

## Correspondence

### Optimum Bandwidth for Waveguide-to-Coaxial Transducers

Mumford<sup>1</sup> has determined a method for optimizing the bandwidth of waveguide-to-coaxial transducers. His equivalent circuit is a coaxial line, of characteristic impedance  $Z_0$ , terminated in a resistance  $R$ , such that:

$$R = 240\pi \frac{b}{a} \frac{\lambda_g}{\lambda} \sin^2 \frac{2\pi l}{\lambda_g} \cos^2 \frac{\pi d}{a} \quad (1)$$

where each of the terms in (1) are as defined by Mumford. After determining the value of  $l$ , at center frequency, he adjusts  $d$  so that:

$R = Z_0$  at center frequency, and achieves bandwidths of the order of 20 per cent for a vswr of 1.10.

Since  $Z_0$  is invariant with frequency, the vswr varies as the product

$$\frac{\lambda_g}{\lambda} \sin^2 \frac{2\pi l}{\lambda}$$

which has a maximum value at center frequency (Fig. 1), for reasons listed here.

$2\pi l/\lambda_g$  is usually about  $80^\circ$ , so that  $\sin^2 2\pi l/\lambda_g$  remains fairly constant for large increases in frequency, but decreases rapidly as frequency is decreased.  $\lambda_g/\lambda$  increases with decreasing frequency, but at a much slower rate than the decrease of  $\sin^2 2\pi l/\lambda_g$ ;

<sup>1</sup> W. W. Mumford, "The optimum piston position for wide-band coaxial-to-waveguide transducers," PROC. IRE, vol. 41, p. 256; February, 1953.

$\lambda_g/\lambda$  also decreases with increasing frequency.

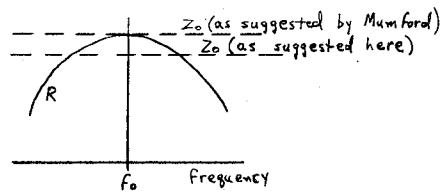


Fig. 1.

From the foregoing, it can readily be seen that even wider bandwidths than those achieved by Mumford are obtainable if  $R$  is made greater than  $Z_0$  at center frequency. In order to determine how much greater than  $Z_0$ ,  $R$  should be, I have found the following equations very useful:

$1.10 = R/Z_0$  at center frequency,  $f_0$ , which is obtained by setting vswr at center frequency equal to 1.10, and leads to:

$$\cos^2 \frac{\pi d}{a} = \frac{Z_0}{240\pi b/a} \cdot \frac{1.10}{\left(\frac{\lambda_g}{\lambda} \sin^2 \frac{2\pi l}{\lambda_g}\right)_{at f_0}} \quad (2)$$

and

$$\left(\frac{R}{Z_0}\right)_{at f_0} = \left(\frac{Z_0}{R}\right)_{at f_L}$$

where  $f_L$  is the low frequency end of the desired band. This yields

$$\cos^2 \frac{\pi d}{a} = \frac{Z_0}{240\pi b/a} \left[ \left( \frac{\lambda_g}{\lambda} \sin^2 \frac{2\pi l}{\lambda_g} \right)_{at f_L} \cdot \left( \frac{\lambda_g}{\lambda} \sin^2 \frac{2\pi l}{\lambda_g} \right)_{at f_0} \right]^{-\frac{1}{2}} \quad (3)$$

Use of (3) has led me to a design which has a calculated vswr of 1.10 or better over a frequency band in excess of 30 per cent.

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### Addendum to Planar Transmission Lines—I\*

If it is desired to use fine wires of diameter  $a$  instead of these flat strips, an elementary argument shows that the characteristic impedance is given very closely by

$$Z = \frac{120}{V_k} \ln \left( \frac{4h}{\pi a} \tanh \frac{\pi d}{2h} \right).$$

The attenuation is given to sufficient accuracy by the relevant formulas of the paper referred to above.

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\* David Park, "Planar transmission lines," vol MTT-3, pp. 8-12; April, 1955.

