[11] S. B. Cohn, "Properties of ridge waveguide," *Proc. IRE*, vol. 35, pp. 783–788, Aug. 1947.
[12] H. Hofmann, private communication.
[13] E. Pic and W. J. R. Hoefer, "Experimental characterization of fin-line discontinuities using resonant techniques," in *1981 IEEE MTT-S Int. Microwave Symp. Dig.*, (Los Angeles, CA), pp. 108–110.

Arvind K. Sharma (S'74–M'80) was born in Jodhpur, Rajasthan, India, on December 4, 1951. He received the B.E. (Hons.) degree in electronics from Birla Institute of Technology and Science, Pilani, Rajasthan, in 1973, and the M. Tech. degree in electronics and communication engineering, and the Ph.D. degree from the Indian Institute of Technology, Delhi, in 1975 and 1981, respectively.

From 1980–1982, he was with the Department of Electrical Engineering, University of Ottawa, Ottawa, Ontario, Canada, as a Research Associate. Since 1982 he has been with the Microwave Technology Center, RCA Laboratories, David Sarnoff Research Center, Princeton, NJ. His areas of research interest include microwave and millimeter-wave integrated circuits, and analytical and numerical methods in electromagnetics.

Dr. Sharma received the Best Paper Award in the Student Paper Contest organized by the IEEE India Section in 1975. He was awarded the IEEE Outstanding Student Member Award in 1975.

Wolfgang J. R. Hoefer (M'71–SM'78) was born in Urmitz/Rhein, Germany, on February 6, 1941. He received the diploma in electrical engineering from the Technische Hochschule Aachen, Aachen, Germany, in 1964, and the D. Ing. degree from the University of Grenoble, Grenoble, France, in 1968.

After one year of teaching and research at the Institut Universitaire de Technologie, Grenoble, France, he joined the Department of Electrical Engineering, the University of Ottawa, Ottawa, Ontario, Canada where he is currently a Professor. During a sabbatical year in 1976–1977, he spent six months with the Space Division of the AEG-Telefunken in Backnang, Germany, and six months with the Institut National Polytechnique de Grenoble, France. His research interests include microwave measurement techniques, millimeter-wave circuit design, and numerical techniques for solving electromagnetic problems.

Dr. Hoefer is a registered Professional Engineer in the province of Ontario, Canada.

Short Papers

A Quasi-Optical Nulling Method for Material Birefringence Measurements at Near-Millimeter Wavelengths

GEORGE J. SIMONIS, MEMBER, IEEE

Abstract —**A quasi-optical technique for the measurement of birefringence is demonstrated at 245 GHz. The technique is applied to crystal quartz. The measured values are compared with values reported at nearby frequencies. The technique is used to determine the difference between the ordinary and extraordinary real indices of refraction directly, rather than by deducing the difference from separate measurements of the two indices. The technique is based on establishing a transmission null, thus providing appreciable sensitivity and precision for the measurement.**

I. Introduction

In the infrared wavelength range, many conventional optical techniques are employed for materials characterization. In the microwave region, fundamental mode waveguide and microwave discrete-frequency sources are brought to bear on the problem with the material of interest often completely filling a section of the waveguide. The near-millimeter-wave region (NMMW—approximately 94 to 1000 GHz) presents particular problems and warrants somewhat specialized approaches. The wavelength is large enough that diffraction effects can be a substantial perturbation to "optical" configurations. The wavelength is small enough that the small waveguide is difficult to work with and to uniformly fill with the sample material. An NMMW technique is described here that employs a quasi-optical configuration to measure sample birefringence directly, without first measuring the magnitudes of the individual indices.

The radiation source is a CO_2-laser-pumped metal-waveguide $C^{13}H_3F$ laser 2 m long emitting at 1.222-mm wavelength (245 GHz). The average power available is much less than 1 mW, but is quite sufficient to provide a good signal-to-noise ratio for the measurements. Such sources typically undergo substantial amplitude fluctuations, but have good frequency stability, operating within a few megahertz of the gain line center of the lasing gas. The optics and sample dimensions are kept greater than 1 in in clear aperature in order to reduce diffraction effects. The source and experiment are isolated in this work by an absorption "pad" in the optical path.

