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Internal Report

THE LEVEL OF NOISE AND INTERFERENCE BETWEEN 216 and 420 Mc, AND THE BEST FREQUENCIES FOR LUNAR OCCULTATION WORK

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Summary

Observations of lunar occultations of radio sources are most effective around 200 Mc. Since TV channels reach up to 216 Mc, the range from 216 to 420 Mc was investigated in detail. Besides interference by signals, the general background noise was measured, too.

The results are given in terms of "fraction of observing time, lost by interference" above various levels of antenna temperature. The distribution function of signal strength turned out to be a power law. On the average over all frequencies, about 15 per cent of time would be lost by interference above 10°K antenna temperature, but some frequencies are much better than the average.

Simultaneous observation at 234, 256 and 405 Mc is suggested, and the results to be expected are estimated. With the 85-foot telescope and parametric amplifiers, about 10% of all sources where predictions of occultations are provided, are below the brightness limit. From all sources where occultations can be observed, only 0.1% would be lost by interference, and spectral indices could be measured for 94%.

I. Introduction

The aim of the present paper is to find the best frequencies for lunar occultation work. Observing occultations is different from most other observations insofar as the resolution limit of the antenna plays no role. The only instrumental limit to be considered then being the brightness limit, one should choose the frequency where the number of visible sources per steradian has its maximum, because at this frequency one can observe the largest number of occultations per year.

Usually, this optimum frequency, ν_{opt}, is a function of receiver noise only (v. Hoerner, 1961, fig. 1). But in occultation work ν_{opt} depends to some extent also on antenna size, because the moon's contribution to the total noise depends on the beamwidth. Some calculations have been made, and the following table gives the optimum frequency, ν_{opt}, for two antenna sizes (85 ft. and 300 ft.), and two receiver noise temperatures (parametric amplifier and maser). The fourth column gives an estimate of the number of observable occultations per year, N_{opt}, at this optimum frequency. The last two columns show the limiting frequencies, at which this number would drop to half of its optimum value.

TABLE 1

The Number of Lunar Occultations per Year

a	T_{rec}	ν_{opt}	N_{opt}	ν_{min}	ν_{max}
m	°K	Mc	occ/year	Mc	Mc
26	200	207	33	106	508
	50	357	110	163	730
100	200	187	1600	96	353
	50	214	3300	125	375

Since predictions are provided (Nautical Almanac Office, Herstmonceux) at a rate of about 30 occultations per year per observatory, an 85-ft. dish with parametric amplifier should be fully satisfactory, provided that one observed not too far away from 200 Mc.

Unfortunately, the range from 174 to 216 Mc is occupied by the high band TV channels, and from then on to over 300 Mc the band is cluttered with interference, mostly from aircraft, radar and military services. In order to find the quietest frequencies and maximum allowable bandwidths, the region from 216 to 420 Mc was investigated in detail. Besides single interferences, the general background noise was observed, too.

The interference problem is especially severe for occultation work, since no observation can be repeated if lost by interference.

II. Method

1. Instruments

For hand scans and motor driven scans, we borrowed from the Navy at Sugar Grove a Special Purpose Receiver, manufactured by Nems-Clarke Company, in the following called Navy receiver. It is tunable from 55 to 900 Mc. The lower limit of detection varies with frequency and corresponds to between 50 and 1000 °K antenna temperature for a total power receiver with 2 Mc bandwidth. This lower limit acts as a threshhold, while for strong signals the output varies with the logarithm of the strength. All signals between the threshhold and 100,000 °K could be measured on one recorder pen.

Motor driven scans were made with a sweep drive, with sweep widths of 4 - 10 Mc; the center frequency was changed every 24 hours. Highest sensitivity was reached with a narrow receiver bandwidth of 1 kc, and very effective discrimination against any type of broadband noise (even lightning) was obtained by rapid sweeping. The sweep rate was 2 sweeps per second.

