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S/N RATIO IMPROVEMENT IN THE PHASE SENSITIVE TECHNIQUE FOR LOW FREQUENCY MEASUREMENTS

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Résumé. — Nous présentons les principes de fonctionnement d'un dispositif amplificateur synchrone à sensibilité de phase réalisé dans le but d'améliorer le facteur de bruit dans l'intervalle des basses fréquences où le bruit *flicker* est très fastidieux. Il est particulièrement utile lorsqu'on doit exécuter des mesures d'absorption ou réflexion thermomodulées.

Abstract. — This paper illustrates the operational principles of a phase sensitive tuned amplifying arrangement built up to improve the signal to noise ratio in the range of the low frequencies where the flicker noise is very troublesome. It is particularly useful when thermo-modulated absorption or reflection measurements must be carried out.

1. Introduction. — The use of the coherent or lock-in amplifier has provided, in recent years, experimental information of extraordinary quality and wealth. This was achieved by the recent development of modulation techniques, reviewed by Cardona [1], that in the field of the optical properties of solids, offer a sharp separation between the critical point contribution and the non-critical background due to the entirely different line shapes of static and modulated optical properties. The advantage can be quantitatively expressed by considering the possibility of lifting a modulation of typically 10^{-5} from the noise background.

Lock-in amplifiers are widely used in such types of experiments when it is necessary to extract a signal of known frequency, buried in the noise, with sufficient noise rejection, and until now no other device has provided the same narrow bandwidth together with its useful operating frequency range and versatility.

Nevertheless some kind of experimental procedures require measurements to be carried out at very low frequencies, where the flicker noise, having a particular $1/\omega^n$ power spectrum (n is a constant), becomes especially troublesome and one may find that a long averaging of the output signal does not increase the signal to noise ratio, so that the measurements are made with great difficulties.

2. Noise. — In fact, it is well known that after a certain gain is achieved by an amplifier, random

fluctuations or noise show up [2] and this is a very important factor in determining the performance of the measuring apparatus [3]. The noise figure is defined as

$$10 \log_{10} (Y/Z)$$

where Y is the total noise power per unit band-width available at amplifier output and the numerator Z is due to source thermal noise. It represents a useful method to specify the amplifier noise, the magnitude of the Johnson noise, which would be present in the case of a noiseless amplifier being

$$V^2 = 4 kTR \Delta\omega$$

relative to a $\Delta\omega$ bandwidth and for a resistive component R of the impedance used to determine the voltage V . Here k is the Boltzmann constant and T the absolute temperature. As recently pointed out [4] the low frequency electrical fluctuations, that is $1/\omega$ noise, seem to be due to the interaction of any current carrier with the scattering potential of an electromagnetic field. From this quantum point of view, the spectral density of current noise may be written as

$$\frac{A}{2} \left(\frac{\omega_1}{\omega_2} \right)^{A\omega^{-1}} \quad (1)$$

where ω_1 and ω_2 are respectively the lowest and the highest frequency of the $1/\omega$ noise measurement and A

a suitable noise coefficient. Integration from ω_1 to ω_2 of the expression (1), which gives the dispersion, shows [4] that a strong percentage of $1/\omega$ noise is already included in the definition of any dc current originating by carrier motion, while decreasing the $1/\omega$ noise coefficient most of the $1/\omega$ noise is limited to lower frequencies.

The necessity of reducing this low frequency noise is so strikingly evident, and is essential for physicists who carry out low frequency modulation measurements, as in thermo-modulated-absorption or -reflection spectroscopy of insulators where the modulation frequency usually ranges from 0.5 to 8.0 Hz.

3. Network description and conclusions. — We have succeeded in achieving a satisfactory reduction of the noise effect on the signal to be measured, adopting the circuit network arrangement reported in figure 1. The

FIG. 1. — Network arrangement.

scheme is made to make a lock-in amplifier work in a harmonic mode so that the output from it has signal components in the neighbourhood of the selected harmonic of the reference frequency. These signal components are then amplified and applied to a second coherent-type amplifier whose phase sensitive detector is referenced at this harmonic frequency. By this technique the noise fluctuations with a $1/\omega^n$ power spectrum can be substantially reduced. The mixer we used really is a transistorized model similar to the one realized by Faulkner and Stannett [5] and operates as a voltage amplifier with a high negative feedback. The basic principle is the fact that a correlation of random noise with a periodic signal tends to zero with increasing averaging time while the correlation of a signal with a replica of itself yields constant independent of integrating time. In essence, a synchronous detector is a cross-correlator that provides an output dc signal that is the time average of the product of the unknown signal plus noise with the reference signal. The reciprocal of the averaging time numerically represents the bandwidth of the detector.

