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PERMANENT INTERCONNECTION TECHNOLOGY

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This paper is concerned with the permanent connection of electronic components into sub-systems and is based on the report of an ERC Working Party that investigated the subject during 1978 and 1979. After an initial description of the interconnection concepts and the relationship the field has to electronic assembly systems in general, a survey is given of the marketing data that is available that defines the economic importance of the field. This survey includes new data obtained by the Working Party. Figures are given for the rest of Europe in general and the UK in particular and it is noted that the Output at Sales Value in the UK of interconnection technology products is almost the same as the Output at Sales Value of ICs in the UK. Within permanent interconnection technology two-thirds of the Output at Sales Value is associated with PWBs and one-third with thick/thin film circuits.

Research work in the field is discussed and a division between immediate time scale problems and those involving a longer time scale is suggested. Twenty-nine immediate time scale R & D problems have been recognized covering all three interconnection technologies; longer time scale problems will be associated with the continuing decrease in the size of add-on electronic components.

It is concluded that large, fast computer systems will require a decrease in the size and spacing of interconnections to match those of the semiconductor chip. This means simultaneous design of semiconductor and associated interconnection structures tasks well-suited to vertically integrated companies. In contrast, many real time subassemblies will benefit from greater chip complexity and need fewer outgoing leads per chip, i.e. at wider spacings – needs that can be met by the development of existing techniques. Finally it is suggested that future distribution of added value in electronic assembly operations is likely to give all sectors of interconnection business a steady upward sales trend, with both hybrid and semiconductor manufacturers seeking specialized subsystems markets to replace their present "all things to all customers" policies.

1. INTRODUCTION

The importance of interconnection systems for electronic components has recently been recognized in Government circles by the formation of a Working Party to look into the magnitude of the business involved and also to make recommendations as to the required research and development work needed to maintain or stimulate activity in the United Kingdom. After approximately two years study, the Working Party reported to the Electronic Research Council in March of this year (1980), and presented to Council a document entitled 'Permanent Interconnection Technology'. The report of the Working Party had been commissioned by the Materials Committee in cooperation with the Solid State Physics and Devices Committee. The report analysed the marketing data available and compared the data with figures obtained by the Working Party itself as the result of a confidential questionnaire, and also discussed the R & D work needed in the field, both in terms of medium term and longer term problems.

This paper summarizes the ERC report. After an initial description of the interconnection technology concept and the relationship the field has to electronic assembly systems in general, a survey is given of the marketing data obtained. The research and development activities considered of importance in the area is then discussed, and a division is made between activities that are of immediate importance to the well-being of the present industry and those longer term projects that may well imply a difference in philosophy.

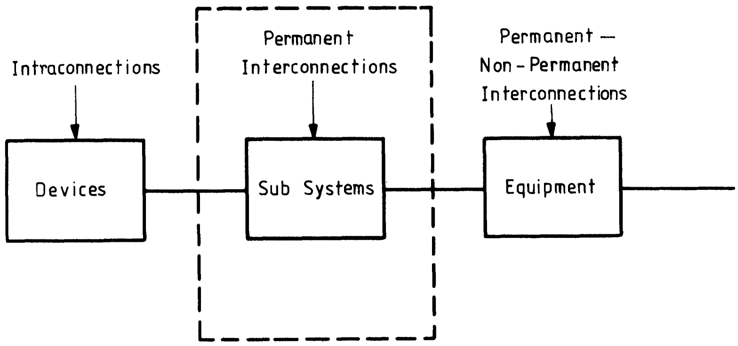

FIGURE 1 Relationship of Interconnection Technology to Device and system development.

2. INTERCONNECTION TECHNOLOGY

Permanent interconnection technology is concerned with the connection of electronic components into subsystems and total equipments. The components involved can be discrete passive and active devices of a simple or complex nature, and the connection system as such must be in a permanent form that does not easily lend itself to reworking and repair. The repair aspect of the definition means that wiring systems using wire, whether using soldered joints or wire wrapping, are not involved in the study, neither are plugs and sockets. The technology is, however, concerned with deposited systems, and includes Printed Wiring,[1] Thick film,[2] and Thin film[3] techniques. These systems can also have the possibility of including passive components prepared within the interconnection system itself, such as the resistors prepared with Thick film methods and the resistors and capacitors made in Thin film.

