ELECTRONICS LETTERS

AN INTERNATIONAL PUBLICATION

CONTENTS

pages 1661-1744

25th September 1997 Vol. 33 No. 20

ANALOGUE ELECTRONICS — page

Current mode chaos generator — 1661
A.S. Elwakil and A.M. Soliman (*Egypt*)

Low-output-impedance class AB bipolar voltage buffer — 1662
H. Barthelemy (*France*)

ANTENNAS

Difference pattern synthesis in small planar phased arrays — 1664
P. Darwood, P.N. Fletcher and G.S. Hilton (*United Kingdom*)

Slot-coupled dielectric resonator antenna using a proximity feed on a perpendicular substrate — 1665
K.W. Leung and M.W. To (*Hong Kong*)

CIRCUIT THEORY & DESIGN

Noise-assisted signal transmission via stochastic resonance in a diode nonlinearity — 1666
X. Godivier, J. Rojas-Varela and F. Chapeau-Blondeau (*France*)

COMMUNICATIONS & SIGNAL PROCESSING

Algorithm for mapping between information bits and channel symbols in MTCM codes — 1668
I.S. Jin, K.C. Whang, K. Cho, J.Y. Ahn and H.S. Oh (*Korea*)

Analysis of instability in feedforward loop — 1669
P.B. Kenington, P.A. Warr and R.J. Wilkinson (*United Kingdom*)

Analysis of *M*-ary FSK square law combiner under Nakagami fading conditions — 1671
J.F. Weng and S.H. Leung (*Hong Kong*)

Analysis of unslotted direct-sequence spread spectrum multiple access network with packet combining — 1673
A. Annamalai and V.K. Bhargava (*Canada*)

Bit error probability of MDPSK in Nakagami fading channels — page 1675
J.F. Weng and S.H. Leung (*Hong Kong*)

Continuous *n*-tuple classifier and its application to face recognition — 1676
S.M. Lucas (*United Kingdom*)

Disk distance measure of speaker recognition — 1678
Shung-Yung Lung (*Taiwan*)

Mitigating array sensor malfunctions with mixed second and fourth order statistics — 1679
W. Pora, J.A. Chambers and A.G. Constantinides (*United Kingdom*)

Nonrecursive decoding algorithm for PR4 channel — 1680
Runsheng He and J.R. Cruz (*USA*)

Power efficient architectures for VSELP speech coders — 1682
Zhenzhong Gu, R. Sudhakar (*USA*) and Kwang Bok (Ed) Lee (*Korea*)

Vocal system phase coder for sinusoidal speech coders — 1683
S. Torres and F.J. Casajús-Quirós (*Spain*)

ELECTROMAGNETIC WAVES

Method for measuring the attenuation and phase constants of a surface wave propagating along an infinite plane — 1685
S.Y.M.R. Stroobandt and F.C. Smith (*United Kingdom*)

INFORMATION THEORY

Arithmetic coding algorithm with embedded channel coding — 1687
G.F. Elmasry (*USA*)

INSTRUMENTATION & MEASUREMENT

High resolution AC temperature field imaging — 1688
B.C. Forget, S. Grauby, D. Fournier, P. Gleyzes and A.C. Boccara (*France*)

(continued on back cover)

THE INSTITUTION OF ELECTRICAL ENGINEERS

Method for measuring the attenuation and phase constants of a surface wave propagating along an infinite plane

S.Y.M.R. Stroobandt and F.C. Smith

Indexing terms: Radar, Electromagnetic wave propagation, Electromagnetic field theory

A method is presented for determining the attenuation and phase constants of a surface wave propagating along an infinite planar layer of metal-backed material. Two input impedance measurements of a rectangular waveguide partially filled with the test material are used to infer the propagation characteristics of the plane surface wave. Measurements are presented which validate the method.

Introduction: Surface waves are waves that propagate along an interface of two different media without radiation [l]. Surface wave absorbing materials are used in radar signature applications where guided waves can contribute to the radar cross-section of a vehicle. Surface wave materials are also used to minimise diffraction caused by impedance discontinuities. Many applications of these materials are associated with propagation over planar or near-planar surfaces. Characterisation of a surface wave material therefore requires a test configuration which is capable of reproducing infinite plane propagation properties without introducing other scattering or propagation mechanisms. The method adopted here uses data from a partially-filled rectangular waveguide to infer the attenuation and phase constants of the fundamental electric mode plane surface wave (components of electric field normal to the surface and in the direction of propagation).

