NOISE IN ELECTRICAL COMMUNICATION

by

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SUMMARY

Subject and Title: Noise in Electrical Communication.

This paper is an attempt made at determining the diurnal variation of atmospheric noise level in Beirut. It includes a brief discussion of radio noise in general, a discription of the apparatus used and the observation technique, followed by a discription of how the results were derived from the observed data. To end, a graphical representation of the relative noise level is presented with a short discussion of results.

Independent of this work a determination was made on the noise induced in the aerial by a motor operating in the building, and its value at 4 different frequencies (0.55; 1.7; 5.5; 16 Mc/s.) determined.

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P R E F A C E

I have chosen to study during my work the diurnal variation of atmospheric noises affecting a receiver on different frequencies. The reason for the choice of my subject was the great increase and development of radio communication in this part of the world, and I hope that inspite of the restricted amount of reliable data obtained, some of it will help in furthering more exact and intense records in this field.

Together with data on atmospheric, I am including some observations on noise produced by the proximity of an electric motor as to the amount induced in the aerial at different frequencies.

If I were able to overcome the numerous difficulties encountered, it was due to the kind advice and suggestions of Professor R.W. Sloane and Mr. F.G. Major. To them I would like to express here my deepest gratitude for the constant encouragement they gave me.

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Noise in Electrical Communication

Noise is an irregular, randomly distributed fluctuation in a circuit or antenna current, which produces an irritating interference with the signal being received - whence the name: noise.

The circuit noise in a receiver is a combination of the following different kinds of noises:

Thermal noise is caused by thermal electron agitation in the resistive component of an impedance. This electron motion produces a current whose average is zero, but whose root mean square gives rise to a voltage fluctuation across the resistor. This fluctuation has been derived by H. Nyquist on thermodynamic basis, and is expressed as follows:

$$\overline{V}^2 = 4\ RkT\ \Delta F \quad (1)\ \ldots\ (1)$$

where R = resistive component of the impedance
k = Boltzmann's constant
T = Absolute temperature of resister
ΔF = Band interval considered

The Schottky effect is due to non continuity of flow of electricity through valves inherent to the atomistic nature of charge. This fluctuation is dependent on space charge and transit time of an electron expressed in terms of period of current oscillation.

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(1) Nyquist, H.: Physical Review, 1928, 32, p. 110.

W. Schottky (1926) has expressed this noise in terms of root mean square current fluctuation as follows:

$$\bar{i}^2 = \Gamma^2 \, 2eI \, \Delta F \quad (1)$$

where e = elementary charge on an electron
I = the total current whose fluctuation is considered
ΔF = frequency band under observation
Γ^2 = an attenuation factor depending on the number of electrodes in series in the valve (the greater the number the greater the fluctuation, which is the sum of fluctuations at each electrode), on the space charge and transit time (at low frequencies space charge reduces noise, while at high frequencies the opposite effect is observed).

Considering electrons as none interfering with each other and acting as impulses of electricity, Schottky, using Fourier analysis, arrived at this above-mentioned result.

Flicker effect (2) is caused by structural rearrangement of the emitting surface. It is important only at low frequencies, and is practically of no importance in radio work. Moreover it can be indefinitely reduced by special treatment of the surface.

Other fluctuations caused by faulty connections, poor insulation, vibration of valve grids, unsufficient filterage of A.C. to D.C., fluctuation in the main voltage, Bakhaussen effect, i.e. fluctuations caused by atomicity of elementary magnets; and local undesirable self excited oscillation; all

(1) Goldman, .: Frequency analysis, Modulation and Noise.
(2) W. Schottky: Physical Review, 28, pp. 74-103, (1926).

these factors may be the cause of current fluctuations appearing in the output as undesirable, hum, shreak, or other form of noise. Yet, extra care in avoiding these phenomena, result in the suppression or at least reduction of this kind of noise output.

The sum of all these effects form what is called the background noise of a receiver and is of the order of 10^{-13} wats/Mc/s in a good receiver.

Onto this background noise is supperposed the antenna noise which besides the desired signal picks up interferences, which consist of man-made noise, sun and galactic noise, and atmospheric noise.

Man-made noise is caused by sparking in motors and discharges; it is local in extent, being caused by weak sources, and tends to distribute itself in the low frequency part of the spectrum.

