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Microcomputer Filtering System to Measure Very Small Transmission Loss of Impulsive Signals

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Synopsis

This paper describes a method for measuring very small transmission loss of impulsive signals. The correlative fluctuations within input and output signals are eliminated effectively by the analog simultaneous differencer. The difference and normal signals are alternately sampled and accumulated by the digitizer and the microcomputer, that is, the microcomputer 2-channels box-car integrator is realized. The difference and normal accumulated data are transferred to the personal computer, which calculates the ratio of the difference to normal accumulated data, *i.e.* the estimated attenuation in nepers. By the experiments of electrical and optical impulse transmissions, the minimum measurable attenuations become respectively 2.7×10^{-4}Np and 6.0×10^{-4}Np. Even the latter value is the smallest so far as the authors know.

1. Introduction

Measurement of transmission factor on electric signals is one of the most fundamental matters for both communication and instrument technology. The latest equipment for this purpose is inclined to have advanced functions such as automated measurement, multiple out-

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put-modes and high accuracy by the aid of microcomputer. On the other hand, both communication and instrumentation by laser light have reached a stage of practical use, though the equipment for measuring transmission factor on optical signals is still complicatedly handled. The use of microcomputer may bring its functional improvements.

Usually, photoelectric signals in this equipment are detected by two analog box-car integrators or lock-in amplifiers[1],[2]. But an accurate transmittance is not always obtained from the detected signals, because the correlative noises between the incident and transit lights do not vanish and also those signal detectors generate drift noises. The authors develope the improved signal detector for measuring the very small absorption loss of pulse laser light through a short path of dilute gas[3],[4]. The detector is composed of the analog simultaneous differencer and the microcomputer 2-channels box-car integrator.

2. Principle of Signal Detection

Fig.1 shows the transmission of a light beam through an optical medium such as glass, liquid or gas. The incident light power p_i is related to the transit light power p_t by the following equation

$$p_t = p_i e^{-\alpha} \qquad (1)$$

where α is the optical attenuation. In the practical measurement of the attenuation, the intensity of light is modulated and the corresponding signal detector is used in order to suppress noise disturbances. For example, a lock-in amplifier corresponds with the light at 50% duty factor and a box-car integrator at much smaller duty factor.

In the measurement of this attenuation, light emitted by the pulse dye-laser has 10-ns pulse width and 100-ms repetition period (at the 10^{-7} duty factor), and its average power in watts is expressed as

$$p = W/T \qquad (2)$$

where W is statistical-average energy of a light pulse in joules and T is period in seconds. By adjusting the power level, p becomes $p_i = W_i/T$ and accordingly $p_t = W_t/T$. Though the energy of each light pulse fluctuates,

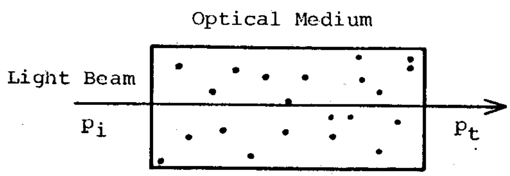

Fig.1 Model of Optical Transmission.

there exists a strong correlation between the incident energy W_{ik} and the transit energy W_{tk} at the k-th pulse shot. The correlative energy fluctuations or the correlative noises could be eliminated by the following equation for the estimated attenuation in 2-times nepers

$$\ln\left(\sum_{k=0}^{M-1} W_{ik}/W_{tk}\right) \tag{3}$$

where M is the pulse number. But the analog or digital operation of Eq.(3) involves some difficulties for the guarantee of accuracy and speed. The very small attenuation $\alpha \ll 1$ as through a short path of dilute gas can bepractically well estimated by the following equation

$$\tilde{\alpha} = \sum_{\ell=0}^{M-1} (W_{i,2\ell+1} - W_{t,2\ell+1}) / \sum_{\ell=0}^{M-1} W_{i,2\ell} \quad . \tag{4}$$

The component of the difference energy at the $(2\ell+1)$-th pulse shot is obtained by the analog circuit and also the component of the incident energy at the 2ℓ-th pulse shot, and the digitized values of those components are accumulated by the microcomputer. The first and last operations are to be called the analog simultaneous differencing and the digital box-car integration respectively. Both operations can suppress the correlative noises and the quantizing noises on digitization.

