

NPL REPORT MAT 23

**Tables of the Complex Permittivity of Dielectric Reference Liquids
at Frequencies up to 5 GHz**

A P Gregory and R N Clarke

JANUARY 2012

Tables of the Complex Permittivity of Dielectric Reference Liquids at Frequencies up to 5 GHz

A P Gregory and R N Clarke
Materials Division, NPL

SUMMARY

This report presents the results of the NPL dielectric reference liquids measurements programme, which was undertaken in the years 1997-2000. The measured results, together with conservatively evaluated uncertainties, were originally published in NPL Report CETM 33 in 2001 [1]. Since that publication, the authors have undertaken further modelling and analysis, which have resulted in improved measurement uncertainties, as reported here. This report therefore supersedes Report CETM 33.

Comprehensive tables of the complex permittivity of high purity methanol, ethanol, propan-1-ol, propan-2-ol (isopropanol), butan-1-ol, dimethyl sulphoxide and ethanediol are presented over a range of temperatures, in most cases at 5° C intervals between 10 °C and 50 °C, at frequencies up to 5 GHz. To make the data more convenient to use, tables of fitted relaxation parameters are also provided. A suitable relaxation equation for each of these polar liquids is selected according to whichever is observed to give the best fit. The Davidson-Cole relaxation equation is used for ethanediol. For the remaining liquids, single-Debye (3 parameters), Debye- Γ (4 parameters), or double-Debye (5 parameters) equations are chosen. Static permittivity measurements are presented for all these liquids, and also for pure water, acetone, silicone fluid and cyclohexane. All the data presented are traceable to UK National Standards. Advisory notes on the use of the tables are provided.

Since the publication of CETM 33 [1] minor corrections to the static permittivity measurements have been made, although these are appreciable in only a few cases. Some minor corrections to the high-frequency data have also been made. The parameters in the relaxation models that have been fitted to the data have been re-estimated and an improved scheme for evaluating the uncertainties associated with the data has been provided, which has in many cases enabled these uncertainties to be reduced. The ethanediol data is now fitted to the Davidson-Cole relaxation equation (instead of the Debye- Γ , as in CETM 33). A journal paper on the static permittivity measurements has been published [2], and a second paper providing technical details of the high-frequency measurements and the new uncertainty evaluation has been submitted for publication [3].

© Crown Copyright 2009
Reproduced by Permission of the Controller of HMSO
and the Queen's Printer for Scotland

ISSN 1754-2979

First Issued March 2009
Revised January 2012

National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

No extracts from this report may be reproduced without the prior written consent of the Managing Director, National Physical Laboratory; if consent is given the source must be acknowledged and may not be used out of context.

Approved by M Cain, Knowledge Leader of the Materials Team, on behalf of S Evans,
Director, Industry and Innovation Division, NPL, and of the Managing Director, NPL

CONTENTS

1. Introduction.....	1
1.1 The NPL Reference Liquid Measurements Programme 1997-2000.....	1
1.2 Summary Description of the Data Supplied in this Report.....	1
1.3 Frequency and Temperature Interpolation Example – Permittivity of Methanol at 2.2 GHz and 22.0 °C	5
2. Relaxation Equations	5
3. Warnings and Disclaimer.....	7
4. Advisory Notes on Use of the Tables	8
5. Purities of the Measured Liquids	13
6. Table of Admittance Cell Measurements of Static Permittivity	14
7. Tables of Fitted Relaxation Parameters	15
8. Tables of Measured and Best-fit Complex Permittivity Data.....	19
9. Results of χ^2 Testing of Fitted Relaxation Models.....	80
10. Validation using new measurements	83
11. Acknowledgements.....	86
12. References.....	87

In this second issue of report MAT 23 (January 2012), some minor changes have been made, and *notes 31–33* on pages 11–12 have been added. *Notes 31–32* report the conclusions from two studies of the validity of the relaxation models (tabulated in Section 7) over an extended frequency range:

- (i) Even pure samples of polar liquids can have significant ionic conductivity, which will affect the complex permittivity (predominantly the imaginary part) at the low-frequency end of the spectrum. A study of the effect of ionic conductivity on the validity of the data at frequencies below 30 MHz is reported on in *note 31*. This was based on further analysis of our measurements and on a literature review.
- (ii) Relaxation models were applied at frequencies up to 10 GHz in some simple experiments using the fitted parameters given in Section 7. For three of the liquids (methanol, ethanediol and DMSO) we obtained evidence that extrapolated complex permittivity maintains a good level of accuracy at frequencies up to 10 GHz – see *note 32*.

None of the tables of data have been changed.

1. Introduction

1.1 The NPL Reference Liquid Measurements Programme 1997-2000

Reference materials are required for calibrating and testing instruments that are used for dielectric measurement. Pure liquids make particularly good reference materials, as they are completely uniform and homogeneous (unlike many solid materials), and if they are of sufficient purity their properties vary negligibly from one sample to another. The liquids measured in this programme also have the advantage of being readily available commercially. The main purpose of the 1997-2000 programme was to obtain measurements of the complex permittivity of common polar liquids (i.e. those with polar molecules), largely alcohols, for the benefit of users of dielectric instrumentation. This programme follows on from similar work carried out at NPL a decade earlier [4, 5], but it covered a wider range of frequencies and temperatures, and employed improved instrumentation and techniques. The results of the 1997-2000 programme were originally published in NPL Report CETM 33 [1] in 2001. Since the publication of that report, the authors have undertaken further analyses of the data that have enabled a better model for the measurement uncertainties to be employed, as reported here. This report therefore supersedes Report CETM 33. Two papers [2, 3] have been written describing in detail the measurement techniques used, so the descriptions given here are brief. In further work [6], it has been demonstrated that the data can be used for calibrating and testing coaxial sensors accurately to achieve consistency between measurements.

At RF and microwave frequencies polar liquids exhibit high permittivity and loss and a distinctive relaxation behaviour that can usually be described empirically using simple formulae such as those derived from the Debye relaxation equation (Section 2). The measurements presented here are particularly relevant for Specific Absorption Rate (SAR) metrology on radio-frequency emitting devices such as mobile phone handsets, because the complex permittivity of human tissue is similar in magnitude to that of the polar liquids measured. Data previously available in the scientific literature has often been patchy in temperature and frequency coverage, and in some cases the uncertainty and traceability of the measurements cannot be determined. What is more, some of the literature sources contradict each other on the dielectric properties of the liquids (this is discussed further in reference [4]). Published literature on methods for measuring polar liquids has been reviewed by the present authors [7]. Reference [7] also cites a number of other sources of published data.

1.2 Summary Description of the Data Supplied in this Report

This report contains measured data (Sections 6 and 8), dielectric relaxation parameters obtained by fitting to the data (Section 7) and a set of numbered notes (Section 4) giving guidance on various aspects of the data provided. Users of this report should read these notes carefully. The relaxation equations are described in Section 2: it should be noted that the choice of model has been made purely on the basis of *best fit over the range of frequencies measured*. The aim is to simplify the use of this data in metrological applications: no attempt is made to derive a physical explanation of the processes underlying these relaxations, and no implication is made that the equations employed will be valid outside the frequency range measured (i.e. above 5 GHz). In Section 9, computed values of the standard ‘chi-squared’ statistical measure of ‘goodness of fit’, χ^2 , are tabulated. Finally, in Section 10 some new

measurements on ethanediol are presented. These measurements were performed in different cells from those used in the 1997-2000 programme as an additional check on the measurements and uncertainty evaluations within this report.

Measurements of complex permittivity were made in the frequency range 30 MHz to 5 GHz using coaxial cells and vector network analysers [3, 4]. The temperature range was 10 °C to 50 °C. One reflection cell (for 30 MHz to 1 GHz) and two transmission cells of different lengths were used: a 14-mm cell for 1 GHz to 5 GHz, and a 40-mm cell for 0.6 GHz to 3 GHz. The coaxial cells were made from precision coaxial line having a 14.29 mm inner-diameter outer conductor (commonly called '14 mm line'). Using three measurement cells for each liquid reduces uncertainties, extends the measured frequency range and increases confidence in the measurements; see Figure 1. As the frequency 1 GHz is within the range of all three cells, measurements at this frequency can be compared directly. There are slight differences in the results presented compared to those given in the report CETM 33 [1]. These are due some additional minor corrections for mechanical imperfections in the measurement cells. The uncertainty analysis has also been improved.

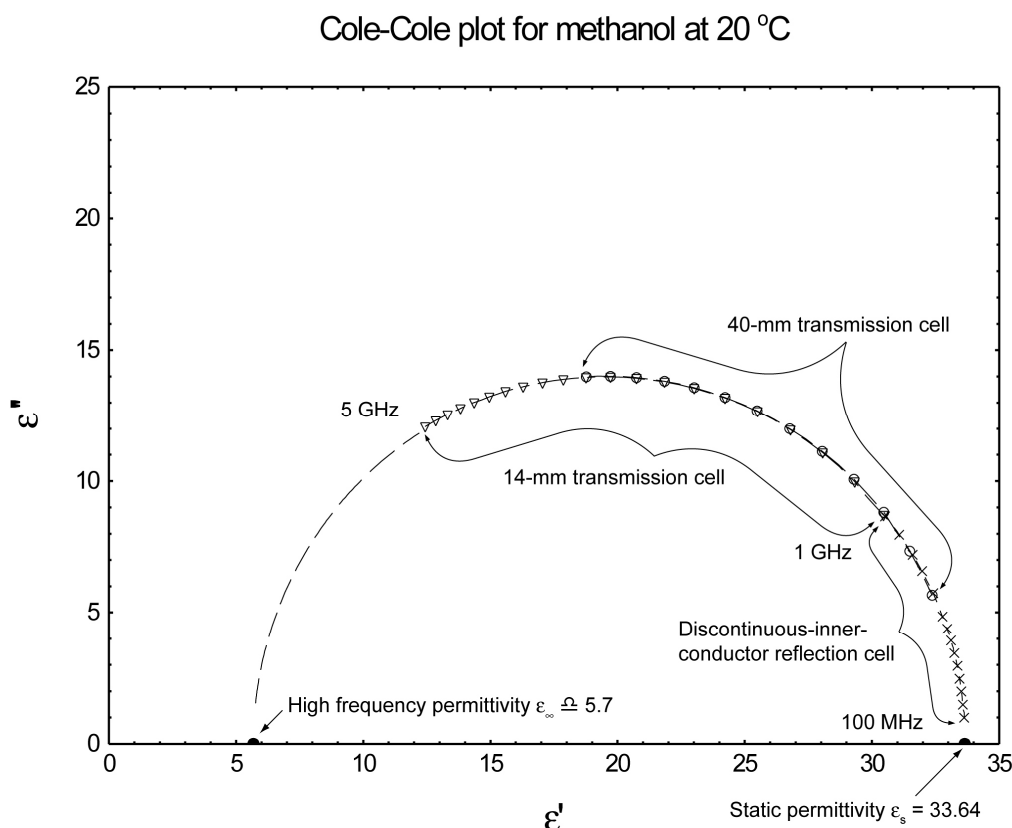


Figure 1: Cole-Cole (single-Debye) plot for methanol at 20 °C, showing all three sets of data, plus the admittance-cell measurement of 'static' permittivity. Uncertainty bars are not discernible on this scale, so have not been plotted. The extrapolated high-frequency permittivity ignores the effects of high-order microwave relaxations and molecular vibrational phenomena that occur in the infrared, and is therefore higher than the square of the optical refractive index.

Static (low frequency) permittivity (tabulated in Section 6) was measured using a micrometer-driven parallel-electrode admittance cell [2]. The cell was used in earlier work at NPL, but for this programme of measurements it was partly re-designed to improve temperature control. For most of the liquids, measurements were at 5° intervals between 5 °C and 50 °C. Two non-polar (low permittivity, low loss) liquids, cyclohexane and Dow-Corning 200 1cS silicone fluid (polydimethylsiloxane), were measured. The polar liquid water was also measured. Reliable low-frequency data for water and cyclohexane are available from other sources [8] (see reference [2] for further discussion), so these are useful as check measurements to increase confidence in this work.

Uncertainties associated with individual complex permittivity measurements were calculated on the basis of the evaluated uncertainties of “input” quantities, such as cell dimensions and S-parameters, using the propagation of uncertainties method given in *UKAS Technical Report M3003* [9] and the *JCGM Guide to Uncertainty in Measurement* [10]. Relaxation parameters determined from the combined data are given in Section 7. These enable complex permittivity to be calculated easily at any arbitrary frequency within the measurement range. Permittivity values derived in this way should, in general, have smaller associated uncertainties than those of the individual measurements.

The tables in Section 8 contain both measured data and ‘best-fit’ data (i.e. data calculated using the fitted relaxation parameters). In almost all cases there is good agreement between the measurements in the coaxial cells and the fitted data. All of the liquids except ethanediol were found to be fitted well by single-Debye, Debye- Γ or double-Debye models within the frequency range of the measurements. Ethanediol data has been fitted by the Davidson-Cole equation. These equations are stated in Section 2, below.

Most of the liquids are fitted by the same relaxation equation at all temperatures. For propan-1-ol, propan-2-ol and butan-1-ol, the double-Debye equation is used where possible, but at the highest temperatures reliable fits cannot be obtained (as the frequency of the second relaxation is too far above the measured range) so the Debye- Γ equation is used instead. Relaxation parameters for both equations are presented for these liquids in Section 7. The equation that is believed to be most satisfactory is used for computing the ‘best-fit’ data shown in the tables in Section 8. The equation used for this is specified in every table in Section 8.

The uncertainties associated with fitted relaxation-equation parameters (Section 7) are evaluated by means of Monte Carlo modelling [3, 11]. This is an advance over the approach taken in report CETM 33 as the systematic frequency dependence of errors in the measured data can now be taken into account. The uncertainties associated with the fitted relaxation parameters themselves are given in Section 7; however a warning should be issued about their use. Strictly, a full correlation analysis (employing covariance matrices with non-zero off-diagonal elements) is required if uncertainties associated with complex permittivities at specific frequencies are to be computed from them – it is formally not sufficient to use the uncertainties associated with the individual fitted model parameters that are given in this report. To overcome this problem, and for the convenience of users of this data, pre-calculated uncertainties associated with the ‘best-fit’ data, based on the appropriate relaxation models, are also tabulated in Section 8 as this avoids the extra complexity of computation using correlation matrices. The mechanism by which these uncertainties were obtained is described in reference [3]. Uncertainties at intermediate frequencies not listed in the tables can be estimated by linear interpolation (see the example in Section 1.3).

Although the authors have taken a thorough approach to uncertainty evaluation, unforeseen experimental errors will inevitably have occurred. A small uncertainty contribution, whose magnitude is based on practical experience with such measurement cells, has therefore been added in quadrature to the uncertainties associated with the ‘best-fit’ data to allow for these errors. For all liquids except propan-2-ol this contribution to the uncertainty is taken to be as follows: for the real part of complex permittivity 0.3 % (for a coverage factor of $k = 2$) of the *change* in the measured permittivity from the *static* value; for the imaginary part 0.3 % (at $k = 2$) of the measured permittivity. This scheme is based on the fact that confidence in the values of the static permittivity, as measured in the admittance cell, is high and so they can to some extent be used to “anchor” the ‘best-fit’ values at lower frequencies (e.g. up to 500 MHz). For propan-2-ol, for which no admittance cell measurements of static permittivity are available, the minimum uncertainty is taken to be 0.3 % (at $k = 2$) for both real and imaginary parts of the permittivity.

In some cases there is a slight divergence between ‘best-fit’ modelled data and the actual measurements at the higher frequencies (indicated by ‘boxes’ in the tables in Section 8 – see *notes 25 and 30*). This is most likely due to the fact that the particular relaxation equation used does not describe the behaviour of the liquid exactly, e.g. because of the influence of a higher-order relaxations, although it could also indicate experimental error. In all cases the uncertainties associated with the ‘best-fit’ data are sufficient to account for the divergence.

Particular note should be taken of the ‘best-fit’ values at zero frequency. The static permittivity value for each liquid was not taken as a parameter to be fitted in the modelling; rather, the *measured* value obtained using the admittance cell [2] was assumed to be the correct value for the *real* permittivity (propan-2-ol is the only an exception here because no admittance cell data is available for it, see *note 30* in Section 4). Thus, for liquids that have a high relaxation frequency, such as dimethyl sulphoxide, it can be seen that at 0.1 GHz (the lowest frequency presented in the tables), the real part of permittivity and its associated standard uncertainty are very close to the values given in the static permittivity table in Section 6. Note also that the *imaginary* permittivity of all liquids is taken to be identically equal to zero at zero frequency in all the relaxation equations¹. Therefore it is inevitable that at the lowest frequencies the uncertainty associated with the imaginary part of permittivity of the ‘best-fit’ data tends also towards zero.

¹ The relaxation models used do not include an ionic conductivity term, but if the ion concentration is low (which we would expect for pure liquids) ionic conduction is negligible at frequencies above ~30 MHz. The ‘best-fit’ data here is presented for use at RF and microwave frequencies only; there is no implication that the conductivity, imaginary permittivity or loss will actually be close to zero for any real liquid at low frequencies (see *note 31*). Note also that the admittance cell measurements of ‘static’ permittivity were actually made at a minimum frequency of 200 kHz to avoid electrode polarisation effects.

1.3 Frequency and Temperature Interpolation Example – Permittivity of Methanol at 2.2 GHz and 22.0 °C

The complex permittivity of methanol at 2.2 GHz at 5 °C steps can be computed by substituting the relaxation parameters given on pages 15–17 into eqn. (1). No data at 22.0 °C is provided, but the complex permittivity at this temperature may be estimated using an interpolation technique. Between the two nearest temperatures (20 °C and 25 °C) linear interpolation gives $\epsilon' = 23.33$ and $\epsilon'' = 13.24$ at 22 °C. Quadratic interpolation (i.e. using a function of the form $y = ax^2 + bx + c$ to connect three points) will give marginally improved accuracy. Use of quadratic interpolation between the three nearest temperatures (15 °C, 20 °C and 25 °C) gives $\epsilon' = 23.35$ and $\epsilon'' = 13.24$ at 22 °C. Investigations have shown that linear interpolation will in almost all cases suffice. For the worst case (ethanediol at frequency 0.9 GHz and temperature 17.5 °C) the discrepancy between the two interpolations is 0.1 in ϵ'' , approximately equal to the uncertainty of the ‘best-fit’ data.

Evaluations of the associated standard uncertainty can be obtained by linear interpolations from the ‘best-fit’ uncertainties given in tables on pages 55 and 56 (columns 3 and 5) to the required frequency and temperature. These uncertainties vary little between 2.0 GHz and 2.5 GHz, and between 20 °C and 25 °C, and there is no reason to suppose that they should be significantly larger or smaller at frequencies and temperatures between these. Hence we obtain $\epsilon' = 23.35 \pm 0.07$ and $\epsilon'' = 13.24 \pm 0.05$ at 22 °C (uncertainties for coverage factor $k = 2$).

The above figures lack a contribution for temperature uncertainty. If the methanol is to be used as a reference sample, then the temperature should be monitored using a calibrated thermometer. Suppose that the uncertainty of the temperature of the methanol (22 °C) is ± 0.4 °C (for coverage factor $k = 2$) arising from the uncertainty associated with the calibration of the thermometer and perhaps an allowance for non-uniformity due to evaporative cooling. From *note 15* we know that the methanol measurements at 20 °C and 25 °C given in this report have an associated temperature measurement uncertainty of ± 0.1 °C for coverage factor $k = 2$. Therefore the expanded uncertainty associated with the temperature measurements is $\sqrt{(0.4 \times 0.4 + 0.1 \times 0.1)} = 0.41$ °C. The equivalent standard uncertainty associated with permittivity at 22 °C is easily evaluated as 0.06 (real part) and 0.07 (imaginary part). These uncertainties can be combined in quadrature to those given above. Hence, the real and imaginary parts of complex permittivity that would be observed accounting for the total temperature measurement uncertainty are $\epsilon' = 23.38 \pm 0.09$ and $\epsilon'' = 13.21 \pm 0.09$ for coverage factor $k = 2$. This analysis follows the *UKAS Technical Report M3003* [9] and the *JCGM Guide to Uncertainty in Measurement* [10].

2. Relaxation Equations

For a polar liquid that exhibits single-Debye relaxation behaviour, the tabulated values of the static permittivity (ϵ_s), the relaxation frequency (f_r) and the high-frequency permittivity limit (ϵ_∞) given in Section 7 allow the complex permittivity (ϵ^*) to be calculated at a given frequency (f) using the equation

$$\epsilon^* = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 + jf/f_r}, \quad (1)$$

where $\epsilon^* = \epsilon' - j\epsilon''$ and $j^2 = -1$. Note that ϵ' and ϵ'' , the real and imaginary parts of permittivity, are both positive numbers. Eqn. (1) is usually referred to as the **Debye relaxation equation** or the **Debye relaxation function**. A plot of ϵ'' vs ϵ' for eqn. (1), often referred to as a Cole-Cole plot, is shown in figure 1.

For a dielectric with two dielectric relaxations (**double-Debye**) this equation becomes:

$$\epsilon^* = \epsilon_\infty + \frac{\epsilon_s - \epsilon_h}{1 + jf/f_{r1}} + \frac{\epsilon_h - \epsilon_\infty}{1 + jf/f_{r2}}. \quad (2)$$

where f_{r1} and f_{r2} are the relaxation frequencies of the two relaxations and ϵ_h is the notional high frequency permittivity limit of the lower frequency relaxation. The maximum frequency of the NPL data is 5 GHz. When a second relaxation at a frequency of greater than approximately 8 GHz was present, we were not able to obtain satisfactory fits to eqn. (2), even though the second relaxation has a significant effect upon ϵ^* . Satisfactory fits were instead made to a simplified version of eqn. (2), in which the positive quantity Γ represents the “tail” of the second relaxation:

$$\epsilon^* = \epsilon_H + \frac{\epsilon_s - \epsilon_H}{1 + jf/f_r} - jf\Gamma. \quad (3)$$

We refer to this as the **Debye- Γ relaxation equation**. Eqn. (3) is found to provide an acceptable level of accuracy at frequencies up to approximately a third of the frequency of the second relaxation. In equation (3), f_r refers to the first (i.e. lowest) relaxation, but the suffix ‘1’ has been dropped for convenience.

