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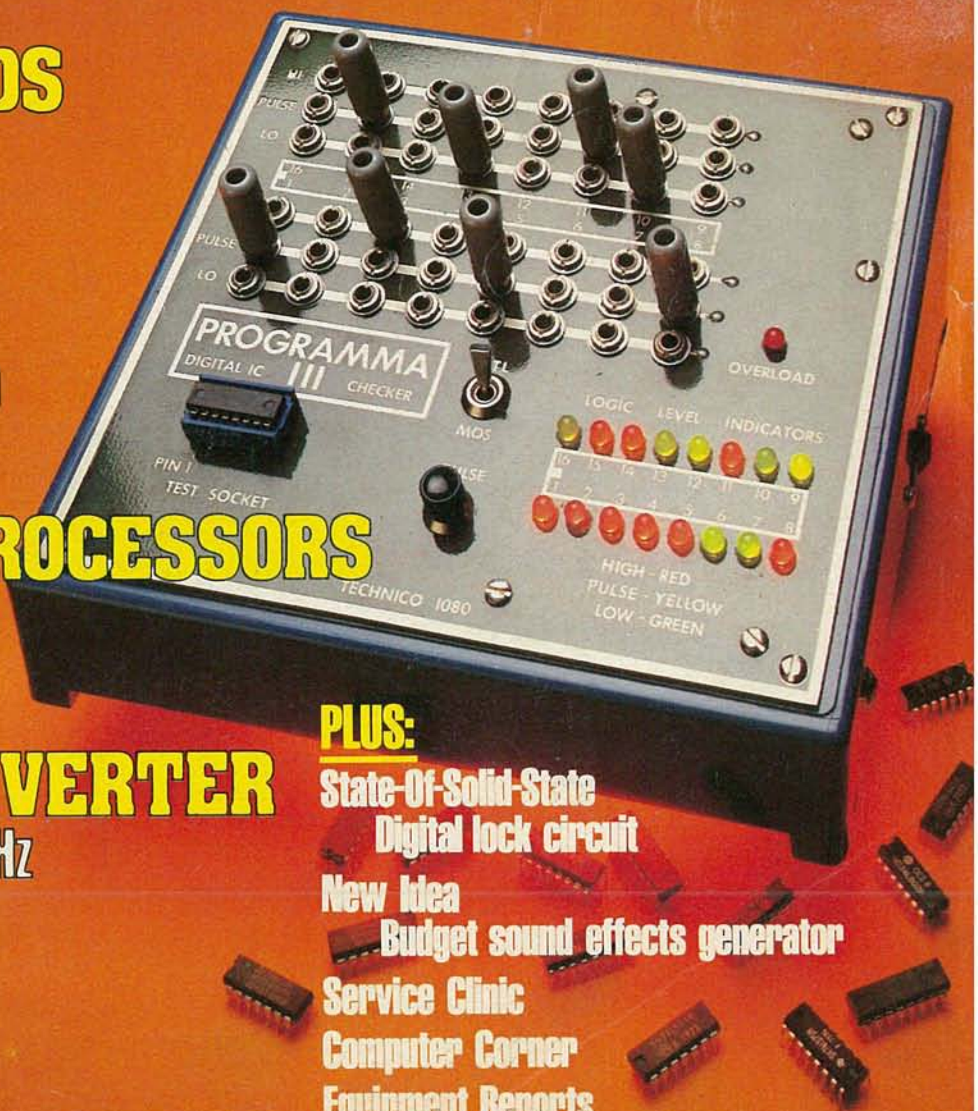