3. Hybrid Signal Detecting System

Fig.2 shows the block diagram of the system for detecting the very small attenuation and Fig.3 shows the signal waveforms illustrating the operation of the system. In this case, the pulse width of the photoelectric currents from the PIN-type photodiodes are about 20ns, and too narrow to difference and digitize. Therefore, the photoelectric currents are to be integrated and re-formed by the charge-to-voltage converters with the transfer coefficient Kp or K'p and the relaxation time τ = 2μs. Then the photoelectric currents resulting from the incident and transit light powers at the time $t \geq kT$ can assume the respective impulses as

$$i_{pk}(t) = Q_{ik}\delta(t-kT); Q_{ik} = K_i W_{ik} \tag{5}$$

and

$$i'_{pk}(t) = Q_{tk}\delta(t-kT); Q_{tk} = K_t W_{tk} \tag{6}$$

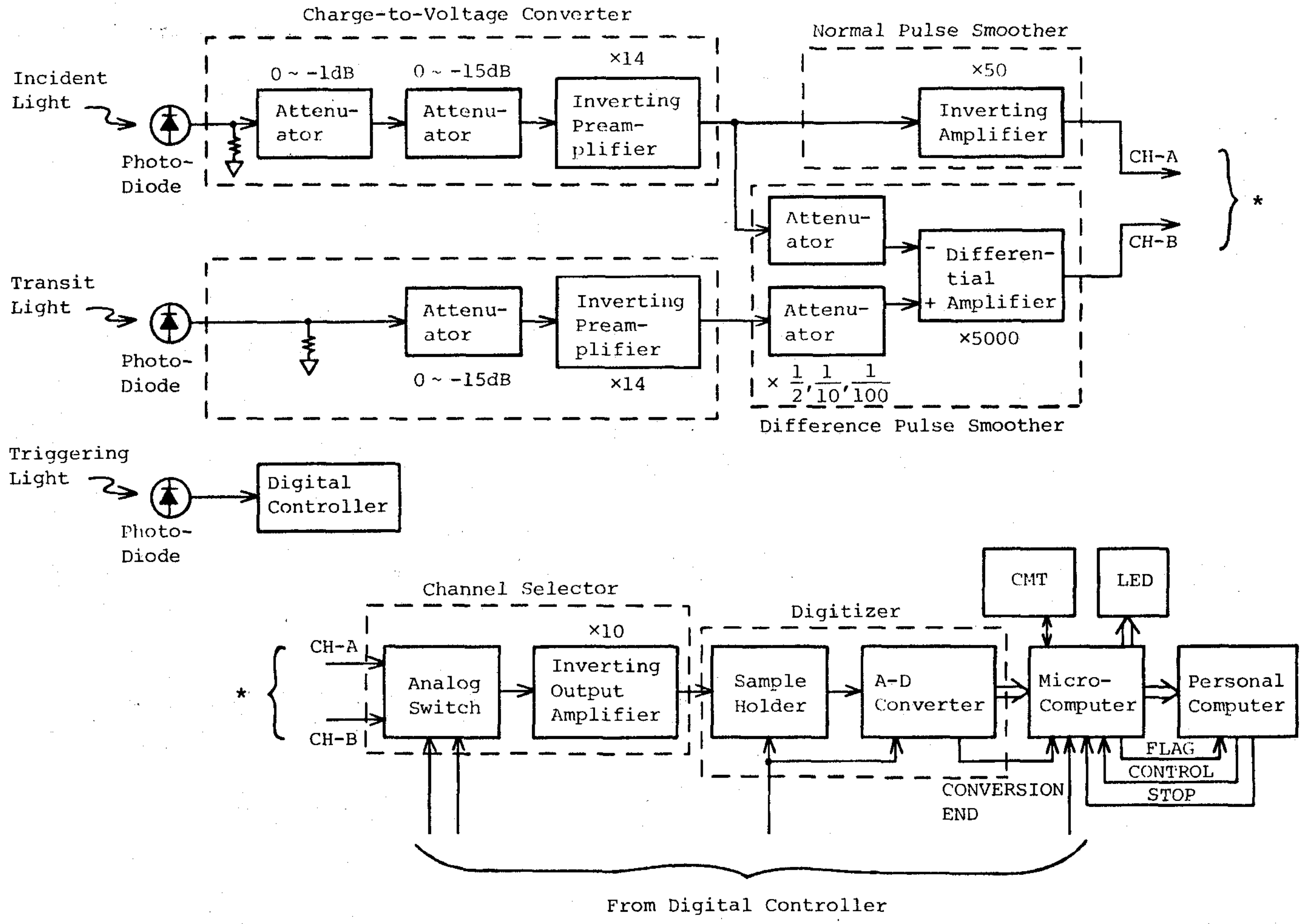

Fig.2 System for Measuring Photoelectric Signals.

where $\delta(t)$ is Dirac's delta function as

$$\int_{-\infty}^{\infty} \delta(t)dt = 1 \tag{7}$$

and Q_{ik} and Q_{tk} are the electric charges from the respective photodiodes with the responsivities K_i and K_t. The corresponding outputs of the charge-to-voltage converters show the identical waveforms as follows:

