Electrolytic Pointing of Fine Wires

In the fabrication of point contact or pulse alloyed diodes for millimeter wavelengths, junction area restrictions require wire points with radii of the order of 10^{-4} inches or less. This paper describes a device and technique for electrolytically pointing metal wires of various sizes to meet these requirements.

A technique for forming points on tungsten wires has been in existence for some time.[1] An extension of this was made by the development of a simple device to point tungsten and other metal wires with consistent results. The device shown in Fig. 1 consists of a container of electrolyte with a copper electrode, a pin vise and a drive mechanism for holding the whisker and a variable ac voltage supply. It has been used to form sharp points on wires from 0.001 inch to 0.007 inch diameter. The feature of this device is that it can be used for either repointing a whisker with minimum amount of material removal or cutting the whisker to length. For most materials, the etching period is controlled automatically by the action of the whisker-electrolyte interface without the need for timers or controls of any kind.

To point the whisker with minimum removal of material, it is lowered into the electrolyte, then withdrawn slowly until a maximum-height meniscus is formed. The voltage is then applied until etching is completed, as indicated by the breaking of the meniscus. When pointing a wire for the first time, two applications of this process may be necessary to change the wire end from the blunt end to a conical point.

Various materials have been pointed using the device described with a 3 to 10 N solution of KOH as an electrolyte. They include

Aluminum[2]	0.002 inch diameter
Aluminum—0.75 per cent Boron[2]	0.003 inch
Molybdenum	0.001 inch to 0.003 inch
Beryllium Copper	0.0015 inch
Phosphor Bronze	0.001 inch to 0.005 inch
Tungsten	0.001 inch to 0.007 inch
Silver Plated Tungsten	0.001 inch
Zinc	0.003 inch.

Pointing these wires takes between a second and several minutes with 3 to 6 volts, 60 cycle, applied. A few experimental trials determine the best etching voltage for the particular wire used. Typically, the resulting point radius is 30×10^{-6} inches with some as small as 15×10^{-6} inches. Fig. 2 is a microphotograph of a 0.001-inch diameter phosphor bronze wire pointed in a 7N solution of KOH.

In addition to these materials, type 302 stainless steel (0.005 inch diameter) and titanium (0.002 inch diameter) have been pointed with a higher applied voltage. An electrolyte strength of 20 N and 6 volts, for example, points these wires in about 15 minutes. Platinum, 10 per cent Ruthenium (0.003 inch diameter), has been electrolytically etched by the same method, taking several hours, resulting in a point that is smooth, but more blunt than with other materials.

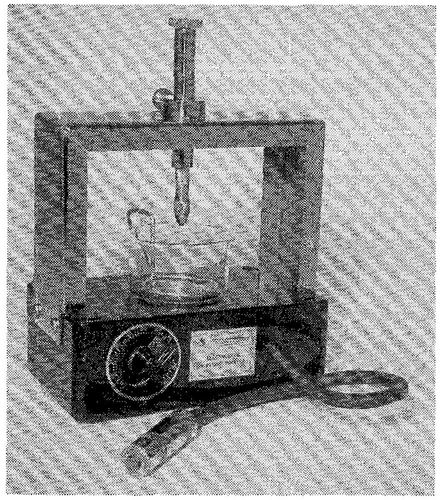

Fig. 1—Electrolytic whisker pointer.

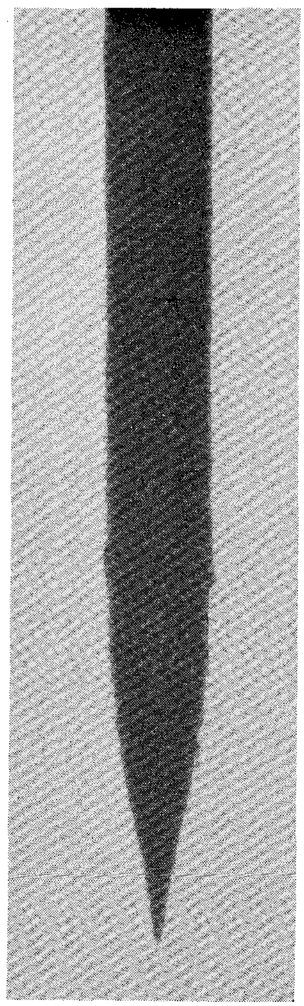

Fig. 2—Electrolytically pointed 0.001-inch diameter phosphor-bronze whisker (photographed at 563×).

Nickel wire can be pointed with the same technique using a different electrolyte developed for use with gold and silver whiskers.[3] The solution consists of 5 per cent by weight of both potassium ferrocyanide and sodium cyanide in water. With this solution a 0.003-inch diameter nickel wire can be pointed in about a minute at 6 volts. The resulting point is quite smooth and spherical but does not have as small a radius as is obtained with most materials, being of the order of 0.002 inch.

