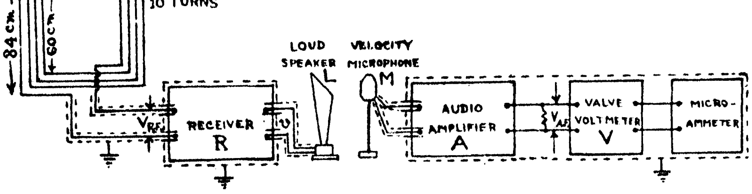

FIG. 1

Fig. 1 shows the block schematic diagram of the measuring equipment. Æ is a square frame aerial with 10 turns of 7/34 copper conductor (outer dimensions=84 cms. × 84 cms. and spacing between turns=1.2 cms) all in the same vertical plane rotatable about vertical axis and has been rendered free of "antenna effects" both in normal (aligned) and cross positions. This aerial shown in Fig. 1 has been used for measurement of vertically or normally polarized component of the electric field intensity for which the frame is placed with its plane in the direction of the source and observations taken at hours when other sources in the same or other directions are not in action. A horizontal aerial (rotatable about horizontal axis) has been used for horizontally or abnormally polarized component.

R is high-class superheterodyne receiving unit designed for medium and short wave bands in which A. V. C. can be switched on and off. The internal noise output (electrical) of the unit is about 100 to 110 micro-volts over the audio-frequency band which is about 100 db below the minimum electrical interference output. L is a high-quality loud-speaker of moving-coil type incorporated in the receiver unit and has uniform response and negligible distortion over the audio-band involved.

M is a velocity ribbon microphone of uniform response and negligible distortion over range 30-10,000 c.p.s. fixed at a distance of 4″ from the loud-speaker for all measurements. The velocity ribbon microphone has been selected for picking up the acoustic output for the following reasons :—(*a*) Its internal noise level is about the lowest ; (*b*) its response characteristic on the low-frequency side extends uniformly up to 30 c.p.s. and it has therefore been deemed suitable for picking up acoustic output of interference consisting of very low frequencies as well ; (*c*) it is a directional microphone most suitable for these measurements since it is undesirable for it to pick up sound from directions other than from the loudspeaker of the receiving equipment ; and (*d*) there is no harmonic distortion in such a microphone.

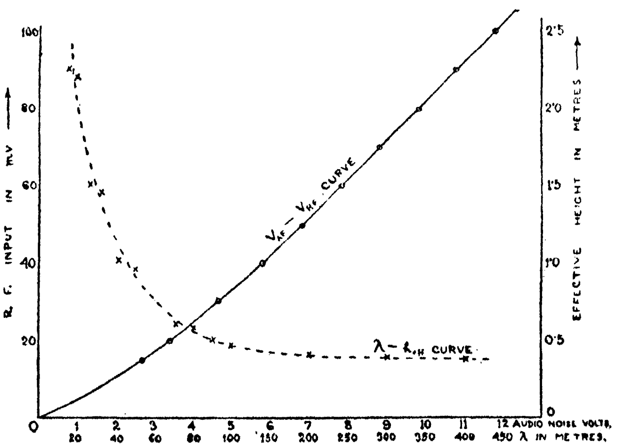

FIG. 2

A is an audio-voltage amplifier unit which is linear and has uniform amplification characteristic over the range 30-9000 c.p.s. V is a special valve voltmeter for measuring audio voltage across a non-reactive impedance connected across the amplifier output.

The measured overall characteristic of the entire equipment showing r.f. receiver input (V_{RF}) against audio noise voltage output (V_{AF}) of the microphone-amplifier is shown in Fig. 2. The variation of the effective height of the frame aerial shown in Fig. 1 with wave-length is also given in Fig. 2.

4. R. F. INTERFERENCE VOLTAGE DEVELOPED FOR DIFFERENT SOURCES

Measurement has been made by equipment in Fig. 1 on the r. f. interference voltage input to the receiver resulting from the vertically polarized electric component of the direct radiation field of source as well as that of radiation field of any wiring along which energy may have been conducted.

J. D. C. Ceiling Fan

The d. c. ceiling fan is generally regarded to be the worst offender. The site of interference source in the fan is the commutator.

(*a*) *Ceilng fans of same design and horse-power but of different makes*

Four ceiling fans (Walter Lock, Dayton, India Electric and Bengal) each of about 1/10 H.P. with same service age and same degree of maintenance applied to them have been examined.

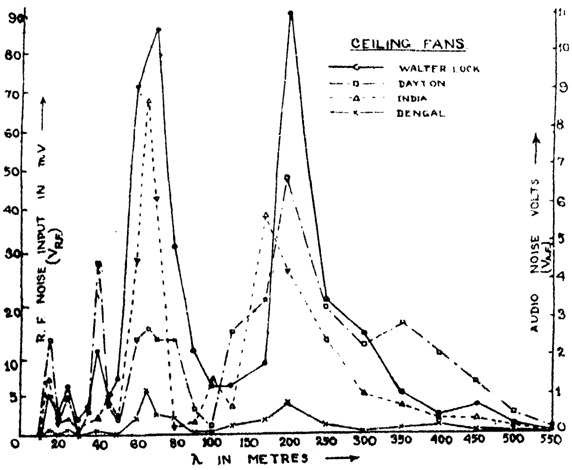

FIG. 3

Fig. 3 shows the radio-frequency noise voltage input (V_{RF}) into the receiver at various short and medium wave-lengths (the band-width associated with each wave-length being about 16 kc/s) measured at 50 feet from the source which is outside the influence of the induction field of the source. The distance over which the effect of induction field can be reasonably expected to exist depends upon the frequency (or wave-length) as well as upon the strength of commutator sparking current component at the frequency. The speed regulator in all cases is adjusted for 300 r.p.m.