$$V_{pk}(t) = (Q_{ik}K_p/\tau) \exp\{-(t-kT)/\tau\} \tag{8}$$

$$V'_{pk}(t) = (Q_{tk}K'_p/\tau) \exp\{-(t-kT)/\tau\} \tag{9}$$

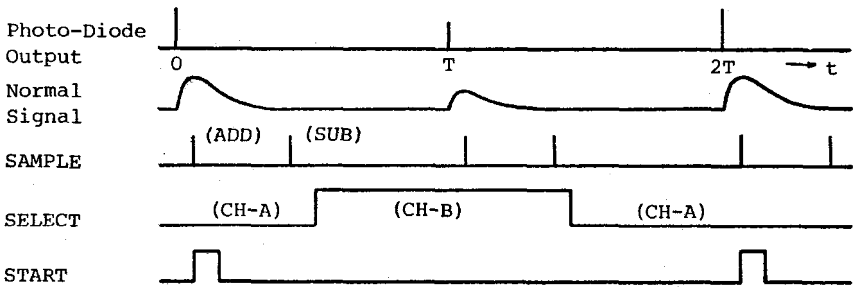

Fig.3 Time Chart of the Box-Car Integration.

Next, those waveforms pass through the normal and difference pulse smoothers with the identical relaxation times τ and the respective low-frequency voltage gains Kn and Kd, to change into the normal signal waveform

$$V_{nk}(t) = \frac{1}{\tau^2} K_i K_p K_n W_{ik}(t-kT) \exp\{-(t-kT)/\tau\} \tag{10}$$

and the difference signal waveform

$$V_{dk}(t) = \frac{1}{\tau^2} K_d (Q_{ik}K_p - Q_{tk}K'_p)(t-kT) \exp\{-(t-kT)/\tau\}$$

$$\simeq \frac{1}{\tau^2} K_i K_p K_d \{W_{ik} - W_{tk}(1+\varepsilon)\}(t-kT) \exp\{-(t-kT)/\tau\} \tag{11}$$

where K'_p is adjusted in advance so as to satisfy

$$K_t K'_p = K_i K_p (1+\varepsilon); \quad \varepsilon \ll 1 \tag{12}$$

and the gains Kn and Kd commonly involve the gain of the following channel selector. The normal and difference signal waveforms rise up slowly below the slew rate of the amplifiers, never to be distorted. K_d is selected to be larger than K_n, typically $K_d = 10K_n$, where the quantizing noises do not exert influence on the difference signals so much.

