Source: Sound and Vision - Spring 1966

E. O. HOLLAND and Miss P. R. K. CHAPMAN

THIN-FILM CIRCUIT MODULES

One of the questions most likely to be asked about the new Mark VII colour camera is, "What are thin-film circuits, how are they made and why are they being used in the camera?'

Thin films are one of the most modern ways of manufacturing electronic circuits. They consist of thin but very robust precision metal films, deposited on to an extremely high-grade glass substrate, to form the passive elements of a circuit to which transistors and diodes are added. The method of manufacture of thin films chosen provides that the passive circuit is completely processed in vacuum, to the point of being provided with a protective coating before it is released to air.

Early in 1961, an investigation into the different types of microelectronics was started in order to assess whether any benefits could be derived by their use in the specialized field of television cameras and studio equipment. It was decided that although silicon-integrated circuits would have their place in new designs, thin-film circuits would be much more suitable for general use.

BASIC REQUIREMENTS OF TV EQUIPMENT

Stability

It is desirable that a colour channel, set up for optimum performance, will remain constant for a long period without needing adjustment. This trend in design was first set by the Mark IV camera, followed by the improved Mark V and considered absolutely necessary for the colour camera chain. Additionally, it is necessary for the equipment to work over an ambient temperature range of −10°C to +40°C with the circuit performance remaining inside the specification. Also the characteristics of the components forming the circuits should not change appreciably during the working life of the camera.

Reliability

As circuitry becomes more complex the reliability factor becomes increasingly important. Added reliability is generally achieved by using improved components, reducing the number of joints or interface surfaces, which can cause noise or intermittent electrical conductivity, improving manufacturing methods and materials, and increasing the robustness of the components.

Repeatability

It is very important that the circuit should be repeatable and maintained to within close limits, so that the performance between the colour channels is as far as possible identical and remains unchanged during the life of the camera. The decision to incorporate thin-film circuit modules in the colour camera became essential after the introduction of more stringent specifications required as a result of colour television.

The key requirement for colour television equipment can be summarized as follows

1. By achieving a life stability of better than 0·2% and very high stability over a wide temperature range the thin-film circuit has made a major contribution to the great stability of the Mark VII camera.
2. A substantial reduction in the number of joints, as compared with the conventional methods of assembly, automatically increased the degree of reliability.
3. The unique method of manufacture adopted, allowing all passive components to be made simultaneously, has resulted in new standards of matched performance previously impossible to achieve.
4. Performance figures between modules shows a very high degree of repeatability, while as a step towards ease of maintenance only 9 types are included amongst the 67 modules employed in the colour camera chain. Fault-finding is restricted to localizing faults to the circuit block.
5. The Mark VII colour television camera is similar in size to the monochrome camera which would not have been possible if conventional components had been used.
6. The ultra-clean manufacturing process also assists in promoting a high degree of reliability.

PREPARATION OF THE THIN-FILM CIRCUITS

It was determined from the initial development programme that nichrome should be used for the resistance elements, nichrome-gold for interconnections, aluminium for capacitance electrodes and silicon oxide for the capacitance dielectric. These are all materials with excellent electrical characteristics, giving a very useful range of values for the components. The materials are deposited on special boro-silicate glass measuring 1½ in.×1 in. in a high-vacuum chamber at a temperature in excess of 250°C. Glass is used as the substrate material in preference to a ceramic because of its better surface finish. To obtain the correct resistance values without adjustment, the surface of the substrate must be very flat and free from defects, and so far no ceramic has been found with a surface as good as micro-sheet glass. As is known, the heat dissipation of ceramics is generally better than that of glass but this has not been found to limit the applications.

The active devices are then soldered on with any components outside the range of obtainable values. The substrate is fitted into a metal can with a base with 15 lead-outs suitable for insertion into a printed wiring board.

The first stage in the making of a thin-film circuit is the designing of the 'photomaster', that is, the pattern which the resistors, capacitors and interconnections will take. This stage is prepared directly from the circuit diagram (Fig. 2) and is made ten times full size to improve the dimensional accuracy and ease of checking. Charts have been calculated for resistance elements to the required sheet resistivity, which give the length and width of the elements for the resistance values at different wattage ratings. Similar charts have also been made to give the area of overlap of the capacitor electrodes. The component elements are cut to size from self-adhesive tapes, which are then moved around on a sheet of plastic with the substrate dimensions marked on it until a suitable layout is obtained. The elements are then fitted with end terminations and the layout checked. This is the first stage of the layout which gives all the layers of the 'thin films' simultaneously. The individual layers of resistors, conductors, etc. are now separated by translating each onto a special material, using a very accurate cutting table. Each of these layers is accurately reduced by ten times on to a stable film.