None of the above equations was found to describe the behaviour of ethanediol adequately over the full measured frequency range. The data is fitted instead by the **Davidson-Cole equation** (eqn. (4)), which is found to be appropriate over this frequency range. The parameter β is positive and smaller than unity.

$$\epsilon^* = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{\left(1 + jf/f_r\right)^\beta}. \quad (4)$$

Elsewhere in this report, the terms *single-Debye*, *double-Debye*, *Debye- Γ* and *Davidson-Cole* are used to indicate eqns. (1) to (4) respectively.

In many publications, eqn. (1) is written as:

$$\epsilon^* = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 + j\omega\tau}, \quad (5)$$

where τ is the relaxation time. The relaxation time is related to the relaxation frequency by $\tau = (2\pi f_r)^{-1}$.

Note that none of the above equations includes a term for ionic conduction. If the ionic conductivity is low (which would be expected for the pure liquids measured here) there is negligible effect on the complex permittivity at RF frequencies.

3. Warnings and Disclaimer

Great care is needed when using dielectric reference liquids as they are easily contaminated and, if allowed to evaporate, they can change temperature very rapidly. The parameterisation of their dielectric properties using the single or double-Debye or related relaxation equations can only be valid over a limited frequency and temperature range. For these reasons careful attention should be given to the notes in this document on the use of the liquids. Some of the liquids are flammable and/or toxic, so standard safety procedures and COSHH guidelines should be followed when they are being used.

The authors of this report hope that the information within it will prove to be useful to others. Several measurement techniques have been employed to increase confidence in the measurements and uncertainty evaluations. However, an underlying metrological problem in this type of RF and Microwave measurement is the fact that the dominant uncertainties relate to systematic errors, which makes them difficult to evaluate. In revising this report, the authors have committed considerable effort to devising models that describe these uncertainties. Despite these improvements, the data presented here may be subject to amendment if better data becomes available. For these reasons the National Physical Laboratory cannot be held liable for any consequences arising from the use of this data elsewhere. The authors have produced two papers on the work [2, 3] so that the techniques that were used can be scrutinised by other workers in the field. We would like to propose that similar careful programmes of measurement should be undertaken in other laboratories, and that the results should be compared with the intention of reaching an international agreement on the properties of these dielectric reference liquids.

4. Advisory Notes on Use of the Tables

The numbered notes below provide guidance on how the data was obtained, and how it should be used. Notes 1–16 give general information about the data within this report. Notes 17–23 are relevant to the admittance cell measurements (Table 6). Other notes apply to Tables in Sections 7 and 8. Where appropriate, cross-references to these notes accompany the Tables.

1. The measurements are traceable to UK National Standards of length, frequency, impedance and attenuation.
2. The results presented are based on measurements of high-purity grades of liquid taken directly from newly opened bottles obtained from commercial chemical suppliers (see Section 5). This contrasts with some of the literature data, where ultra-pure samples have been especially prepared. In previous work at NPL no significant property differences have been found between high-purity samples of high loss liquids sourced from different suppliers, but it should be noted that the uncertainties presented do not account for variations in composition.
3. Users are advised always to use fresh samples of dielectric liquid, as a number of these liquids are hygroscopic (i.e. they absorb water from the atmosphere, which changes their dielectric properties). Certain liquids may also be subject to oxidation if left exposed to the atmosphere. Most of the liquids are volatile, so evaporative cooling can significantly change their dielectric properties. In general, guidelines for dielectric liquid handling presented in the NPL *‘Guide to the characterisation of dielectric materials at RF and microwave Frequencies’* [12] are recommended.
4. Dimethyl sulphoxide (DMSO) and ethanediol are found to be particularly hygroscopic. A beaker of either liquid left exposed to air is observed to increase in temperature as a result of exothermic reaction, and at the same time the real part of permittivity is observed to increase. Any laboratory using these liquids should be aware of these problems.
5. Measurements are given in 5 °C steps. Permittivity is observed to vary fairly linearly with temperature, so interpolation allows values at intermediate temperatures to be estimated. Simple linear interpolation will often be sufficient, although quadratic interpolation will generally give better accuracy. An example is given in Section 1.3. Static permittivity and other relaxation parameters can also be interpolated to other temperatures if required.
6. Columns 2–5 in the Tables listed in Section 8 give the ‘best-fit’ permittivity, and the associated expanded uncertainty obtained by Monte Carlo modelling at selected frequencies. The authors have followed a thorough approach to uncertainty evaluation, but nevertheless unforeseen experimental errors could have occurred. For this reason the ‘best-fit’ standard uncertainties presented include a minimum uncertainty that has been added in quadrature. For more information about the evaluations of uncertainty see Section 1.2 and reference [3].
7. The ‘best-fit’ data given at selected frequencies in columns 2–5 in the tables in Section 8 are computed from the relaxation parameters given in Section 7. Linear interpolation can be used to evaluate the uncertainty associated with the ‘best-fit’ data at frequencies and temperatures between those listed in the tables in Section 8 – see the example in Section 1.3. Note that *one should not* evaluate the complex permittivity *uncertainty* for any given frequency and temperature directly from the uncertainties associated with the relaxation

parameters given in Section 7. This will lead to erroneous values for the uncertainties because no correlation data are presented in the tables. Correlations *have* been taken into account, however, in the individual uncertainties presented in the tables, so interpolation is the best approach to use to derive uncertainties associated with frequencies and temperatures not explicitly included in the tables.

8. For this new report the measured data has been re-processed. Although they are small, cell expansion effects at temperatures above and below room temperature are now more thoroughly accounted for. A more comprehensive uncertainty evaluation has been used than was possible in Report CETM 33. Several uncertainty contributions have been reduced in magnitude, and in many cases overall measurement uncertainties are appreciably reduced.
9. The fitted relaxation parameters and their associated uncertainties (Section 7) were obtained from data at many more measurement frequencies than can be included in the Tables in Section 8.
10. To help to identify experimental errors every set of measurements began and ended with measurements at 20 °C, which were compared as a check. Furthermore, for each liquid a measurement at 20 °C was performed on at least two separate occasions in each cell.
11. Uncertainties are derived in accordance with references [9] and [10], and are stated as expanded uncertainties with a coverage factor of $k = 2$, approximately equivalent to a 95 % confidence interval.
12. Permittivity expanded uncertainties in the Tables of data (Section 8) that were evaluated as being less than 0.01 have been rounded up to 0.01.
13. Some of the data may appear to be presented with more decimal places than is strictly necessary. The reason for this is that rounding to fewer decimal places would in these cases obscure trends in the data that are much smaller than the absolute uncertainties, but are nevertheless significant as permittivity changes.
14. The expanded uncertainties associated with the measured data, ‘best-fit’ data, and fitted relaxation parameters (Sections 6, 7 and 8) do not include contributions associated with the temperature measurement. Users of the data in this report should combine the uncertainty associated with the temperature of the reference sample that is being used with the uncertainty given in *note 15*. A simple calculation (Section 1.3) allows an evaluation of the uncertainty associated with the ‘best-fit’ permittivity that includes an overall temperature contribution to be made.
15. Uncertainties associated with the temperature of the measurements presented here are taken to be ± 0.2 °C at 40 °C and above, and ± 0.1 °C at all other temperatures (both at coverage factor $k = 2$).
16. The evaluations of uncertainty have been subject to careful scrutiny in preparing this report. In nearly all cases the data from the new analysis is self-consistent and plausible. Discrepancies between the measurements made using the three coaxial cells are observed to be larger for the two highest permittivity liquids, DMSO and ethanediol. Additional measurements on ethanediol were performed in 2008–9; see Section 10. These measurements provide evidence that supports the view that, despite the discrepancies observed, the ‘best-fit’ values, and their associated uncertainties, have not been subject to errors significantly greater than those accounted for by the uncertainties quoted.

17. Static permittivity ϵ_s was calculated from measurements of AC capacitance in the frequency range 200 kHz to 1 MHz [2]. For pure polar liquids without ionic contaminants at these frequencies measurement errors in the real part of the permittivity caused by electrode polarisation effects and direct conductivity between the electrodes become negligible, yet the real part of the permittivity differs insignificantly from its ‘static’, i.e. notional DC, value (as can be confirmed by computation from the relaxation equations for these frequencies).
18. The static permittivity results for acetone (Section 6) at 45 °C and 50 °C are shown italicised since bubbling in the liquid occurred within the admittance cell, which might have affected the results. The boiling point of acetone is 56 °C.
19. The non-polar liquids cyclohexane and silicone fluid have very low loss and therefore almost constant permittivity throughout the measured frequency range. The admittance cell used is not of ideal design for measurements on low-loss low-permittivity liquids, but the measurements have proved useful as a check on our uncertainty evaluation procedures. The static permittivity results given for cyclohexane, a long-established dielectric reference liquid, are consistent with those given by Kienitz and Marsh [8].
20. The admittance cell used here was designed for measurement of static permittivity in the range 5 to 40. Static permittivity measurements on water (which has higher permittivity) were undertaken to enable the results to be compared to those of Kienitz and Marsh [8], Ellison [13] and Kaatze [14] to increase confidence in results for the other liquids. The data presented is not intended to replace that published in these papers. The measurements of the static permittivity of water were made on distilled samples. However, there is every reason to believe that deionised (low DC conductivity) water will have virtually identical dielectric properties.
21. Since the publication of Report CETM 33, a minor correction to the static permittivity measurements has been made for electrode expansion. In the worst case, that of water at 50 °C, the permittivity is reduced from 70.06 to 69.99. At 20 °C there is no correction. Where appropriate, other tables in the report have been re-calculated.
22. Since the publication of Report CETM 33, evaluated uncertainties associated with the measurements of the static permittivity of water have been slightly increased, following a re-evaluation of the data. As stated in *note 15*, the measurements on water were undertaken only for validation purposes.
23. The relaxation frequencies of water and acetone are much higher than the maximum frequency that could be measured using the available equipment; hence only the static permittivity results are given.
24. The tabulated static permittivities (in both Sections 6 and 7) are admittance cell low-frequency measurements [2]. The remaining relaxation parameters (eqns. (1)–(4)) were determined by fitting to the combined coaxial cell high-frequency measurement results [3]. The reason for choosing this strategy instead of obtaining all the relaxation parameters at once from admittance cell and coaxial cell data combined is that the uncertainties associated with the admittance cell are thought to be better understood.
25. The fitted relaxation parameters and their associated expanded uncertainties (Section 7) were obtained with the assumption that the model used (eqns. (1)–(4)) can accurately describe the dielectric behaviour within the frequency range of the data. Results for all the polar liquids were each successfully fitted to one of the relaxation equations. These

measurements only extended up to 5 GHz. Measurements at higher frequencies would for many of the polar liquids (particularly those with longer-chain molecules) reveal additional relaxations, which the fitted parameters do not describe. For a number of liquids, the presence of a second relaxation at a higher frequency is evident from the data, but the frequency range of data was not sufficient to allow its fitting to eqn. (2) (double-Debye). For these liquids data has been fitted to eqn. (3) (Debye- Γ) instead. Very approximately, this equation is accurate to within the quoted uncertainties up to a third of the frequency of the second relaxation. In some of the tables a box has been placed over 'best-fit' data where the trend of the data would suggest that the Debye- Γ relaxation equation is approaching its upper frequency limit.

26. For propan-1-ol, propan-2-ol and butan-1-ol, liquids, parameters for both double-Debye (eqn. 2) and Debye- Γ (eqn. 3) equations are given in Section 7. At the highest temperatures the frequency of the second relaxation is so far above the measured range that it becomes impossible to obtain a reliable fit to the double-Debye equation; hence data is only given for the Debye- Γ equation. However, it should be noted that in some cases (e.g. propan-1-ol at 35 °C) there is significant divergence between the Debye- Γ equation and the data at the highest frequencies – see *note 25*. The equation that was used for computing the 'best-fit' values and the uncertainties given is specified in every table in Section 8. For propan-2-ol the static permittivity is fitted using the high-frequency data because a measurement using the admittance cell was not made – see *note 30*.
27. The frequency range for the measurements on ethanol is sufficient only to allow reliable fitting by the Debye- Γ equation. However, as there is a second Debye relaxation, the real part of permittivity diverges from the Debye- Γ equation at frequencies above 4 GHz. Where appropriate a box has been placed over the 'best-fit' data to indicate this. The quoted uncertainties are adequate to account for the discrepancy at the measured frequencies – see *note 25*. If the Debye- Γ equation is applied at frequencies much above 5 GHz, significant errors can be expected. In a future report, the authors intend to publish data for ethanol at higher frequencies.
28. During measurements using the coaxial cells, liquid samples were circulated through pipes for a number of hours as part of the temperature control system, by means of a peristaltic pump. As some of the liquids are hygroscopic, exposure of liquids to air was kept to a minimum. There is a greater chance of water absorption from the air occurring in the coaxial cell measurements than in the static permittivity measurements. This is because the latter were made in a sealed system. The uncertainties shown do not include a contribution for this possible effect.
29. The ethanediol results are fitted to the Davidson-Cole equation. This is a change from Report CETM 33. See *note 33*.
30. Measurements on propan-2-ol were made only in the 40-mm transmission cell (up to 3 GHz), and the reflection cell. No admittance-cell measurements of static permittivity were undertaken, and there are no published data available that the authors considered to be reliable enough to use. Therefore the 'best-fit' static permittivity was obtained by fitting to high frequency data only. The fact that there is no static permittivity value to act as an 'anchor' means that differences between the actual behaviour and that predicted by the relaxation equation can be apparent at low as well as high frequencies. Therefore the 'best-fit' ϵ_s values published in Section 7 of this report are expected to show deviations from measurements that would be obtained using an admittance cell ("boxes" are used to highlight deviations at the lowest frequencies in some of the Tables in Section 6). The

double-Debye equation is expected to provide a more accurate value for static permittivity than the Debye- Γ equation, but it was only possible to fit the double-Debye equation to the complex permittivity data at the lower temperatures.

31. The relaxation equations used in this report assume that there is no conduction from free ions and electrons, but in practice polar liquids can exhibit significant conduction at the lowest frequencies, causing actual values of the imaginary part of permittivity to deviate from those calculated. This effect is not significant for the measurements on pure samples that are presented in this report at the measured RF frequencies, i.e. 30 MHz and above, but users of this report should be aware that the relaxation equations may not be reliable if applied at frequencies below ~ 10 MHz. Measurements obtained using the reflection cell show that the imaginary part of measured permittivity increases rapidly as the frequency is reduced below 10 MHz. While uncertainties at these frequencies are large, methanol showed a more rapid increase than any of the other liquids, suggesting a higher conductivity (see *note 32*).

If complex permittivity ϵ^* is calculated at frequencies of ~ 10 MHz and below using the relaxation equations on pages 5 – 6, a correction for ionic conductivity σ could in principle be applied. Corrected permittivity is given by $(\epsilon^*)_{\text{corr}} = \epsilon^* - j\epsilon_c''$ where $\epsilon_c'' = \sigma / (2\pi f \epsilon_0)$. The quantity ϵ_0 is the permittivity of free space, 8.854×10^{-12} F/m, and f is the frequency in Hz. A satisfactory correction may not be possible because: (i) Even a small amount of ionic contamination has a large effect. (ii) There are electrode polarisation effects [2] in systems that use metal electrodes. These vary considerably according to the cleanliness and surface condition of electrodes. For pure polar liquids the effect on the real part of permittivity is almost negligible above 100 kHz (see *note 17*), but for the imaginary part this may not be the case. (iii) To the authors' knowledge, published conductivity data presently available for the polar liquids measured here is very limited. (iv) It is normally assumed that σ is a purely real quantity that does not vary with frequency, but this might not be the case: theoretical models for the conductivity of weak electrolytes (such as the Debye-Falkenhagen effect [15]) predict that σ varies with frequency and is complex. Such effects, if they occur, appear to be small [16].

Our measurements with the reflection cell when compared with 500 Hz conductivity data given in reference [17] provide some limited evidence that σ is frequency independent. Methanol has a higher intrinsic conductivity than the other pure liquids measured (or water), so it is the best liquid to consider here. The conductivity of methanol [17] is given as $\sigma = 1207 \times 10^{-7}$ S/m at 20 °C from which we compute $\epsilon_c = 0.07$ at 30 MHz. At this temperature and frequency we measured $\epsilon'' + \epsilon_c = 0.32 \pm 0.22$. From Debye equation parameters (page 17) we calculate $\epsilon'' = 0.30$. While this is consistent, the measurement uncertainties at these frequencies are clearly too large to make this test definitive.

32. While it is possible to apply relaxation models at frequencies above the maximum frequency of the measurements (5 GHz) errors in the computed permittivity will occur for significant extrapolations (see *note 25*). In the case of ethanol, the Debye- Γ equation used here has reached its upper limit by 5 GHz. However, recent measurements at NPL have demonstrated that good accuracy is maintained at frequencies up to at least 10 GHz for three liquids: methanol (single-Debye equation), DMSO (single-Debye equation) and ethanediol (Davidson-Cole equation). These are also the most useful of the measured liquids at frequencies above 5 GHz as they have the highest permittivity.

5. Purities of the Measured Liquids

The information below is obtained from the manufacturers' data sheets.

Liquid	Min. assay	Max. water content
Acetone	99.5%	0.1%
Butan-1-ol	99.5%	0.1%
Cyclohexane	99.8%	0.01%
Dimethyl sulphoxide	99.5%	0.1%
Ethanediol	99.5%	0.1%
Ethanol	99.8%	0.2%
Methanol	99.8%	0.05%
Propan-1-ol	99.5%	0.1%
Propan-2-ol	99.7%	0.1%
Dow-Corning 200 1cS Silicone fluid (polydimethylsiloxane)	N/A	N/A

6. Table of Admittance Cell Measurements of Static Permittivity

Temperature °C										
	5	10	15	20	25	30	35	40	45	50
Acetone	22.80±0.04	22.21±0.04	21.65±0.04	21.13±0.04	20.59±0.04	20.10±0.04	19.60±0.04	19.12±0.04	18.68±0.04	18.19±0.04
Butan-1-ol	20.25±0.04	19.54±0.04	18.86±0.04	18.19±0.04	17.53±0.04	16.89±0.04	16.26±0.04	15.65±0.04	15.03±0.04	14.44±0.04
Cyclohexane		2.040±0.002	2.033±0.002	2.024±0.002	2.015±0.002	2.008±0.002	2.000±0.002	1.992±0.002	1.984±0.002	1.975±0.002
Dimethyl - Sulphoxide	Below melting point (18 °C)									
Ethanediol	45.60±0.06	44.31±0.06	43.08±0.06	41.89±0.06	40.75±0.06	39.66±0.06	38.60±0.06	37.63±0.06	36.63±0.06	35.71±0.06
Ethanol	27.66±0.04	26.79±0.04	25.95±0.04	25.16±0.04	24.43±0.04	23.64±0.04	22.88±0.04	22.16±0.04	21.45±0.04	20.78±0.04
Methanol	36.86±0.06	35.74±0.06	34.68±0.06	33.64±0.06	32.66±0.06	31.69±0.06	30.78±0.06	29.85±0.06	28.95±0.06	28.19±0.06
Propan-1-ol	23.37±0.04	22.61±0.04	21.88±0.04	21.15±0.04	20.42±0.04	19.75±0.04	19.07±0.04	18.40±0.04	17.76±0.04	17.11±0.04
Silicone fluid	2.351±0.002	2.336±0.002	2.322±0.002	2.307±0.002	2.294±0.002	2.279±0.002	2.265±0.002			
Water	86.04±0.20	84.04±0.20	82.15±0.20	80.29±0.20	78.55±0.20	76.68±0.20	75.02±0.20	73.31±0.20	71.64±0.20	69.99±0.20

Comments:

Further information on the measurements in this table is given in reference [2].

Uncertainties are shown at coverage factor $k = 2$, approximately equivalent to 95 % Confidence Level.

Temperature measurement uncertainties are not included in the uncertainties given above.

The estimated temperature uncertainties are $\pm 0.2^\circ\text{C}$ for 5, 40, 45 and 50°C measurements, and $\pm 0.1^\circ\text{C}$ for all other measurements.

Acetone measurements at 45 and 50°C are shown italicised as they may have been affected by bubbles within the measurement cell (the boiling point of acetone is 56°C).

The silicone fluid is Dow-Corning grade 200 polydimethylsiloxane (1 centiStokes).

Propan-2-ol was not measured in the admittance cell in this programme, and so is omitted from the table.

Water and cyclohexane were measured so that the accuracy of the admittance cell could be tested by comparison with reference [8].

If polar liquids are measured in cells with electrodes, electrode polarisation effects will cause the apparent permittivity to be larger than the tabulated values at frequencies below $\sim 100\text{ kHz}$ – see reference [2]. The error increases rapidly as the frequency drops and at LF can be very large indeed. If ionic contaminants are present these effects will be greater and can be significant at frequencies well above 100 kHz .

7. Tables of Fitted Relaxation Parameters

In the tables below, uncertainties are shown at coverage factor of $k=2$, approximately equivalent to 95 % confidence level. Temperature measurement uncertainties are not included in the overall uncertainties (see *note 14*) and Section 1.3. The estimated temperature uncertainties are ± 0.2 °C for 40, 45 and 50 °C measurements, and ± 0.1 °C for all other measurements (see *note 15*). For some of the liquids two tables are provided giving data fitted to different relaxation equations (see *note 26*). The recommended values at each temperature can be identified as they are shown in a non-italicised font.

Temperatures are given in °C and relaxation frequencies (f_r , f_{r1} and f_{r2}) are given in GHz.

Butan-1-ol (Debye- Γ , eqn. 3) – See note 26. Recommended range 45-50 °C.

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_H	unc.	Γ	unc.
10	19.54	0.04	0.171	0.001	3.412	0.014	0.079	0.002
15	18.86	0.04	0.212	0.001	3.422	0.013	0.075	0.002
20	18.19	0.04	0.261	0.001	3.406	0.009	0.068	0.001
25	17.53	0.04	0.322	0.001	3.416	0.013	0.066	0.002
30	16.89	0.04	0.397	0.002	3.418	0.014	0.061	0.003
35	16.26	0.04	0.487	0.003	3.419	0.014	0.058	0.003
40	15.65	0.04	0.596	0.004	3.418	0.017	0.054	0.004
45	15.03	0.04	0.728	0.005	3.418	0.018	0.051	0.005
50	14.44	0.04	0.883	0.007	3.416	0.022	0.047	0.007

Butan-1-ol (Double-Debye, eqn. 2) – See note 26. Recommended range 10-40 °C.