The normal and difference signals at each pulse shot are sampled and accumulated by the digitizer and the microcomputer, as mentioned below. At first, while the channel selector passes the normal signal on the channel A (CH-A), the digitizer samples its peak value at $t = \tau+2\ell T$ and the microcomputer stores the value in the addition mode and a little later after the normal signal vanishes they sample and store the off-set value in the subtraction mode. Thus, the component of the normal signal is obtained with the suppression of electric drift noises. Secondly, while selecting the channel B(CH-B), the component of the difference signal is obtained from its peak value at $t = \tau+(2\ell+1)T$ and the off-set value at its vanishing. With alternation of the channel selector, the respective components are accumulated in the microcomputer. Hence the 2-channels box-car integrator is realized. Fig.4 shows the circuit diagram of the digital controller.

When finishing the accumulation, the microcomputer displays the accumulated data on the LED and transfers them to the personal computer, in which the ratio of the differnce to normal data

$$\tilde{\beta} = (K_d/K_n)(\tilde{\alpha}-\varepsilon) \quad (13)$$

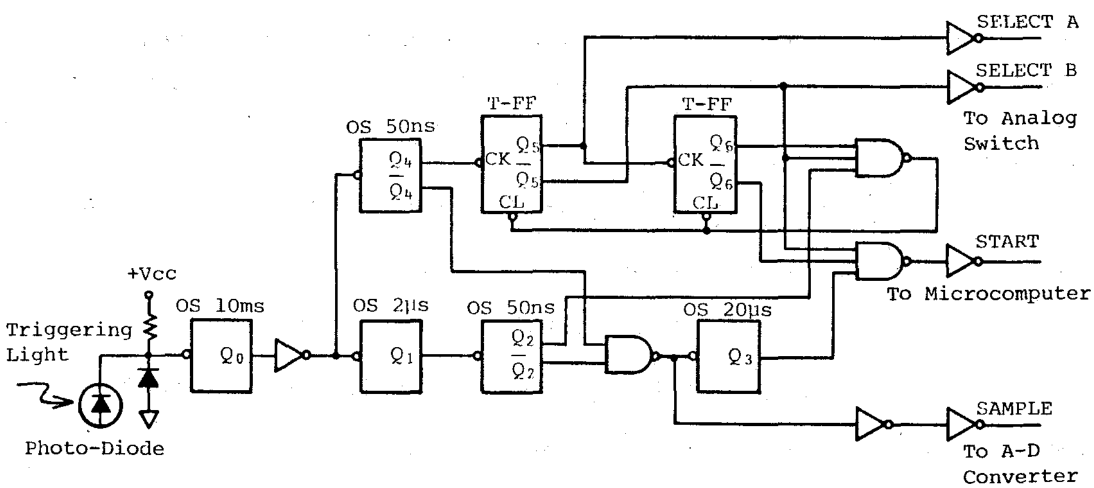

Fig.4 Digital Controller.

is calculated. Where the optical medium does not exist, by another calculation, is obtained the following value

$$\tilde{\beta}' = -(K_d/K_n)\varepsilon \quad , \qquad (14)$$

so the estimated attenuation

$$\tilde{\alpha} = (K_n/K_d)(\tilde{\beta}-\tilde{\beta}') \qquad (15)$$

is calculated.

4. Algorithm of Box-Car Integration

The microcomputer is composed of the 8-Bit CPU (8080A), the 0.75-kByte ROM, the 1-kByte RAM, the parallel I/O port and the interface for the cassette magnetic tape (CMT). The I/O port is divided into the 8-Bit Port A, Port B and Port C. Port A is assigned for data outputs, Port B for data inputs, the upper 4 Bits in Port C for control signal outputs (FLAG etc.) and the lower 4 Bits in Port C for control signal inputs (START and CONTROL). Some measurement programs are recorded on the CMT, from which the program for a certain measurement is loaded on the RAM.

