Electrodeposited Rhodium in Co-axial Radio-Frequency Circuits

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Rhodium is widely used over a silver electrodeposit on the current-carrying and sliding contact surfaces of co-axial line assemblies and also as a general protective treatment. In this article recommendations for thickness of deposits are given, together with some suggestions on design of the contact elements to achieve long life and consistent performance.

The extensive use of radio as a navigational aid has resulted in the employment of higher and higher frequencies or, in the more usual phrase, of shorter wave lengths. At these high frequencies, corresponding with only centimetric wave lengths, it is no longer possible to employ normal types of circuits consisting of coils and capacitors, and use must be made of co-axial conductors or lines, generally fabricated from rigid tubular members. These co-axial circuits are displaced by wave guide elements only at still higher frequencies.

In co-axial circuits the electrical parameters are established by the mechanical dimensions and by the electrical conductivity of the current-carrying surfaces. The dimensions of the circuit—either the internal volume of a cavity or the actual electrical length of a co-axial line—frequently have to be adjustable, and this adjustment is usually achieved either by having a section of the line made telescopic in form, or by arranging movable contact elements which short the inner member of the co-axial line to the outer.

While such mechanical assemblies offer few problems in the experimental or laboratory stages, they can present major design problems in apparatus subjected to continuous use and to atmospheric conditions which can frequently be corrosive. Successful operation is critically dependent on the stability of electrical contact performance and on freedom from fluctuations of contact resistance during the adjustment of the apparatus.

It is well known that at high frequencies substantially all the current flowing in a circuit is confined to the surfaces of the conductors. In the case of a co-axial line, therefore, practically all the current flows on the outside of the inner conductor and on the inside of the outer one. In resonant circuits having a high Q value the magnitude of the current can, of course, be high, and the losses in the circuit can also be high if the current-carrying surfaces are insufficiently good conductors. The Q value of any resonant coil or line is inversely proportional to the circuit resistance and it follows that for the highest value of Q the total circuit losses must be reduced to a minimum. By far the greatest loss in a well-designed resonant line is resistive, and it becomes necessary to employ high conductivity current-carrying surfaces.

The obvious choice for these surfaces is silver, and the most usual procedure is to electrodeposit the silver on to a suitable base metal assembly. Care must be taken, however, to ensure that the deposit is hard, of fine grain, and of a type giving a low radio-frequency resistance. The thickness of the silver electrodeposit is in practice not unduly critical. A thickness of 0.0005 inch (12.5 μ) is generally adequate for radio-frequency purposes, although thicker deposits are often used as a means of obtaining added protection in corrosive atmospheres.

Silver having been chosen as a surface conductor on purely electro-technical grounds, it now becomes necessary to ensure its suitability in practice, and two difficulties emerge. First, silver, while not subject to oxidation, is readily tarnished by sulphur compounds and is attacked by salt spray or sea water immersion. Thus it becomes necessary to give the silver a protective coating which will not adversely affect the radio-frequency performance.

Secondly, while silver-to-silver forms an excellent contact combination from an electrical point of view, the rubbing or sliding of two silver surfaces can lead to galling and rapid self-destruction of the surfaces. Indeed, the mutual sliding of two clean silver surfaces can lead to partial cold welding. Here again, there is need of a further surface treatment to overcome the mechanical difficulties and to provide two contact surfaces which remain electrically clean and undamaged throughout their life.

A very thin electrodeposit of rhodium on to the silver surfaces can meet all these requirements, provided that certain factors are borne in mind when designing the apparatus.

Freedom from Oxidation and Tarnish

Rhodium, one of the six metals of the platinum group, is a very hard, white metal, entirely free from oxidation or tarnish, and possessing remarkable resistance to wear. Certain of its physical properties are given in the table below. Its complete freedom from film formation makes rhodium an excellent contact material where there is no appreciable voltage, and provides a very stable, as well as a low, contact resistance. Some indication of the order of contact

Properties of Rhodium

Specific gravity	**12.4**
Melting point, °C	**1960**
Thermal conductivity, *C.G.S. units*	**0.36**
Resistivity, *microhms per cm cube at 20° C*	**4.7**
Temperature coefficient of resistance (0 *to* 100° C) *per* °C	**0.0046**
Thermal e.m.f. against platinum, (0 *to* 100° C) *microvolt per* °C	**7.0**
Vickers hardness (*electrodeposited*)	**800**