The critical elements in the configuration are wire grating polarizers made at Harry Diamond Laboratories. They are made using a machine shop lathe in an approach [1] similar in some

Manuscript received June 25, 1982; revised November 22, 1982.
The author is with the Army Electronics Research and Development Command, Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783.

respects to that of Sentz *et al.* [2]. Two polarizers and two reflectors on a micrometer-driven translation stage taken together constitute an NMMW element similar to that described by Martin and Puplett [3] in their polarizing interferometry. This element constitutes a synthetic "material" with tunable birefringence for any wavelength of interest, provided the wavelength is large compared to the wire spacing. This synthetic "material" has been used in the construction and testing of polarizing duplexers/isolators which will be discussed elsewhere [4].

II. Experimental Procedure

The configuration shown in Fig. 1 is assembled and aligned without the birefringent sample, which is to be studied, in position. The gratings near the source and the detector are crossed relative to each other and are oblique to the incident beam so that multiple reflections from them are not a problem. The polarization passed by the first grating is split into two equal components with the relative phase shift between them adjustable in the birefringent element and then recombined. The birefringence is adjusted so that the two polarizations are in phase. The recombined signal is then optimally blocked by the final grating, and the transmission through the configuration to the detector is at a minimum (less than 0.1 percent).

The sample is mounted on an accurately indexed rotating mount and inserted in front of a previously positioned aperture (not shown) in the beam at the position shown in Fig. 1. The birefringence of the sample will induce more than minimal leakage through the last grating, except when the optical axis of the sample is either parallel or perpendicular to the polarization of the incident radiation on the sample. The optic axis of the crystal quartz sample is carefully determined and indexed by rotating the sample in the beam.

The optic axis of the sample is then rotated to be at 45° to the incident polarization. This results in considerable NMMW leakage through the last grating to the detector until the sample birefringent optical path difference Δnd is nulled out by a compensating birefringent optical path difference $2\Delta L + m\lambda/2$ in the adjustably birefringent element, where m is some integer. The amount of equivalent birefringence (Δn) inserted in order to get back to a transmission null is determined from the change in the reading of the micrometer and converted to birefringence as described in Fig. 1. There is a certain degeneracy to the possible birefringence values as determined by this method, but the order of magnitude is usually known in advance from existing higher or lower frequency results and, in any event, this degeneracy can be removed by measuring samples of the same material with different thicknesses.

Multiple reflections from the sample surfaces can also be a problem. The crystalline quartz samples reported on here were antireflection (AR) coated to avoid this problem. The ordinary index of refraction of crystalline quartz at 245 GHz is 2.107 ± 0.002^5, calling for an AR coating $\lambda'/4$ thick (where λ' is the wavelength in the coating) with an index of $\sqrt{2.107}$ or 1.45. The index of polyethylene is fortuitously 1.43. Also, polyethylene is commercially available in thin sheets of various thicknesses down to 25 μm under various trade names, and is one of the lowest loss NMMW materials known. We bonded the desirable number of sheets of polyethylene together using a small amount of fluorinated vacuum grease as the adhesive between sheets and to the sample. We were concerned about the amount of loss that the vacuum grease might introduce, so we measured the transmission of polyethylene laminations by themselves. Fig. 2 shows the transmission measured with the NMMW laser for various lamination thicknesses of polyethylene sheets. The solid line is the calculated transmission versus thickness of a solid layer of polyethylene, using an index of 1.43 and a power absorption coefficient of 0.2 cm^{-1}. The reported absorption of polyethylene in the data base [11] varies between 0.2 and 0.02 cm^{-1}. The observed loss is probably due to a combination of polyethylene and vacuum grease absorption, but is not significant for the thicknesses needed for the AR coatings. Transmission of the AR-coated crystalline quartz was measured to be in excess of 99 percent. These coatings have been observed to give stable AR-coating effects in our laboratory for over two years.

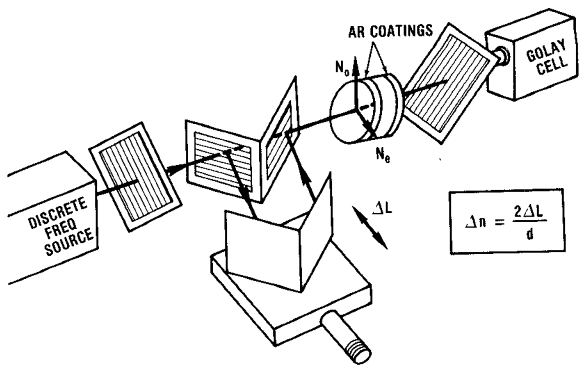

Fig. 1. Experimental configuration for measurement of birefringence.