For closer investigation of the quieter parts of the spectrum, a receiver was built up from available parts, in the following called Lab receiver. We observed total power in order to make identification of signals possible by hearing them in the speaker and by seeing their exact frequency in a spectrum analyser. A crystal mixer was used, with a stub for rejecting the image frequency and a low-pass filter for avoiding any mixing with higher harmonics of the local oscillator. The stub gave an effective attenuation of 36 to 45 db; if the image frequency contained many extremely strong interferences, two stubs had to be used with about 70 db attenuation. In many cases, the Navy receiver was set on the image frequency for checking. Between mixer and filter, and between filter and stubs, two line stretchers were necessary for getting the lowest noise figure for each frequency. The bandwidth was 2 Mc, the time constant 2 sec.

During the latter 1/3 of the observations, a clock driven switch put the receiver alternately for 10 minutes on a dummy load and for 20 minutes on antenna, for measuring the general background noise.

The overall receiver noise on load was between 700 and 1300 °K; with 2 Mc bandwidth and 2 seconds time constant, this should give an average rms fluctuation of 0.5 °K. The gain stability (within 10 minute intervals) could be brought to 0.2% on the average, and for 1/3 of the time to 0.1%. Peak to peak fluctuations on load (within 2 minute intervals, averaged over 5 adjacent intervals) were found to be 0.9 °K at best and 1.3 °K on average. If the peak to peak fluctuations on load were larger than 2.5 °K, no background noise measurements were taken.

The output was given with different gains on 3 pens of a Sanborn recorder, so that any interference between the lower limit of 1 to 3 °K and 100,000 °K could be measured.

Calibration for the first pen was made with 10 °K from a noise tube. Then, a signal generator with a dipole outside the house was adjusted to give the same deflection as the 10 °K, and second and third pen, as well as the Navy receiver, were calibrated in many steps by varying the output of the signal generator.

The measurements were made at the Lowe House, which is the quietest place on the observatory site. Both Navy and Lab receiver were connected to adjustable vertical dipoles on top of two chimneys.

For both receivers, the frequency usually was changed once a day, except for the best frequencies where up to four days were needed in order to get a better statistical sample.

2. Evaluation

For getting quantitative results, two questions had to be answered. First, how to compare single, short signals, appearing as narrow spikes on the records, with longer periods of crowded interference. Second, how to compare observations on average frequencies, made with the Navy receiver and a lower limit of, say, 1000 °K, with observations on the best frequencies with the Lab receiver, where no interference above 300 °K was observed.

As to the first question, observing time was divided into blocks of 2.5 minutes duration, and the number of blocks containing interference were counted without regard to how many spikes a block contained. In each such block only the largest deflection was measured. In this way, one can give the result in terms of "percentage of observing time, lost by interference" above various levels of antenna temperature.

The second question could be answered because it turned out that the distribution of interference strength is a fairly well defined function of the strength and is about the same for various frequencies. Thus, all measurements with the Navy receiver were extrapolated down to 10 °K, and the final comparison of all frequencies was made by plotting the percentage of observing time, lost by interference above 10 °K, as a function of frequency. Observations with the Navy receiver and scan widths of 4 - 10 Mc were always reduced to 2 Mc, the bandwidth of the Lab receiver.

III. Results

1. Distribution of Signal Strength

Figure 1 shows the percentage of time, lost by interfering signals above antenna temperature T. The observations were grouped first according to the receiver used, and second according to the amount of interference observed, and the average of each group is drawn. This graph represents approximately the cumulative distribution of signal strength; cumulative, because signals above T are used; and approximately, because of our method of counting only the strongest deflection within blocks of 2.5 minutes duration. The approximation is good as long as Q << 100%.

We see that the cumulative distribution could be described fairly well by a power w with a slope of about 1/2

$$F(T) \approx \text{const } T^{-1/2}$$

ich gives for the distribution of signal strength

$$f(T)\, dT \approx \text{const } T^{-3/2}\, dT$$

The main point of this graph is that it enables us to compare non-overlapping observations by means of extrapolation. It also could be used, with at least some confidence, to make predictions below 1 °K, the limit of our measurements.