Figure 1 defines the area covered by Permanent Interconnection technology. The progression in complexity from devices on the left of the diagram to equipment on the right indicates the relationship between the various levels of construction involved. Two things need to be added. Firstly by the term 'Devices' one includes VLSI[4,5] as well as discrete monofunctional components, and therefore there is a high degree of complexity already possible in this area. Secondly, the permanent interconnections under consideration are mainly, but by no means exclusively, associated with the subsystems, and this is indicated by the dotted boundary around this area. However, the boundary is not fixed – there are permanent interconnection requirements in both the device and the equipment areas.

3. MARKET DATA

3.1 Introduction

In order to determine the economic importance of permanent interconnection technology, the working party spent some time in analysing the marketing data available. It found, initially, that the data was not complete enough or self consistent and, therefore, it was decided to obtain some independent figures by means of a questionnaire that was sent to a large number of relevant companies. The results of both the analysis and of the independent questioning are presented in this section.

3.2 Background Data

In order to make judgement of the importance of a particular technology, it is necessary to look at the size of the total markets involved. Table I gives the world market for electronic equipment in billions of dollars (Dollars $\times 10^9$) for '78 and '79.[6] Table II, from the same reference,[6] gives the figures for components alone. It is possible to obtain more detail for the figures of Table II, and these are given, in the case of W. Europe, in Table III.[6] This table gives the figures for both the active and passive markets, with

TABLE I
World market for electronic equipment (after Ref.6.) (B$)

	'78	'79	% Growth
W. Europe	33	37	12
U.S.	68	77	13
Japan	20	23	15

TABLE II
World market for components (after Ref.6.) (B$)

	'78	'79	% Growth
W. Europe	8.2	8.7	6
U.S.	10.7	11.7	9
Japan	7.8	8.4	8

TABLE III
W. Europe market for components (after Ref.6.) (B$)

	'78	'79	% Growth
Passive	4.2	4.4	6.4
Discrete Semi.	1.0	1.0	3.4
ICs	1.2	1.3	11.9
Opto electronics	0.11	0.12	12.3
Tubes	1.8	1.8	4.2
TOTALS	8.2	8.7	

the active market, with a total of 4.0 B$ for '78 and 4.3 B$ for '79 (growth of 6.4%), being subdivided into four areas. Three points need to be made. Firstly, all the figures in the last three Tables have been given at constant 1978 values – i.e. the growth figures quoted are real increases. Secondly, the market figures are rounded whereas the % increase values given have been calculated on the original data. Finally, it can be seen from Table III that the size of the passive component market is the same as the active market, with the growth rates also being the same.

Details of the passive component market in W. Europe are given in Table IV.[6] In this table the seven largest passive component areas are noted together with the total component figure from Table III. Figures for one of the permanent interconnection technology methods now appear in Table III in the row for 'printed wiring boards'.

TABLE IV
W. Europe market for passive components (after Ref.6.) (B$)

	'78	'79
Capacitors. Fixed	0.87	0.92
Connectors	0.58	0.64
PWBs	0.55	0.60
Relays	0.37	0.38
Resistors. Fixed	0.29	0.29
Switches	0.26	0.27
Potentiometers	0.24	0.25
TOTAL (All components)	8.21	8.74

TABLE V
1979 production for ICs and PWBs for W. Europe countries (after Ref.7.) (M$)

	IC	PWB
Austria	–	–
Belgium	4	26
Denmark	–	14
Finland	–	–
France	105	91
Italy	124	16
Netherlands	34	11
Norway	–	–
Spain	5	14
Sweden	11	14
Switzerland	57	11
U.K.	211	85
W. Germany	364	94
TOTAL	915	367

