Demonstration Wave Machine 1003491

Instruction sheet

06/18 ALF

1. INTRODUCTION

The purpose of the Wave Motion Demonstrator is to show--with mechanical waves--many properties and behaviors common to various types of waves. The equipment is patterned after the wave demonstrator developed in the early 1960's by Dr. John N. Shive of Bell Telephone Laboratories. The purpose of this manual is to acquaint the operator with the operation of this apparatus and the many demonstrations which can be performed on it. Demonstrations on this equipment can be of interest from the elementary school level through the college level.

2. COMPONENTS AND SPECIFICATIONS**

The Wave Demonstrator consists of:

One wide section approx. 91.5cm long with seventy-three (73) inertia bars 45.7cm long

One narrow section approx. 91.5cm long with seventy-three (73) short inertia bars 22.8cm long

One exponentially tapered section approx. 59.7cm long with 45.7cm bars on one end and 22.8cm bars on the other end

(These three sections are constructed of 5/32 inch steel rod with a rectangular slot milled in their center to hold a spring steel wire approx. 0.040 inch square which is soldered in place with 5% silver-95% tin. The "A" shaped bases lie flat facilitating storage and transportation of the equipment while protecting the bars from accident. The tips of the rods on one side are painted with fluorescent paint).

- **One terminal clamp** which connects to any desired rod causing reflection.

One dashpot consisting of a lightweight piston which clips to any bar and dissipates the energy of the wave in a container of water, thus minimizing reflection.

- **Two couplers** to connect the different demonstrator sections together.

**Specifications and design subject to change.

3. SET-UP

By grasping the ends of either half of the base, tilt it up cautiously, freeing the bars from the foam strip as necessary to prevent excessive twisting of the central steel wire (Fig. 1-A). Connect the horizontal slotted metal fasteners to the screw in the end to form the "A" bases. The equipment is now ready for use. To prevent accidental damage to the wave demonstrator it should be stored and transported while laying flat so the cross bars are protected by the base.

4. OPERATION

Waves are produced by simply providing a vertical displacement of the bars, usually the end ones (Fig. 2-A). CAUTION: Do not use larger amplitude than is necessary for the demonstrations. Large amplitudes, especially with short pulses or short wavelengths, may permanently damage the central spring or loosen the bars on the spring.