2. Interference Level as Function of Frequency

All measurements have been reduced to give the fraction of time, lost by interference above 10 °K antenna temperature, for a receiver with 2 Mc bandwidth. The result is shown in figure 2.

Additional information is given at the bottom line, where all frequencies are marked on which an interfering signal was constantly on for longer than 20 minutes (mostly for many hours). These "constant" interferences are worse for actual observation than the occasional ones, and their frequencies should be avoided. The same holds for radar pulses, occurring with 1 - 8 °K antenna temperature around 218 and 225 Mc every 15 or 20 seconds for many hours.

On the average, about 15% of observing time would be lost by interference above 10 °K. There are a few "holes" in the spectrum with less interference; unfortunately, however, the lower the frequency, the more shallow are these holes, whereas for lunar occultation work one should not choose too high a frequency.

The only frequencies good for observation are 405 and 332 Mc (navigational aide, "glide slope", from 328.6 to 335.4 Mc). Not good but still usable are 256, 242 and 235 Mc, but in case of these one should always observe at two frequencies simultaneously.

3. Application to Different Bandwidths and Temperature Limits

Figures 1 and 2 can be applied to give the amount of interference also if a bandwidth $B \neq 2$ Mc and a lower limit $T \neq 10$ °K are to be used for actual observations.

First, for our measurements we used a vertical dipole, whereas actual observations will use a feed illuminating a dish which looks at the sky with a narrow beam. Interference, then, will enter only through spillover and through sidelobes far off the main beam. This will reduce the antenna temperature of a signal by some shielding factor which, averaged over all beam positions, we call s (where T, feed = T, dipole/s). Second, the antenna temperature of a narrowband signal is proportional to 1/B. Third, the number of interfering signals per time is proportional to B.

Thus, if observations are to be made with bandwidth B and a shielding factor s, and if the amount of interference is wanted above antenna temperature T_o, we have to find

$$Q_i = \frac{B}{2\text{Mc}} Q\left(\frac{s}{2} \frac{B}{\text{Mc}} T_o\right)$$

The first step is to read Q(10 °K) from figure 2 for the frequency in question. This value we enter as a point on the vertical line T = 10 °K in figure 1; then, we shift this point (parallel to the lines drawn) to the temperature $T = sBT_o/2\text{Mc}$, and read Q(T). Finally, we multiply by B/2Mc (provided that Q << 100%) and obtain Q_i, the fraction of time lost by interference for the observation in question. The result, of course, represents a statistical expectation.

4. General Background Noise

The term "general background noise" will be used for low-level, broadband, unidentified noise fluctuations of longer duration (distant cars and trucks, motors, working machinery). Peak to peak fluctuations within 2 minute intervals were measured and averaged over 5 adjacent intervals, both on load, T_l, and on antenna, T_a, load and antenna being calibrated separately with 10 °K from a noise tube; measurements were taken only if $T_l \leq 2.5$ °K. The background noise, T_n, then is

$$T_n = \sqrt{T_a^2 - T_l^2}$$

which defines it as a peak to peak fluctuation, too. In many cases, it was below the limit of detection, and only an upper limit could be given. The measurements were grouped according to day, hour, and frequency.

First, we show in table 2 the average values of T_n for working days and weekends. The difference is well pronounced.

TABLE 2.

Average Background Noise (Peak to Peak in 2 Minutes) on Working Days and Weekends, Between 8:00 AM and 4:30 PM. For Frequencies between 234 and 342 Mc.

Days	T_n in °K
Monday through Friday	2.09
Saturday	1.10
Sunday	0.98

Second, we ask for the dependence on frequency, for working hours only. The result as given in table 3 is extremely uncertain. The frequency was usually changed in small steps, and, as a result, all frequencies summarized in one line of table 3 are mostly observed under similar conditions of weather and working activity, whereas these conditions will have been different from one line to the next one. Since the first line contains only a small number of measurements because of much interference by radar, its low noise value has not much weight. The general increase of background noise with decreasing frequency should be regarded as real.

