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A SIMPLE METHOD OF AUTOMATIC OPTICAL TRANSMISSION PLOTTING

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A simple method of automatic optical transmission plotting

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A simple electronic analog divider is described for plotting the transmittance or reflectance characteristics of optical materials as a function of wavelength. It is designed with commercially available integrated circuits and it automatically takes the ratio of any two signals connected to its inputs. The output is recorded as the spectrum is scanned by a monochromator.

Absorption, reflection, and transmission measurements of materials at optical frequencies require laborious data taking or elaborate equipment with mechanical choppers, mirrors, electronic comparison and null detector circuits.^{1,2}

In this paper, a very simple method of plotting optical transmission of thin films is presented. The main function is performed by an electronic analog divider circuit which takes the ratio of the transmitted light I_t to the reference light I_0 , and thus the transmittance T is automatically plotted as a function of wavelength on an X-Y recorder. The system, which is also adaptable to absorption and reflection measurements, can also be used in choosing optical detectors with identical spectral responses.

An experimental set-up for measuring the optical transmission of a thin film sample is shown in Fig. 1. A 35 W 6 V incandescent light bulb L, used as the light source, is placed at the input slit of a scanning optical monochromator. At the exit slit, a 50% reflecting mirror M_1 produces two beams at right angles to each other forming the reference and the transmitted beams. A photomultiplier tube is placed in front of each of these beams and the outputs of the photomultipliers are connected to the respective inputs of the divider circuit which produces an output signal proportional to the

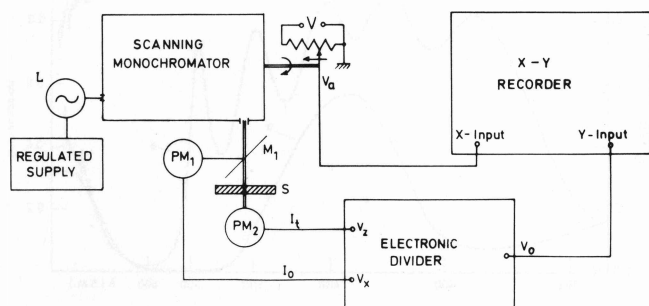


FIG. 1. Experimental set-up. S is the optical sample, L the light source, M_1 50% reflecting mirror, PM_1 and PM_2 the reference and the transmission photomultipliers, V_a the scanning voltage.

transmittance of the sample S , i.e., $T = (I_t/I_0)$. The scanning voltage of the monochromator and the output voltage of the divider are connected to the respective X and Y inputs of an X - Y recorder. As the spectrum is scanned by the monochromator, the optical transmission of a sample is automatically plotted as a function of wavelength on a graph paper. Such a transmission measurement is immune to the fluctuations of a light source since the dividing function is performed instantaneously.

Figure 2 shows the schematic diagram and the necessary components for the divider circuit.³ Motorola MC 1595L multiplier is used in conjunction with MC 1741G operational amplifier to perform the division operation. All of the necessary passive component values can be found in the manufacturer's manual.⁴

The divider has two inputs referred to as V_x and V_z and the output is equal to $V_0 = -K(V_z/V_x)$, where K is a scaling factor and is equal to 10 for the circuitry shown in Fig. 2. V_x is required to be positive at all times. Since the photomultipliers produce negative going signals, the refer-

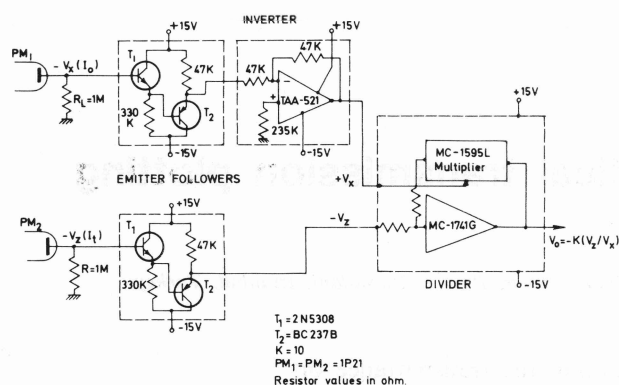


FIG. 2. Schematic diagram of the divider and its associated circuitry.

ence signal I_0 , which is connected to the X input of the divider, should be inverted. A buffer stage is also needed to prevent the low impedances of the divider circuit from loading the photomultiplier outputs. To satisfy these requirements, an emitter-follower for each input and an inverter for the X input are used. Complementary emitter followers with high β matched pair Darlington transistors or zero offset FET source followers⁵ will reduce any adverse offset voltages or loading effects of the buffer stages to a minimum. It should also be noted that the divider itself introduces considerable internal error at very low signal voltages.