There are several methods of making thin-film circuits from the photomaster patterns and some examples are as follows:

Selective Etching is a method where the substrate is coated with a monitored layer of nichrome and a thicker layer of gold. The gold is first etched to form the interconnection pattern with an etchant that does not attack the nichrome. Another etchant which does not attack the gold is then used to etch the nichrome to the resistance-element pattern. The acid-resist pattern is formed by a photo-lithographic process, requiring additional processing and handling.

The In-Contact Mask method consists of coating the

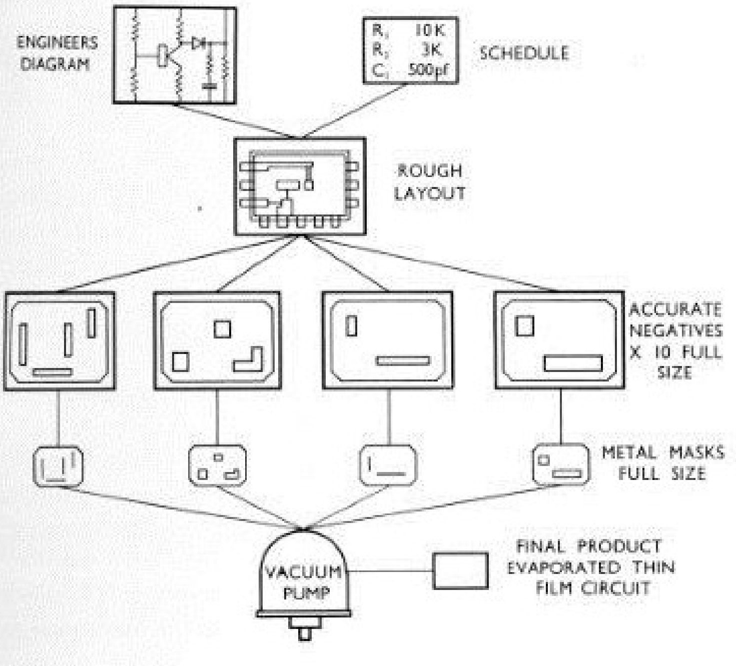


Fig. 1. The stages of construction of thin-film circuits.

