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Auto-switching filter array for frequency measurement of unstable signals

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A bandpass filter whose center frequency is switched automatically is described. The frequency filter makes it possible to measure the frequency of the signal which has fluctuating amplitude and is accompanied by considerable noise. Twelve bandpass filters whose center frequencies are located slightly apart from each other and connected in parallel, discriminate the signal and the noise. From the bandpass filters paralleled, only the output with the largest amplitude among all is selected by photocoupler switches. The frequency range of the filter array is two decades and easily expandable. An application to laser-Doppler anemometer is also described.

INTRODUCTION

Among several methods for frequency measurement, the simplest is the use of a frequency counter. However, it is not effective when the signal is fluctuating in amplitude and mixed with considerable noise. A frequency tracker or a spectrum analyzer is used in such conditions, but the former is complicated and the latter is inefficient.[1]

A bandpass filter whose center frequency is tuned to the signal reduces the noise component and the fluctuation of the signal amplitude, and makes it possible to measure the frequency even with an ordinary frequency counter. When the signal frequency component is larger than the noise, we can follow the signal with moving frequency by selecting the signal from the bandpass filter which has the largest output. Since this method employs no feedback loop, it works well even for unstable signals. The automatic switching technique will be described in this paper.

I. DESIGN AND TEST OF A FILTER ARRAY

The autoswitching filter array which we designed this time, covers a frequency range from 165 Hz to 11 kHz (as their center frequencies) with 12 bandpass filters (see Fig. 1). The center frequencies of the filters are determined so that they are in the same ratio to the next and their Q values are 2.5. The ratios and Q values must be adjusted to the characteristic of noise. The Q value is large enough to reject the second harmonics and noise at half-frequency. The slope of the filters is 6 dB/oct.

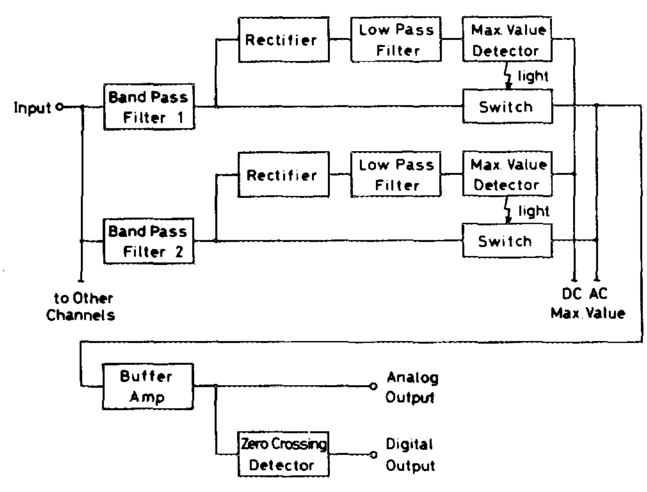

FIG. 1. Block diagram of the autoswitching filter array. There are 12 bandpass filters in practice.

The outputs of the filters go through rectifiers, lowpass filters, and maximum value detectors. The time constant of the lowpass filter is 1.25 s. It has to be determined so that sufficient attenuation is obtained at the lowest end of the moving signal frequency (about 100 Hz). The time constants of all lowpass filters must be the same because rapid fluctuation of the signal causes undesirable switching. The maximum value detector is composed of a wired-OR connection of ideal diodes as shown in Fig. 2. Each OP amplifier works as a comparator. When the diode of one channel is ON, those of the others are turned OFF. We use LED-CdS photocouplers (Moririca MCD-521H) as the diodes and get the mixed output of the bandpass filters through the CdS variable resistors. The resistance of the CdS in ON state is about 2 kΩ while those in OFF state are quite large. Turned-off channels contribute, therefore, to a negligible portion of the output current to the buffer amplifier. The signal from the buffer amplifier is divided into two outputs, one of which is a direct analog output and the other is a digital output through a zero-crossing detector. The risetime of the photocoupler is about 3 ms. The total response is limited by the lowpass filters and can be several tens of Hz by taking the time constant of those small enough.

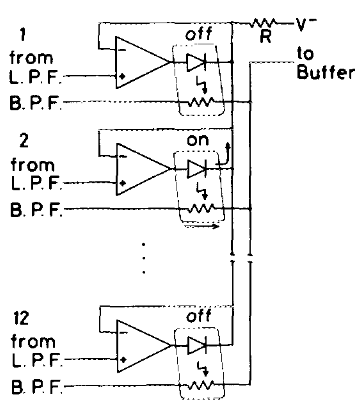

FIG. 2. Maximum value detector. When the second channel has the maximum value, the diode of the channel becomes ON state, and those of the other channels become OFF.

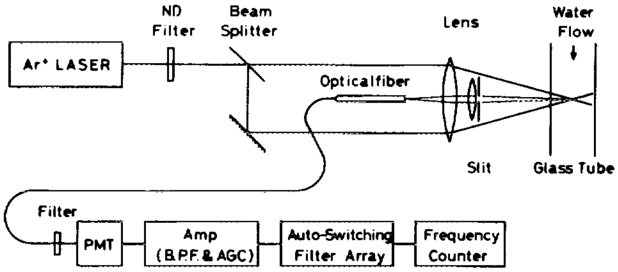

FIG. 3. Experimental arrangement to measure the velocity of water flow by laser-Doppler technique.

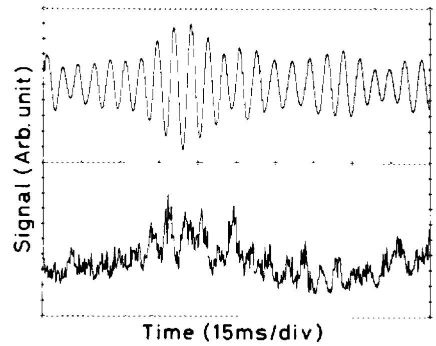

FIG. 4. The effect of the autoswitching filter array. It shows (upper) output signal and (lower) input signal of the filter. When the spectrum of the noise is widely spread, the effect will be large.

II. APPLICATION FOR A LASER-DOPPLER ANEMOMETER

The signal of a laser-Doppler anemometer is modulated by the low-frequency noise. The autoswitching filter array is found to be effective in such a condition.

The experimental setup is shown in Fig. 3. The beam of an Ar^+ laser is divided and crossed at an angle of 6° in the glass tube in which water flows. The backscattered light from the cross point is collected through a slit and a lens, and led into an optical fiber. The light through an interference filter is detected by a photomultiplier. The current from the photomultiplier goes through a low noise amplifier which is comprised of a bandpass filter with the cut-off frequencies of 110 Hz and 40 kHz and an AGC amplifier, and flows into the autoswitching filter array. The output selected from the filter array gives the signal so much improved in S/N ratio as can be seen in Fig. 4 that an ordinary frequency counter is able to work. Since the filter array has wide frequency range, it can respond to the change of the water velocity well.

III. DISCUSSION

Examination confirmed that the autoswitching filter array is quite useful for the measurement of the frequency of sinusoidal signals with a moving frequency, a fluctuating amplitude, and noise. This system has the following advantages: it is simple and efficient, it works automatically and needs no preceding adjustment in every measurement, and it is easily expandable in frequency range because of its wired-OR logic.

[1]F. Durst, A. Melling, and J. H. Whitelaw, *Principles and Practice of Laser–Doppler Anemometry* (Academic, New York, 1981).