To illustrate how a $Z-\theta$ transmission line chart can be used to determine the transmission characteristics of a sandwich, an example will be considered. For this example, the polarization is perpendicular to the plane of incidence, $\lambda_0=3.2$ cm $=1.26$ inch, $\theta_0=45^\circ$, $d_1=0.05$ inch, $\mu_1=1$, $\epsilon_1=6$, $d_2=0.21$ inch, $\mu_2=0.8(1+j0.05)$, $\epsilon_2=4(1-j0.2)$, $d_3=0.07$ inch, $\mu_3=1$, and $\epsilon_3=4$. Now $\eta_{0\perp}=\eta_{4\perp}=1.414$, $\eta_{1\perp}=0.426$, $\eta_{2\perp}=0.481/\underline{7.9^\circ}$, $\eta_{3\perp}=0.535$, $\alpha_1=\alpha_3=0$, $\alpha_2=0.721$ nepers per inch, $\beta_1=(2\pi)(1.861)$ radians per inch, $\beta_2=(2\pi)\cdot(1.317)$ radians per inch, and $\beta_3=(2\pi)(1.485)$ radians per inch.

The point $Z_1=\eta_{0\perp}/\eta_{1\perp}=3.317$ is plotted on a Z-θ chart, as in Fig. 2 (below). The

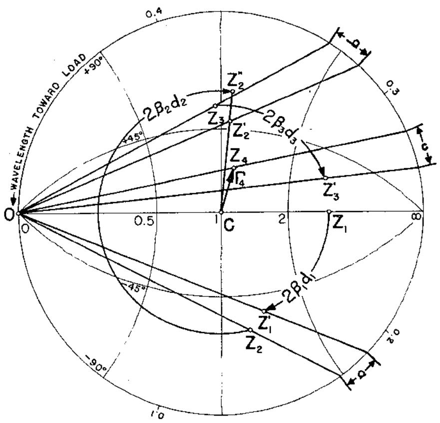

Fig. 2—Graphical construction for example.

point Z_1 is rotated through the angle $2\beta_1d_1$ or $(1.861)(0.05)\lambda=0.093\lambda$ to obtain $Z_1'=1.40/\underline{-54^\circ}$. The point $Z_2=(\eta_{1\perp}/\eta_{2\perp})Z_1'=1.24/\underline{-61.9^\circ}$ is plotted. The point Z_2 is rotated through the angle $2\beta_2d_2$ or $(1.317)\cdot(0.21)\lambda=0.278\lambda$ to obtain Z_2''. The distance $\overline{CZ_2''}e^{-2\alpha_2d_2}=\overline{CZ_2''}e^{-0.0303}=0.739\overline{CZ_2''}$ is measured from C along the line CZ'' to locate the point $Z_2'=1.07/\underline{49^\circ}$. The point $Z_3=(\eta_{2\perp}/\eta_{3\perp})Z_2'=0.96/\underline{56.9^\circ}$ is plotted. The point Z_3 is rotated through the angle $2\beta_3d_3$ or $(1.485)(0.07)\lambda=0.104\lambda$ to obtain $Z_3'=2.98/\underline{25^\circ}$. The point $Z_4=(\eta_{3\perp}/\eta_{3\perp})Z_3'=1.13/\underline{25^\circ}$ is plotted.

The magnitude of the voltage reflection coefficient is $\overline{CZ_4}$/(radius of chart) $=0.23$ Now

$$|E_4^+| = \frac{\overline{OC}}{\overline{OZ_1}}\frac{\overline{OZ_1'}}{\overline{OZ_2}}\frac{\overline{OZ_2'}}{\overline{OZ_3}}\frac{\overline{OZ_3'}}{\overline{OZ_4}}e^{\alpha_1d_1+\alpha_2d_2+\alpha_3d_3}$$
$$= 1.10$$

and the ratio of power transmitted to power incident is 0.826. The angle of E_4^+ is

$$a-b-c+\beta_1d_1+\beta_2d_2+\beta_3d_3$$
$$= 360^\circ(0.014-0.016-0.016+0.093+0.278+0.104)$$
$$= 164.5^\circ,$$

and the increase in phase retardation due to the sandwich is

$$\Phi=164.5^\circ-(360^\circ/1.26)(0.33)\cos 45^\circ=9.78^\circ.$$

A graphical construction for determining the transmission characteristics of a sandwich has the advantage that the effect of the individual layers is presented in visual form. Ways to vary the parameters to obtain a desired result may be suggested by a study of the chart.

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Measurement of Reflection Coefficients through a Lossless Network

Often it is not convenient to measure a reflection coefficient directly. In some such cases, the following procedure may be used. The arrangement of components shown in Fig. 1 will be considered. It will be assumed that lines Nos. 1 and 2 are lossless. These lines may be transmission lines, waveguides, or one of each.

Fig. 1—Arrangement for measuring reflection coefficients.

First, a matched load is connected to line No. 2 and the matching network is adjusted until the reflection coefficient in line No. 1 is zero. Next, the matched load is replaced by a short circuit. The magnitude of the reflection coefficient in line No. 1 should be one. This should be checked experimentally. A voltage null in line No. 1 is located and designated the *short-circuit point.* Finally, the short circuit is replaced by the unknown impedance. The reflection coefficient $\mathbf{\Gamma}_1$ in line No. 1 is measured relative to the short-circuit point. The reflection coefficient $\mathbf{\Gamma}_2$ in line No. 2 related to the point where the short circuit was connected is the same as $\mathbf{\Gamma}_1$.

