MODERN CIRCUIT TECHNOLOGY

Metal Finishing Processes in Printed Circuits and Electronic Assemblies

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By W. Macleod Ross

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Foreword

Foreword

THE first edition of this book was produced by a series of happy coincidences, leading to a team of authors, all members of the Printed Circuit Group of the Institute of Metal Finishing, contributing their expertise to its compilation.

The success of the book is not surprising when it is remembered that, although a wealth of information is published in Journals throughout the world, there is little collated information on the applications of the metal finishing arts and sciences to the production of electronics equipments.

In considering the production of a second edition, three points had to be considered. Firstly, the electronics industry is still moving ahead very rapidly and considerable updating is essential in any book on this subject to keep abreast of developments. Secondly, the first edition was in essence a collection of articles by different experts and, in consequence, there was some duplication in the chapters. Thirdly, although the scope of the first edition was somewhat larger than the original conception, there were still areas not adequately covered.

For these reasons this edition has been completely revised and is presented in discrete and reasonably self-contained sections. It is believed that this presentation will benefit both the reader who is seeking information and he who reads for pleasure. A great deal of new material has been added, much of which has not been published elsewhere.

Breakdown of some of the articles has meant that it is no longer practicable to head each chapter by the author's name. For that reason I would like here to acknowledge the contributions made by the following to the chapters noted:

R. D. Jones, C.Eng., F.I.E.E.	Chapters 2 and 21
R. Carrington, C.Eng.M.I.E.E., M.I.Prod.E.	Chapter 4
P. Millett, F.I.M.F., M.B.I.M., A.I.R.T.	Chapter 6
J. J. Butler, A.R.P.S., A.M.I.O.P.	Chapter 7
G. C. Wilson, F.I.M.F.	Chapters 10, 11 and 24
R. H. C. Lee	Chapters 10 and 24
C. J. Thwaites, M.Sc., A.R.S.M., F.I.M., F.I.M.E.	Chapter 18
V. W. Locke	Chapter 20
P. G. Vivian, F.I.M.F.	Chapter 23
G. D. R. Jarrett, A.I.M.F., M.B.I.M., A.I.Corr.T	Chapters 23 and 27
G. S. Strickland	Chapters 24 and 25
A. A. Ward, M.S.E.E., A.I.M.F.	Chapter 29
H. G. Manfield	Chapter 30

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W. MacLeod Ross, B.Sc., T.Eng., F.I.M.F., F.I.Corr.T., F.I.Q.A.

PART ONE

GENERAL

Metal Finishing Processes in Printed Circuits and Electronics Assemblies

CHAPTER 1

An Introduction to Electronic Assemblies and Metal Finishing

JUST WHEN 'electronics' became household terminology is obscure. The 'black box' was commonplace at the beginning of World War Two, when scientists with mysterious devices began to appear in the Armed Services to provide new methods of detecting enemy ships, submarines, and aircraft. However, electronic equipments were in the home and in industry many years before. The foundation stone of modern electronic circuitry, the semiconductor, appeared in the first crystal radio sets although many years passed before any real attempts were made to understand fully their unique properties.

Electronic assemblies and equipments now take many forms and industry as a whole depends upon the ingenuity of the electronics industry for essential controls. The range of equipments covers a size spectrum from miniature hearing aids (and 'bugging' devices!) to the most complex data processing and storage equipment occupying thousands of square feet. The common factor is that they perform their functions by the manipulation of electrons. Each consists of a circuit, or series of circuits, which by transmitting, receiving, modifying, or storing, the energy derived from the movement of electrons produces a pulse of energy, an audible or visual signal, a motion, or just a memory.

Some of the applications of the metal finishing arts and sciences in these equipments are immediately obvious. The glossy polyester or urethane finish on a television receiver, the chromium-plated plastics knob on a transistor radio, the black crackle finish on a transmitter illustrate the outward decorative and protective finishes which are easily seen manifestations of the metal finishing trades involvement with the electronics industry. It is, however, inside the case that the real contribution becomes apparent. Just as the metal finishing industry depends upon the electronics industry to provide control gear and other vital equipment, so does the electronics industry depend upon metal finishing expertise for a very large proportion of its basic techniques. No modern circuit could be produced in its present form without the application of or extension of a metal finishing technique. For example, printed circuits and microelectronic circuits are produced by highly developed forms of the crafts originating in the printing, engraving, and allied trades.