Temp.	ϵ_s	unc.	f_{r1}	unc.	ϵ_h	unc.	f_{r2}	unc.	ϵ_∞	unc.
10	19.54	0.04	0.167	0.001	3.528	0.016	4.878	0.354	2.914	0.027
15	18.86	0.04	0.207	0.001	3.527	0.016	5.259	0.452	2.914	0.033
20	18.19	0.04	0.257	0.001	3.505	0.010	5.865	0.416	2.900	0.026
25	17.53	0.04	0.318	0.002	3.506	0.016	5.979	0.861	2.921	0.052
30	16.89	0.04	0.393	0.002	3.501	0.019	6.433	1.232	2.923	0.074
35	16.26	0.04	0.483	0.003	3.493	0.021	7.234	2.019	2.902	0.115
40	15.65	0.04	0.592	0.004	3.484	0.024	8.139	3.349	2.883	0.181

7. Tables of Fitted Relaxation Parameters (continued)

Dimethyl Sulphoxide (Single-Debye, eqn. 1) – *See notes 4 and 33.*

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_∞	unc.
20	47.13	0.06	7.555	0.116	6.802	0.575
25	46.49	0.06	8.323	0.226	6.501	1.003
30	45.86	0.06	9.077	0.281	6.357	1.144
35	45.19	0.06	9.924	0.341	5.984	1.264
40	44.53	0.06	10.733	0.460	5.828	1.558
45	43.86	0.06	11.588	0.565	5.637	1.760
50	43.19	0.06	12.477	0.697	5.410	2.002

Ethanediol (Davidson-Cole, eqn. 4) – *See notes 4, 29 and 33, and Section 10.*

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_∞	unc.	β	unc.
10	44.31	0.06	0.599	0.006	4.543	0.079	0.833	0.006
15	43.08	0.06	0.764	0.008	4.568	0.104	0.841	0.008
20	41.89	0.06	0.962	0.009	4.745	0.110	0.856	0.008
25	40.75	0.06	1.190	0.017	4.700	0.210	0.859	0.014
30	39.66	0.06	1.451	0.025	4.712	0.297	0.864	0.018
35	38.60	0.06	1.756	0.034	4.739	0.410	0.871	0.024
40	37.63	0.06	2.101	0.049	4.840	0.538	0.879	0.031
45	36.63	0.06	2.484	0.065	4.782	0.702	0.880	0.039
50	35.71	0.06	2.912	0.096	4.856	0.984	0.885	0.053

Ethanol (Debye- Γ , eqn. 3) – *See note 27*

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_H	unc.	Γ	unc.
10	26.79	0.04	0.596	0.003	4.624	0.021	0.075	0.007
15	25.95	0.04	0.700	0.003	4.590	0.023	0.071	0.008
20	25.16	0.04	0.829	0.003	4.531	0.017	0.059	0.005
25	24.43	0.04	0.964	0.005	4.505	0.033	0.056	0.012
30	23.65	0.04	1.124	0.007	4.471	0.043	0.054	0.014
35	22.88	0.04	1.303	0.008	4.439	0.052	0.053	0.016
40	22.16	0.04	1.511	0.010	4.410	0.066	0.050	0.018
45	21.45	0.04	1.745	0.013	4.394	0.086	0.049	0.022
50	20.78	0.04	2.010	0.016	4.378	0.108	0.044	0.025

7. Tables of Fitted Relaxation Parameters (continued)

Methanol (Single-Debye, eqn. 1) – See note 33

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_∞	unc.
10	35.74	0.06	2.262	0.019	5.818	0.104
15	34.68	0.06	2.532	0.023	5.698	0.131
20	33.64	0.06	2.822	0.019	5.654	0.104
25	32.66	0.06	3.141	0.033	5.563	0.176
30	31.69	0.06	3.490	0.040	5.450	0.204
35	30.78	0.06	3.862	0.048	5.388	0.228
40	29.85	0.06	4.283	0.059	5.251	0.260
45	28.95	0.06	4.738	0.072	5.107	0.295
50	28.19	0.06	5.175	0.088	5.224	0.325

Propan-1-ol (Debye- Γ , eqn. 3) – See note 26. Recommended range 35-50 °C.

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_H	unc.	Γ	unc.
10	22.61	0.04	0.272	0.001	3.775	0.015	0.078	0.003
15	21.88	0.04	0.331	0.001	3.763	0.015	0.073	0.003
20	21.15	0.04	0.401	0.001	3.739	0.011	0.064	0.002
25	20.42	0.04	0.488	0.002	3.735	0.016	0.061	0.004
30	19.75	0.04	0.589	0.003	3.724	0.016	0.058	0.005
35	19.07	0.04	0.709	0.004	3.712	0.018	0.055	0.006
40	18.40	0.04	0.852	0.005	3.697	0.023	0.051	0.007
45	17.76	0.04	1.019	0.007	3.692	0.028	0.049	0.009
50	17.11	0.04	1.218	0.009	3.684	0.037	0.047	0.011

Propan-1-ol (Double-Debye, eqn. 2) – See note 26. Recommended range 10-30 °C.

Temp.	ϵ_s	unc.	f_{r1}	unc.	ϵ_h	unc.	f_{r2}	unc.	ϵ_∞	unc.
10	22.61	0.04	0.268	0.001	3.862	0.017	6.871	1.010	3.126	0.075
15	21.88	0.04	0.328	0.002	3.844	0.017	7.302	1.358	3.121	0.097
20	21.15	0.04	0.398	0.002	3.821	0.012	7.629	1.055	3.142	0.069
25	20.42	0.04	0.485	0.003	3.804	0.020	8.290	2.621	3.129	0.162
30	19.75	0.04	0.586	0.003	3.791	0.023	8.860	3.394	3.105	0.207
35	19.07	0.04	0.707	0.004	3.774	0.027	9.638	3.943	3.076	0.229

7. Tables of Fitted Relaxation Parameters (continued)

Propan-2-ol (Debye- Γ , eqn. 3, ϵ_s fitted) – *Limited data. See notes 26 and 30.
Recommended range 30-50 °C.*

It may be noted that the fitted ϵ_s values for the Debye- Γ equation are significantly different from those obtained for the Double-Debye equation – see note 30 for explanation. Debye- Γ parameters in italics are outside of the recommended temperature range, 30-50 °C, and should not be used.

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_H	unc.	Γ	unc.
10	20.97	0.14	0.229	0.002	3.474	0.015	0.072	0.002
15	20.40	0.11	0.287	0.002	3.478	0.014	0.069	0.003
20	19.79	0.07	0.360	0.001	3.473	0.010	0.062	0.002
25	19.09	0.09	0.452	0.002	3.471	0.015	0.057	0.003
30	18.37	0.07	0.565	0.003	3.466	0.015	0.052	0.004
35	17.65	0.07	0.702	0.003	3.462	0.016	0.047	0.005
40	16.93	0.06	0.870	0.003	3.458	0.017	0.042	0.006
45	16.21	0.06	1.072	0.004	3.454	0.018	0.038	0.007
50	15.50	0.05	1.315	0.005	3.451	0.020	0.035	0.008

Propan-2-ol (Double-Debye, eqn. 2, ϵ_s fitted) – *Limited data. See notes 26 and 30.
Recommended range 10-25 °C.*

Temp.	ϵ_s	unc.	f_{r1}	unc.	ϵ_h	unc.	f_{r2}	unc.	ϵ_∞	unc.
10	21.73	0.13	0.217	0.001	3.573	0.019	5.037	0.240	3.045	0.031
15	20.89	0.11	0.277	0.002	3.566	0.018	5.545	0.390	3.035	0.040
20	20.11	0.07	0.351	0.002	3.557	0.013	5.721	0.446	3.057	0.037
25	19.30	0.10	0.443	0.003	3.551	0.022	5.999	1.024	3.065	0.073
30	18.50	0.09	0.557	0.004	3.538	0.026	6.655	1.829	3.056	0.112

8. Tables of Measured and Best-fit Complex Permittivity Data

Butan-1-ol at 10 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	15.31	0.04	7.07	0.04	15.22	0.08	7.08	0.06				
0.2	10.10	0.05	7.90	0.03	10.03	0.05	7.87	0.05				
0.3	7.31	0.05	6.84	0.03	7.27	0.04	6.79	0.04				
0.4	5.90	0.05	5.74	0.02	5.89	0.04	5.70	0.03				
0.5	5.13	0.05	4.87	0.02	5.13	0.04	4.84	0.03				
0.6	4.67	0.05	4.21	0.02	4.67	0.03	4.18	0.02				
0.7	4.38	0.05	3.70	0.02	4.39	0.03	3.68	0.02				
0.8	4.18	0.05	3.30	0.01	4.19	0.03	3.29	0.02				
0.9	4.04	0.05	2.98	0.01	4.05	0.03	2.98	0.02				
1.0	3.94	0.05	2.72	0.01	3.94	0.03	2.72	0.02	3.94	0.03	2.72	0.02
1.2	3.80	0.05	2.33	0.01					3.80	0.03	2.32	0.02
1.5	3.67	0.05	1.93	0.01					3.67	0.03	1.93	0.02
1.8	3.59	0.05	1.67	0.01					3.59	0.03	1.67	0.01
2.0	3.55	0.05	1.54	0.01					3.54	0.03	1.54	0.01
2.5	3.47	0.05	1.31	0.01					3.46	0.04	1.31	0.01
3.0	3.41	0.05	1.16	0.01					3.41	0.04	1.16	0.01
3.5	3.36	0.05	1.05	0.01					3.36	0.04	1.05	0.01
4.0	3.31	0.05	0.97	0.01					3.32	0.04	0.97	0.02
4.5	3.27	0.05	0.90	0.01					3.29	0.04	0.91	0.02
5.0	3.23	0.05	0.84	0.01					3.26	0.04	0.86	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *note 26*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 15 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	15.96	0.03	6.02	0.04	15.92	0.06	6.00	0.05				
0.2	11.46	0.04	7.69	0.03	11.44	0.05	7.67	0.04				
0.3	8.47	0.05	7.20	0.03	8.46	0.04	7.18	0.03				
0.4	6.76	0.05	6.31	0.02	6.76	0.03	6.29	0.03				
0.5	5.76	0.05	5.48	0.02	5.77	0.03	5.47	0.03				
0.6	5.15	0.05	4.80	0.02	5.16	0.03	4.79	0.02				
0.7	4.75	0.05	4.25	0.02	4.76	0.03	4.25	0.02				
0.8	4.48	0.05	3.81	0.02	4.48	0.03	3.82	0.02				
0.9	4.28	0.05	3.45	0.01	4.29	0.02	3.46	0.02				
1.0	4.14	0.05	3.16	0.01	4.14	0.02	3.17	0.02	4.15	0.03	3.16	0.02
1.2	3.94	0.05	2.70	0.01					3.95	0.03	2.70	0.02
1.5	3.77	0.05	2.24	0.01					3.77	0.03	2.25	0.02
1.8	3.66	0.05	1.93	0.01					3.67	0.03	1.94	0.02
2.0	3.61	0.05	1.77	0.01					3.61	0.03	1.78	0.01
2.5	3.52	0.05	1.50	0.01					3.51	0.04	1.50	0.01
3.0	3.45	0.05	1.32	0.01					3.45	0.04	1.32	0.01
3.5	3.39	0.05	1.19	0.01					3.40	0.04	1.19	0.01
4.0	3.34	0.05	1.09	0.01					3.36	0.04	1.09	0.02
4.5	3.30	0.05	1.01	0.01					3.33	0.04	1.02	0.02
5.0	3.26	0.05	0.94	0.01					3.30	0.04	0.96	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 20 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	16.26	0.03	4.97	0.03	16.23	0.06	4.96	0.05				
0.2	12.65	0.03	7.14	0.03	12.64	0.05	7.13	0.04				
0.3	9.72	0.03	7.29	0.03	9.71	0.04	7.27	0.03				
0.4	7.79	0.04	6.72	0.02	7.80	0.04	6.71	0.03				
0.5	6.57	0.04	6.02	0.02	6.58	0.03	6.01	0.03				
0.6	5.78	0.04	5.38	0.02	5.79	0.03	5.37	0.03				
0.7	5.24	0.04	4.82	0.02	5.25	0.03	4.82	0.02				
0.8	4.87	0.04	4.36	0.02	4.88	0.03	4.36	0.02				
0.9	4.60	0.04	3.97	0.01	4.61	0.03	3.97	0.02				
1.0	4.40	0.04	3.64	0.01	4.41	0.03	3.65	0.02	4.39	0.03	3.62	0.03
1.2	4.12	0.04	3.13	0.01					4.12	0.03	3.10	0.02
1.5	3.89	0.04	2.59	0.01					3.88	0.03	2.57	0.02
1.8	3.75	0.04	2.22	0.01					3.74	0.03	2.22	0.02
2.0	3.68	0.04	2.04	0.01					3.67	0.03	2.03	0.02
2.5	3.57	0.04	1.71	0.01					3.55	0.04	1.71	0.01
3.0	3.49	0.05	1.49	0.01					3.48	0.04	1.49	0.01
3.5	3.42	0.05	1.34	0.01					3.42	0.04	1.33	0.01
4.0	3.37	0.05	1.22	0.01					3.37	0.04	1.22	0.02
4.5	3.33	0.05	1.13	0.01					3.34	0.04	1.13	0.02
5.0	3.29	0.05	1.05	0.01					3.30	0.04	1.06	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 25 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	16.27	0.03	4.02	0.03	16.26	0.06	3.99	0.04				
0.2	13.55	0.03	6.34	0.03	13.58	0.05	6.32	0.04				
0.3	10.92	0.04	7.03	0.03	10.96	0.04	7.02	0.03				
0.4	8.93	0.04	6.87	0.03	8.97	0.04	6.87	0.03				
0.5	7.54	0.04	6.40	0.02	7.58	0.03	6.41	0.03				
0.6	6.58	0.04	5.86	0.02	6.61	0.03	5.88	0.03				
0.7	5.90	0.04	5.35	0.02	5.93	0.03	5.37	0.03				
0.8	5.41	0.04	4.89	0.02	5.43	0.03	4.91	0.02				
0.9	5.05	0.04	4.49	0.02	5.07	0.03	4.51	0.02				
1.0	4.78	0.04	4.15	0.02	4.80	0.03	4.17	0.02	4.77	0.04	4.13	0.03
1.2	4.40	0.04	3.59	0.01					4.39	0.04	3.55	0.02
1.5	4.07	0.04	2.98	0.01					4.06	0.03	2.97	0.02
1.8	3.88	0.04	2.56	0.01					3.88	0.03	2.56	0.02
2.0	3.79	0.04	2.35	0.01					3.78	0.04	2.34	0.02
2.5	3.64	0.04	1.96	0.01					3.63	0.04	1.96	0.01
3.0	3.54	0.04	1.70	0.01					3.54	0.04	1.70	0.01
3.5	3.47	0.05	1.52	0.01					3.47	0.04	1.52	0.01
4.0	3.41	0.05	1.38	0.01					3.42	0.04	1.38	0.02
4.5	3.36	0.05	1.27	0.01					3.37	0.04	1.27	0.02
5.0	3.32	0.05	1.18	0.02					3.34	0.04	1.19	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 30 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	16.08	0.03	3.21	0.03	16.06	0.07	3.18	0.05				
0.2	14.14	0.03	5.43	0.04	14.15	0.06	5.40	0.04				
0.3	11.96	0.03	6.48	0.03	11.98	0.05	6.47	0.04				
0.4	10.08	0.04	6.73	0.03	10.11	0.05	6.73	0.04				
0.5	8.61	0.04	6.55	0.02	8.64	0.04	6.55	0.03				
0.6	7.52	0.04	6.19	0.02	7.55	0.04	6.20	0.03			7.53	0.08
0.7	6.70	0.04	5.78	0.02	6.73	0.04	5.79	0.03			6.71	0.05
0.8	6.10	0.04	5.37	0.02	6.12	0.04	5.39	0.03			6.10	0.04
0.9	5.63	0.04	4.99	0.02	5.66	0.04	5.01	0.03			5.64	0.03
1.0	5.28	0.04	4.65	0.02	5.30	0.04	4.67	0.03	5.27	0.04	5.29	0.02
1.2	4.78	0.04	4.06	0.02					4.78	0.04	4.78	0.02
1.5	4.33	0.04	3.41	0.01					4.33	0.04	4.33	0.02
1.8	4.07	0.04	2.94	0.01					4.07	0.04	4.07	0.02
2.0	3.95	0.04	2.70	0.01					3.94	0.04	3.94	0.02
2.5	3.75	0.04	2.25	0.01					3.74	0.04	3.74	0.01
3.0	3.62	0.04	1.95	0.01					3.62	0.04	3.63	0.02
3.5	3.54	0.04	1.73	0.01					3.53	0.04		
4.0	3.47	0.05	1.56	0.01					3.47	0.04		
4.5	3.41	0.05	1.43	0.01					3.42	0.04		
5.0	3.37	0.05	1.33	0.02					3.38	0.04		

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 35 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	15.74	0.03	2.54	0.02	15.72	0.07	2.51	0.05				
0.2	14.39	0.03	4.53	0.03	14.40	0.06	4.50	0.04				
0.3	12.70	0.03	5.75	0.03	12.73	0.05	5.72	0.03				
0.4	11.06	0.03	6.30	0.03	11.11	0.05	6.29	0.04				
0.5	9.65	0.04	6.42	0.03	9.70	0.05	6.42	0.04				
0.6	8.51	0.04	6.28	0.02	8.55	0.04	6.29	0.03				
0.7	7.61	0.04	6.02	0.02	7.65	0.04	6.04	0.03	8.53	0.08	6.24	0.07
0.8	6.90	0.04	5.71	0.02	6.93	0.04	5.73	0.03				
0.9	6.34	0.04	5.39	0.02	6.38	0.04	5.42	0.03	7.62	0.05	5.99	0.04
1.0	5.90	0.04	5.08	0.02	5.93	0.04	5.11	0.03	6.90	0.04	5.70	0.03
1.2	5.26	0.04	4.52	0.02					6.35	0.03	5.37	0.02
1.5	4.67	0.04	3.84	0.02								
1.8	4.32	0.04	3.33	0.01					5.90	0.04	5.06	0.03
2.0	4.15	0.04	3.07	0.01					5.26	0.04	4.48	0.03
2.5	3.89	0.04	2.56	0.01					4.68	0.04	3.83	0.03
3.0	3.73	0.04	2.21	0.01					4.33	0.04	3.33	0.02
3.5	3.62	0.04	1.96	0.01					4.16	0.04	3.06	0.02
4.0	3.54	0.04	1.77	0.01					3.89	0.04	2.56	0.02
4.5	3.47	0.05	1.62	0.02					3.73	0.04	2.21	0.01
5.0	3.42	0.05	1.50	0.02					3.62	0.04	1.96	0.02
									3.54	0.04	1.77	0.02
									3.49	0.04	1.62	0.02
									3.44	0.04	1.50	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 40 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	15.31	0.04	2.01	0.02	15.29	0.08	1.97	0.05				
0.2	14.40	0.03	3.70	0.03	14.40	0.06	3.67	0.04				
0.3	13.16	0.03	4.93	0.03	13.18	0.06	4.89	0.04				
0.4	11.84	0.03	5.67	0.03	11.88	0.06	5.64	0.04				
0.5	10.58	0.04	6.03	0.03	10.63	0.06	6.02	0.04				
0.6	9.48	0.04	6.13	0.03	9.53	0.05	6.12	0.04				
0.7	8.55	0.04	6.05	0.02	8.61	0.05	6.05	0.04	9.50	0.10	6.08	0.08
0.8	7.78	0.04	5.88	0.02	7.83	0.05	5.89	0.04	8.56	0.06	6.01	0.04
0.9	7.15	0.04	5.65	0.02	7.20	0.05	5.67	0.04	7.79	0.05	5.86	0.03
1.0	6.63	0.04	5.41	0.02	6.69	0.05	5.43	0.04	7.16	0.04	5.63	0.02
1.2	5.85	0.04	4.91	0.02					6.65	0.06	5.38	0.04
1.5	5.10	0.04	4.26	0.02					6.65	0.06	5.38	0.04
1.8	4.64	0.04	3.74	0.02					5.87	0.05	4.87	0.04
2.0	4.43	0.04	3.45	0.01					5.12	0.05	4.24	0.03
2.5	4.08	0.04	2.90	0.01					4.67	0.05	3.73	0.03
3.0	3.87	0.04	2.51	0.01					4.44	0.05	3.45	0.03
3.5	3.73	0.04	2.22	0.01					4.08	0.05	2.90	0.02
4.0	3.63	0.05	2.00	0.01					3.87	0.05	2.51	0.02
4.5	3.55	0.05	1.83	0.02					3.73	0.05	2.22	0.02
5.0	3.49	0.05	1.69	0.02					3.64	0.04	2.00	0.02
									3.56	0.04	1.83	0.02
									3.51	0.04	1.69	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 45 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	14.81	0.04	1.57	0.02	14.79	0.07	1.55	0.05				
0.2	14.22	0.03	2.98	0.03	14.21	0.06	2.95	0.04				
0.3	13.34	0.03	4.11	0.03	13.35	0.06	4.07	0.04				
0.4	12.34	0.03	4.92	0.03	12.36	0.06	4.89	0.04				
0.5	11.31	0.03	5.44	0.03	11.34	0.06	5.42	0.04				
0.6	10.33	0.03	5.73	0.03	10.37	0.06	5.71	0.04				
0.7	9.45	0.04	5.84	0.03	9.49	0.06	5.82	0.04				
0.8	8.68	0.04	5.82	0.02	8.72	0.06	5.81	0.04				
0.9	8.01	0.04	5.72	0.02	8.06	0.05	5.71	0.04				
1.0	7.44	0.04	5.58	0.02	7.50	0.05	5.57	0.04	7.46	0.06	5.52	0.04
1.2	6.54	0.04	5.21	0.02					6.57	0.06	5.14	0.04
1.5	5.63	0.04	4.64	0.02					5.67	0.06	4.60	0.03
1.8	5.05	0.04	4.13	0.02					5.10	0.06	4.11	0.03
2.0	4.78	0.04	3.83	0.02					4.81	0.06	3.82	0.03
2.5	4.33	0.04	3.24	0.01					4.34	0.06	3.25	0.02
3.0	4.06	0.04	2.81	0.01					4.06	0.05	2.82	0.02
3.5	3.90	0.04	2.49	0.01					3.88	0.05	2.50	0.02
4.0	3.79	0.04	2.25	0.02					3.75	0.04	2.25	0.03
4.5	3.71	0.04	2.06	0.02					3.66	0.04	2.05	0.03
5.0	3.66	0.04	1.91	0.02					3.59	0.04	1.90	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 26*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Butan-1-ol at 50 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	14.30	0.04	1.24	0.01	14.28	0.09	1.21	0.07				
0.2	13.90	0.03	2.38	0.02	13.90	0.07	2.36	0.05				
0.3	13.30	0.03	3.37	0.03	13.30	0.07	3.34	0.04				
0.4	12.56	0.03	4.16	0.03	12.59	0.07	4.13	0.04				
0.5	11.76	0.03	4.75	0.03	11.80	0.07	4.72	0.04				
0.6	10.96	0.03	5.15	0.03	11.00	0.07	5.13	0.05				
0.7	10.19	0.03	5.40	0.03	10.24	0.07	5.38	0.05				
0.8	9.47	0.04	5.52	0.03	9.53	0.07	5.51	0.05				
0.9	8.82	0.04	5.55	0.02	8.89	0.07	5.54	0.06				
1.0	8.25	0.04	5.52	0.02	8.32	0.07	5.51	0.06	8.26	0.07	5.46	0.05
1.2	7.29	0.04	5.32	0.02					7.32	0.07	5.24	0.04
1.5	6.25	0.04	4.89	0.02					6.30	0.07	4.85	0.04
1.8	5.55	0.04	4.44	0.02					5.61	0.07	4.43	0.03
2.0	5.21	0.04	4.17	0.02					5.25	0.07	4.16	0.03
2.5	4.64	0.04	3.58	0.02					4.66	0.06	3.59	0.02
3.0	4.29	0.04	3.13	0.02					4.30	0.06	3.14	0.02
3.5	4.08	0.04	2.78	0.02					4.07	0.05	2.79	0.03
4.0	3.93	0.04	2.51	0.02					3.90	0.05	2.52	0.03
4.5	3.82	0.04	2.29	0.02					3.79	0.05	2.30	0.03
5.0	3.75	0.04	2.12	0.03					3.70	0.05	2.12	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 26*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 20 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	47.12	0.06	0.53	0.01	47.13	0.14	0.50	0.06				
0.2	47.10	0.06	1.07	0.01	47.10	0.15	1.05	0.06				
0.3	47.07	0.06	1.60	0.01	47.03	0.16	1.59	0.08				
0.4	47.02	0.06	2.13	0.01	46.95	0.17	2.12	0.11				
0.5	46.95	0.06	2.66	0.01	46.78	0.20	2.63	0.14				
0.6	46.88	0.06	3.18	0.01	46.64	0.23	3.15	0.17				
0.7	46.79	0.06	3.70	0.01	46.48	0.26	3.64	0.21	46.80	0.16	3.14	0.06
0.8	46.68	0.06	4.22	0.01	46.29	0.31	4.12	0.24	46.70	0.16	3.70	0.08
0.9	46.57	0.06	4.74	0.02	46.04	0.35	4.55	0.28	46.57	0.18	4.21	0.12
1.0	46.44	0.06	5.25	0.02	45.85	0.40	5.04	0.31	46.48	0.48	4.89	0.50
1.2	46.14	0.06	6.25	0.02					46.38	0.17	5.24	0.03
1.5	45.60	0.06	7.70	0.02					46.21	0.60	6.14	0.13
1.8	44.96	0.06	9.09	0.03					45.56	0.47	7.66	0.04
2.0	44.49	0.06	9.98	0.03					44.90	0.41	9.07	0.07
2.5	43.15	0.07	12.03	0.04					44.92	0.15	9.11	0.04
3.0	41.64	0.08	13.83	0.06					44.40	0.38	9.96	0.08
3.5	40.00	0.09	15.38	0.08					43.08	0.42	12.00	0.06
4.0	38.30	0.09	16.68	0.10					41.59	0.41	13.81	0.10
4.5	36.57	0.10	17.73	0.13					41.60	0.16	13.86	0.09
5.0	34.85	0.10	18.56	0.16					39.97	0.39	15.39	0.12
									38.29	0.37	16.70	0.15
									36.57	0.36	17.79	0.15
									34.87	0.34	18.67	0.18