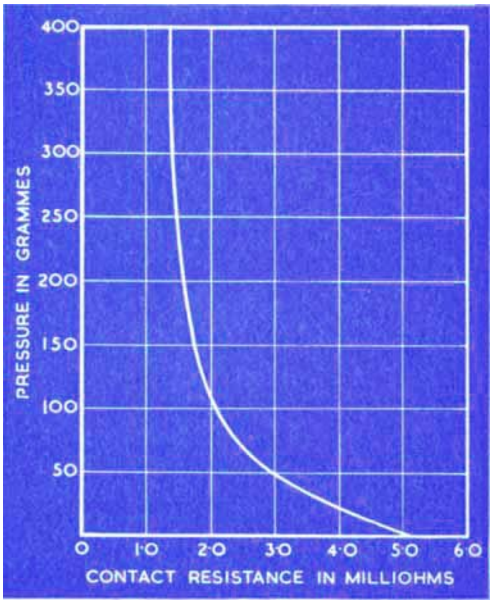

Fig. 1—Effect of increasing pressure on the contact resistance of electrodeposited rhodium

resistances obtained with electrodeposited rhodium is given in Fig. 1, which shows a series of determinations, employing point contact, in which variations in contact pressure from 1 to 400 grams produced a change in contact resistance of only 5.0 to 1.4 milliohms.

For purposes of clarifying the two problems, that of protection and of contact performance, they will be treated separately although they are, of course, intimately related.

Protection of Silver Surfaces

The simple protection of silver surfaces against tarnish and discoloration due to handling is readily achieved by depositing a very thin film of rhodium, and practice has shown that for extended exposure to industrial atmospheres a rhodium thickness of 0.000015 inch (0.375 μ) should be regarded as a minimum, although 0.00002 inch (0.5 μ) is more usually employed. If, however, the components are liable to be subjected to much heavier attack, such as for instance by salt spray, somewhat heavier rhodium deposits are necessary, and in extreme cases heavier silver underlays are desirable.

The electrodeposition of rhodium should follow as soon as possible after the deposition of the silver undercoat, and it is usual to silver and rhodium plate the whole of a radio-frequency component in addition to the current-carrying surfaces.

Provision of Sliding Contact Surfaces

Under certain conditions, electrodeposited rhodium can give exceptionally satisfactory electrical performance for long periods of use, but, as stated previously, for the best results certain factors must be considered in the design of the circuit components.

It must be realised that electrodeposited rhodium has a hardness of around 800 VPN, and that the deposit usually has little thickness. In view of this great hardness compared with any of the usual base metals, and in particular with the silver undercoat (which normally has a hardness of 100 VPN), care must be taken to avoid high point-loading of the rhodium film. Excessive loading of this sort will fracture the rhodium deposit, exposing sharp cutting edges which will rapidly destroy both rhodium and silver deposits. (The effect may be admirably demonstrated by pressing a marble into the sugar icing of a cake). Fortunately this situation can be avoided by maintaining the radius of contact zones sufficiently large, by applying contact pressures by means of low-rate spring elements, and by reducing contact pressures.

The last statement would appear to be contrary to normal practice where good contact performance is demanded, but it must be remembered that rhodium is completely free from tarnish or other films, and that the contact resistance between two rhodium plated surfaces is reaching its stable value with pressures of 50 to 100 grams (Fig. 1). A typical resistance value at the latter pressure would be approximately

0.002 ohm. Bearing in mind that for sliding contact surfaces the rhodium deposit is heavier than previously specified for protection, the pressures indicated above can safely be used without incurring damage.

For a multi-fingered sliding "short" for a co-axial line the desirable thickness of rhodium will, of course, be dependent on the anticipated life and frequency of sliding. For the surface of the lines deposits of 0.0002 inch (5 μ) to 0.0005 inch (12.5 μ) thickness are normal, while the tips of the contact fingers, which get the greatest wear, may have a deposit as thick as 0.001 inch (25 μ). Deposits in excess of 0.001 inch are seldom used owing to the difficulty of maintaining a bright smooth surface.

As a measure of economy it is customary to increase the thickness of the rhodium only over those areas where sliding contact takes place, the remainder of the surfaces being given the protective treatment already discussed.

