VARIABLE-PERMITTIVITY ARTIFICIAL DIELECTRICS

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Summary. The use of liquid suspensions as a new class of microwave artificial dielectrics was explored. Liquid media were constructed with permittivities dependent on the strength of a low-frequency electric control field. Operating characteristics were measured for a 50 KW, 360° Ku-band waveguide phase shifter employing a practical liquid-suspension dielectric. Other applications are in electrically variable wideband lenses and in the analog control of phased arrays.

The media investigated were solid-in-liquid suspensions whose permittivities could be changed by applying a low-frequency electric biasing field. The physical interaction responsible was similar to the one that occurs between light and pure liquids in the optical Kerr effect. In essence, suspensions were constructed as models of Kerr liquids scaled to the microwave region. While the controllable birefringence of a pure Kerr liquid is due to polarization and ordering of its molecules by an applied electric field, the artificial dielectrics used for this study achieved variable microwave birefringence as a result of induced polarization and alignment of their relatively larger solid components. Thus, the assymmetric, micron-size suspended solids corresponded to individual molecules of a pure Kerr liquid.

Early in this work, a brief search was made for simple liquids composed of large molecules which could show a directly useful Kerr effect at microwave frequencies. Such liquids may exist, but the suspension modelling approach quickly uncovered enough new ground to fully occupy available research personnel.

In order to simultaneously optimize suspension stability and response time, the addition of surfactants was found to be required. Some of these surface-active chemicals, however, tended to increase losses. Searching for components that minimized the cost of this sort of trade-off produced two practical artificial dielectrics. Both were electrically similar but one used fluorocarbon and the other hydrocarbon components. The work presented here is based on the more easily reproducible hydrocarbon system, made of benzene loaded with 8mg/cc of 1 u-diameter aluminum platelets and 16mg/cc of alkyl polyoxyethylene-amine.

All measurements were made using the cell shown in Fig. 1, which was designed as a K_u-band phase shifter. The electrode shown in front of the cell was normally supported in the H-plane in the center of the guide, with a fine wire connecting it to an external feed-through. When voltage was applied to the lead an electric field was impressed on the artificial dielectric in the microwave E-plane. This causes an increase in permittivity for the TE_{10} mode, so propagation time for that mode increased with applied voltage. Liquid was retained in the guide by thin mylar end windows. The teflon wedges shown tapered the liquid column and thereby afforded a smooth impedance transition to the rest of the circuit. The developmental artificial dielectrics described here underwent gradual settling if left at rest. To avoid this, they were circulated at 1cc/sec through small tubes in the broadwall to stabilize their electrical properties. Although control fields could have been D.C. or A.C., 15 KHz sine waves were used for this work to preclude sweeping of any residual free ions. No conduction current was required to control the dielectric.

When a microwave signals having E-field amplitude comparable to that of the control field were sent through the cell there could in theory have been an increase in phase delay due only to the signal. To avoid this, the rotational inertia of the suspended particles was adjusted so that they could re-orient only in times long compared to the signal pulsewidth. In this way, signals much larger than the control field could be accurately delayed. The cell shown here operated successfully at more than 50 KW peak, 50 w. average power in the 15 to 18 GHz band.

The change in phase delay through the cell with control voltage at 16.5 GHz is shown in Fig. 2. The change in phase delay was approximately proportional to the change in permittivity over the range of the data. Thus, the permittivity of the artificial dielectric was almost linearly proportional to the applied control field. The dielectric constant changed by 7×10^{-4} per r.m.s. volt per cm of control field.

Loss was essentially frequency independent. VSWR was less than 1.2:1 over the band. The dashed curve in Fig. 3 shows absorption loss with increasing controlled phase delay for a suspension having half the loading concentrations of the one normally used. The solid curve is for the standard liquid used for all other data. Probably neither depends strongly on control field because absorption was due to inherent loss in the benzene and residual water. The waveguide shell and epoxy-fiberglass electrode supports contributed 1.2 db of the losses.

When a control field was applied to the artificial dielectric there was a short time-lag before a new permittivity was established. If a field larger than that required to cause a given phase delay in the steady-state was applied, the time to reach that phase delay was then considerably reduced. Fig. 4 shows the time lag to reach phase delays of $\pi/2$ and π vs. control voltage amplitude. The shape of the curves may reflect increasing drag force opposing particle alignment as particle rotation speed increases.