Theory: If a planar perfect electrical conductor is coated with a single homogeneous and isotropic layer of material of thickness h, the propagation constant β of the E-mode plane surface wave is given by the solutions of the following dispersion equation:

$$\frac{\sqrt{k_1^2-\beta^2}}{\sigma_1+j\omega\varepsilon_1}\tan\left(h\sqrt{k_1^2-\beta^2}\right)=\frac{-j\sqrt{k_0^2-\beta^2}}{j\omega\varepsilon_0} \qquad (1)$$

where k, and k_0 are the TEM plane-wave propagation constants in the material and free space, respectively, and σ_1 and ε_1 are the intrinsic electrical properties of the test material. If the measurement method uses planar or electrically large cylindrical surfaces to support the surface wave, it can be difficult to separate the surface wave mode from other scattering and propagation mechanisms (eqn. 1 can be shown to apply to propagation over electrically large coated cylinders). However, if the wave is constrained by the vertical and horizontal walls of a rectangular waveguide, as shown in Fig. 1, a modified surface wave mode can propagate whose attenuation and phase constants are governed by the following dispersion equation:

$$\frac{\sqrt{k_1^2-\left(\frac{n\pi}{a}\right)^2-\beta_m^2}}{\sigma_1+j\omega\varepsilon_1}\tan\left(h\sqrt{k_1^2-\left(\frac{n\pi}{a}\right)^2-\beta_m^2}\right)=$$
$$\frac{-\sqrt{k_0^2-\left(\frac{n\pi}{a}\right)^2-\beta_m^2}}{j\omega\varepsilon_0}\tan\left((b-h)\sqrt{k_0^2-\left(\frac{n\pi}{a}\right)^2-\beta_m^2}\right) \qquad (2)$$

where a and b are the horizontal and vertical dimensions of the waveguide, respectively, β_m is the propagation constant of the waveguide mode and n is the waveguide mode number corresponding to rectangular type modes in the horizontal plane. Clearly $\beta \neq \beta_m$; however, the only significant difference between eqns. 1 and 2 is the *tan* function on the right hand side (RHS) of eqn. 2. The argument of the *tan* function on the RHS of eqn. 2 is complex for surface wave modes, regardless of whether the intrinsic properties of the test material are real or complex. If the height b of the waveguide is chosen large enough as to ensure that tan $((b-h)\sqrt{k_0^2-(n\pi/a)^2-\beta_m^2}) \approx j$, eqn. 2 becomes identical to eqn. 1 except for the known term $(n\pi/a)^2$. Provided b is sufficiently large, comparing eqn. 1 and eqn. 2 gives the propagation constant of a surface wave along an infinite planar layer:

$$\beta = \sqrt{\left(\frac{n\pi}{a}\right)^2 + \beta_m^2} \quad (3)$$

The accuracy of the *tan* function approximation may be checked after a measurement has taken place by inserting the measured value of β_m into the RHS of eqn. 2.

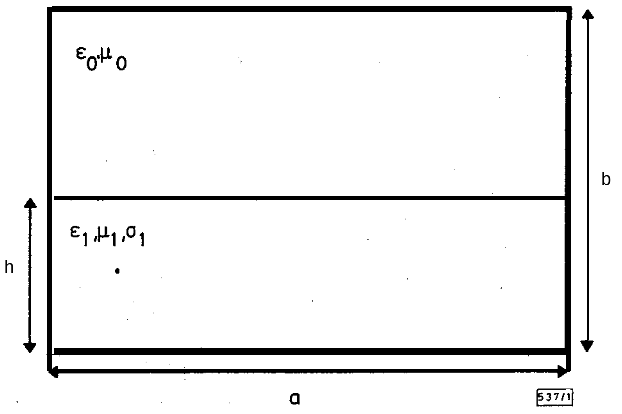

Fig. 1 *Partially-filled rectangular waveguide supporting modified surface wave propagation*