Design Considerations

To attempt to deal with the design considerations for all types of co-axial line components would be far too complex and lengthy a matter, and it is proposed to consider by way of example a typical shorting assembly as manufactured by two alternative methods. The various design points dealt with will be applicable to other types of components, and should form a sound basis for sliding contact design.

In that class of apparatus where stability and performance are paramount, ease of manufacture and cost being of secondary importance, the sliding shorts or "top hats" are usually machined from the solid or fabricated from tubular elements in phosphor-bronze or beryllium-copper. The general appearance of these parts is as shown in Fig. 2, in which a section view of one half of a shorting bridge is given.

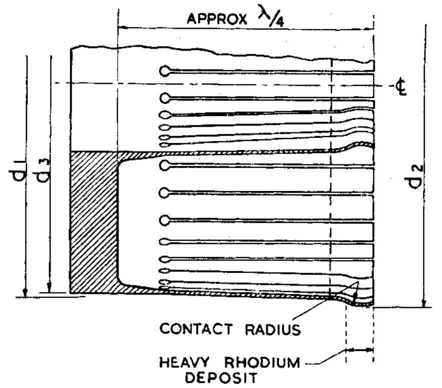

Fig. 2—A section of one half of a typical shorting bridge

d_1 Internal diameter of outer co-axial tube

d_2 Diameter of unloaded contact fingers

d_3 Base diameter of "top hat"

It will be noted that the walls of the components have been thinned down over substantially their full length so that each finger of the contact has adequate flexibility, independent of the neighbouring fingers, to give the desired contact pressure, and for this pressure to be only slightly modified by variation of finger deflection. In other words the fingers have a long-law characteristic.

(The appendix gives the well known formulae for calculating deflection and stress in flat cantilever springs, which are sufficiently close approximations to the separate finger springs under discussion.)

The diameter of the top hat is greatest at the contact end by such an amount that insertion into the outer tubular member of the line will produce the desired individual contact finger deflection. The base end of the assembly is somewhat less in diameter than the bore of the outer tube. Under these conditions slight variation of tube diameter or slight irregularity of shape or alignment of the top hat operating mechanism will produce substantially no variation in contact pressure.

Having established the conditions of contact pressure, it is now necessary to consider the shape of the contact surfaces. There are three design factors to be considered in this connection. First, where two

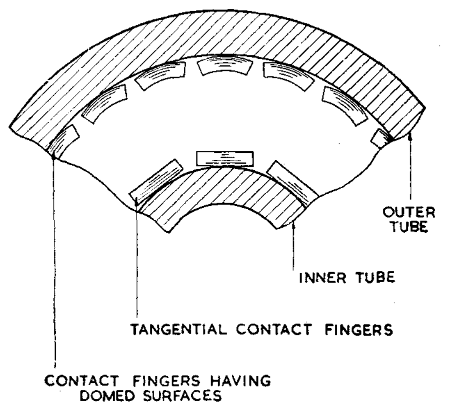

Fig. 3—Contact areas of the springs bearing on the inner surface of a co-axial line should be shaped in both axial and circumferential directions

rhodium plated surfaces are in rubbing contact it is always desirable for one of these contacts, in this case the finger contacts, to be dome shaped, but the radius of doming must be large. A small dome will lead to rapid wear owing to scoring of the surfaces by the cutting edge formed as the contact zone wears. Typical minimum radii are usually of the order of 0.125 inch (3 to 4 mm).

Secondly, reference to Fig. 3 will show the necessity of shaping the contact areas of the springs in both axial and circumferential senses where these springs bear on the inside of a tubular line. Insufficient care in achieving such a form will lead to very rapid scoring and to failure of the contact surfaces. In the case of contacts bearing on the outer surfaces of lines there is, of course, no problem, as a cylindrical contact surface lies with its axis tangential to the tubular member.

It might seem that the various simple design factors mentioned above are unnecessarily elaborate and represent a penalty to be paid when using rhodium contact surfaces. This is not so, as all the points mentioned are valid whatever contact material is used, and only represent good design. It is true, however, that failure to observe these points will nullify the very considerable advantages offered by rhodium contact surfaces in the type of apparatus under discussion.

