FM Reflectometric Measurement of Group Velocities of Microwave Transmission Lines

Yong-Hyun Park[1] · Jeong-Hae Lee[2]

Abstract

In this paper, frequency modulated(FM) reflectometry is proposed to measure group velocity of microwave transmission line. Various microwave transmission lines such as periodically loaded conducting posts in a waveguide and nonradiative dielectric(NRD) guide are adopted to measure their group velocity. The result compared with that from network analyzer shows good agreement, indicating the validity of our measurement method.

Key words : FM Reflectometry, Group Velocity, Periodically Loaded Conducting Posts In A Waveguide, Nrd Guide.

Ⅰ. Introduction

The dispersion characteristics of microwave transmission line are very important parameters which should be considered in microwave circuit design. For instance, in a microwave tube such as traveling wave tube[1], it is desirable that an electron beam should interact in velocity synchronism with an electromagnetic wave resulting in an exchange of energy from the wave to the beam. Thus, it is obvious to have knowledge of dispersion characteristics.

Previously, frequency modulated(FM) reflectometer technique is utilized in the measurement of plasma density profile[2] and of the distance of the target[3]. In this paper, FM reflectometry is first applied to measurement of group velocity of microwave transmission line to investigate its dispersion characteristics. The conventional perturbation method[4] has difficulty in finding small perturber material and obtaining impedance matching. Especially, if the transmission line such as nonradiative dielectric(NRD) guide[5] is filled with a dielectric, the dispersion characteristic of the transmission line cannot be measured with perturbation method. However, FM reflectometry can measure the dispersion characteristics of any transmission line more easily, rapidly, and accurately.

In this paper, various microwave transmission lines such as periodically loaded conducting posts in a waveguide and NRD guide are adopted to measure their group velocities using FM reflectometry. The results will be compared with those from network analyzer to validate our measurement method.

Ⅱ. Principle of FM Reflectometry

A schematic diagram of FM reflectometer system is shown in Fig. 1. It consists of frequency modulated source(HP83620A), directional coupler(Mini-Circuit ZFSC-2-10G-S), circulator(Ditom D3C6012), and mixer (Mini-Circuit ZMX-10G-S). FM signal is launched into the transmission line with short end. The reflected signal from the short end is mixed with the reference signal. Then, IF port of mixer generates beat frequency. This beat frequency includes the information of group velocity of the transmission line.

Fig. 2 shows the operation principle of FM reflectometry. For FM reflectometry, the transmitted signal is continuous, but constantly changing in frequency. Because a finite time is required for the signal to travel

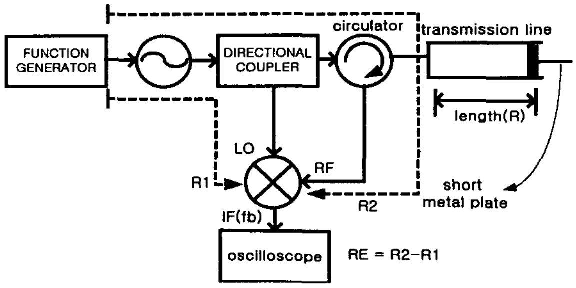

Fig. 1. FM reflectometer system.

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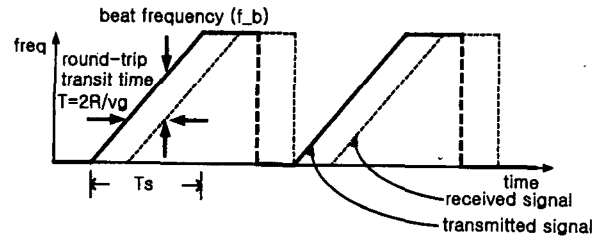
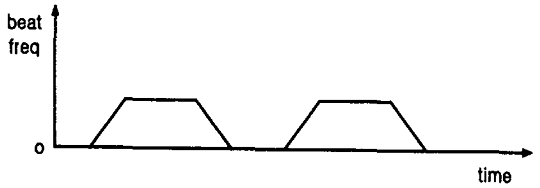


(a) Relation between the transmitted and received signal



(b) Beat frequency versus time

Fig. 2. Principle of FM Reflectometry.

to the target and back, there will be a difference in instantaneous frequency between the transmitted and received signal[2].

