Velocity of an RF Pulse Signal Propagating in a Waveguide

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***Abstract*— An RF pulse signal has been used to investigate the velocity of a wave propagating in a waveguide. Contrary to a recent report, the measurements demonstrate that an RF pulse signal cannot travel faster than light. The energy of the signal is transported at the "subluminal" group speed that can be measured.**

I. Introduction

CAN an energy signal travel faster than light? According to the traditional electromagnetic theory and relativity principle, the answer is definitely no. Recently, however, it was reported [1] that the leading edge of a pulse-modulated microwave signal propagating in a waveguide with a velocity equal to the phase velocity, or faster than the speed of light, had been measured. In order to check that claim, we performed the experiment that will now be described. Our results do not support the discovery reported in [1].

II. Experiment Setup

The experiment setup, shown in Fig. 1, consists of a pulse generator, a synthesized sweeper, microwave components, WR-90 series waveguides, and an oscilloscope. The Picosecond Pulse Lab PSPL-6000 pulse generator has two TTL outputs, +TTL and −TTL, which are 180° phase offset. The transition duration (rise or fall time) of the TTL pulse is less than 5ns. The +TTL output triggers the Tektronix-7854 oscilloscope and the −TTL output modulates the HP-8341B synthesized sweeper. The output waveform (RF pulse) from the signal generator is shown in Fig. 2. The RF pulse signal is sent to the waveguide through a coaxial to waveguide adapter. Ahead of the adapter, a 6-dB attenuator is used to minimize the effect of the reflections from the coaxial to waveguide adapter on the signal generator. The waveguide line used in this setup is in fact a cascade of 5 straight sections. The first waveguide section (6 inches long) is used to filter the possible high-order modes excited by the adapter. The remaining four sections are one foot each and are used as the delay line. The interface between the 6-inch line and the 4-foot line is referred to as reference plane A, and the other end of the 4-foot line is referred to as reference plane B (see Fig. 1). A waveguide isolator is connected between the load end of the 4-foot section and the detector. The isolator is to absorb reflections from the detector, thereby dampening possible multiple bounces that could lead to distortion of the transition regions of the envelope. The detector used is an HP-X424A crystal detector.

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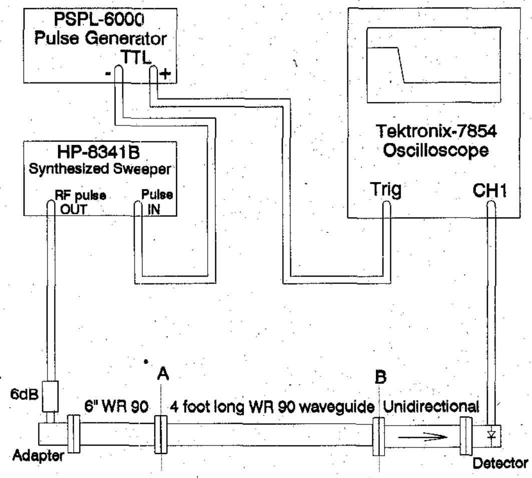

Fig. 1. Experimental setup.

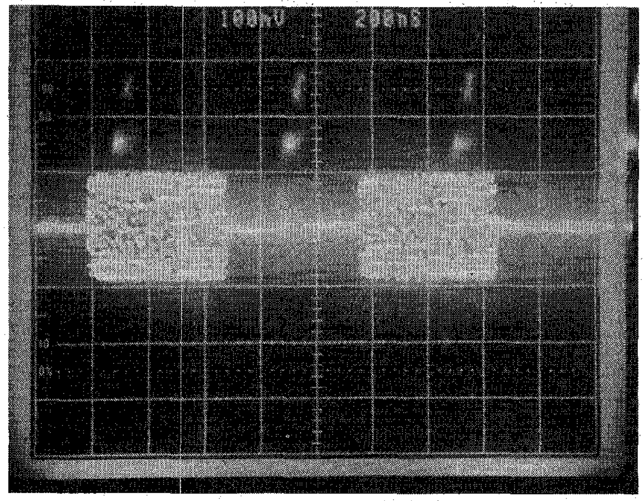

Fig. 2. Output pulse-modulated waveform from the signal generator.

The crystal detector captures the envelope of the modulation of the RF pulse; the latter is fed to the vertical channel of a Tektronix 7A26-7854 oscilloscope. The observed rise or fall transition time of the RF pulse envelope is about 5 ns.

III. Experimental Procedures and Measurement Results

The experiment performed involved establishing the falling edge of the RF pulse envelope detected by the crystal detector at reference planes A and B. (Either the rising or the falling edge could have been used to perform the measurement as shown in Fig. 2. The falling edge was chosen because it was clean and easy to interpret.) The measurement at the

