THE INFLUENCE OF NOISE ON RADAR METEOR OBSERVATIONS

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Summary

An experimental investigation has been made of the minimum detectable echo power from meteor trails, using radar techniques at 69 Mc/s, with incoherent detection.

For optimum signal-to-noise ratio the pulse width must exceed the cathode-ray tube spot width. Extraterrestrial noise is predominant at 69 Mc/s, and the receiver noise figure is found to be of only second order importance. Variations in the effective aerial temperature introduce corresponding variations in the observed meteor rate, and must therefore be considered when meteor rates are being compared.

Using artificial echoes, a minimum detectable signal-to-noise ratio of 8 db is found. The most important parameter is the total received signal energy. Both these results are in agreement with published theories. No further reduction in the size of the smallest observable meteor is likely through receiver improvement. The important features of the receiver are described.

I. Introduction

In the radar detection of meteor trails the minimum detectable electron density, and therefore also the observed echo rate, depends on the parameters of the radar system (Kaiser 1953). Hence, if absolute echo rates and trail density comparisons between different observing stations are to be made, these parameters must be known accurately. The aerial gain and beam shape, the transmitter power, the wavelength, and the echo range can all be measured to a reasonable order of accuracy, but the minimum detectable echo power is not so readily obtained.

The accurate calculation of the minimum detectable signal power in a radar receiver (Norton and Omberg 1947 ; Goldman 1948 ; Lawson and Uhlenbeck 1950 ; Ross 1951 ; Spencer 1951) requires the knowledge of a large number of parameters which are not all easily determinable. Therefore, for the purpose of estimating meteor magnitudes, it was preferable to find the minimum detectable signal power by direct measurement.

The radar system for the detection of meteors uses conventional incoherent pulse techniques, and includes a 69 Mc/s transmitter with a peak power of 80 kW and a pulse recurrence frequency of 150 $\sec^{-1}$, an aerial array with a gain of 120 relative to an isotropic source and half-power beam widths of 14° and 22°, and a receiver with a noise figure of $2\cdot0$. The signals are displayed on an intensity-modulated cathode-ray tube, and recorded on film moving continuously at right angles to the time base at a speed of $1\cdot23\times10^{-2}$ cm $\sec^{-1}$. Further details of the receiver are given in Appendix I.

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II. Bandwidth Limitations

The first bandwidth limitation is well known. With incoherent detection, the lowest possible value of the minimum detectable signal requires optimum setting of the pre-detection bandwidth (Goldman 1948 ; Spencer 1951). Video bandwidths wider than the optimum have negligible effect, but a bandwidth less than the pre-detection width degrades the signal-to-noise ratio.

In addition, however, because of the finite spot size the cathode-ray tube behaves as a low-pass filter (Ridenour 1947), since events occurring within the time taken for the spot to travel a distance equal to its own diameter are not resolved. It is therefore desirable to have the cathode-ray tube bandwidth wider than the pre-detection bandwidth, i.e. the cathode-ray tube spot width should be shorter than the signal pulse.

Meteor trails occur at a height of approximately 100 km. Hence with a low-elevation radiated beam a maximum range of about 900 km is required for the complete recording of echoes. The spot width thus represents more

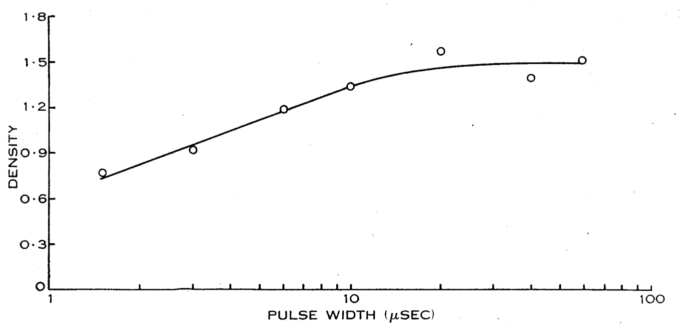

Fig. 1.—Variation of trace density with pulse width. (Pulse voltage = 15 V.)

kilometres range, or microseconds, than in conventional radar systems, and *pulse widths longer than usual must be used* if the optimum signal-to-noise ratio is to be achieved.

A series of measurements was made by applying to the cathode-ray tube grid a pulse of adjustable width, but of insufficient voltage to saturate the screen. The resultant film densities were measured on a microdensitometer (Tait and Chalklin 1953). The results, shown in Figure 1, demonstrate that the low-pass filter action of the cathode-ray tube produces appreciable loss with pulses shorter than 20 μsec width.