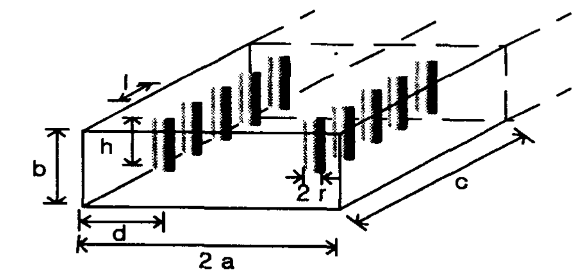
In the above signal model, the dispersion effects of the structure were ignored since $f_0 >> \triangle f$. Therefore, the round-trip transit time T is simply given by

$$T=\frac{2R}{v_g} \tag{1}$$

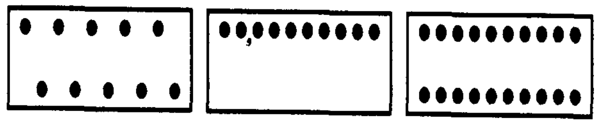
where v_g is the group velocity and R is the length of transmission line. The greater the target range, the greater will be the frequency difference. Mixing the transmitted and received signal produces a beat frequency(f_b) equal to the difference between two frequen- cies. The relationship between f_b and T is given by the equation (2). Therefore, the group velocity of microwave transmission line can be determined from a beat frequency.

$$\frac{f_b}{T}=\frac{\Delta f}{T_s} \tag{2}$$

In the FM reflectometry, the system calibration is very important to measure the group velocity of transmission line. A number of factors can introduce measurement errors in FM reflectometry. The length of cables and waveguides connecting the various components introduce an error known as the residual path-length error. In the Fig. 1, the length of the signal path from the transmitted and received signal should ideally be equal to that of the local oscillator signal. If these two signal path lengths (R_1, R_2) are not equal, as is usually the case, a target at zero range will not produce



(a)



(b) (c) (d)

Fig. 3. Structure of periodically loaded conducting posts in a rectangular waveguide.
(a) Three dimension view
(b) Glide type(top view)
(c) Straight type(top view)
(d) Parallel type(top view)

a zero beat frequency, and all range measurement will be erroneous. To take into consideration this error, the equation (3) becomes.

$$f_{b-c}=\frac{2R_E}{v_c}\frac{df}{dt} \tag{3}$$

where f_{b-c} is the beat frequency in the waveguide cut-off, df/dt is the rate of change of the transmitter frequency, $R_E\,(=R_2-R_1)$is the residual path length error, and v_c is the group velocity of coaxial waveguide. From equation (2), R_E is.

$$R_E=\frac{f_{b-c}v_cT_s}{2\Delta f} \tag{4}$$

where T_s is sweep time and $\triangle f$ is a frequency deviation.

$$f_{b-w}=\frac{2\Delta f}{T_s}\left(\frac{R_E}{v_C}+\frac{R}{v_{g-w}}\right) \tag{5}$$

$$v_{g-w}=\frac{R}{\left(\frac{f_{b-w}T_s}{2\Delta f}-\frac{R_E}{v_c}\right)} \tag{6}$$

where R is waveguide length, $f_{b\text{-}w}$ is the beat frequency with waveguide, and $v_{g\text{-}w}$ is the group velocity of waveguide. The group velocity of microwave transmission line can be determined using the equation (6).

Ⅲ. Various Microwave Transmission Lines

3-1 Periodically Loaded Conducting Posts in a Rectangular Waveguide

The structure of periodically loaded conducting posts in a rectangular waveguide is shown in Fig. 3.