To understand the special needs of the electronics industry with respect to metal finishing, it is useful to have some very basic knowledge of the materials employed. It can be readily appreciated that all circuits are made up from 'active' devices, which give gain control and are typified by valves, transistors, and ferromagnetic pot cores, and from 'passive' elements such as capacitors, resistors, and conductors. These in turn are fabricated from three broad classes of material—conductors, semi-conductors and insulators. It must be appreciated by the metal finisher working for the electronics industry that the division between these three classes is not an absolute one and that the properties of a given material can be modified inadvertently by misapplication of a process or by insufficient attention to cleanliness, purity, or even temperature. It is well known that the conductivity of an electrodeposited metal is less than that of the same basic metal in cast or wrought form: a single crystal metal of very high purity has a conductivity which is higher than that normally found: an insulator which has a very low conductivity even when damp may develop current leakage paths when the surface is handled.

Conduction

Conduction takes place in two ways. The first is electrolytic or ionic conduction and is well-known to the plating chemist. It is always associated with the movement of ions and with chemical electrode reactions. Therefore, it should be obvious that contamination of an insulator by polar or ionisable matter will produce conduction in the presence of an applied potential and will probably produce migration and corrosion. It is usual to select as insulating materials those which are essentially non-polar. In addition, as high dielectric constants increase ionic conduction by reducing the energy needed to produce ionisation it is normal to select materials of low dielectric constant (compatible with circuit needs). The introduction of polar material at any stage during manufacture and use can nullify the circuit designer's efforts.

The second form of conduction, and that most important to the electronic circuit, is conduction by electrons. A simple view of the atom sees a central nucleus around which rotate electrons. The nucleus contains positively charged protons and the electrons are negatively charged, the electron charge being equal and opposite to that of one proton. In a neutral atom, there will be as many electrons orbiting around the nucleus as there are protons in the nucleus. The electrons are not free to assume any orbit they choose around the nucleus but must normally inhabit specific orbits or shells. In addition, as each electron must be unique, only a certain number of electrons can occupy a given shell. The total number of shells and of electrons vary with the size of the atom but in all cases only those electrons in the outer shells which determine the valency of the atom can, under certain circumstances, be dislodged from the valence shell and become free. A free electron will carry one unit of current by moving under an applied potential. This current is naturally negative and the positive countercurrent is carried by the holes left in the valence shell by the removal of the electron. (If an electron is removed from a neutral atom a net positive charge remains.)

The number of free electrons or the energy required to free an electron determines whether the material is a conductor, a semiconductor, or an insulator. The band theory, of great importance in the semiconductor world, visualises the energy required to create free electrons as the difference between two energy bands—the conduction band and the valence band. Most metals have these bands overlapping and conduction is readily achieved at low electrical potentials. Insulators have a finite and high difference in the energy of these bands and the voltage needed to make an electron jump this 'forbidden gap' will be high. In other words insulators are characterised by a scarcity of free electrons and while they will conduct current when subjected to voltages the currents are relatively minute and require high voltages to produce them. That is, insulators must be viewed as conductors of very high resistivity. The resistivity is such that the current may be neglected for power equipment but it can be of critical importance in electronic equipment. Intermediate betweeen insulators and conductors lie the semiconductors. With semiconductors the forbidden gap is small and at absolute zero temperature an intrinsic semiconductor such as silicon or germanium (see Chapter 13) does not receive enough energy to permit electrons to jump the energy gap. If therefore all the electrons are in the valence shell or band at absolute zero the semiconductor will be an insulator. At normal temperatures the thermal energy available is sufficient to enable some of the electrons to enter the conduction band and conduction is possible.

It is important to remember that the difference between insulators and conductors is only one of degree. The band structure can be drastically altered by several influences. Large inputs of energy, thermal radiation, light, gamma radiation, and so on, can transfer electrons to the conduction band and reduce the resistivity; dislocations in crystal lattices or the presence of foreign atoms in a crystal will distort the band structure and alter the conductivity of metals; the inclusion of impurities in insulators or semiconductors can create local energy levels in the forbidden gap reducing the energy needed to produce free electrons and hence conduction. This last is readily illustrated by the deliberate addition of certain impurities or dopants to intrinsic semiconductors—one part of an appropriate impurity per million parts of pure semiconductor will increase the conductance seventy times. Band distortion can be employed to explain why copper or silver deposited from apparently identical solutions by two different suppliers can vary in conductance by factors greater than ten. To find the reason for the different results it is necessary to investigate the level of trace impurities, to examine the plating conditions very critically, and to evaluate the effects of pre- and post-plating treatments.

The foregoing may help to illustrate why the electronics industry must exercise more care than most in selecting and applying finishes and processes. While selection is often dictated as in other industries by mechanical and chemical properties, the electrical and physical behaviour of the material is usually more important. Another factor which must be considered in many cases is that mild corrosion which would be of no concern structurally may produce peculiar effects on an electronic component. A typical example is the choice of protective finish for a u.h.f. aerial. If the corrosion product formed is a semiconductor the aerial will soon be rendered ineffective.