It will be seen on comparison of the experimental curves that (*a*) the "Bengal Fan" gives in general the lowest noise voltage level for wave-lengths in short and medium wave bands, (*b*) all the four fans examined give very high noise voltage on the wave-length ranges 55-80 metres and 150-250 metres, (*c*) all the fans (except the Bengal fan) give high noise voltage on the wave-length range 13-15 metres, 26-28 metres, 35-45 metres, 130-150 metres and 250-350 metres and (*d*) all the fans give low noise voltage on the wave-length range 16-22 metres, 28-32 metres, 45-50 metres, 90-110 metres and 400-545 metres.

(*b*) *Effect of speed regulation*

Four ceiling fans (Walter Lock, India Electric, Siemens and Bengal) have been examined for the effect of speed regulation. Investigation has been carried on three speeds—"full," "medium" and "slow." Full, medium and slow speeds were respectively 520, 300 and 120 r.m.p. for Bengal Fan ; 380, 250 and 100 r.p.m. for India Fan; 350, 220 and 100 r.p.m. for Siemens Fan and 250, 150 and 80 for Waiter Lock Fans fitted with our regulators.

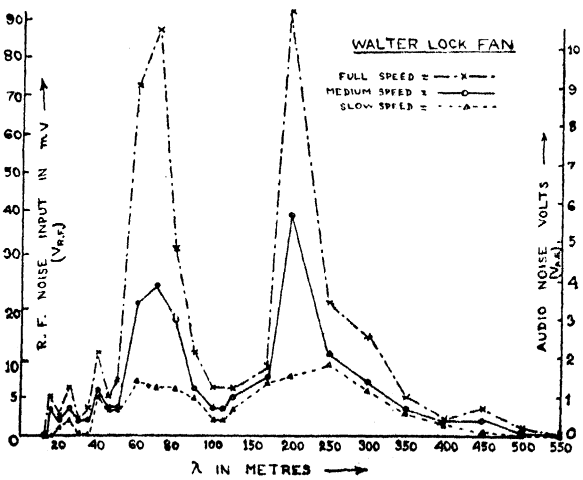

FIG. 4(*a*)

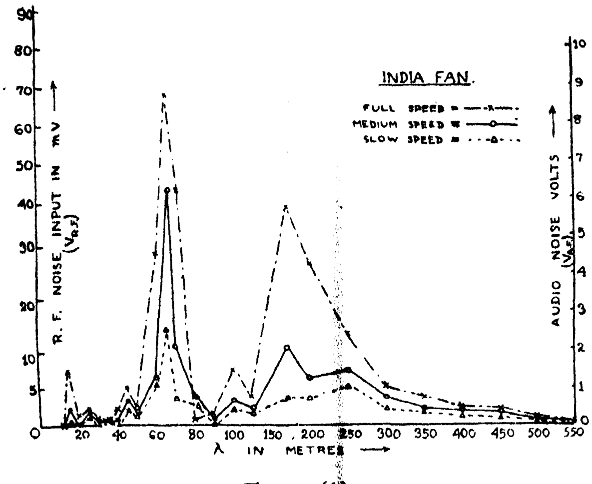

Fig. 4(*b*)

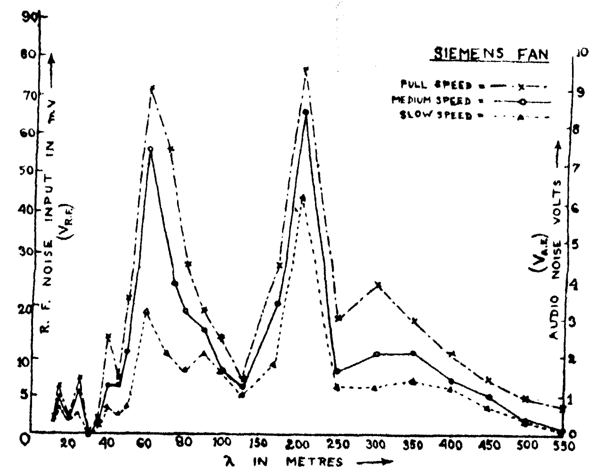

Fig 4(*c*)

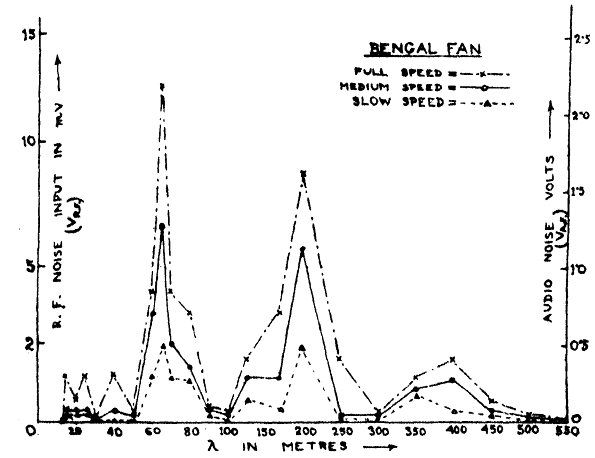

Fig. 4(*d*)

Fig. 4(*a*), 4(*b*), 4(*c*) and 4(*d*) show the radio-frequency noise voltage input (V_{RF}) into the receiver at various short and medium wave-lengths measured at 50 feet from the sources under different speed conditions.