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Manuscript received January 6, 1964.
The work reported in this paper has been sponsored in part by the National Aeronautics and Space Administration, Washington, D. C., under Contract No. NASw-259 and NASw-662.

[1] W. G. Pfann, "An Electrolytic Method for Pointing Tungsten Wires," Amer. Inst. Mining Met. Engrs., New York, N. Y., Tech. Publ. No. 2210, Metals Technology; June, 1947.

[2] Smooth regular points are not obtained with these. The point radii are typically 0.00025 inch.

[3] S. Kita, private communication.

Analogy Between a Modulated Electron Beam in a Plasma and Transmission Lines

We shall consider a modulated electron beam passing through a plasma medium. The following assumptions shall be made in the analysis which closely follows Bloom and Peter:[1]

1) To linearize the equations, a small signal analysis is employed.
2) The analysis is one dimensional; motion of the particles is taken along the z axis.
3) Thermal motion and collisions are neglected in the plasma, where the ions are assumed stationary.

The ac quantities which vary as $e^{j\omega t}$ are given in a coordinate system which moves with the dc velocity u_0 of the electron beam. Both the dc and ac quantities are, in general, functions of z.

The equation of motion for the electron beam is

$$j\omega v_b + \frac{d}{dz}(u_0 v_b) = \eta E; \quad \eta = \frac{e}{m}\cdot \tag{1}$$

In the essentially one-dimensional beam-plasma system, we have

$$\frac{I_b}{\sigma_b} + \frac{I_p}{\sigma_p} + j\omega\epsilon_0 E = 0 \tag{2}$$

where σ_b and σ_p are, respectively, the cross sections of the electron beam and of the plasma, and I_b and I_p are the total ac currents of the beam and of the plasma, respectively.

$$\frac{I_b}{\sigma_b} = \rho_{0b} v_b + u_0 \rho_b; \quad \frac{I_0}{\sigma_0} = \rho_{0b} u_0 \tag{3}$$

$$\frac{I_p}{\sigma_p} = \rho_{0p} v_p. \tag{4}$$

Manuscript received January 9, 1964.

[1] S. Bloom and R. W. Peter, "Transmission-line analog of a modulated electron beam," *RCA Rev.*, vol. 15, pp. 95–112; March, 1954.

The equation of continuity for a homogeneous electron beam is

$$\frac{1}{\sigma_b}\frac{dI_b}{dz} + j\omega\rho_b = 0. \tag{5}$$

From (1), (2), (3) and (5), we obtain

$$\frac{dI_b}{dz} = \left(\frac{j\omega I_0}{2u_0V_0}\right)V_b, \tag{6}$$

where, under the small signal conditions, the ac beam voltage is

$$V_b = \frac{u_0 v_b}{\eta}. \tag{7}$$

The equation of motion for the lossless plasma is

$$j\omega v_p = \eta E, \tag{8}$$

from which, by using (2) and (4), we obtain

$$I_p = \frac{\sigma_p}{\sigma_b}\cdot\frac{\omega_p^2}{\omega^2}\cdot\frac{1}{\left(1-\frac{\omega_p^2}{\omega^2}\right)}\cdot I_b. \tag{9}$$

By proper manipulation of (1), (2), (7) and (8), the following equation is obtained:

$$\frac{dV_b}{dz} = \frac{j}{\omega\epsilon_0\sigma_b}\frac{1}{\left(1-\frac{\omega_p^2}{\omega^2}\right)}\cdot I_b. \tag{10}$$

It is noted that (6) is the same equation derived by Bloom and Peter for the case of a modulated beam.[1] Eq. (10) is, however, modified by the factor

$$\left(\frac{1}{1-\frac{\omega_p^2}{\omega^2}}\right),$$

which takes the presence of plasma into account. It may be shown that these two simultaneous differential equations [(6) and (10)] describing the beam-plasma interaction are formally identical with those of the transmission line loaded with lumped resonant circuits, as shown in Fig. 1. We have, from Fig. 1,

$$\frac{dV}{dz} = jXI; \qquad \frac{dI}{dz} = jBV. \tag{11}$$

There is, therefore, a complete correspondence if line voltage V and line current I correspond to the ac beam voltage V_b and the ac beam current I_b respectively.