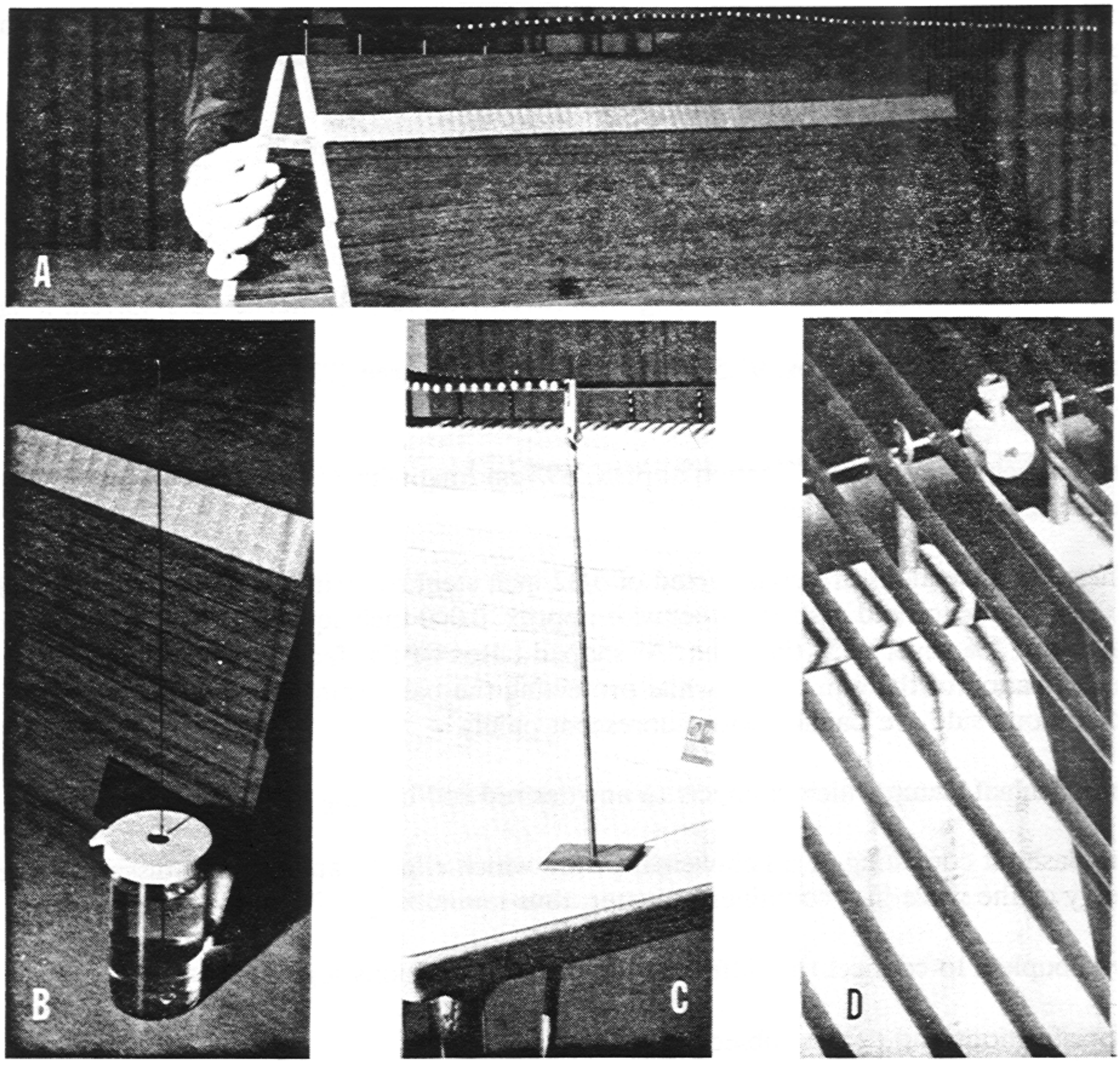

Figure 1. A - base set-up; B - dashpot; C - terminal clamp or nodal clamp; D - coupling two sections together

5. DEMONSTRATIONS

A. Wave Propagation

Give the end bar of the wide (slow) wave demonstrator a small sharp up and down disturbance. Repeat, only this time send a small pulse followed by a larger pulse (Fig. 2-A,B). Both waves travel with the same speed. Reflection can be minimized by use of the water-filled dashpot. Connect the dashpot piston to the far end inertia bar about midway between the central wire and the tip of the rod. (Fig. 1-B). Now repeat with the narrow (fast) wave demonstrator. To minimize reflection the piston of the dashpot should be connected to the far end bar as near the pivot as the dashpot can be positioned. The speed of the waves can be measured by timing a single pulse as it makes several trips, reflecting at either a free or clamped end (Fig. 1-C).