This structure consists of off-centered conducting posts, whose inserting height is adjustable. Thus, three structures such as glide, straight, and parallel type can be obtained by control of the inserting height as shown in Fig. 3. (b), (c), and (d), respectively. To avoid the complexity of fabrication, the radius (r) of a post, the distance(l) between posts, and the distance (d) of a post from a sidewall were selected as 1 mm, 12 mm, and 5 mm. respectively. The length of c is 2 m long. The rectangular waveguide is WR-90. This structure was designed to be utilized in the interaction circuit of broad band Gyro-TWT[1]. This interaction circuit can be made less dispersive by periodically loading conducting posts, which is required for broadband interaction circuit of Gyro-TWT.

3-2 NRD Guide

Nonradiative dielectric(NRD) guide, first proposed by Yoneyama and Nishida[5], is a low-loss transmission line having a unique feature that it can suppress radiation almost completely. It consists of a parallel-plate guide with a dielectric trip inserted between the plates as shown in Fig. 4.

The dominant LSM_{11} mode is the desirable operating mode of the NRD guide and the LSE_{11} mode is considered as parasitic. The dispersion characteristic of LSM_1 is showed in equation (7).

$$\beta^2 = k_0^2\varepsilon_r - (\pi/a)^2 - \beta_y^2$$
$$\beta_y \tan(\beta_y b/2) = \varepsilon_r \zeta \qquad (7)$$
$$\zeta^2 = k_0^2(\varepsilon_r - 1) - \beta_y^2$$

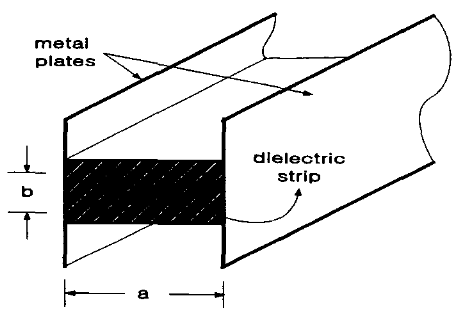
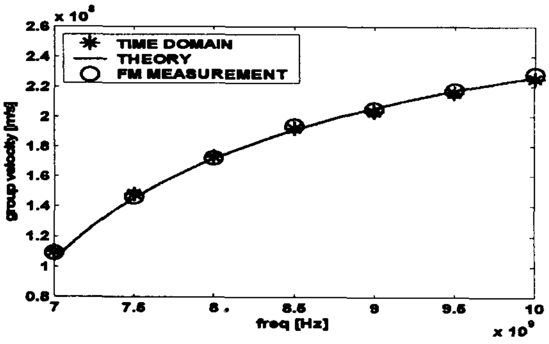
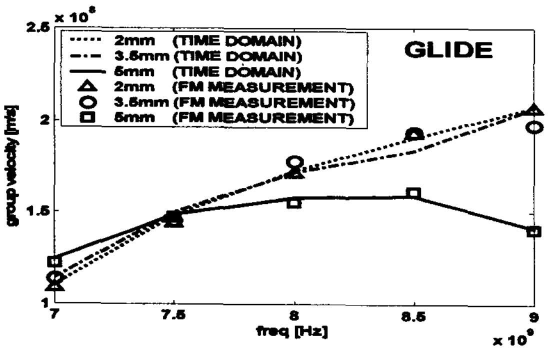


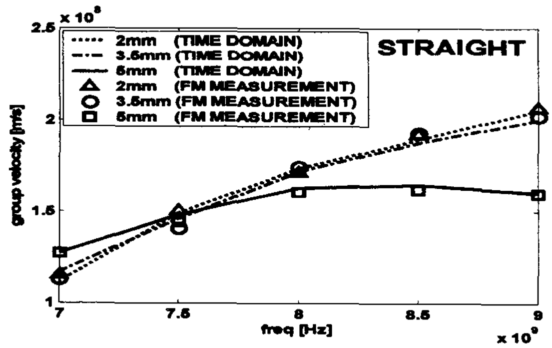
Fig. 4. Geometry of NRD guide.(a = 17.6[mm], b = 18.5[mm], ε_r = 2.08).