## Contributors

Carlos M. Angulo (S'50-A'52-M'52-M'56) was born in Pinto (Madrid) Spain, in 1921. He received the degree of Ingeniero

de Telecomunicacion from the Escuela Oficial de Telecomunicacion in Madrid, Spain, in 1946; the M.E.E. degree in communication engineering in 1951 and the D.E.E. in electrophysics in 1955, both from the Polytechnic Institute of Brooklyn.

C. M. ANGULO

From 1946 to 1948, Dr. Angulo worked as an assistant technical director of Transradio Espanola S.A. in Madrid in radio telegraphy and radio telephony. In 1947 he became a re-

search associate of the Spanish Council of Scientific Research in Madrid and he worked in electroacoustics.

Dr. Angulo joined the Polytechnic Institute of Brooklyn as a research associate in 1949 and as instructor of electrical engineering in 1950; his research during this period was in microwaves. He became an assistant professor of engineering in 1952 and associate professor in 1955, at Brown University, Providence, R. I., where he is at present doing research in antennas and propagation, and teaching.

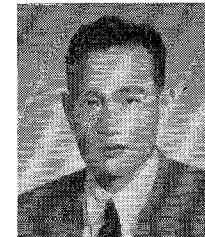
During the summer of 1956, Dr. Angulo was a visiting research associate professor at the Control Systems Laboratory of the University of Illinois working in propagation problems.

He is a member of Tau Beta Pi, Sigma Xi, and the American Association for the Advancement of Science.

Tsung-Shan Chen (A'48-M'55) was born in Hopei, China, on February 2, 1913. He received the B.S. from Tangshan Chiao-

Tung University, China, in 1933, and the M.S. from Purdue University in 1934. He attended M.I.T. and received the S.M. in 1935 and the Sc.D. in 1938, both in electrical engineering.

He was professor of electrical engineering at the National Central University, China, until 1947. He joined RCA in 1951, and has been working in the Microwave Tube Advanced Development Section of the Tube Division at Harrison, N. J.



Rabindra Ghose (M'53-SM'54) was born in Howrah, India, on September 1, 1925. He graduated in electrical engineering from the College of Engineering and Technology, Bengal, India, 1946. From June, 1946 to February, 1949 he served the College of Engineering and Technology as an instructor of electrical engineering. He received a post-graduate diploma from the Indian Institute of Science in 1948; M.S. in electrical engineering from the University of Washington, Seattle, in 1952; M.A. in mathematics, and Ph.D. in electrical engineering from the University of Illinois in 1954. He was also awarded the professional degree of Electrical Engineer by the University of Illinois in 1956.

Dr. Ghose served the Corps of Signals, India, as a technical officer from 1949 to 1951. During 1951 and 1954 he served the University of Washington and the University of Illinois as a research fellow. From 1954 to 1956 he was a member of the technical staff at RCA. He is now with the Ramo-Wooldridge Corporation in Los Angeles, Calif.

Dr. Ghose is an associate member of the Institute of Electrical Engineers, London, and a member of Sigma Xi, Eta Kappa Nu, and Pi Mu Epsilon.



R. N. GHOSE

Polytechnic Institute in 1947. He served in the Army Signal Corps during World War II.



I. GOLDSTEIN

Mr. Goldstein attended Brooklyn Polytechnic Institute in 1943-1944 as a member of ASTP studying electrical engineering. He pursued graduate studies at M.I.T. in 1947-1948, and joined Raytheon Manufacturing Company in 1947 as an electronics engineer. In 1948 he

joined the microwave laboratory as a design and development engineer of components used in radar, beacons, countermeasure systems, and relay equipment. In 1954 he transferred to the Missile Systems Division as a senior engineer and then as section head of the microwave components group.

He is a member of the RETMA Subcommittee on Waveguides and Fittings.