The Sun and Galactic noises reaching us from the surrounding stellar bodies, originate in eruptions on the surface of these bodies, which are probably similar in origin to sun spots with, presumably, radiation proportional to the size of the emmitting body. The spectral distribution of this noise tends to be more intense in the lower region, which speaks in favour of a rather prolonged, gross electrical disturbance similar to a thunder-storm, rather than of molecular or atomic transactions diluted throughout the space (1). Another fact is that the noise sources tend to be localized at definite points; The Scorpio-Sagitarius region (center of our galaxy, with a radiation of about 13.2×10^{-21} ΔF ΔW) and the Cygnus region located in a cone of about 2° and having a power fluctuation of about 75%, which would be hard to explain on the basis of an infinite summation of atomic sources. (2) It is true that it is difficult to explain the noise level on the account of definitely located sources whose emissive intensity would have to be some 10^{12} times that of the sun.

Normally the sun noise is imperceptible, being about 10^{-4} times the thermal noise of a receiver; but during spots, the radiation increases some 10^{5} times, reaching a level of about 10^{-13} watts/m²/Mc-s band. At the same time, due to extra ultra-violet radiation, the reflecting D layer is ionised and communication is impaired due to attenuation brought about by excessive absorption (it varies as λ^{-2}). some 20 minutes after an eruption on the sun, a magnetic storm reaches the earth and impaires communication conditions for several days (4 - 5). These fadings are cyclic and are related to the rotation of the sun, their periods coinciding: 27.4 days.

Yet under normal conditions, these extra-terrestrial noises are negligible in power as compared with terrestrial noise, called statics. Statics may be man-made or natural.

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(1) J.L. Pawsey, <u>Nature</u>, <u>157</u>, p. 158 (1946).

(2) J.S. Hey, <u>Nature</u>, <u>158</u>, p. 234 (1946).

Man-made statics are caused by sparking in motors or electric discharges; they are local in nature, being relatively weak. Sparks of appreciable strength tend to be of long duration, so that man-made statics are more important in the long wave part of the spectrum.

Natural statics, or atmospherics, may be subdivided into two groups: local and remote.

Local atmospherics may be of two kinds as characterised by the effect they produce on the receiver: 1) Sudden, loud outbursts associated with a near by lightening discharge; 2) Continuous whisper occasioned by the passage of an electrically charged, low cloud over the antenna, which discharges some charge to ground through the aerial, with a consequent noise output. Local noise is closely associated with local conditions of the atmosphere: humidity, dryness of winds, and heat. They are characterised by a uniform distribution throughout the spectrum, with a slight decrease at high frequencies; they fluctuate but slightly with time, as long as the source persists. Being sporadic in nature, they are less important, on the average, than the noise due to remote atmospherics.

Remote atmospherics are characterised by being a maximum at low frequencies and decrease rather rapidly in power at higher frequencies. Their power fluctuates widely as a function of transmissibility of radio waves: increasing by night, decreasing by day in direct relation to the amount that is transmitted to that which is absorbed. The summer-winter fluctuation is governed by two factors acting in opposite directions: transmissibility (that is worse in summer) and source strength that is maximum in the hot part of the year. Fluctuations are also due to the fact that during the process of multiple reflections and until the wave reaches the receiver, intensities vary, because, the discharges occuring more often cloud-to-earth, i.e. vertically, rather than cloud-to-cloud, i.e. obliquely with horizontal tendency, the wave tends to be vertically polarised and may be badly reduced by a reflection under Brewsterian incidence. Most remote atmospherics come from tropical regions, and in fact, East-West directivity eliminates most of this noise. Polar regions are also intense noise producers; but the cause is not thunder storms but the Aurora, which is a magnetic disturbance brought about by the same increases in Solar activity. A great part of statics originate in mountainous regions, where cloud and ice formation tends to accumulate electricity. On the other hand the sea is a very poor noise source.

The power of atmospherics varies widely with source, time, and frequency. Excluding local lightning discharge effect, the electric field strength in the wave may vary from 0.1 to 1000 $\mu V/m.$, depending on transmissibility and source activity.

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- Location and Surroundings -

The observations were carried out from the Engineering-Physics Building of the American University of Beirut.

The aerial was located on the roof of the building and extended in an East-West direction, with the lead to the receiver taken on its East side.

The sight was as follows: from West to North extended the sea with no major interfering obstacle interposed: undistorted reception to be expected from this side. To the East, extending from North to South, lay the Lebanon Mountains (2000-3000 meters high) possible reflectors and dispersors of waves, so that directive readings in this direction would be misleading. To the South lay the city with its generous man-made noise and a special contributor, the tram line, distant some 200 meters from the observation spot. Also, the cliff to the south, with its vegetation of trees extending above the aerial and distant from it only some 20 meters, were not to favour the precision of readings. To this must be added the frequent motor operation inside the building, which often interfered seriously with taking readings, for, being of purely local character, their presence was a pure nuisance.

