Letters

Attenuation and Phase-Shift Coefficients in Dielectric-Loaded Periodic Waveguides

B. MINAKOVIC AND S. GOKGOR

Abstract—**Attenuation in a waveguide, periodically loaded with dielectric disk, i.e., partially filled, can be considerably higher than when it is completely filled. For a relatively small dielectric loss, phase coefficients are negligibly affected.**

Attenuation and phase-shift calculations have been carried out for a number of modes propagating in a circular waveguide [1], [2], periodically loaded with dielectric disks (Fig. 1). The analysis includes both metal and dielectric losses.

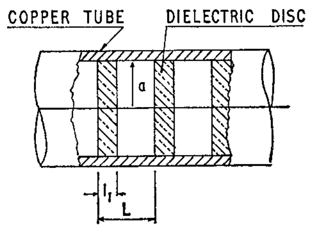

Fig. 1. Periodic waveguide loaded with dielectric disks.

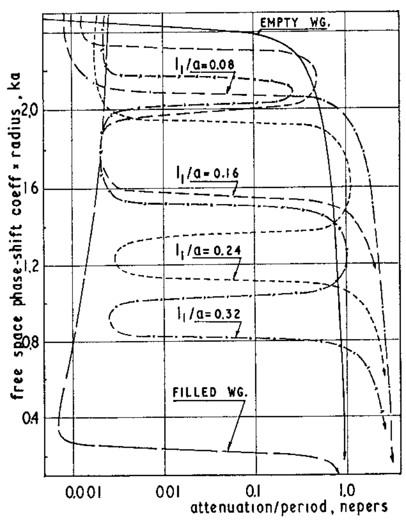

Fig. 2. Typical solution for attenuation coefficients: TM_{01} mode, $L/a=0.4$, relative dielectric constant 95 (titanium dioxide); $\tan\delta=5\times10^{-4}$; radius 5.33 mm.

The explicit expressions for attenuation and phase-shift coefficients were derived by setting up an appropriate complex wave matrix for each uniform region within one period, then cascading all matrices, and finally applying Floquet's theorem to account for periodicity. The expressions were computer tabulated for a range of parameters of practical interest, and one of the typical solutions is given in Fig. 2.

An interesting and somewhat unexpected feature of these results is that in a number of cases, attenuation is considerably higher when a waveguide is partially filled, i.e., disk loaded, than when it is completely filled. This is evident from Fig. 2, where for $l_1/a=0.32$ and 0.24, attenuation is 0.0026 and 0.0030 Np/period, respectively, against 0.0012 and 0.0016 for a completely filled guide. Similar results were obtained for TE_{11} and TE_{01} modes, both in a circular waveguide.

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B. Minakovic is with the Department of Engineering Science, Oxford University, Oxford, England.
S. Gokgor is with the Allen Clark Research Centre, Plessey Company Ltd., Towcester, England.

Phase-shift coefficients are negligibly affected by loss, except in the vicinity of stopbands, and even then by only about 0.01 percent. This is a typical figure for relatively low-loss loading but, of course, it would increase for a very lossy material.

References

[1] B. Minakovic, "Studies in electron acceleration," Dep. Eng. Sci., Univ. of Oxford, Oxford, England, Rep. 1014, 1966.
[2] S. Gokgor, "A study of pulse compression structures," D. Phil. thesis, Dep. Elec. Sci., Univ. of Oxford, Oxford, England, 1971.

Comments on "Calculation of Capacitance Coefficients for a System of Irregular Finite Conductors on a Dielectric Sheet"

A. B. BIRTLES AND B. J. MAYO

Abstract—**An improvement in Patel's method using triangular conductor subsections is presented.**

Further to the analysis given in the above paper by Patel,[1] it may be of interest to note that work of a similar nature has been performed by the authors of the present letter using conductor subsections in the shape of triangles as well as rectangles.

In general, this involves a knowledge of integrals of the type

$$I=\int_{y_1}^{y_2}\int_{x_g(y)}^{x_h(y)}\frac{dx\,dy}{\sqrt{x^2+y^2+t^2}}$$

which, in the case when x_g and x_h are linear functions of y, describe in essence the electrostatic potential distribution due to a uniformly charged triangular sheet. Integrals of this type have been evaluated in closed form [1], and are given below.