Finishing Range

To illustrate the application of metal finishing techniques in the electronics industry, it is useful to examine some typical electronic modules in detail. Figure 1.1 shows the development which has taken place in the last few years in u.h.f./v.h.f. transmitting and receiving equipment. Both units provide communication and navigational facilities for military and civil aircraft. The advance in design and packaging techniques is well displayed by the difference in size. More important to the prospective user, the smaller equipment is an order of magnitude more reliable than the one which uses twice the power and occupies five times the space.

It is easy to look at the picture and assume that the collection of equipment on the left of the figure required more metal finishing than do the three boxes on the right. This is an erroneous concept. The volume is less and standard paints and metal deposits are needed in lesser amounts but without continuous advance in techniques of application and in knowledge of the properties required and obtained, the new equipment could not have been built in the form shown. The metal finishing sciences and arts are essential contributors to the new design philosophy.

Figures 1.2 to 1.5 show one of the more significant aspects—the confusion of wires often seen in older equipments has been replaced by a small number of harnesses connecting some of the parts inside the main case one to the other and to the external socket connections mounted on the case. Neat packages filling the internal space to the maximum effect are the order of the day. This is the age of maximum packaging density using modules, each performing a distinct function within the whole, which are fabricated with the aid of printed circuits, hybrid circuits or mixtures of thin film and thick film circuits with passive and active components bonded to the surface, and solid state circuits, or fully integrated circuits.

The backbone of the new technology is the printed circuit and much of the succeeding space in this book is devoted to describing the materials and techniques employed in their manufacture. Printed circuits have progressed from the early screen printed and etched patterns on phenolic impregnated paper (then of indifferent quality compared to the modern phenolic paper board) to fine line printed components, plated-through hole boards, edge-plated boards, and multilayer boards having multiple layers of circuitry in the same thickness as that which used to carry one layer on the surface. In many instances the materials employed as bases, for example silicone impregnated glass cloth laminates, are very easily damaged by processing solutions and the ingenuity of the metal finishing technician is stretched to find methods of cleaning, etching, and metallisation which do not

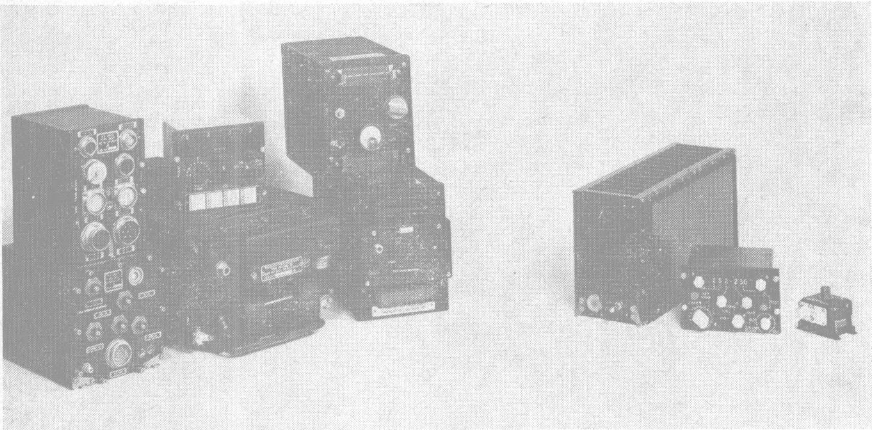

Fig. 1.1 The modern u.h.f./v.h.f. airborne radio transmitter/receiver on the right takes up less than a quarter of the volume and yet does much more than the equipment on the left, designed and built some twelve years previously.
(Courtesy Plessey Avionics and Communications)

degrade the laminate mechanically or produce unacceptable changes in the dielectric properties. Careful thought and experimental analysis is needed at each stage, whether the end product is a communications set for military and civil aircraft or a 'transistor' radio for the teenage market.