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- Apparatus -

The measuring apparatus consisted of the aerial input, a radio-set used as an amplifier, a noise generator of known power output, and an output meter, connected as outlined in Fig. 1.

The Aerial system consisted of an inverted L, extending in an East-West direction, with the lead down on the East side. It was suspended some 3.5 meters above the concrete roof of the building and distant some 7 meters from the supporting rod on the concrete water tank on the East, and a wooden supporting pole on the West side. Simple aerial insulators were used. The aerial consisted of a twisted, 7 strand copper wire 27 meters long and the lead down of a 3 strand copper wire imbedded in a plastic insulator and 23 meters long. The lead went down parallel to the wall some 7 meters and entered the room through a metal frame.

An auxilliary directional antenna was available. It was of an adjustable size, having its vertical sides made of a copper tube with a copper rod inside it. Its perimeter could be varied from 200 to 300 cms. for resonance at 12.5 to 22 meter wave length.

The Radio Set Amplifier was a Hellicrafter Skyrider 23 model, with a modified circuit. The input was through the aerial connection, and the output taken either from the secondary of the loudspeaker transformer (500 Ω impedance) for meter measurement, or directly from the plate of the power amplifying valve for Cathode Ray Oscillascope measurements. The radioset was in a metal case and the input to the C.R.O. was through a shielded coaxial cable 150 cms. long (and hence of low attenuation factor at Audio Frequencies) A 1000 $\mu\mu$f condenser was inserted in series with the output lead, for safety against D.C. compounds. Fig. 2 shows the circuit of the set as modified.

The noise generator was an A 2087, temperature limited diode, with a plate current rated 20 mA, continuous 5 mA under plate voltage of 100 Volts D.C. The noise output was taken from the plate and fed through a 0.01 μf. condenser into the amplifier through a multi-throw switch. The circuit is shown in Fig. 3.

The Measuring Apparatus consisted of an A.F. current meter 0/0.1/1.0 Amps. which was used accross the secondary of the output loudspeaker transformer (500 Ω impedance), the speaker being plugged out.

A C.R.O. was used continuously while taking readings. It was connected to the plate of the power amplifier to detect the nature of the incoming noise and allow accounting for for sudden signals or continuous noise due to motors being switched on in the building: the loudspeaker being disconnected, this was the only survey of the incoming noise.

In the case of continuous sparking transients, meter readings being impossible to take, resort was made to the C.R.O. on which the constant noise could be differentiated from the suddenly deflecting potential : the time lag of the C.R.O. being insignificant, while the inertia of the meter movement would not allow readings between two close transients. This was particularily helpful during ringing of bells, intermittent motor operation or other long interval transient.

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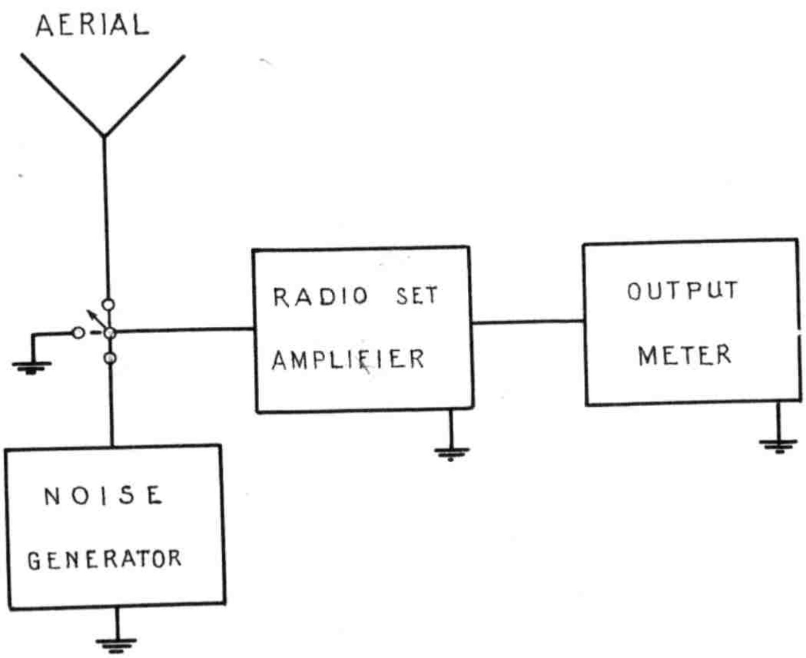
BLOCK DIAGRAM