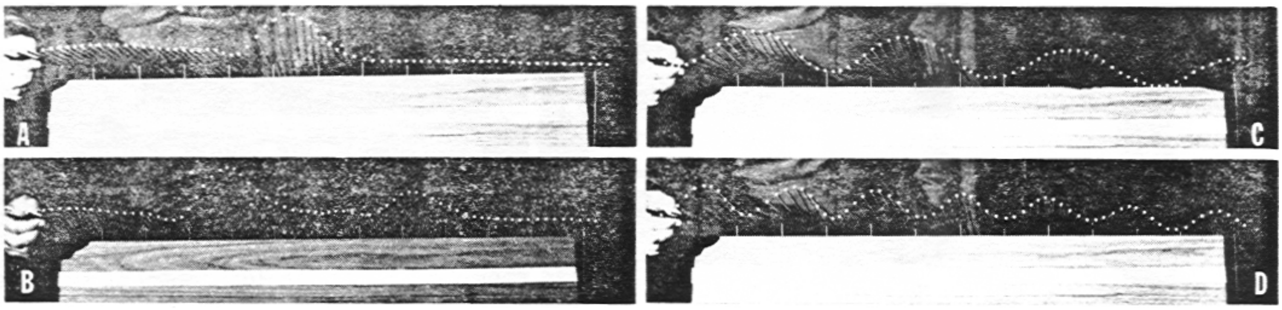

Figure 2. A,C - propagation of disturbances; C,D - periodic waves

B. Periodic Waves

With the dashpot attached to the slow wave demonstrator for minimum reflection, send periodic disturbances at various frequencies. Observe how the wavelength is dependent on frequency (Fig. 2-C,D). Repeat with the fast wave demonstrator and observe the relationship of wavelength to speed. This dependence of wavelength on wave speed and frequency can more easily be demonstrated when the two wave demonstrators are coupled together (Fig. 8-A).

Note that energy is transmitted in the disturbance, a general property of waves which could in principle be used to heat the water in the dashpot or do other work.

C. Reflection of Waves

With the far end of the slow wave demonstrator free, start a single sharp crest traveling down the demonstrator. Since there is no mechanism by which energy can be extracted at the end, the wave is totally reflected (Fig. 3-A,B,C,D). Note that the crest reflects as a crest and a trough reflects as a trough, that is to say the phase is preserved. Close observation shows there is usually a small ripple trailing the main disturbance. This can be used to determine the direction of propagation of the disturbances in the photographs. Now connect a clamp to the far end and repeat. Since there is no mechanism by which energy can escape through the clamped end, the wave is reflected (Fig. 3-E,F,G,H). Note that the reflected wave is inverted relative to the initial wave. The crest reflects as a trough and the trough as a crest, the phase is changed by 180 degrees. A convenient model to explain this is that since the end must be a node, the reflected wave must be out of phase with the incident wave at the end. In summary, there is no phase change upon reflection from the free end and a 180 degree phase change upon reflection from the clamped end. Similar behaviors are observed for reflections of sound, electric, and electromagnetic waves.