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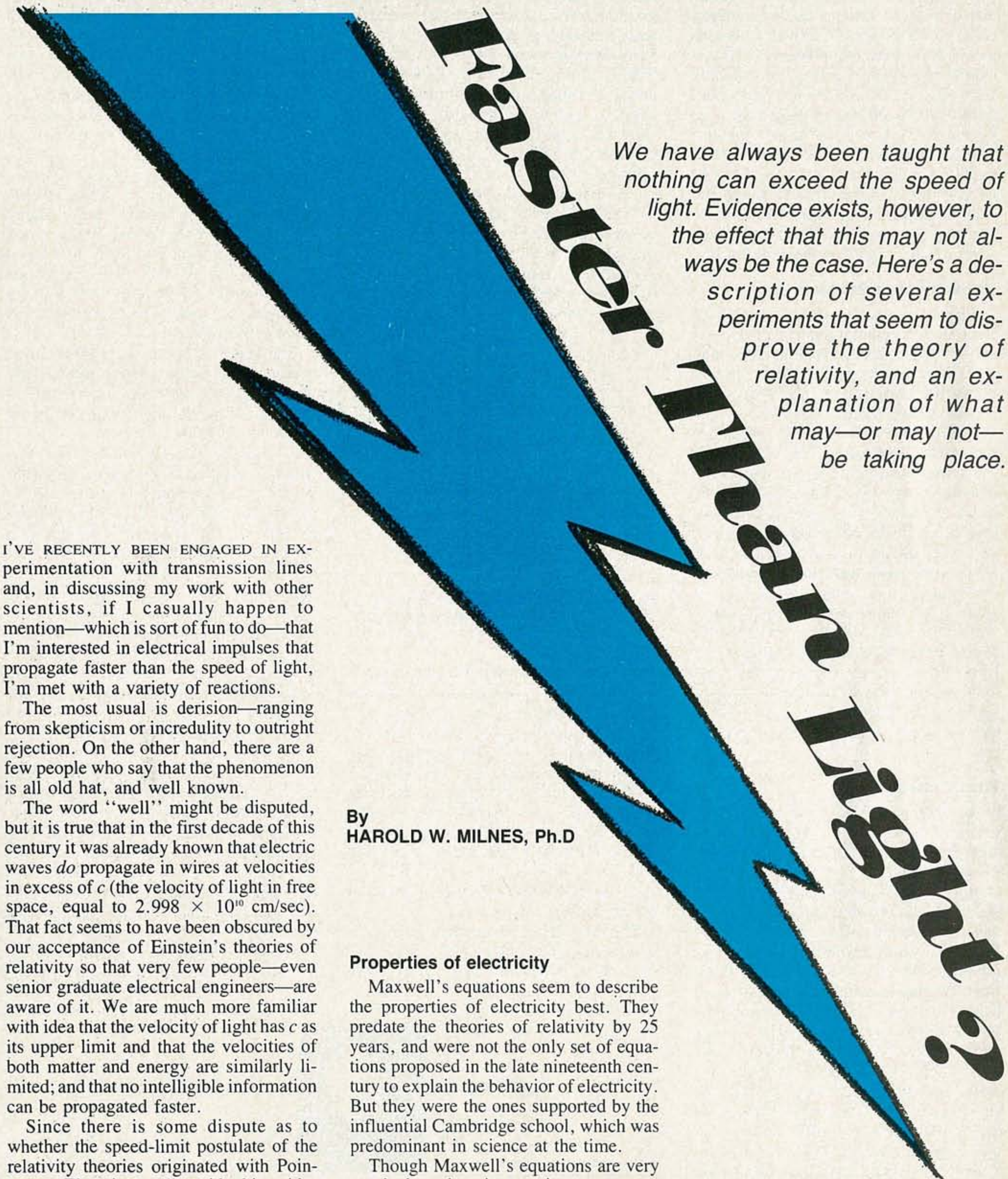

We have always been taught that nothing can exceed the speed of light. Evidence exists, however, to the effect that this may not always be the case. Here's a description of several experiments that seem to disprove the theory of relativity, and an explanation of what may—or may not—be taking place.