The theoretical basis for this procedure is the well-known equation

$$\mathbf{\Gamma}_1=\frac{a\mathbf{\Gamma}_2+b}{c\mathbf{\Gamma}_2+d}.$$

Since $\mathbf{\Gamma}_1=0$ when $\mathbf{\Gamma}_2=0$, $b=0$. Since the various components are lossless, $\Gamma_1=1$ when $\Gamma_2=1$. Consequently, $|c\mathbf{\Gamma}_2+d|$ is equal to a constant for all values of $\mathbf{\Gamma}_2$ such that $\Gamma_2=1$. This requires that $c=0$. Now $\mathbf{\Gamma}_1=(a/d)\mathbf{\Gamma}_2$, where $a/d=1$. When $\mathbf{\Gamma}_1$ is referred to the short-circuit point, $a/d=1$ and $\mathbf{\Gamma}_1=\mathbf{\Gamma}_2$.

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Contributors

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A. Clavin (A'51) was born in Los Angeles, Calif., June 17, 1924. He received his B.S. degree in electrical engineering from U.C.L.A. in 1948 and became a member of the technical staff of Hughes Aircraft Co. During his six years there, he concerned himself with the design of microwave components, antennas and radomes.

Mr. Clavin received his M.S. degree in 1954 from U.C.L.A. and joined Litton Industries, where he worked on the development of ferrite microwave components. Later that year he became a senior antenna and microwave engineer at Canoga Corp., where he has continued his work in the development of ferrite components.

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For a photograph and biography of S. B. Cohn, see the March, 1955 issue of the Transactions of the IRE-PGMTT.

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B. A. Dahlman

B. A. Dahlman graduated from the Royal Institute of Technology in Stockholm, Sweden, in 1951. He served in the Swedish Navy for one year, and while in service was engaged in radar work at the Research Institute of National Defense.

He continued his radar studies until 1952 when he joined the RCA Laboratories at Princeton, N. J. for research on microwave circuits and transistors. Mr. Dahlman returned to Sweden in 1954 and is now with Magnetic AB in Stockholm.

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S. Hopfer was born in Rexingen, Germany in 1914. He came to the United States in 1940, and received the B.A. degree from West Virginia University in 1944. He was awarded a teaching fellowship from Cornell University, and received the M.A. degree in 1946 from Cornell. In 1954, he received the Ph.D. degree in physics from the Polytechnic Institute of Brooklyn.

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Since 1946, Dr. Hopfer has been with the Polytechnic Research and Development Co., where he is section head in charge of microwave research and component development.

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E. J. Nalos was born in Prague, Czechoslovakia, September 10, 1924. In 1946 he received the degree of Bachelor of Applied Science in electrical engineering, and in 1947, the degree of Master of Applied Science from the University of British Columbia. He was a research and teaching assistant at the Microwave Laboratory at Stanford University under a Sperry Gyroscope Co. fellowship, obtaining his Ph.D. in 1951. He was a research associate at the Microwave Laboratory, where he was active in high-power microwave tube research and the student laboratory instruction program until 1955. Dr. Nalos is presently working on high-power traveling-wave tubes for the General Electric Microwave Laboratory in Palo Alto, Calif.

E. J. Nalos

He is a member of Sigma Xi.

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For a photograph and biography of D. Park, see the April, 1955 issue of the Transactions of the IRE-PGMIT.

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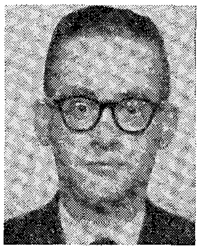

P. I. Sandsmark

He worked with the Royal Norwegian Navy as a radar engineer in 1951 and with the British Thomson-Houston Co., England, as a microwave engineer in 1952. Since 1953 he has been a member of the technical staff of the Bell Telephone Laboratories, where he has been engaged in the development of circular waveguide for use in microwave radio relay systems. Mr. Sandsmark is also continuing his graduate work at the Polytechnic Institute of Brooklyn.

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Henry Schwiebert (A'50) was born in New York, N. Y., on April 8, 1921. He received a B.E.E. degree from the Polytechnic Institute of Brooklyn in 1946. At Hazeltine Electronics Corp. from 1942 to 1948, he worked on development of rf components and pulse circuitry for IFF and telemetering applications. He joined the staff of Wheeler Laboratories in 1948, and as assistant chief engineer, specialized in the design of microwave components for radar applications. In 1955 he joined Teletronics Laboratory as assistant chief engineer.

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From 1944 to 1946, while in the Navy, he was in the Centimeter Wave Research Section at the Naval Research Laboratory in Washington, D. C. He joined the U. S. Navy Electronics Laboratory in 1947, and is presently a group leader in the Radar Equipment Section in charge of uhf and microwave component design for the radar branch.

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H. A. Wheeler (A'27–M'28–F'35) was born in St. Paul, Minn., on May 10, 1903. He received the B.S. degree in physics from George Washington University in 1925, and from 1925 to 1928 he studied in the physics department of Johns Hopkins University. He joined the Hazeltine Corporation in 1924 and was in charge of their Bayside laboratory from 1930 to 1937. He later became vice-president and chief consulting engineer of the corporation.

H. A. Wheeler

He has specialized in the design of radio receivers (including FM and TV), the theory of communication networks, radar (including IFF during World War II), antennas, and microwave equipment.

In 1946 Mr. Wheeler opened his own consulting office in Great Neck, N. Y. He is now president of Wheeler Laboratories, Inc. From 1950 to date, he has been serving part-time as consultant to the Office of the Secretary of Defense in the fields of guided missiles and electronics.

Mr. Wheeler is a fellow of the American Institute of Electrical Engineers, an associate member of the Institution of Electrical Engineers, and a member of Sigma Xi. He received the Morris Liebmann Memorial Prize in 1940.