It will be seen from the figures that, on decreasing the speed, the radio-frequency noise voltage (V_{RF}) at the various short and medium wave-lengths decreases. It will be noticed that the peaks (obtained at full speed) on certain wave-length ranges in case of Walter Lock and India Electric fans get reduced or disappear when the speed is reduced to 'slow' and thus the effect of speed reduction is to decrease or eliminate completely the interference on certain wave-lengths.

Table I shows the reduction of noise level in decibels on speed reduction on typical wave-lengths.

TABLE I

Fan Make	Wave-length (metres)	Reduction of noise voltage in *db* on changing from	
		Full to medium speed	Full to slow-speed
Walter Lock	70	8.7 *db*	19.1 *db*
	200	6.1 ,,	17.3 ,,
India Electric	66	3.0 ,,	11.0 ,,
	170	9.0 ,,	18.1 ,,
Siemens	60	2.0 ,,	9.0 ,,
	200	2.0 ,,	4.0 ,,
Bengal	66	5.0 ,,	13.0 ,,
	200	3.0 ,,	10.4 ,,

II. D. C. Pumping Installation

The d. c. pumping installation (whether for domestic or other purpose) interferes severely with the broadcast reception. The sites of interference sources in the installation are commutator, switchgear, contactor, etc.

Measurements have been taken on a d. c. pumping installation with 2 H.P. G.E.C. motor at 200 feet from it, the motor running at about the full speed (28,000 r.p.m.),

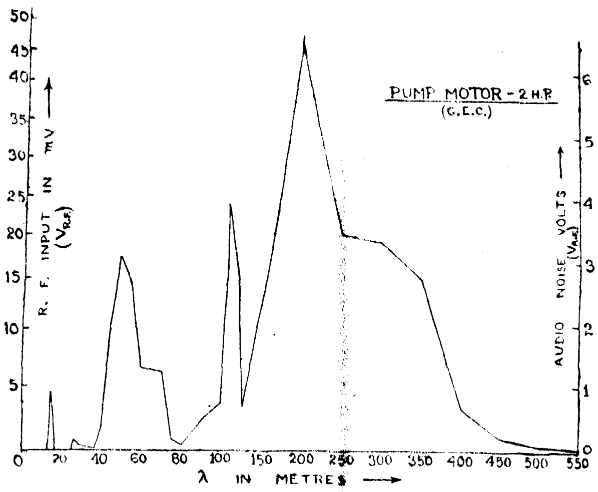

FIG. 5

Fig. 5 shows the radio-frequency noise voltage input (V_{RF}) at various short and medium wave-lengths measured at 200 feet from the source.

It will be seen therefrom that the noise voltage is (*a*) considerably high on the wave-length range 175-240 metres, (*b*) quite high on about 14 metres and on wave-length ranges 42-72 metres, 92-175 metres and 240-400 metres and (*c*) low on other wave-lengths.

It would also appear that a d. c. pumping installation of the type would not, in general, interfere with short wave-lengths from 12 to 40 metres (except on 14 metres).

III. D. C. Operated Refrigerator

The refrigerator operated from the d c. mains causes interference on a comparatively larger number of wave-lengths in short and medium wave bands. The sites of interference sources in the refrigerator are commutator, switch and relay circuit.

Measurements have been taken on a typical refrigerator manufactured by Frigidaire Co. (U.S.A.) and fitted with ¼-H.P. motor at 50 feet from it, the motor running at about the full speed (1200 r.p.m.).

Fig. 6 shows the radio-frequency noise voltage input (V_{RF}) at various short and medium wave-lengths measured at 50 feet from the source.

It will be seen therefrom that unlike other sources (previously discussed) the refrigerator causes disturbance over larger number of wave-length ranges. The noise voltage is (*a*) very high on range 38-46 metres and on 120 metres, (*b*) high on ranges 36-38 metres, 46-88 metres, 110-120 metres, 130-150 metres

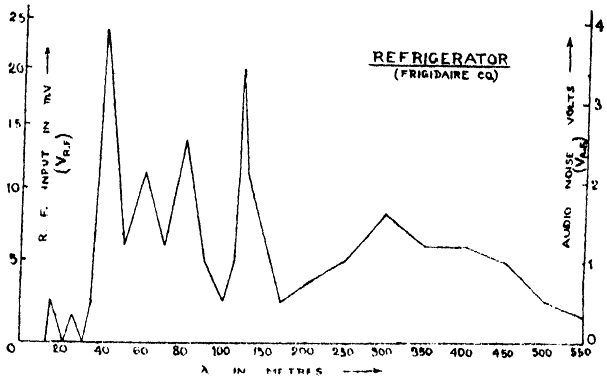

FIG. 6

and 250-450 metres and (*c*) low on other wave-lengths specially on the range 12-36 metres.

5. POLARIZATION OF GROUND-WAVE INTERFERENCE SIGNALS

To examine the state of polarization of the ground-wave interference signals, a receiving point outside the influence of induction field has been so chosen that there are no radiating wirings in the vicinity of the point to modify the receiver input voltage developed from the electric component (vertically polarized or horizontally polarized) of the direct-ray field. The consideration of sky ray does not come in at all for distance involved here.

