DIELECTRIC CONSTANT AND TAN DELTA OF SOME LOW LOSS LIQUIDS IN V-BAND

I. J. MAKHIJA & A. L. DAWAR

Defence Science Laboratory, Delhi

(*Received* 10 *July* 1970 ; *revised* 3 *September* 1970)

Real and imaginary parts of complex relative permittivity (relative dielectric constant and loss factor) of some low loss liquids in the frequency range 26-40 G Hz/s at room temperature have been measured. Standard method of impedance change measurement at an air-dielectric interface and attenuation measurements on a liquid filled guide have been used to compute the two parts. The results of measurements on carbon tetrachloride, *n*-heptane and benzene are given.

Measurements of the relative dielectric constant (hereafter called dielectric constant) and loss factor of liquids by wave-guide method have been reported by a number of workers notable amongst which are Surber[1], Crouch[2] and Von Hippel[3,4]. These methods were, however, more suited for medium and high loss dielectrics.

Recently Dagg & Reesor[5,6] have described a method for measuring the complex relative permittivity of low loss liquids. In this method, measurement of real part ϵ' makes use of reflectionless termination in a liquid filled guide whereas that of imaginary part ϵ'' makes use of a reflecting short in a long section of liquid filled guide. This method has been extended in frequency range 26-40 G Hz/s.

THEORETICAL CONSIDERATIONS

The complex reflection coefficient for a plane wave incident normally on the interface of a lossless dielectric of dielectric constant ϵ' (real part of the relative permittivity) is given by the special case of Fresnel equation[7].

$$r e^{-jr'} = \frac{1-\sqrt{\epsilon'}}{1+\sqrt{\epsilon'}} \tag{1}$$

For lossy dielectrics ϵ' has to be replaced by

$$(\epsilon' \sec \delta)\, e^{-j\delta} = \epsilon' (1 - j \tan \delta) \tag{2}$$

and for low loss dielectrics (terms of the order of $\tan^2 \delta$ are neglected) the absolute magnitude of the reflection coefficient r from (1) comes out to be

$$r = \frac{\sqrt{\epsilon'}-1}{\sqrt{\epsilon'}+1} \qquad \text{for } \epsilon' > 1 \tag{3}$$

Interface Reflection in a Wave-guide

For wave-guide propagating *TE* wave with cut off wave length λ_c, ϵ' is to be replaced by $\frac{\epsilon' - p}{1 - p}$ where $p = \left(\frac{\lambda}{\lambda_c}\right)^2$.

It is important to note that only interface reflection is taken into account and this can be achieved with the arrangement shown in Fig. 1 where the dielectric is terminated by a reflectionless load. Equation (3) for a wave-guide (substituting $\frac{\epsilon' - p}{1 - p}$ for ϵ') turns out to be

$$\epsilon' \simeq \frac{(1 + r)^2 - 4\, r\, p}{(1 - r)^2} \tag{4}$$

Since r is related to the voltage standing wave ratio σ by $r = \frac{\sigma - 1}{\sigma + 1}$, equation (4), in the case of a low loss dielectric, reduces to

$$\epsilon' \simeq \sigma^2 (1 - p) + p \tag{5}$$

Measurement of voltage standing wave ratio therefore yields the value of ϵ' in the case of low loss dielectrics.

Attenuation Constant

As is well known, the propagation constant for an air-filled guide γ_g is given by

$$\gamma_g = \alpha_c + j\, \frac{2\,\pi}{\lambda_g} \tag{6}$$

$$\lambda_g = \frac{\lambda}{(1 - p)^{\frac{1}{2}}} \tag{7}$$

α_c being the attenuation due to conductor loss in the walls of wave-guide, λ_g, the guide wave length and λ, the free space wave length. The propagation constant for the dielectric filled guide γ_d is then

$$\gamma_d = (\alpha'_c + \alpha_d) + j\, \left(\frac{2\,\pi}{\lambda_d}\right) \tag{8}$$

where

$$\alpha_d = \frac{\pi\, \epsilon''}{\lambda\, (\epsilon' - p)^{\frac{1}{2}}} \tag{9}$$

