APPARATUS FOR TEACHING PHYSICS: Speed of a Pulse in a Transmission Line

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Ronald I. Rank

ceeds. As the system tends to equilibrium, we find this charge tends to more than 5.2% of the total charge in our particular experiment. This fact seems valid when we recall that at equilibrium the total charge will have spread equally to all surfaces of the total surface area, and we can easily show that the surface area of the sphere is 1/19 of this total area.

In actual practice, discharge, friction, and gravity, will usually cause a greater charge to remain on scope *A* when motion ceases, but the point will be sufficiently clear.

Speed of a Pulse in a Transmission Line

Ronald I. Rank
Glenbrook South High School
Glenview, Illinois 60025

A good demonstration involving the measurement of a high speed electrical pulse and the examination of its nature upon reflection can be very useful. The demonstration involves the application of a square wave to a pulse shaping circuit in the form of an RC differentiating network. This creates a sharply rising pulse of short duration from the square wave. This pulse is then applied to a coaxial cable of known length which is terminated with a variable resistance. If the pulse is of short enough duration, an ordinary cathode-ray oscilloscope is capable of resolving the *incident* pulse and its *reflected* counterpart. If the horizontal sweep rate of the oscilloscope and the length of the cable are known, the speed of the pulse can be calculated. The nature of the reflected pulse under varying terminal loads can also be examined by observing the trace on the screen of the oscilloscope.

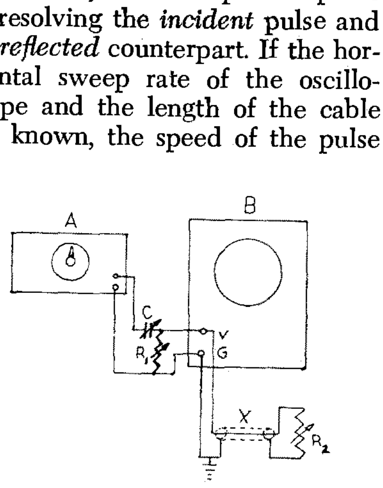

Fig. 2. Circuit diagram of the complete demonstration.

The basic circuit arrangement is schematically represented in Fig. 2. In the diagram, *A* is an RCA Model WA-44C sine-square audio generator. Other types may be used if they are capable of generating a 200-kHz square wave. *B* is a Simpson Model 458 colorscope. A Heath Model 10-12 professional oscilloscope was used with comparable results. Of course a Tetronix Model 531A with type *A* plug-in can be used if it is readily available. R_1 and R_2 are Heath Model 1N-11 decade resistances. *C* is a Heath Model 1N-27 decade capacitance. *X* is type RG-58A/U coaxial cable. It is assumed that any type of coaxial cable can be used. The cable sections were connected together with Cinch Jones phono pin plug and pin plug jacks. These or their equivalents can be purchased at any electronics supply house.

A 300 ft length of coaxial cable is adequate if the oscilloscope has a horizontal sweep frequency rate capable of displaying two cycles of a 200-kHz square wave from the audio generator. The length of cable used in the demonstration described was 288 ft or approximately 87 m. This odd length was utilized simply because 300 ft were purchased and 12 ft of the cable were used in another project. The cable is available in 100 ft lengths and can be joined using audio plugs and jacks so that it may be easily shortened or lengthened to show differences in travel time. Verification of the fact that the pulse is really reflected is also accomplished by changing the length of cable. The relatively inexpensive audio jacks and plugs were used in preference to the normal BNC type coaxial connector because some shorting difficulties were encountered when the BNC type was used. The soldered joints of the audio plugs are very solid and reliable.

The procedure to use in performing the demonstration is relatively simple. The 200-kHz square wave is applied to the *RC* differentiating circuit with the coaxial cable disconnected. R_1 and C_1 and the output attenuator of the audio generator are adjusted until a sharply defined pulse such as shown in Fig. 3 is obtained. For RG-58A/U cable, a value of $R_1 =$ 50 ohms, $C_1 = 200$ picofarad gave the best results. The nominal impedance of the RG-58A/U cable is 50 ohms, thus the 50 ohm value of R_1 was the expected optimum value. The end of the cable at the oscilloscope was terminated with two alligator clips, one connected to the inner conductor and one to the outer shield. This arrangement makes for ease of connection of the cable to R_1 as shown in Fig. 2. When the cable is first connected, some adjustment of the vertical gain and horizontal synchronization controls of the oscilloscope may be necessary for a stable pattern. Alligator clips were used on the other end of the cable to connect it to R_2. The value of R_2 is set to a maximum value, which was about one megohm for the decade resistance used. A photograph of the trace obtained and the general layout of the apparatus is shown in Fig. 4. The cable was threaded around the room on some hooks mounted in the ceiling, and the end and all of the junctions hang down to the experimental setup. This arrangement is not necessary. The cable can merely be strung around the room or left on the

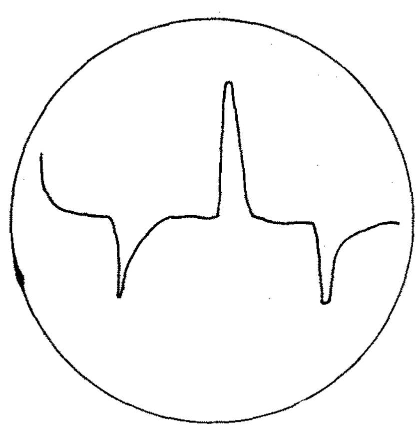

Fig. 3. The pulse obtained when the 200-kHz square wave was applied to the RC differentiating circuit.