For obtaining r. f input voltages due to vertically polarized and horizontally polarized components of the electric vector, aerials of the type discussed in section 3 have been employed. Knowing the voltages developed in the aerials and their effective heights, the ratio of horizontally polarized component (E_H) to vertically polarized component (E_V) has been estimated at various wave-lengths.

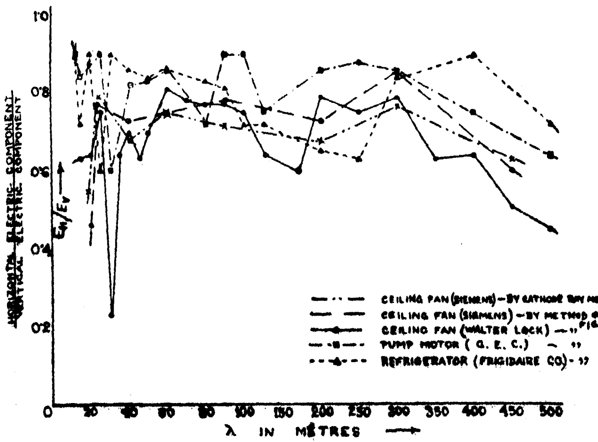

FIG. 7

Fig. 7 shows the ratio plotted against wave-length for ceiling fan (1/10 H.P.), pumping installation (2 H.P.) and refrigerator (¼ H.P.) situated at 50, 200 and 50 feet respectively from the receiving point. It will be seen that the ratio (E_H/E_V) decreases on wave-lengths above 400 metres and also below 40 metres and that the average ratio for equipments examined varies from 0.7 to 0.8 over the range 40-400 metres.

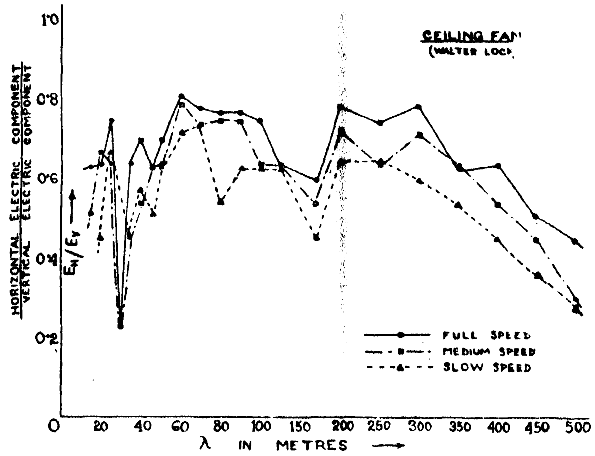

FIG. 8

Fig. 8 shows the ratio plotted against wave-length for ceiling fan at three different speeds. It will be seen that the ratio decreases in general as the speed is reduced.

The ratio of the components as well as the elliptical patterns have also been obtained by an alternative method—by connecting up the vertical and horizontal aerials of almost same effective height to two exactly similar superheterodyne receiving units (loud-speakers disconnected) with same beating oscillator and applying their electrical outputs to two pairs of plates of a cathode-ray oscillograph tube. Fig. 7 shows that ratio E_H/E_V for "Siemens fan" obtained by cathode-ray oscillograph and previous method is more or less in agreement. Patterns observed at various wave-lengths from 19 to 450 metres show a number of ellipses (due to various interference signal components accepted by receiver) superimposed on one another, some of them being more agitated than others.

6. PROPAGATION OF R. F. INTERFERENCE SIGNAL IN TYPICAL SURROUNDINGS

The mode of propagation of r. f. interference signal from the source to the receiving point (in typical surroundings) is more complex than that of either atmospheric disturbance or broadcast signal. In majority of cases the sources of interference are situated either within the very premises of the listener or in premises adjacent to his. It is only in exceptional cases that badly maintained electrical equipments interfere with radio reception at distant receiving points.

Taking the common case, it will be realized that a number of electrical wirings of various types invariably run vertically or horizontally or both ways between the position of interfering equipment and proximity of the receiving point. It is more or less impossible to ignore the part played by them in modern premises. It may therefore be said that the interference signal is likely to be propagated from the source to the receiving point (situated outside the influence of induction field of the source) simultaneously (*a*) as radiated ground wave and (*b*) as wave conducted by the electrical wiring to the vicinity of the receiving aerial whence it is either radiated to be picked up by the receiving equipment or transferred to it by induction depending upon separation between wiring and receiving aerial, wave-length, power, etc. The consideration of sky ray for distances involved here does not arise at all.

The propagation of signal along the electrical wiring can take place either as that of potential difference between the two conductors themselves or of potential difference between the mean potential of conductors and earth known in subsequent paragraghs as 'symmetrical' and 'asymmetrical' propagations respectively.

It will be seen in the following portions of the present section how far the mode of propagation suggested above holds good in an actual case. Table II shows the measured values of r. f. interference voltage input resulting from the vertically polarized electric component of the radiation field of the source as well as of any wiring radiating the conducted energy.