Fig. 1



SCHEMATIC DIAGRAM

OF MODIFIED CIRCUIT OF SKYRIDER 23

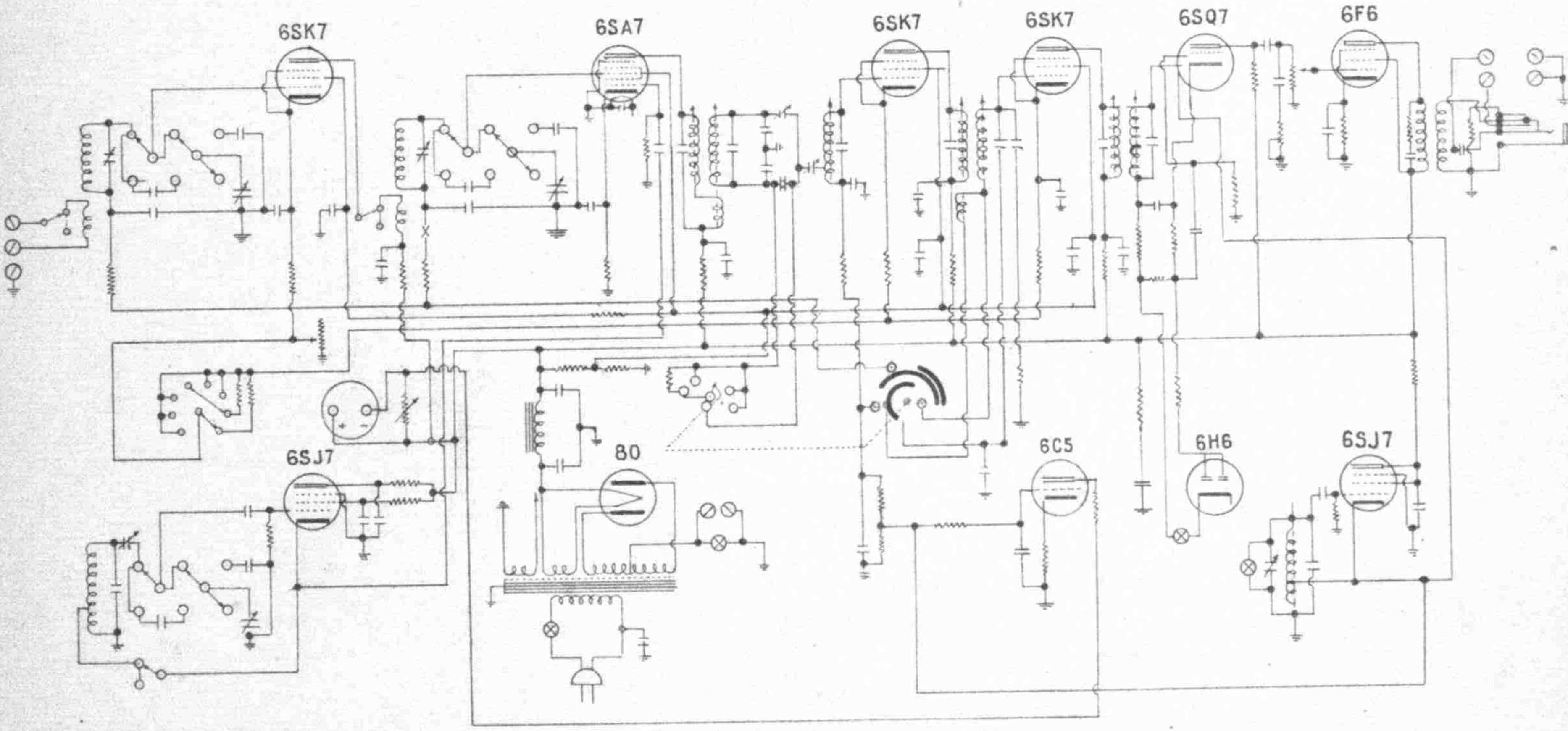
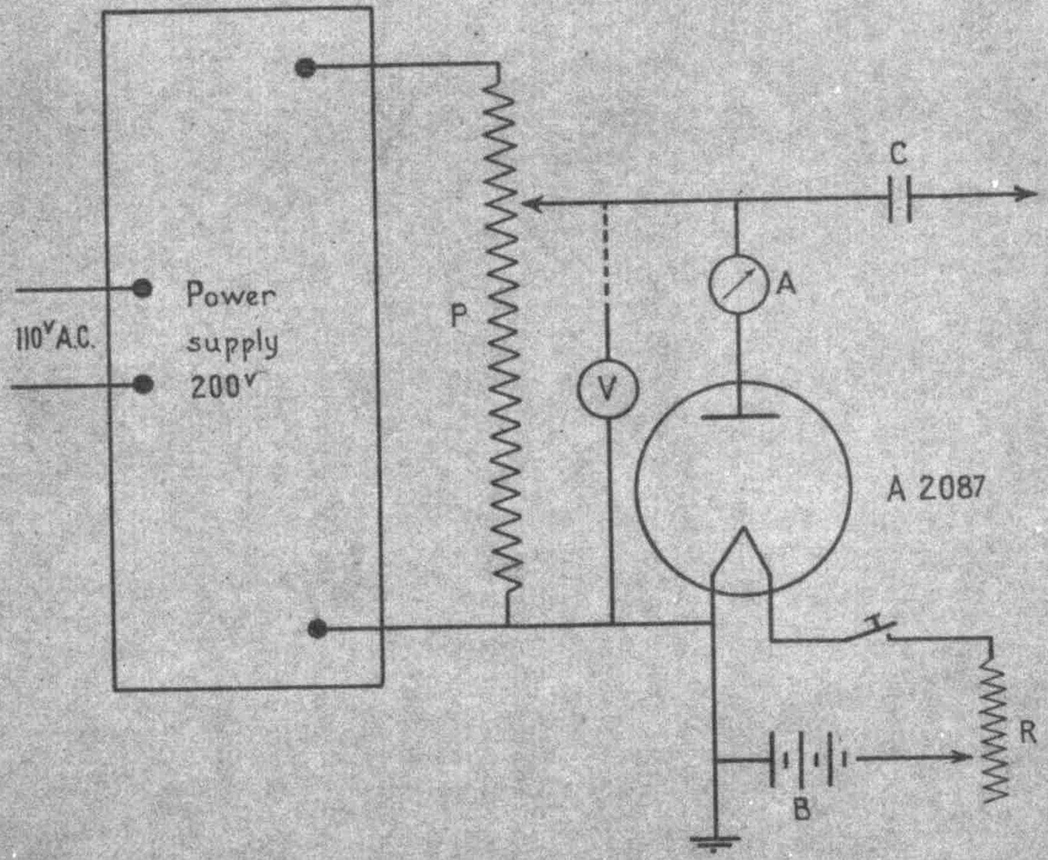