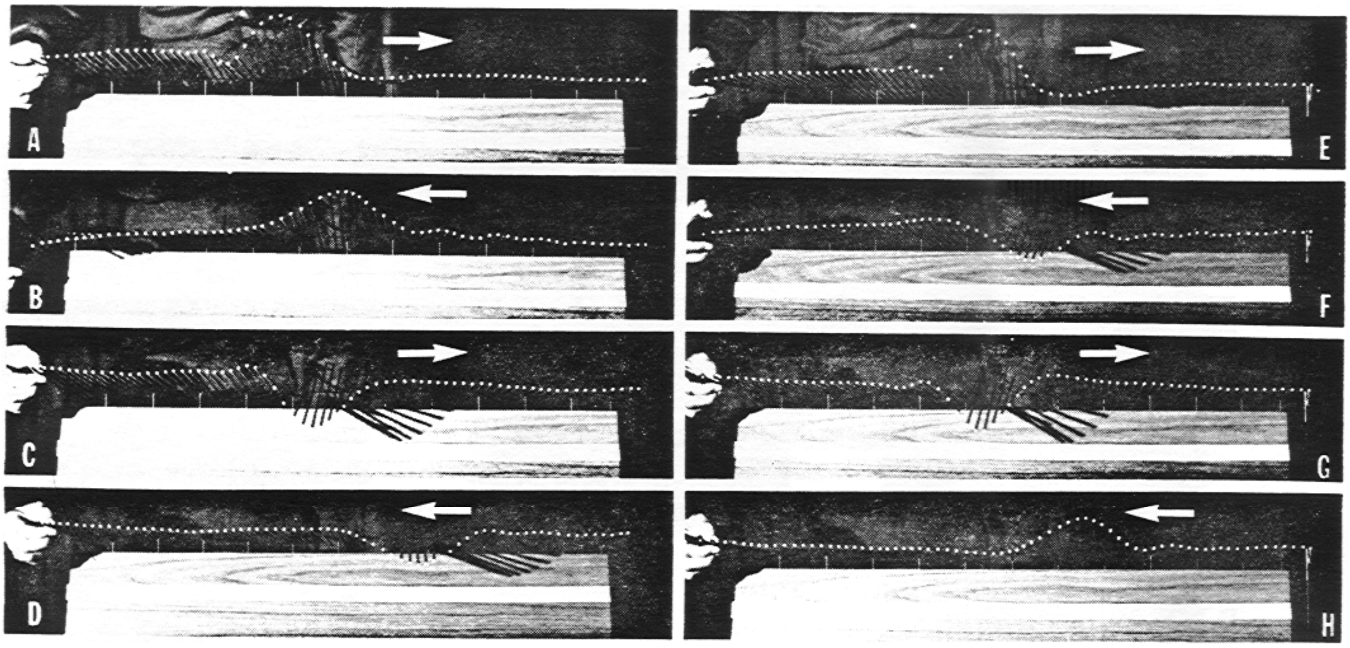

Figure 3. A through D - reflection from free end; E through H - reflection from clamped end

D. Constructive and Destructive Interference of Waves, Superposition

Simultaneously start short up disturbances, or crests, from both ends of the slow speed wave demonstrator (Fig. 4-A,B). Observe that the amplitudes add at their point of interference. Repeat, simultaneously starting a crest from one end a down disturbance, or trough, from the other end (Fig. 4-C,D). Observe that the amplitudes add at their point of interference. In both cases after they pass each other, the waves are unaltered (Fig. 4-E).

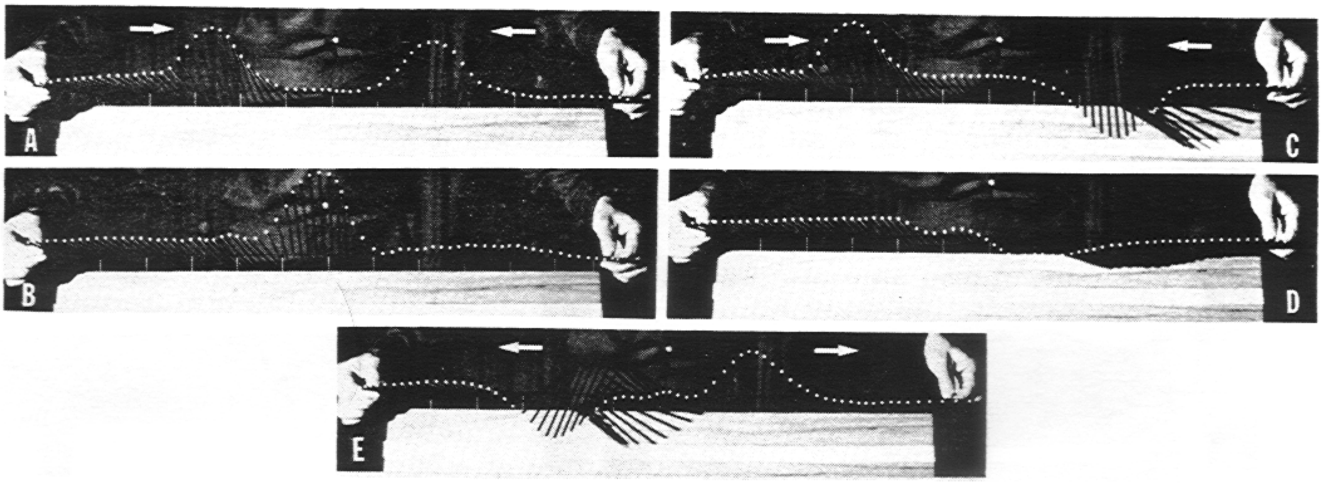

Figure 4. A,B - interference of waves in phase; C,D - interference of waves out of phase; E - waves unchanged after interference

E. Standing Waves and Resonance

Interference of periodic waves is observed by sending disturbances from one end and allowing them to reflect either from a free or clamped end. Initially, clamp the far end. The end held in the hand and driven is "almost" clamped so there will be phase reversal upon reflection at both ends. By sending periodic waves of the proper frequency from one end, resonance can be established in any one of many modes (Fig. 5). Successive waves are initiated only when waves reflected from the far end return to the driven end. Some practice is required to get the "feel" for the proper frequencies. Sensing feedback from the apparatus helps greatly in establishing the resonant frequencies. Note that the length of the wave demonstrator is always an integral multiple of a half wavelength.