TABLE II

Distance from source (yds.)	Ceiling Fan—Walter Lock		Electric Tool—Electromag. Tool Co.	
	R. F. Voltage input (mv.) on		R. F. Voltage input (mv.) on	
	$\lambda = 15$ m.	$\lambda = 450$ m.	$\lambda = 15$ m.	$\lambda = 400$ m.
10	14	4.5	160	42
15	7	3.5	82	31
20	4.5	2.0	29	28
25	3	1.0	14	24.5
30	1	0.5	10.05	23.5
50	0.4	0.2	6	21.6

Calculation of r. f. noise voltage input

The r. f. noise voltage input due to vertically polarized electric component of the direct radiation field of the source as well as of wiring radiating the condutted energy has been calculated for ceiling fan and electric tool.

I. Ceiling fan – Walter Lock (1/10 H. P.).

The necessary design data for motor in the above ceiling fan are as follows :—

Armature diameter = D_A = 9 cms. ;
Commutator diameter = D_c = 4 cms. ;
Effective embedded length of loop of commutated coil = l_c = 12 cms. ;

Effective free portions of loop of commutated coil = $l_f = \frac{3\pi D_A}{n}$;

Number of turns/slot = M = 70 ;
Number of poles = n = 2 ;
Armature current = I_A = 0.4 amperes ;
Brush contact resistance = r_b = 5 ohms ;
R. P. M. (at full speed) = 250 ;
Brush thickness = 6 mms. ; and mica insulation thickness = 1 mm.

Then, by calculation,

Current in commutated coil $I_c = I_A / n$ = 0.2 amperes.

t_c = time of commutation (during which current change take place) = .01 sec.

$L_r = 8M^2 (l_c + 0.1 l_f) \times 10^{-8}$ Henries $= 128 \times 49 \times 10^{-6}$ Henries.

E_s = Reactance voltage (sparking voltage)

$$= L_r \cdot \frac{I_c - (-I_c)}{t_c} \times 10^{-8} \text{ volts} = L_r \cdot \frac{2I_c}{t_c} \times 10^{-8} \text{ volts.}$$

= 250 mv.

I_s = sparking current = 50 m.a. (max.).

The sparking current for this fan may be regarded to consist of current components of various frequencies (almost as in continuous spectrum from 0.5 Mc/s to 30 Mc/s. The representative current strength (I) (for vertical component) over a band-width of 16 Kc/s (*i.e.*, 8 Kc/s on either side of the frequency under consideration) associated with 0.66 Mc/s (*i.e.*, 450 metres) component may be estimated to 2 m.a. and over the same band-width associated with 20 Mc/s (*i.e.*, 15 metres) about 0.5 m.a.

The *euqivalent* effective height of the fan aerial at 0.66 and 20 Mc/S has been arrived at to be 58.5 metres and 6.5 metres respectively. Taking appropriate absorption factor A_1 for medium and short wave-lengths, the vertical component of electric intensity of the direct (radiation) field in the two cases has been obtained from the equation

$$E_\nu = 377 \cdot \frac{h\,I}{\lambda D} A_1 \text{ mv/m} \qquad \dots (6)$$

where h and λ are in metres, D in Kms. and I in amperes. The voltage developed in the receiving aerial of effective height h_r is given by

$$V_a = E_\nu \,.\, h_r \qquad \dots (7)$$

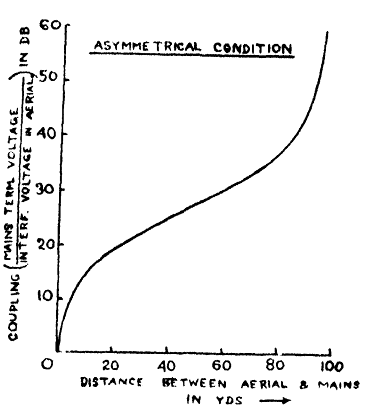

FIG. 9(*a*)

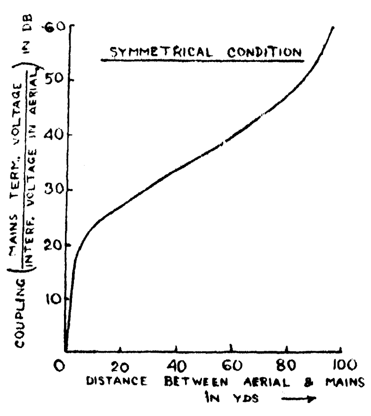

FIG. 9(*b*)

To calculate the voltage developed in the aerial (V_a') on account of the vertical component of radiation field of electric wiring along which the interference voltage has been conducted from the source to the vicinity of the receiving aerial, use has been made of experimental curves (Figs. 9) showing coupling factor (R. F. voltage on the mains wiring at the point divided by interferenee voltage in aerial) for different separations between the wiring and the aerial. Transmission over mains has been considered both for symmetrical and asymmetrical conditions which give results not much different from each other in this particular case. The total r.f. noise voltage input $= V_{RF} = V_r + V_c$ since individual voltages V_r and V_c due to pure radiation and conduction – radiation respectively are in the same phase.

Table III shows the voltages arrived at by calculations.

