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THE THICK FILM INTEGRATED CIRCUIT

The Research Group of Microelectronics Specialty

Abstract

This paper gives a brief introduction of an independent branch of the integrated circuit --- the thick film integrated circuit : its essential features, general technique, and the specialities of its application. It also presents the thick film circuit HM-7509-YHF10 with strong ability against interference.

In accordance with the teachings of our great leader Chairman Mao that "all research laboratories and affiliated workshops of advanced technological institutions that are capable of production should, in addition to fulfilling pedagogical and scientific research purposes, engage in production whenever possible", we, the Research Group of Microelectronics Specialty, being led by the principle of Class Struggle and dependent on the Working Class, have in the past several years succeeded in welding the forces of teaching, research and production into a solid base within the institute, and have produced various kinds of single-crystal components and integrated circuits in response to the need of technological revolution and innovation in some units. Ever since the revolutionary experiment in education that took place in Chao Yang Academy last year, we are even more determined than before in the pursuit of education for the proletariat. In order to meet the imperative demand of equipments pertinent to the present status of data processing control operation in the industry, we have committed ourselves to the research and development of the thick film integrated circuit.

Essential Features of the Thick Film Circuit

The thick film integrated circuit was originally developed on the basis of the ceramic capacitor. Because of its many outstanding features, considerable attention has been given to bring about its realization in production since its inception in the 50's of this century. Recently, it has undergone very rapid development, and has become an independent branch in the realm of microelectronics. At present, the most widely used type of the integrated circuit is the semiconductor integrated circuit, which, unfortunately, suffers from certain deficiencies in regard to the integration of passive components, being limited both in variety and in the range of component parameters : some components are as yet unable to be integrated, and for those that are integrable, their parameters are often hard to control technically and have rather poor tolerance. Consequently, integration of certain high percision, large capacity circuits, especially linear integrated circuits, encounters some limitations. Up to the present, the thick film integrated circuit is not yet able to have tis integrated active components, but, on the basis of the integrated passive components, we can attach small-sized active components onto it, thereby making up for the inadequacy of the semiconductor integrated circuit.

The thick film integrated circuit employs simple techniques to manufacture, is flexible in assembly, has rather high yield, is convenient for mass production, and hence enjoys lower costs. Its passive components are stable in performance, exhibit a wider range of parameter values, have more variety, and offer more freedom in design. When combined with different types of encapsulated microscopically sized single-crystal diodes and transistors, capacitors, inductors, and semiconductor integrated circuits, the thick film circuit can perform many kinds of logic functions. Another salient feature of the thick film circuit passive components is that high capacity performance as well as multi-layered networks are made possible, thus providing an indispensable method of packaging for solid-state devices. Accordingly, the thick film circuit has a very promising future in the area of high-capacity hybrid integrated circuits and large-scale hybrid integrated circuits. At present, the volume of a single chip of the thick film circuit is larger than that of the semiconductor integrated circuit. On the other hand, it has a higher packing density, and can perform many logic functions on a single chip. Therefore, it does not occupy more space in the whole system than does a semiconductor integrated circuit (e.g. HTL) that performs the same amount of logic functions. Since the thick film circuit is especially stable, rugged and reliable, and shows strong ability against interference, it is very well received insofar as production is concerned.

Fabrication Technique of the Thick Film Circuit

Thick film circuits are fabricated on ceramic substrates that have various specifications in sizes of 15mm x 20mm, 20mm x 30mm, and 10mm x 15mm. One-dimensional, two-dimensional, and multi-layered networks can be fabricated on the substrates. The ceramic substrates are generally required to have good insulation property, small dielectric constant, great mechanical strength, high thermal conductivity, ability to resist deformation under high-temperature annealing, and a flat and smooth surface.

The entire fabrication process of the thick film circuit includes : planar layout of the entire circuit, cutting of silk-screening stencils and subsequent printing of patterns for the refractory conducting paths and resistors, baking, firing of the conducting paths and resistors, anodization, adjustment of resistance values, soldering of various kinds of appliqued components, passivation, encapsulation, ageing, and testing.

The first step in the process is monolithic layout. On the basis of the modelling of performance for the individual circuits, one must give an overall consideration of the characteristics of each component used, the special properties of the thick film, the desired electrical parameters in the circuit, the requirement on thermal conductivity, and the pecularities concerning the assemblage of the appliqued components, in order to realize properly, accurately, and compactly the individual circuits on the ceramic substrate. This is indeed a complex and elaborate process. For digital circuits, if the layout of the art master is judiciously carried out, it can be used for several circuits at the same time. In fact, we have succeeded in making two art masters which can be used in the two-dimensional printing for each of the circuits HM-7509-YHF10, HM-7510-YH_1, and HM-7510-YH_2, thus increasing immensely the production efficiency.