TABLE 3

Average Background Noise During Working Hours At Various Frequencies

Mc	T_n in °K
218-225	(1.4)
234, 235	2.2
256	2.3
326-342	2.0
390-420	0.9

Third, we plot in figure 3 the dependence of the background noise on hour, for frequencies between 234 and 342 Mc only, for working days and for weekends. The increase in noise during working hours is well pronounced. The peaks around 8:00 AM and 4:30 PM indicate that a good deal of our background noise arises from cars, while the minimum around lunch time shows how the noise goes down with the working activity.

In connection with the noise it might be interesting to know the distances from the Lowe House, where the measurements were made, to various possible sources of noise, as given in table 4.

TABLE 4

Distances from Receiver at Lowe House

To	Distance in m	Line of Sight
300 Ft. Telescope	300	Clear
Phase meas. site	330	Clear
Road to 300 ft. tel.	460	Clear
Road to 140 ft. tel.	800	Partly clear
140 Ft. Telescope	1200	Scattered trees, bushes
Route 28	1800	Forest
Cass road	2200	Scattered trees, houses
NRAO Works Area	2400	Small Forest

Finally, some dependence with the weather was observed, too. On rainy days, and also after a rainfall (high humidity of the air), the noise was larger than usual. But no measurements of weather conditions were taken.

Identified sources are not included in the above figures, but notes were made about the worst offenders. For illustration, some examples follow. The noisiest observatory truck gave 2 - 5 °K from the road to the 300-ft. telescope. Trucks and bulldozers gave up to 30 °K when working at the phase measuring site. A cement mixer at the 300-ft. road was measured with up to 25 °K. Electrical welding at the works area was sometimes about 3 °K, but most of the time not observable. Welding at the 140-ft. telescope was not observable. A couple in a car with idling motor, at 2:00 AM on 300-ft. road, gave 4 °K.

IV. Frequency and Bandwidth for Lunar Occultations

For the selection of frequency and bandwidth, one has to consider the interference level as well as the brightness limit (for which we suggest a signal to rms-noise ratio of 10). For illustration, we give an example for observation with the 85-ft. telescope, assuming an overal system noise of 200 °K, a time constant of 2 seconds, and a shielding factor of 12 db, observing at 405 Mc. If we now take a bandwidth of 5 Mc, then only 1.4% of time is lost by interference; but from all sources where predictions of occultations are provided, 41% would be below our brightness limit and could not properly be observed. On the other extreme, if we take a bandwidth of 35 Mc, only 2.5% of the sources are below the brightness limit, but 10% of time is lost by interference. A compromise between these two opposing demands leads to the bandwidths suggested in table 5.

There are two reasons for observing at least at two frequencies simultaneously: first, to minimize the hazard of losing an occultation by interference; second, in case that no interference occurs, to measure the spectral index of the source and to find out whether or not its diameter and position depend on frequency. For the second purpose, the one frequency should be as high, the other one as low as possible. Furthermore, since there is so much interference toward the lower side, observation at two lower frequencies seems to be necessary.

TABLE 5.

Frequencies and Bandwidths Suggested

Q_i = Fraction of Time Lost by Interference

Q_b = Fraction of Sources Below Brightness Limit

p = Background Noise Ratio (see text)

ν	B	Q_i	Q_b	p
Mc	Mc	%	%	
234	4	16.2 } 3.1 combined	12	0.75
256	4	18.8 }	15	0.58
405	15	3.1	9	0.58

In conclusion, simultaneous observation is suggested at the three frequencies listed in table 5. For the two lower frequencies, the observations should be recorded separately, and the information gained should then be combined. In this way, only 3.1% of the observable occultations will be lost by interference at the lower end, approximately equal to that at the high frequency. Thus, spectra could be obtained for all but 6.2% of the sources. The odds for getting interference on all three frequencies is only 0.1%. The fraction of prediction-sources below our brightness limit is around 10%, but this cannot easily be improved because of the large spread in the brightness of these sources.

Finally, we ask for the role played by the background noise. The last column of table 5 gives the ratio

$$p = \frac{\text{general background noise}}{\text{receiver noise + sky + spillover}}$$

for observation with parametric amplifier (200 °K) and a shielding factor of 12 db. The values given are for the position where the present measurements are made. Since they are below 1, the background noise would be, in the average, no severe trouble; but this might well be different at the position of the 85-ft. telescope. Shielding of cars, trucks and machinery might become necessary.