TABLE III

Distance from source (yds.)	λ=15 metres			λ=450 metres		
	V_r (mv.)	V_c (mv.)	V_{RF} (mv.)	V_r (mv.)	V_c (mv.)	V_{RF} (mv.)
10	12.96	0.28	13.24	3.78	.37	4.15
20	4.05	0.17	4.22	1.89	.22	2.11
30	1.8	0.11	1.91	1.26	.15	1.41
50	1.08	0.07	1.15	0.76	.14	0.90

II. Electric Tool—(Electro-magnetic Tool Co.) (1/4 H. P.).

The necessary design data for motor in the above tool are as follows :—

Armature diameter $= D_A = 5$ cms. ;

Commutator diameter $= D_c = 2.5$ cms. ;

Effective embedded length of loop of commutated coil $= l_e = 10$ cms. ;

Effective free portions of loop of commutated coil $= l_f = \frac{3\pi D_A}{n}$;

No. of turns/slot $= M = 200$;

No. of poles $= n = 2$;

Armature current $= I_A = 0.9$ ampere ;

Brush contact resistance $= r_b = 5$ ohms ; Brush thickness $= 4$ mm. ;

Mica insulation thickness $= 1$ mm. ;

R. P. M. (when at full speed) $= 500$.

Then, by similar calculations as before, $I_c = 0.45$A ; $t_c =$ time of commutation $= .005$ sec. ; $L = 384 \times 10^{-4}$H ; sparking voltage $E_s = 6.9$V and sparking current $I_s = 1.4$A.

With similar consideration as in the previous case, the representative current strength (I) (for vertical component) over a band-width of 16 Kc/s associated with 0.75 Mc/s (*i.e.*, 400 metres) component may be estimated to about 31 m.a. and over the same band-width associated with 20 Mc/s (*i.e.*, 15 metres) to about 11 m.a. The equivalent effective height of the tool (placed at 7 feet above ground on an insulating stand) at 0.75 and 20 Mc/s has been obtained to be 34 and 3 metres respectively. The voltage developed in the receiving aerial due to vertical electric component of direct radiation field in two cases has been similarly calculated. The voltages developed in the receiving aerial due to radiation from wiring under symmetrical (S) and asymmetrical (A) conditions are much different in this case.

The r.f. noise voltage input to receiving equipment is shown in Table IV.

TABLE IV

Distance from source (yds.)	$\lambda = 15$ metres					$\lambda = 400$ metres				
	V_r (mv.)	V_i (mv.)		V_{RF} (mv.)		V_r (mv.)	V_i (mv.)		V_{RF} (mv.)	
		S	A	S	A		S	A	S	A
10	125	.25	.07	125.25	125.07	41.13	.32	.08	41.45	41.21
20	39	.8	.14	39.8	39.14	20.14	1.0	.18	21.14	20.32
30	18	.3	.8	18.3	18.8	14.0	.4	.11	14.4	14.11
50	15.4	.24	.6	15.64	16.0	10.5	1.5	.50	12.0	11.0

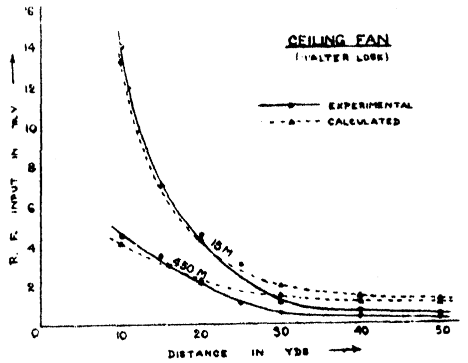

FIG. 10(*a*)

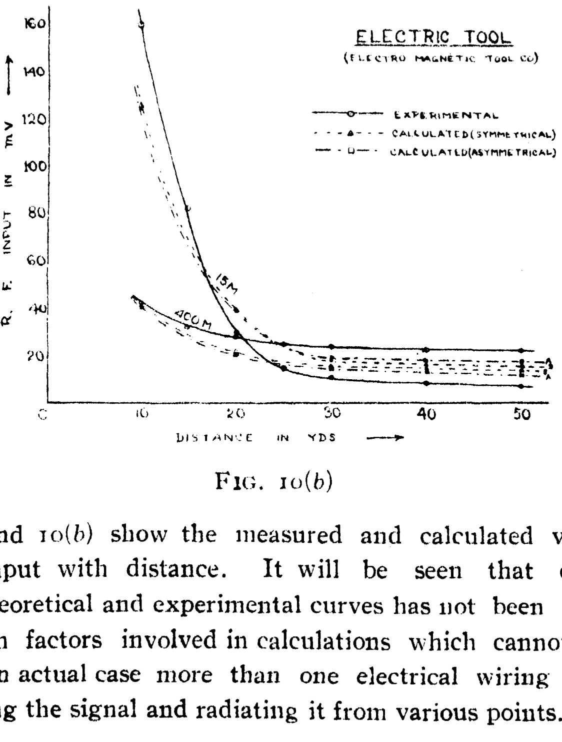

FIG. 10(*b*)

Fig. 10(*a*) and 10(*b*) show the measured and calculated variations of r.f. noise voltage input with distance. It will be seen that complete agreement between theoretical and experimental curves has not been obtained due to certain uncertain factors involved in calculations which cannot be eliminated. It is likely that in actual case more than one electrical wiring has been taking part in conducting the signal and radiating it from various points.

Horizontal polar diagram of sources

The horizontal polar diagrams of sources installed in typical surroundings on representative wave-lengths in medium and short wave bands have been obtained. The variation of r.f. noise voltage with distance in different directions depends upon (*a*) the nature of structural construction and fittings at various distances in different directions and their conductive properties, (*b*) the distance, (*c*) the frequency or wave-length, and (*d*) the proximity or presence of electrical wirings at various distances in different directions. Diagrams obtained for (*a*) Dayton ceiling fan and (*b*) G.E.C. pump motor are shown in Figs. 11(*a*) and 11(*b*) respectively.