By
HAROLD W. MILNES, Ph.D

I'VE RECENTLY BEEN ENGAGED IN EXperimentation with transmission lines and, in discussing my work with other scientists, if I casually happen to mention—which is sort of fun to do—that I'm interested in electrical impulses that propagate faster than the speed of light, I'm met with a variety of reactions.

The most usual is derision—ranging from skepticism or incredulity to outright rejection. On the other hand, there are a few people who say that the phenomenon is all old hat, and well known.

The word "well" might be disputed, but it is true that in the first decade of this century it was already known that electric waves *do* propagate in wires at velocities in excess of *c* (the velocity of light in free space, equal to 2.998×10^{10} cm/sec). That fact seems to have been obscured by our acceptance of Einstein's theories of relativity so that very few people—even senior graduate electrical engineers—are aware of it. We are much more familiar with idea that the velocity of light has *c* as its upper limit and that the velocities of both matter and energy are similarly limited; and that no intelligible information can be propagated faster.

Since there is some dispute as to whether the speed-limit postulate of the relativity theories originated with Poincare or Einstein, we'll avoid taking sides and simply refer to it as the *c*-hypothesis. It is recognized by relativism (the science of relativity) that the so-called wave velocity of electricity—that is to say, the velocity at which the crest of a sinusoidal, continuously emitted, electrical signal moves through a conductor—can sometimes exceed the velocity of light. That forms an exception to the *c*-hypothsis.

Properties of electricity

Maxwell's equations seem to describe the properties of electricity best. They predate the theories of relativity by 25 years, and were not the only set of equations proposed in the late nineteenth century to explain the behavior of electricity. But they were the ones supported by the influential Cambridge school, which was predominant in science at the time.

Though Maxwell's equations are very good where there is a continuous current-flow, they are known to be subject to certain errors, particularly in describing phenomena involving moving isolated charges. It is precisely when treating the behavior of those discrete charges that it is best to modify the equations to agree with relativity as we currently understand it.

When derived directly from Maxwell's unmodified equations, the velocity, v, of sinusoidal waves in transmission lines is given by the following formula: $v = 1/\sqrt{LC}$. The values of L and C are not the total inductance and capacitance of the line, but represent its specific inductance and capacitance—that is to say, its inherent inductance and capacitance determined on a per-centimeter basis—in henries and farads, respectively.

If L and C were both in the micro-micro (10^{-12}) range, then v would be greater than c, and a condition would arise where either the unmodified Maxwell equations would fail, or the c-hypothesis would no longer apply, for the two are mutually contradictory. It's not hard to find a conductor whose inherent capacitance is in the range of micro-micro farads (picofarads) per centimeter, to position it so that its inherent inductance is in the range of micro-micro henries (picohenries) per centimeter, and then run a series of experiments to see which theory holds water. That's what I've been doing.

Basis for experiments

The experiments described below show that there are a number of ways to get the results needed to reach a conclusion. They can be performed by anyone with a little knowledge of electronics, and do not require a large cash outlay—all you need are an oscilloscope and a squarewave generator. You will be able to see for yourself that electric pulses do, indeed, propagate in conductors at velocities faster than c, but you are also warned that the results do not establish the validity of the equation $v = 1/\sqrt{LC}$ (though it is more likely to be true than would be the c-hypothesis, if it were applied to the speed of propagation of electrical wavetrains). In many cases I've observed the speed of propagation of squarewave trains to be greater than $100c$—one-hundred times the speed of light. In most instances the speeds have been beyond the capabilities of my equipment to measure.

Requirements

In experiments relating to the velocity of electrical signals, it is essential to use squarewave pulses or trains of pulses. Doing so makes it easy to determine the starting and ending points of a particular signal, and to measure the time delay—if any—introduced. Also, a transmission line can distort the signal it carries. It is possible, however, to avoid such difficulties by using a line long enough so that the delay predicted by the c-hypothesis would exceed the time period of a single cycle. On the face of the oscilloscope, the trace of the output signal from the line would then be displaced at least one full wavelength with respect to the trace of the input signal. For a 1-MHz pulse, that means using a wire at least 3×10^4 cm long, which would give a delay (under the c-hypothesis) of at least one μs; I use lines about 400 meters (1200 feet) long, which allows for pulses somewhat longer than a microsecond. Since too long a line can distort a waveform, the shorter a line you use, the better, just as long as you can get measurable results.