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REFERENCES

Hoerner, S. v. 1961, Pub. NRAO 1, 19.

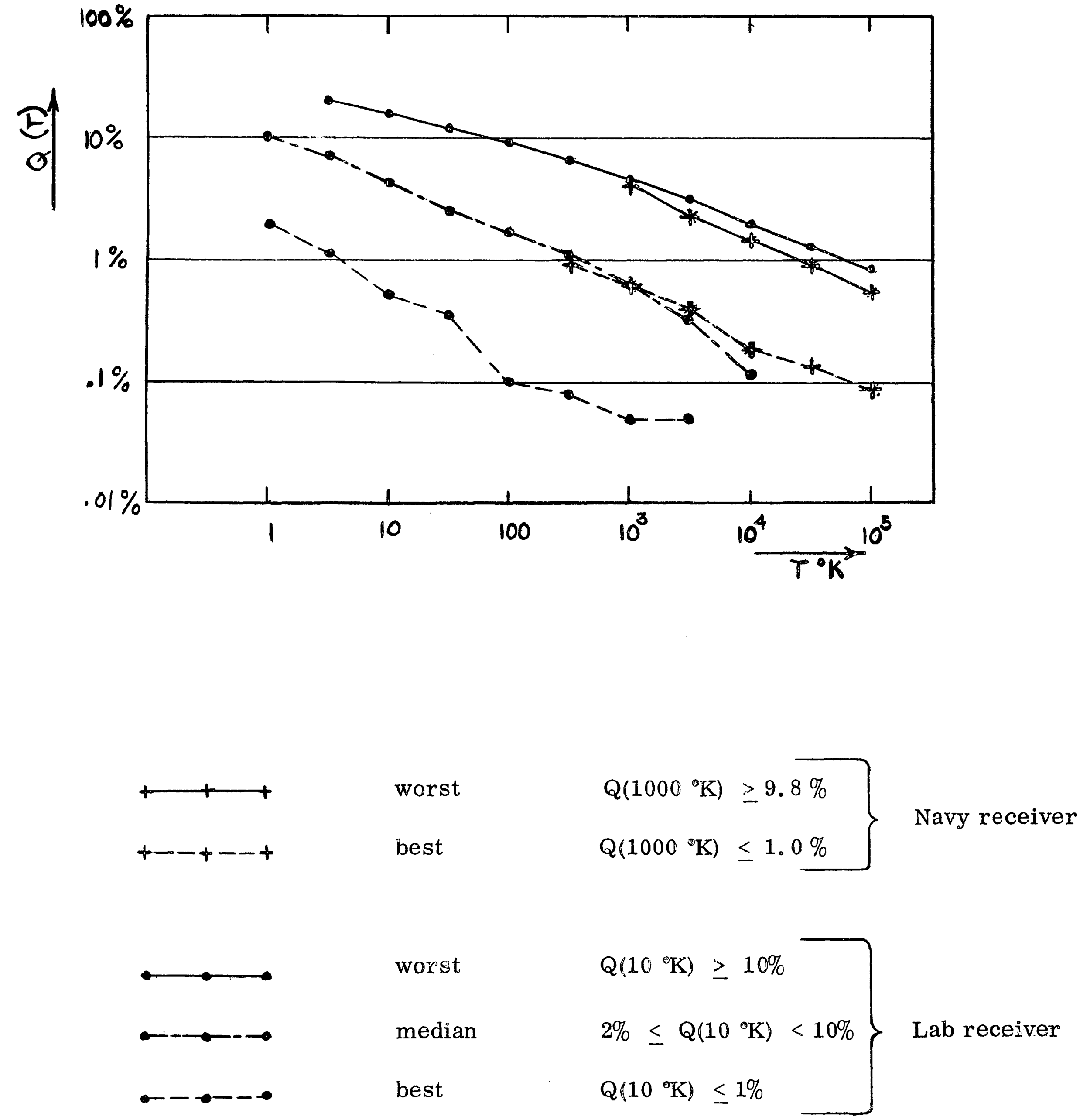

Fig. 1 -- Distribution of signal strength; for good, median and bad frequencies.