W. Delmar Hershberger (A'37-SM'45-F'54) was born on May 10, 1903, in Wellman, Iowa. He received the A.B. degree in 1927 from Goshen College, the A.M. in physics in 1930 from George Washington University, and a Ph.D. in electrical engineering in 1937 from the University of Pennsylvania. From 1927 to 1931 he was employed at the Naval Research Laboratory working on target detection using the pulse-echo ultrasonic method, and from 1931 to 1936 at the Signal Corps Laboratories on target detection employing microwaves. From 1937 to 1949 he was employed by the Radio Corporation of America and worked on the development of a 500 mc pulse-type altimeter and obstacle detection equipment used in 1938.

During the war Dr. Hershberger worked on various radar system problems and after the war was active in the study of materials using the methods of microwave spectroscopy. Since 1949 he has served as a Professor of Engineering at the University of California, Los Angeles, and he spent the year 1955-1956 at the University of Leiden, Netherlands, as a Fulbright Research Scholar. He served four years as a member of the Board of Directors and in 1954 as Chairman of WESCON.

He is a member of the American Physical Society, the American Association for the Advancement of Science, Sigma Xi, and Tau Beta Pi.



Clarence W. Jones was born in Canton, Me., on August 17, 1918. He received the B.S. degree in electrical engineering from the University of Maine in 1942 and the

M.S. degree in electrical engineering from Washington University, St. Louis, Mo., in 1952. He was a member of the staff of the M.I.T. Radiation Laboratory from 1942 through 1945. From 1946 to 1952, he was employed as a radar engineer at the Emerson Electric Mfg. Co., St. Louis, and in 1952 Mr. Jones joined the staff of Lincoln Laboratory where he has been engaged in microwave component and

tr tube development.

Mr. Jones is a member of Tau Beta Pi and Phi Kappa Phi, and an associate member of Sigma Xi.



C. W. JONES

D. D. King (M'46) was born on August 7, 1919, in Rochester, N. Y. He received the A.B. degree in engineering sciences from

Harvard College in 1942 and the Ph.D. degree in physics from Harvard University in 1946. He was a teaching fellow in physics and communication engineering in 1943, serving as a staff member of the pre-radar Officer's Training School at Craft Laboratory, Harvard University.

He was a research associate there during 1945. In 1946 he was appointed research fellow in electronics, and in 1947, assistant professor of applied physics in Harvard.

In 1948, Dr. King was appointed associate professor of physics in the Institute for Cooperative Research of Johns Hopkins University, in 1950, assistant director, and in 1955, director of the Radiation Laboratory. He became vice-president, research, of Electronic Communications, Inc.

Dr. King is a member of Sigma Xi and the American Physical Society.



Alan C. Macpherson was born in Washington, D. C., on December 24, 1920. He received the B.S. degree in physics from the

University of Maryland in 1943 and the M.A. degree in physics from George Washington University in 1950. From 1943-1946 he worked on radar, proximity fuse production, and special purpose electronic tubes. In 1947 he joined the NBS where he dealt with

precision measurements of power and impedance at microwave frequencies. He is now with the Naval Research Laboratory, Washington, D. C.

He is a member of Sigma Pi Sigma, RESA, and the American Physical Society.

Richard C. Mackey (S'50-A'53) was born in Los Angeles, Calif., on July 27, 1926. He received the B.S. degree in engineering in

1950 from the University of California, Los Angeles, and the M.S. degree in 1952 from the same institution.

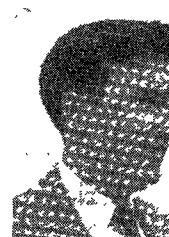
Mr. Mackey has been employed since 1950 at the University of California, Los Angeles, where

he is now an assistant engineer and associate in engineering. His work has been in connection with research on the properties of materials at microwave frequencies, including gas spectroscopy and paramagnetic resonance. He has also worked in the fields of electronic instrumentation and microwave frequency standards and stabilization.

Mr. Mackey is a member of Tau Beta Pi and Sigma Xi.



