MICROWAVE MEASUREMENTS WITH ACTIVE SYSTEMS

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Abstract

A new system for microwave dielectric measurements is described. The system with sample comprises a microwave oscillator whose frequency and amplitude provide the desired information. Preliminary results pertaining to sensitivity, dynamic range and time resolution are presented.

Introduction

Conventional systems for the determination of microwave dielectric constant are "passive" in the sense that the quantities of interest are determined from a shift in space or time phase, or frequency, in a passive element such as a microwave bridge or cavity resonator, the microwave energy required for the measurement being derived from an external source. The approach based on the measurement of a shift in time phase suffers from certain shortcomings: the readings are ambiguous to factors of 2π and depend, essentially, on the measurement of an amplitude, this amplitude deriving from the phase interference between a reference signal and a sampling signal, both at the same frequency. Thus, the sensitivity to small phase shifts is limited by the ability to measure amplitudes. On the other hand, at larger phase shifts the output becomes nonlinear and requires correction. Moreover, it is difficult to read and interpret phase shift data in cases in which rapid variations of the dielectric constant occur in time. Another important disadvantage of the phase method is the fact that it is essentially a bridge-balancing method and usually requires the intervention of a human operator.

Space-phase measurement methods derive from standing-wave methods and thus require mechanical elements that can provide accurate displacements of detector probes used to measure standing-wave ratios and the variation in the location of nodes caused by the presence of the medium being measured. These are usually expensive.

The other basic method, the frequency-shift method, depends on the ability to observe a response curve in a microwave resonator of some kind. The changes in the response curve caused by the medium, namely, the changes in amplitude, width, and shape of the response curve are then used to determine the real and imaginary parts of the dielectric constant. However, this technique requires that the total system exhibit a high enough Q so that shifts and changes in the response curve can be observed. This requirement implies certain limitations on the maximum loss that can be introduced into the system. Moreover, the frequency shift must be observed by visual means, as must the change in Q; it is frequently difficult to achieve accurate visual measurements without a certain amount of inconvenience.

Experimental Arrangement

In contrast with the passive systems discussed above, the approach described in the present work makes use of an "active" system in which a positive-feedback loop containing a broadband microwave (TWT) amplifier is introduced in order to provide positive gain. The entire configuration, including the measurement element (cavity, etc.) and the sample, then comprises a microwave oscillator. The frequency and amplitude of the oscillator signal can be used to determine the real and imaginary parts of the dielectric constant at microwave frequencies. This technique was originally developed in connection with a microwave-diagnostic system used in plasma physics[1] but has many features that should make it useful in other applications.

Figure 1 illustrates the basic concepts of an active system. The primary element is the loop made up of the cavity resonator, which contains the sample, the TWT amplifier, the loop attenuator, and the isolators. With the attenuator adjusted properly the total gain around the loop can be made positive and slightly greater than unity so that the system is capable of oscillation at any frequency within the passband of the amplifier. The particular frequency at which oscillation actually occurs is then determined by the resonator-sample combination, which plays the role of a tunable transmission filter; the oscillation frequency is thus determined by the dielectric constant of the sample.

The chief characteristic feature of the system is the fact that the output appears in the form of a frequency rather than a phase. This means that cw output data can be read directly on a microwave digital frequency counter or can be converted to a dc voltage by means of a microwave frequency discriminator for plotting or control purposes. The time response of the system is inherently fast, being limited only by the slewing time of the oscillator and the response of the discriminator. Since the output datum is a frequency rather than a phase, the ambiguity of factors of 2π characteristic of phase measurements is eliminated. Furthermore, since frequency can usually be measured with much higher accuracy than phase, the system is capable of high accuracy and sensitivity. Finally, since the amplifier provides an effective negative resistance which can compensate for the positive resistance in the system, the inherent passive Q need not be high. This feature relaxes requirements on the fabrication of the conventional microwave elements.

