8.16 DIGITAL SIGNAL PROCESSING OF THE FETAL HEART SOUND

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Besides the commonly used noninvasive methods of fetal monitoring, like Elektrocardiogram (ECG) and Ultrasonogram the Phonocardiogram (PCG) is a powerful means to determine the fetal health state.

For the analysis of the fetal Phonocardiogram it is necessary to extract characteristic parameters, as fetal heart rate or heart sound intervals from the signal, which is recorded by a microphone from the maternal abdomen.

In general strong interferences, as maternal heart sound as well as background noise superpose the fetal heart sound by orders of magnitude. Therefore, first of all, interference suppression has to be accomplished.

There are three principal ways of improving the signal to noise ratio:

1. Bandpass filtering
2. Matched filtering
3. Correlation analysis

The first two methods require the frequency spectrum of the fetal heart sound. The third choise provides this frequency spectrum by coherent averaging of the signal followed by Fourier Transform. The fetal QRS - complex serves as time reference.

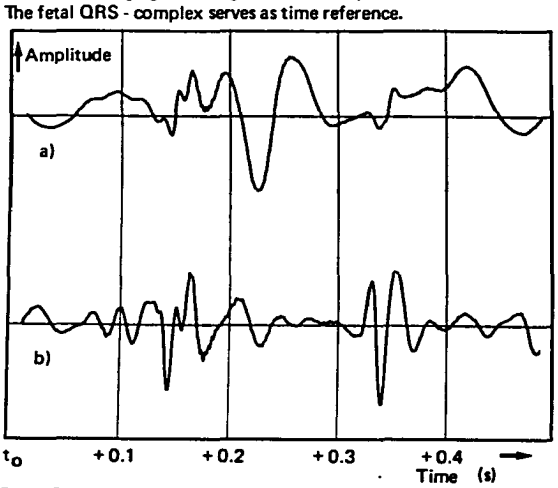

Fig 1. Phono signal recorded from the maternal abdomen
a) Unfiltered signal
b) Fetal heart sound after averaging of 20 sweeps.

Averaging will improve the signal to noise ratio by a factor $\sqrt{N}$ (N = number of average cycles).
The template of the processed fetal heart sound, obtained in this way consists of two significant portions, the first and the second heart sound. The respective frequency spectra result by performing Fast Fourier Transform (FFT).
The spectrum of the maternal signal, characterized by sounds of heart and blood stream in the iliac region can be obtained in the same manner, except differentiation of heart sounds.

The background noise, a statistical signal, generated for example by maternal movement shows its highest frequency components in the lower frequency band. Its spectrum results by subtraction of determined spectra from the spectrum of the unfiltered signal.

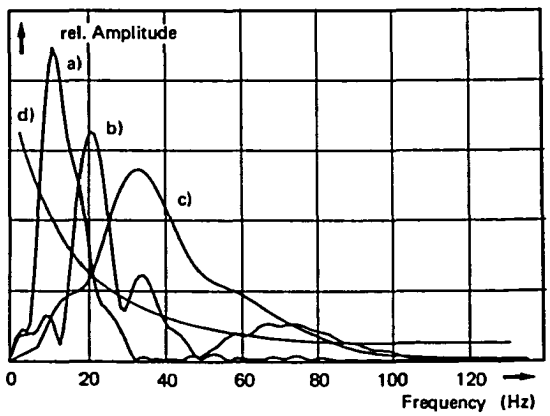

Fig 2. Frequency spectra of abdominal signal calculated by FFT.
a) Maternal sound
b) First heart sound of the fetus
c) Second heart sound of the fetus
d) Background noise

All spectra, shown in Fig 2, are needed to design optimal filter characteristics. The separation of the different signal components from each other will be successful if the passband characteristic is adjusted to the wanted component spectrum, e.g. the first heart sound.

The application of digital computing permits a simple realization of such filters.
There are two possibilities of performing digital filtering:

1. In frequency domain, by multiplication of the spectrum of the signal with the transfer function.
2. In time domain, by convolution of the signal with the impulse response of the filter.

In addition to the effective noise suppression, the separation of the first and the second heart sound is achieved by using adapted digital filters. This separation of the heart sounds is a basic requirement for the heart rate calculation or the exact measurement of the heart sound intervals.

The Phonocardiogram processed in this way, together with Electrocardiogram and Ultrasonogram improves the commonly used methods of continuous recording of the fetal heart rate.

Lit.:
1. A.F.L. VETH: Modelling of the Foetal Circulation
2. A.V. OPPENHEIM: Digital Signal Processing
3. F.H. NETTER: Atlas der Medizin, Band 1: Herz