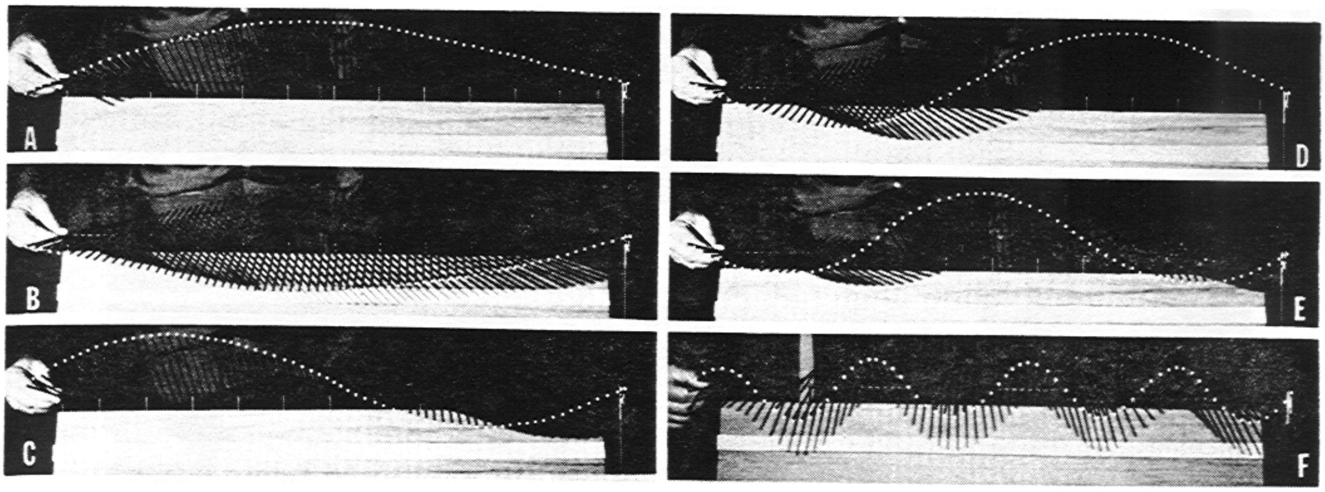

Figure 5. Standing waves with nodes at both ends. A,B - mode 1; C,D - mode 2; E - mode 3; F - mode 8.

If the far end is left free, resonance will again occur at many frequencies with an antinode at the free end and a node at the driven end (Fig. 6).Note that the length is an odd multiple of a quarter wavelength.