The first operation is an amplitude modulation of the

signal at the frequency ω_0 . Then the signal assumes the form :

$$E = E_0 \cos \Omega t \cos \omega_0 t = \frac{1}{2} E_0 [\cos (\omega_0 + \Omega) t + \cos (\omega_0 - \Omega) t].$$

A low-pass filter rejects the sum frequencies and passes the different ones that lie within its pass-band. In particular, the difference frequency due to components of the signal at the reference frequency is zero or dc. The periodical signals form a very particular class because the same information will be found repeated many times. Any information is buried in the noise. The fluctuation of the observed signal value is due to the changes in the aleatory variable representing the superimposed noise. The possibility of increasing the S/N ratio by available data accumulation, owing to the signal periodicity, is well known. The fluctuations are then reduced by the factor $1/\sqrt{N}$, with N number of signal period upon which the sum is performed. This operation represents the principle of the sampling technique. At the sampling output a low-pass filter gives a mean value proportional to the instantaneous value of the signal. Obviously the S/N ratio is limited by the filter-sampling set. In particular one can consider the synchronous detection as a variable gain system with a gain 1 during a half period and zero elsewhere. It is possible to show that the noise spectral densities $N_i(\omega)$, at the input, and $N_o(\omega)$, at the output, are connected by a relation of the following type :

$$N_o = \frac{N_i}{4} + \sum_{-\infty}^{+\infty} N_i(\omega - n\omega_0)$$

where n is an integer different from zero and ω_0 the frequency of the signal. Consequently it is possible to evaluate at the output the mean square of the fluctuations to which only the odd harmonics of the resonance frequency contribute. To avoid the measurement being affected by this noise one can reduce the noise spectral density multiplying the signal (plus noise) by $\cos \omega_0 t$, so that the system is then equivalent to a synchronous detector with a selective filter at the input. In this case the mean square value of the fluctuations (assuming a white noise at the input) is proportional to the cut-off frequency ω_c of the output filter and the signal to noise ratio improves with increasing the quantity $1/\omega_c$.

The signal is then fed to a harmonic generator so that a signal may appear at a harmonic of the basic reference frequency. To this purpose, sample standard circuits can be used depending on the required order of the harmonic in use. If even harmonics are of interest, the harmonic generator provides the proper frequency component of a Fourier series of this type :

$$V(t) = V_0 \left[\frac{1}{\pi} + \frac{1}{2} \sin \omega t - \frac{2}{\pi} \sum_{K=1}^{\infty} \frac{\cos K\omega t}{K^2 - 1} \right] \quad (K \text{ even})$$

where V_0 is the peak value of the input voltage and $V(t)$ is the output waveform which, apart from the fundamental one, only contains even harmonics. If odd (3rd or higher) harmonics operation is desired, the waveform resulting from the generator is included in a harmonic structure of this type :

$$V(t) = \frac{4 V_0}{\pi} \sum_{K=0}^{\infty} (-1)^K \frac{\cos(2K+1)\omega t}{\cos(2K+1)}.$$

The frequency-multiplied signal thus obtained is sent to a commercial lock-in amplifier tuned to the proper frequency of the selected harmonic of interest. Reference voltage is supplied, through a second harmonic generator, by the oscillator which drives the suitable modulating system and the mixer at the basic frequency. In order to assure proper voltage levels, if a high order harmonic is used, it is convenient to insert some intermediate low noise amplifier : we have used the PAR model 113 providing a calibrated gain from $\times 10$ to $\times 10^4$ and adjustable high and low-frequency rolloffs that allow the bandwidth to be reduced. Particular care must be paid in calibrating the above-described apparatus. In fact, one has to estimate the signal levels after the elaboration by each circuit component in order to operate on the effective value of the signal to be measured. This is easily achieved by using the internal calibration oscillator that equips most of the commercial lock-in amplifiers, some calibrated low-noise amplifiers and an oscilloscope. The improve-

ment in the S/N ratio principally depends on the operating harmonic, but also on the electronic apparatus used. We have normally obtained improvement factors of about 10 and 20 operating in the 2nd and 4th harmonic of the mixer output respectively, ranging the basic frequencies between 1.5 and 6.0 Hz.

The obtained increase of the order of magnitude of S/N ratio is satisfactory, and may also determine a good performance of thermomodulation experiments. In this case the frequency to be used, especially on the insulators, comes out from a compromise between signal strength and noise level and is usually fixed at a few cycles per second [6], when flicker noise is particularly disturbing. Hence, measurements are made with great difficulty since long time averaging can result in no net improvement in signal to noise ratio. In conclusion, the possibility of working with a frequency higher than the thermomodulating one, allowing the experimenter to work in more convenient conditions, reduces the problems of electronic drift due to long averaging. Therefore, a good gain in the quality of the chart recording is obtained as a consequence of the increased stability of the measurements, and the reproducibility of each measurement allows an appreciable decrease of the experimental uncertainty.

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References

- [1] CARDONA, M., *Solid State Physics*, Suppl. 11 (New York : Academic Press) 1969.
- [2] RYDER, J. D., *Engineering Electronics* (Tokyo : Kogakusha Company) 1967, pp. 176-179.
- [3] COOR, T., PAR Technical Note T-198 A.
- [4] HANDEL, P. H., *Phys. Lett.* **53A** (1975) 438.
- [5] FAULKNER, E. A. and STANNETT, R. H., *Electron. Engng.* **36** (1964) 159.
- [6] GRANDOLFO, M., SOMMA, F., VECCHIA, P., *Phys. Rev.* **B5** (1972) 428.