Fig. 2.

CIRCUIT DIAGRAM OF GENERATOR



B = Lead cell storage battery, 6V.
R = Variable resistance 5.8 Ω 8 Amp
C = Ceramic condensor 0.01 μf.
A = Milliammeter 0/50 mA.
P = Potentiometer 5500 Ω 30 Amp
V = Voltmeter 0/150V, disconnected while the generator is in use

- Measuring and Calculation Procedure -

Having no continuous recorder, I resorted to taking, as often as possible, at set hours, sets of 10 or more readings, depending on their stability, for each wave length, at intervalvs of 5 or 10 seconds, and took their average as representing the actual value at that time of the day. The wave lengths turned to were kept as fixed as possible, with unavoidable shifts in case a transmitted signal would appear. The frequencies used, were: 0.55, 1.7, 5.5, 11, 16, 34 Mc/s. with deviations less than 6% in either direction. To insure the absence of a signal, the loudspeaker of the radio was left on during tuning up to a wave length. In case the frequency had to be adjusted between two signalling stations a fine adjustment was attained by minimising the riple over the noise curves on the C.R.O. screen. Motor sparking which manifested themselves as continuous noise power of higher intensity where checked out by their producing a typical switching wave pattern which was detectable by the C.R.O.

Having checked for the absence of man-made interferance, the loudspeaker was disconnected and the output sent through the meter. Any transient occuring while taking readings would manifest itself by a sharp kick on the meter: if it were of a transient switch type, it was disregarded; if it were associated with cracking in the loudspeaker of a recurrent type resembling lightning cracks, an average of 25 readings was taken and the deflections taken as a function of time.

For identification of the nature of noise, the C.R.O. screen was the primary indicator. In case a strange wave form would occur, the loudspeaker would be plugged in to identify the noise. If the interferance was in a narrow band, the frequency would be changed; if extending throughout a wide band, meter readings would be abandoned and C.R.O. readings taken.

Calculations were carried out as follows:

1.- The average of each set of readings was taken to represent the average voltage fluctuation at that time. This gave three readings: 1) Back ground noise (B);

2) Generator noise (G);

3) Aerial contribution (A).

2.- The squares of these readings were taken to be proportional to the corresponding noise power : B^2 , G^2 , A^2.