Irving Goldstein (A'48-M'55) was born in Worcester, Mass., on December 19, 1920. He received the B.S. degree in electrical engineering (cum laude) from Worcester



A. C. MACPHERSON

George C. Messenger (S'51-A'53) was born in Brattleboro Vt., on July 20, 1930. He received the B.S. degree in physics from Worcester Polytechnic Institute in 1951. He has since done graduate work in electrical engineering at the Moore School, University of Pennsylvania.



G. C. MESSENGER

Mr. Messenger joined Philco Corporation in 1951 where he has been a staff member of the Research Division. He has worked primarily in the field of semiconductor device design, being associated with microwave mixer diodes, and high-frequency transistors.

Mr. Messenger is a member of the American Physical Society.

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Mr. Messenger is a member of the American Physical Society.

## Contributors

Henry J. Riblet (M'55) was born July 21, 1913, at Calgary, Canada. He received the Ph.D. from Yale University in 1939 and taught mathematics thereafter for three years at Adelphi College and at Hofstra College. He joined the M.I.T. Radiation Laboratory in 1942 and at the close of the war was in charge of one of the three developmental sections of the Antenna Group. From 1946 to 1948 he headed the vf group at the Submarine Signal Company. He is presently employed by the Microwave Development Laboratories, Inc., of which he was a co-founder.

He is a member of the American Mathematical Society and the American Physical Society.



H. J. RIBLET

a research associate at the Radiation Laboratory of Johns Hopkins University working on back-scattering studies, millimeter techniques, and, most recently, problems in dielectric image line transmission. He is now on the faculty of electrical engineering at Columbia University.

Mr. Schlesinger is a member of Sigma Xi and Phi Kappa Phi.



Friedrich J. Tischer (SM'55) was born in Plan, Austria, in 1913. He received his preparatory education at the Realgymnasium in Budweis and attended the University of Prague from 1932 to 1938. In 1937 he received the Master's degree in electronics and was awarded the Ph.D. degree in technical sciences from the University of Prague in 1938.

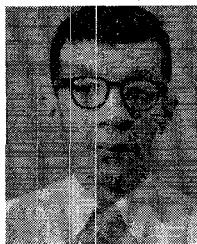


F. J. TISCHER

He then joined the Telefunken Laboratories, Berlin, where he worked in the field of television and microwaves. In 1941, he founded the Tischer Physical Research Laboratory at Budweis and Aigen, Austria.

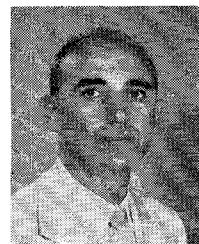
Dr. Tischer joined the staff of the Royal Institute of Technology in Stockholm, Sweden in 1947, where he directed the activities in microwave research. In 1954 he came to the United States and conducted research in microwaves with the Research Division, Ordnance Missile Laboratories, Redstone Arsenal, Army Guided Missile Center until August, 1956, at which time he joined the staff of the department of electrical engineering, Ohio State University, as an associate professor and a research associate in the Antenna Laboratory.

Herbert G. Pascalar (S'50-A'51) received the Bachelor of Science degree in electrical engineering from Union College in Schenectady, N. Y., and the M.E.E. degree from Syracuse University in 1947 and 1950 respectively.



H. G. PASCALAR

From 1951 to 1954 he engaged in radar microwave development at Radio Corporation of America, in Camden, N. J. Since 1954, Mr. Pascalar has been a staff member of Lincoln Laboratory at Massachusetts Institute of Technology.



S. P. SCHLESINGER

S. Perry Schlesinger (M'55) was born in New York City on October 9, 1918. He received the B.S. degree from Michigan State in 1941, an M.S.E. from Union College in 1950 and is now working toward a Doctorate at Johns Hopkins University.

In 1946, following war service as a destroyer engineer officer, Mr. Schlesinger joined the General Electric Company, subsequently serving as an assistant professor of electrical engineering on the faculties of Union College and the U. S. Naval Academy. From 1953 through 1956 he was