Q(T) = Fraction of time, lost by interference above T °K antenna temperature

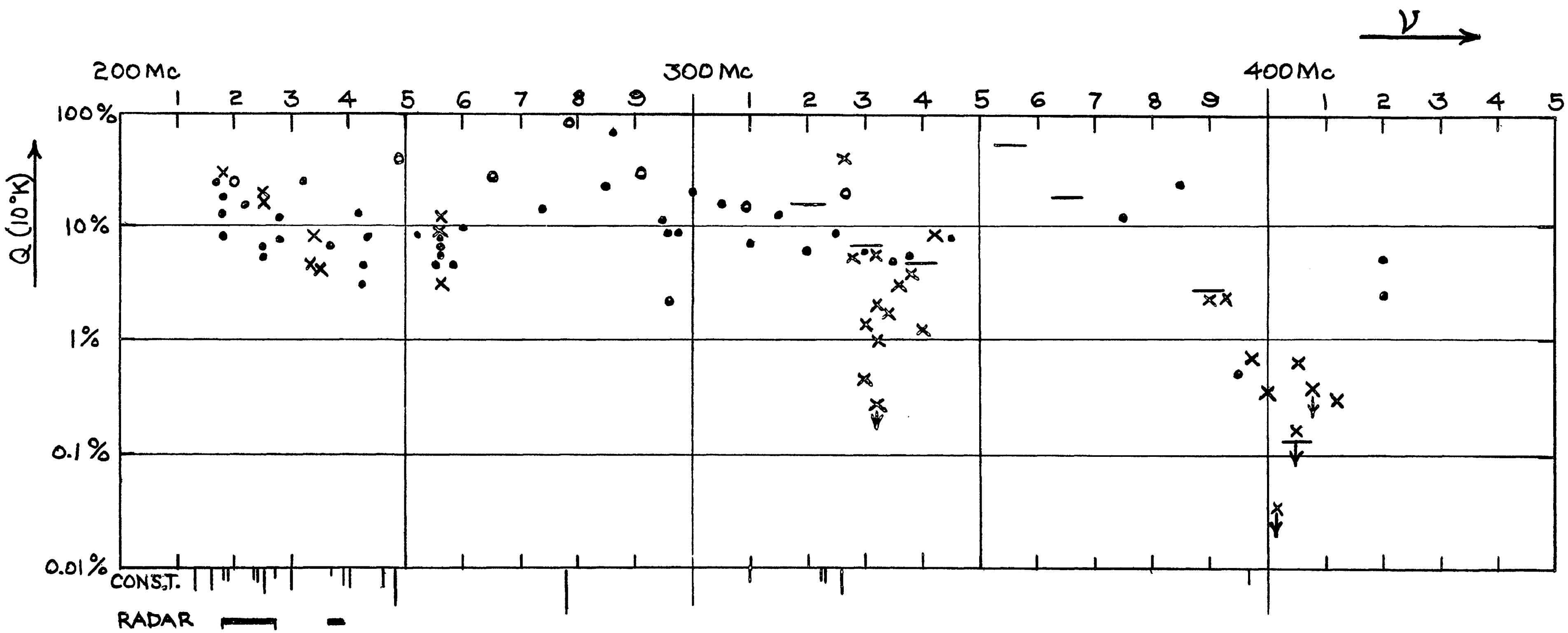

Fig. 2 -- Fraction of time, lost by interference above 10 °K

- o Hand scan
- • Motor sweep, 4 - 10 Mc wide } Navy receiver
- — 8 Mc bandwidth
- X 2 Mc bandwidth } Lab receiver
- ↓ upper limit only