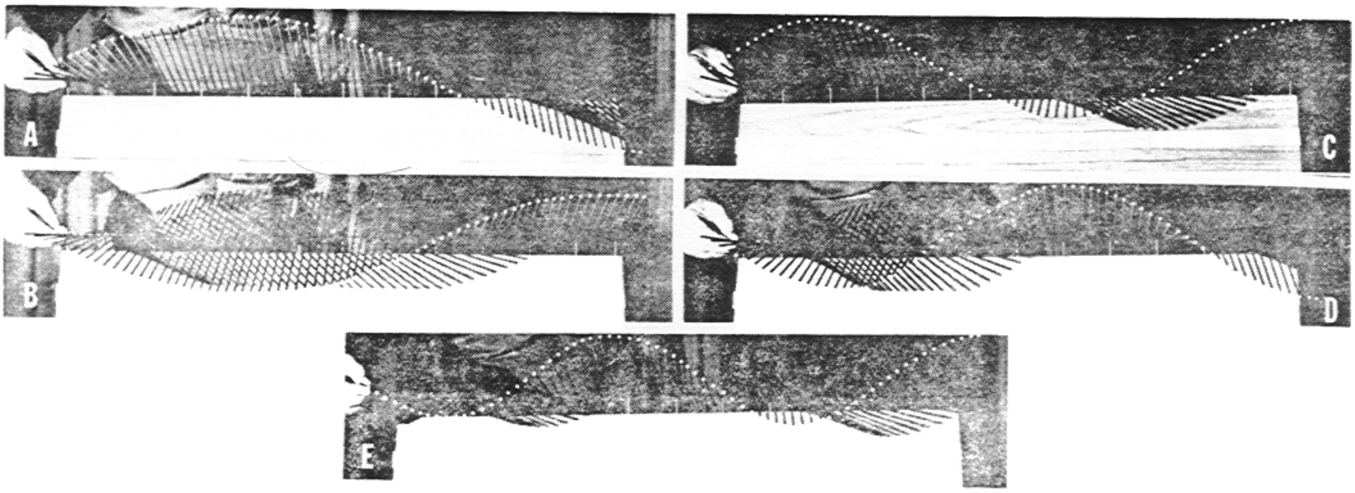

Figure 6. Standing waves with a node at one end. A,B - mode 2; C,D - mode 3; E - mode 4.

A third way to produce standing waves is with antinodes at both ends. This is somewhat difficult and requires a little more practice. By holding the end of the wire or the end bar near the wire very loosely, standing waves with antinodes on each end can be produced (Fig. 7). These modes are similar to those occurring in resonant open pipes with length always an integral multiple of a half wavelength.

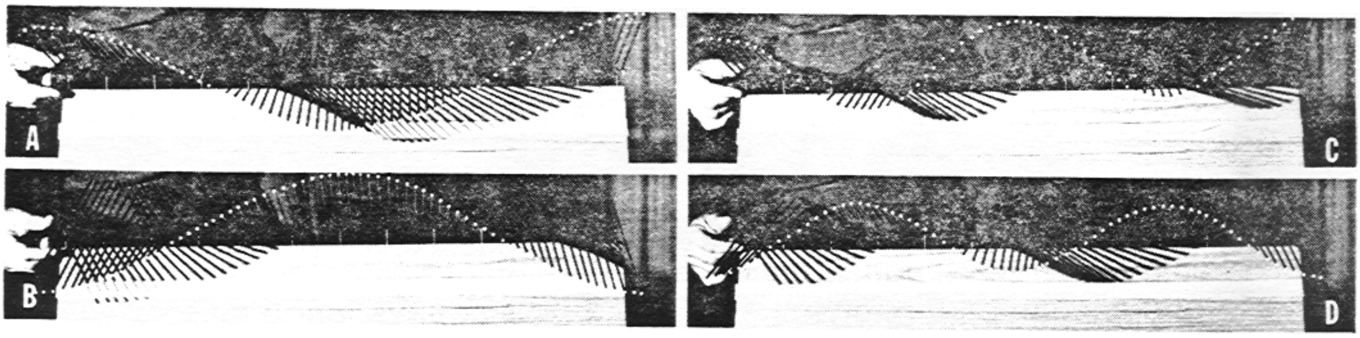

Figure 7. Standing waves with antinodes at both ends. A,B - mode 2; C,D - mode 4.

F. Impedance Matching

If the slow wave speed demonstrator is coupled to the fast wave speed demonstrator (Fig. 1-D), a significant portion of the wave is reflected at the boundary since the impedances of the two sections are quite different (Fig. 8-B,C). This is why sound is not easily transmitted from air into water and is mostly reflected.

If the tapered section is now coupled between the wide and narrow sections, the wave is transmitted with little reflection at the boundary (Fig. 8-D-F). The tapered section serves as an impedance matching "transformer". Many electrical circuits must have impedance matching transformers. Another interesting example of this is the function of the middle ear containing three small bones. Sound energy entering the ear must enter the fluid of the inner ear (or cochlea). The middle ear serves as an impedance matching device between the air and the cochlea.