Many of the modules seen in the figures employ hybrid integrated circuits. These are essentially tiles of glass or ceramic on to which are deposited resistive and conductive patterns, either by high vacuum techniques or by screening mixtures of

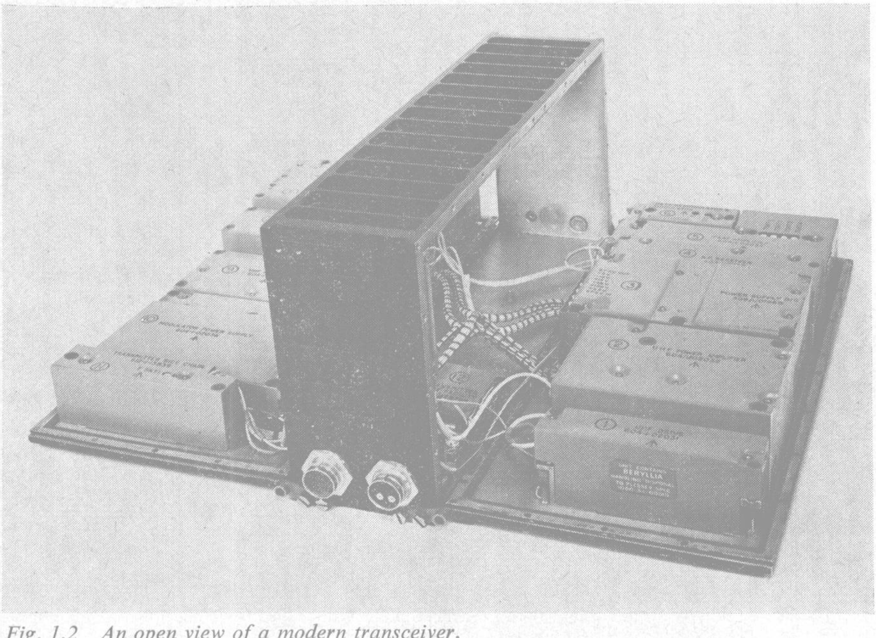

Fig. 1.2 An open view of a modern transceiver.
(Courtesy Plessey Avionics and Communications)

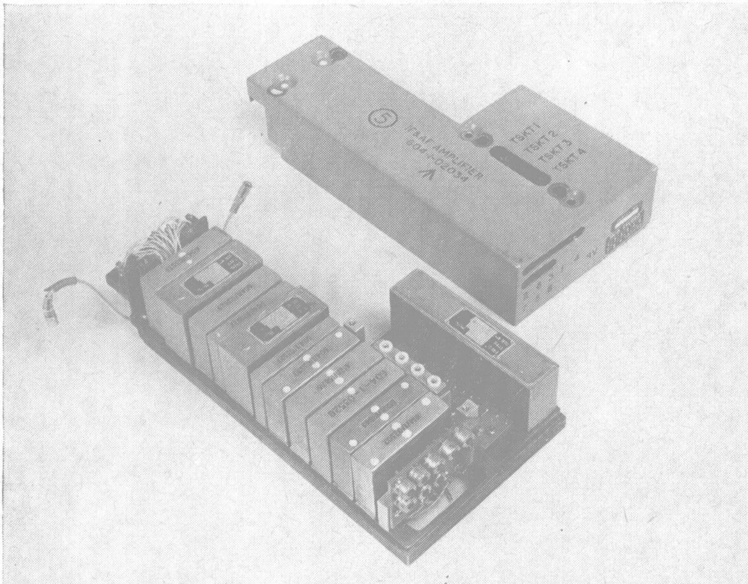

Fig. 1.3 An IF/AF amplifier. (*Courtesy Plessey Avionics and Communications*)

