Rapid Pulsed Microwave Propagation

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Abstract—**Transit time measurements of the leading edge of pulse modulated microwaves in open space and inside a rectangular waveguide have been performed. Both measurements show that a part of the energy associated with the leading edge of the pulse propagates with the phase velocity. Calibration techniques and repeated measurements confirm this phenomenon.**

I. Introduction

It has been well known that the phase velocity of microwaves in air is greater than the speed of light [1]-[6]. It has also been stated that, the phase velocity is purely a geometrical quantity and energy can propagate only with the group velocity which can serve as signals for communicating information [1], [4], [7].

This letter reports that a leading edge of pulse modulated microwaves propagates with a velocity equal to the phase velocity in a waveguide system or in open space, under specific conditions. When an observer is interested in an angular direction θ different from the original direction of propagation of the TEM wave, the apparent phase velocity v_p in open [2]-[6], [8] or in guided structures is equal to $v_p = c/\cos\theta$, where c is the speed of light [1]-[6], [8].

II. Experimental Setup—Results

A. Transmission Through a Waveguide

An X-band klystron producing microwave of 8.202 GHz carrier was modulated externally through a pulse generator HP 715A [8]. The pulse generator was triggered through the trigger output of a time domain reflectometer HP 1415A. Microwave signals modulated with pulses of 22 ns rise time pulse duration 50 ns and 147 Kpps pulse repetition rate travelling through a slotted X-band waveguide and a section of WR 90 waveguide were received at the other end. The distance between transmitter tunable probe detector and receiver detector was 1.658 m. A time resolution of 1 ns/cm and 0.5 ns/cm was set on the TDR scope. The time between the leading edge of incident and received pulses was measured by connecting and disconnecting a cable of 1.75 m long from the time domain reflectometer HP 1415A to the transmitter and the receiver detector alternately. Average transit times of pulse modulated microwave signals propagating inside the waveguide were measured over 30 trials. Pictures of incident and received pulsed microwave signals are shown in Figs. 1 and 2, with the sweep speed of 200 ns/cm and 1 ns/cm, respectively. The carrier frequency is 8.202 GHz. In Fig. 1, the evidence of pulse transmitted (upper negative notch) is received (lower positive notch) at the receiver is shown. In Fig. 2, only the leading edges transmitted pulse (upper trace) and received pulse (lower trace) are shown and the transit time was 3.30 ns for this transmission. The transit time is the time between the leading edges of transmitted pulse and the received pulse. Since Figs. 1 and 2 are obtained with pulse modulated microwaves, to the author's knowledge to date, this is the first evidence that the leading edge of the pulse modulated microwaves travelled with the velocity equal to the phase velocity. This contrast conventional phase veloc-

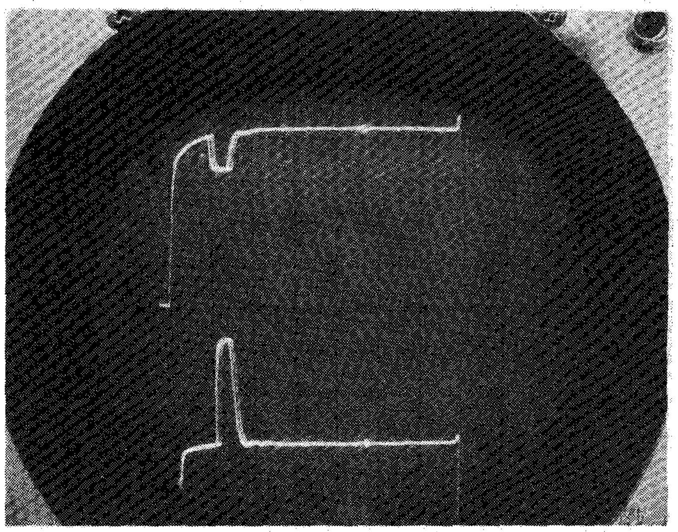

Fig. 1. Photograph of detected pulse modulated transmitted signals (upper) and received signals (lower), in a waveguide.