3.- Back ground noise power, (B^2), was subtracted from both other powers, the difference being taken as the contribution to power: $P_A \propto A^2 - B^2$; $P_G \propto G^2 - B^2$.

4.- The generator contribution was reduced to a 5 mA plate current contribution, as a standard, by a simple ratio:

$P_G' = \frac{P_G}{I_p} \times 5$. This is justifyable, because the noise power is directly proportional to the plate current, as given in Schottky's formula.

5.- The ratio of the aerial contribution to P_G' was taken as the wanted noise ratio - the frequency band response of the radio set amplifier having been kept constant throughout, the observations of P_G' are a constant standard.

- Power of Man-Made Noise -

A trial was made to determine the amount of interference that entered the receiver through the aerial due to a motor being operated in the building. For that purpose the background noise level, that of the generator, and of the aerial having been determined, the motor was switched on while the aerial was: 1) disconnected, 2) connected to the radio set. The contribution to noise power, by the motor, was deduced in a manner similar to that for atmospherics:

If:

B = Background noise
A = Aerial noise
G' = Generator at I_p mA

M + B = Motor with the aerial switched off
M + A = Motor with the aerial on

(All of these were read on the output current meter)

Therefore: $$\frac{\left[(M + A)^2 - A^2\right] - \left[(M + B)^2 - B^2\right]}{(G^2 - B^2) \times 5/I_p}$$ is the desired noise value.

Also: $$\frac{(M + B)^2 - B^2}{(G^2 - B^2) \times 5/I_p}$$ is the noise induced in the radio set with the aerial switched off.

- Results -

It may be seen from the graph of noise power variation with time, that the noise power on the two extreme bands, 0.54 and 16 Mc/s, decrease towards noon and then rise up in the evening. The 5.5 Mc/s. band shows this to a lesser extend, having a slight decrease along the day and a rise in the evening. On the contrary, the 1.7 Mc/s. band has actually a rise from 10:00 o'clock till 18:00.

It is interesting to notice, in this connection the noise distribution of a motor disturbance: the maximum at around 1.7 Mc/s and a still large value at about 5.5 Mc/s may, perhaps, explain the misbehaviour of the 1.7Mc/s curve: in fact, during the day time the cooperation of the town motors, and especially active contribution of building motors (vacuum cleaners) at the close of classes - about 17:00 - may account for the maximum in the 1.7 Mc/s. curve at that time. The lack of such pronounced variation in the other curve may be, perhaps, partly explained by the smaller effect on them of the motors, so that the atmospheric noise level decrease might be more important than this contribution. In fact, during day time, the town motor noise being presumably constant the decrease is seem on the 0.54, 5.5, 16 Mc/s. curves. At the time at which town life starts, the morning, this noise increases and might be accused of causing the increase and the inflexion in the 5.5 and 16 Mc/s. curves respectively. Unfortunately no such corresponding increase is seen in the 1.7 or 0.54 curves, so that no generalisation may be reached.

Also the increase of noise power at night might be a sum of two effects: greater transmissibility of atmospheric noise and the lighting of the town with its tremundous noise due to the fluorescent illumination (discharge tubes), which comes to replace the motor noise and tends to maintain man-made noise even at night.

As to the graph of noise power v.s. frequency, its resemblance to the motor noise curve points to the effect of the proximity of town, whose neighbourhood is to be necessarily avoided in case of atmospheric noise measurements.

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Noise Power on Different Frequencies for different times of the day

(All powers are refered to the noise input of a diode with a temperature limited plate current of 5 mA.)

Frequencies in Mc/s.		0.54	1.7	5.5	16
Local time	7 - 9	0.467	6.99	1.14	0.775
	9 - 11	0.00979	0.73	32.49	0.565
	15 - 17	0.0100	15.74	6.44	0.136
	17 - 19	0.00120	16.90	6.56	1.625
	19 - 21	0.123	1.88	27.18	0.480

Logarithm of the Noise Power

Frequencies in Mc/s.		0.54	1.7	5.5	16
Local time	7 - 9	$\bar{1}.668$	0.844	0.057	$\bar{1}.889$
	9 - 11	$\bar{3}.991$	$\bar{1}.863$	1.512	$\bar{1}.752$
	15 - 17	$\bar{2}.000$	1.197	0.809	$\bar{1}.134$
	17 - 19	$\bar{3}.079$	1.228	0.817	0.211
	19 - 21	$\bar{1}.090$	0.274	1.434	$\bar{1}.681$

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- Motor Noise -

Noise induced in the aerial

(All powers are refered to the noise input of a diode with a temperature limited plate current of 5 mA.)