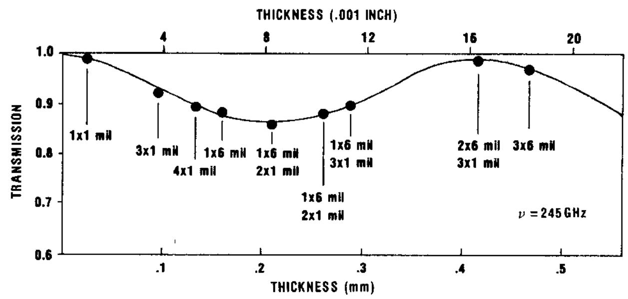

Fig. 2. Theoretical and experimental transmission of various polyethylene lamination thicknesses. The labels on the data points indicate the nominal layer thicknesses and numbers of layers used in each lamination.

Other materials with different indices could not be AR coated with pure polyethylene-sheet laminations, but could perhaps be AR coated with "loaded" polyethylene. The loading could even be a selected powdered amount of the material to be AR coated. Loading of polyethylene has been reported in the past for the fabrication of far-infrared transmission filters [6]. The AR coating would require a more uniform loading of the polyethylene than is needed for the transmission filters.

Some birefringent materials have substantially different indices and/or power absorption coefficients for the two incident polarizations. This results in different losses and AR coating requirements for the two polarizations. A null can still be achieved by rotating the first grating and changing the relative magnitude of the two polarization constituents by a calibrated amount without AR coatings. Allowance must then be made in the treatment of the data for the effect of multiple reflections in the sample. It is of interest to note that this apparatus would provide a convenient means of quickly inspecting other materials also, such as plastics and ceramics, which sometimes have an unintended and troublesome birefringence.

III. Results

Two samples of natural Brazilian crystalline quartz with thicknesses of 6 mm and 3.564 mm and the optic axis in the plane of the surface ("x" and $(1\bar{2}10)$ orientations, respectively) were

TABLE I
COMPARISON OF MEASURED BIREFRINGENCE WITH SOME OTHER AVAILABLE VALUES

Measurement Frequency	1 kHz	35 GHz	245 GHz	245 GHz	600 GHz	890 GHz
Δn	0.047±.002*	0.047±.002*	0.0466±.0015	0.047±.001	0.0468±.003*	0.048±.001
reference	7	8	this work	this work	9	10
sample thickness	1.5 mm	4 mm	3.564 mm	6.000 mm	1.0497 mm, 4.7873 mm	0.228 mm to 25.71 mm

* Uncertainties have been conservatively deduced from information available in the references.

studied. The thickness measurement accuracy and actual thickness nonuniformities result in a thickness uncertainty of ±0.01 mm. This is relatively crude when compared to sample thickness accuracies of some of the other references cited in Table I relating to the birefringence of crystalline quartz. However, our birefringence accuracy is still similar to theirs, since a sample thickness error in our experiments proportionately affects the *difference* between the ordinary and extraordinary indices, rather than the individual indices whose difference is usually subsequently taken. The quoted thickness uncertainty is actually somewhat conservative since the *average* thickness is more accurately known, and the average thickness determines the location of the signal minimum. The results are presented in Table I along with some other birefringence values from the work of others at neighboring frequencies. Our quoted results are actually each the average of several repetitions of the measurement. The other references were identified in an extensive survey of the NMMW materials spectroscopy literature [11]. Our 245-GHz results compare favorably with the other values. Our quoted uncertainty is based on the combined effects of the reproducibility of the micrometer settings and our estimate of possible systematic errors. Substantially greater accuracy can be achieved using this technique, if needed, by more elaborate attention to the procedure, sample preparation, and thickness measurement, and the use of thicker samples and lower leakage gratings.

ACKNOWLEDGMENT

The author wishes to express his appreciation for the timely loan of desirable crystal quartz samples by C. Tschiegg and A. Henins of the National Bureau of Standards, Gaithersburg, MD.