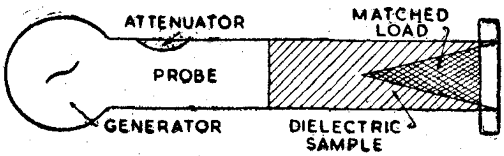

Fig. 1—Arrangement for the measurement of interface reflection.

for low loss liquids. λ_d is the wave length in the dielectric filled guide and α_c' is the attenuation caused by the wall loss in the presence of the dielectric and is related to α_c by

$$\alpha_c' = \frac{\left[\epsilon' + \left(\frac{2b}{a}\right)p\right]\left[1-p\right]^{\frac{1}{2}}}{\left[1+\left(\frac{2b}{a}\right)p\right]\left[\epsilon'-p\right]^{\frac{1}{2}}} \cdot \alpha_c \qquad (10)$$

a and b being the wide and the narrow dimensions of the guide respectively.

Determination of α_d

It is clear from (9) that ϵ'' can be calculated from α_d, which in turn can be measured experimentally. This is derived from the measurement of total attenuation constant $\alpha = \alpha_c' + \alpha_d$ and α_c which is related to α_c' by (10).

Attenuation Constant Measurement with a Variable Short Circuit

The basic arrangement for the measurement of attenuation constant α is given in Fig. 2. For a cell of reasonable length filled with a low loss liquid, the absolute magnitude of reflection coefficient r depends upon the position of the short and the attenuation caused by the dielectric and the two are related[8] by

$$\alpha = \frac{1}{2l}\log_e \frac{\{(1+r_{max})(1+r_{min})\}^{\frac{1}{2}} + \{(1-r_{max})(1-r_{min})\}^{\frac{1}{2}}}{\{(1+r_{max})(1+r_{min})\}^{\frac{1}{2}} - \{(1-r_{max})(1-r_{min})\}^{\frac{1}{2}}} \qquad (11)$$

or in terms of the voltage standing wave ratio

$$\alpha = \frac{1}{2l}\log_e \frac{(\sigma_{max}\,\sigma_{min})^{\frac{1}{2}} + 1}{(\sigma_{max}\,\sigma_{min})^{\frac{1}{2}} - 1} \qquad (12)$$

since

$$\sigma = \frac{1+r}{1-r}$$

$\sigma_{max.}$ and $\sigma_{min.}$ will occur when the returning wave from the short and the first reflected wave from the air-dielectric interface are in phase and out of phase respectively. The determination of α therefore involves the measurement of $\sigma_{max.}$ and $\sigma_{min.}$ which can be easily measured by varying the position of short.

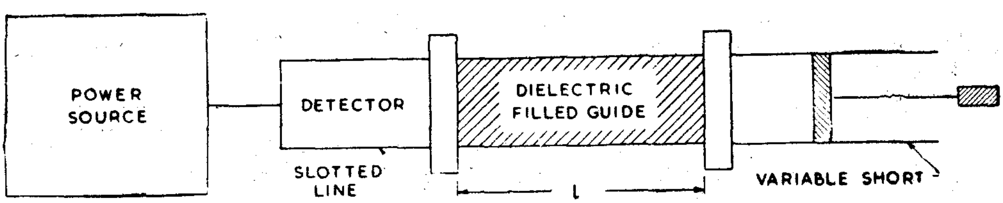

Fig. 2—Basic arrangement for the measurement of attenuation constant a.

The attenuation constant α_c due to wall losses alone can be measured by draining out the dielectric from the wave-guide and finding the voltage standing wave ratio with empty guide connected, and is given by

$$\alpha_c = \frac{1}{2l} \log_e \left[\frac{\sigma + 1}{\sigma - 1} \right] \tag{13}$$

EXPERIMENTAL PROCEDURE

A block diagram of the experimental setup is given in Fig. 3. A wave-guide cell of about 50 cm length used in vertical position was employed as impedance and attenuation cell with a thin mica window on the generator side and a sliding termination† and variable short†† were used alternately on the other side for the two measurements. The liquid was filled from the top. The mica window (0·001 in.) was sufficiently thin and introduced only a negligible impedance transforming action.