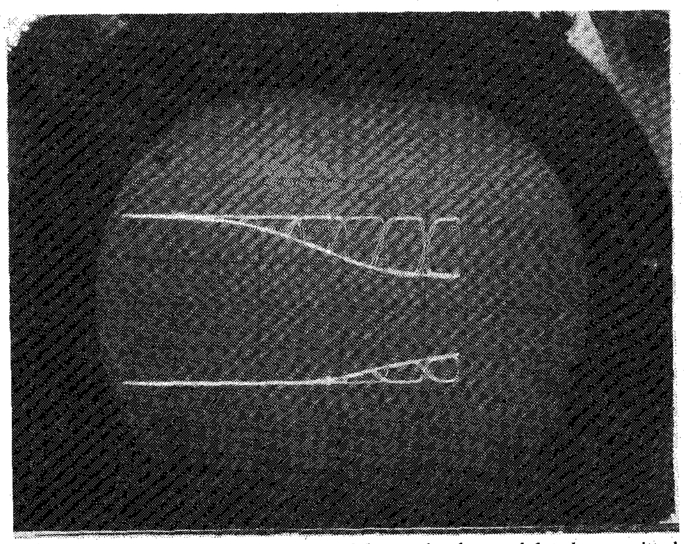

Fig. 2. Photograph of leading edge of detected pulse modulated transmitted signals (upper) and received signals (lower), 3.3 ns later.

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ity measurement calculating from the waveguide wavelength and operating frequency by standing wave detector and frequency meter [1], [3], [8]. The observed propagation velocity of the leading edge 5.0245×10^8 m/s agrees with the theoretical phase velocity 5.0242×10^8 m/s based on well-known equations found in literature [1]–[6]. If this communication was done by the group velocity 1.791×10^8 m/s, then it would have taken the transit time of 9.26 ns. This was not observed in this time domain measurement.

B. Transmission Through Air

An open end of a X-band waveguide was used as a transmitter radiator [8] and a horn of 7.1 × 9.5 cm and 14.4 cm long as a receiver, separated over a distance of 42.7 cm face to face is shown in Fig. 3. As a first step at this distance, the receiver was moved to 18 cm off the direction of the center axis of the transmitter waveguide. Then the receiver horn was moved further to 44 cm off the center axis of the transmitting waveguide. In both cases at that position, the receiver antenna was initially oriented parallel to the geometrical axis of radiation and then it was tilted toward the transmitter.

In Fig. 4 pictures of detected transmitter (upper trace) and receiver (lower trace) leading edges of pulse modulated microwaves are shown. The carrier frequency was 8.245 GHz. In a nondispersive media such as an open air space, all Fourier components of pulse modulated microwaves travel in unison, or with the same velocity $c/\cos\theta$ [2], [6], [8]. Therefore, there should not be distortion on the received pulse when observed in time domain. The sweep rate was set at 1 ns/cm and the total transit time was 2.66 ns. From this the theoretical transit time of 1.246 ns for the microwave signal propagation inside the waveguide portion before launching to the air and after receiving by the receiver antenna must be subtracted. Then an open space propagation transit time of 1.414 ns resulted for a distance of 61.3 cm between the two antenna apertures, center to center. This means that the speed of propagation was 4.336×10^8 m/s. This contrasts with theoretical phase velocity $c/\cos\theta = 4.30 \times 10^8$ m/s [2]–[6], [8]. Calibration of this system done by placing the transmitter and the receiver face to face and comparing with the intrinsic velocity 3×10^8 m/s showed that the system accuracy was 0.1%.

If this pulse transmission is done by group velocity 2.09×10^8 m/s it would have taken the transit time of 2.933 ns, which was not observed in this time domain experiment.

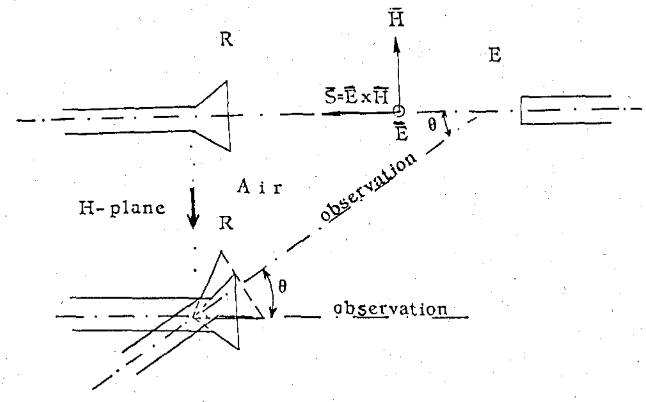

Fig. 3. Experimental setup to measure phase velocity in air.