all reduced to 2 Mc bandwidth

Const: Carrier, being on for over 20 minutes

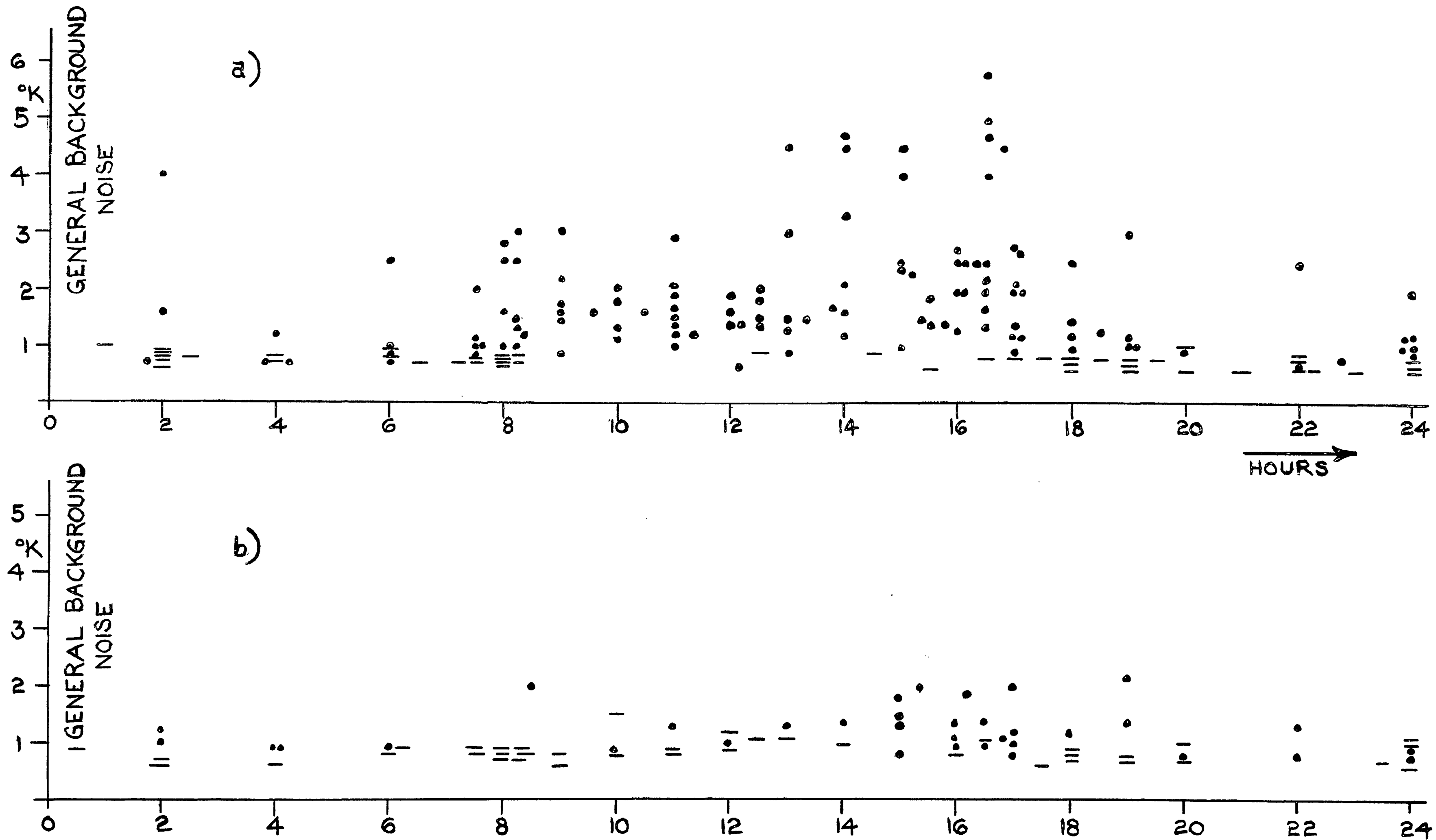

Fig. 3 -- General background noise as function of hour and day, for frequencies from 234 to 342 Mc.

a) Monday through Friday
b) Saturday and Sunday
• measured value
— upper limit