3.3 Permanent Interconnection Technology Data

Tables I–IV have given the background information available that defines the size of the total markets for equipment and components. Comparison can be made between the markets and production of interconnection systems and that of ICs and Table V gives such figures for ICs and PWBs for thirteen countries of W. Europe.[7] It can been seen that for certain countries PWB production is greater than ICs. However, in the case of the two largest producers, the UK and W. Germany, the ratio of PWB to IC production is 1 : 0.4 and 1: 0.25 respectively. PWBs can be manufactured in a variety of forms, and predictions have been made as to the sizes of these markets in 1982.[8] Table VI gives these figures in the terms of 1978 values.

The data so far discussed has been in terms of the markets available or production. A figure that is also of interest in examining marketing information is that of Open Market or Open Market Usage, and the derived term Total Market Usage. The former term is defined as the national purchases, including imports,

TABLE VI
World PWB market in 1982 at 1978 values (after Ref.8.) (M$)

Single sided	200
Double sided	700
Multilayer	450
Flexible	180
Others	50
TOTAL	1580

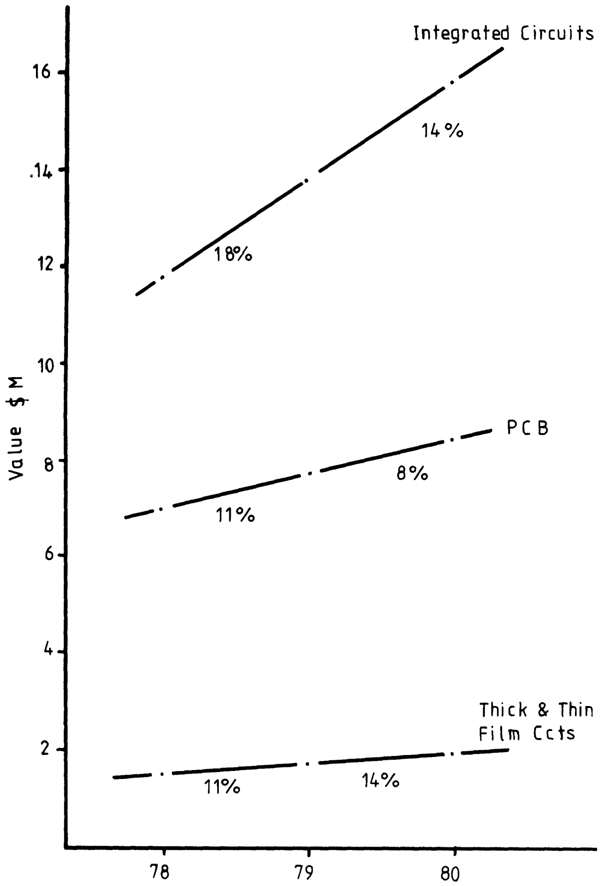

FIGURE 2 Total Market Usage of ICs., PWBs., and Thick and Thin film circuits in W. Europe (at November 1979 values). (After Ref. 9.)