If precise measurements are to be made (beyond just determining that something is taking place), it is necessary to define exactly where waves begin and end. The falling and rising edges of squarewave pulses—particularly the former—make good reference-points that can be easily traced through progressive stages of deformation induced by line-distortion. That is illustrated in Fig. 1-b, where α' and β' are images of the falling and rising edges α and β of the original wave, shown in Fig 1-a. Thus, a squarewave pulse is considered from one successive falling (or rising) point to the next similar point, and waves that have been generated from it as the waveform that exists between the images of those points. The marking points are nearly always accompanied in the output waveform by sharp overshoot spikes immediately following them, as shown.

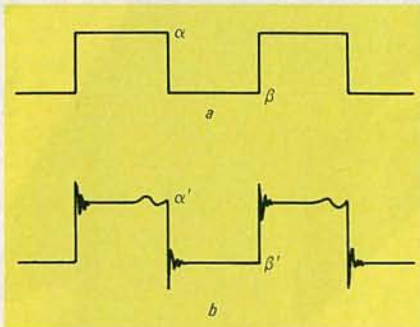

FIG. 1—ORIGINAL SQUAREWAVE (*a*) and its image (*b*). Pulses are measured from one rising (or falling) edge to the next.

The hookup for studying the delay is shown in Fig. 2. Resistor R is used to provide a signal at B. A dual-trace oscilloscope is not an absolute necessity, since the input and output points can be monitored separately by transferring a probe from one to the other. If the delay were 1⅓ μs, as a line 400 meters long would imply under the c-hypothsis, and the oscilloscope's maximum sweep-rate was .1 μs/cm, then you would obtain an easily discernable displacement of 1 mm on the screen.

The delay circuit should be constructed so that the values of L and C are quite small. The procedure used in the first experiment shows one way to accomplish that. A very fine wire is selected, so as to keep the surface area, and, hence the inherent capacitance, small. Number 40 copper wire is the finest generally available, but it is so fragile that I prefer use No. 35 steel sound-recording wire (available from Fidelitone, 3001 Malmo Dr., Arlington Heights, IL 60005) which is quite satisfactory, despite its high resistance of one-ohm-per-cm.

As shown in Fig. 3-a, a hundred notches were cut, one cm apart, in two insulating boards, and the boards were separated from one another by 99 cm. The wire was strung tightly back and forth, forming a series of 100 parallel lines, each one meter long (when the turns at the end are taken into account). The total length was exactly 100 meters.

The value of L was kept quite small because the wires are noninductively wound, and the direction of current flow in any one line the reverse of that in the two adjacent lines.

A second, similar, plane was constructed and placed beneath the first, but with its wires running perpendicular to the first's. An air gap of one cm separated the two planes. Then a third and fourth plane were stacked beneath those, with the direction of the wires alternating. The planes were connected to one another, forming a continuous transmission line 400 meters long.

The capacitive effect of the planes is illustrated in Fig. 3-c and depends on the proximity of the wire surfaces to one another. I am aware of no practical way to measure inherent capacitance, but a crude upper estimate can be made by noting that the circumference of No. 35 wire is .025 cm, so that the total exposed surface of the 400-meter line is 1000 square cm. Two plates, each of area 500 square cm, separated by 1 cm of air dielectric, have a capacitance of 4.425×10^{-11} farads; the total inherent capacitance must be very much less than that. On a per-centimeter basis it is less than 1.106×10^{-15} farads—well below the picofarad range mentioned earlier. Obviously, the capaci-