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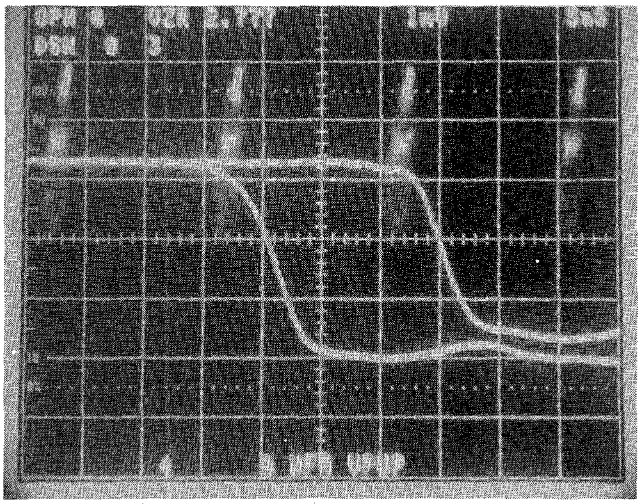
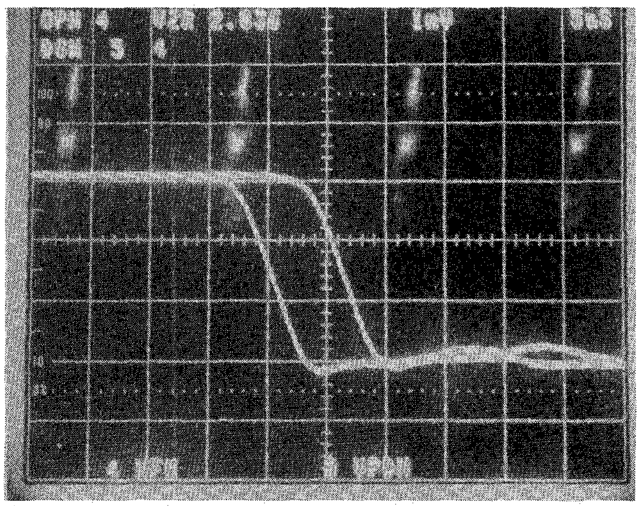


(a)



(b)

Fig. 3. Detected envelope of the pulse-modulated signals. First falling transition at reference plane A (no delay) Second falling transition at reference plane B (after 4 foot WR 90 waveguide delay). (a) Modulation frequency of 7 GHz. (b) Modulation frequency of 12 GHz.

reference plane A was made with the 4-foot waveguide section removed. The measurements at the reference plane B involved the detection of the signal after it traveled through the 4-foot waveguide section. Measuring the delay τ between the two waveforms enabled us to calculate the wave speed $v = \frac{l}{\tau}$. The accuracy of the measurement procedure was estimated to be about 5%.

Fig. 3 shows oscilloscope displays of the detected envelopes at reference planes A and B for two carrier frequencies, 7 GHz and 12 GHz. In this figure, the first falling transition corresponds to the direct through waveform and the second one to the waveform after the insertion of the 4–foot WR 90 waveguide (at reference plane B). It is obvious that the traveling time is longer at 7 GHz than at 12 GHz, or that the wave travels faster at higher frequencies. Fig. 4 shows the variation of the wave speed with frequency. The dotted curve represents the theoretical calculation based on the equation

$$v = c \cdot \sqrt{1 - \left(\frac{f_c}{f}\right)^2}, \qquad (1)$$

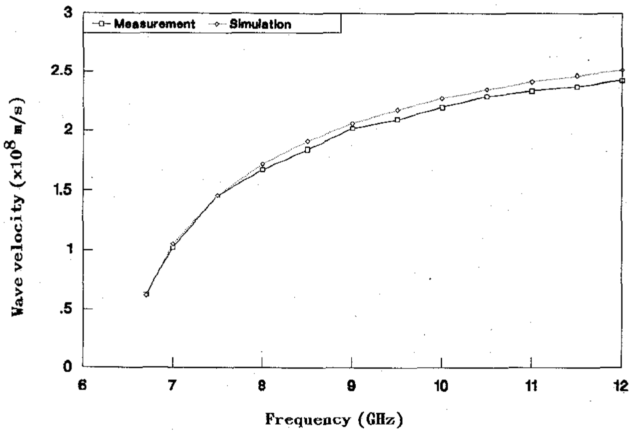


Fig. 4. Wave velocity versus frequency.

where c is the speed of light in vacua and f_c is the cutoff frequency of the waveguide. The second (solid) curve exhibits the measured data. Fig. 4 demonstrates that the agreement between measurements and simulation is within the range of the system accuracy. From Figs. 3 and 4, it is also obvious that the wave speed increases with frequency. This tells us that the speed measured is the group and not the phase speed.

In closing, we wish to cite several possible reasons for the erroneous results reported in [1]. a) The measured delay time is only a few nanoseconds but the transient time of the pulse-modulated signal used in [1] was about 22 ns. The amount of jitter in a 22 ns pulse is a possible source for error. The oscillograms presented in [1] show fuzzy displays that support the possibility of the presence of significant jitter. b) The crystal detectors used to observe the two waveforms may have different transient properties; e.g., if the detector observing the first waveform is slower, the observed delay time will be less than the actual delay, leading one to believe that the signal propagates faster. c) The HP-1415A TDR used in [1] is an outdated instrument with questionable accuracy. d) The high-order modes excited by adapters and detectors can degrade the accuracy of measurements. Although the different modes would still travel at subluminal group speeds, they would travel at different speeds, leading to a deformation in the waveform shape. Such a situation could result in an error in detecting the pulse propagation speed, particularly if one took into consideration the delay between the 50% points on the transition edges of the waveform. If the waveform start point (which is very hard to define) is used, the results are guaranteed to accurately reflect a propagation speed slower than the speed of light.

IV. Conclusion

Contrary to the claim in [1], a pulsed microwave signal in a waveguide cannot travel faster than light. Its energy is transported at the subluminal group speed that can be measured.

References

[1] G. C. Giakos and T. K. Ishii, "Rapid pulsed microwave propagation," *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 374–375, Dec. 1991.