Since we have emphasized developing devices utilizing the liquid dielectric concept rather than exploring materials per se, a great deal is still unknown about exactly how they work. One nearly blank area is the interaction between microwaves and the chemical charge layer surrounding each suspended particle, and the related question of whether the electrical and physical shape of a particle is the same. Other unexplored areas are the effects of varying particle assymmetry, the use of high-permittivity dielectrics as loading material and the use of chemical systems other than simple suspensions as artificial dielectrics.

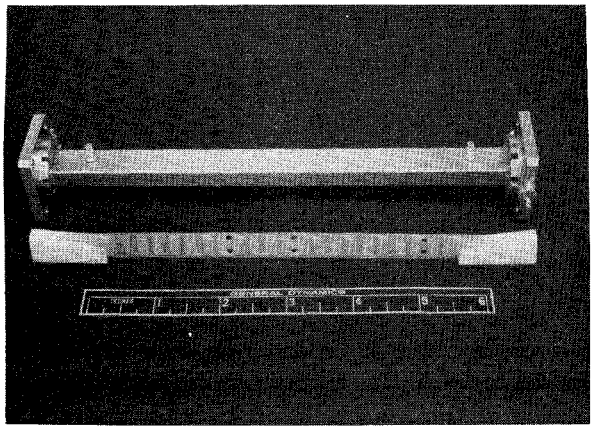

Figure 1. Phase shifter, showing main control electrode and impedance matching wedges.

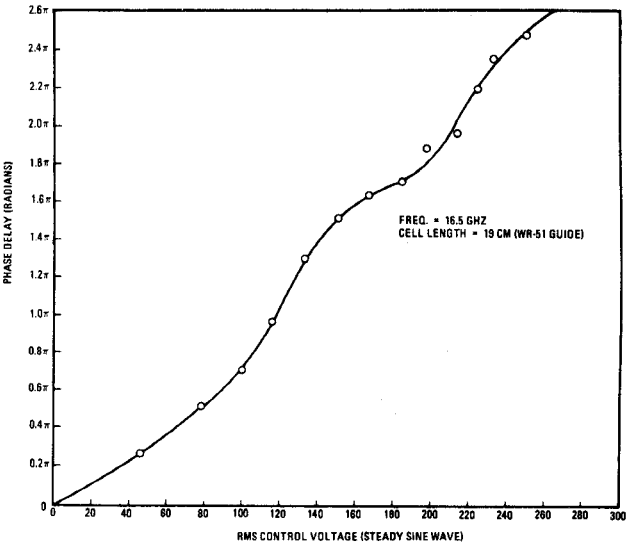

Figure 2. Relative phase delay of device as a function of steady-state control voltage.

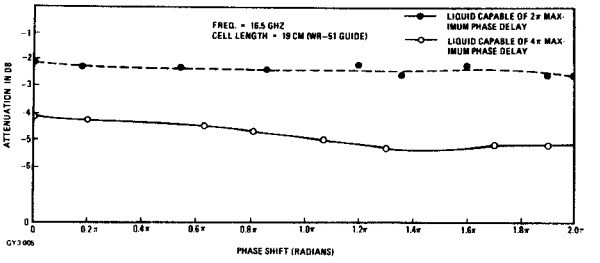

Figure 3. Power loss of phase shifter for two liquid dielectrics as a function of steady-state controlled phase delay.

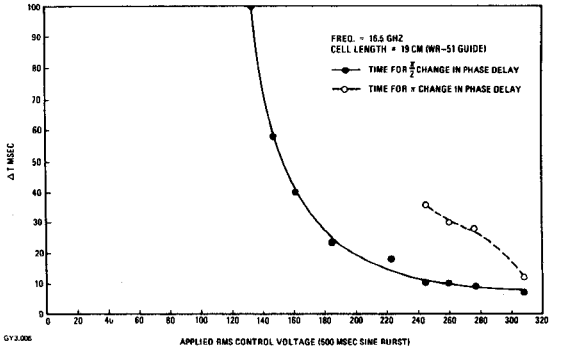

Figure 4. Response time of phase shifter as a function of control voltage amplitude.

Notes