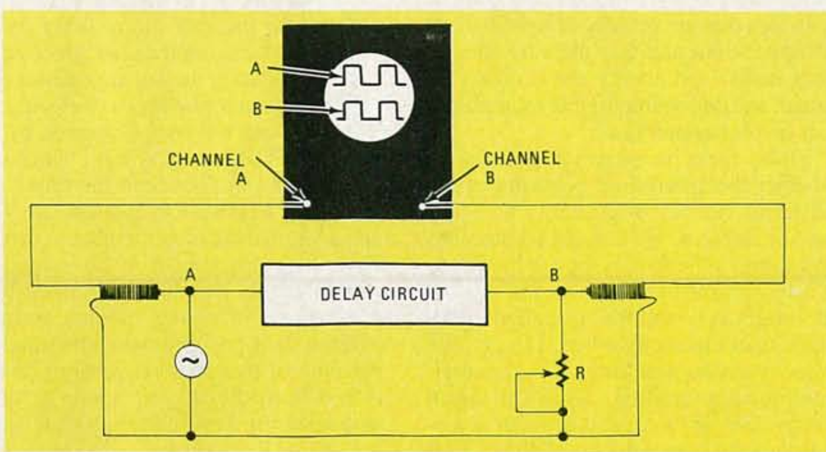

FIG. 2—DEVICE USED BY THE AUTHOR to compare a delayed signal with the original.

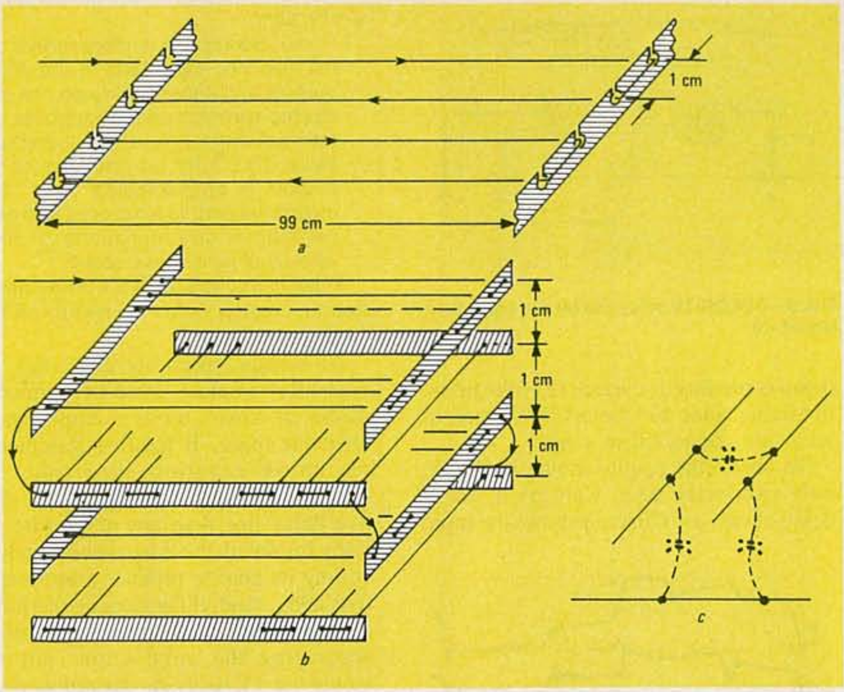

FIG. 3—APPARATUS USED TO CONSTRUCT a 400-meter delay line is shown in *a* and *b*; equivalent capacitance is shown in *c*.

