## MEASUREMENT OF BATTERY NOISE AND RESISTOR-CURRENT NOISE AT SUBAUDIO FREQUENCIES

Using a low-noise low-frequency parametric convertor as a preamplifier, narrowband noise measurements have been carried out on wirewound resistors, two types of dry Leclanché batteries and two types of carbon resistor. Wirewound resistors and one of the types of battery exhibited no measurable excess noise. An ordinary carbon resistor was found to produce $10^8$ times its thermal noise at 3 c/s when passing 4A. The noise power produced by the second type of battery was linearly related to its current.

To enable noise-spectrum measurements to be made on a device which has no available power gain, the noise contribution from a measuring preamplifier must be comparable to that of the device itself or, if possible, much lower. The noise-power contribution from a conventional amplifying device increases in a $1/f$ law at frequencies of less than 1 kc/s, down to 200 c/s. It is not possible, therefore, to obtain even a fairly accurate measurement of the noise from a device which may not exhibit $1/f$ noise above, say, 20 c/s.

Using a low-noise low-frequency parametric convertor,* it is possible to extend the flicker-noise-free region down to less than 10 c/s. For example, with a 1 kΩ source resistance the amplifier has a noise figure of 2 dB at 1 kc/s, rising to 9 dB at 10 c/s and then rising proportionally to $1/f$. Hence noise-spectrum measurements may be made on a device whose noise power is comparable to that of a 1 kΩ resistor and whose $1/f$ region can begin as low as 10 c/s.

The technique used for measuring battery noise was to connect two batteries of the same type back to back in series with the 1 kΩ source resistance. Each battery current was fixed by a parallel resistor. Negligible current flows through the source resistance. Three measurements were then taken of the r.m.s. value of the amplified noise signal:[1] one with the batteries replaced by a short circuit, one with a signal from a standard noise generator in series with the source resistance, and one with the batteries in circuit. Calculation of the excess noise introduced by the batteries and their loads could then be made.

It was found that a 9 V dry Leclanché battery, constructed from six cylindrical cells connected in series with soldered connections, passing 7 mA through a wirewound resistor, produced no measurable noise. One may conclude from this that the battery is not producing any significant noise, and the wirewound resistor is not producing any significant noise voltage across the battery. It is therefore possible to use this battery for investigating current noise in resistors.

The technique for measuring current noise in resistors was to use two batteries in a centre-tapped arrangement to feed current through two resistors which, in parallel, gave the required source resistance. The reason for using two batteries each time is that the parametric convertor has a direct-coupled input, and, rather than introduce unknown effects by decoupling with a necessarily large capacitor, it was thought wiser to return the input to ground by using two batteries. Assuming that the batteries are identical, the noise from one of them can be calculated.

The second type of battery on which measurements were made was constructed from six rectangular cells stacked one on top of another. The noise-power spectrum of this battery is shown in Fig. 1.

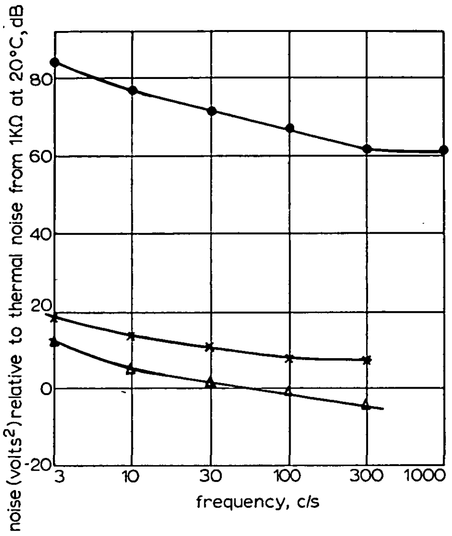


**Fig. 1** *Noise-power spectra*
● ordinary carbon resistor
× cracked-carbon resistor
△ 9 V battery

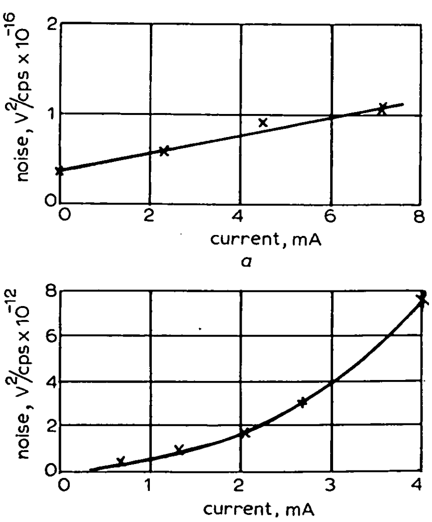


**Fig. 2** *Dependence of noise power on current*
*a* Battery
*b* Ordinary carbon resistor

Current-noise measurements were made on 2 kΩ resistors of three types: 10% ¼ W carbon, 1% ¼ W high-stability cracked carbon, and 5% 6 W wirewound. No measurable current noise was observed for wirewound resistors. The noise spectra for the two types of carbon resistors are shown in Fig. 1.

The dependence of the noise power of the second type of battery and the 10% carbon resistor on the current passed was investigated by measuring the noise power as a function of current, the centre frequency of the measurement being constant. Fig. 2 illustrates the results obtained.

### Conclusions

From the results obtained for the two types of battery, one may conclude that the construction of the second type leads to a battery which is noisier at low frequencies. The noise power is linearly related to the current passed. It is seen that cracked-carbon resistors are very much quieter than ordinary carbon ones, although they still exhibit flicker noise. Both types of resistor tend to have a constant noise power at frequencies near 1 kc/s.

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### Reference

1 SUTCLIFFE, H.: 'Noise-spectrum measurement at subaudio frequencies', *Proc. IEE*, 1965, **112**, p. 301

* Knott, K. F.: unpublished

## RADIATION RESISTANCE OF AN ELLIPTICAL LOOP ANTENNA WITH CONSTANT CURRENT IN COMPRESSIBLE PLASMA*

The radiation resistance of an elliptical loop antenna with constant current in compressible plasma is found by using a two-fluid magnetohydrodynamic model. The finite but small dimensions of the elliptical wire are taken into consideration in evaluating the contributions from the ion- and electron-plasma modes.

Radiation resistances of some elementary electromagnetic sources in a compressible plasma are of great current interest. Kuehl[1] and Seshadri[2] have investigated the case of an electric dipole by using a two-fluid magnetohydrodynamic plasma model. In this communication the radiation resistance of an elliptical loop antenna with constant current is considered. The medium is an unbounded fully ionised macroscopically neutral plasma consisting of electrons and singly charged ions. The collisions between the particles are neglected, and the plasma as a whole is assumed to be at rest. Let $N_e$, $V_e$, $P_e$, $m_e$ and $(-e)$, respectively, be the average number density, the velocity, the perturbed pressure, the mass and the charge

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