Additional Comment on Fabry-Perot Type Resonators*

In a recent paper on Fabry-Perot type resonators,[1] Culshaw makes reference to a note of mine[2] to the effect that one of the rather lengthy formulas (5) in my paper is incorrect. I should like to point out the errors as they appeared in our internal research report:

1) A "$\frac{nb\lambda}{\gamma}$" should have been a "$\frac{nb\lambda}{8}$."

2) A "$\frac{\pi}{b\lambda}$" should have been a "$\frac{2\pi}{b\lambda}$."

These are, however, typographical errors, as can be seen from the fact that the final numerical values and graphs given by Culshaw reproduce mine down to the fourth decimal place.

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* Received November 11, 1962, revised manuscript received December 12, 1962.

[1] W. Culshaw, "Further considerations on Fabry-Perot type resonators," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-10, pp. 331–339; September, 1962.

[2] C. L. Tang, "On Diffraction Losses in Laser Interferometers," Raytheon Research Div., Waltham, Mass., Tech. Memo T-320, October 23, 1961.

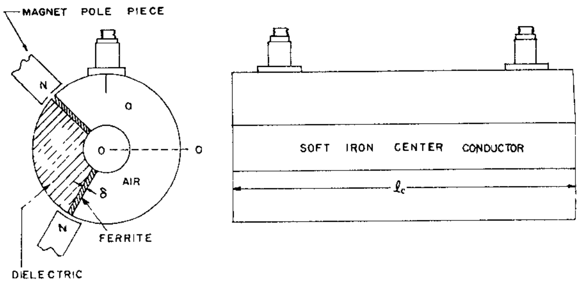

Fig. 1—Experimental cavity showing the arrangement of the dielectric and ferrite materials. Type M-063 ferrite manufactured by Motorola Solid State Electronics Department was used inside the cavity along with Stycast Hi-K dielectric material ($K_e=15$) manufactured by Emerson Cuming, Inc.

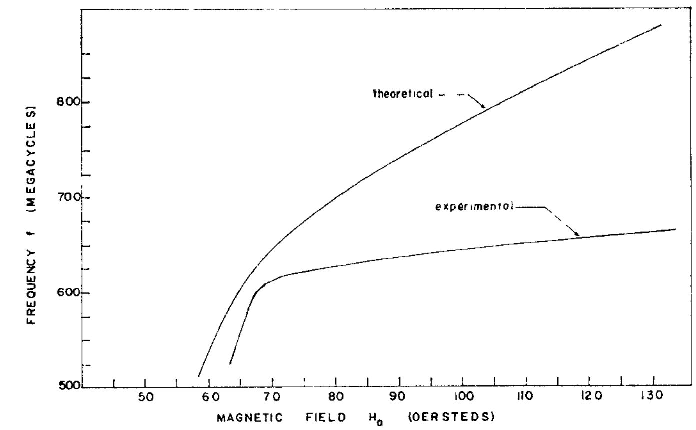

Fig. 2—Tuning curves for experimental and theoretical results.

$\beta=\pi/l_c$ radians/cm.
$\delta=0.382$ cm
$a=1.75$ cm
$c=1.35$ cm
$l_c=7.62$ cm
$K_d=15$
$K_f=13$

A Ferrite-Tuned Coaxial Cavity*

This communication presents a calculation of the electromagnetic wave propagation constant β in a coaxial cavity partially loaded with ferrite and dielectric materials. The cavity was designed to operate around 600 Mc. The advantage of using a coaxial cavity compared to a rectangular cavity at 600 Mc is the fact that a coaxial cavity is much smaller than a rectangular cavity. Electronically tuned cavities have been built utilizing ferrite materials in the X-band frequency range.[1] However, until recently no ferrite materials have been produced that could be used feasibly in the UHF frequency range. Tuning cavities with ferrites has certain advantages that some other electronically tuned cavities do not have with regard to power relations. For example, cavities have been built that are electronically tuned with the use of varactor diodes.[2] These types of cavities cannot tolerate medium power levels, whereas, ferrite materials can withstand higher powers.

An experimental cavity was constructed and it is shown in Fig. 1. The outer conductor was constructed from a brass pipe with a $1\frac{1}{4}$-inch inside diameter. The inner conductor was constructed from a soft iron rod. The reasons for using the iron center conductor was so that the applied magnetic field would be more uniform in the ferrite and the applied magnetic field would be perpendicular to both the inner and outer conductors. The propagation constant β has been derived previously for the loaded waveguide and the loaded coaxial line.[3] The results were given in a slightly different form than those which are presented below.

$$\begin{aligned}(F^2\beta^2 + k_m{}^2\rho^2) &\cosh K_a a \sin k_m\delta \\ &+ \beta F K_a \sinh K_a a \sin k_m\delta \\ &- K_a \rho k_m \sinh K_a a \cos k_m\delta \\ &+ k_d K_a \sinh K_a a \sin k_m\delta \tan k_d c \\ &+ k_d K_m \rho \cosh K_a a \cos k_m\delta \tan k_d c \\ &+ k_d \beta F \cosh K_a a \sin k_m\delta \tan k_d c = 0\end{aligned}$$

where $F=-j\rho/\theta$. (See Button[3] for the definition of other symbols.)

