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Wave demonstration device

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to lower the voltage to the photocell to avoid overheating it.

The dc behavior of the circuit, as observed with a voltmeter or by watching the lamp, is simple. The negative feedback tries to maintain the op amp's summing point (− input) at zero volts. It does so by adjusting the light intensity so that the photocell resistance remains equal to that of the resistor R. A dc voltmeter between the op amp's summing point and ground will read approximately zero as long as the feedback is in control. If the lamp is moved too far from or too close to the photocell, then the summing point voltage becomes nonzero and the lamp goes fully on or off.

The dc analysis gives a convincing demonstration of negative feedback at work. More interesting, though, is an ac study of the circuit. An oscilloscope connected to the op amp output shows a waveform swinging between op amp limits. The duty cycle, and to some extent the frequency, vary as the lamp is moved. A corresponding small oscillation occurs at the summing point, where the average voltage stays near zero. The output oscillation shows that the feedback loop is slower than the amplifier. The timescale for the oscillation is fixed by the response time of the lamp and photocell. If the experiment is performed in a room with fluorescent lights, the oscillation may lock into a multiple of the line frequency. With the slow response times the ILB behaves more like an electromechanical servo than an all-electronic circuit. We ask students to speculate on what would happen if an LED and photodiode were used in place of the lamp and photoconductive cell. Then, with the feedback loop faster than the amplifier, the ac and dc behavior would be the same, and the amplifier output would not show oscillations. In this case the circuit would be analogous to an all-electronic servo. Such considerations help students understand clearly the similarities and differences between mechanical and all-electronic servos.

We have used the intelligent light bulb in both our "Electronics for Scientists" course, where we ask students for a detailed analysis of the ac behavior, and in our non-science-oriented "Electronics for the Intimidated," emphasizing only dc behavior. For both groups of students the circuit evokes a fascination with optoelectronic devices and feedback control, and leads to productive thinking about negative feedback.

[1]H. Malmstadt, C. Enke, and S. Crouch, *Electronic Measurements for Scientists* (Benjamin, New York, 1974).

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Students often have difficulty gaining an understanding of wave motion without effective demonstrations being performed in the lecture. Many excellent approaches utilizing ripple tanks, waves on a spring, chain, rope, etc., are customarily employed. Perhaps the most well-known device for demonstrating many of the effects of wave motion is the shive or bell wave motion machine.[1] The purpose of the present note is to describe a simple, inexpensive device which can be easily constructed by a teacher or student and can be used to demonstrate many of the properties of wave motion.

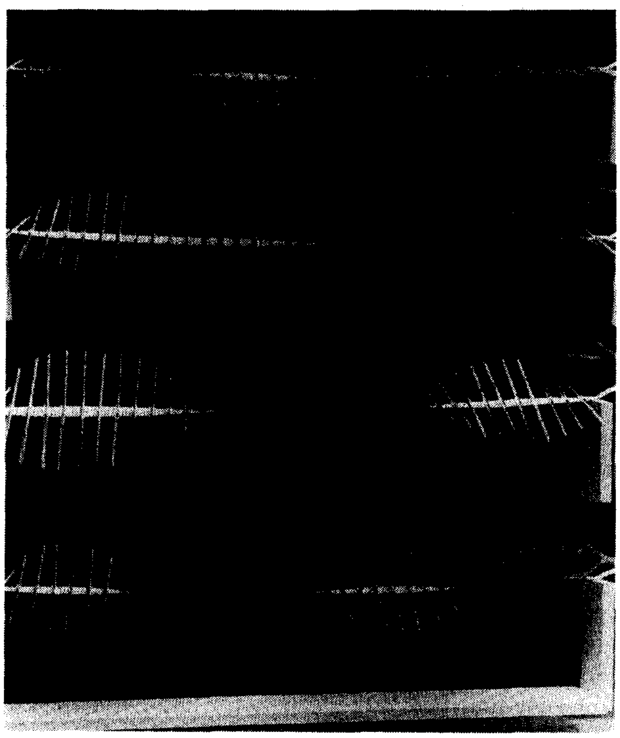

Fig. 1. Wave demonstration apparatus showing a single traveling pulse and standing wave patterns of first, second, and third overtones.

The wave device shown in Fig. 1 was constructed by stitching plastic soda straws to 0.75-in. seamstress elastic at 1-in. intervals. This distance changes to about 1.25 in. after stretching. The elastic may be held by two people for the demonstration or may be mounted in a simple frame. To simulate a second medium, a second section may be made by using either straws or sticks of different rotational inertia or by using the same size straws with elastic of different width to change the torsion constant. The two sections may be attached with small seamstress snaps.

The top photograph in Fig. 1 shows a single pulse traveling along the device, and the following photographs show standing wave patterns of first, second, and third overtones.

The device with appropriately constructed sections can be used to demonstrate traveling waves, several standing wave patterns, reflection from a fixed or free end, reflection at an interface, and impedance matching.

[1]Science Teaching Catalog, The Ealing Corp., 22 Pleasant St., South Natick, MA 01760, 1976-77 ed., p. 656.