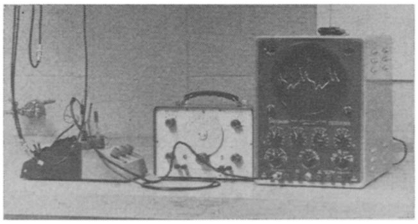

Fig. 4. Photograph of the experimental set up. The pattern on the screen is the same as shown in Fig. 5 The cable is shown hanging from the ceiling. Different connectors than described in the text are shown because the photograph was made before the phono pin-plug type connectors were installed. The terminating resistance R_2 is not shown.

spool on which it is purchased if the other end can be pulled out for mounting of the clips or connectors. In Figs. 5, 6, and 7, A and C are the applied pulses when the other end of the cable is an *open* end ($R_2 = 1$ megohm), B and D are the reflections of A and C, respectively. If the length of the cable is shortened approximately 30 m (100 ft) at a time by disconnecting the cable sections one at a time, the distance A–B and C–D become less, indicating that B and D are indeed reflections.

The wavelength of the original square wave as displayed on the screen of the oscilloscope was measured as 8 cm. The period of the 200-kHz wave was 5×10^{-6} sec. Therefore, the sweep rate was 6.3×10^{-7} sec/cm of travel. Accordingly, in Fig. 5 the distance between A-B and also C-D was found to be 1.5 cm. The time for the incident pulse to travel to the end of the cable and back was therefore 9.4×10^{-7} sec. Since the total distance travelled was 2×88 m $= 176$ m, the speed of the pulse was approximately 2×10^8 m/sec. For a coaxial cable, the speed of a pulse may be calculated from $v = ck^{-1/2}$, where v is the speed of the pulse, c is the speed of light in a vacuum and k is the dielectric coefficient of the insulating material of the inner conductor of the cable. For type RG-58A/U, the insulating material is polyethylene with a dielectric coefficient of 2.25 at 23°C, which yields a speed of 2×10^8 m/sec. Therefore, the experimental results agree quite well with theory. It was also noted that when the cable was *open*, the pulse was reflected in phase. The distances A-B and C-D when the cable was shortened to approximately 60 m was 1.1 cm and when shortened to about 30 m the distance became roughly 0.6 cm.

When the full length of the cable was used and R_2 was reduced gradually to 50 ohms, the amplitude of the reflected pulse diminished from maximum to zero. This pattern is shown in Fig. 6. This agrees with the theory of impedance matching of loads to transmission lines. When the value of R_2 was adjusted to 0 ohms (the line was *shorted*), the pattern of Fig. 7 was obtained. The reflected pulses have shifted in phase by 180°, while the distance between incident and reflected pulses had remained at 1.5 cm. This then demonstrates the phase reversal of an electric pulse, which is also observed in mechanical pulses in springs, wave machines, and other similar demonstration pieces.

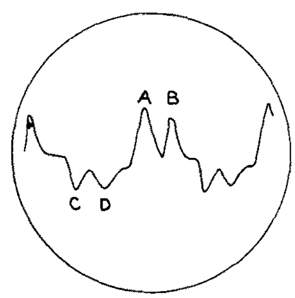

Fig. 5. Pattern obtained when cable termination was one megohm.

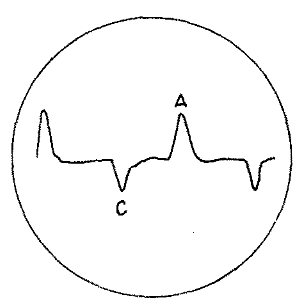

Fig. 6. Pattern obtained when cable termination was 50 ohm.

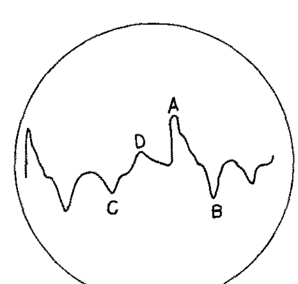

Fig. 7. Pattern obtained when cable termination was 0 ohm.

Floor and Table Protector

Alfred M. Eich, Jr.
Charles F. Brush H.S.
Lyndhurst, Ohio

Many experiments require masses to be dropped toward or suspended above a table top or the floor. Even the most careful students have accidents that permanently mar surfaces or damage equipment. Leftover rubber sponge carpet padding makes an excellent absorber. Use three 9 × 9 in. pieces stacked and loosely hand-stitched together with string for maximum protection. Single squares can be used under masses hanging from steel yards, spring scales and the like.

Brief communications reporting new equipment, short cuts, improvement of existing apparatus, or information which, while not new, is not generally known to teachers of high school physics are welcomed. Write a short informal note to:

Herbert H. Gottlieb
Martin Van Buren High School
Queens Village, New York 11427

Calendar

October

1 **Laser Clinic for high school physics teachers in the Wisconsin, Iowa, and Illinois area, Wisconsin State University–Platteville, Platteville, Wisconsin 53818.** James H. Hensley, Wisconsin State University–Platteville, Platteville, Wisconsin 53818.

24–25 **AAPT Illinois Section; Southern Illinois University; Edwardsville, Illinois.** M. A. Hakeem, Physics Dept., Southern Illinois University.