Type *QK* 289, 290, 291 and 292 Klystrons were used to give a frequency coverage of 26-40 G Hz/s. The Klystrons were used in modulated operation (square wave reflector modulation of 1000 Hz/s) and the standing wave ratios were measured with a (PRD Electronics Inc., U.S.A.) 277B standing wave indicator. Sufficient care was taken in keeping the probe position in slotted line to a minimum insertion. The standing wave indicator had an accuracy of 0·5%. Since ϵ' and $\tan\delta$ are functions of σ^2 and $\sigma_{max.}$ $\sigma_{min.}$, the overall accuracy of our observations is about 1%. All measurements were made at room temperature of about 28°C.

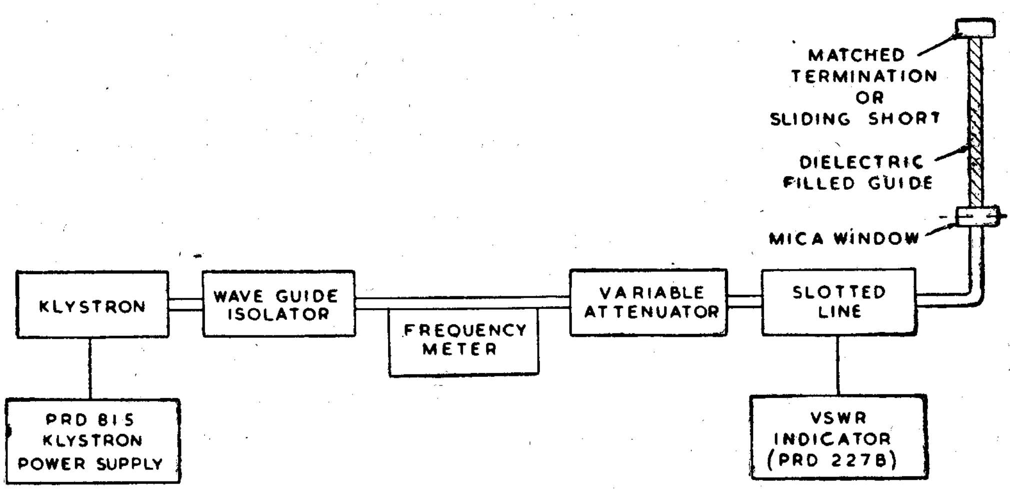

Fig. 3—Block diagram of the experimental setup.

†Supplied by Narda Microwave Corporation, U. S. A.

††Supplied by Microlab/FXR, U. S. A.

RESULTS AND DISCUSSION

Fig. 4 shows the variation of the dielectric constant with frequency for three low loss liquids namely carbon tetrachloride*, *n*-heptane** and benzene‡. The mean measured values for the three liquids are 2·14, 1·9 and 2·3 respectively, which agree well with the values quoted by Von Hippel[4] and Dagg & Reesor[5,6].

Fig. 5 and 6 give the plots of tan $\delta \times 10^4$ against frequency (solid lines) for the three liquids. The attenuation losses due to walls and the short as measured by α_c accounted for 20 to 40% of the total attenuation α. Our values for tan $\delta \times 10^4$ at 35 G Hz/s for the three liquids are 10·1, 10·0 and 12·6 respectively. The values for carbon tetrachloride and benzene agree well with those measured by Whiffen[9] by cavity resonator method (shown in dotted lines). We have not come across the values for *n*—heptane in this frequency range. However, if the results of Dagg & Reesor[6] are extrapolated to these frequencies, the agreement is quite close.

