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Phase Sensitivity and (or?) Short Time Analysis of the Hearing Organ

A very pronounced phase effect has been observed listening to a repetitive random binary sequence.

Periodic binary sequences may be obtained from a digital shift-register with modulo-2 adder feedback (Fig. 1). The shift-register consists of cascaded flip-

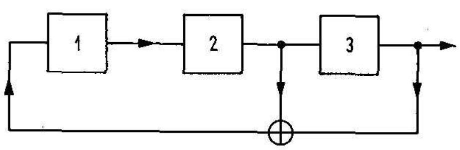

Fig. 1. A digital shift-register with modulo-2 adder feedback.

flops with memory elements driven at the desired rate by external clock pulses. The outputs of certain flip-flops are added modulo-2 and their sum is fed back to the first stage of the shift-register [1].

It may be shown mathematically that the maximum length of a sequence is $N=2^n-1$, where n is the number of flip-flops. The autocorrelation function of this so called maximum length sequence (MLS-signal) is given in Fig. 2. Note that the period $T=N\,\Delta T$, where

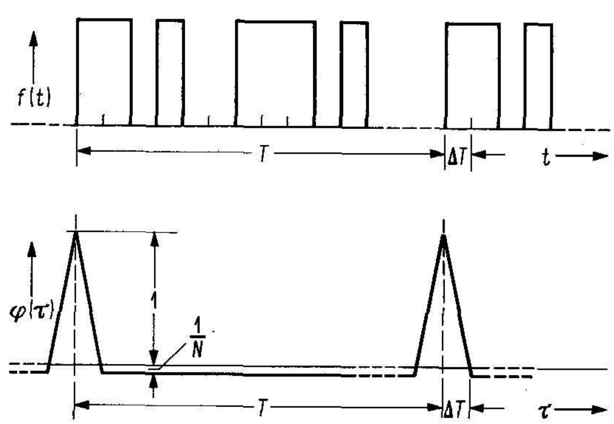

Fig. 2. A maximum length sequence $f(t)$ and its autocorrelation function $\varphi(\tau)$.

$\Delta T=1/f_c$, f_c being the clock frequency. The power spectrum is a discrete spectrum with lines at multiples of f_c/N, and equivalent to the power spectrum of a periodic pulse with pulse width ΔT.

However, notwithstanding this spectral equivalence, the MLS-signal and the periodic pulse produce a very different sound impression. For low repetition frequencies (for instance 10 Hz) where the periodic pulse has a rattling sound and, in fact, one perceives the spark-like effect of every separate pulse, the MLS-signal sounds like white noise whispering with a certain cadence. For higher repetition frequencies (for instance 200 Hz) both signals are tonal and have a definite pitch (200 Hz), but contrary to the periodic pulse the MLS-signal has a noisy character (a first impression is that of a periodic pulse with added coloured background noise). Above about 700 Hz the two signals sound alike.

This difference of sound character, notwithstanding the equality of the power spectra, is manifest in the Fourier spectrum. The phases of the Fourier components of the periodic pulse are all equal to zero. On the contrary, those of the MLS-signal have a random distribution. Thus, the MLS-signal is a clear example of the invalidity of what is called Ohm's law, viz. the phase insensitivity of the hearing organ.

In fact, this phase sensitivity shows that the hearing organ is performing a short-time analysis by means of which it discerns both the temporal features and the periodicity characteristics of a signal. This may be confirmed by the fact that the MLS-signal shows the residue effect. Note that the limit of phase sensitivity (700 Hz) is about the limit of existence of the residue (800 Hz) [2]. However, one may ask how the periodicity will be detected by the hearing organ, because the periodicity of the MLS-signal is by no means obvious (see the oscillograph pattern). For this an autocorrelational mechanism seems necessary.

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F. A. Bilsen
Technological University
Delft, Netherlands

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[2] Ritsma, R. J., Existence region of the tonal residue. J. Acoust. Soc. Amer. **34** [1962], 1224.