Results

Preliminary experiments with an active system have been devoted to an evaluation of response time and sensitivity. The response time has been investigated in experiments on turbulent gas flow. In these experiments two coaxial cylindrical chambers are arranged so that they share a common orifice, which is covered by a mylar diaphragm. One chamber is evacuated and the other is filled with the working gas at a pressure sufficient to rupture the diaphragm. The chamber under vacuum is connected, through a line with low vacuum impedence, to a microwave cavity, which is the sensing element of the active microwave system. The experiment consists of establishing a pressure sufficient to rupture the diaphragm and observing the fluctuations in the refractive dielectric index of the gas in the vacuum chamber, these being caused by the turbulent flow of the gas that rushes in to fill the chamber. Fig. 2a shows the results of an experiment carried out with helium. Results obtained with argon are shown in Fig. 2b and with Freon 12 (dichlorodi-flurométhane) in Fig. 2c. In all cases the pressure in the pressure chamber in 30 psi and the time scale (absicca) is 2 msec/div. The ordinate in these figures is the output from the frequency discriminator and is proportional to the frequency generated by the active system. In these preliminary experiments the discriminator is an uncalibrated wavemeter cavity which is adjusted so that the steady-state frequency of the active system (prior to rupture of the diaphragm) is displaced from the peak of the resonance curve. Slope detection is then used to measure the frequency deviation from the steady-state value.

Although they have not been studied in any detail, it is belived that certain aspects of the gas dynamic flow can be tentatively identified in these figures: 1)the rapid and turbulent buildup of pressure from the vacuum level, 2)the overpressure as the compressional wave is reflected from the end of the evacuated chamber, 3)the relaxation to equilibrium. We note that in Fig. 2a fluctuations with characteristic times of the order of 400 μsec are easily observed. As expected, the characteristic times associated with the transient turbulent phenomena increase with the molecular weight of the gas. The molecular weights are as follows: He = 8, Ar = 36, Freon 12 = 120. In this connection it is of interest to note that the microwave part of the system is capable of a response time of 0.2 μsec[1].

The experiments to investigate the sensitivity of the active system are carried out with a high-Q cavity as the resonant structure, in order to increase the sensitivity to small perturbations. For example, it is possible to observe the passage of a single grain of table salt through the cavity. Typical results are shown in Fig. 3a and Fig. 3b. In Fig. 3a the grain of table salt is dropped into the cavity from a height of approximately 1 inch; in Fig. 3b it is dropped from a point approximately 20 inches above the cavity. The difference in the velocity with which the salt grain enters the cavity is indicated by the difference in pulse width in the two figures. In each case the time scale is 20 msec/cm. The periodic waveform on the baseline is due to spurious noise modulation of the TWT.

Acknowledgement

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References

1. R. C. Ajmera and H. Lashinsky, "Plasma Impedence Element in an Active Fabry-Perot Microwave Resonator", Applied Physics Letters, Vol. 13, No. 3, pp 96-98, 1 August 1968