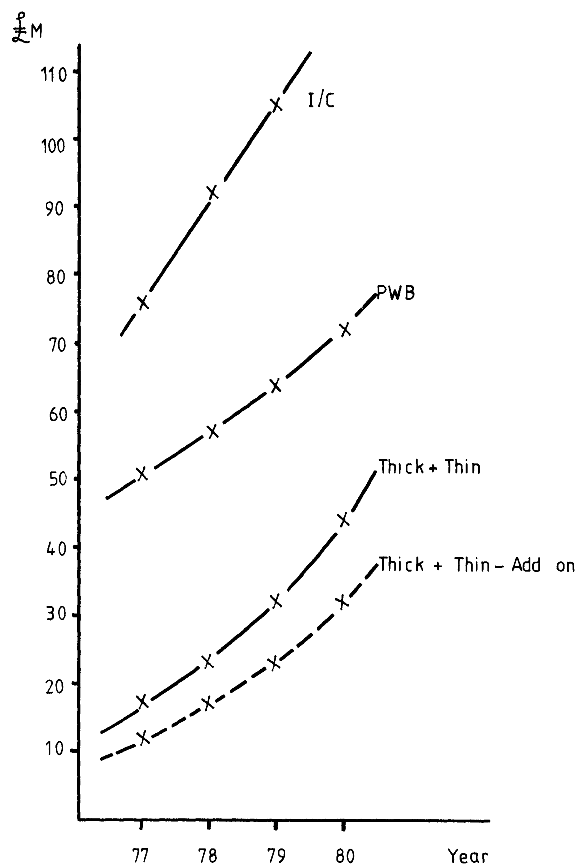

FIGURE 3 Output at Sales Value in the UK for ICs., PWBs., and Thick and Thin film circuits. (In the latter case showing the effect of add-on components.) (After Ref. 10.)

and the latter is defined as the Open Market Usage plus the transfer value of home 'in-house' manufacture. Figure 2 gives such figures for W. Europe for not only ICs and PWBs but also for the other two permanent interconnection methods combined, namely Thick film and Thin film.[9] These figures are at November 1979 values and give predictions made in 1979 of the expected 1980 values. Percentage growth values are noted between the relevant points.

Marketing data obtained from the Working Party questionnaire relates to the position in the UK. Output at Sales Value was one of the figures obtained and this is defined as the total national manufacture at sales value including 'in-house' output at transfer value. Such a figure includes direct exports. Output at Sales Value is shown over the last four years in Figure 3,[10] where the IC value is also shown for comparison. In Figure 3 the data is given for PWBs and for the sum of Thick film plus Thin film. It may seem inappropriate to compare in economic terms the manufacture of hybrid circuits (Thick film and Thin film circuits), with unpopulated PWBs. Hybrid circuits, by definition include add-on components and frequently represent operational modules performing specific electronic functions, whereas PWBs include none of the devices which will most certainly be added to them in succeeding stages of use. Nevertheless the Working Party has made such a comparison since the two products in the form described represent manufactured products as made in industry and as supplied at identifiable cost from one type of manufacturer to another. It is argued that the two major branches of the interconnection industry are structured in this way. Figure 3 gives the data assessed in this manner. If, however, one needs to compare the interconnection contribution in Thick and Thin film circuits with PWBs, where no add-on components are involved, the purchase price of the

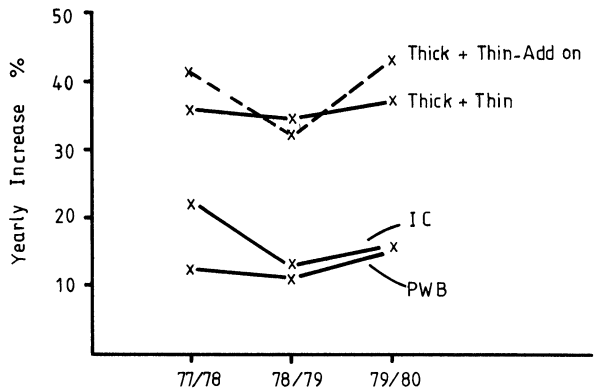

FIGURE 4 % Increase in Output at Sales Value in UK (After Ref. 10)

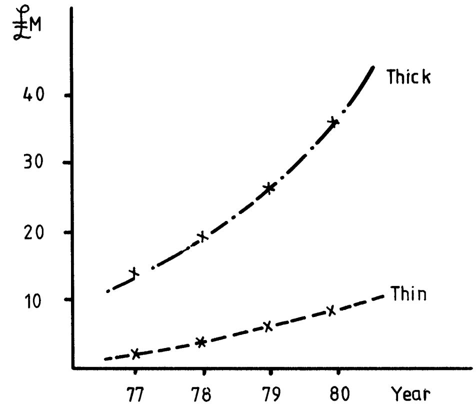

FIGURE 6 Output at Sales Value in the UK of thick and thin film circuits separately (After Ref. 10)

add-on components in the Thick and Thin film circuits must be deducted from the output at sales value. Such data had been obtained by the Working Party and the resultant values are shown as the lowest curve in Figure 3. It is of interest to note that the effect of the add-on components is about 30% of the total Thick and Thin film circuit value.