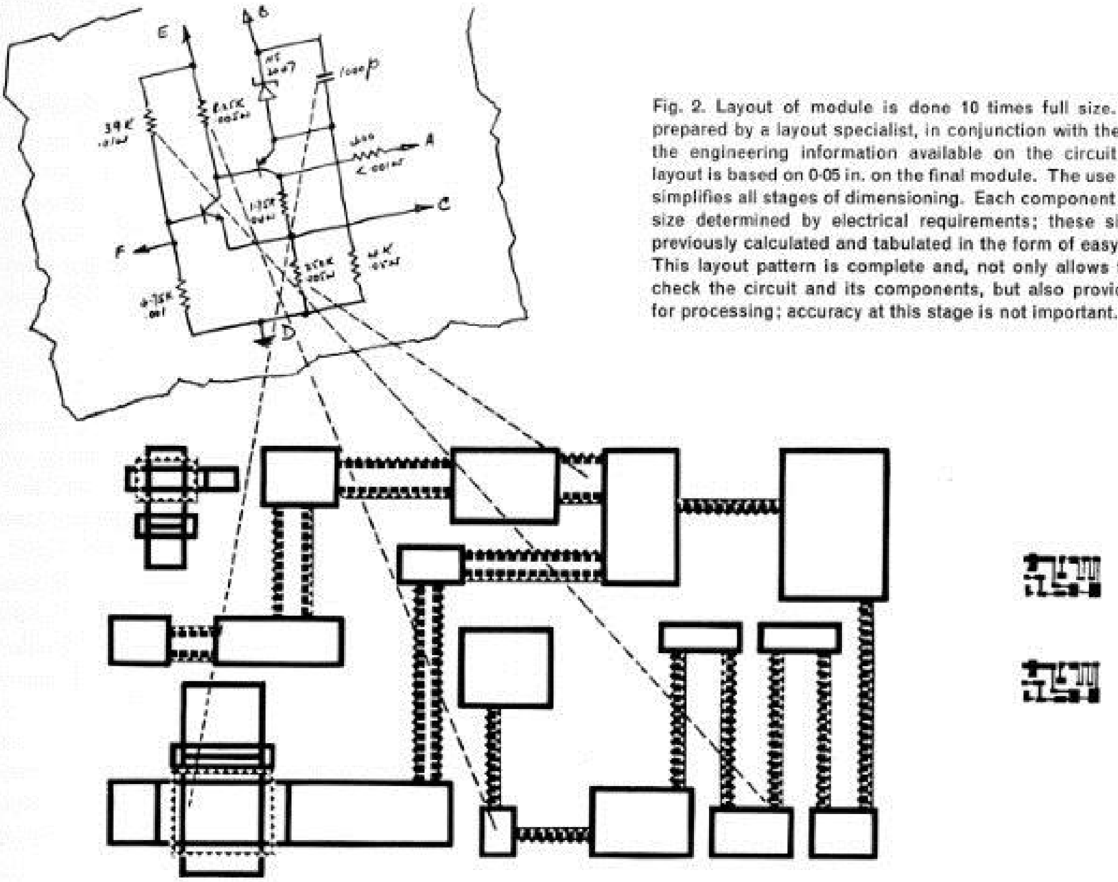


Fig. 2. Layout of module is done 10 times full size. This layout is prepared by a layout specialist, in conjunction with the engineer, from the engineering information available on the circuit diagram. The layout is based on 0·05 in. on the final module. The use of a grid greatly simplifies all stages of dimensioning. Each component has its physical size determined by electrical requirements; these sizes have been previously calculated and tabulated in the form of easy-to-read charts. This layout pattern is complete and, not only allows the engineer to check the circuit and its components, but also provides information for processing; accuracy at this stage is not important.

substrate with copper and etching away the resistor pattern. A monitored layer of nichrome is then evaporated over the substrate. It is re-etched to remove the copper mask with its overlay of nichrome, leaving nichrome in the required resistance-element pattern. This process is then repeated for interconnection pattern, but using a photo-sensitive resist for the mask and gold for the coating.

Discrete Metal Masks are made by etching a thin metal sheet (0·002 in.–0·006 in. thick) usually copper or stainless steel. A mask is made for each stage of evaporation and to obtain the best results they are etched from both sides. When the mask has been accurately measured it is put in close contact with the substrate inside the vacuum chamber, and the metal or dielectric is evaporated through it, to form the required pattern.

The first two methods described suffer from the hazards of a considerable amount of handling, together with the etching of metals in strong acid solutions. This combination could lead to a poor product.

The last, namely the out-of-contact mask method, was chosen as the most likely system to produce products of quality and reliability, and to this end a turret mechanism was designed to produce a number of circuits simultaneously in one vacuum cycle (Fig. 3).

This method was chosen because it has several distinct advantages over the other approaches:

1. Perfect cleanness of the substrate throughout the process.

2. Deposition of all the metals and dielectrics in quick succession are carried out in high vacuum at high temperature.

3. Circuit substrate is protected by a robust layer of silicon oxide, before air is admitted to the vacuum chamber.

4. Superior electrical characteristics of the components, due to deposition under controlled conditions in vacuum.

The Processing Equipment

The substrate cleaning and inspection apparatus, together with the vacuum chamber, are housed in a clean-air cabinet (Fig. 4). This has an electrostatic air filter which removes dust particles greater than 0·01 micron from the air. The substrate, which is finally cleaned by ionic bombardment in vacuum, retains its perfect cleanness throughout the whole of the process.

The turret has six positions, each being dowelled, relative to the plate holding the substrates. The individual masks have dowel location to the turret plate so that the substrate is accurately positioned at each stage relative to the relevant mask. The rotation of the turret and the positioning are carried out during the vacuum process without the need to admit air. A number of circuits are processed together, and these can be similar or completely different.

The turret assembly includes a number of other devices such as a resistor, which monitors the value of the metal film being deposited and which also operates an automatic shutter when the correct value has been reached. The assembly also makes use of electrodes to produce ionization, a film-thickness monitoring device, a shutter operated by push-buttons, thermocouples for measurement of substrate temperature and a radiant heater for heating the substrate.

Several advantages have been observed during the development of the circuits. It was found that if silicon oxide was put over the resistance elements under controlled conditions, the temperature coefficient of the resistors could be centred around 0 ±10 parts per 10^6 per °C with a considerable improvement in the stability of the resistors. Silicon oxide is used both as dielectric material and as a protection for the capacitors.