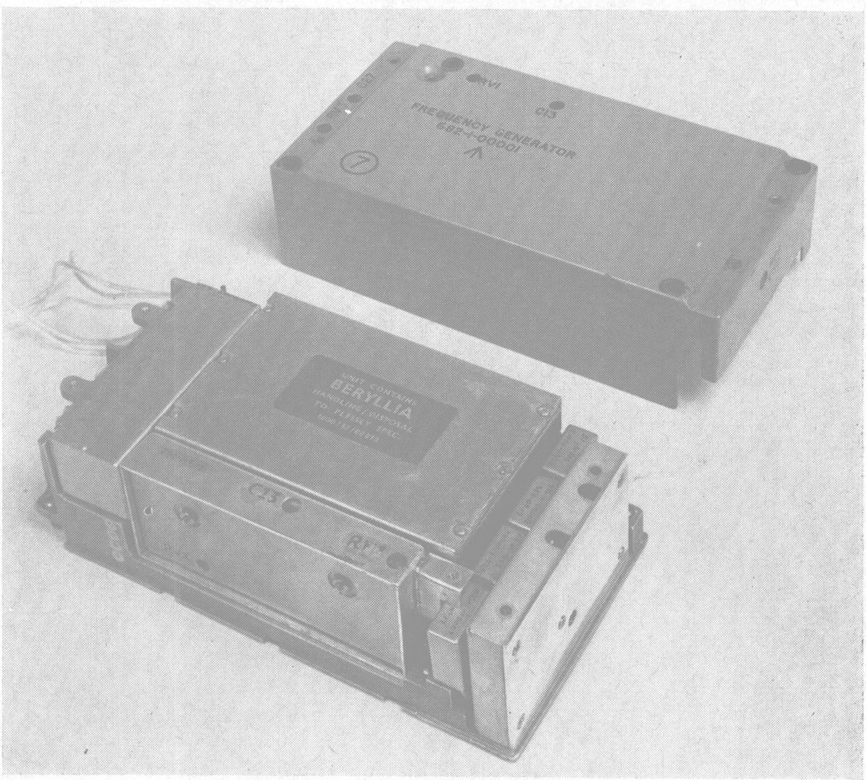

Fig. 1.4 A modern frequency generator for an airborne transceiver.
(*Courtesy Plessey Avionics and Communications*)

metals, oxides, and glasses on to the surfaces and firing to produce a bonded structure. Active components in the form of integrated circuit chips are then attached by various methods and connections made. In the revision of this book the opportunity has been taken to introduce a new section, Part Three, describing the basic methods of fabricating solid state circuits, thin film circuits, thick film circuits and hybrids. It will be seen that the essential operations are still developments from other branches of the metal finishing sciences, metallisation, production of surface coatings, and conversion coating, although it must not be assumed that a technologist in the 'macro' areas can step straight into the microminiature area without very thorough training and an appreciation of the scale reduction and its effects on the processes in terms of purity, cleanliness, and so on.

Hybrid and integrated circuits are seldom seen by the user of the equipment. Whereas the printed circuits are normally visible, see for example Figures 8.5, 8.6, and 8.7, the microminiature circuits are usually encased in plastics encapsulants or sealed into metal cans or boxes, such that all that is visible is a small package with wires or pins protruding to which connection is made.

The conventional aspects of metal finishing may be seen on chassis parts, connector blocks, cases, and the like. In Figure 1.3 the chassis is fabricated from an aluminium casting. Aluminium has several advantages for electronic mounting. Castings may be made to close tolerances, minimising machining; the resultant part is both strong and light; thermal conductivity is high, an important consideration when packing density is high and there is a need to dissipate excess heat generated by the circuitry quickly and uniformly; finally a thin anodic film on an aluminium surface is a good insulator, or more correctly, a bad conductor of electricity. It would appear then that aluminium is an ideal alloy for many uses and that the

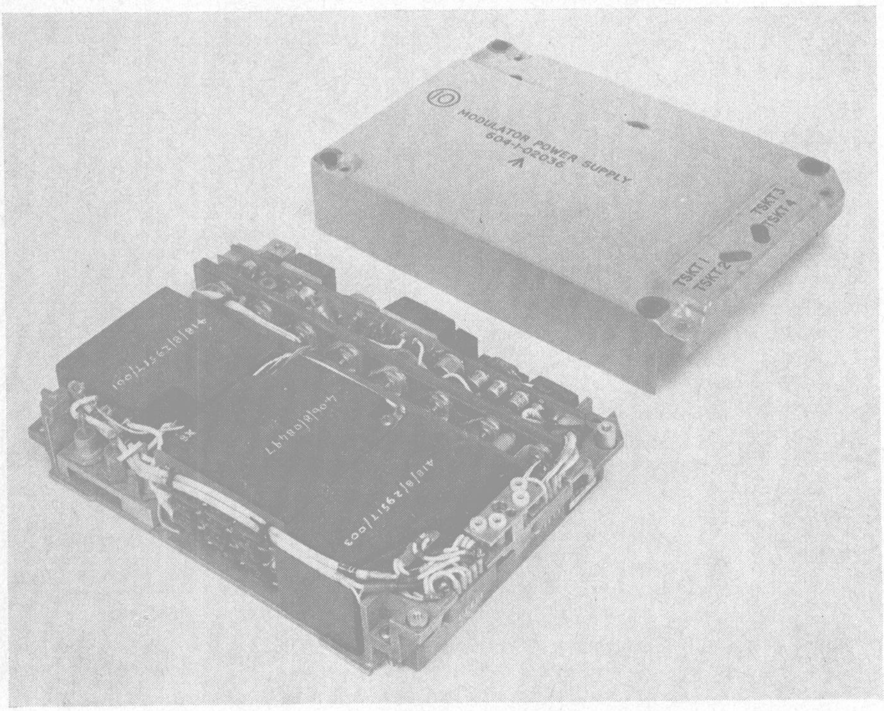

Fig. 1.5 The modulator power supply unit for the equipment on the right of Fig. 1.1.
(Courtesy Plessey Avionics and Communications)