Microscope measurements were also made of short-duration meteor echoes, and gave a mean value of 56 μsec for the spot width. (Statistically significant variations occurred between films because of the variation of spot size with the brilliance control setting.) This time interval is longer than the value given by the microdensitometer method. Soller, Starr, and Valley (1948), however, find that microscope readings of cathode-ray traces are about double those recorded by other methods which approach more closely the conditions of visual observation. The present figures are in fair agreement with this conclusion, and a value of 20 μsec was therefore taken as the minimum desirable pulse length.

III. Effects of External Noise

The minimum detectable signal is reduced by decreasing the receiver noise level. Extraterrestrial noise, however, is always present, and the effective aerial temperature, for an aerial beam more than a few degrees wide, is always greater than 1500 °K at 69 Mc/s (Norton and Omberg 1947 ; Moxon 1949). A reduction in internal receiver noise, if the latter is already low, may therefore produce little improvement. The total effective noise input power to the receiver (P_n) is

$$P_n=(F_e+F-1)kTB,$$

where F_e=the ratio of the effective aerial temperature (T_a) to the receiver temperature (T=290 °K)
=external noise factor,
F=receiver noise figure,
k=Boltzmann's constant,
B=receiver bandwidth.

The meteor echo rate for sporadic meteors is inversely proportional to the minimum detectable signal voltage (Kaiser 1953), hence

$$(N_2/N_1)^2=(F_e+F_1-1)/(F_e+F_2-1), \qquad \ldots\ldots\ldots\ldots (1)$$

where N_2 (or N_1) is the meteor echo rate for a receiver noise figure of F_2 (or F_1). It can be seen that, if F_e is large compared with F, variations in F should produce little difference in the echo rate.

This independence of N_2/N_1 and F was verified experimentally in the following manner. The sporadic meteor echo rate was measured for consecutive 19 min intervals, and echo rates of the order of 60 per hour were obtained. On alternate 19 min periods the receiver noise figures were $2\cdot01\pm0\cdot02$ and $6\cdot3\pm0\cdot2$ respectively, the higher noise figure being obtained by reducing the gain of the first stage of the receiver. The meteor echo rates obtained with these two noise figures were virtually unchanged, giving a ratio $N_2/N_1=0\cdot9\pm0\cdot2$, whereas in the absence of external noise (F_e=0) the ratio would have been $0\cdot44$. It is therefore apparent that external noise has much more effect on the echo rate than receiver noise. Quite apart from any inherent variation in real meteor rate with time, due to the Earth's rotation and translation, the observed or apparent meteor rate must also be a function of the equivalent aerial temperature.

The ratio of the maximum to minimum aerial temperatures is of the order of 6 (Shain 1954) or 10 (Hey, Parsons, and Phillips 1948). The corresponding ratio of echo rates is $0\cdot44$ or $0\cdot34$, assuming a minimum temperature of 1500 °K and $F=2\cdot0$. It is therefore important that the aerial temperature be considered when comparing echo rates, even if these rates are obtained with the same equipment.

IV. Measurement of the Minimum Detectable Signal Power

Because noise introduces random variations in the observation of a signal, various definitions of the minimum detectable signal ($P_{\text{min.}}$) are possible. The value of $P_{\text{min.}}$ adopted here will be that having a 90 per cent. probability of detection, as assumed by Lawson and Uhlenbeck (1950).

The minimum observable signal was determined experimentally for the receiver of known noise factor by the following method. A pulsed signal generator was used to produce artificial echoes of 1·0 sec duration, since this is the effective integrating time on the film. More than 200 echoes, random in amplitude, range, and echo separation time, were recorded photographically for each test. The fraction detected in each amplitude group was assumed to be

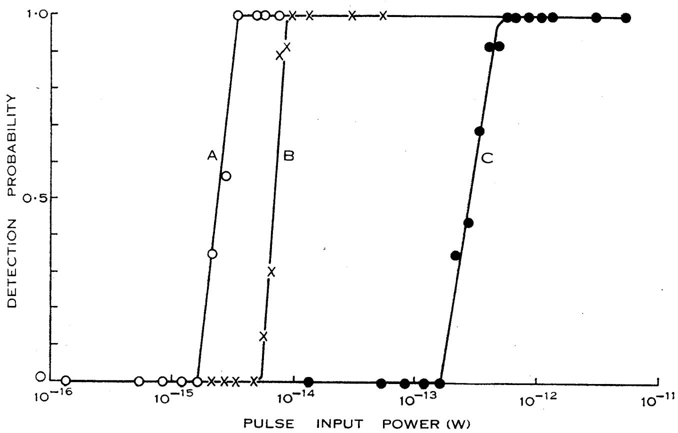

Fig. 2.—Detection probability as a function of pulse input power. The size of the points includes the estimated experimental error.

Curve A: I.F. bandwidth = 63 kc/s; pulse width = 26 μsec; $P_{\text{min.}} = 0\cdot30 \times 10^{-14}$ W (7·8 db above noise).