By suitable orientation of the coordinate axes, the triangular subsection under consideration may be defined by the three points (x_1, y_1), (x_2, y_1), and (x_3, y_2). The result then is

$$I=t[F_6(a_2,b_2,u_2)-F_6(a_2,b_2,u_1)-F_6(a_1,b_1,u_2)+F_6(a_1,b_1,u_1)]$$

where

$$\begin{aligned}
u_1 &= y_1/t;\\
u_2 &= y_2/t;\\
a_1 &= (x_1y_2-x_3y_1)/(t(y_2-y_1));\\
a_2 &= (x_2y_2-x_3y_1)/(t(y_2-y_1));\\
b_1 &= (x_3-x_1)/(y_2-y_1);\\
b_2 &= (x_3-x_2)/(y_2-y_1);\\
F_6(a,b,u) &= F_2+aF_5+(a+(b^2/a))F_{11};\\
F_2 &= u\sinh^{-1}[(a+bu)/(1+u^2)^{1/2}];\\
U &= 1+a^2+2abu+(1+b^2)u^2;\\
F_5 &= (1+b^2)^{-1/2}\log[U^{1/2}+u(1+b^2)^{1/2}+ab(1+b^2)^{-1/2}];\\
q &= (a^2+b^2)/|a|;\\
\gamma &= 1+(b^2/a^2);\\
\alpha &= \gamma+((a^2+b^2)^2/a^2);\\
T &= [\alpha((bu+a)^2/(au-b)^2)+\gamma]^{1/2};\\
F_{11} &= 1/q\tan^{-1}(T/q),\ \text{for } q>0;\\
&= -1/T,\ \text{for } q=0.
\end{aligned}$$

In the case of a right-angled triangle $(x_3=x_1)$, the last two terms in the expression for I simplify to $-F_1(a_1,u_2)+F_1(a_1,u_1)$, where

$$F_1(a,u)=a\sinh^{-1}[u/(1+a^2)^{1/2}]+u\sinh^{-1}[a/(1+u^2)^{1/2}]+\tan^{-1}[(1+a^2+u^2)^{1/2}/au].$$

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A. B. Birtles is with the Water Resources Board, Reading, Berks., England.
B. J. Mayo is with EMI Ltd., Hayes, Middlesex, England.
[1] P. D. Patel, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 862–869, Nov. 1971.

The use of triangular (in addition to rectangular) subsections results in a more precise modeling of conductors of complex shapes, particularly when curved edges are involved. This in turn can lead to a reduction in the total number of subsections required for the analysis of a specific geometry, accompanied by a similar reduction in the order of the matrix requiring inversion.

As a consequence, a computational limitation on Patel's method may be alleviated to some degree. When consideration is given to the fact that the matrix will possibly be ill conditioned [2], a smaller number of subsections is doubly beneficial. It is also shown in [1] that for a given specified accuracy, a further reduction in the number of subsections can be achieved by irregular subdivision of conductors in a manner related to the expected charge distribution. Thus the smallest subsections are employed where the charge density is changing most rapidly with position, at conductor edges, for example.

References

[1] A. B. Birtles, B. J. Mayo, and A. W. Bennett, "A computer technique for solving three dimensional electron optics and capacitance problems," *Proc. Inst. Elec. Eng.*, vol. 120, no. 2, p. 213, Feb. 1973.
[2] C. W. Bostain and P. H. Wiley, "Concerning the moment solution for the charge distribution on a square conducting plate," *Proc. IEEE* (Lett.), vol. 59, p. 1639, Nov. 1971.

Comments on "An Analytical Equivalent Circuit Representation for Waveguide-Mounted Gunn Oscillators"

D. N. SINGH

In the above paper,[1] the authors have tried to explain the experimentally observed mode-switching phenomenon in waveguide-mounted Gunn oscillators on the basis of nonlinear behavior of the device. It has been shown in Fig. 6(a)[1] that the device susceptance decreases to zero at 8.18 GHz, as a result of which the condition of oscillation given by (4) cannot be satisfied. This leads to the mode switching observed at this frequency. In our opinion, the device susceptance cannot become zero over the entire frequency band of interest. It is not possible for the dynamic nonlinearities to make the device susceptance go to zero, even at the mode-switching frequency. In fact, the device susceptance will always remain capacitive, while the load susceptance presented to the device chip can become zero, inductive, or capacitive, depending upon the operating frequency and the particular circuit parameters. For steady-state oscillations, the load susceptance presented to the device chip should always be inductive, and the frequency switching may occur once the load susceptance becomes capacitive. However, the load conductance presented to the device chip should also be lower than the device conductance for the steady-state oscillations to build up. It is just possible that the load conductance may be more favorable for λg mode of operation rather than for $\lambda g/2$ mode of operation. This may also cause mode switching, as pointed out by Eisenhart and Khan [1]. It is highly probable that the mode switching is caused by this effect, rather than due to the nonlinearity of the device parameter as pointed out by Jethwa and Gunshor.