Thirdly, it is obviously desirable in precision apparatus to have the point of contact to the co-axial line as near as possible to the tips of the contact fingers, for it is here that the current path suffers a discontinuity in passing from the co-axial surface to the inner surface of the top hat. It will be seen in Fig. 2 that the lengths of the top hat fingers are made to approximate to $\lambda/4$, or of course to $N\lambda/4$ where N is odd, as at these points in a resonant line the current flowing is a minimum. Frequently it is not possible to achieve a full quarter-wave in the top hat, but there is real advantage in approaching as near the quarter-wave length as possible.

The choice of the number of fingers to

Design Formulæ

The well-known formulæ for deflection and stress in simple flat springs of rectangular cross-section, clamped at one end, are as follows:

$$\delta = \frac{4\,P\,l^3}{E\,b\,t^3} \quad \text{and} \quad f = \frac{6\,P\,l}{b\,t^2}$$

where δ = deflection in inches
P = load in pounds
l = length in inches
E = Young's modulus in pounds per sq. in.
b = width in inches
t = thickness in inches
f = working stress in pounds per sq. in., normally approximately 75 per cent of proof stress (0.1 per cent extension)

The following values for Young's modulus and for proof stress may be considered typical:

Beryllium-copper	E	= 18×10^6 pounds per sq. in.
(heat treated)	Proof stress	= 150×10^3 pounds per sq. in.
Phosphor bronze	E	= 16×10^6 pounds per sq. in.
(BS 407/2—Hard)	Proof stress	= 62×10^3 pounds per sq. in.

be used will, of course, depend on the dimensions of the lines in question. For very small diameter lines only a few contact fingers are possible by virtue of the small physical dimensions. It is, however, always desirable to keep the number of contacts large so as to obtain stability of contact performance, and more important still to ensure, as nearly as possible, continuity of the skin current sheet and freedom from excitation of the back end of the line.

As a guide, a line of 1 inch diameter (25 mm) will usually have some 30 fingers, correspondingly more being used for larger diameters.

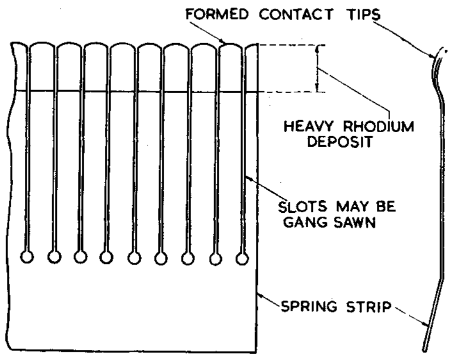

Fig. 4—Method of fabricating sliding members from strip material

Quantity Production

In the less critical type of apparatus, and where quantities demand a simplified manufacturing technique, it is now common practice to fabricate sliding shorts from strips of spring material, pre-slotted, formed, electroplated, polished, and finally wrapped round and soldered to a solid back plate.

The general principle is self-explanatory and is illustrated in Fig. 4. The fact that the diameter on which the spring strip is wrapped may be such that there is not an integral number of fingers round the circumference is of little importance, provided that the fingers are small in width, as a gap between the ends of the strip of half-a-finger width has little or no effect on performance.

The advantages of this method of construction are obvious, as the forming, slotting, plating and polishing processes are carried out while the material is in the flat state, thus simplifying handling problems.

It is customary to silver plate the strip all over its surface, but to restrict rhodium plating to the spring fingers only, and to restrict the heavy rhodium to the spring finger contact areas.

Electrodeposition of Ruthenium

Very little work has been carried out on the electrodeposition of ruthenium although it is known that deposits have been obtained from dilute solutions of ruthenium nitroso salts. An investigation recently completed at the Atomic Energy Research Establishment, Harwell, by A. C. Littlejohn (A.E.R.E. C/R 1892, 1956) shows that, under certain conditions, uniform deposits of ruthenium may be obtained on copper cathodes from solutions of ruthenium nitroso trichloride in dilute hydrochloric acid.

Numerous runs were carried out, using a platinum anode, at constant potential, but it was found in all cases that once an initial coating of ruthenium had been deposited at low current density, the current gradually increased to very high values and brittle deposits were obtained. Constant potential electrolysis was therefore dropped in favour of constant current electrolysis. In these experiments current densities up to 20 mA/cm^2 were used, and the deposits were considerably improved.

Conditions finally recommended for successful deposition include a solution of 5×10^{-3} M $Ru(NO)Cl_3$ + 0.5N HCl, and a current density between 2 and 5 mA/cm^2.