Curve B: I.F. bandwidth = 300 kc/s; pulse width = 8 μsec; $P_{\text{min.}} = 0\cdot85 \times 10^{-14}$ W (5·4 db above noise).

Curve C: I.F. bandwidth = 300 k/cs; pulse width = 3 μsec; $P_{\text{min.}} = 40 \times 10^{-14}$ W (22·0 db above noise).

the detection probability of that amplitude. (Each echo was made to appear as a pair of dots or lines by displacing the time base slightly on alternate sweeps. The probability of random noise producing two pulses of large amplitude with the correct spacing is very small, so the number of chance guesses should be small, and has been neglected.)

The detection loss with pulse widths shorter than optimum (here about 20 μsec) is clearly apparent from Figure 2. The minimum detectable power of 7·8 db above the noise level is in agreement with the experimental result of 8 db obtained by Gérardin (1954) for an intensity modulated radar system, and further confirms a theoretical analysis due to Ross (1951). When the receiver is connected to an aerial, $P_{\text{min.}}$ will be 8 db above the total noise power of $(F_e+F-1)kTB$. An appreciable decrease in $P_{\text{min.}}$ is only possible if coherent detectors are used (Goldman 1948; Smith 1951; Tucker and Griffiths 1953).

Curve A in Figure 2 was for optimum conditions. For curve B the pulse width was shorter, and the predetection bandwidth wider than the optimum suggested by Figure 1, but the pulse energies for these two curves in Figure 2 are equal within the experimental error. This confirms the results obtained by Goldman (1948), and by Woodward and Davis (1950), who analyse receiver performance in terms of information theory and find that the significant parameter is the ratio of the total received signal energy to the noise power per unit bandwidth. Their analyses assume coherent detection, but also hold for incoherent detection if the signal-to-noise ratio is large. The energy equivalence between curves A and B suggests that a signal power of 8 db above the noise is sufficiently large for the latter qualification to hold.

In the experiment described above the integrating time is of the order of $1\cdot0$ sec, but most meteor trail echoes do not last for this length of time at 69 Mc/s. Variation in the trail duration, if less than the integration time, will cause an inverse variation in $P_{\text{min.}}$. Assuming an average echo duration of $0\cdot1$ sec, the value of $P_{\text{min.}}$ in Figure 2 must be multiplied by 10.

V. The Minimum Detectable Meteor Magnitude

Taking as average values for meteor trail detection an aerial temperature of 2000 °K, and a range of 480 km, together with the radar parameters described above, the minimum trail density ($\alpha_{\text{min.}}$) is $2\cdot4\times10^{12}$ electrons per metre. From Kaiser's equation (1953) this value is equivalent to a zenithal magnitude of $+9$. Polarization effects are small and have been neglected in this calculation. A perfectly noiseless receiver would only reduce $\alpha_{\text{min.}}$ to $2\cdot1\times10^{12}$ m^{-1}. It therefore appears that $\alpha_{\text{min.}}$ at 69 Mc/s can only be reduced further by increasing the radiated power density. This can be achieved either by increasing the mean transmitter power considerably, or by increasing the aerial gain. No further decrease in $\alpha_{\text{min.}}$ is likely through receiver improvement.

Meteors show longer durations with decreasing radar frequency. This implies a greater integration time, and allows smaller meteors to be detected. Extraterrestrial noise, however, also increases with decreasing frequency, so the change in observed meteor rate on moving to lower frequencies can be expected to be less than that arising from the frequency effect alone.

In the comparison of trail densities and rates it would be preferable to specify the minimum detectable energy rather than the minimum detectable power.

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Appendix I

A 69 Mc/s receiver was constructed for the detection of echoes from meteor trails. The receiver noise has been reduced by using a cascode radio frequency amplifier (Wallman, MacNee, and Gadsden 1948). Provision is made for adjustment of the source impedance by using a Π-network to couple the aerial to the radio-frequency amplifier. The network capacitors are variable, and have been calibrated. Once the optimum source impedance and optimum detuning have been determined with the help of a noise generator, the network constants can be adjusted to suit a wide range of aerial impedances. Correct neutralization gave a noise figure of $1\cdot6$. Since such low values of receiver noise are unimportant, a noise figure of $2\cdot0$ has been used to allow for any small variations in input tuning and neutralization.

The relationship between signals differing largely in amplitude was required to be known for meteor velocity measurements. A logarithmic I.F. characteristic satisfies this requirement, and the circuit suggested by Croney (1951) was used as it is instantaneous and requires no critical matching of components. Five amplifying stages and six detectors are used, and the output is closely logarithmic over a range of at least 60 db. For linear receiver operation all detectors but the last are biased off by returning the cathodes to $+25$ V.