It has also been mentioned[1] that the mode switching also occurs in the case of reduced height waveguide cavities. The mode-switching frequency has been reported to be 9.3 GHz—a value much higher than in the case of full height waveguide. However, no mention has been made of the height of the waveguide used during these investigations. This is an important parameter, as the actual mode-switching frequency will be very much dependent on the height of the waveguide.

Thus it is clear from the above discussions that it is the characteristics of the circuit, and not of the device, which are responsible for the phenomenon of mode switching and it should be possible to avoid the mode switching over a frequency band of interest by suitable circuit design.

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The author is with the Microwave Engineering Group, Tata Institute of Fundamental Research, Bombay, India.
[1] C. P. Jethwa and R. L. Gunshor, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 565–572, Sept. 1972.

References

[1] R. L. Eisenhart and P. J. Khan, "Some tuning characteristics and oscillation conditions of a waveguide-mounted transferred-electron diode oscillator," *IEEE Trans. Electron Devices*, vol. ED-19, pp. 1050–1055, Sept. 1972.

Reply[2] by C. P. Jethwa[3] and R. L. Gunshor[4]

It is clearly stated in our paper that we have not tried to explain the experimentally observed mode switching on the basis of any single aspect of the device–circuit interaction. What we have done is to describe what the linear model indicates is occurring in the mode-switching regions of the tuning curves. The question of nonlinearity enters in the observation that in the region of mode switching, the experimentally observed tuning curves tend to pull up slightly from the curves predicted using the linear device mode. This effect, combined with the observation of nonsinusoidal device waveforms in this region, tends to support the suggestion that nonlinear aspects of the device behavior affect mode switching.

Singh makes the rather obvious comment that mode switching may take place from the $\lambda g/2$ to the λg mode as a switch to a more favorable load conductance. A careful reading of our paper will show that we also make this observation (see Section IV), and in fact we show that the load resistance rises rapidly just before mode switching (see our Fig. 7).

It is not difficult for us to think of the device as essentially capacitive from a physical point of view; however, the concept of steady-state susceptance is another matter. It is well known that the concept of device susceptance for a nonlinear device in which there may be other than the fundamental frequency present is not trivial. In fact, it can be shown that the device susceptance (at the fundamental frequency) is a function of the amplitude and phase of the other components. It is therefore not surprising to see the device susceptance vary with frequency in such a way as to suggest a large variation in "capacitance." We find that when the capacitive susceptance tends *toward* zero rapidly, this corresponding to the pulling up of the tuning curves (nonlinearities?), mode jumping occurs. In the paper by Tsai *et al.* [1], one can see a 2 to 1 variation in device susceptance corresponding to a 10-percent variation in frequency.

Finally, the reduced height waveguide is one half the full waveguide height.

References

[1] W. C. Tsai, F. J. Rosenbaum, and L. A. MacKenzie, "Circuit analysis of waveguide-cavity Gunn-effect oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 808–817, Nov. 1970.

[2] Manuscript received April 9, 1973.
[3] C. P. Jethwa is with the Department of Electrical Engineering and System Science, Michigan State University, East Lansing, Mich. 48823.
[4] R. L. Gunshor is with the School of Electrical Engineering, Purdue University, West Lafayette, Ind. 47907.

Trigonometric Functions and the Smith Chart

J. T. SENISE

***Abstract*—Sines and cosines can be read directly on the Smith chart.**

Smith, in his excellent book on the Smith chart [1], states that "the sine and cosine functions of α are not directly obtainable from the Smith chart."

Actually, $\sin \alpha$ and $\cos \alpha$ may be obtained very easily, as shown in Fig. 1.

A straight line joining $A(0, 0)$ to α ("angle of reflection coefficient") on the peripheral scale of the chart crosses the straight line through $B(1, 0)$ and $D(0, 1)$ at the point $P(p, q)$ of coordinates $p = \cos \alpha$, $q = \sin \alpha$.

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The author is with the Department of Electrical Engineering, Escola de Engenharia Mauá, São Paulo, Brazil.