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 25 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	46.48	0.06	0.48	0.01	46.50	0.14	0.45	0.06				
0.2	46.47	0.06	0.96	0.01	46.48	0.14	0.94	0.06				
0.3	46.44	0.06	1.44	0.01	46.42	0.15	1.43	0.08				
0.4	46.40	0.06	1.92	0.01	46.36	0.17	1.91	0.11				
0.5	46.35	0.06	2.39	0.01	46.21	0.19	2.37	0.14				
0.6	46.28	0.06	2.87	0.01	46.11	0.22	2.85	0.17				
0.7	46.21	0.06	3.34	0.01	45.97	0.26	3.31	0.20				
0.8	46.12	0.06	3.81	0.01	45.81	0.30	3.73	0.24				
0.9	46.03	0.06	4.27	0.02	45.60	0.34	4.12	0.27				
1.0	45.92	0.06	4.74	0.02	45.45	0.39	4.59	0.30	46.03	0.46	4.41	0.51
1.2	45.68	0.06	5.65	0.02					45.76	0.60	5.55	0.14
1.5	45.23	0.06	6.98	0.02					45.20	0.47	6.94	0.04
1.8	44.70	0.07	8.26	0.03					44.64	0.41	8.23	0.07
2.0	44.31	0.08	9.08	0.03					44.23	0.38	9.06	0.07
2.5	43.18	0.09	11.02	0.04					43.12	0.41	10.99	0.06
3.0	41.89	0.11	12.76	0.06					41.84	0.42	12.73	0.09
3.5	40.48	0.13	14.29	0.10					40.44	0.39	14.28	0.11
4.0	38.99	0.15	15.61	0.13					38.96	0.38	15.62	0.13
4.5	37.44	0.16	16.73	0.18					37.43	0.37	16.76	0.14
5.0	35.89	0.16	17.65	0.22					35.89	0.35	17.71	0.17

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 30 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''
0.1	45.86	0.06	0.44	45.88	0.14	0.40						
0.2	45.84	0.06	0.87	45.86	0.15	0.85						
0.3	45.82	0.06	1.30	45.81	0.16	1.30						
0.4	45.78	0.06	1.74	45.76	0.18	1.74						
0.5	45.74	0.06	2.17	45.63	0.21	2.15						
0.6	45.69	0.06	2.60	45.55	0.25	2.59				45.63	0.16	2.55
0.7	45.63	0.06	3.03	45.42	0.29	3.00				45.56	0.15	3.01
0.8	45.56	0.06	3.45	45.29	0.34	3.39				45.48	0.17	3.43
0.9	45.48	0.06	3.88	45.10	0.40	3.73				45.43	0.19	3.77
1.0	45.39	0.06	4.30	44.97	0.46	4.18	45.49	0.44	3.99	45.34	0.17	4.30
1.2	45.18	0.06	5.13				45.26	0.60	5.05	45.15	0.15	5.12
1.5	44.81	0.06	6.35				44.77	0.47	6.32	44.76	0.16	6.35
1.8	44.37	0.07	7.54				44.30	0.41	7.51	44.34	0.15	7.55
2.0	44.03	0.07	8.30				43.95	0.38	8.28	43.98	0.15	8.33
2.5	43.07	0.09	10.11				43.01	0.41	10.10	43.02	0.15	10.13
3.0	41.97	0.11	11.77				41.91	0.42	11.75	41.93	0.15	11.79
3.5	40.75	0.13	13.26				40.70	0.39	13.26			
4.0	39.44	0.15	14.58				39.40	0.38	14.59			
4.5	38.07	0.16	15.72				38.03	0.37	15.74			
5.0	36.66	0.17	16.69				36.65	0.36	16.75			

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 35 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	45.19	0.06	0.40	0.01	45.23	0.14	0.36	0.06				
0.2	45.17	0.06	0.79	0.01	45.22	0.15	0.78	0.07				
0.3	45.15	0.06	1.18	0.01	45.18	0.16	1.18	0.09				
0.4	45.13	0.06	1.58	0.01	45.14	0.18	1.58	0.12				
0.5	45.09	0.06	1.97	0.01	45.02	0.21	1.95	0.15				
0.6	45.05	0.06	2.36	0.01	44.96	0.24	2.35	0.19				
0.7	45.00	0.06	2.75	0.01	44.85	0.29	2.73	0.23				
0.8	44.94	0.06	3.14	0.01	44.73	0.34	3.08	0.27				
0.9	44.87	0.06	3.53	0.01	44.59	0.39	3.39	0.31				
1.0	44.80	0.06	3.91	0.01	44.48	0.45	3.79	0.35	44.96	0.41	3.60	0.53
1.2	44.63	0.06	4.67	0.02					44.73	0.60	4.61	0.16
1.5	44.31	0.06	5.79	0.02					44.30	0.47	5.77	0.04
1.8	43.94	0.07	6.88	0.02					43.91	0.40	6.86	0.06
2.0	43.66	0.07	7.59	0.02					43.61	0.37	7.58	0.07
2.5	42.85	0.09	9.29	0.03					42.81	0.41	9.29	0.06
3.0	41.91	0.11	10.86	0.05					41.86	0.42	10.85	0.08
3.5	40.85	0.13	12.30	0.08					40.82	0.39	12.30	0.10
4.0	39.71	0.15	13.59	0.11					39.67	0.38	13.60	0.11
4.5	38.50	0.17	14.75	0.15					38.46	0.38	14.75	0.12
5.0	37.25	0.18	15.75	0.19					37.22	0.36	15.78	0.14

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *note 4*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 40 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	44.53	0.06	0.36	0.01	44.59	0.15	0.33	0.07				
0.2	44.52	0.06	0.72	0.01	44.57	0.15	0.70	0.08				
0.3	44.50	0.06	1.08	0.01	44.54	0.17	1.08	0.11				
0.4	44.48	0.06	1.44	0.01	44.51	0.19	1.44	0.14				
0.5	44.45	0.06	1.80	0.01	44.42	0.23	1.77	0.18				
0.6	44.41	0.06	2.16	0.01	44.36	0.28	2.14	0.23				
0.7	44.37	0.06	2.51	0.01	44.27	0.34	2.49	0.27				
0.8	44.32	0.06	2.87	0.01	44.18	0.41	2.80	0.32				
0.9	44.26	0.06	3.22	0.01	44.06	0.49	3.09	0.37				
1.0	44.20	0.06	3.57	0.01	43.96	0.57	3.47	0.41	44.41	0.47	3.26	0.54
1.2	44.05	0.06	4.27	0.02					44.18	0.61	4.23	0.18
1.5	43.79	0.06	5.31	0.02					43.78	0.46	5.28	0.05
1.8	43.47	0.07	6.31	0.02					43.45	0.40	6.28	0.07
2.0	43.23	0.07	6.97	0.02					43.21	0.37	6.94	0.07
2.5	42.54	0.09	8.55	0.03					42.53	0.41	8.56	0.06
3.0	41.73	0.11	10.03	0.05					41.69	0.42	10.02	0.08
3.5	40.81	0.14	11.41	0.07					40.79	0.39	11.40	0.09
4.0	39.81	0.16	12.66	0.10					39.80	0.38	12.66	0.11
4.5	38.74	0.19	13.80	0.15					38.72	0.38	13.80	0.11
5.0	37.63	0.21	14.81	0.19					37.62	0.37	14.82	0.13

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 45 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	43.86	0.06	0.33	0.01	43.93	0.14	0.30	0.07				
0.2	43.85	0.06	0.66	0.01	43.93	0.15	0.65	0.08				
0.3	43.83	0.06	0.99	0.01	43.90	0.16	0.99	0.10				
0.4	43.81	0.06	1.32	0.01	43.87	0.19	1.32	0.14				
0.5	43.79	0.06	1.65	0.01	43.79	0.23	1.63	0.18				
0.6	43.76	0.06	1.97	0.01	43.76	0.27	1.97	0.22				
0.7	43.72	0.06	2.30	0.01	43.67	0.33	2.30	0.26				
0.8	43.68	0.06	2.63	0.01	43.58	0.40	2.58	0.31				
0.9	43.63	0.06	2.95	0.01	43.47	0.48	2.85	0.36				
1.0	43.58	0.06	3.27	0.01	43.38	0.56	3.20	0.40	43.83	0.45	2.94	0.53
1.2	43.45	0.06	3.92	0.02					43.60	0.61	3.90	0.20
1.5	43.23	0.06	4.87	0.02					43.24	0.46	4.84	0.05
1.8	42.96	0.06	5.80	0.02					42.96	0.40	5.76	0.06
2.0	42.75	0.07	6.41	0.02					42.75	0.37	6.37	0.07
2.5	42.16	0.09	7.88	0.03					42.18	0.40	7.91	0.07
3.0	41.46	0.11	9.27	0.04					41.43	0.42	9.27	0.08
3.5	40.66	0.14	10.58	0.06					40.66	0.39	10.57	0.09
4.0	39.79	0.17	11.79	0.09					39.79	0.38	11.79	0.10
4.5	38.85	0.19	12.90	0.13					38.84	0.38	12.89	0.11
5.0	37.86	0.21	13.90	0.18					37.85	0.37	13.90	0.12

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Dimethyl sulphoxide at 50 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	43.19	0.06	0.30	0.01	43.27	0.15	0.27	0.09				
0.2	43.18	0.06	0.61	0.01	43.27	0.16	0.59	0.09				
0.3	43.17	0.06	0.91	0.01	43.25	0.18	0.90	0.13				
0.4	43.15	0.06	1.21	0.01	43.24	0.22	1.21	0.17				
0.5	43.13	0.06	1.51	0.01	43.18	0.27	1.50	0.22				
0.6	43.10	0.06	1.81	0.01	43.15	0.34	1.82	0.28				
0.7	43.07	0.06	2.11	0.01	43.08	0.42	2.12	0.33				
0.8	43.04	0.06	2.41	0.01	43.02	0.52	2.38	0.39				
0.9	42.99	0.06	2.71	0.01	42.91	0.62	2.63	0.44				
1.0	42.95	0.06	3.01	0.01	42.87	0.74	2.97	0.50	43.20	0.48	2.67	0.54
1.2	42.84	0.06	3.60	0.01					43.01	0.62	3.60	0.22
1.5	42.65	0.06	4.48	0.02					42.67	0.46	4.46	0.06
1.8	42.42	0.07	5.34	0.02					42.43	0.40	5.30	0.07
2.0	42.24	0.07	5.90	0.02					42.26	0.37	5.87	0.07
2.5	41.73	0.09	7.28	0.02					41.78	0.41	7.31	0.07
3.0	41.13	0.11	8.59	0.04					41.11	0.42	8.58	0.08
3.5	40.43	0.14	9.82	0.06					40.44	0.39	9.81	0.09
4.0	39.67	0.17	10.98	0.09					39.68	0.38	10.99	0.10
4.5	38.84	0.20	12.06	0.12					38.83	0.39	12.04	0.10
5.0	37.96	0.23	13.04	0.17					37.96	0.37	13.03	0.12

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 4

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 10 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	43.48	0.06	5.40	0.04	43.53	0.14	5.28	0.08				
0.2	41.23	0.05	10.09	0.07	41.35	0.14	9.95	0.09				
0.3	38.09	0.07	13.67	0.08	38.26	0.15	13.54	0.11				
0.4	34.63	0.08	16.06	0.08	34.81	0.16	15.95	0.13				
0.5	31.24	0.10	17.47	0.07	31.39	0.16	17.35	0.15				
0.6	28.16	0.10	18.14	0.07	28.30	0.16	18.05	0.17				
0.7	25.45	0.11	18.30	0.07	25.55	0.17	18.16	0.18	28.31	0.18	18.23	0.15
0.8	23.13	0.11	18.13	0.06	23.19	0.17	17.96	0.19	25.55	0.12	18.42	0.09
0.9	21.14	0.11	17.77	0.06	21.20	0.17	17.56	0.20	23.17	0.11	18.27	0.08
1.0	19.46	0.11	17.29	0.06	19.53	0.17	17.02	0.21	21.15	0.09	17.88	0.08
1.2	16.81	0.11	16.20	0.06					19.43	0.18	17.31	0.09
1.5	14.06	0.11	14.57	0.06					16.74	0.17	16.22	0.08
1.8	12.24	0.11	13.13	0.05					14.00	0.16	14.55	0.09
2.0	11.34	0.11	12.30	0.05					12.20	0.14	13.08	0.09
2.5	9.77	0.11	10.60	0.05					11.30	0.13	12.27	0.09
3.0	8.77	0.11	9.31	0.05					9.80	0.10	10.55	0.09
3.5	8.09	0.11	8.30	0.05					8.81	0.09	9.30	0.08
4.0	7.59	0.12	7.51	0.05					8.13	0.08	8.32	0.07
4.5	7.22	0.12	6.85	0.05					7.65	0.08	7.55	0.06
5.0	6.93	0.12	6.31	0.05					7.28	0.07	6.93	0.06
									6.98	0.07	6.41	0.06

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 15 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	42.58	0.06	4.18	0.03	42.61	0.13	4.10	0.06				
0.2	41.16	0.06	8.00	0.06	41.22	0.13	7.91	0.07				
0.3	39.05	0.06	11.22	0.07	39.12	0.13	11.11	0.08				
0.4	36.53	0.07	13.72	0.08	36.61	0.14	13.59	0.10				
0.5	33.86	0.08	15.52	0.08	33.91	0.14	15.36	0.12				
0.6	31.23	0.10	16.71	0.07	31.30	0.15	16.55	0.14				
0.7	28.76	0.10	17.41	0.07	28.80	0.15	17.19	0.15				
0.8	26.51	0.11	17.74	0.07	26.52	0.16	17.47	0.16				
0.9	24.49	0.11	17.79	0.06	24.51	0.16	17.49	0.17				
1.0	22.70	0.11	17.66	0.06	22.73	0.16	17.30	0.18	22.71	0.21	17.64	0.09
1.2	19.74	0.11	17.07	0.06					19.70	0.21	17.09	0.08
1.5	16.50	0.11	15.83	0.06					16.46	0.18	15.82	0.09
1.8	14.25	0.11	14.54	0.06					14.22	0.16	14.50	0.10
2.0	13.12	0.11	13.75	0.06					13.08	0.14	13.71	0.10
2.5	11.12	0.11	12.02	0.06					11.15	0.12	11.97	0.10
3.0	9.83	0.11	10.64	0.06					9.88	0.10	10.63	0.09
3.5	8.95	0.11	9.54	0.06					9.00	0.09	9.56	0.08
4.0	8.31	0.11	8.65	0.06					8.37	0.09	8.69	0.07
4.5	7.83	0.11	7.92	0.06					7.90	0.08	7.98	0.07
5.0	7.46	0.11	7.30	0.06					7.53	0.08	7.39	0.07

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 20 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	41.57	0.06	3.27	0.02	41.59	0.13	3.21	0.06				
0.2	40.66	0.05	6.37	0.04	40.70	0.13	6.30	0.06				
0.3	39.25	0.05	9.13	0.05	39.28	0.13	9.04	0.08				
0.4	37.48	0.05	11.48	0.06	37.51	0.14	11.35	0.10				
0.5	35.49	0.05	13.38	0.07	35.49	0.15	13.20	0.12				
0.6	33.41	0.06	14.83	0.07	33.43	0.16	14.63	0.14				
0.7	31.33	0.07	15.88	0.06	31.32	0.17	15.62	0.16				
0.8	29.33	0.07	16.60	0.06	29.31	0.17	16.29	0.17				
0.9	27.44	0.08	17.04	0.06	27.44	0.18	16.68	0.19				
1.0	25.70	0.08	17.26	0.06	25.72	0.18	16.84	0.20	25.55	0.23	17.14	0.09
1.2	22.66	0.09	17.24	0.06					22.46	0.24	17.13	0.08
1.5	19.10	0.09	16.56	0.06					18.91	0.21	16.43	0.10
1.8	16.50	0.09	15.58	0.05					16.32	0.18	15.43	0.11
2.0	15.15	0.10	14.89	0.05					14.99	0.16	14.77	0.11
2.5	12.70	0.10	13.25	0.05					12.64	0.13	13.14	0.11
3.0	11.10	0.10	11.86	0.05					11.05	0.11	11.77	0.10
3.5	9.99	0.10	10.70	0.05					9.95	0.10	10.66	0.09
4.0	9.19	0.10	9.74	0.06					9.17	0.09	9.74	0.08
4.5	8.59	0.10	8.94	0.06					8.57	0.09	8.97	0.08
5.0	8.13	0.10	8.26	0.06					8.11	0.08	8.32	0.07

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 25 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	40.55	0.06	2.59	0.02	40.57	0.12	2.54	0.05				
0.2	39.96	0.06	5.08	0.04	39.99	0.12	5.04	0.06				
0.3	39.02	0.06	7.39	0.05	39.03	0.13	7.34	0.07				
0.4	37.80	0.06	9.47	0.06	37.79	0.14	9.39	0.09				
0.5	36.38	0.06	11.26	0.07	36.32	0.15	11.14	0.11				
0.6	34.81	0.07	12.77	0.07	34.76	0.16	12.63	0.14			34.90	0.16
0.7	33.18	0.08	13.99	0.07	33.09	0.17	13.77	0.16			33.25	0.13
0.8	31.53	0.09	14.95	0.07	31.42	0.18	14.67	0.18			31.59	0.12
0.9	29.91	0.10	15.67	0.06	29.81	0.19	15.32	0.20			29.96	0.11
1.0	28.35	0.10	16.19	0.06	28.26	0.20	15.75	0.21	28.30	0.25	28.42	0.11
1.2	25.47	0.11	16.73	0.06					25.38	0.27	25.50	0.10
1.5	21.85	0.11	16.73	0.06					21.77	0.24	21.85	0.09
1.8	19.01	0.11	16.21	0.06					18.92	0.20	19.00	0.10
2.0	17.48	0.11	15.72	0.07					17.38	0.18	17.47	0.10
2.5	14.60	0.11	14.37	0.07					14.56	0.15	14.60	0.13
3.0	12.64	0.11	13.08	0.08					12.63	0.13	12.66	0.16
3.5	11.26	0.10	11.93	0.08					11.26	0.12		
4.0	10.26	0.10	10.94	0.09					10.26	0.10		
4.5	9.49	0.10	10.09	0.10					9.51	0.10		
5.0	8.90	0.10	9.36	0.10					8.92	0.09		