The essential feature to be considered here is that the series impedance is capacitive for $\omega > \omega_p$ and inductive for $\omega < \omega_p$. This behavior is very similar to a continuous multicavity klystron or easitron where the resonators are tuned at a frequency such that they present a lossless negative susceptance to the electron beam. It is known in this case of an inductive circuit admittance that there exist increasing waves in the system.[2] For $\omega < \omega_p$, therefore, the beam-plasma system would lead to growing and decaying waves, as has been verified experimentally by several authors.[3,4]

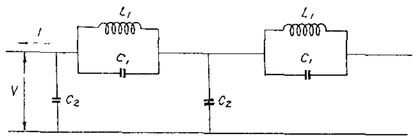

Fig. 1—Line analog of an electron beam in a lossless plasma.

$$C_2 = \epsilon_0\sigma_b\left(\frac{2\pi}{\lambda_p}\right)^2 \text{farads}/m \qquad C_1 = \epsilon_0\sigma_b \text{ farads}/m$$

$$L_1 = \frac{1}{\eta\sigma_b\rho_{0p}} \text{ henrys}/m \qquad \omega_p^2 = \frac{1}{L_1C_1}.$$

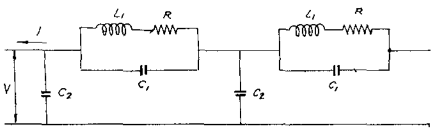

Fig. 2—Line analog of an electron beam in a plasma, with collisions taken into account.

$$R = \nu L_1 = \frac{\nu}{\eta\sigma_b\rho_{0p}} \text{ ohms}/m$$

where ν = plasma collision frequency.

Losses in the plasma from collision effects are readily included in the analog line by the introduction of a resistive component in the line series impedance, as shown in Fig. 2.

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[2] J. R. Pierce, "Waves in electron streams and circuits," *Bell Sys. Tech. J.*, vol. 30, pp. 626–651, July, 1951.

[3] G. D. Boyd, L. M. Field and R. W. Gould, "Excitation of plasma oscillations and growing plasma waves, *Phys. Rev.*, vol. 109, pp. 1393 1394; February, 1958.

[4] G. F. Freire, "Interaction effects between a plasma and a velocity-modulated electron beam," Microwave Lab., Stanford University, Stanford Calif.; Tech. Rept. No. 890; February, 1962.

Correction to "A Method for Measuring the Directivity of Directional Couplers"

B. C. Yates of the Radio Standards Laboratory, National Bureau of Standards, Boulder, Colo., has brought to the attention of the authors of the above paper[1] errors in some of the equations for error limits. The authors have investigated the difficulty and derived correct equations. If one uses the erroneous expressions, error limits are obtained which are much too conservative.

The equations in question are numbered (18) and (19). The correct expressions are

$$20\log_{10}\frac{1-|\Gamma_{2i}|^2}{1-\left|\frac{\Gamma_{2i}}{K}\right|} \geq \epsilon_{II,1} \geq 20\log_{10}\frac{1-|\Gamma_{2i}|^2}{1+\left|\frac{\Gamma_{2i}}{K}\right|}, \tag{18}$$

and

$$\epsilon_{II,2} = 20\log_{10}\frac{1-|\Gamma_{2i}|^2}{1-\left|\frac{\Gamma_{2i}}{K}\right|^2}. \tag{19}$$

It should be noted that the approximation $y/2 \approx (\Gamma_{2i}/K)$ is no longer needed in the derivations of (18) and (19), and that (19) can represent a correction rather than an error limit if $|\Gamma_{2i}|$ and $|K|$ are known. In order for (18) and (19) to hold,

$$|\Gamma_{2i}| < \frac{1-\frac{1}{|K|}}{1+\frac{1}{|K|}},$$

but the values of $|\Gamma_{2i}|$ and $|K|$ normally encountered will be found to satisfy this inequality.

The graphs of Fig. 5, which were based upon (18) and (19), are no longer correct. However, it was found that, for procedure 1, a sufficiently accurate answer can be obtained by dividing the decibel error limits by 3.

Fig. 5 does not give the correct results for procedure 2. However, it was found that for $|K^2| > 10$, (19) can be considered as insensitive to directivity, and equal to 20 $\log_{10}(1-|\Gamma_{2i}|^2)$.

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Manuscript received January 10, 1964.

[1] G. E. Schafer and R. W. Beatty, IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 419–422; October, 1958.

Multifrequency Microwave Generation Using a Large Capacitance Tunnel Diode

Fundamental, simultaneous oscillation at two discrete microwave frequencies has been experimentally verified using an inexpensive tunnel diode. The diode possesses relatively high junction capacitance of 90 pf (see Fig. 1).

The diode, whose cost is below three dollars, was a 1N3718 and was mounted in an impedance transformation waveguide mount,[1] as illustrated in Fig. 1. In this case the effects of package and junction capacitance are not reduced. The diode package is performing as a cavity resonator, resonating in the X band. The diode was found to oscil-

Manuscript received November 12, 1963; revised January 27, 1964.

[1] C. C. Hoffins and K. Ishii, "Microwave tunnel-diode operation beyond cutoff frequency," PROC. IEEE (*Correspondence*), vol. 51, pp. 370–371; February, 1963.