## Surface Loss of Silver Plated Metal Plates at 9,000 mc and Its Correlation with Surface Roughness*

Many researchers[1-3] have reported that waveguide attenuation and surface conductivity of metal plates and wires were greater than expected from the theory (due to their surface roughness), and the discrepancy was most remarkable in silver-plated samples.

Surface loss of the metal samples by the cavity method was measured, and simultaneously their surface condition by the mechanical stylus and electron micrograph methods, was measured, to investigate in more detail their correlation with each other. The mechanical stylus method was used to measure the microscopic surface roughness, while the electron micrograph was intended to investigate the microscopic detail of the surface condition.

The relative surface loss of a metal plate can be measured from the variation of the $Q$s of the cylindrical cavity by fitting it at one end of the cavity. This is because the $Q$ of the cylindrical cavity varies according to the surface loss of its end plates. A $TE_{021}$ mode flat, cylindrical cavity, with a diameter of 12.5 cm and an axial length which was variable from 1.8–2.2 cm, was used in the 9,000 mc band in order to determine the loss of the end plates.

To avoid the influence of other spurious modes upon the value of $Q$, the cavity was provided with a choke noncontact flange at the contact point between the cylindrical wall of the cavity and the metal sample, and the wave absorber was inserted behind the variable end plate. The sample plates used were cylindrical discs of 14.0 diameter and maintained mechanical rigidity of 1.0 cm thickness. Suppose that two metal plates, of which the surface attenuation relative to pure copper is $A_1$ and $A_2$ respectively, are attached closely to one end of the cavity, and the values of the half-power bandwidth of the resonance curve are measured as $\triangle f_1$ and $\triangle f_2$ respectively. Then the following equation is obtained at 9,000 mc for the cavity described above:

$$\Delta f_2 - \Delta f_1 = 194\ (A_2 - A_1)\ \text{kc}.$$

Therefore, the unit difference, $A_2 - A_1 = 1.0$, corresponds to the frequency difference of 194 kc. Data was obtained directly from the oscilloscope trace; the measurement of the relative surface loss is accurate within 3 per cent.

The interesting results are illustrated in Fig. 1. The profilgraphs (vertical length is 1,000 magnification, horizontal length is 50 magnification) of the four samples in the direction parallel to the flow of the wall-current, and their electron micrographs (chromium-shadowed methylmetha-Al replica, 7,500 magnification) are presented. Sample (a) is a well finished pure copper and the ratio of its measured loss to the theoretical value is not more than 1.03, while sample (b), (c) and (d) are silver-plated brass, and their relative attenuations are 1.23, 1.50 and 2.05 respectively. The surface finishing of these samples is as follows: (a) lathe finishing and buffing; (b) lathe finishing, buffing, silver-plating several tens of microns thick and buffing; (c) lapping, thin silver-plating several microns thick and buffing; and (d) lathe finishing, paper polishing and silver-plating several microns thick.