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 30 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	39.53	0.06	2.07	0.02	39.54	0.13	2.03	0.06				
0.2	39.13	0.06	4.09	0.03	39.15	0.13	4.06	0.06				
0.3	38.50	0.06	6.01	0.04	38.49	0.14	5.97	0.08				
0.4	37.66	0.05	7.80	0.05	37.63	0.15	7.72	0.10				
0.5	36.65	0.06	9.42	0.06	36.56	0.16	9.29	0.13				
0.6	35.50	0.06	10.85	0.06	35.43	0.18	10.69	0.16			35.54	0.15
0.7	34.26	0.07	12.09	0.06	34.14	0.20	11.87	0.18			34.29	0.13
0.8	32.97	0.07	13.14	0.06	32.82	0.22	12.85	0.21			32.99	0.12
0.9	31.65	0.08	14.01	0.06	31.51	0.24	13.65	0.24			31.67	0.12
1.0	30.33	0.08	14.72	0.06	30.19	0.25	14.26	0.26	30.29	0.26	30.38	0.11
1.2	27.79	0.09	15.69	0.06					27.73	0.29	27.82	0.11
1.5	24.35	0.10	16.31	0.06					24.29	0.27	24.36	0.10
1.8	21.47	0.10	16.28	0.06					21.40	0.23	21.47	0.10
2.0	19.85	0.10	16.05	0.06					19.76	0.21	19.83	0.11
2.5	16.65	0.10	15.13	0.07					16.61	0.17	16.63	0.14
3.0	14.37	0.10	14.03	0.08					14.35	0.15	14.37	0.19
3.5	12.72	0.10	12.98	0.10					12.71	0.13		
4.0	11.50	0.10	12.01	0.11					11.49	0.12		
4.5	10.56	0.10	11.15	0.12					10.57	0.11		
5.0	9.83	0.10	10.40	0.12					9.84	0.10		

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 35 °C

Freq.		Best-fit (Davidson-Cole)				Reflection cell				14-mm transmission cell				40-mm transmission cell			
GHz	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	
0.1	38.51	0.06	1.67	0.01	38.52	0.12	1.64	0.06									
0.2	38.25	0.06	3.32	0.02	38.25	0.12	3.29	0.06									
0.3	37.82	0.06	4.91	0.03	37.80	0.13	4.88	0.08									
0.4	37.23	0.06	6.42	0.04	37.19	0.14	6.37	0.10									
0.5	36.52	0.06	7.83	0.05	36.42	0.16	7.74	0.12									
0.6	35.69	0.06	9.13	0.05	35.59	0.18	9.01	0.15					35.69	0.15	9.07	0.08	
0.7	34.78	0.06	10.30	0.06	34.61	0.20	10.11	0.18					34.77	0.13	10.26	0.06	
0.8	33.79	0.06	11.35	0.06	33.61	0.22	11.10	0.21					33.78	0.12	11.32	0.07	
0.9	32.76	0.07	12.26	0.06	32.56	0.24	11.95	0.23					32.75	0.12	12.22	0.06	
1.0	31.71	0.07	13.06	0.06	31.49	0.26	12.64	0.26	31.67	0.26	12.89	0.13	31.73	0.12	13.06	0.05	
1.2	29.58	0.08	14.29	0.05					29.52	0.31	14.18	0.09	29.58	0.11	14.30	0.06	
1.5	26.51	0.09	15.41	0.05					26.46	0.29	15.35	0.09	26.51	0.10	15.43	0.06	
1.8	23.76	0.09	15.86	0.06					23.70	0.25	15.78	0.12	23.76	0.10	15.90	0.08	
2.0	22.14	0.10	15.90	0.06					22.07	0.23	15.87	0.12	22.12	0.11	15.94	0.09	
2.5	18.77	0.10	15.49	0.07					18.74	0.19	15.44	0.12	18.75	0.14	15.53	0.13	
3.0	16.25	0.11	14.71	0.09					16.23	0.16	14.70	0.12	16.24	0.20	14.76	0.20	
3.5	14.35	0.10	13.83	0.11					14.33	0.14	13.81	0.12					
4.0	12.91	0.10	12.95	0.12					12.90	0.13	12.95	0.11					
4.5	11.79	0.10	12.12	0.14					11.79	0.12	12.14	0.11					
5.0	10.91	0.10	11.37	0.15					10.92	0.11	11.41	0.10					

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 40 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''
0.1	37.57	0.07	1.37	37.53	0.13	1.34						
0.2	37.39	0.07	2.72	37.34	0.13	2.70						
0.3	37.09	0.07	4.04	37.02	0.14	4.03						
0.4	36.68	0.07	5.31	36.59	0.15	5.28						
0.5	36.17	0.07	6.53	36.02	0.17	6.46						
0.6	35.58	0.06	7.67	35.44	0.20	7.59				35.52	0.15	7.60
0.7	34.90	0.06	8.73	34.70	0.23	8.58				34.84	0.13	8.67
0.8	34.17	0.06	9.71	33.94	0.26	9.50				34.11	0.12	9.66
0.9	33.38	0.07	10.61	33.14	0.29	10.33				33.32	0.12	10.52
1.0	32.56	0.07	11.41	32.28	0.33	11.05	32.50	0.28	11.25	32.53	0.12	11.39
1.2	30.84	0.07	12.76				30.72	0.35	12.68	30.81	0.11	12.73
1.5	28.24	0.08	14.18				28.15	0.32	14.13	28.21	0.10	14.18
1.8	25.75	0.08	15.01				25.65	0.27	14.93	25.73	0.10	15.02
2.0	24.22	0.09	15.31				24.12	0.25	15.28	24.19	0.10	15.33
2.5	20.87	0.09	15.43				20.81	0.21	15.39	20.84	0.13	15.46
3.0	18.21	0.10	15.03				18.16	0.18	15.03	18.19	0.20	15.08
3.5	16.13	0.10	14.39				16.07	0.16	14.39			
4.0	14.49	0.10	13.66				14.44	0.15	13.68			
4.5	13.20	0.10	12.93				13.16	0.14	12.96			
5.0	12.16	0.10	12.22				12.14	0.13	12.27			

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 45 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	36.59	0.07	1.13	0.01	36.55	0.12	1.10	0.07				
0.2	36.46	0.07	2.24	0.01	36.42	0.12	2.23	0.06				
0.3	36.25	0.07	3.34	0.02	36.19	0.13	3.33	0.08				
0.4	35.96	0.07	4.41	0.03	35.89	0.15	4.39	0.11				
0.5	35.60	0.07	5.44	0.03	35.47	0.17	5.39	0.13				
0.6	35.17	0.06	6.43	0.04	35.05	0.19	6.37	0.17				
0.7	34.68	0.06	7.37	0.04	34.49	0.22	7.26	0.20	35.10	0.15	6.38	0.07
0.8	34.14	0.06	8.26	0.04	33.91	0.26	8.08	0.24	34.60	0.12	7.32	0.05
0.9	33.55	0.06	9.08	0.04	33.31	0.29	8.85	0.28	34.06	0.12	8.21	0.06
1.0	32.92	0.06	9.85	0.04	32.65	0.33	9.54	0.32	33.47	0.12	9.02	0.06
1.2	31.57	0.06	11.20	0.04					32.86	0.28	9.66	0.17
1.5	29.44	0.07	12.78	0.04					31.49	0.36	11.14	0.12
1.8	27.31	0.08	13.87	0.05					29.37	0.33	12.73	0.08
2.0	25.93	0.08	14.36	0.05					27.23	0.28	13.79	0.10
2.5	22.78	0.09	14.97	0.07					25.86	0.26	14.33	0.11
3.0	20.12	0.10	14.98	0.09					22.74	0.22	14.93	0.12
3.5	17.93	0.11	14.65	0.11					20.08	0.20	14.99	0.13
4.0	16.15	0.11	14.13	0.14					17.89	0.18	14.66	0.13
4.5	14.71	0.11	13.55	0.16					16.12	0.17	14.15	0.12
5.0	13.53	0.11	12.94	0.19					14.68	0.15	13.58	0.13
									13.51	0.14	12.98	0.13

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanediol at 50 °C

Freq. GHz	Best-fit (Davidson-Cole)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	35.68	0.07	0.94	0.01	35.60	0.13	0.92	0.08				
0.2	35.59	0.07	1.87	0.01	35.51	0.13	1.86	0.08				
0.3	35.44	0.07	2.79	0.02	35.34	0.15	2.78	0.10				
0.4	35.23	0.07	3.69	0.02	35.12	0.17	3.67	0.13				
0.5	34.97	0.07	4.57	0.03	34.82	0.19	4.52	0.17				
0.6	34.66	0.07	5.42	0.03	34.52	0.23	5.36	0.21			34.53	0.15
0.7	34.30	0.07	6.24	0.03	34.09	0.27	6.14	0.25			34.16	0.12
0.8	33.90	0.06	7.02	0.04	33.66	0.32	6.87	0.30			33.77	0.12
0.9	33.45	0.06	7.77	0.04	33.20	0.37	7.57	0.35			33.32	0.13
1.0	32.98	0.06	8.48	0.04	32.69	0.43	8.21	0.40	32.89	0.29	8.27	0.20
1.2	31.94	0.06	9.76	0.04					31.86	0.38	9.70	0.15
1.5	30.23	0.07	11.36	0.04					30.14	0.34	11.31	0.08
1.8	28.45	0.07	12.58	0.04					28.36	0.29	12.50	0.10
2.0	27.26	0.08	13.20	0.05					27.18	0.28	13.18	0.10
2.5	24.41	0.09	14.19	0.06					24.37	0.24	14.16	0.12
3.0	21.87	0.11	14.57	0.09					21.83	0.22	14.60	0.13
3.5	19.68	0.12	14.55	0.12					19.63	0.21	14.59	0.12
4.0	17.84	0.13	14.28	0.15					17.79	0.19	14.33	0.13
4.5	16.29	0.13	13.88	0.18					16.24	0.17	13.93	0.13
5.0	14.99	0.13	13.40	0.22					14.95	0.16	13.47	0.13

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 4 and 29

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 10 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	26.18	0.04	3.62	0.02	26.17	0.10	3.57	0.06				
0.2	24.55	0.03	6.70	0.04	24.59	0.09	6.62	0.05				
0.3	22.31	0.04	8.92	0.05	22.39	0.09	8.83	0.06				
0.4	19.91	0.05	10.29	0.04	20.01	0.08	10.20	0.06				
0.5	17.63	0.05	10.95	0.04	17.76	0.08	10.88	0.07				
0.6	15.63	0.06	11.13	0.04	15.77	0.08	11.07	0.07				
0.7	13.94	0.06	10.99	0.04	14.07	0.08	10.95	0.07				
0.8	12.54	0.06	10.68	0.04	12.66	0.08	10.64	0.08				
0.9	11.38	0.06	10.27	0.03	11.51	0.07	10.24	0.08				
1.0	10.43	0.06	9.82	0.03	10.56	0.07	9.79	0.08	10.55	0.08	9.82	0.05
1.2	9.01	0.06	8.92	0.03					9.09	0.08	8.94	0.05
1.5	7.65	0.06	7.72	0.03					7.70	0.08	7.73	0.04
1.8	6.81	0.07	6.75	0.03					6.86	0.07	6.78	0.04
2.0	6.43	0.07	6.22	0.03					6.46	0.07	6.24	0.04
2.5	5.82	0.07	5.19	0.02					5.83	0.07	5.22	0.03
3.0	5.47	0.07	4.46	0.02					5.45	0.06	4.49	0.03
3.5	5.25	0.07	3.93	0.02					5.21	0.06	3.96	0.04
4.0	5.11	0.07	3.53	0.03					5.04	0.05	3.55	0.03
4.5	5.01	0.07	3.22	0.03					4.91	0.05	3.23	0.03
5.0	4.93	0.07	2.98	0.03					4.82	0.05	2.98	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 15 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	25.52	0.04	3.00	0.02	25.51	0.08	2.95	0.05				
0.2	24.34	0.03	5.66	0.03	24.37	0.08	5.59	0.04				
0.3	22.64	0.03	7.76	0.04	22.70	0.08	7.68	0.05				
0.4	20.69	0.04	9.23	0.04	20.78	0.07	9.15	0.05				
0.5	18.73	0.05	10.14	0.04	18.83	0.07	10.07	0.06				
0.6	16.90	0.05	10.60	0.04	17.02	0.07	10.54	0.06				
0.7	15.27	0.06	10.73	0.04	15.38	0.07	10.68	0.06				
0.8	13.85	0.06	10.64	0.04	13.97	0.07	10.60	0.07				
0.9	12.64	0.06	10.42	0.03	12.76	0.07	10.38	0.07				
1.0	11.61	0.06	10.11	0.03	11.73	0.07	10.07	0.07	11.75	0.09	10.09	0.05
1.2	10.01	0.06	9.38	0.03					10.12	0.09	9.39	0.05
1.5	8.41	0.06	8.29	0.03					8.50	0.08	8.30	0.04
1.8	7.40	0.06	7.34	0.03					7.48	0.08	7.37	0.04
2.0	6.92	0.06	6.80	0.03					6.98	0.08	6.83	0.04
2.5	6.14	0.06	5.72	0.03					6.18	0.07	5.76	0.04
3.0	5.69	0.07	4.94	0.02					5.70	0.06	4.98	0.04
3.5	5.41	0.07	4.36	0.03					5.39	0.06	4.39	0.04
4.0	5.22	0.07	3.91	0.03					5.18	0.05	3.93	0.04
4.5	5.09	0.07	3.56	0.03					5.03	0.05	3.57	0.03
5.0	5.00	0.07	3.29	0.04					4.91	0.05	3.29	0.03

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 20 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	24.86	0.04	2.46	0.01	24.83	0.08	2.45	0.04				
0.2	24.03	0.03	4.71	0.03	24.01	0.08	4.70	0.04				
0.3	22.77	0.03	6.62	0.03	22.76	0.08	6.60	0.04				
0.4	21.26	0.03	8.10	0.04	21.25	0.07	8.07	0.05				
0.5	19.66	0.03	9.15	0.04	19.64	0.07	9.12	0.05				
0.6	18.07	0.03	9.83	0.04	18.05	0.07	9.79	0.06				
0.7	16.57	0.04	10.21	0.04	16.56	0.07	10.17	0.06				
0.8	15.21	0.04	10.36	0.04	15.20	0.07	10.30	0.07				
0.9	14.00	0.04	10.33	0.03	13.99	0.07	10.27	0.07				
1.0	12.93	0.05	10.19	0.03	12.94	0.07	10.12	0.07	12.97	0.10	10.12	0.05
1.2	11.20	0.05	9.72	0.03					11.22	0.10	9.66	0.05
1.5	9.36	0.05	8.82	0.03					9.39	0.09	8.78	0.05
1.8	8.14	0.06	7.94	0.03					8.17	0.09	7.92	0.05
2.0	7.56	0.06	7.42	0.03					7.58	0.08	7.39	0.04
2.5	6.57	0.06	6.31	0.02					6.59	0.07	6.30	0.04
3.0	5.99	0.06	5.47	0.02					5.99	0.07	5.48	0.04
3.5	5.63	0.06	4.83	0.02					5.61	0.06	4.84	0.04
4.0	5.38	0.06	4.34	0.02					5.35	0.06	4.34	0.04
4.5	5.21	0.06	3.94	0.02					5.15	0.06	3.94	0.03
5.0	5.08	0.06	3.62	0.02					5.01	0.05	3.62	0.03

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 25 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	24.22	0.04	2.05	0.01	24.15	0.08	2.02	0.04				
0.2	23.61	0.03	3.97	0.03	23.56	0.08	3.94	0.04				
0.3	22.67	0.03	5.67	0.03	22.63	0.07	5.62	0.04				
0.4	21.50	0.03	7.08	0.04	21.47	0.07	7.01	0.05				
0.5	20.21	0.04	8.17	0.04	20.18	0.07	8.11	0.05				
0.6	18.87	0.04	8.97	0.04	18.85	0.08	8.90	0.06				
0.7	17.55	0.05	9.51	0.04	17.54	0.08	9.44	0.06				
0.8	16.30	0.05	9.84	0.04	16.30	0.08	9.75	0.07				
0.9	15.15	0.05	9.99	0.04	15.16	0.08	9.90	0.07				
1.0	14.10	0.05	10.01	0.03	14.12	0.08	9.92	0.08	14.13	0.10	9.92	0.05
1.2	12.32	0.06	9.80	0.03					12.35	0.10	9.71	0.05
1.5	10.33	0.06	9.15	0.03					10.36	0.10	9.09	0.05
1.8	8.95	0.06	8.39	0.03					8.98	0.10	8.37	0.05
2.0	8.26	0.06	7.91	0.03					8.29	0.09	7.88	0.05
2.5	7.08	0.06	6.83	0.03					7.10	0.08	6.83	0.05
3.0	6.37	0.06	5.97	0.03					6.36	0.07	5.99	0.05
3.5	5.91	0.06	5.30	0.03					5.88	0.06	5.31	0.05
4.0	5.60	0.06	4.76	0.04					5.55	0.06	4.78	0.04
4.5	5.38	0.06	4.33	0.04					5.31	0.06	4.35	0.04
5.0	5.22	0.06	3.98	0.05					5.13	0.06	3.99	0.03

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 30 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	23.50	0.04	1.70	0.01	23.44	0.08	1.68	0.05				
0.2	23.06	0.04	3.32	0.02	23.03	0.08	3.29	0.04				
0.3	22.37	0.04	4.79	0.03	22.34	0.08	4.76	0.04				
0.4	21.49	0.03	6.08	0.04	21.46	0.08	6.04	0.05				
0.5	20.48	0.04	7.15	0.04	20.46	0.08	7.10	0.06				
0.6	19.40	0.04	8.00	0.04	19.38	0.08	7.95	0.07				
0.7	18.29	0.04	8.64	0.04	18.28	0.09	8.59	0.07				
0.8	17.20	0.05	9.10	0.04	17.19	0.09	9.04	0.08				
0.9	16.16	0.05	9.41	0.04	16.16	0.09	9.34	0.09				
1.0	15.18	0.05	9.58	0.03	15.18	0.09	9.50	0.09	15.21	0.11	9.48	0.05
1.2	13.43	0.05	9.63	0.03					13.48	0.11	9.55	0.05
1.5	11.37	0.06	9.28	0.03					11.42	0.11	9.24	0.05
1.8	9.85	0.06	8.71	0.03					9.91	0.11	8.70	0.05
2.0	9.07	0.06	8.30	0.03					9.12	0.10	8.29	0.05
2.5	7.70	0.06	7.31	0.03					7.72	0.09	7.32	0.05
3.0	6.83	0.06	6.46	0.03					6.83	0.07	6.49	0.05
3.5	6.26	0.06	5.77	0.04					6.24	0.06	5.79	0.05
4.0	5.87	0.06	5.21	0.04					5.84	0.06	5.23	0.04
4.5	5.60	0.06	4.75	0.05					5.54	0.06	4.77	0.04
5.0	5.39	0.07	4.37	0.06					5.32	0.06	4.38	0.04

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 35 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	22.77	0.04	1.41	0.01	22.77	0.08	1.39	0.05				
0.2	22.46	0.04	2.78	0.02	22.47	0.08	2.75	0.04				
0.3	21.95	0.04	4.05	0.03	21.96	0.08	4.01	0.04				
0.4	21.29	0.04	5.19	0.03	21.31	0.08	5.16	0.05				
0.5	20.51	0.03	6.19	0.04	20.55	0.08	6.15	0.05				
0.6	19.65	0.04	7.04	0.04	19.69	0.08	6.98	0.06				
0.7	18.75	0.04	7.73	0.04	18.79	0.09	7.68	0.07				
0.8	17.83	0.04	8.27	0.04	17.87	0.09	8.20	0.08				
0.9	16.92	0.04	8.67	0.04	16.98	0.09	8.61	0.09				
1.0	16.04	0.04	8.96	0.03	16.10	0.10	8.89	0.10	16.11	0.11	8.85	0.05
1.2	14.42	0.05	9.25	0.03					14.50	0.12	9.17	0.05
1.5	12.37	0.05	9.21	0.03					12.46	0.12	9.17	0.04
1.8	10.78	0.05	8.85	0.03					10.87	0.12	8.85	0.05
2.0	9.93	0.05	8.54	0.03					10.00	0.11	8.55	0.05
2.5	8.38	0.05	7.69	0.03					8.42	0.09	7.72	0.06
3.0	7.37	0.06	6.90	0.04					7.38	0.08	6.94	0.06
3.5	6.68	0.06	6.22	0.04					6.67	0.07	6.25	0.05
4.0	6.21	0.06	5.64	0.05					6.18	0.07	5.67	0.05
4.5	5.87	0.06	5.17	0.05					5.81	0.06	5.19	0.04
5.0	5.61	0.07	4.77	0.06					5.54	0.06	4.78	0.04

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 40 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	22.08	0.05	1.17	0.01	22.08	0.09	1.15	0.06				
0.2	21.85	0.05	2.32	0.02	21.86	0.08	2.30	0.04				
0.3	21.49	0.05	3.41	0.02	21.49	0.08	3.38	0.04				
0.4	21.00	0.04	4.41	0.03	21.01	0.08	4.38	0.05				
0.5	20.41	0.04	5.32	0.03	20.43	0.09	5.29	0.06				
0.6	19.74	0.04	6.12	0.04	19.76	0.09	6.07	0.07				
0.7	19.02	0.04	6.81	0.04	19.05	0.10	6.77	0.08				
0.8	18.27	0.04	7.38	0.04	18.30	0.11	7.32	0.10				
0.9	17.51	0.04	7.85	0.04	17.56	0.11	7.80	0.11				
1.0	16.75	0.04	8.22	0.04	16.80	0.12	8.16	0.12	16.79	0.13	8.12	0.05
1.2	15.29	0.04	8.70	0.03					15.35	0.14	8.61	0.05
1.5	13.35	0.05	8.95	0.03					13.42	0.14	8.91	0.04
1.8	11.75	0.05	8.83	0.03					11.82	0.14	8.82	0.05
2.0	10.86	0.05	8.64	0.03					10.92	0.13	8.64	0.05
2.5	9.16	0.05	7.98	0.03					9.19	0.10	8.02	0.07
3.0	8.00	0.06	7.28	0.04					8.01	0.08	7.33	0.07
3.5	7.20	0.06	6.63	0.04					7.18	0.08	6.68	0.06
4.0	6.63	0.06	6.07	0.05					6.59	0.07	6.11	0.05
4.5	6.21	0.07	5.58	0.06					6.15	0.07	5.62	0.05
5.0	5.90	0.07	5.17	0.07					5.82	0.06	5.19	0.05