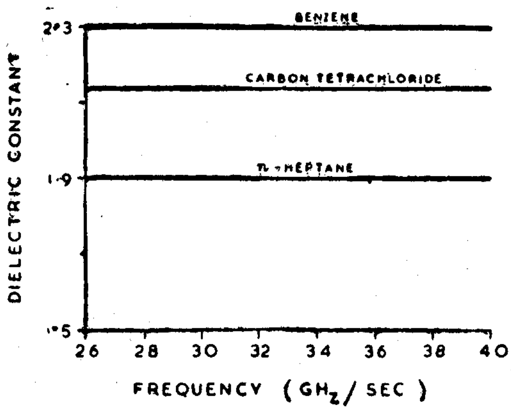

Fig. 4—Variation of dielectric constant with frequency for three low loss liquids.

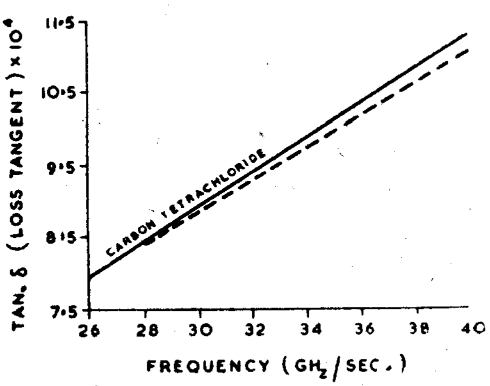

Fig. 5—Variation of dielectric loss with frequency for carbon tetrachloride.
(—) present work, (...) due to Whiffen.

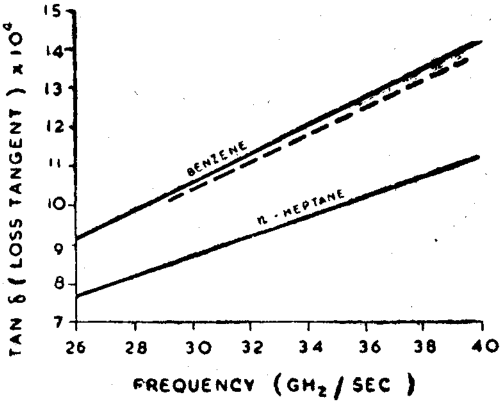

Fig. 6—Variation of dielectric loss with frequency for *n*-heptane and benzene.
(—) present work, (...) due to Whiffen.

It is difficult to explain whether these losses in the non-polar liquids are due to rotational or vibrational transitions. As discussed by Whiffen[9] a plausible explanation is that these molecules do possess an induced dipole moment of about 0·1 D which arise from distortion in the liquid state.

*Supplied by British Drug Houses, India.
**Supplied by E. Merck A. G. Darmstadt, Germany.
‡ Supplied by ACCO Industries, India.

ACKNOWLEDGEMENT

Thanks are due to the Director, Defence Science Laboratory, Delhi for permission to publish this work.

REFERENCES

1. SURBER, W. H., *J. Appl. Phys.*, 19 (1948), 514.
2. CROUCH, G. E., *J. Chem. Phys.*, 16 (1948), 364.
3. ROBERTS, S. & VON HIPPEL, A. R., *J. Appl. Phys.*, 17 (1946), 610.
4. VON HIPPEL, A. R., "Dielectric Materials and Applications", (John Willey and Sons Inc.), 1954.
5. DAGG, I. R. & REESOR, G. E., *Canadian J. Phys.*, 41 (1963), 1314.
6. DAGG, I. R. & REESOR, G. E., *Canadian J. Phys.*, 43 (1965), 1552.
7. MONTGOMERY, C. G., "Technique of Microwave Measurements", Vol. 11, Radiation Lab. Series (McGraw Hill Book Co. Inc., New York), 1947.
8. WIND, M. & RAPAPORT, H., "Hand Book of Microwave Measurements, Vol. I and II", (Polytechnic Institute of Brooklyn, U. S. A.).
9. WHIFFEN, D. H., *Trans. Faraday Soc.*, 46 (1950), 124.