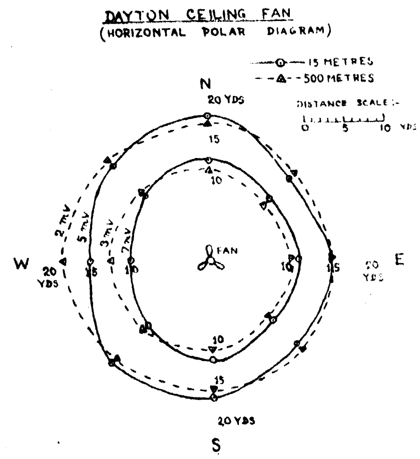

FIG. 11(*a*)

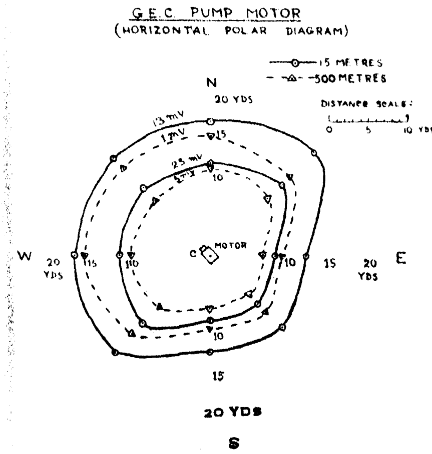

FIG. 11(*b*)

It will be seen therefrom that (*a*) Dayton ceiling fan gives on 15 metres almost the same r.f. noise voltage at the same distance on all sides and on 500 metres greater noise voltage at the same distance on the western side, and (*b*) pump motor gives on both wave-lengths the lowest r.f. noise voltage at the same distance on the south-eastern side.

For the ceiling fan the greater noise voltage on the western side may be due to the presence of wiring on that side and for pump motor the lowest noise voltage on the south-eastern side may be due to the screening effect of the rest of the motor behind the commutator C, the other factors remaining the same.

7. ANALYSIS OF AUDIO NOISE

The section relates to study as to the frequency components in the audio-frequency band resulting from r.f. noise voltage input and the distribution of power in the same.

It has been discussed in section 2 that an electrical equipment is more or less an interference source of continuous spectrum type and further the receiver picks up the r.f. interference spectrum lying in band accepted by it.

The frequency components in the audio noise band shall depend upon (*a*) the r.f. interference spectrum about the r.f. frequency under consideration and the degree to which it could be regarded as continuous and (*b*) the band-width accepted by the receiver employed; whereas the distribution of power in the band shall depend upon (*a*) the amplitudes of the radio frequency components in the portion of spectrum accepted by the receiver, (*b*) the degree to which the interference spectrum could be regarded as continuous, and (*c*) the performance of the receiver with regard to the various components in the band accepted.

For analysis and estimation of power in different portions of the band, the output of the microphone amplifier in Fig. 1 has been arranged to pass through each of the several narrow band-pass filters of negligible attenuation at a time. From measurement of the total output voltage as well as of output voltages of the several filters (the voltages being measured across the same impedance), the distribution of power in different portion of the band has been ascertained.

Table V shows the results of analysis on the pick-ups of r.f. interference spectrum (vertical component) from ceiling fans running at different speeds on short and medium wave-lengths.

It will be seen therefrom that (*a*) the frequencies in the audio noise band roughly lie between 30 and 8000 c.p.s. and (*b*) over 80 to 90% of the power is within the range 30 to 800 c.p.s. and over 42 to 53% of the power is in the range 30-150 c.p.s. Further it will be observed that the effect of motor speed variation on the distribution of power in the audio band is complex. It can only be said that the effect of reducing speed is to lower the power percentage in the frequency range above 400 c.p.s. (except over portion of band 1200-2000 c.p.s. in certain cases) but the frequency limits of the audio band remain the same.

TABLE V

Sub-bands of the audio band	G. E. C. Fan						Bengal Fan					
	Percentage noise voltage						Percentage noise voltage					
	$\lambda = 25$ m.			$\lambda = 300$ m.			$\lambda = 25$ m.			$\lambda = 350$ m.		
(c.p.s.)	Full	Medium	Slow	Full	Medium	Slow	Full	Medium	Slow	Full	Medium	Slow
	%	%	%	%	%	%	%	%	%	%	%	%
30-60	23.1	29.6	29.6	29.6	29.6	35.8	36	36	40	36	40	40
60-150	19.4	19.4	19.4	12.9	19.4	13.2	16.5	19.6	15.6	19.6	15.6	20.9
150-250	12.5	12.0	12.0	16.4	9.9	9.9	14.8	16.7	16.7	16.7	16.7	15.5
250-400	8.8	8.1	11.9	4.9	10.2	10.2	16.7	14.0	11.7	11.7	14.0	9.9
400-800	16.6	14.9	14.1	9.1	7.8	7.8	6.2	5.5	6.2	7.8	5.5	5.5
800-1200	9.4	5.8	2.8	11.1	7.1	10.1	4.6	2.9	4.5	1.7	2.9	2.9
1200-2000	2.5	3.5	4.4	8.3	9.3	6.3	1.2	2.3	2.3	3.5	2.3	2.3
2000-4000	6.2	5.7	4.8	6.2	5.7	5.7	2.7	2.0	1.7	2.1	1.7	2.1
4000-8000	1.5	1.0	1.0	1.5	1.0	1.0	1.3	2.0	1.3	0.9	1.3	0.9

Table VI shows the results of analysis on similar pick-ups from pump and refrigerator. It will be seen therefrom that about 90% of the power is within the range 30-1200 c.p.s. for noises both from pump and refrigerator.