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 25 and 27*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 45 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	21.39	0.05	0.98	0.01	21.39	0.09	0.96	0.06				
0.2	21.23	0.05	1.94	0.01	21.24	0.08	1.92	0.04				
0.3	20.96	0.05	2.86	0.02	20.96	0.08	2.84	0.04				
0.4	20.60	0.04	3.73	0.02	20.62	0.08	3.71	0.05				
0.5	20.16	0.04	4.54	0.03	20.18	0.09	4.52	0.06				
0.6	19.65	0.04	5.27	0.03	19.67	0.09	5.25	0.07				
0.7	19.09	0.04	5.93	0.03	19.12	0.10	5.91	0.08				
0.8	18.49	0.04	6.50	0.03	18.51	0.10	6.46	0.09				
0.9	17.87	0.04	6.99	0.03	17.91	0.11	6.96	0.11				
1.0	17.23	0.04	7.41	0.03	17.28	0.12	7.37	0.12	17.28	0.13	7.31	0.05
1.2	15.97	0.04	8.02	0.03					16.03	0.14	7.93	0.05
1.5	14.20	0.04	8.50	0.03					14.27	0.15	8.46	0.04
1.8	12.66	0.05	8.61	0.03					12.74	0.15	8.60	0.04
2.0	11.77	0.05	8.55	0.03					11.83	0.14	8.55	0.05
2.5	9.98	0.05	8.13	0.04					10.03	0.11	8.17	0.07
3.0	8.71	0.06	7.56	0.04					8.72	0.09	7.62	0.07
3.5	7.79	0.06	6.98	0.05					7.77	0.08	7.04	0.06
4.0	7.12	0.07	6.45	0.06					7.08	0.08	6.50	0.05
4.5	6.62	0.07	5.97	0.07					6.56	0.07	6.02	0.05
5.0	6.25	0.08	5.55	0.08					6.16	0.06	5.59	0.05

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 27

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Ethanol at 50 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	20.74	0.05	0.82	0.01	20.71	0.10	0.81	0.07				
0.2	20.62	0.05	1.62	0.01	20.60	0.08	1.61	0.05				
0.3	20.42	0.05	2.41	0.02	20.40	0.09	2.39	0.05				
0.4	20.16	0.05	3.16	0.02	20.15	0.09	3.13	0.06				
0.5	19.82	0.04	3.86	0.02	19.82	0.10	3.84	0.07				
0.6	19.44	0.04	4.52	0.03	19.44	0.11	4.49	0.08				
0.7	19.01	0.04	5.13	0.03	19.02	0.11	5.10	0.10				
0.8	18.54	0.04	5.67	0.03	18.55	0.12	5.62	0.12				
0.9	18.04	0.04	6.16	0.03	18.07	0.13	6.12	0.13				
1.0	17.53	0.04	6.59	0.03	17.56	0.15	6.54	0.15	17.56	0.14	6.48	0.06
1.2	16.47	0.04	7.27	0.03					16.52	0.15	7.18	0.06
1.5	14.91	0.04	7.93	0.03					14.98	0.17	7.88	0.04
1.8	13.48	0.04	8.23	0.03					13.56	0.16	8.22	0.04
2.0	12.62	0.04	8.29	0.03					12.69	0.15	8.30	0.05
2.5	10.82	0.05	8.12	0.03					10.87	0.12	8.17	0.07
3.0	9.46	0.06	7.72	0.04					9.48	0.10	7.79	0.07
3.5	8.45	0.06	7.24	0.05					8.44	0.09	7.31	0.06
4.0	7.68	0.07	6.76	0.06					7.65	0.09	6.83	0.06
4.5	7.11	0.08	6.31	0.07					7.04	0.08	6.37	0.06
5.0	6.66	0.08	5.90	0.08					6.58	0.07	5.96	0.06

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 27

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 10 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	35.68	0.06	1.32	0.01	35.71	0.12	1.32	0.06				
0.2	35.51	0.06	2.63	0.02	35.53	0.12	2.64	0.06				
0.3	35.22	0.06	3.90	0.03	35.23	0.13	3.93	0.07				
0.4	34.83	0.06	5.13	0.03	34.82	0.14	5.18	0.09				
0.5	34.35	0.06	6.31	0.04	34.30	0.15	6.34	0.12				
0.6	33.77	0.06	7.42	0.04	33.70	0.17	7.45	0.14				
0.7	33.12	0.06	8.45	0.05	33.01	0.19	8.47	0.17	33.74	0.14	7.42	0.07
0.8	32.41	0.06	9.41	0.05	32.26	0.21	9.39	0.20	33.06	0.12	8.47	0.05
0.9	31.65	0.06	10.28	0.05	31.49	0.24	10.24	0.23	32.34	0.11	9.42	0.06
1.0	30.85	0.07	11.07	0.05	30.64	0.26	10.98	0.26	31.54	0.11	10.24	0.05
1.2	29.17	0.08	12.39	0.05					30.75	0.23	10.95	0.13
1.5	26.60	0.09	13.78	0.05					29.12	0.30	12.27	0.10
1.8	24.14	0.09	14.58	0.05					26.58	0.29	13.71	0.07
2.0	22.61	0.09	14.85	0.06					24.12	0.25	14.56	0.10
2.5	19.29	0.09	14.89	0.07					22.58	0.23	14.82	0.11
3.0	16.66	0.08	14.38	0.09					19.27	0.19	14.86	0.12
3.5	14.63	0.08	13.64	0.10					16.66	0.16	14.37	0.12
4.0	13.07	0.08	12.82	0.10					14.65	0.15	13.66	0.12
4.5	11.85	0.08	12.01	0.10					13.10	0.13	12.87	0.11
5.0	10.90	0.08	11.24	0.10					11.89	0.12	12.09	0.11
									10.95	0.11	11.36	0.10

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 15 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	34.63	0.06	1.14	0.01	34.66	0.11	1.14	0.05				
0.2	34.50	0.06	2.28	0.01	34.53	0.11	2.29	0.04				
0.3	34.28	0.06	3.39	0.02	34.29	0.11	3.41	0.05				
0.4	33.97	0.06	4.47	0.03	33.97	0.12	4.50	0.07				
0.5	33.59	0.06	5.51	0.03	33.57	0.13	5.55	0.09				
0.6	33.14	0.06	6.50	0.04	33.10	0.14	6.55	0.10				
0.7	32.62	0.06	7.44	0.04	32.53	0.15	7.47	0.12				
0.8	32.05	0.06	8.33	0.04	31.93	0.17	8.33	0.14				
0.9	31.43	0.06	9.15	0.04	31.30	0.19	9.13	0.17				
1.0	30.77	0.06	9.90	0.04	30.60	0.21	9.85	0.19	30.69	0.22	9.76	0.14
1.2	29.36	0.07	11.22	0.04					29.36	0.30	11.09	0.11
1.5	27.15	0.08	12.71	0.04					27.16	0.30	12.65	0.06
1.8	24.95	0.08	13.69	0.05					24.96	0.26	13.67	0.10
2.0	23.54	0.09	14.10	0.05					23.53	0.24	14.08	0.10
2.5	20.37	0.09	14.49	0.07					20.37	0.20	14.47	0.11
3.0	17.75	0.08	14.29	0.09					17.77	0.17	14.27	0.12
3.5	15.65	0.08	13.76	0.10					15.68	0.16	13.77	0.12
4.0	13.99	0.07	13.10	0.11					14.03	0.14	13.13	0.11
4.5	12.67	0.08	12.39	0.11					12.72	0.13	12.45	0.11
5.0	11.61	0.08	11.68	0.11					11.68	0.12	11.78	0.11

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 20 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	33.60	0.06	0.99	0.01	33.56	0.10	0.99	0.05				
0.2	33.50	0.06	1.97	0.01	33.45	0.10	1.98	0.04				
0.3	33.33	0.06	2.94	0.02	33.30	0.11	2.96	0.05				
0.4	33.09	0.06	3.89	0.02	33.05	0.11	3.92	0.07				
0.5	32.79	0.06	4.81	0.02	32.72	0.12	4.84	0.08				
0.6	32.43	0.06	5.69	0.03	32.35	0.14	5.74	0.10				
0.7	32.02	0.06	6.54	0.03	31.92	0.15	6.58	0.12	32.37	0.14	5.67	0.07
0.8	31.56	0.05	7.34	0.03	31.44	0.16	7.35	0.14	31.94	0.11	6.53	0.04
0.9	31.06	0.05	8.10	0.04	30.94	0.18	8.11	0.16	31.48	0.11	7.34	0.05
1.0	30.52	0.05	8.81	0.04	30.36	0.20	8.78	0.18	30.96	0.10	8.07	0.05
1.2	29.35	0.05	10.08	0.04					30.46	0.21	8.70	0.14
1.5	27.47	0.06	11.60	0.04					30.46	0.11	8.82	0.04
1.8	25.55	0.06	12.69	0.04					29.32	0.29	9.97	0.12
2.0	24.28	0.06	13.20	0.04					27.44	0.31	11.54	0.06
2.5	21.33	0.06	13.89	0.05					25.50	0.26	12.67	0.09
3.0	18.79	0.06	13.97	0.06					24.24	0.24	13.18	0.10
3.5	16.68	0.07	13.67	0.07					21.30	0.21	13.88	0.11
4.0	14.95	0.07	13.18	0.08					18.76	0.18	13.97	0.12
4.5	13.55	0.07	12.60	0.08					16.66	0.16	13.70	0.12
5.0	12.42	0.07	11.98	0.08					14.95	0.15	13.23	0.11
									13.56	0.14	12.67	0.11
									12.43	0.13	12.08	0.11

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 25 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	32.63	0.06	0.86	0.01	32.67	0.10	0.87	0.05				
0.2	32.55	0.06	1.72	0.01	32.58	0.10	1.73	0.04				
0.3	32.42	0.06	2.56	0.02	32.44	0.10	2.58	0.05				
0.4	32.23	0.06	3.40	0.02	32.25	0.11	3.43	0.06				
0.5	31.99	0.06	4.21	0.02	32.00	0.12	4.24	0.08				
0.6	31.71	0.06	4.99	0.03	31.72	0.13	5.05	0.09				
0.7	31.38	0.06	5.75	0.03	31.36	0.14	5.79	0.11	31.63	0.13	4.97	0.06
0.8	31.01	0.06	6.48	0.03	30.97	0.16	6.50	0.13	31.29	0.11	5.74	0.03
0.9	30.60	0.06	7.18	0.03	30.56	0.18	7.18	0.15	30.91	0.10	6.47	0.04
1.0	30.17	0.06	7.83	0.04	30.09	0.20	7.83	0.17	30.49	0.10	7.14	0.04
1.2	29.21	0.06	9.03	0.04					30.13	0.19	7.70	0.14
1.5	27.63	0.07	10.54	0.04					29.21	0.28	8.92	0.14
1.8	25.96	0.07	11.69	0.04					27.60	0.31	10.48	0.05
2.0	24.84	0.08	12.28	0.04					25.93	0.27	11.67	0.08
2.5	22.15	0.08	13.20	0.06					24.81	0.25	12.25	0.09
3.0	19.73	0.08	13.53	0.08					22.13	0.21	13.20	0.10
3.5	17.65	0.07	13.47	0.10					19.72	0.19	13.54	0.11
4.0	15.90	0.07	13.16	0.11					17.64	0.17	13.49	0.11
4.5	14.44	0.07	12.72	0.12					15.90	0.16	13.20	0.11
5.0	13.23	0.07	12.21	0.13					14.45	0.15	12.78	0.11
									13.25	0.13	12.29	0.12

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 30 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	31.67	0.06	0.75	0.01	31.72	0.10	0.75	0.05				
0.2	31.60	0.06	1.50	0.01	31.64	0.10	1.51	0.05				
0.3	31.50	0.06	2.24	0.01	31.53	0.11	2.26	0.05				
0.4	31.35	0.06	2.97	0.02	31.39	0.11	3.00	0.07				
0.5	31.16	0.06	3.68	0.02	31.20	0.13	3.72	0.09				
0.6	30.94	0.06	4.38	0.02	30.97	0.14	4.43	0.11				
0.7	30.68	0.06	5.06	0.03	30.69	0.16	5.10	0.13	30.88	0.13	4.37	0.07
0.8	30.38	0.06	5.71	0.03	30.38	0.18	5.74	0.15	30.60	0.11	5.05	0.03
0.9	30.05	0.06	6.34	0.03	30.06	0.20	6.36	0.17	30.30	0.10	5.71	0.04
1.0	29.70	0.06	6.95	0.03	29.68	0.22	6.97	0.20	29.96	0.10	6.31	0.04
1.2	28.92	0.06	8.07	0.03					29.65	0.18	6.81	0.14
1.5	27.60	0.06	9.52	0.03					29.65	0.18	6.81	0.14
1.8	26.18	0.07	10.69	0.04					28.91	0.27	7.95	0.15
2.0	25.20	0.07	11.32	0.04					27.58	0.31	9.47	0.05
2.5	22.79	0.08	12.42	0.06					26.15	0.27	10.67	0.07
3.0	20.54	0.08	12.97	0.08					25.17	0.25	11.29	0.08
3.5	18.53	0.07	13.12	0.10					22.77	0.21	12.41	0.10
4.0	16.79	0.07	13.00	0.12					20.53	0.20	12.97	0.11
4.5	15.31	0.06	12.71	0.13					18.52	0.18	13.13	0.11
5.0	14.05	0.07	12.32	0.14					16.80	0.17	13.03	0.11
									15.32	0.15	12.75	0.12
									14.07	0.14	12.38	0.12

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 35 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	30.76	0.06	0.66	0.01	30.79	0.10	0.66	0.05				
0.2	30.71	0.06	1.31	0.01	30.73	0.10	1.32	0.04				
0.3	30.63	0.06	1.96	0.01	30.64	0.10	1.97	0.05				
0.4	30.51	0.06	2.60	0.01	30.53	0.11	2.62	0.07				
0.5	30.36	0.06	3.23	0.02	30.39	0.12	3.26	0.08				
0.6	30.18	0.06	3.85	0.02	30.22	0.13	3.89	0.10				
0.7	29.97	0.06	4.46	0.02	29.98	0.15	4.50	0.12				
0.8	29.74	0.06	5.04	0.02	29.74	0.17	5.07	0.14				
0.9	29.47	0.06	5.61	0.03	29.49	0.19	5.63	0.16				
1.0	29.18	0.06	6.16	0.03	29.18	0.21	6.18	0.19	29.11	0.17	6.03	0.14
1.2	28.54	0.06	7.20	0.03					28.53	0.26	7.07	0.16
1.5	27.45	0.06	8.57	0.03					27.41	0.31	8.51	0.05
1.8	26.25	0.07	9.72	0.03					26.22	0.27	9.70	0.06
2.0	25.41	0.07	10.37	0.04					25.36	0.25	10.33	0.07
2.5	23.28	0.07	11.58	0.05					23.25	0.22	11.56	0.09
3.0	21.22	0.08	12.30	0.07					21.21	0.20	12.30	0.10
3.5	19.33	0.07	12.63	0.10					19.32	0.19	12.65	0.10
4.0	17.64	0.07	12.69	0.11					17.64	0.18	12.72	0.11
4.5	16.16	0.06	12.55	0.13					16.17	0.16	12.60	0.11
5.0	14.88	0.06	12.28	0.14					14.90	0.15	12.36	0.11

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 40 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	29.84	0.07	0.57	0.01	29.90	0.11	0.58	0.06				
0.2	29.80	0.07	1.15	0.01	29.85	0.10	1.16	0.05				
0.3	29.73	0.07	1.71	0.01	29.78	0.11	1.73	0.06				
0.4	29.64	0.07	2.28	0.01	29.70	0.12	2.31	0.07				
0.5	29.52	0.07	2.83	0.02	29.58	0.13	2.86	0.09				
0.6	29.38	0.07	3.38	0.02	29.45	0.15	3.42	0.12				
0.7	29.21	0.07	3.92	0.02	29.27	0.17	3.96	0.14	29.34	0.14	3.38	0.08
0.8	29.02	0.07	4.44	0.02	29.07	0.19	4.48	0.17	29.14	0.11	3.91	0.03
0.9	28.81	0.07	4.95	0.02	28.88	0.22	4.98	0.20	28.96	0.10	4.43	0.04
1.0	28.58	0.06	5.45	0.03	28.63	0.25	5.49	0.22	28.72	0.10	4.90	0.04
1.2	28.06	0.06	6.39	0.03					28.54	0.19	5.31	0.15
1.5	27.16	0.06	7.67	0.03					28.07	0.28	6.28	0.18
1.8	26.16	0.07	8.79	0.03					27.16	0.32	7.63	0.07
2.0	25.45	0.07	9.43	0.03					26.14	0.28	8.77	0.07
2.5	23.60	0.07	10.71	0.05					25.43	0.26	9.41	0.07
3.0	21.75	0.08	11.56	0.07					23.59	0.22	10.70	0.09
3.5	20.00	0.07	12.05	0.09					21.75	0.21	11.56	0.10
4.0	18.39	0.07	12.27	0.11					19.99	0.20	12.06	0.09
4.5	16.94	0.07	12.28	0.13					18.39	0.19	12.29	0.10
5.0	15.66	0.07	12.15	0.14					16.96	0.17	12.31	0.12
									15.69	0.16	12.20	0.11

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 45 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	28.94	0.07	0.50	0.01	29.02	0.10	0.52	0.06				
0.2	28.91	0.07	1.00	0.01	28.99	0.10	1.02	0.05				
0.3	28.85	0.07	1.50	0.01	28.93	0.10	1.52	0.06				
0.4	28.78	0.07	2.00	0.01	28.87	0.11	2.03	0.07				
0.5	28.69	0.07	2.49	0.01	28.79	0.12	2.51	0.09				
0.6	28.57	0.07	2.97	0.02	28.69	0.14	3.02	0.11				
0.7	28.44	0.07	3.45	0.02	28.54	0.16	3.49	0.13	28.56	0.14	2.97	0.08
0.8	28.29	0.06	3.91	0.02	28.39	0.18	3.95	0.16	28.40	0.11	3.45	0.02
0.9	28.12	0.06	4.37	0.02	28.25	0.21	4.40	0.18	28.24	0.09	3.91	0.04
1.0	27.93	0.06	4.82	0.02	28.04	0.24	4.86	0.21	28.05	0.09	4.33	0.04
1.2	27.51	0.06	5.67	0.02					27.93	0.18	4.68	0.15
1.5	26.78	0.06	6.86	0.03					27.56	0.26	5.57	0.18
1.8	25.94	0.06	7.92	0.03					26.81	0.32	6.84	0.07
2.0	25.34	0.06	8.54	0.03					25.95	0.28	7.91	0.06
2.5	23.76	0.07	9.84	0.04					25.35	0.26	8.53	0.06
3.0	22.13	0.07	10.78	0.06					23.77	0.22	9.83	0.08
3.5	20.53	0.07	11.39	0.08					22.14	0.21	10.78	0.09
4.0	19.03	0.07	11.75	0.11					20.54	0.21	11.40	0.09
4.5	17.64	0.07	11.91	0.13					19.05	0.19	11.76	0.10
5.0	16.39	0.06	11.90	0.15					17.68	0.17	11.92	0.11
									16.43	0.17	11.93	0.11

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Methanol at 50 °C

Freq. GHz	Best-fit (Single-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	28.18	0.07	0.44	0.01	28.17	0.11	0.46	0.07				
0.2	28.16	0.07	0.89	0.01	28.14	0.11	0.90	0.06				
0.3	28.11	0.07	1.33	0.01	28.10	0.11	1.34	0.07				
0.4	28.05	0.07	1.76	0.01	28.05	0.13	1.78	0.09				
0.5	27.98	0.07	2.20	0.01	27.99	0.14	2.22	0.11				
0.6	27.89	0.07	2.63	0.01	27.92	0.16	2.66	0.14				
0.7	27.78	0.07	3.05	0.02	27.80	0.19	3.08	0.17				
0.8	27.65	0.07	3.47	0.02	27.69	0.22	3.49	0.20				
0.9	27.52	0.07	3.88	0.02	27.58	0.26	3.90	0.23				
1.0	27.36	0.06	4.28	0.02	27.42	0.30	4.31	0.26	27.28	0.19	4.12	0.16
1.2	27.02	0.06	5.05	0.02					27.01	0.27	4.95	0.19
1.5	26.41	0.06	6.14	0.02					26.38	0.33	6.12	0.09
1.8	25.71	0.06	7.13	0.02					25.66	0.28	7.11	0.07
2.0	25.21	0.06	7.72	0.03					25.15	0.26	7.69	0.06
2.5	23.84	0.07	9.00	0.04					23.81	0.22	8.98	0.08
3.0	22.41	0.07	9.96	0.05					22.40	0.21	9.98	0.09
3.5	20.98	0.08	10.66	0.08					20.96	0.22	10.68	0.08
4.0	19.60	0.07	11.11	0.10					19.59	0.20	11.15	0.10
4.5	18.30	0.07	11.37	0.12					18.30	0.18	11.42	0.11
5.0	17.10	0.07	11.48	0.14					17.11	0.18	11.54	0.10

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 10 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	20.32	0.03	6.15	0.04	20.31	0.09	6.14	0.06				
0.2	15.90	0.04	9.01	0.04	15.91	0.07	9.00	0.05				
0.3	12.18	0.05	9.35	0.03	12.19	0.06	9.34	0.05				
0.4	9.67	0.05	8.71	0.03	9.69	0.05	8.71	0.04				
0.5	8.04	0.05	7.86	0.03	8.05	0.05	7.85	0.04				
0.6	6.97	0.05	7.05	0.03	6.99	0.04	7.05	0.04				
0.7	6.25	0.05	6.33	0.02	6.26	0.04	6.33	0.03				
0.8	5.74	0.06	5.73	0.02	5.75	0.04	5.73	0.03				
0.9	5.38	0.06	5.22	0.02	5.39	0.04	5.23	0.03				
1.0	5.10	0.06	4.79	0.02	5.11	0.04	4.79	0.03	5.14	0.04	4.81	0.03
1.2	4.73	0.06	4.11	0.02					4.75	0.04	4.13	0.03
1.5	4.41	0.06	3.40	0.01					4.41	0.04	3.41	0.02
1.8	4.22	0.06	2.91	0.01					4.23	0.04	2.93	0.02
2.0	4.14	0.06	2.67	0.01					4.13	0.04	2.67	0.02
2.5	3.99	0.06	2.22	0.01					3.99	0.04	2.23	0.01
3.0	3.89	0.06	1.93	0.01					3.89	0.05	1.93	0.01
3.5	3.82	0.06	1.72	0.01					3.82	0.05	1.73	0.02
4.0	3.76	0.06	1.57	0.01					3.76	0.04	1.58	0.02
4.5	3.71	0.06	1.45	0.01					3.71	0.04	1.46	0.02
5.0	3.66	0.06	1.35	0.02					3.68	0.04	1.36	0.01