The printed conducting paths are used for interconnections within the circuits, terminals of resistors, soldering points for the appliqued components and external leads. The refractory conducting paths must have good solderability, good electrical conductivity, good adherence to the substrate, and ability to withstand thermal and mechanical stresses without falling off or fracturing. The refractory silver glaze made for this purpose at the present time is a mixture of silver oxide, bismuth oxide, boric acid and an organic solution.

The thick film resistor is made from the printing of a resistor glaze, the mostly widely used of which is the palladium-silver glaze, consisting of palladium oxide, silver powder, a fixed proportion of glass grits, and an organic solution. Although the palladium-silver glaze is rather expensive, it has excellent electrical and technical properties. After firing, the thick film resistor is only about tens of microns thick, occupying almost no space at all, thereby increasing the packing density. It is stable in performance, having a controllable temperature coefficient of resistance in the order of 100ppm/°C. Its sheet resistance value can vary over a wide range of, according to the literature, 1Ω/□ to 100MΩ/□ . Experiments indicate, however, that the upper and lower extremes of the range are not easily reproducible. The sheet resistance values that we can control without difficulty and normally use are in the range 100Ω/□ to 50KΩ/□ .

As for the appliquéd components, we use various specifications of single-crystal devices manufactured by our own Research Group, mainly 3DK2 and 2CK20. Owing to the packaging consideration in the local area, we have switched to using model CB10 external capacitors made of ethylene polyphenyl derivatives manufactured by the Talien Wireless #4 Factory. This type of capacitor has very small size and good insulation, and is convenient for ageing and soldering.

In particular, it is stable in performance and resistant to damage, thereby greatly enhancing the tuning efficiency of a large amount of thick film circuits.

The basic fabrication technique of the thick film circuit has essentially ripened. However, the increasingly demanding requirements of the present-date equipments have pushed the development even further, and there are some recent activities that are worthy of attention. For example, computer-aided optimization of the planar layout can lead to better arrangements of components and improvement in speed and precision in the circuit. To increase the degree of integration, a so-called "fine-line" technique has recently been developed. The resolution of most drafts currently attainable is about 0.5mm ~ 1mm, with 0.5mm ~ 1mm tolerance. The application of the "fine-line" technique can improve the resolution to 0.1mm, with 0.1mm tolerance. The thick film resistor made by the present method shows a somewhat large deviation in value after firing. It has been brought to our to attention recently that a so-called "contact printing" technique can help reduce the deviation to 5% after firing and thus eliminate the need to fine-adjust the resistance values, which is rather remarkable.

Applications

The thick film circuit finds applications in many areas, but is mostly used in data processing control in the industry. At present, there are many kinds of serialized products in encapsualted forms in this country. The principal encapsulated products manufactured by us are in the form of upright metal encapsulation, each of which is hermetically sealed, has 14 leads and an exterior case measuring 20mm x 22mm x 6mm. There is another type of encapsulation called flat ceramic encapsulation, which has an exterior case measuring 20mm x 30mm, or 15mm x 20mm. These two types of encapsulated devices are shown in figure 1.

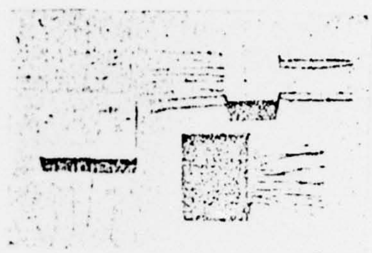


Fig. 1 Thick Film Integrated Circuit Devices

Under the direction of Chairman Mao's policy in proletariat education, we are determined to take the pathway of open-door education, to insist on education for the political service for the proletariat. Thus,we have produced thick film circuits for the special purposes of the digital control-line cutting machine for some units. Here we choose the HM-7509-YHF10 as an example to illustrate its technical characteristics.

The HM-7509-YHF10 is a discrete logic device, whose circuit and logic function performance are shown in figure 2 and figure 3 respectively.