TABLE VI

Sub-bands of the audio band (c.p.s.)	PUMP Percentage noise voltage		REFRIGERATOR Percentage noise voltage	
	λ = 15 m.	λ = 300 m.	λ = 45 m.	λ = 300 m.
	%	%	%	%
30-60	35.9	42.0	19.4	15.3
60-150	17.8	16.9	13.5	17.6
150-250	5.7	5.3	10.1	16.1
250-400	9.7	8.7	16.7	10.0
400 800	7.8	8.1	17.0	14.7
800-1200	10.3	6.3	11.2	13.5
1200-2000	2.6	4.8	7.5	6.2
2000-4000	8.7	6.4	3.7	5 0
4000-8000	1.5	1.5	1.6	1.6

8. ESTIMATION OF SIGNAL/TOTAL NOISE ON VARIOUS METRE-BANDS

The section relates to the representative values of (equivalent) interference field-strength on various wave-length bands (accommodating the broadcasting stations) at the receiving aerial situated at given distance from the source outside its induction field as well as the estimation of the ratio of signal to total noise (including "atmospheric" and "man-made static") and is meant for direct application to the actual problem.

The estimated equivalent field-strength values shown here for short wave-length bands can be taken as representative figures for the whole of the wave-band associated with the various wave-lengths as follows:—11-metre band (25.6-26.6 Mc/s); 13-metre band (21.45-21.75 Mc/s); 16-metre band (17.75-17.85 Mc/s); 19-metre band (15.1-15.35 Mc/s): 25-metre band (11.7-11.9 Mc/s); 31-metre band (9.5-9.7 Mc/s); 41-metre band (7.2-7.3 Mc/s); 49-metre band (6.0-6.2 Mc/s); 60-metre band (4.9-5.1 Mc/s); 80-metre band (3.65-3.85 Mc/s); and 90-metre band (3.43-3.23 Mc/s).

Those shown for medium wave-lengths are representatives for smaller band-width of about 18 kc/s associated with each of them.

Table VII gives the *equivalent* normally polarized component of the electrical field intensity (in milli-volts/metre) on different wave-length bands. The distance of the source from receiving aerial has been 50 feet for ceiling fan and refrigerator with wiring running in a normal way and 200 feet for pumping installation without much wiring nearby. The *equivalent* abnormally polarized component of the electrical field intensity can be obtained by multiplying the figures in Table VII by the ratios of E_H/E_V shown in Figs. 7 and 8.

TABLE VII

Source	Milli-volts/metre on metre-bands													
	11	13	16	19	25	31	41	49	60	80	90	250	350	450
(1) India Electric Ceiling Fan (1/10 H.P.)	1 2	2.8	2.4	1.0	1.03	1 0	1.67	4 0	40	8.2	3.0	33.3	9.2	5.4
(2) Frigidaire and Co. Refrigerator (motor horse power = 1/4 H.P.)	0	0.4	0.8	0.25	0 86	0 67	8.3	14	14.7	23.6	12	13	15.9	16.2
(3) G.E.C. Pumping Installation (motor horse power = 2 H.P.).	0	0.7	0.3	0	0.22	0.25	1.25	10.5	9	0.9	4	52	41	8.1

TABLE VIII

Electrical source	Signal/Total Noise Ratio											
	19-metre DELHI				25-metre DELHI				370-metre CALCUTTA			
	Signal Strength (quasi-max)	Atmospheric strength	Man-made strength	Ratio	Signal strength (quasi-max)	Atmospheric strength	Man-made strength	Ratio	Signal strength	Atmospheric strength	Man-made strength	Ratio
	mv/m	mv/m	mv/m	db	mv/m	mv/m	mv/m	db	mv/m	mv/m	mv/m	db
(1) India Electric Ceiling Fan (at 50 ft. distance).	3.0	0.2	1.0	8	4.0	0.3	1.03	9.6	120	3	5 4	23 1
(2) Frigidaire & Co. Refrigerator (at 50 ft. distance).	3.0	0.2	0.25	16.4	4.0	0.3	0.86	10.8	120	3	16.2	16.0
(3) G. E. C. pumping installation (at 200 ft. distance).	3.0	0.2	0	23.5	4.0	0.3	0.22	17.8	120	3	8.1	20.8

It will be seen that by taking all the sources examined (*a*) the 11, 16, 19, 25, and 31-metre bands appear to be the best for use and (*b*) the 13, 41, 90 and 400-metre bands are better than others.

The ratio of signal/total noise has been estimated for three cases, namely, (*a*) Delhi 19-metre day transmission, (*b*) Delhi 25-metre night transmission and (*c*) Calcutta 370-metre medium wave transmission as shown in Table VIII. Normally polarized components for both signal and noise were taken. Signal strength as measured at the Communication Engineering Laboratories (Calcutta) during March-April, 1941, atmospheric peak strength as measured[12] during summer (non-thundery days) and man-made static strength as obtained above have been taken to estimate the ratio.

9. ACKNOWLEDGMENT

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