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 15 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	20.35	0.03	5.04	0.03	20.34	0.07	5.03	0.05				
0.2	16.99	0.03	8.04	0.04	16.99	0.06	8.02	0.04				
0.3	13.66	0.04	9.01	0.03	13.66	0.05	9.00	0.04				
0.4	11.09	0.05	8.88	0.03	11.11	0.05	8.88	0.04				
0.5	9.27	0.05	8.32	0.03	9.27	0.04	8.31	0.04				
0.6	7.99	0.05	7.65	0.03	8.00	0.04	7.65	0.04				
0.7	7.08	0.05	7.00	0.03	7.09	0.04	6.99	0.03	8.00	0.08	7.61	0.08
0.8	6.43	0.05	6.41	0.02	6.44	0.03	6.40	0.03	7.09	0.05	6.96	0.04
0.9	5.95	0.05	5.89	0.02	5.96	0.03	5.89	0.03	6.43	0.04	6.39	0.03
1.0	5.58	0.05	5.44	0.02	5.59	0.03	5.43	0.03	5.95	0.03	5.86	0.02
1.2	5.08	0.05	4.70	0.02					5.62	0.04	5.44	0.03
1.5	4.64	0.05	3.91	0.02					5.09	0.04	4.70	0.03
1.8	4.38	0.05	3.35	0.01					4.65	0.04	3.91	0.02
2.0	4.27	0.06	3.06	0.01					4.39	0.04	3.36	0.02
2.5	4.07	0.06	2.55	0.01					4.27	0.04	3.07	0.02
3.0	3.95	0.06	2.20	0.01					4.08	0.04	2.55	0.01
3.5	3.87	0.06	1.96	0.01					3.95	0.05	2.20	0.01
4.0	3.80	0.06	1.77	0.01					3.87	0.05	1.96	0.02
4.5	3.74	0.06	1.63	0.02					3.80	0.04	1.77	0.02
5.0	3.69	0.06	1.52	0.02					3.75	0.04	1.63	0.02
									3.71	0.04	1.52	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 20 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	20.12	0.03	4.10	0.03	20.13	0.07	4.09	0.05				
0.2	17.66	0.03	6.97	0.04	17.67	0.06	6.95	0.04				
0.3	14.87	0.03	8.36	0.04	14.89	0.05	8.35	0.04				
0.4	12.44	0.04	8.70	0.03	12.47	0.05	8.71	0.04				
0.5	10.54	0.04	8.49	0.03	10.56	0.04	8.48	0.04				
0.6	9.11	0.04	8.04	0.03	9.14	0.04	8.05	0.04				
0.7	8.05	0.04	7.51	0.02	8.06	0.04	7.51	0.04	9.14	0.09	8.00	0.08
0.8	7.25	0.05	6.98	0.02	7.27	0.04	6.99	0.03	8.07	0.05	7.49	0.04
0.9	6.65	0.05	6.49	0.02	6.66	0.04	6.50	0.03	7.27	0.04	6.97	0.03
1.0	6.18	0.05	6.04	0.02	6.19	0.03	6.04	0.03	6.66	0.03	6.48	0.02
1.2	5.52	0.05	5.28	0.02					6.19	0.05	6.03	0.04
1.5	4.94	0.05	4.42	0.02					6.20	0.03	6.05	0.02
1.8	4.59	0.05	3.80	0.01					5.52	0.04	5.27	0.03
2.0	4.44	0.05	3.48	0.01					0.04	0.03	0.02	0.02
2.5	4.18	0.05	2.89	0.01					4.93	0.04	4.42	0.03
3.0	4.03	0.05	2.49	0.01					4.59	0.04	3.80	0.02
3.5	3.92	0.05	2.20	0.01					4.59	0.04	3.82	0.01
4.0	3.84	0.05	1.99	0.01					4.44	0.04	3.48	0.02
4.5	3.78	0.05	1.82	0.01					4.44	0.04	3.49	0.01
5.0	3.73	0.06	1.68	0.01					4.18	0.05	2.89	0.02
									4.03	0.05	2.49	0.02
									3.92	0.05	2.20	0.02
									3.85	0.04	1.99	0.02
									3.79	0.04	1.82	0.02
									3.74	0.04	1.69	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 25 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell				40-mm transmission cell					
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	19.74	0.03	3.29	0.02	19.77	0.07	3.27	0.04								
0.2	18.00	0.03	5.87	0.04	18.04	0.06	5.85	0.04								
0.3	15.82	0.03	7.46	0.04	15.87	0.06	7.45	0.04								
0.4	13.69	0.04	8.19	0.03	13.75	0.05	8.20	0.04								
0.5	11.86	0.05	8.34	0.03	11.90	0.05	8.34	0.04								
0.6	10.37	0.05	8.17	0.03	10.42	0.04	8.20	0.04					10.39	0.10	8.13	0.09
0.7	9.19	0.05	7.84	0.03	9.23	0.04	7.84	0.04					9.20	0.06	7.81	0.04
0.8	8.26	0.05	7.43	0.03	8.30	0.04	7.45	0.04					8.27	0.04	7.42	0.03
0.9	7.54	0.05	7.01	0.03	7.58	0.04	7.03	0.04					7.54	0.04	6.99	0.03
1.0	6.96	0.05	6.60	0.02	7.00	0.04	6.61	0.04	6.97	0.05	6.58	0.04	6.97	0.03	6.60	0.02
1.2	6.12	0.05	5.87	0.02					6.12	0.05	5.85	0.03	6.13	0.02	5.87	0.02
1.5	5.36	0.05	4.98	0.02					5.35	0.05	4.97	0.03	5.36	0.02	4.99	0.02
1.8	4.90	0.05	4.31	0.02					4.90	0.05	4.30	0.03	4.90	0.02	4.32	0.02
2.0	4.69	0.05	3.96	0.02					4.69	0.05	3.95	0.02	4.69	0.02	3.97	0.02
2.5	4.35	0.05	3.29	0.01					4.35	0.05	3.29	0.02	4.35	0.02	3.30	0.01
3.0	4.15	0.05	2.83	0.01					4.15	0.05	2.83	0.02	4.14	0.02	2.83	0.01
3.5	4.01	0.05	2.50	0.01					4.01	0.05	2.50	0.02				
4.0	3.92	0.06	2.25	0.02					3.92	0.04	2.25	0.02				
4.5	3.84	0.06	2.05	0.02					3.85	0.04	2.05	0.02				
5.0	3.78	0.06	1.90	0.03					3.79	0.04	1.90	0.02				

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 30 °C

Freq. GHz	Best-fit (Double-Debye)				Reflection cell				14-mm transmission cell				40-mm transmission cell			
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	19.30	0.04	2.65	0.02	19.31	0.08	2.63	0.05								
0.2	18.08	0.03	4.89	0.03	18.11	0.07	4.86	0.04								
0.3	16.44	0.03	6.50	0.04	16.47	0.06	6.47	0.04								
0.4	14.68	0.04	7.46	0.04	14.73	0.06	7.45	0.04								
0.5	13.02	0.04	7.92	0.03	13.07	0.06	7.90	0.04								
0.6	11.58	0.04	8.02	0.03	11.64	0.06	8.04	0.05					11.59	0.11	7.96	0.09
0.7	10.36	0.05	7.91	0.03	10.41	0.05	7.91	0.05					10.37	0.06	7.87	0.05
0.8	9.36	0.05	7.67	0.03	9.41	0.05	7.68	0.05					9.36	0.05	7.65	0.03
0.9	8.54	0.05	7.37	0.03	8.58	0.05	7.38	0.05					8.53	0.04	7.34	0.03
1.0	7.86	0.05	7.04	0.03	7.91	0.05	7.04	0.05	7.90	0.06	7.01	0.04	7.87	0.03	7.03	0.03
1.2	6.85	0.05	6.38	0.02					6.87	0.06	6.36	0.04	6.85	0.03	6.38	0.02
1.5	5.89	0.05	5.52	0.02					5.90	0.05	5.51	0.03	5.88	0.03	5.52	0.02
1.8	5.29	0.05	4.83	0.02					5.31	0.05	4.83	0.03	5.29	0.02	4.83	0.02
2.0	5.02	0.05	4.45	0.02					5.03	0.05	4.45	0.03	5.01	0.02	4.45	0.02
2.5	4.57	0.05	3.73	0.02					4.58	0.05	3.73	0.02	4.56	0.02	3.72	0.01
3.0	4.31	0.05	3.21	0.01					4.31	0.05	3.21	0.02	4.30	0.02	3.21	0.01
3.5	4.13	0.05	2.83	0.01					4.14	0.05	2.83	0.02				
4.0	4.01	0.05	2.55	0.02					4.01	0.04	2.55	0.03				
4.5	3.92	0.06	2.32	0.02					3.93	0.04	2.32	0.02				
5.0	3.84	0.06	2.14	0.03					3.86	0.04	2.14	0.02				

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 35 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	18.77	0.04	2.13	0.02	18.79	0.07	2.11	0.05				
0.2	17.94	0.03	4.02	0.03	17.96	0.07	4.00	0.04				
0.3	16.74	0.03	5.53	0.03	16.77	0.06	5.50	0.04				
0.4	15.36	0.03	6.59	0.04	15.41	0.06	6.58	0.04				
0.5	13.97	0.04	7.26	0.04	14.01	0.06	7.23	0.04				
0.6	12.66	0.04	7.61	0.03	12.72	0.06	7.60	0.05				
0.7	11.49	0.04	7.72	0.03	11.53	0.06	7.69	0.05				
0.8	10.47	0.04	7.67	0.03	10.52	0.06	7.65	0.05				
0.9	9.59	0.04	7.52	0.03	9.66	0.06	7.51	0.05				
1.0	8.85	0.05	7.30	0.03	8.91	0.05	7.28	0.05	8.91	0.07	7.25	0.04
1.2	7.69	0.05	6.79	0.02					7.73	0.06	6.75	0.04
1.5	6.52	0.05	6.02	0.02					6.56	0.06	5.99	0.03
1.8	5.77	0.05	5.34	0.02					5.82	0.06	5.33	0.03
2.0	5.43	0.05	4.95	0.02					5.46	0.06	4.94	0.03
2.5	4.86	0.05	4.17	0.02					4.87	0.06	4.18	0.03
3.0	4.52	0.05	3.60	0.02					4.52	0.05	3.61	0.03
3.5	4.32	0.05	3.18	0.02					4.30	0.05	3.19	0.03
4.0	4.18	0.05	2.86	0.02					4.14	0.05	2.87	0.03
4.5	4.08	0.05	2.61	0.02					4.03	0.04	2.61	0.03
5.0	4.01	0.05	2.41	0.03					3.94	0.04	2.40	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 40 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	18.20	0.04	1.71	0.01	18.22	0.08	1.69	0.05				
0.2	17.63	0.03	3.28	0.02	17.65	0.07	3.25	0.04				
0.3	16.78	0.03	4.62	0.03	16.81	0.07	4.59	0.04				
0.4	15.74	0.03	5.68	0.04	15.80	0.07	5.65	0.04				
0.5	14.63	0.03	6.44	0.04	14.68	0.07	6.40	0.05				
0.6	13.53	0.04	6.95	0.03	13.60	0.07	6.94	0.05				
0.7	12.47	0.04	7.25	0.03	12.53	0.07	7.22	0.06				
0.8	11.51	0.04	7.38	0.03	11.58	0.07	7.36	0.06				
0.9	10.65	0.04	7.39	0.03	10.73	0.07	7.38	0.06				
1.0	9.88	0.04	7.31	0.03	9.96	0.07	7.29	0.07	9.94	0.08	7.25	0.05
1.2	8.62	0.04	7.00	0.02					8.67	0.08	6.95	0.05
1.5	7.28	0.04	6.39	0.02					7.34	0.07	6.36	0.04
1.8	6.39	0.04	5.78	0.02					6.44	0.07	5.77	0.04
2.0	5.96	0.04	5.40	0.02					6.00	0.07	5.40	0.03
2.5	5.23	0.05	4.62	0.02					5.25	0.07	4.63	0.03
3.0	4.79	0.05	4.02	0.02					4.80	0.06	4.03	0.03
3.5	4.52	0.05	3.56	0.02					4.51	0.05	3.57	0.03
4.0	4.34	0.05	3.20	0.02					4.31	0.05	3.21	0.03
4.5	4.21	0.05	2.92	0.03					4.17	0.05	2.92	0.03
5.0	4.11	0.05	2.69	0.03					4.06	0.05	2.69	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-1-ol at 45 °C

Freq. GHz	Best-fit (Debye- Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	17.63	0.04	1.37	0.01	17.65	0.08	1.36	0.05				
0.2	17.24	0.04	2.67	0.02	17.25	0.07	2.64	0.04				
0.3	16.64	0.03	3.83	0.03	16.66	0.07	3.80	0.04				
0.4	15.88	0.03	4.80	0.03	15.93	0.07	4.78	0.04				
0.5	15.03	0.03	5.59	0.04	15.06	0.07	5.55	0.05				
0.6	14.14	0.03	6.18	0.04	14.19	0.07	6.17	0.05				
0.7	13.25	0.04	6.60	0.03	13.29	0.07	6.57	0.06				
0.8	12.40	0.04	6.87	0.03	12.45	0.07	6.85	0.06				
0.9	11.60	0.04	7.02	0.03	11.66	0.07	7.01	0.07				
1.0	10.86	0.04	7.08	0.03	10.93	0.07	7.06	0.07	10.91	0.08	7.01	0.05
1.2	9.59	0.04	7.00	0.03					9.63	0.08	6.94	0.04
1.5	8.13	0.04	6.61	0.02					8.18	0.08	6.58	0.04
1.8	7.11	0.04	6.12	0.02					7.16	0.08	6.11	0.04
2.0	6.59	0.04	5.79	0.02					6.64	0.08	5.78	0.03
2.5	5.70	0.04	5.04	0.02					5.72	0.07	5.05	0.03
3.0	5.15	0.04	4.43	0.02					5.15	0.06	4.45	0.04
3.5	4.79	0.04	3.95	0.02					4.78	0.06	3.96	0.04
4.0	4.55	0.05	3.56	0.03					4.52	0.05	3.58	0.04
4.5	4.38	0.05	3.25	0.03					4.34	0.05	3.26	0.03
5.0	4.25	0.05	3.00	0.03					4.20	0.05	3.00	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See note 26

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 10 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	18.55	0.10	6.91	0.08	18.63	0.16	6.98	0.07				
0.2	13.39	0.06	9.07	0.07	13.42	0.12	9.15	0.09				
0.3	9.81	0.05	8.65	0.05	9.82	0.09	8.71	0.08				
0.4	7.70	0.04	7.65	0.04	7.72	0.07	7.68	0.07				
0.5	6.45	0.03	6.68	0.03	6.46	0.06	6.71	0.07				
0.6	5.67	0.03	5.87	0.03	5.69	0.05	5.88	0.06			5.70	0.08
0.7	5.15	0.03	5.21	0.02	5.17	0.05	5.21	0.05			5.18	0.05
0.8	4.80	0.03	4.67	0.02	4.81	0.05	4.66	0.05			4.82	0.04
0.9	4.55	0.02	4.23	0.02	4.56	0.05	4.22	0.05			4.56	0.03
1.0	4.37	0.02	3.86	0.02	4.36	0.04	3.85	0.04			4.38	0.03
1.2	4.12	0.02	3.30	0.01							4.12	0.02
1.5	3.90	0.02	2.72	0.01							3.90	0.02
1.8	3.77	0.02	2.32	0.01							3.77	0.02
2.0	3.71	0.02	2.13	0.01							3.72	0.02
2.5	3.60	0.02	1.77	0.01							3.60	0.02
3.0	3.53	0.02	1.54	0.01							3.54	0.02

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 26 and 30

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 15 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''
0.1	18.89	0.10	5.54	18.99	0.16	5.60						
0.2	14.95	0.07	8.24	15.01	0.13	8.32						
0.3	11.54	0.05	8.66	11.56	0.10	8.73						
0.4	9.18	0.04	8.15	9.20	0.08	8.18						
0.5	7.63	0.04	7.39	7.65	0.07	7.42						
0.6	6.60	0.03	6.65	6.63	0.06	6.67				6.64	0.08	6.62
0.7	5.90	0.03	5.99	5.92	0.05	5.99				5.92	0.05	5.99
0.8	5.41	0.03	5.43	5.42	0.05	5.41				5.43	0.04	5.43
0.9	5.05	0.03	4.95	5.06	0.05	4.94				5.05	0.03	4.93
1.0	4.78	0.02	4.55	4.78	0.04	4.52				4.79	0.03	4.55
1.2	4.42	0.02	3.91							4.42	0.02	3.91
1.5	4.10	0.02	3.23							4.10	0.02	3.23
1.8	3.92	0.02	2.76							3.91	0.02	2.76
2.0	3.83	0.02	2.52							3.84	0.02	2.51
2.5	3.69	0.02	2.10							3.68	0.02	2.09
3.0	3.59	0.02	1.81							3.60	0.02	1.81

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 20 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''	ϵ'	unc.	ϵ''
0.1	18.87	0.08	4.37	0.04	0.16	4.42	0.05					
0.2	16.05	0.06	7.14	0.05	0.14	7.21	0.07					
0.3	13.12	0.05	8.20	0.05	0.11	8.27	0.08					
0.4	10.76	0.04	8.24	0.04	0.09	8.28	0.08					
0.5	9.02	0.04	7.83	0.03	0.08	7.85	0.08					
0.6	7.77	0.03	7.27	0.03	0.07	7.28	0.07			7.81	0.09	7.23
0.7	6.88	0.03	6.69	0.03	0.06	6.69	0.07			6.89	0.05	6.69
0.8	6.22	0.03	6.16	0.02	0.06	6.15	0.07			6.23	0.04	6.15
0.9	5.73	0.02	5.68	0.02	0.05	5.67	0.06			5.73	0.03	5.65
1.0	5.36	0.02	5.26	0.02	0.05	5.22	0.06			5.36	0.03	5.26
1.2	4.84	0.02	4.56	0.02						4.84	0.02	4.56
1.5	4.38	0.02	3.79	0.01						4.38	0.02	3.80
1.8	4.12	0.02	3.25	0.01						4.11	0.02	3.25
2.0	4.00	0.02	2.97	0.01						4.00	0.02	2.96
2.5	3.80	0.02	2.46	0.01						3.79	0.02	2.46
3.0	3.67	0.02	2.12	0.01						3.68	0.02	2.12

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See notes 26 and 30

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 25 °C

Freq. GHz	Best-fit (Double-Debye)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.
0.1	18.54	0.10	3.39	0.04	18.63	0.16	3.42	0.04				
0.2	16.63	0.08	5.92	0.06	16.70	0.14	5.99	0.06				
0.3	14.35	0.06	7.34	0.06	14.39	0.12	7.40	0.07				
0.4	12.22	0.05	7.87	0.05	12.25	0.11	7.90	0.08				
0.5	10.47	0.05	7.86	0.04	10.47	0.09	7.88	0.08				
0.6	9.10	0.04	7.57	0.04	9.11	0.08	7.59	0.08				
0.7	8.05	0.04	7.17	0.03	8.04	0.07	7.17	0.08	9.16	0.10	7.53	0.09
0.8	7.24	0.04	6.74	0.03	7.24	0.07	6.72	0.07				
0.9	6.61	0.03	6.31	0.03	6.61	0.06	6.29	0.07	8.08	0.06	7.17	0.05
1.0	6.12	0.03	5.91	0.03	6.12	0.06	5.87	0.07	7.26	0.04	6.74	0.03
1.2	5.42	0.03	5.21	0.02					6.62	0.04	6.28	0.03
1.5	4.79	0.02	4.39	0.02					6.13	0.03	5.91	0.02
1.8	4.41	0.02	3.79	0.02					5.42	0.03	5.22	0.02
2.0	4.24	0.02	3.47	0.01					4.78	0.02	4.40	0.02
2.5	3.96	0.02	2.88	0.01					4.41	0.02	3.79	0.01
3.0	3.79	0.02	2.47	0.01					4.25	0.02	3.46	0.02
									3.95	0.02	2.88	0.01
									3.79	0.02	2.48	0.01

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 30 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	17.92	0.09	2.56	0.02	18.12	0.15	2.63	0.04				
0.2	16.71	0.08	4.70	0.04	16.87	0.14	4.83	0.05				
0.3	15.09	0.07	6.19	0.04	15.18	0.13	6.33	0.06				
0.4	13.39	0.06	7.05	0.04	13.44	0.12	7.15	0.07				
0.5	11.82	0.05	7.42	0.04	11.82	0.11	7.50	0.08				
0.6	10.47	0.05	7.47	0.04	10.47	0.10	7.52	0.08				
0.7	9.35	0.05	7.32	0.03	9.33	0.09	7.33	0.08				
0.8	8.43	0.04	7.06	0.03	8.41	0.08	7.05	0.09				
0.9	7.68	0.04	6.76	0.03	7.68	0.08	6.73	0.08				
1.0	7.07	0.04	6.44	0.03	7.07	0.07	6.38	0.08				
1.2	6.17	0.03	5.81	0.03								
1.5	5.32	0.03	4.99	0.02								
1.8	4.80	0.02	4.35	0.02								
2.0	4.57	0.02	4.00	0.02								
2.5	4.19	0.02	3.33	0.01								
3.0	3.98	0.02	2.87	0.01								