This measurement is explained according to the flow chart in Fig.5. If the START signal (see Fig.3) is detected, four sets of data are read through Port B in order, when the addition and subtraction on the CH-A and then those on the CH-B are executed. Generally, A-D converter works as limitter for the over-level input. Here, if the output codes of the 8-Bit A-D converter in use show 11111111 (for-1.27v) or 00000000 (for 1.28v), the mark of over-level is indicated in the LED and the flow is stopped promptly. If the input level is not over, the addition and subtraction repeat with the binary double precision (of 16 Bits) and two sets of accumulative data continue to be stored in each pair register.

When the number of the accumulative repetition reaches the number (≤256) which is previously stored in another register, each accumulated data of binary number are converted into those of 4-digit decimal number and displayed on the LED. A negative number is indicated by • mark in the LED. Thus, both accumulated data take the numbers within the range from -9999 to +9999 and if either data are out of this range, they become ineffective together with the error marking.

The accumulated decimal data are transferred to the personal computer by 1 digit. The order of a transfer becomes the following. Receiving the data-request signal CONTROL, the microcomputer puts 1-digit data on the data bus of Port A and at the same time the FLAG signal on Port C, to be informed to the personal computer. Then the personal computer reads 1-digit data.

On the execution of this program, 0.35ms is required through a set of addition and subtraction on the CH-A and CH-B, and 0.77ms, from the end of accumulation to the data display. Therefore, the minimum period of the repetitive pulse signals measurable by this program is expected to be 0.35/2 = 0.175ms.

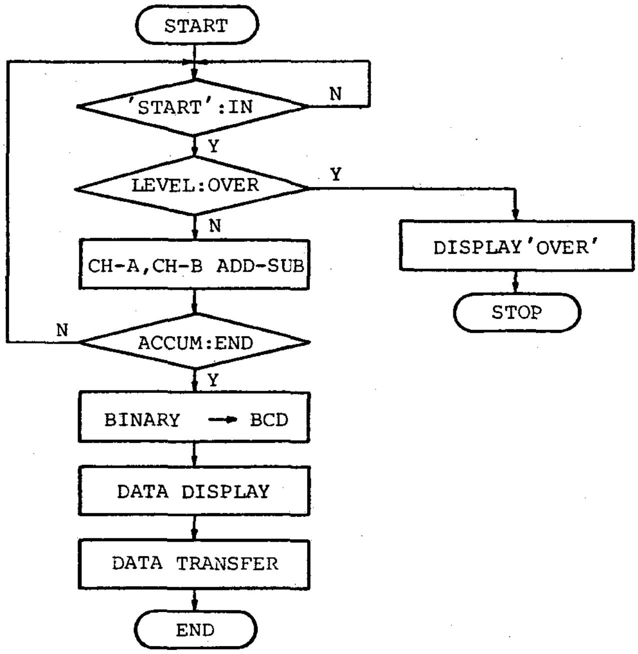

Fig.5 Flow Chart of the Box-Car Integration.

5. Performance of the Signal Detecting System

At first, the quasi-signals with 10-ns pulse width and 100-ms repetition period, generated from an electric pulse source, are measured where the pulse distributor and the variable attenuator of very small loss are used as supplement and the instrument parameters of K_d/K_n = 10 and M = 100 are chosen. The characteristic of measured vs. given attenuation shows a fine linearity and the minimum measurable attenuation 2.7×10^{-7}Np is recognized, which originates in the non-correlative system noises.

Next, using the 4500-Å pulse light emitted by the pulse dye-laser and the beam splitter and the optical attenuator, zero attenuation of the empty glass-made cell for gas is measured. Its standard deviation leads to the minimum measurable attenuation 6.0×10^{-4}Np. Therefore, it is shown that the non-correlative noises generate at the greater magnitude in the optical than electronic system. However, even the latter measurable value is the smallest so far as the authors know.

6. Conclusion

The filtering system for measuring the very small transmission loss of impulsive signals is developed, which is composed of the analog simultaneous differencer and the microcomputer 2-channels box-car integrator. The minimum measurable attenuation by the system shows an order of 10^{-4}Np, which is the smallest so far as the authors know. This filtering system can be applied to the measurements of the very small attenuation in both optical and electrical signal transmissions.

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