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The Double-Swept-Frequency Locating Reflectometer

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***Abstract*—A swept-frequency-type reflectometer is newly developed which is capable of measuring the distances to the reflection locations and reflection magnitudes in the coaxial line or waveguide, using a double-swept-frequency (DSF) source and a bandpass filter. The principle of this reflectometer and experimental results obtained at 2 GHz are given.**

INTRODUCTION

In the measurements of coaxial-line or waveguide systems, it is often required to know the locations of reflections and their magnitudes. For this purpose, two types of reflectometers have been developed. One is the time-domain reflectometer, and the other is the swept-frequency-type reflectometer. In the latter-type reflectometer, we make a frequency analysis of the beat signal between the reference and reflected waves when the frequency of the incident wave is swept. In this type, Hollway's comparison reflectometer [1] and Somlo's locating reflectometer [2] are useful. Further, the set of this kind of reflectometer with the audio spectrum analyzer is commercially available [3]. These swept-frequency-type reflectometers are characterized by the beat frequency analysis. On the contrary, without making the frequency analysis of the beat signal, a successful reflectometer is newly designed by using a DSF source and a bandpass filter.

PRINCIPLE

Let us consider a transmission line without frequency characteristics. When the input signal is fed to the transmission line, the reflected wave returns to the incident port with time delay proportional to the distance from a reflection location. As the frequency of the incident wave is swept with the triangular waveform, a slight difference of the frequency occurs between the incident and reflected signals. Then the beat frequency (f_b) is given as follows [4];

$$f_b = 4f_r \Delta f l / v_p \tag{1}$$

where f_r is the repeating frequency (we define this repeating as the primary sweeping) of the triangular waveform signal, Δf is the swept microwave bandwidth, l is the distance from the incident port to the reflection location, and v_p is the phase velocity in the transmission line. When there are a number of reflection locations in the line, the beat signal consists of many frequency components.

As we make the frequency analysis of the beat signal, the reflection locations and the magnitudes become known. Each beat frequency corresponds to the distance l, and the amplitude of this beat component is proportional to the reflection coefficient at l. Calibration by the standard mismatch gives the exact reflection coefficient.

In general, we obtain the location and the magnitude of reflections using an ordinary spectrum analyzer [3]. Instead, in this paper, we propose a new method to separate the reflections without the spectrum analyzer.

From (1),

$$l = f_b v_p / (4 f_r \Delta f) = k f_b / f_r \tag{2}$$

where $k = v_p/(4\Delta f)$. If we extract a constant f_b component from the beat signal by a bandpass filter, l is obtainable from the sweeping either f_r or Δf. If Δf is fixed, the final form of (2) is available. This form means that the distance l can be obtained by varying primary sweep frequency f_r (we define varying the primary sweep frequency f_r as the secondary sweeping) since k and f_b are constant. In conclusion, it is obvious that the reflection locations and the magnitudes can be taken by doubly (primary and secondary) sweeping the oscillator frequency instead of the spectrum analyzing. We call this method the DSF locating reflectometer.

EXPERIMENTAL METHOD

Fig. 1 shows the experimental arrangements of the DSF locating reflectometer. The frequency of the sweep oscillator is frequency-modulated (primary sweeping) with the triangular waveform signal by the function generator. The primary sweep frequency is f_r. The swept microwave bandwidth Δf is preset in the oscillator. The output signal of the function generator is swept repetitively (secondary sweeping) by the internal sweep function. The period of the secondary sweeping is taken to be much longer (over ten times) than that of the primary sweeping. Therefore, the primary sweep frequency f_r is gradually increased. These aspects are shown in Fig. 1. The signal, synchronized with the secondary sweep, is connected to the X axis of a CRT, and indicates the reflection location. The microwave output power of the sweep oscillator is leveled by ALC system, and fed to a 3-dB directional coupler, where the incident and reflected waves from the test line are sampled. To use the 3-dB directional coupler for the sampling [2] is useful to obtain good linearity up to full reflection. The crystal detecter, which plays as a homodyne mixer, connected to the coupler yields the beat signal. This beat signal is filtered by the bandpass filter (center frequency: 1 kHz, corresponds to f_b, bandwidth: 100 Hz). The output signal of the filter is amplified by the audio amplifier, and rectified by a diode. The rectified signal connected to the Y axis of the CRT shows the reflection magnitude.

The test line used is the cascade connection of the coaxial line (5D2V: 50 Ω) and the waveguide (WRJ-2: 1.7–2.6 GHz). The coaxial-line system is composed of two parts; ca 100-cm and ca 30-cm lines connected with the coaxial adaptor. The waveguide system is composed of a coaxial-to-waveguide transducer, a stub section, and a dummy load. The stub section is used for checking the reflection effect of a stub.

The microwave frequency range swept in the sweep oscillator is 2.00–2.45 GHz (Δf = 450 MHz), and the primary sweep frequency f_r is swept from 20–100 Hz by the secondary sweep signal with the frequency of 1 Hz or less. Hence the CRT display is obtained at a rate of once per second or less.

RESULTS AND DISCUSSIONS

Fig. 2 shows the experimental results. Fig. 2(a) is the CRT display when the stub is removed and Fig. 2(b) is the result when the stub is inserted into the waveguide by 1 cm. The test line used is shown in

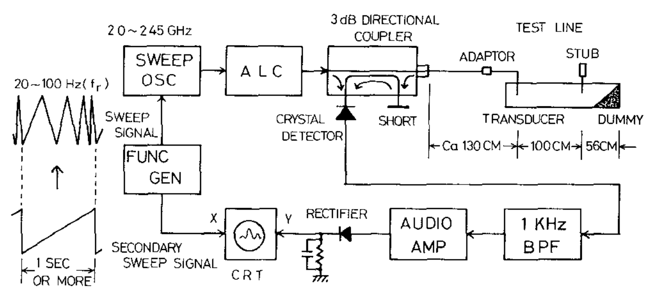

Fig. 1. Experimental setup of the double-swept-frequency locating reflectometer.