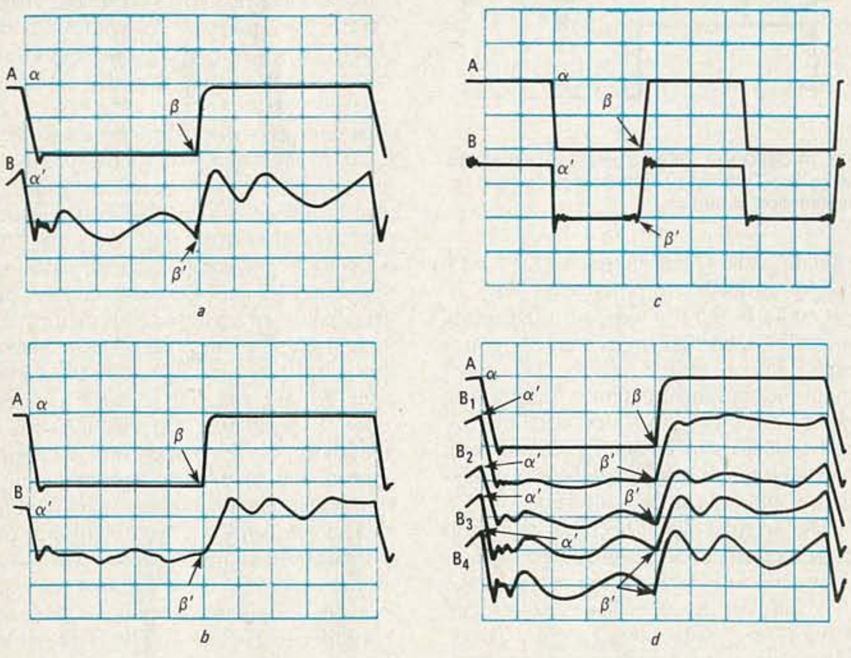

FIG. 4—ORIGINAL AND IMAGED signals for three different frequencies: 1 MHz (*a*), 0.8340 MHz (*b*), and 0.3579545 MHz (*c*). Fig. 4-*c* shows images probed at 100, 200, 300, and 400-meter points.

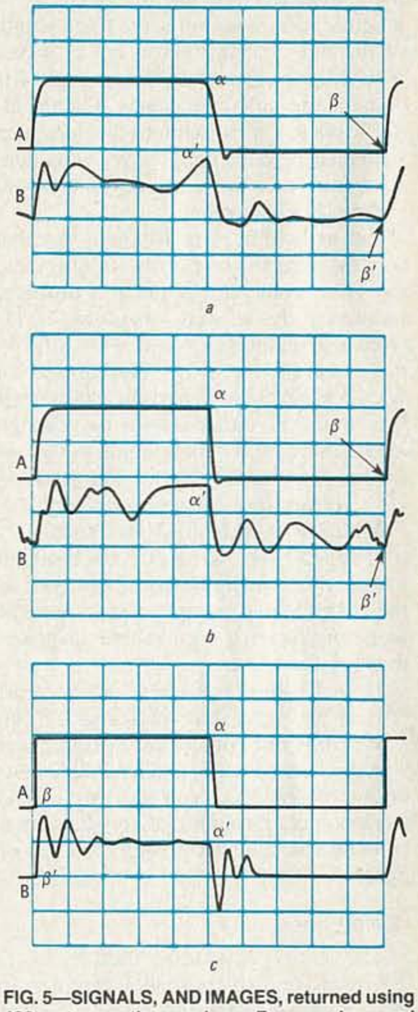

FIG. 5—SIGNALS, AND IMAGES, returned using 480-meter continuous loop. Frequencies used are the same as those indicated for Fig. 4.

tance could be further reduced by separating the wires and the planes by more than one cm, but it is unnecessary to do so.

When a squarewave signal is fed to one end of the device, the transit time to the other end is so brief that it is undetectable at the highest sweep-rate of a 15-MHz oscilloscope. According to the *c*-hypothesis, the output waveform should be displaced by at least 13 cm with respect to the input waveform, but the α′ and β′ points match the α and β points to within the precision that the instrument permits.