Figure 4 gives the % increase in Output at Sales Value for the data in Figure 3. These values have been calculated at constant value, so that inflation factors have been allowed for. It is also of interest to compare the Output at Sales Value for the two technologies of PWBs and Thick film + Thin film circuits as a % of the total interconnection business in the UK. This is done in Figure 5, and it can be seen that as well as a continued growth in the business, the % associated with PWBs appears to be falling and the % associated with film circuits is rising.

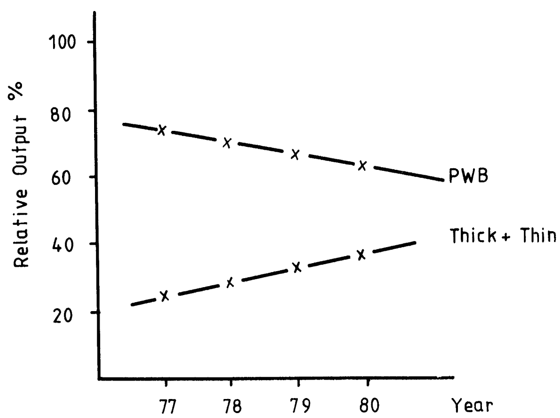

FIGURE 5 Relative % of total interconnection Output at Sales Value occupied by the two technologies, PWBs., and film circuits (After Ref. 10)

The Output at Sales Value of the two film interconnection systems has been analysed from the Working Party data.[10] Figure 6 shows this data, where it can be seen that Thin film circuits account for approximately 1/5 of the total output in this sector.

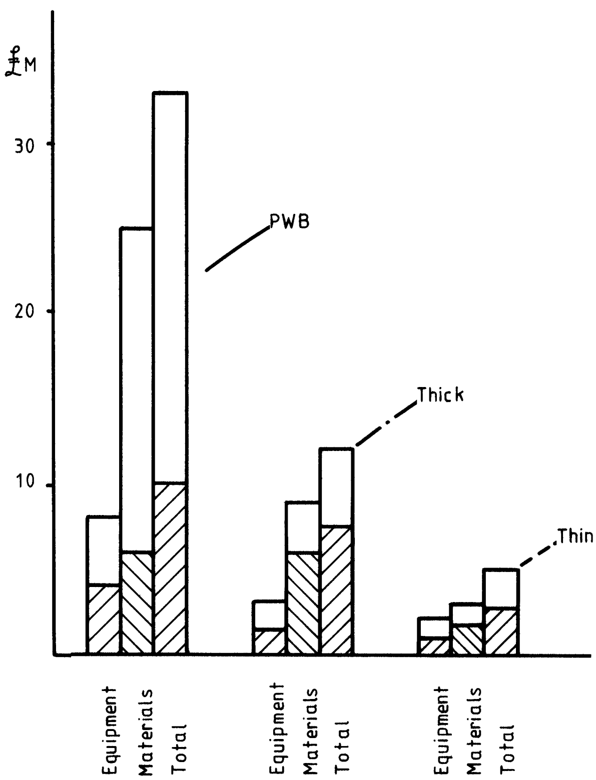

FIGURE 7 Expected annual spend in the UK in 1980 for Equipment and Materials in the three interconnection technologies. (Imports shown as hatched areas.) (After Ref. 10)

TABLE VII
U.K. Output at sales value and total market usage for interconnection products (£M) (after Ref. 10.)

	1978	1979	1980
Output at Sales Value:–			
PWBs	58	64	74
Film Circuits	24	32	44
TOTAL	82	96	118
Total Market Usage:–			
PWBs	63	70	78
Film Circuits	36	45	60
TOTAL	99	115	138

A considerable amount of data was collected and analysed by the Working Party giving the value and the sources of equipment and materials bought by UK manufacturers.[10] Figure 7 summarizes this data, both in terms of the three interconnection technologies and also in terms of the UK reliance on equipment and materials from outside of the country. Details are given in the Appendix.