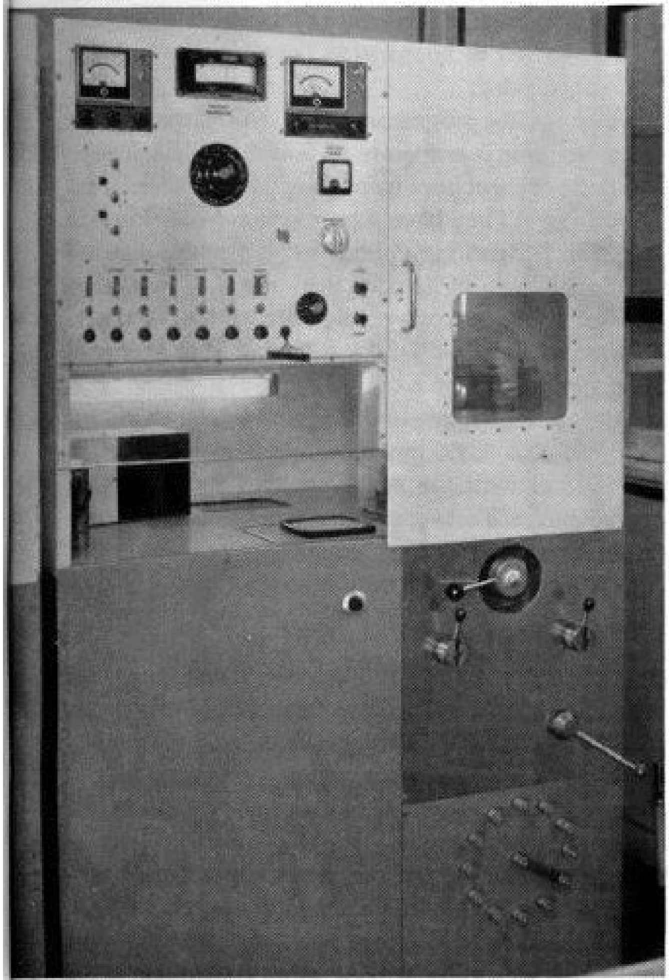


Fig. 4. The substrate and cleaning inspection apparatus together with a vacuum chamber housed in a clean-air cabinet with an electrostatic air filter.

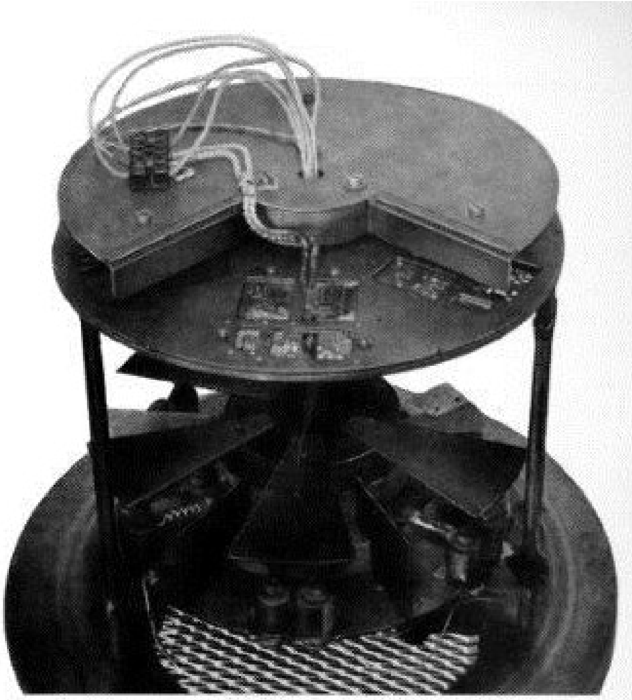


Fig. 3. A conventional turret mechanism capable of producing a number of circuits simultaneously in a one cycle vacuum.

MANUFACTURE

In the manufacture of thin-film circuits there are the following major processes.

Substrates are chemically cleaned and inspected in the clean-air cabinet and then put into the vacuum chamber, which has been previously set up for evaporation. When the pressure has reached about 20 microns the substrates are given a final cleaning by ionic bombardment, and when the evaporation pressure is reached the substrates are heated to a temperature in excess of 250°C.

The materials are then evaporated through their appropriate masks in the following sequence

(a) Resistors
(b) Interconnections
(c) Lower electrodes of capacitors
(d) Dielectric and protection for resistors
(e) Upper electrodes of capacitors
(f) Protection for the capacitors.

Air is then let into the vacuum chamber, and the substrates removed, placed in an oven, aged and annealed, after which the components values are measured.