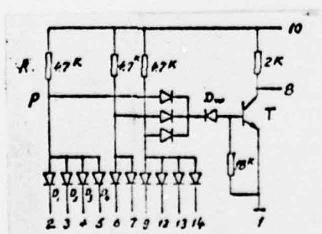


Fig. 2 HM-7509-YHF10 Circuit

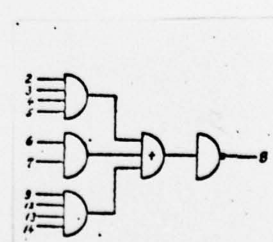


Fig. 3 HM-7509-YHF10 Logic Functions

HM-7509-YHF10 is a gate circuit that can perform multi-logic functions. All of its components are housed inside a hermetically sealed metal case. The logic functions that it performs are the same as done by other ordinary circuits. We choose to analyze a group of logic gates in the following paragraphs. The performance of the rest of the circuit can be deduced by similar arguments.

With the use of positive logic, the output is low (logical "0") when all of the inputs are high (logical "1"). When one or more of the inputs are low, the output is high. The logical relation can be written thus :

$$\bar{8} = 2 \cdot 3 \cdot 4 \cdot 5$$

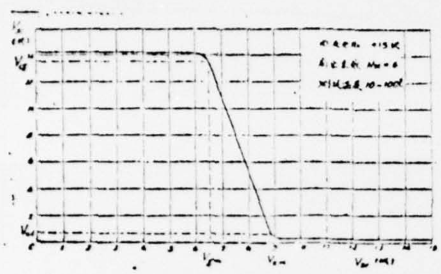
Simple operational principles : When one or more of the inputs are low (low is taken to be 0.5 volts; however, because the voltage drop across the semiconductor junction of our home-made $3DK_2$ is small, low is actually at 0.2V), the gate current flows from the source V_{cc}, through the gate resistor R, into the input diode(s), causing the input diode(s) to be positively biased and the potential at the point P to be clamped at 0.2 + 0.7 = 0.9V. With the reverse breakdown voltage of the Zener diode D_W equal to approximately 7V, the potential at P causes D_W to be non-conducting, thereby putting the transistor T to be in the cut-off condition. Thus the output becomes high. Since the leakage current of $3DK_2$ is very small, the output potential can get as high as 14.2V.

When all of the inputs are high (14.2V; the inputs can be the outputs made of similar transistors in the previous stage), all the input diodes become reverse-biased, and the voltage of the source V_{cc} causes D_W to reach breakdown. A current I_b = (15 - 7 - 0.7 x 2)/4.7 = 1.4mA will then flow into the transistor T. With R_b equal to 18KΩ, very little current flow into R_b. If T has a sufficiently high value of β, T will be in saturation, and the output becomes low at 0.2V.

In order to improve the ability against interference, which means having to increase the threshold voltage, a source of 15V is used, at which time the threshold voltage takes the value of 7.5V. The use of the non-linear component D_w in place of potential-dividing resistors for the separate logic circuits raises the gate shut-off potential, thus improving the ability against interference significantly. When the input is low, the noise margin Δ"0" = V_{gm}-V_{cd}. With the gate shut-off potential equal to 7V, and the output potential at 0.2V, Δ"0" = 6.8V. Owing to the slight variations in parameter values during fabrication, the minimum value of the gate shut-off voltage is 6.5V. Now if the input is low, the noise margin becomes 6.3V, which is 0.7V higher than that of the semiconductor integrated circuit. When the input is high, the noise margin Δ"1" = V_{cg}-V_{km}, with high output level V_{cg} at 14.2V, and the open-gate potential V_{km} equal to 8.5V. Owing to the slight variations in parameter values during fabrication, the maximum value of the open-gate potential is 9V. Now if the input is high, the noise margin Δ"1" becomes 5.2V, which is 0.7V higher than Δ"1" = 4.5V of the HTL circuit. Transfer character as in Fig. 4.

From the view-point of gate efficiency, with R equal to 4.7KΩ, the gate current is 3.2 mA approximately. From figure 4, it can be seen that if the output is loaded with similar transistors and that the collector current is 20mA, which corresponds to a fan-out of coefficient N_o=6, the low level can still be maintained at 0.2 V. If two $3DK_2$ are used in parallel, its load capacity can be raised further

When the fan-out of this circuit is equal to 6, its transfer characteristics remain the same even if it is tested at a capacity 20% higher than is specified at the temperature range 10~100° C.



Source Voltage = 15 V
Fan-out $N_{sc}=6$
Temperature
Range: 10~100°

Figure 6. Transfer characteristics of HM-7509-YHF10.

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