3.4 *Summary*

Table VII summarizes the UK Output at Sales Value and the Total Market Usage for interconnection technology, as derived by the Working Party.[10] It should be noted that the 1979 Output at Sales Value for permanent interconnection products at £96M compares with the inflation corrected figure of £105M for the UK Output at Sales Value for integrated circuits, derived from the data given by Mackintosh.[7]

4. RESEARCH AND DEVELOPMENT

4.1 *Introduction*

It was felt by the Working Party that it was of considerable interest to establish a concensus of opinion on the R & D projects that should be followed in the immediate and longer term future in order to maintain and increase the viability of interconnection technology in the UK. Such a study did not lead to a detailed review of present activity and, therefore, this paper does not attempt to examine existing programmes in the field. A list of discussion topics was drafted and examined with respondents, either directly or by correspondence, to obtain a concensus of opinion. Such discussion topics did not attempt to limit the areas under examination – Printed Wiring, Thick film and Thin film systems were all considered, and thus all methods of deposition and preparation were of interest.[1, 2, 11] It was felt by the Working Party that this was an important aspect of their analysis, since a narrow confinement of the study to only one interconnection technique would have given a biased view of the problems that needed to be solved.

The discussion topics were structured into four main groups, and Table VIII summarizes these.

4.2 *Immediate Projects*

It is not possible in the space available to detail all the considerations that lead from the discussion areas to the recommendations that the Working Party made with regard to immediate projects. However, the results of these considerations are given in Table IX – there are 29 project requirements in all. These projects, although classified as 'immediate', relate to time scales of between 1 and 5 years. Problems involving shorter periods were felt to be of such pressing importance as to be already under consideration by industry.

It is a difficult task to derive an order of priority for the projects listed in Table IX. It can argued that all the projects concerned with PWB development should take low priority on the grounds that such products have been around for many years and, therefore, there is little hope of any major advances in the field at this time. Also it has been pointed out[12] that the cost per unit area of a ceramic film circuit is about the same as that of a 4-layer PWB, but that the interconnection density can be ten times higher. Hence very substantial benefits in size and weight of the assemblies, and in economic terms as well, can result from transferring from the interconnection technologies of the multilayer PWB to some form of hybrid system. Furthermore it has been suggested that the fragmented nature of the PWB industry does not make this sector readily capable of undertaking major R & D work or taking widespread advantage of research outputs, with 'too many of the companies being too small and undercapitalized'.[13] However, such strictures are not true for all companies involved in PWB production. Improved PWB systems will be required if only to match the large number of pins per device and the line widths that will be required by the improvements to integrated circuit devices that will take place,[14] and there are firms capable of this work.

TABLE VIII
Discussion areas used to give an analysis of immediate R & D requirements in interconnection technology (after Ref. 10.)

Area	Sub-area	Detailed interest
Deposited Components	Printed Wiring	Conductive elements Resistive elements
	Thick film	Conductors & Resistors Dielectrics
	Thin film	
Substrates	Printed Wiring	
	Thick film	Standard substrates Non-standard substrates
	Thin film	
Added Components	Semi C. chips	Procurement & transport Attachment methods Removal/replacement Testing after assembly Reliability in hybrid circuits Problems of large area chips
	Passive Components – without leads Components – with leads Passive Components – – attachment to Thick film circuits Microwave hybrid circuits	
Packaging	Hermetic Plastic Design Concepts Attachment of Packaged modules	

Arguments can also be advanced against expenditure on resistive thin film problems. Low TCR films were investigated in the 1960s, e.g. Ref. 15, and little improvement can be expected now. Nevertheless, realization of the potential of such components is now with us, and due to the better understanding of the nature of the conducting processes in thin metal layers, advances are being made in this area of technology.

The Working Party also felt that the establishment of a priority list of projects implied that some of the projects were of a second class nature. As no such implications are wished, no priorities have been assigned to the list in Table IX.