This equation may be written symbolically as

$$F(f_0, H) = 0$$

where f_0 is the resonant frequency of the cavity and H is the applied static magnetic field. Hence, one could obtain the resonant frequency by knowing the magnetic field.

The IBM-650 digital computer was programmed to solve this equation for our case. Fig. 2 shows the results obtained by computation and by experiment.

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* Received December 7, 1962; revised manuscript received December 20, 1962. The research reported here was supported by the Wilcox Electric Company, Kansas City, Mo.

[1] C. E. Fay, "Ferrite-tuned resonant cavities," PROC. IRE, vol. 44, pp. 1446–1449; October, 1956.

[2] S. T. Eng, "Characterization of microwave variable capacitance diodes," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-9, pp. 11–22; January, 1961.

[3] K. J. Button, "Theory of nonreciprocal ferrite phase shifters in dielectric-loaded coaxial line," *J. Appl. Phys.*, vol. 29, pp. 998–1000, June, 1958.

Some Remarks Concerning "Conditions for Maximum Power Transfer"*

In these TRANSACTIONS Shulman[1] studied the conditions for maximum power transfer.

It should be noted that in the *Comptes rendus de l'Academie des Sciences* (Paris, France, vol. 252, pp. 689–691; January 30, 1961) we studied this problem in the general case on the Smith Diagram. The method de-

* Received December 3, 1962.

[1] C. Shulman, "Conditions for maximum power transfer," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES (*Correspondence*), vol. MTT-9, pp. 453–454; September, 1961.

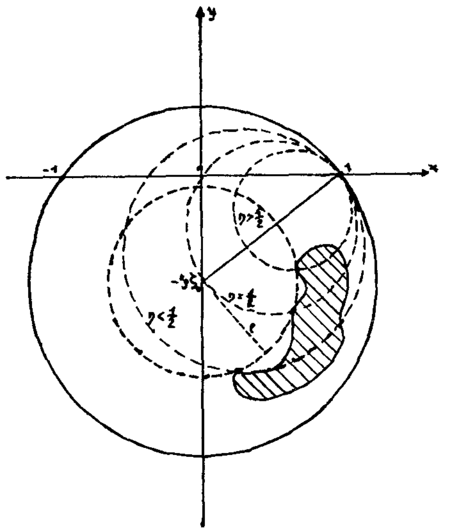

Fig. 1.

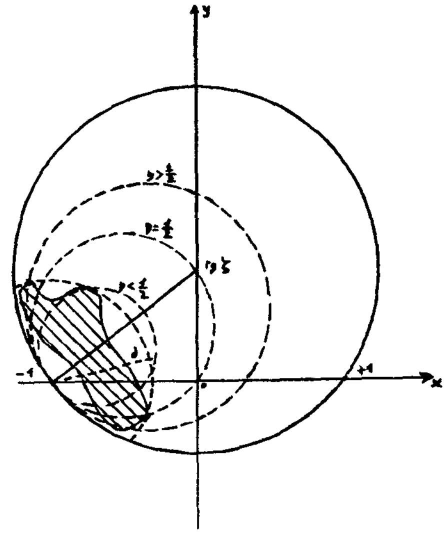

Fig. 2.

veloped gave the solution of the problem directly, without any cut and try.

As the question may present some technical interest, copy of our manuscript follows.

SÉANCE DU 30 JANVIER 1961, p. 689.
ÉLECTRONIQUE.—*Sur le problème de l'adaptation.* Note de MM. Louis Castagnetto et Jean-Claude Matheau, présentée par M. Léopold Escande.

On détermine à l'aide du diagramme de Smith, les conditions d'adaptation optimale d'une charge à un élément actif lorsque les domaines de variation des impédances sont préalablement imposés.

Soient $R_0+jX_0=|Z_0|e^{j\zeta_0}$ l'impédance du générateur, $R+jX=|Z|e^{j\zeta}$ celle de la charge et $S=x+jy$ son coefficient de réflexion.

$|E|e^{j\phi}$ étant l'amplitude complexe de la force électromotrice du générateur, la puissance complexe absorbée par la charge s'écrit

$$H = P + jQ = \frac{|E|^2}{8Z_0^*}(1+S)(1-S^*)$$
$$= \frac{|E|^2}{8Z^*}|1+S|^2.$$

Alors:

$$P = \frac{|E|^2}{8R_0}(1-\rho^2\cos^2\zeta_0) = \frac{|E|^2}{8R}d^2\cos^2\zeta,$$

où ρ est, dans le plan du coefficient de réflexion, la distance du point S au point $(0, -tg\zeta_0)$ et d la distance du point S au point $(-1, 0)$.