The transistors, diodes, etc. are soldered onto the substrate and this assembly is fitted to the base and can,

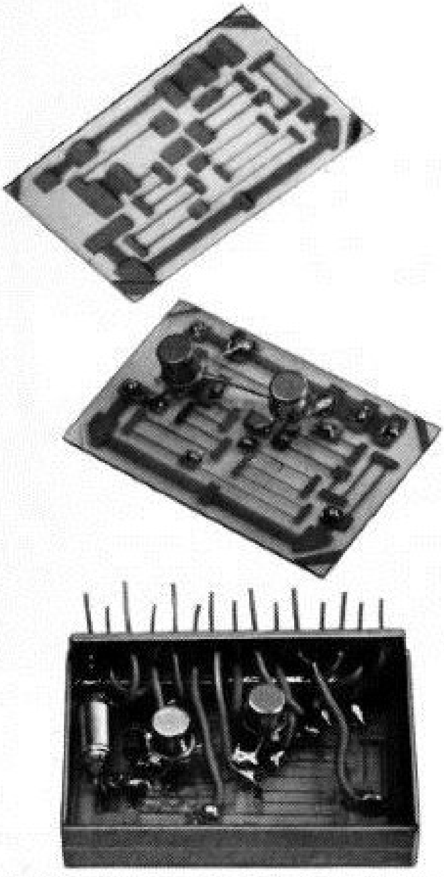
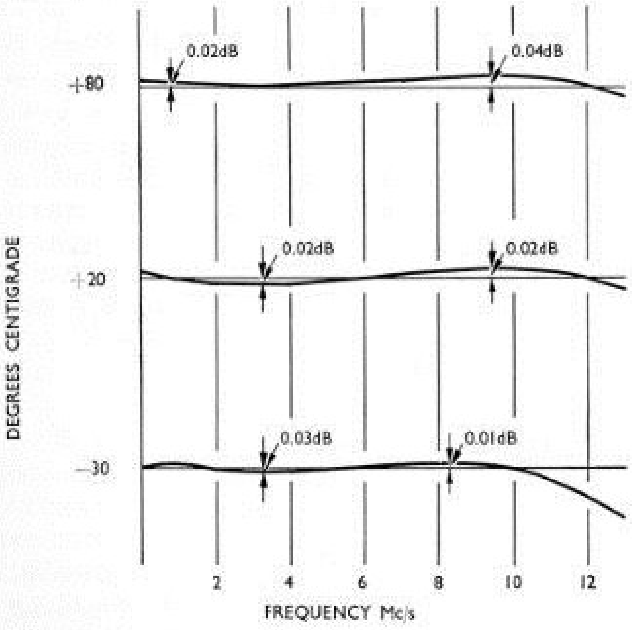


Fig. 5. The basic substrate with additional transistors and diodes as fitted to a base in a metal can.



EFFECT OF TEMPERATURE ON FREQUENCY RESPONSE OF A THIN FILM AMPLIFIER MODULE

Fig. 6.

as shown in Fig. 5. After the modules have been carefully inspected they are then subjected to additional tests:

(a) Dropped onto a very hard surface from a height of 3 ft

(b) Vibrated for 5 minutes

(c) Subjected to 3 temperature cycles varying between −20°C to +70°C

(d) Finally dynamically tested to a very stringent performance specification.

Inspection at all stages of processing and quality control continues in parallel with production.

As a result of the development programme many hundreds of resistors are on life-test, half of which being rated at 1½ W/sq. in. (the usual rating of Marconi resistance elements) and half at four times this rating. These resistors have already exceeded a life-test of over 16,000 hours without failure. The tolerances of the resistors are usually ±5%, but in certain cases ±2½% is obtained with a life stability of better than 0·2%. The range of values is from about 50 Ω to 50 kΩ although this range can be extended where necessary.

The capacitor programme which was started after the resistance test is not quite so lengthy although some hundreds of capacitors have been on life-test for about 8,000 hours. They have a power factor of better than 0·005, and a working voltage of 30 V with a catastrophic breakdown of greater than 100 V. Temperature coefficients are from approximately +50 to +100 parts in 10^6 per °C with a ±15% tolerance over a range of values from 50 pF to 8,000 pF.

Video amplifier modules have now been on life-test for more than 4,000 hours cycling between −55°C to +85°C and with the supply voltage being switched every 2 hours. Tests prove that this design of amplifier can withstand rigorous conditions without falling below the specification requirements.

FUTURE TRENDS

Now that thin films have become a reality, and are contributing to the success of the Mark VII camera, an interesting period lies ahead. Because of the many advantages previously outlined, it can be expected that there will be a more general use of modules in new designs of equipment.

As new processes become proven, by extensive testing, we may expect to see a wider range of values of components appearing on the substrate. New-type transistor packaging will be more compatible to the thin-film substrate, which in turn will enable more elegant and sophisticated devices to be produced.