4.3 *Longer Term Projects*

For longer time scale problems, it is recognized that microminiaturization will be a major driving force in the progress of interconnection technology. This will involve the scaling down of sizes of the interconnections. The increased use of VLSI, particularly with regard to the further development of large scale computers, will demand interconnection technologies that will have sub-micron line definition compatible with the connections to the chips themselves, and with the criteria of reduced interconnection lead length so as not to limit operational speed at low power.

Some of the specific areas that need investigation have been highlighted by an NRC report recently published[16] and considered by the Working Party. Six areas were suggested as being of special interest and these are:

a) Inorganic resists such as As-S and Ge-Se that do not have to be removed, as with present systems, because of temperature limitations imposed by subsequent device or substrate processing.

TABLE IX
Immediate R & D project recommendations in interconnection technology (after Ref. 10.)

Activity	Investigation recommendations
Deposited Components	Low temperature electroless Cu for PWBs – with particular reference to understanding adhesion of such deposits. Improvement to finish of Cu foils – for the semi-additive processes thinner foils have definite process and economic advantages but suffer from poor finish and porosity. Translation of software for N.C. PWB systems – from one system to another. Economics of different PWB processes – i.e. a full cost analysis of the economics of subtractive, semi-additive, additive and photoplating technology. Base metal conducting and resistive systems – to give low cost conductors and low cost general purpose resistors. Improvements in dielectric materials – both in yield and performance. High stability resistive films – (TCR $<$ 25ppm/deg. C.). Accelerated life testing of resistors – particularly with regard to a method of relating accelerated life tests to long term stability. Reduction of line width in resistors – down to 1 μm or less.
Substrates	Dimensionally highly stable PWBs – using fine weave glass cloths and/or improved resins. Low dielectric loss substrates – for use for strip lines and microwave applications. Investigation of different substrates including multilayer systems, plasma sprayed metals (e.g. Al_2O_3) and low alkalie ceramics.
Added Components	Epoxy mounting of devices – the use of organic adhesives that have a long shelf life, are only one-part and have a low curing temperature. Printed circuit boards for beam leads and tape bonded semi conductors – suitable PWB metallizations required. Chip replacement systems – including use of eutectics. Removability is essential for the more expensive circuits. Reliability assessment of semi conductor chips after mounting. Attachment problems of large chips – including heating effects (thermal managment). Automatic semi conductor chip placement systems. Low stress passive component mounting systems – that minimize bond and performance degradation due to expansion mismatch stresses during temperature cycling. Failure of ceramic capacitors at low voltages Low cost printable conducting adhesives – use of non precious metals.
Packaging	Sealing of ceramic encapsulation systems. Welding techniques for encapsulation – epoxy resin systems are thought of as not being good enough for high reliability applications. Determination of testing standards – e.g. criteria for water vapour measurement in packages at a sufficiently sensitive level as to be appropriate for a package life of 10 years or more. Degradation effects of mechanical stresses developed by plastic encapsulation (particularly if components subsequently are cycled to – 10°C or less). Chemical effect of organic encapsulants of reliability of components. The use of soft materials can reduce mechanical stress whilst at the same time still giving chemical protection. Methods of attachment of rigid multi-lead packages – in order to increase the packing density.

b) High definition lithography that will be capable of sub-micron definition – such techniques include those of X-ray, Electron beam, and Plasma etching.

c) Improved interconnection systems based on conventional techniques but using alternative materials such as silicides.

d) New interconnection materials such as polymerics – these are conductors but do not contain metallic atoms – e.g. polythiazyl, $(SN)_x$; poly-acetylene, $(CH)_x$. Also anisotropic conductors such as graphite intercalation compounds are of interest.

e) Further investigation of the problems and limitations imposed by electromigration.

f) Improved ultra thin insulators.

5. DISCUSSION AND CONCLUSIONS

5.1 Market Data

The data obtained from the Working Party questionnaire has been correlated with a wide variety of published market information. The figures for the three areas of permanent interconnection technology have been found to be in reasonable agreement with the published data and has shown the economic importance of interconnection systems. The conclusions from this study have been summarized in Table VII.