Typical input and output waveforms are shown in Figs. 4-a–4-d for three different frequencies. In case you feel that the precise alignment of the curves is somehow related to the length of the line, in Fig. 4-d the traces are shown at 0, 100, 200, 300, and 400 meters from the input point; the deformation is continuous in between. The value of R was set at 5000 ohms and the total resistance of the device was 40,000 ohms.

A second experiment

The apparatus just described is the least cumbersome for laboratory use that I have developed so far. In case you think that the observed effect is dependent on the design of the wire array, I'll describe a second experiment I performed. In that, I ran 480 meters (1600 feet) of No. 35 steel wire in a giant loop once around the city block where I live. The specific inductance of the loop can be considered so small as to be negligible, and the inherent capacitance even less than that in the first experiment.

The results were essentially the same, and the waveforms are shown in Figs. 5-a–5-c for three different frequencies. In that experiment, the value of R was 3500 ohms, and the resistance of the line 48,000 ohms. The displacement of the signals should have been at least 16 cm if the waves propagated at velocity *c* through the line. There was considerable difficulty in obtaining clean signals because of noise interference; the line could not be shielded or terminated without altering its essential L and C characteristics. Furthermore, shielded cables are well-known delay lines and their cores are frequently coiled on themselves to enhance the delay effect, depending on the design of various manufacturers. The line picked up so much random noise from broadcast signals that even the input squarewave was fuzzily indistinct on the oscilloscope. To obtain the clean signals shown, I found that it was necessary to perform the experiment between 3 AM and 4 AM on a Sunday morning when the local TV stations and airport beacon were off the air.

It was impossible, of course, to lead the output probe along the loop as had been done in the previous experiment. However, the fact that the input and output waves corresponded may be deduced by using some elementary arithmetic and from the fact that no significant displacement occurred at several different, independent, frequencies.

Suppose that, under the *c*-hypothesis, the transit time of the line were $T = length/c$, where length is the fixed length of the line. In that time $n = Tf$ waves would have entered the line, where f is equal to the signal-frequency. For an output wave to appear without displacement with respect to the input wave, a frequency would have to be chosen that would make n a whole number.

Let us assume, for instance, that that was the case for one of the frequencies, say f_1. It could not occur at a different frequency, f_2, as well, unless $n_2 = Tf_2$ were also an integer. Now, $T = n_1/f_1 = n_2/f_2$, so $f_1/f_2 = n_1/n_2$. The number of waves, in whole or in part, in a 480-meter line would be either one or two, which means that f_1/f_2 would be equal to 1, 2, or ½; that is, either $f_1 = f_2$, $f_1 = 2f_2$, or $f_1 = ½f_2$. The test frequencies used were: $f_1 = 1$ MHz, $f_2 = 0.8340$ MHz, and $f_3 = 0.3579545$ MHz; none of them bears an integer relationship to the others, yet, as the corresponding graphs show, none of them produced a measurable displacement of the waves.

I regard this experiment as the most critical one I have so far performed. It can lead to only one conclusion: An electrical signal in a conductor, under suitable conditions of very low L and C values, can be made to pass through that conductor at a velocity considerably greater than that of light.

Delay lines

The one-μs delay lines used in color-TV receivers are probably familiar to most **Radio-Electronics** readers. One is shown in Fig. 6-a, along with its schematic representation (Fig. 6-b). Of some 15 of the devices I've studied, no two have had precisely the same characteristics. Typically, though, they consist of a coil of fine wire, about 27 meters (80 feet) long, wound as a single layer on a form one cm (0.4-inch) in diameter. Beneath the windings lies a strip of foil covering about a third of the tube. When that strip is connected to ground, the inherent capacitance of the line is increased to the point that, when combined with the small inductance of the winding, a one-μs delay of the signal passed through the line results. If the strip is simply left floating—unconnected to ground—no measurable delay is produced, even if 15 of the units, involving some 405 meters (1300 feet) of wire, are connected in series.