Frequency	Noise Power	Logarithm of Noise Power.
0.54	13.7	1.13
1.7	197.6	2.30
5.5	32.2	1.51
16.0	8.9	0.95

Noise induced by the motor in the radio set with the aerial switched off.

Frequency	Noise Power	Logarithm of Noise Power
0.55	10.56	1.024
1.7	6.45	0.810
5.5	0.41	$\bar{1}$.613
16	0.65	$\bar{1}$.813

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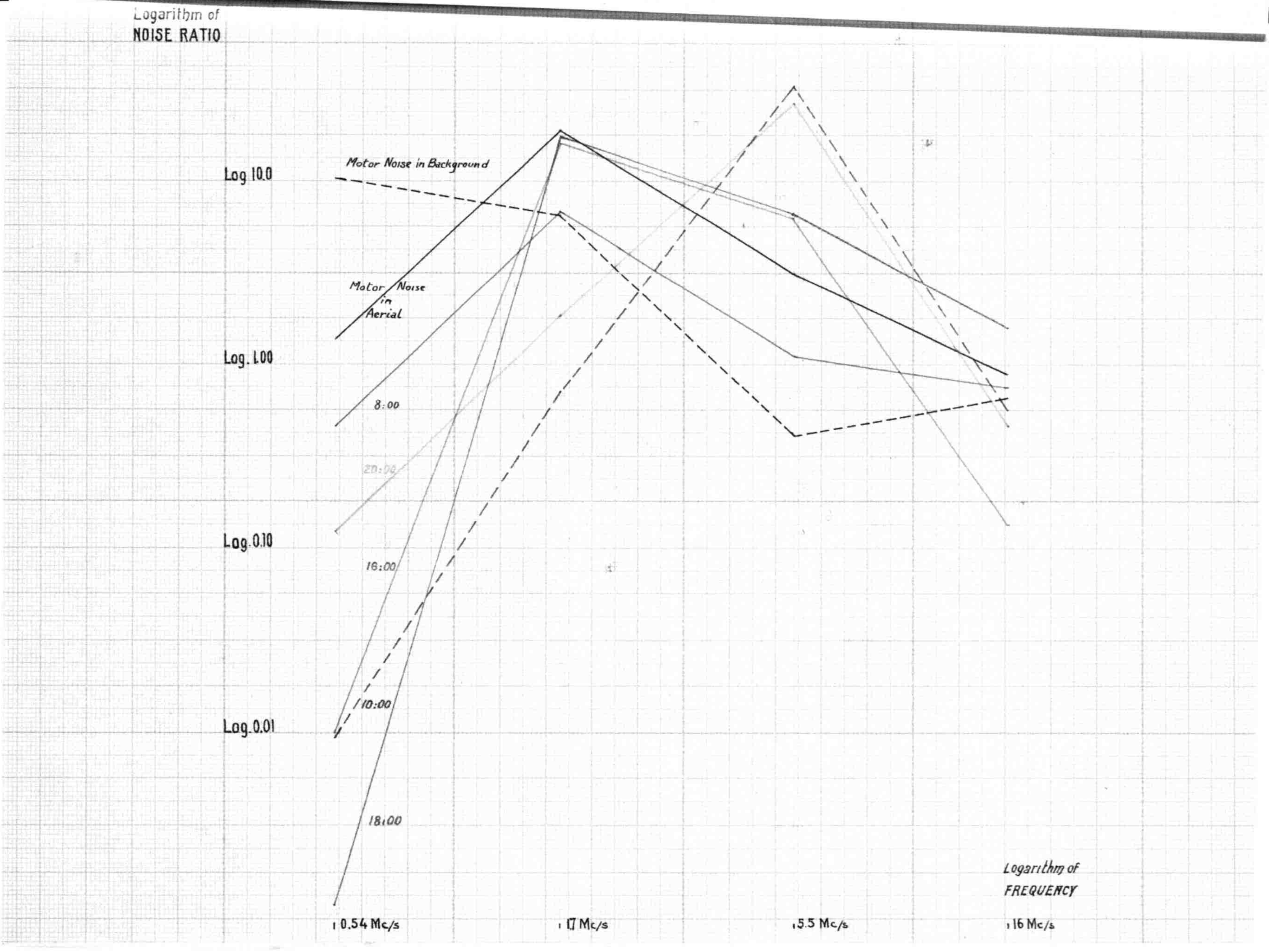