Figure 3 shows the various voltages applied to the divider inputs and Fig. 4 shows the corresponding outputs. Figure 3(a) is a linearly increasing voltage V_a (output voltage of the scanning monochromator) and Fig. 4(a) is the divider output when the same V_a is connected to both X and Z inputs of the divider. This curve shows the effectiveness of the divider for various input voltage levels. Figures 3(b) and 3(c) show the spectral outputs of the reference signal I_0 and the transmitted signal I_t (without the sample S) of the corresponding photomultipliers (1P21). Figure 4(b)

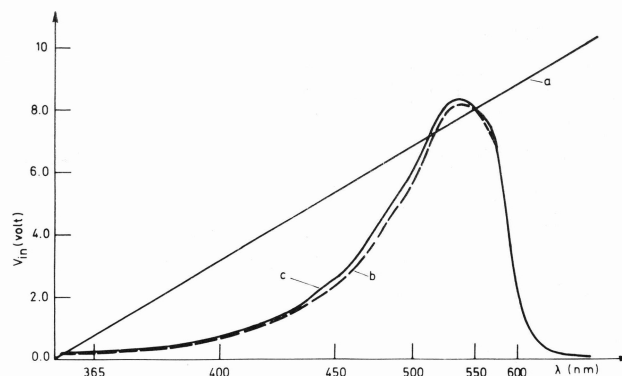


FIG. 3. Various voltages applied to the divider; (a) V_a , scanning voltage; (b) I_0 , output voltage of PM_1 ; (c) I_t , output voltage of PM_2 .

shows the divider output if the same photomultiplier signal I_0 is connected to both inputs of the divider. Figure 4(c) shows the ratio of the transmitted signal [Fig. 3(c)] and the reference signal [Fig. 3(b)] of the photomultiplier outputs. This ratio of (I_t/I_0) exceeds unity at various wavelengths due to different spectral responses of the PM tubes. With the two unmatched photomultipliers, the actual transmittance of a sample can be found by normalizing the transmittance curve to the previously recorded transmittance curve (without the sample S) given in Fig. 4(c). Figures 4(d) and 4(e) are the transmission characteristics of a Kodak Wratten Filter No. 47 and a 98% reflective He-Ne gas laser multi-layer mirror (coated for 6328 Å wavelength), respectively.

The response of the divider to low input voltage levels can be seen from all the curves of Fig. 4. The offset voltages and the loading effects of the buffer stages introduce large output errors at low voltage levels. The internal noise of the photomultipliers may also introduce additional error on the divider output at these low input levels.

If other light detectors with low input impedances are used, one can eliminate the emitter-followers at the input stages. If positive going detector signals are available, the inverter at the X input of the divider can also be eliminated.

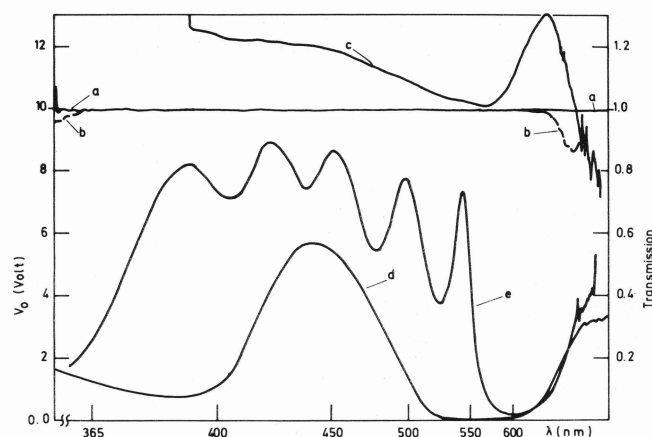


FIG. 4. Output of the divider: (a) for $V_x = V_z = V_a$; (b) for $V_x = V_z = I_0$; (c) I_t/I_0 (no sample); (d) Transmittance of a Kodak Wratten Filter No. 47; (e) transmittance of a 98% reflective multi-layer He-Ne laser mirror (coated for 6328 Å).

In addition to measuring optical properties of thin film materials, the divider can be used with spectrophotometers with the elimination of regulated light supplies, mechanical choppers, and complex optical and electronic components.

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¹*The Encyclopedia of Spectroscopy*, edited by G. L. Clark (Reinhold, New York, 1960).

²*Applied Optics and Optical Engineering*, edited by R. Kingslake (Academic, New York, 1969), Vol. 5.

³The choice of elements in Fig. 2 was dictated by the components that were readily available in our laboratories.

⁴"Linear Integrated Data-Book," Motorola, 2nd ed. 1972, p. 7.

⁵J. Sherwin, *Electron. Des.* **18**, No. 12, 80 (1970).