REFERENCES

[1] G. J. Simonis, F. Weiser, G. L. Wood, and J. M. Bowersett, "Fabrication, characterization, and applications of wire gratings for near-millimeter wave purposes," Harry Diamond Laboratories Tech. Rep., in preparation.
[2] A. Sentz, M. Pyee, C. Gastaud, J. Auvroy, and J. P. Letur, "Construction of parallel grids acting as semitransparent flat mirrors in the far infrared," *Rev. Sci. Instr.*, vol. 49, pp. 926–927, July 1978.
[3] D. H. Martin and E. Puplett, "Polarized interferometric spectrometry for the millimetre and submillimetre spectrum," *Infrared Phys.*, vol 10, pp. 105–109, 1969
[4] G. J. Simonis and R. D. Felock, "Near-millimeter wave polarizing duplexer/isolator," *Int. J. Inf. Millimeter Waves*, vol. 4, Mar. 1983
[5] G J Simonis and R. D. Felock, "Index of refraction determination in the near-millimeter wavelength range using a mesh Fabry-Perot resonant cavity," *Appl Opt.*, vol 22, pp. 194–197, Jan. 1983.
[6] Y. Yamada, A. Mitsuishi, and H Yoshinaga, "Transmission filters in the far-infrared region," *J. Opt. Soc Am.*, vol. 52, pp. 17–19, Jan. 1962.
[7] J Fontanella, C. Andeen, and D. Schuele, "Low-frequency dielectric constants of α-quartz, sapphire, MgF_2, and MgO," *J Appl Phys.*, vol. 45, pp 2852–2854, July 1974.
[8] R. G. Jones, "The measurement of dielectric anisotropy using a microwave open resonator," *J. Phys. D: Appl. Phys.*, vol. 9, pp. 819–827, 1976.
[9] E. E. Russell and E. E. Bell, "Measurement of the optical constants of crystal quartz in the far infrared with the asymmetric Fourier-transform method," *J. Opt. Soc Am.*, vol. 57, no. 3, pp. 341–348, Mar. 1967.
[10] D. Charlemagne and A. Hadni, "Sur la biréfringence et le pouvoir rotatoire du quartz dans l'infrarouge lointain á la température de l'azote liquide et a température ordinaire," *Optica Acta*, vol. 16, no. 1, pp. 53–60, 1969.
[11] G. J. Simonis, "Index to the literature dealing with the near-millimeter-wave properties of materials," *Int J. Infrared Millimeter Waves*, vol. 3, pp. 439–469, July 1982.

Large Signal Design of GaAs FET Oscillators Using Input Dielectric Resonators

ABELARDO PODCAMENI, MEMBER, IEEE, AND
LUIS AFONSO BERMUDEZ, MEMBER, IEEE

***Abstract*—A dielectric resonator may be placed at the input of an active two-port device (FET or microwave transistor) yielding a stable frequency source. For this input configuration, a large signal design is presented. The method is simple, and power output prevision is also reached. The practical results obtained with an X-band medium-power oscillator are presented.**

I. INTRODUCTION

Frequency-stable microwave sources are utilized in telecommunications and strategic applications. The GaAs FET is an efficient device for power generation from about 4 GHz upwards [1]. The frequency stabilization with a dielectric resonator [2] may contribute to obtain compact, lightweight, and economical oscillators.

In a previous work, Abe *et al.* [3] have presented a particular configuration using the dielectric resonator as a band-stop filter [4]. More recently, Mori *et al.* [5] used the dielectrical resonator as a frequency selective feedback device yielding a basic oscillator covering the 9–14-GHz band. However, neither of these two design methods is straightforward. Experimental adjustments were necessary, and if an output power prevision is desired, troublesome large signal analysis [6]–[9] must be carried out.

On the other hand, the configuration which uses the dielectric resonator placed at the FET input is also possible [10], [11]. However, a simple procedure taking into account large signal effects is not presently available. Hence, in this short paper, this oscillator configuration together with large signal analysis will be focused on. The resonator operates as a reflection-mode resonant cavity. Large signal measurements will yield the existing oscillatory conditions at the FET input. The dielectric resonator is then easily positioned. Similarly, an accurate output prevision may also be performed. This approach has been successfully used for fixed and narrow-band oscillators and consists, basically, of two steps: characterizing the resonator, and obtaining simplified large signal data from the active device.

II. DIELECTRIC RESONATOR CHARACTERIZATION

When a dielectric resonator is placed beside a microstrip line, magnetic field coupling will exist. Usually, for this type of application, a cylindrical resonator is preferred. In this case, the

Manuscript received July 22, 1982; revised November 29, 1982 This work was supported by Telecommunicações Brasileiras S/A under contracts 017/79 and 88/80 PUC-TELEBRÁS.

A Podcameni is with the Universidade Católica do Rio de Janeiro, Rua Marques de São Vincente 209, Rio de Janeiro 22453, RJ Brasil.
L. Bermudez is with the Departmento de Engenharia Elétrico, Universidade de Brasilia, Brasilia, 70910, DF Brasil

0018-9480/83/0400-0358$01.00 ©1983 IEEE