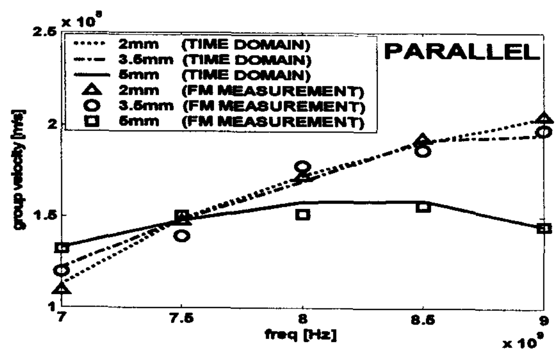
(a) Measured group velocity without posts



(b) Measured group velocities of glide type



(c) Measured group velocities of straight type



(d) Measured group velocities of parallel type

Fig. 5. Measured group velocities of various periodically loaded conducting posts in a rectangular waveguide.

where β is a propagation constant and a, b are the dimension of NRD waveguide. In this experiment, NRD guide was designed to avoid rectangular wave guide cut-off in the pass-band and to operate in the single mode. Also the transition of NRD guide was made with tapered shape.

Ⅳ. Measurement Results

Fig. 5. shows the measured group velocities of periodically loaded conducting posts in a rectangular waveguide for various types using FM reflectometry. The group velocity can also be measured by time domain function of network analyzer (HP8510C). These measured results are shown in Fig. 5. to compare. As can be seen, the measured results from both measurement techniques show good agreement, indicating the validity of our measurement technique.

As the inserting height increases, the group velocities of all three types are getting flatter in Fig. 5. (b), (c), and (d). This indicates that the linearity of dispersion characteristics can be obtained by adjusting the height of posts. Thus, these structures could be utilized for the interaction circuit of broadband Gyro-TWT. It is also observed that the dispersion curves of straight and glide type are almost same. However, the parallel type generates slower wave than the other types at the same condition since its loading effects are much larger.

Fig. 6. shows the measured group velocity of LSM_{11} mode of NRD guide using FM reflectometry and time domain function of network analyzer. The LSM_{11} mode has its electric field component predominantly parallel to the plates and hence forms the low-loss propagating mode. This mode can be exited by means of a TE_{10} mode rectangular waveguide feed oriented such that its E-field lies parallel to the metal walls of the NRD guide. The horn antenna was used to waveguide to NRD guide transition carefully. The compared measurement results show good agreement.

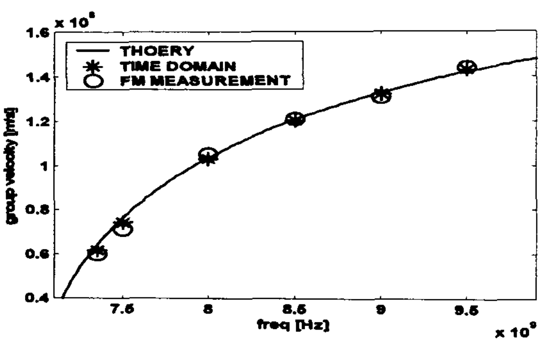


Fig. 6. Measured group velocities of NRD guide. (LSM_{11} mode, a=17.6 [mm], b=18.5 [mm], ε_r=2.08)

Ⅴ. Conclusions

The group velocities of various microwave transmission line were measured using FM reflectometry. Periodically loaded conducting posts in a waveguide and NRD guide, which can be utilized in the interaction circuit of broad band Gyro-TWT and low loss millimeter-wave circuits, respectively, are adopted to study their dispersion characteristics. The measurement results compared with that from network analyzer show good agreement, indicating the validity of our measurement method.

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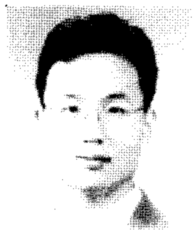

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