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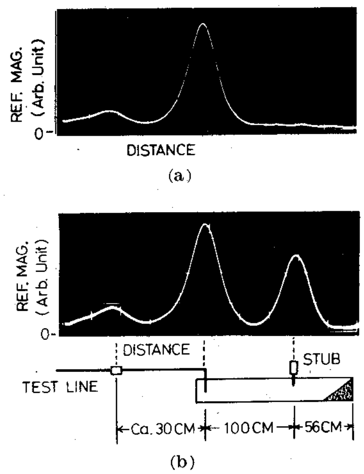

Fig. 2. CRT display of the reflections in the test line. (a) Without stub. (b) With stub.

the bottom of the figure. The distance scale of the locating plot is nonlinear in the present experiment, because the primary sweep frequency is increased linearly with time. If the primary sweep frequency is increased inversely proportional to time, the linear scale on the distance will be obtained when the v_p is constant over the test line. The ordinate indicates the reflection magnitude. As the unit of this axis is arbitrary, the reflection magnitude should be calibrated by a standard mismatch for further experiments.

Reflections are observed at the coaxial adaptor, the coaxial-to-waveguide transducer, and the stub. Furthermore, the reflection effect of the stub is clearly manifested. From the results, distance resolution at the coaxial adaptor is about 18 cm, at the transducer 31 cm, and at the stub 74 cm. The distance resolution drops quasi-linearly with distance different from the other reflectometers [1]–[3]. The reason is given as follows. In the present method, the distance resolution is mainly limited by two factors; the swept microwave bandwidth Δf and the bandpass filter's Q. The former is a fundamental limiting value on distance resolution, and universally applicable to all types of locating devices (in time domain, the rise time of the step function or the width of the spectrum of the pulse). It has been shown [1] that the shape of a reflection spectrum is approximately given by the function $|\sin \chi/\chi|$: $\chi = 2\pi \Delta f l'/v_p$ where l' is the distance from the center of the reflection spectrum. The resolution distance Δl (bandwidth of the main lobe) of the reflection is obtained from the equation $|\sin \chi/\chi| = 0.5$. The result is given as follows with rough approximation:

$$\Delta l \approx \sqrt{3} v_p / \pi \Delta f. \tag{3}$$

This equation indicates that the resolution is subjected to the swept bandwidth Δf, and the wider the swept bandwidth Δf, the better the resolution becomes. However, as the wide bandwidth sweep involves the unnegligible frequency characteristics, which elicit the error in the results and impair the distance resolution, in the test line, the allowable maximum swept bandwidth should be chosen. In the used test line, the swept bandwidth 450 MHz (Δf) is nearly allowable maximum. From (3), the 450-MHz sweep gives the resolution of about 23 cm in the coaxial line, and about 48 cm in the waveguide. However, in the present method, the latter (bandpass filter's Q) injures the fundamental resolution when the resolution distance Δl is shorter than the length determined by the bandwidth of the bandpass filter, because the reflection at distance l is always detected by the 1-kHz bandpass filter, and the filter's bandwidth determines the practical resolution. Now the resolution distance Δl is given by

$$\Delta l = \lambda_r l / Q \tag{4}$$

where λ_r is the waveguide-wavelength ratio for free space. Finally, the axial resolution drops quasi-linearly with distance in the present method. The experimental results on the axial resolution approximately agree with the results calculated from (3) and (4).

When the axial resolution is impaired by the filter's Q, the narrower bandwidth of the filter will improve the resolution. However, practical minimum bandwidth exists, because narrower bandwidth than the primary sweep frequency f_r resolves the primary sweep frequency f_r in the beat signal since the beat signal is modulated (repeated) with the primary sweep frequency f_r, and spurious spectra appear around the main reflection spectrum. This aspect complicates the interpretation of the results, therefore, f_r is the practical minimum bandwidth.

There are no limitations of measurable distance in the DSF locating reflectometer since the mechanical scanning component [2], whose movable length limits the measurable distance, is not involved in the present method. As we make the secondary sweep signal frequency lowered, the farther reflection can be detected.

The capability of measuring the small reflection is determined by the S/N value of the whole measuring system. In our experimental set, it is certified to be possible to measure the reflection coefficient of 0.0001 or less.

Though the DSF locating reflectometer does not include the function of Smith chart display [1], [2], it might be the minimum of equipment for the purpose of obtaining reflection locations and the magnitudes.

CONCLUSION

The DSF locating reflectometer makes it possible to obtain the locating plot of the reflection in the transmission line without spectrum analysis. This reflectometer has large merit in that, though the measuring system is very simple, the reflection spectrum can be directly observed on the CRT with real time, and would be very useful for the measurements of coaxial-line or waveguide systems.

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Slotted Line Measurements for Propagation Constant in Lossy Waveguide

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Abstract—**The propagation coefficient in a slotted waveguide partially loaded with a lossy dielectric can be determined accurately, in terms of the measured standing-wave pattern, by means of a computer program solving a set of transcendental equations. This determination is a necessary step in a permittivity measurement technique which was recently proposed by several authors.**

A novel technique to measure the permittivity of strip materials utilizing a partially loaded slotted line was recently presented in several publications [1]–[3]. Bhartia and Hamid [1] state that *the simplicity and the greater accuracy possible in the physical measurements make this method more accurate than previous methods.* Another factor in favor of this method is that it does not require delicate

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