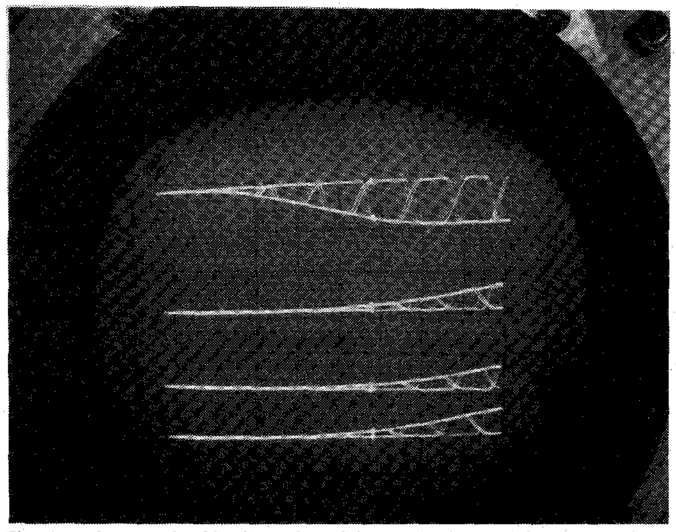
Fig. 4. Photograph of leading edge of detected pulse modulated transmitted signals (upper most) and received signals (lower), 2.660 ns, later, in air. The upper most and the second traces display the leading edges of transmitter and of the receiver pulse respectively. Receiver horn is directly facing toward the transmitter waveguide aperture. Third and the bottom traces depict the leading edges of received pulses when the receiver is moved parallel to 18 cm (22.85 degrees off) and 44 cm (45.9 degrees off) from original position respectively and oriented towards the transmitter.

III. Conclusion

Our experimental results, both in a waveguide and in the air, do not show visible disintegration of the pulse in the range of PRR and pulse rise time tested. Instead according to our experimental observation, measurement of the phase velocity was possible by detecting arriving microwave signals. This evidence is contrary to the statements that the phase velocity cannot be measured, it cannot be used for communications of a message or signaling and devoids of any direct physical significance. Indeed, our experimental observation shows that the leading edge of the pulse modulated microwaves propagates with the phase velocity $c/\cos\theta$ in a preferred direction in open space. Only when θ was chosen to be 0, it was c. This observation opens a way for rapid digital microwave communications using the $c/\cos\theta$ principle.

References

[1] G. C. Southworth, *Principles and Applications of Waveguide Transmission*. Princeton, NJ: D. Van Nostrand Company, 1959, pp. 173–174.
[2] S. A. Schelkunoff, "Transmission theory of plane electromagnetic waves," *Proc. IRE*, pp. 1457–1492, Nov. 1937.
[3] H. J. Reich, P. F. Ordung, H. L. Krauss, and T. G. Scalnik, *Microwave Theory and Techniques*. Princeton, NJ: D. Van Nostrand Company, 1953, pp. 91–111.
[4] H. A. Atwater, *Introduction to Microwave Theory*. Malabar, FL: R. E. Krieger Publishing Company, 1981, pp. 81–83.
[5] T. K. Ishii, *Microwave Engineering*. Washington, DC: Horcourt Brace Jovanovich, 1989, pp. 40–41.
[6] J. C. Slater, *Microwave Transmission*. New York: McGraw-Hill, 1942, pp. 94–95, p. 127, pp. 136–137.
[7] R. K. Patria, *The Theory of Relativity*. London: Pergamon Press, 1974, pp. 107–108.
[8] G. C. Giakos, "Detection of non-TEM waves in open media," Ph.D. dissert., Marquette Univ., Milwaukee, WI, Aug. 1991.