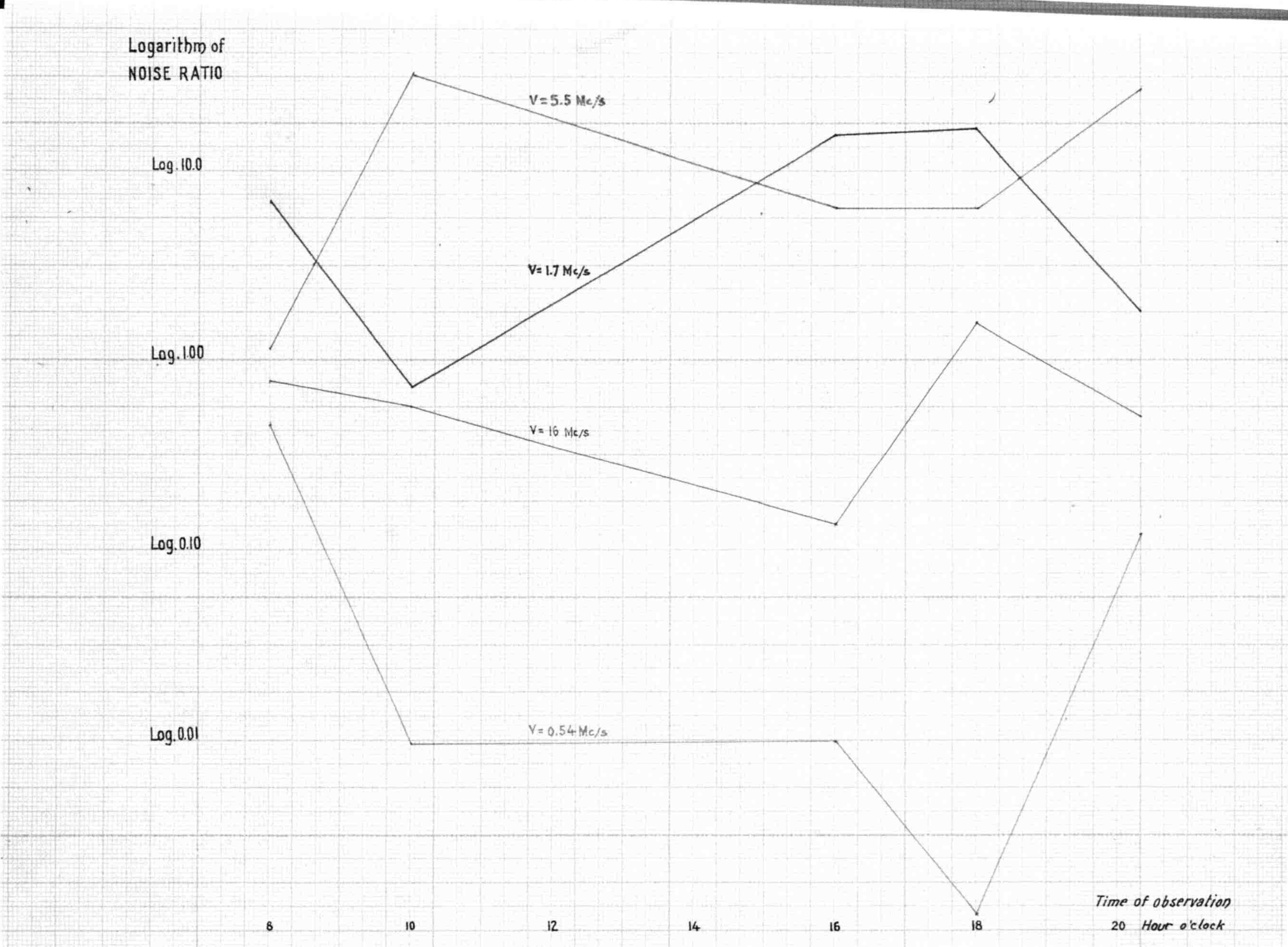


Logarithm of
NOISE RATIO
Log 10.0
Log. 1.00
Log. 0.10
Log. 0.01
Motor Noise in Background
Motor Noise in Aerial
8:00
20:00
16:00
10:00
18:00
Logarithm of
FREQUENCY
0.54 Mc/s
1.7 Mc/s
5.5 Mc/s
16 Mc/s



Logarithm of
NOISE RATIO
Log. 10.0
Log. 1.00
Log. 0.10
Log. 0.01
V = 5.5 Mc/s
V = 1.7 Mc/s
V = 16 Mc/s
V = 0.54 Mc/s
8
10
12
14
16
18
20
Time of observation
Hour o'clock