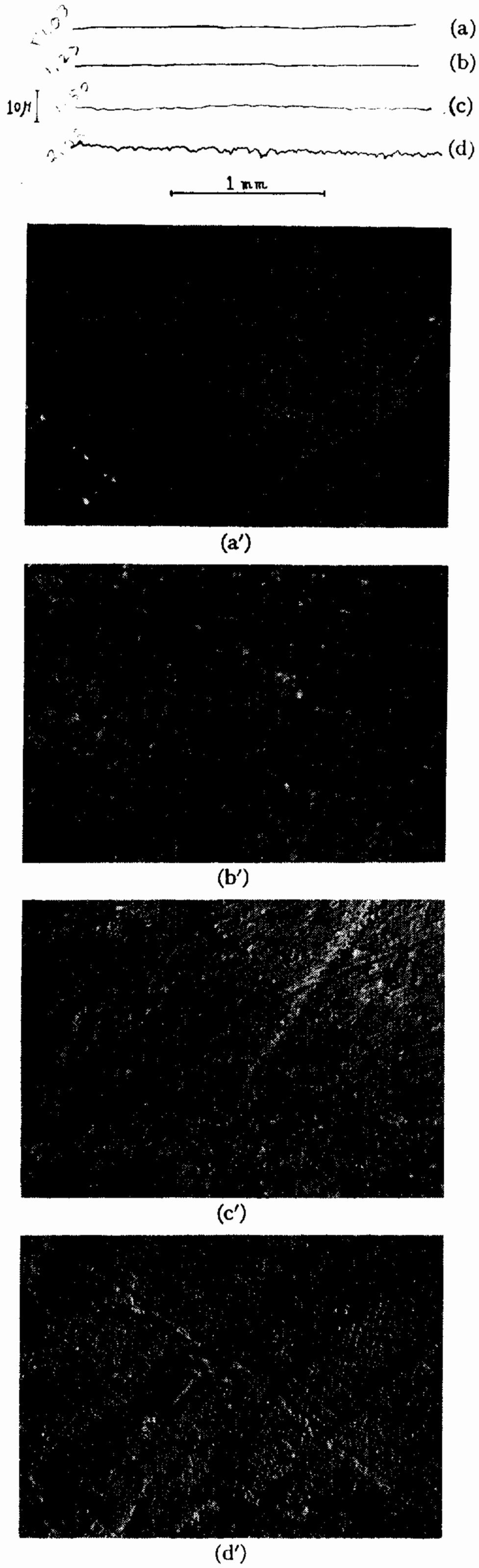


Fig. 1—Profilgraphs (magnification 1,000×50) and electron micrographs (magnification 7,500); (a) (a') copper plate (rel. loss 1.03), (b) (b'), (c) (c') and (d) (d') silver-plated samples (rel. loss 1.23, 1.50 and 2.05, respectively).

From the profilgraphs, electron micrographs and measured values of the surface loss, it can be seen that the surface loss increases rapidly with an increase in roughness of the surface. However, further inspection of the electron micrographs, indicates that there is considerable difference between the surface conditions of the pure copper sample and silver-plated sample; many silver particles irregularly deposited on the surface are visible in sample (b), the best one obtained in our laboratory. Moreover, not only the irregularly deposited silver particles, but also many abrupt seams and holes are visible on the surface of the usual silver-plated samples, (c) and (d).

The defective character of the silver-plated samples is considered the main cause of abnormal surface loss. This can be explained also from the experimental fact that the surface loss of the pure copper or brass plates varies in a systematic fashion with the roughness of their surfaces, as is known from the profilgraphs. The surface loss of the silver-plated samples does not always coincide with the microscopic roughness shown in their profilgraphs, but varies according to the microscopic appearance of the electron micrographs. Investigation is now being made on the relation between microscopic surface conditions, silver-plating, and finishing procedures.

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[1] S. P. Morgan, Jr., "Effect of surface roughness on eddy current losses at microwave frequencies," *Jour. Appl. Phys.*, vol. 20, pp. 352–362; April, 1949.

[2] A. C. Beck and R. W. Dawson, "Conductivity measurements at microwave frequencies," Proc. I.R.E., vol. 38, pp. 1181–1189; October, 1950.

[3] F. A. Benson, "Waveguide attenuation and its correlation with surface roughness," *Proc. IEE, part III*, vol. 100, pp. 85–90; 1953.

## On Isotropic Antennas*

A few years ago, I wrote a note[1] in which I concluded that an isotropic antenna is impossible. Although my conclusion was partially correct, my discussion may have been too brief to be easily understood. A few additional remarks appear to be in order.

A radiating antenna located at the origin of a spherical co-ordinate system was considered. In order for the conclusion to be correct, it must be possible to express the electric field intensity, at a great distance from the antenna, in the form

$$\begin{aligned} E = \frac{1}{r}\{ &[f_1(\theta,\phi)\sin(\omega t-\beta r) \\ &+ f_2(\theta,\phi)\cos(\omega t-\beta r)]\boldsymbol{u}_\theta \\ &+ [f_3(\theta,\phi)\sin(\omega t-\beta r) \\ &+ f_4(\theta,\phi)\cos(\omega t-\beta r)]\boldsymbol{u}_\phi\}, \end{aligned}$$

where $\boldsymbol{u}_\theta$ and $\boldsymbol{u}_\phi$ are the unit vectors in the $\theta$ and $\phi$ directions, respectively. Many antennas do not satisfy this condition, e.g., antennas that move.

According to Brouwer's theorem,[2] there exist directions $(\theta_1, \phi_1)$ and $(\theta_2, \phi_2)$ such that $f_1(\theta_1, \phi_1) = f_3(\theta_1, \phi_1 = 0$ and $f_2(\theta_2, \phi_2) = f_4(\theta_2, \phi_2) = 0$. If $(\theta_1, \phi_1) = (\theta_2, \phi_2)$, there is no radiation in the $(\theta_1, \phi_1)$ direction. If $(\theta_1, \phi_1) \neq (\theta_2, \phi_2)$, the radiation in these directions must be linearly polarized.

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* Received by the IRE, November 8, 1954.

[1] H. F. Mathis, "A short proof that an isotropic antenna is impossible," Proc. I.R.E., vol. 39, p. 970; August, 1951.

[2] L. E. J. Brouwer, "On continuous vector distributions on surfaces," *Proc., Royal Acad. (Amsterdam)*, English edition, vol. 11, pp. 850–858; 1909. Or, "Over continue vectordistributies op oppervlakken," *Proc., Koninklijke Akademie van Wetenschappen (Amsterdam)*, Dutch edition, vol. 11, pp. 896–904; 1909.