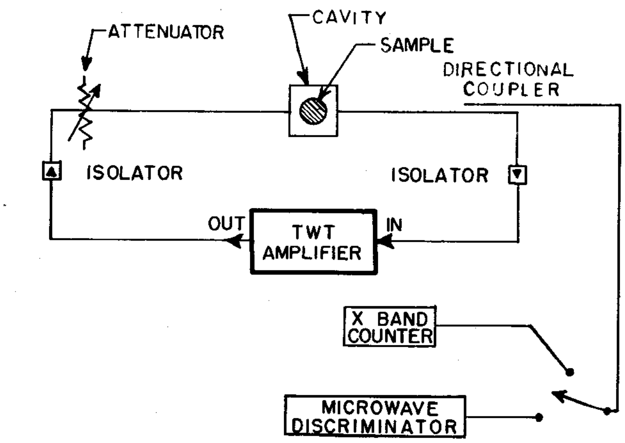

FIG. 1

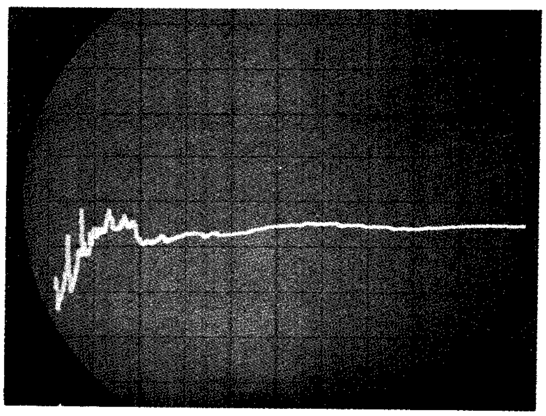

FIG. 2a

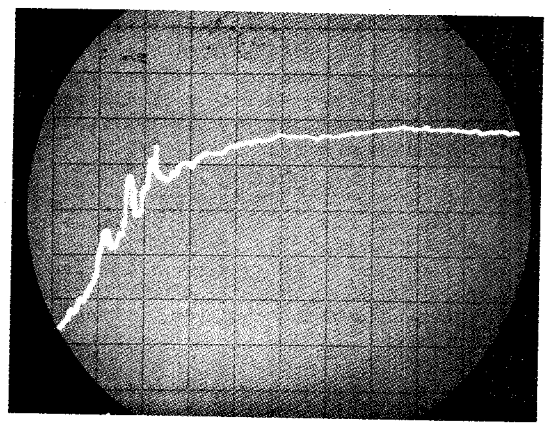

FIG. 2b

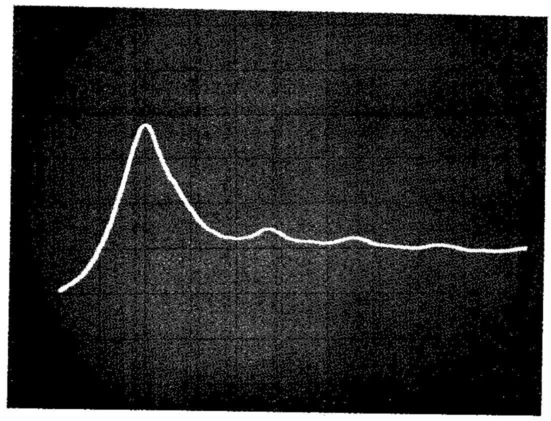

FIG. 2c

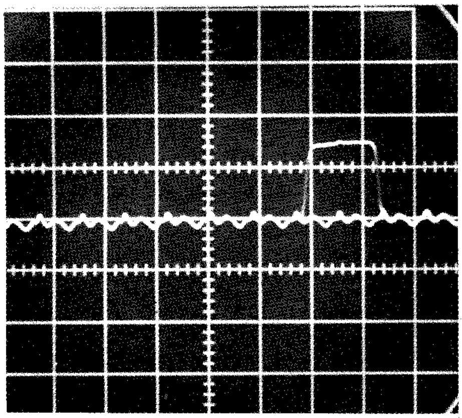

FIG. 3a

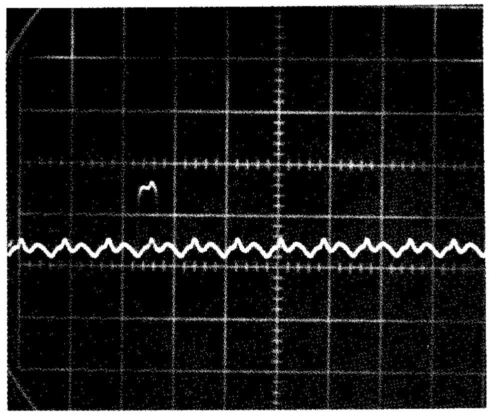

FIG. 3b