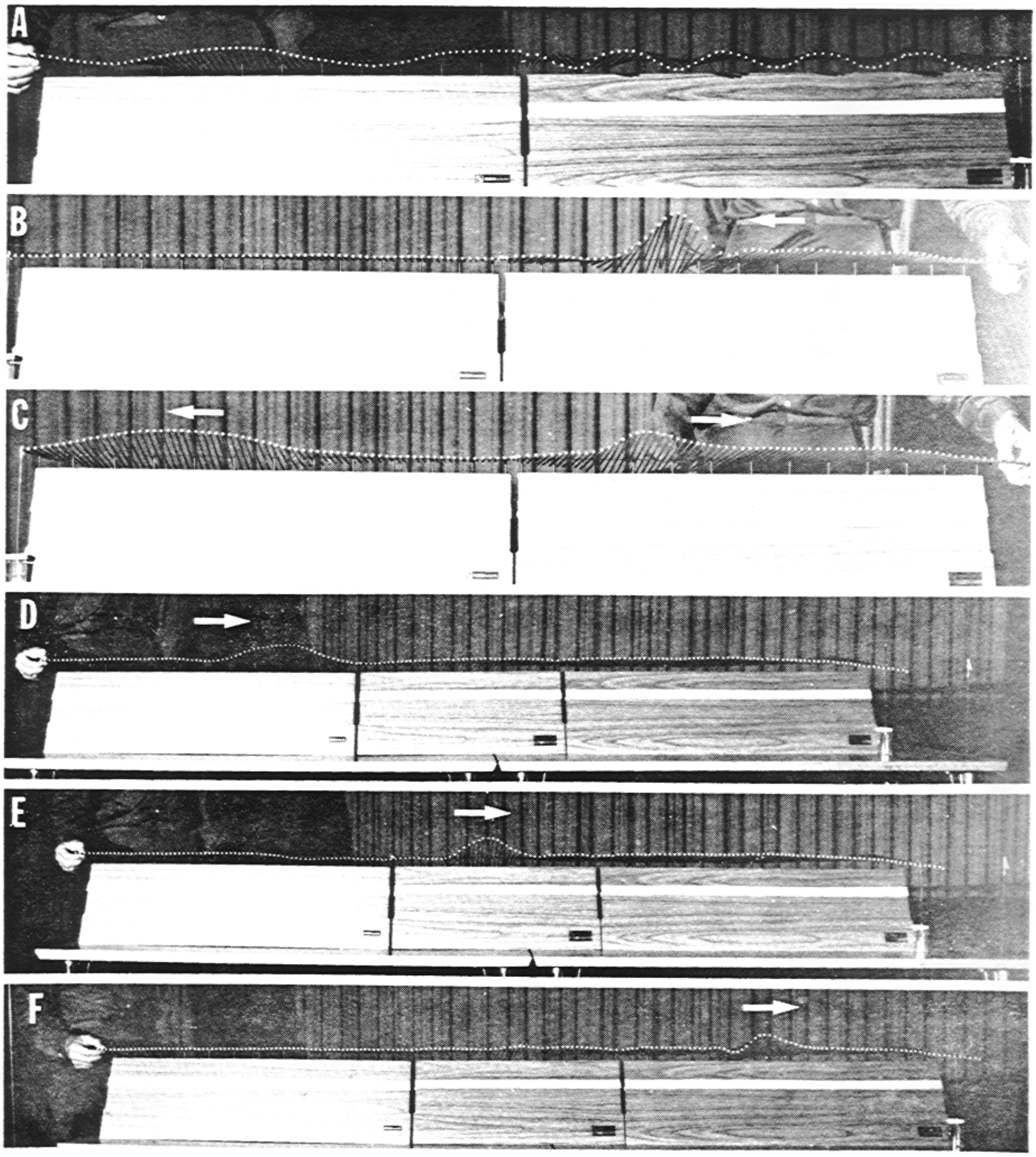

Figure 8. B,C - Partial reflection at a boundary; D,E,F - impedance matching.