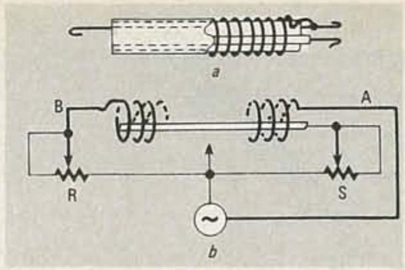

FIG. 6—COLOR-TV delay line (*a*) and equivalent circuit (*b*).

To obtain the results shown in Fig. 7, only two delay lines were used, for a delay of two μs. Curve A shows the input signal; curve D the output signal—with the foil grounded to produce a delay. To get curve B, the foil was left floating and it can be seen that the α' and β' points match the α and β points. If a one-megohm potentiometer is inserted at point "S" (in Fig. 6-b), between the foil and ground, and its setting varied from one megohm to zero, a continuous gradation of effects can be followed.

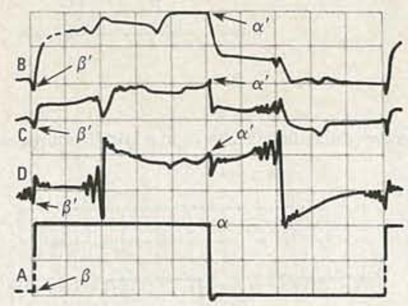

FIG. 7—ORIGINAL SIGNAL and images returned using two TV delay-lines in series. See text for explanation of curves.

The original signal becomes more and more deformed; some of the peaks predominate, as can be seen in curve C, and it is hard to decide where the original wave is, and where the delayed wave is. The α' and β' points identifying the original wave remain evident for a long time but, in due course, they are almost obliterated, although they always remain vestigial, even in curve D. It really becomes a matter of subjective opinion whether the new wave is merely some deformation of the old, or whether a delay of the input signal has taken place.

Facts vs. literature

The statements made in the literature relating to the velocity of electric signals in conductors are contradictory, misleading, and seem to ignore experimental evidence. How is the $v = 1/\sqrt{LC}$ formula reconciled with the *c*-hypothesis? W.C. Johnson, in *Transmission Lines and Networks* says:

> "...the product LC is independent of the size and separation of the conductors and depends only on the dielectric constant and permeability of the insulating medium. The numerical value $1/\sqrt{LC}$ for air-insulated conductors is approximately 3×10^8 meters/second, which checks with experimental determinations of the velocity of light in free space."

What is free space? It is a mathematical fiction, created to suit the results of Maxwell's equations.

At certain times, its properties conveniently simulate those of conducting media; at others, those of empty and interstellar space. If the first statement of the above equation were true, then coaxial cable would not be a more effective delay line than any other wire similarly insulated; there would be no point in coiling its core to produce a more effective delay. And, if the velocity of electrical pulses were unaffected by the distance separating the conductors, not only would the TV delay-device not work, but other delay devices that depend on an overlay of one substrate of a printed-circuit board upon another would also be ineffective. Inherent capacitance is distinctly dependent on wire size and surface area. The assurance that all is well and checks with the velocity of light, *c*, is just that—an *assurance*, unfounded in fact.

The very analysis that persuades us that v equals $1/\sqrt{LC}$—a result that may be nearly correct—has other consequences that are rather surprising. They are: "the velocity of propagation is independent of frequency," and "a pulse can be propagated down a line without distortion." In real life, the latter is obviously false, as my graphs illustrate. Nor is the former true, for we can find current texts that state "...in matter, velocity depends on frequency." Experimental evidence agrees, but to what extent, my limited equipment cannot measure accurately.

The analyses of both Brillouin and Sommerfeld claim to explain why Maxwellian and relativistic theories both support the *c*-hypothesis, and the phenomenon being discussed. They depend entirely on the effects of dispersion (the dependency of the velocity of electromagnetic waves on frequency) and, if dispersion is not assumed, they are invalid. **R-E**

"Radio is just like TV—only the picture tube blew."