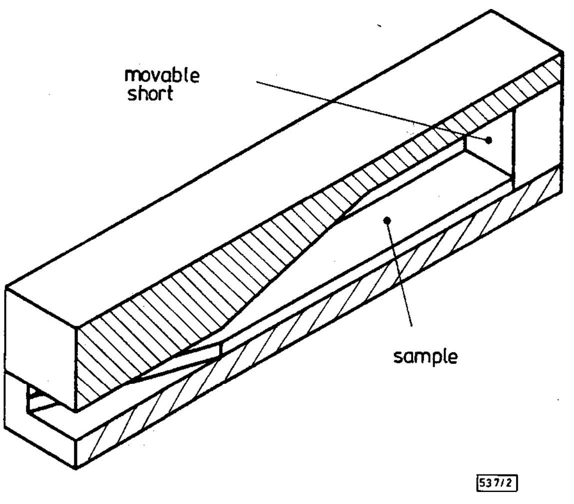

Fig. *2 Cutaway view of plane surface wave simulator cell (not to scale)*

Experimental system: The experimental system shown in Fig. 2 is based on an X-band rectangular waveguide test cell. The test material is placed on the floor of the test cell and is tapered in the H-plane to provide a matched transition between the empty and partially-filled sections of the waveguide. The matched transition converts the fundamental empty waveguide mode (TE_{10}, i.e. $n = 1$) into the fundamental modified surface wave mode. After the transition the waveguide height is increased to 34.04mm, via a taper on the upper horizontal wall of the waveguide. The partially-filled waveguide is terminated with a short circuit at the furthest end of the test cell. For many materials used in surface wave applications, analysis has shown that the *tan* function approximation results in an error in β of < 1%. The error can be reduced by increasing the height of the waveguide, but this has the disadvantage that the size of the test cell and the minimum sample length both increase.

Two reflection coefficient measurements are made of the uniform section of waveguide using different lengths of the shorted test cell. From these two measurements the propagation constant β_m can be obtained using standard transmission line theory. The reflection data are calibrated using a third measurement which defines the phase reference plane; source match and directivity errors are reduced using time domain filtering. The length of the test cell is chosen to ensure that the time domain response of the sample is isolated from the two error responses. When β_m has been measured, the infinite plane surface wave absorption and phase constants are obtained from eqn. 3.

Results: Measurements have been performed using high molecular weight polyethylene. Material thicknesses of 3.25 and 6.15mm were used. Because polyethylene has very low losses, only results relating to the phase constants have been calculated. The measurement of lossy materials is made marginally easier by the reduction in the magnitude of the source match error. Fig. 3 shows the measured and predicted phase constants for a fundamental mode plane surface wave supported by an infinite planar layer of 3.25 and 6.15mm metal backed polyethylene. The results show good agreement between measured and predicted values. Owing to the higher impedance mismatch between the empty and partially-filled sections of waveguide, an increase in ripple is seen in the data for the 6.15mm sample. However, improved tapering between the empty and partially-filled sections of X-band waveguide would reduce this error.

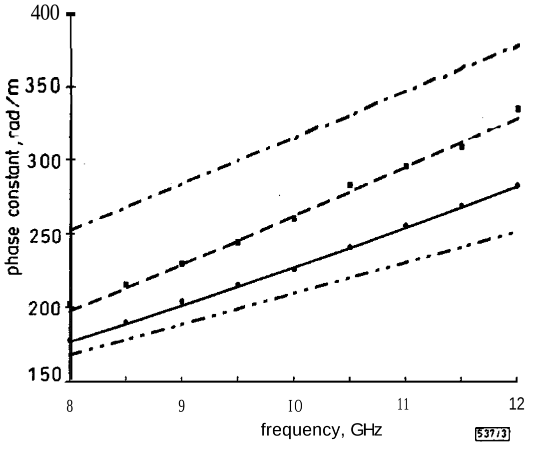

Fig. 3 *Measured and predicted phase constants for fundamental electric mode plane surface wave supported by infinite planar sheet of metal-backed polyethylene*

Conclusions: A method has been developed for measuring the attenuation and phase constants of a fundamental mode plane surface wave propagating along an infiite planar layer of metal-backed material. The method can be used to characterise the surface wave absorbers used in radar signature applications. The dimensions of the test sample depend on the waveguide band under investigation; in the case of the X-band test cell the minimum sample dimensions are 22.86 x 300mm² (the larger dimension is approximate). There exists a small inherent inaccuracy in the method due to confinement of the surface wave by the upper horizontal wall of the waveguide; however, the inaccuracy can be detected in the measured data and minimised, if necessary, using alternative cell dimensions. The cell has been designed to interrogate the fundamental electric mode plane surface wave. A similar approach can be used to interrogate the fundamental magnetic mode plane surface wave.

Acknowledgments: The authors wish to thank the Defence Evaluation and Research Agency for their financial support and A. Van de Capelle and G. Vandenbosch of the ESAT-TELEMIC division at K.U. Leuven, Belgium for the use of vector network analyser equipment.

16 July 1997
Electronics Letters Online No: 19971129

S.Y.M.R. Stroobandt and F.C. Smith *(Department of Electronic Engineering, University of Hull, Hull, HU6 7RX, United Kingdom)*

References

1 BARLOW, H.M., and BROWN, J.: 'Radio surface waves' (Oxford University Press, 1962) p. 5