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 35 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	17.37	0.08	1.99	0.01	17.52	0.15	2.03	0.04				
0.2	16.58	0.08	3.75	0.03	16.72	0.14	3.84	0.04				
0.3	15.46	0.07	5.14	0.03	15.54	0.14	5.25	0.06				
0.4	14.17	0.06	6.12	0.04	14.22	0.13	6.21	0.07				
0.5	12.87	0.06	6.73	0.04	12.89	0.12	6.80	0.08				
0.6	11.66	0.05	7.04	0.04	11.67	0.11	7.09	0.08				
0.7	10.58	0.05	7.13	0.03	10.55	0.10	7.14	0.09				
0.8	9.63	0.05	7.07	0.03	9.61	0.10	7.05	0.09				
0.9	8.83	0.04	6.92	0.03	8.82	0.09	6.90	0.09				
1.0	8.15	0.04	6.72	0.03	8.13	0.09	6.66	0.09				
1.2	7.08	0.04	6.24	0.03								
1.5	6.01	0.03	5.52	0.02								
1.8	5.34	0.03	4.89	0.02								
2.0	5.02	0.03	4.53	0.02								
2.5	4.50	0.02	3.81	0.02								
3.0	4.20	0.02	3.29	0.02								

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 40 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	16.75	0.08	1.53	0.01	16.87	0.14	1.55	0.04				
0.2	16.25	0.08	2.95	0.02	16.36	0.14	3.01	0.04				
0.3	15.50	0.07	4.16	0.02	15.57	0.14	4.24	0.05				
0.4	14.58	0.07	5.13	0.03	14.63	0.13	5.19	0.06				
0.5	13.59	0.06	5.84	0.03	13.60	0.13	5.90	0.07				
0.6	12.59	0.06	6.32	0.03	12.60	0.12	6.37	0.08				
0.7	11.64	0.06	6.61	0.03	11.61	0.12	6.62	0.09				
0.8	10.76	0.05	6.75	0.03	10.72	0.11	6.72	0.10				
0.9	9.97	0.05	6.77	0.03	9.95	0.11	6.74	0.11				
1.0	9.26	0.05	6.71	0.03	9.23	0.11	6.65	0.11				
1.2	8.10	0.04	6.45	0.03								
1.5	6.85	0.04	5.91	0.03								
1.8	6.01	0.03	5.35	0.02								
2.0	5.60	0.03	5.01	0.02								
2.5	4.91	0.03	4.29	0.02								
3.0	4.50	0.02	3.73	0.02								

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 45 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	16.10	0.07	1.18	0.01	16.18	0.14	1.19	0.04				
0.2	15.78	0.07	2.31	0.01	15.86	0.14	2.35	0.04				
0.3	15.28	0.07	3.32	0.02	15.34	0.13	3.38	0.04				
0.4	14.65	0.07	4.19	0.02	14.70	0.13	4.23	0.05				
0.5	13.93	0.06	4.91	0.02	13.96	0.13	4.95	0.07				
0.6	13.17	0.06	5.46	0.03	13.19	0.13	5.49	0.08				
0.7	12.40	0.06	5.87	0.03	12.38	0.13	5.87	0.09				
0.8	11.65	0.05	6.14	0.03	11.61	0.12	6.10	0.10				
0.9	10.94	0.05	6.32	0.03	10.92	0.12	6.28	0.11				
1.0	10.27	0.05	6.40	0.03	10.24	0.12	6.34	0.11				
1.2	9.12	0.04	6.38	0.03								
1.5	7.77	0.04	6.09	0.03								
1.8	6.79	0.03	5.68	0.02								
2.0	6.30	0.03	5.39	0.02								
2.5	5.44	0.03	4.72	0.02								
3.0	4.90	0.02	4.16	0.02								

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26* and *30*

8. Tables of Measured and Best-fit Complex Permittivity Data (continued)

Propan-2-ol at 50 °C

Freq. GHz	Best-fit (Debye-Γ)			Reflection cell			14-mm transmission cell			40-mm transmission cell		
	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.	ε'	unc.	ε''	unc.
0.1	15.43	0.07	0.91	0.01	15.49	0.14	0.92	0.04				
0.2	15.23	0.07	1.80	0.01	15.29	0.13	1.83	0.04				
0.3	14.90	0.07	2.62	0.01	14.95	0.13	2.67	0.05				
0.4	14.48	0.07	3.37	0.02	14.52	0.14	3.40	0.06				
0.5	13.98	0.07	4.02	0.02	14.01	0.14	4.06	0.07				
0.6	13.42	0.06	4.57	0.02	13.45	0.14	4.60	0.08				
0.7	12.84	0.06	5.02	0.02	12.82	0.14	5.03	0.10				
0.8	12.25	0.06	5.38	0.02	12.21	0.14	5.35	0.11				
0.9	11.66	0.06	5.65	0.02	11.64	0.14	5.62	0.12				
1.0	11.09	0.05	5.84	0.02	11.05	0.14	5.79	0.14				
1.2	10.03	0.05	6.04	0.03								
1.5	8.69	0.04	6.03	0.03								
1.8	7.64	0.04	5.80	0.02								
2.0	7.09	0.04	5.60	0.02								
2.5	6.06	0.03	5.05	0.02								
3.0	5.39	0.03	4.54	0.02								

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.

See *notes 26 and 30*

9. Results of χ^2 Testing of Fitted Relaxation Models

To allow the quality of the relaxation model fits to be assessed, the χ^2 -value of fitted data (χ^2_{data}) has been computed at each temperature. This is shown in the tables below. Values of the χ^2 distribution (χ^2_{dist}) were calculated using a *Matlab* function according to the number of degrees of freedom (see below). For adequate fits we expect $\chi^2_{\text{data}} < \chi^2_{\text{dist}}$. In principle, the number of degrees of freedom is the number of measured points less the number of fitted parameters. As uncertainties associated with the real and imaginary parts relate to partly correlated effects (e.g. through phase errors) it is expected that, the number of degrees of freedom (η) falls within the following limits:

$$m - n < \eta < 2m - n, \quad (6)$$

in which m is the number of complex points and n is the number of fitted parameters. The χ^2 values in the tables below were computed at the 95 % quartile for both of the limits in eqn. (6). As can be seen, a high level of compliance with condition $\chi^2_{\text{data}} < \chi^2_{\text{dist}}$ is obtained. In practice experimental runs in which several temperatures were measured always began and ended with 20 °C measurements. These enable extra checks to be made, e.g. for drift. To illustrate this, entries in the table are given with and without the final 20 °C measurements (asterisks indicate that they are included). In computing the χ^2 -value, all the available sets of data were used, including data from additional experiments for checking results at 20 °C.

Butan-1-ol: χ^2 computed at the 95% quartile

T °C	m	χ^2_{data}	$\chi^2_{\text{dist}}(m-n)$	$\chi^2_{\text{dist}}(2m-n)$	Model
10	76	53.9	92.8	177.4	Double-Debye $n=4$
15	76	42.1	92.8	177.4	
20	117	55.2	92.8	177.4	
	*193	193.8	222.1	428.6	
25	76	38.6	92.8	177.4	
30	76	30.3	92.8	177.4	
35	76	25.3	92.8	177.4	
40	76	27.1	92.8	177.4	Debye- Γ $n=3$
45	76	70.8	94.0	178.5	
50	76	50.3	94.0	178.5	

* See text above for explanation.

DMSO: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
20	119	56.0	143.2	272.8	Debye <i>n</i> =2
	*191	90.3	222.1	426.5	
25	70	23.4	88.2	166.4	
30	70	20.3	88.2	166.4	
35	70	15.1	88.2	166.4	
40	70	13.7	88.2	166.4	
45	70	13.8	88.2	166.4	
50	70	13.3	88.2	166.4	

Ethanediol: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
10	76	63.5	93.9	178.5	Davidson-Cole <i>n</i> =3
15	76	57.3	93.9	178.5	
20	76	86.8	93.9	178.5	
	*152	165.2	178.5	342.5	
25	76	43.8	93.9	178.5	
30	76	36.0	93.9	178.5	
35	76	28.3	93.9	178.5	
40	76	29.7	93.9	178.5	
45	76	25.2	93.9	178.5	
50	76	38.9	93.9	178.5	

Ethanol: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
10	76	135.4	93.9	178.5	Debye-Γ <i>n</i> =3
15	76	124.1	93.9	178.5	
20	127	81.1	151.0	289.0	
	*254	338.3	289.0	558.4	
25	76	76.5	93.9	178.5	
30	76	65.4	93.9	178.5	
35	86	92.0	105.6	200.3	
40	76	93.8	93.9	178.5	
45	76	133.2	93.9	178.5	
50	76	182.2	93.9	178.5	

The measurements on ethanol show a slight but systematic deviation from the Debye-Γ equation. This is most evident at frequencies above 4 GHz and at temperatures below 30 °C. See note 27.

Methanol: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
10	74	30.5	92.8	179.6	Debye <i>n</i> =2
15	74	25.6	92.8	179.6	
20	115	59.2	138.8	264.2	
	*189	86.3	219.9	422.2	
25	74	26.2	92.8	179.6	
30	74	19.3	92.8	179.6	
35	74	25.2	92.8	179.6	
40	74	14.3	92.8	179.6	
45	74	12.5	92.8	179.6	
50	74	36.2	92.8	179.6	

Propan-1-ol: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
10	76	14.7	92.8	177.4	Double-Debye <i>n</i> =4
15	76	11.5	92.8	177.4	
20	117	28.8	138.8	266.4	
	*193	98.7	222.1	428.6	
25	76	18.7	92.8	177.4	
30	76	17.9	93.9	178.5	Debye-Γ <i>n</i> =3
35	76	63.8	93.9	178.5	
40	76	47.4	93.9	178.5	
45	76	48.7	93.9	178.5	
50	76	38.2	93.9	178.5	

Propan-2-ol: χ^2 computed at the 95% quartile

T °C	<i>m</i>	χ^2_{data}	$\chi^2_{dist}(m-n)$	$\chi^2_{dist}(2m-n)$	Model
10	35	13.6	43.8	84.9	Double-Debye <i>n</i> =5 †
15	35	12.4	43.8	84.9	
20	35	7.5	43.8	84.9	
	*70	22.8	84.8	163.1	
25	35	8.8	43.8	84.9	Debye-Γ <i>n</i> =4 †
30	35	24.5	45.0	86.0	
35	35	17.6	45.0	86.0	
40	35	12.8	45.0	86.0	
45	35	11.8	45.0	86.0	
50	35	10.0	45.0	86.0	

† For propan-2-ol only, static permittivity is fitted as an admittance cell measurement is not available.

* See text above for explanation.

10. Validation using new measurements

To help to improve confidence in the data, a limited number of new measurements were made in 2008–2009 on ethanediol. This liquid was chosen since the discrepancies between measurements from the reflection and transmission cells were noted to be larger than for the other liquids in the original data, so some further investigation was merited. Compared to the original set of measurements the following changes were made: (i) Different Vector Network Analyser models were used, (ii) all of the cells had been renewed, (iii) a 12 mm length transmission cell was used in place of the 14 mm cell, and (iv) the reflection cell used a 7 mm length truncated inner-conductor, whereas in the 1997–2000 programme a 5 mm length conductor had been used. The new sets of data at 20 °C and 40 °C are presented overleaf. The ‘best-fit’ data and uncertainties (columns 2–5) were computed from the new transmission-line cell data, and the original admittance cell measurements of static permittivity (Section 6). As with the uncertainty computations for the original data, the uncertainties associated with the ‘best-fit’ data include an additional uncertainty contribution that is applied in quadrature to account for unforeseen errors; see Section 1.2, page 3.

As noted above, the original data for ethanediol (pages 35–43) showed some larger than expected discrepancies between the measurements made using the three cells. However, it was not possible to deduce which set of data was most in error from the data available. Comparison with the new data shows that the measurements originally made with the 14 mm cell probably have the largest discrepancy. The discrepancies observed lie close to the expected uncertainty limits but are by no means implausible in the light of the uncertainty evaluation that has been used. It is nevertheless possible that an actual error occurred, e.g. the cables changed properties by more than the amount allowed for, or the bead seals in the cell leaked (which is not allowed for at all).

Despite the above comments, the new data are observed to be in good agreement with the original data. Furthermore, relaxation parameters fitted to the new data (see the table below) are also in reasonable agreement, as the discrepancies between the two sets of ‘best-fit’ data lie within the ranges that would be expected from the quoted uncertainties. We believe that this additional set of data for ethanediol helps to validate the original data and provides confidence in both the tabulated data and the evaluations of uncertainty that have been presented in this report.

Parameters of the Davidson-Cole equation (eqn. 4) fitted to the validation data

Temp.	ϵ_s	unc.	f_r	unc.	ϵ_∞	unc.	β	unc.
10	44.31	0.06	0.605	0.006	4.626	0.086	0.836	0.006
15	43.08	0.06	0.770	0.009	4.584	0.123	0.842	0.009
20	41.89	0.06	0.957	0.011	4.557	0.123	0.846	0.008
25	40.75	0.06	1.196	0.019	4.873	0.235	0.868	0.015
30	39.66	0.06	1.462	0.028	4.962	0.334	0.877	0.021
35	38.60	0.06	1.781	0.038	5.251	0.433	0.898	0.027
40	37.63	0.06	2.079	0.056	4.533	0.658	0.863	0.036

The above parameters may be compared with those determined from the data measured the 1997–2000 programme shown on page 16.

2008-9 validation measurements - ethanediol at 20 °C

Freq. GHz	†Best-fit (Davidson-Cole)			Reflection cell			12-mm transmission cell			40-mm transmission cell		
	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.
0.1	41.57	0.06	3.27	0.02	41.57	0.10	3.17	0.05				
0.2	40.67	0.05	6.36	0.04	40.69	0.11	6.23	0.06				
0.3	39.26	0.05	9.12	0.05	39.31	0.12	8.98	0.09				
0.4	37.49	0.05	11.46	0.06	37.55	0.14	11.32	0.11				
0.5	35.51	0.05	13.35	0.06	35.54	0.15	13.18	0.14				
0.6	33.43	0.06	14.80	0.06	33.46	0.17	14.61	0.16			33.45	0.16
0.7	31.36	0.07	15.86	0.06	31.37	0.18	15.65	0.18			31.39	0.13
0.8	29.36	0.07	16.58	0.06	29.36	0.19	16.34	0.20			29.41	0.12
0.9	27.49	0.08	17.02	0.06	27.48	0.20	16.72	0.22			27.52	0.11
1.0	25.75	0.08	17.24	0.06	25.73	0.21	16.91	0.24	25.79	0.22	25.77	0.10
1.2	22.71	0.09	17.23	0.06					22.65	0.24	22.70	0.09
1.5	19.16	0.09	16.57	0.06					19.15	0.23	19.13	0.09
1.8	16.56	0.10	15.61	0.06					16.57	0.21	16.51	0.09
2.0	15.21	0.10	14.93	0.06					15.24	0.19	15.16	0.09
2.5	12.75	0.10	13.32	0.06					12.79	0.16	12.74	0.11
3.0	11.13	0.10	11.94	0.06					11.19	0.13	11.16	0.13
3.5	10.01	0.10	10.79	0.06					10.07	0.12		
4.0	9.19	0.10	9.84	0.06					9.28	0.11		
4.5	8.58	0.10	9.03	0.06					8.68	0.10		
5.0	8.11	0.10	8.35	0.07					8.21	0.09		

†The best-fit data are calculated from the validation measurements only.

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.
The above table may be compared with the 1997–2000 data, page 37.

2008-9 validation measurements - ethanediol at 40 °C

Freq.		†Best-fit (Davidson-Cole)				Reflection cell				12-mm transmission cell				40-mm transmission cell			
GHz	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	ϵ'	unc.	ϵ''	unc.	
0.1	37.57	0.06	1.37	0.01	37.54	0.11	1.28	0.06									
0.2	37.39	0.06	2.73	0.02	37.38	0.11	2.58	0.07									
0.3	37.09	0.06	4.05	0.03	37.09	0.13	3.88	0.10									
0.4	36.68	0.05	5.32	0.03	36.71	0.15	5.13	0.13									
0.5	36.17	0.05	6.53	0.04	36.21	0.19	6.28	0.17									
0.6	35.57	0.05	7.68	0.04	35.60	0.23	7.39	0.21					35.45	0.15	7.71	0.07	
0.7	34.90	0.06	8.74	0.05	34.92	0.27	8.44	0.25					34.77	0.13	8.72	0.06	
0.8	34.16	0.06	9.72	0.05	34.18	0.31	9.38	0.30					34.03	0.12	9.65	0.07	
0.9	33.38	0.06	10.61	0.05	33.38	0.36	10.24	0.34					33.29	0.12	10.48	0.06	
1.0	32.55	0.06	11.42	0.05	32.55	0.41	11.01	0.39	32.50	0.26	11.12	0.14	32.56	0.12	11.33	0.05	
1.2	30.83	0.07	12.76	0.05					30.86	0.33	12.44	0.14	30.83	0.11	12.81	0.05	
1.5	28.23	0.08	14.19	0.05					28.37	0.37	14.09	0.07	28.19	0.10	14.20	0.06	
1.8	25.76	0.08	15.02	0.05					25.85	0.33	15.00	0.11	25.72	0.10	15.06	0.07	
2.0	24.22	0.09	15.32	0.06					24.28	0.30	15.32	0.13	24.14	0.10	15.42	0.08	
2.5	20.89	0.10	15.45	0.07					20.91	0.25	15.47	0.14	20.81	0.13	15.44	0.12	
3.0	18.24	0.11	15.06	0.09					18.26	0.21	15.09	0.14	18.18	0.20	15.01	0.20	
3.5	16.15	0.11	14.44	0.12					16.17	0.19	14.45	0.14					
4.0	14.52	0.11	13.72	0.15					14.56	0.17	13.72	0.14					
4.5	13.22	0.11	13.00	0.17					13.28	0.16	13.02	0.13					
5.0	12.17	0.11	12.31	0.20					12.23	0.15	12.32	0.12					

†The best-fit data are calculated from the validation measurements only.

Uncertainties are shown at coverage factor of $k = 2$, approximately equivalent to 95% confidence level.
The above table may be compared with 1997–2000 data, page 41.

11. Acknowledgements

This work was carried out in two projects funded by the Electrical Programme of the National Measurement System Policy Unit (NMSPU) of the UK Government's Department of Trade and Industry (now the Department for Innovation, Universities and Skills, DIUS). The two projects covered the original measurements and their reporting (1997–2001) and the more recent (2006–8) re-analysis of the uncertainties and presentation of the measured data, as described here and in reference [3].

The authors gratefully acknowledge contributions made by various colleagues, in particular, Dean Wells of the NPL workshop who made the coaxial cells, Maurice Cox of NPL for his contributions to the new evaluation of uncertainties [3], and Tim Hodgetts, formerly of DERA & QinetiQ, who produced modal analysis software for the programme of work on reference liquids.

In preparing the second issue of this report, two studies of the validity of the relaxation models over an extended frequency range were made. These studies were supported by the European Programme *Implementing Metrology in the European Research Area Plus* (iMERA+) under the EC Grant Agreement No. 217257 between the European Commission and EURAMET: Project T4.J07 “Traceable measurement of field strength and SAR for the Physical Agents Directive” 2008–2010. Our findings are summarised in *notes 31 & 32* on page 12.

12. References

- [1] A P Gregory A P and R N Clarke 1 ‘Tables of the Complex Permittivity of Dielectric Reference Liquids at Frequencies up to 5 GHz’, *NPL Report CETM 33*, 2001, ISSN 1467-3932
- [2] A P Gregory and R N Clarke, ‘Traceable Measurements of the Static Permittivity of Dielectric Reference Liquids over the Temperature Range 5 – 50 °C’, *Meas. Sci. Technol.*, **16**, pp. 1506-1516, 2005.
- [3] A P Gregory, R N Clarke and M G Cox, ‘Traceable Measurement Of Dielectric Reference Liquids Over The Temperature Interval 10 °C – 50 °C Using Coaxial-Line Methods’, *Meas. Sci. Technol.*, **20**, article 75106, 2009.
- [4] S Jenkins, T E Hodgetts, R N Clarke and A W Preece, 1990, ‘Dielectric measurements on reference liquids using automatic network analysers and calculable geometries’. *Meas. Sci. Technol.*, **1**, pp. 691-702, 1990.
- [5] NPL Dielectrics Database (ECDDDB), Release 1, National Physical Laboratory, 2001. This database has been superseded, but the data can be obtained from NPL if required.
- [6] A P Gregory and R N Clarke, ‘Dielectric metrology with coaxial sensors’, *Meas. Sci. Technol.*, **18**, pp. 1372-1386, 2007.
- [7] A P Gregory and R N Clarke, ‘A Review of RF and Microwave Techniques for Dielectric Measurements on Polar Liquids’, *IEEE Trans. Dielect. and Elec. Insulation*, **13** (4) pp. 727-743, 2006
- [8] H Kienitz and K N Marsh, ‘Recommended reference materials for relaxation of physicochemical properties’, *Pure & Appl. Chem.* **53**, pp. 1847-1862, 1981 International Union of Pure and Applied Chemistry: Commission on Physicochemical Measurements.
- [9] ‘The expression of uncertainty and confidence in measurement’, Technical Report M3003, United Kingdom Accreditation Service (Feltham, UK).
- [10] JCGM 100:2008, ‘Evaluation of measurement data — Guide to the expression of uncertainty in measurement’ (GUM). Joint Committee for Guides in Metrology, 2008.
- [11] M G Cox and P M Harris, ‘SSfM Best Practice Guide No. 6, Uncertainty evaluation’, Technical Report DEM-ES-011, National Physical Laboratory, Teddington, UK, 2006.
- [12] R N Clarke (Ed.), 2003, ‘A Guide to the characterisation of dielectric materials at RF and microwave Frequencies’, The Institute of Measurement and Control (IMC) and The National Physical Laboratory (NPL), London, ISBN 0 904457 38 9.
- [13] W J Ellison, ‘Permittivity of Pure Water, at Standard Atmospheric Pressure, over the Frequency Range 0–25 THz and the Temperature Range 0–100 °C’, *J. Phys. Chem. Ref. Data*, **36** (1) pp. 1-18, 2007.
- [14] U Kaatze, ‘Complex Permittivity of Water as a Function of Frequency and Temperature’, *J. Chem. Eng. Data*, **34** (4), pp. 371-374, 1989.
- [15] A Chandrau and B G Bagchi, ‘Frequency dependence of ionic conductivity of electrolyte solutions’, *J. Chem. Phys.*, **112** (4), pp. 1876-1886, 2000.
- [16] J E Anderson ‘The Debye-Falkenhagen effect: experimental fact or fiction?’, *J. of Non-Crystalline Solids*, **172-174** (2), pp. 1190-1194, 1994.
- [17] M Prego, O Cabeza, E Carballo, C F Franjo and E Jimenez, ‘Measurement and interpretation of the electrical conductivity of 1-alcohols from 273 K to 333 K’, *J. of Molecular Liquids*, **89**, pp. 233-238, 2000.