L'impédance du générateur étant donnée ainsi que le domaine de variation de S la puissance maximale absorbée par la charge sera obtenue aux points S où ρ atteint sa borne inférieure. On peut alors choisir, parmi l'ensemble des points donnant la valeur maximale, ceux qui correspondent au rendement maximal.

Le rendement s'écrit

$$\eta = \frac{R}{R+R_0}.$$

Les courbes à rendement constant (R constant dans le plan des impédances) se transforment par l'homographie donnant S, en un faisceau de cercles tangents au point $(1, 0)$ centrés sur le segment $[(0, -\text{tg}\,\zeta_0), (1, 0)]$.

L'ensemble de ces cercles figurant dans le diagramme de Smith, la détermination de l'adaptation optimale est alors immédiate (Fig. 1).

D'une façon similaire, si l'impédance Z est donnée ainsi que le domaine de variation de S, l'impédance variable étant maintenant Z_0, la puissance maximale absorbée par la charge sera obtenue aux points S où d atteint sa borne supérieure. Les courbes à rendement constant forment un faisceau de cercles tangents au point $(-1, 0)$ et centrés sur le segment $[(-1, 0), (0, \text{tg}\,\zeta)]$.

Le choix du point donnant la puissance maximale avec le rendement maximal se fait encore immédiatement (Fig. 2).

Si les domaines de variation sont donnés dans le plan Z il suffit de passer au plan S pour résoudre le problème.

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Author's Comment[2]

Castagnetto and Matheau essentially have solved the same problem treated in my correspondence.[1] The main difference is that the entire description is carried out in the reflection coefficient plane rather than the impedance plane. They take the question one step further by exchanging the role of source and load impedance. The equations are correct and convenient to use on the Smith Chart.

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Discontinuities Appear in the Repeller Current of a Reflex Klystron Detector*

It is known that reflex klystrons are usable as microwave detectors.[1-4] When the repeller current was plotted against acceleration grid (which is anode) voltage, Koctienko, Deviatkov, and Lebed[5] found discontinuities. Whitford[4] did not find these discontinuities for the 726A reflex klystron. Koctienko, *et al.*, explained that the discontinuities were attributed to the appearance and disappearance of the virtual cathode when the klystron began or stopped oscillation. Whitford explained that the beam current density of the 726A reflex klystron was sufficiently high to maintain the virtual cathode at all times.

The author found discontinuities in the repeller current as shown by a broken line in Fig. 1 when the 2K25 reflex klystron was used as a microwave detector. These discontinuities were explained in this case from the viewpoint of electronic regenerative action instead of by the appearance and disappearance of the virtual cathode. In this analysis, for simplicity, a plane parallel electrode reflex klystron as shown in Fig. 2 was assumed. The repeller was connected to the cathode and the virtual cathode was assumed to always exist in front of the actual cathode. Another virtual cathode in front of the repeller was not considered at this time because of low repeller current on the order of microamperes. Initial energy δ, which consisted of Φ, average thermal energy of electrons converted into kinetic energy at the emission and energy of the electric field intensity E_0 at the virtual cathode surface to pull the electron out of the potential dip to the virtual cathode surface where the potential was zero was assumed. The repeller current due to the acceleration grid voltage V_g and the initial energy is given by

$$i_{r0} = C\frac{\xi I_0}{U_{g0}}U_{r0} \tag{1}$$

where

C is a ratio of total charge at the repeller to the total charge at the grid, ξ is the beam transmission factor of the grids, I_0 is the grid current, and

$$I_0 \approx K_0V_g^{3/2}. \tag{2}$$

This approximate relation was verified by the experiment. K_0 is a proportionality constant between the grid current and the grid voltage. U_{g0} is the velocity of electron

* Received October 31, 1962; revised manuscript received December 21, 1962. This research was supported by University Committee on Research Grant, Marquette University, Milwaukee, Wis. A part of this report was presented at the URSI-IRE Meeting, Ottawa, Ont., Canada, October 15, 1962.

[1] A. E. Harrison, "Klystron Tubes," McGraw-Hill Book Co., Inc., New York, N. Y., 1st ed.; 1947.
[2] S. A. Kornelov and O. N. Kazbekova, "Detection in the cathode circuit of an under excited reflex klystron," *Radiotekh. i Elektron.*, vol. 4, pp. 475–481; March, 1959.
[3] K. Ishii, "Detector uses reflex klystron," *Electronic Ind.*, vol. 18, pp. 77–79; November, 1959.
[4] B. G. Whitford, "The reflex klystron as a microwave detector," IRE TRANS. ON ELECTRON DEVICES, vol. ED-8, pp. 131–134; March, 1961.
[5] A. I. Koctienko, M. N. Deviatkov, and A. A. Lebed, "On the application of virtual cathodes for the detection of microwave signals," *Radiotekh. i Elektron.*, vol. 4, pp. 482–488; March, 1959.