5.2 Permanent Interconnection Technology and Microelectronics

A widespread misconception is that 'microelectronics' is only 'silicon chips'. This is not so – in fact microelectronics is clearly defined in BS 9400/9450 as 'The concept of the construction and use of highly miniaturized electronic circuits'. PWBs and Thick and Thin film technologies are a vital and integral part of microelectronics. The viability of the total microelectronic circuit business is related to the need to interconnect the circuits or devices and it is thus no use developing sophisticated integrated circuit systems if the technology is not available to interconnect these systems in a manner that is effective in terms of system performance, reliability, size and cost. Such considerations apply equally well to the use of components other than chips, and the Working Party saw clear examples in surface acoustic wave devices, microwave systems including integrated optics, Hall effect switches and sensors, memory systems including low temperature devices and bubble memories, implantation medical electronics and displays.

5.3 Semiconductor Technology

With reference to the semiconductor microelectronic market, it is possible to divide the present and future activity into two areas.

1) The use of high density systems such as VLSI and Josephson technology.[17] The essence of this approach is to provide a large, high speed, digital computing system at low cost. In order not to lose the speed inherent in the chip design itself it is vital for the interconnection system to the high density devices to be designed by the device manufacturer as part of the system itself.

2) The use of LSI and Discrete devices. In this area chip manufacturers are interested in making standard products that will be used by the system designer as he wishes. Such an approach will waste space over that involved in 1), if only because of the packaging that the chip manufacturer will use to protect his circuits. The use of a standard chip will also imply redundancy in the chip design and application. If the market is large enough, however, the chip manufacturer will still be interested in mounting his chips in his own total sub systems, and selling these. (e.g. Texas and hand calculators.)

Even the use of chips by a separate system designer is subject to change. It can be argued that as the LSI chips become more complex, fewer and fewer of them will be required and hence added value in making up whole circuits will be reduced. In these circumstances, either the chip manufacturer will be forced to make the whole function, or he will not sell his chips, or conversely, the circuit manufacturer will have to make the required chips himself. If this trend is coupled with that of the considerable amount of research that is going into the problem of yield improvement in chip manufacture, and the effect that this will have on the economic manufacture of only small numbers of chips – down to 5 per design is being quoted – then it is possible to predict that the open market hybrid business as a separate entity will get relatively smaller, but the total need for interconnection technology will increase rapidly within the context of the system house of chip manufacturer's own business. However, it must be emphasized that the widening application of electronics in the coming years will lead to large increases in the total interconnection business including both open and in house manufacture. The effect in the UK depends on the nature of investment in this country. For full involvement in the high density systems, it can be argued that this could only be done effectively in terms of a European (EEC) based approach, that would enable us in Europe to compete with the investment being made in the US or Japan. The use of LSI and Discrete devices is the other approach, and such a development has been implied by the NEDC Electronic Components Sector Working Party report.[18] This document identifies the need for volume production of selected multi-application semiconductor circuits, and notes that this can be done in one of three ways:

1) Investment by an existing company.

2) A joint venture between a UK based company and one from overseas.

3) A UK owned company (e.g. INMOS).

All these possibilities, and particularly those of 1) and 3), would imply a considerable activity on the part of the interconnection circuit manufacturer as distinct from the chip manufacturer, in making complete systems. Research in the UK should, therefore, be directed towards improving interconnection technology as a separate business.

6. SUMMARY

This Paper had been concerned with the permanent interconnection of electronic components into sub systems. A marketing survey has been given that has included new data obtained by an Electronics Research Committee Working Party on Permanent Interconnection Technology, and the economic importance of the technology has been clearly demonstrated.

Research work needed in the field has been discussed in terms of immediate and long term time scales, and the problem areas that need investigating have been itemized.

The following major conclusions have been reached:

1) The economic importance of Permanent Interconnection Technology has been demonstrated. The output at sales value in the UK of interconnection technology products is very nearly as great as the output at sales value of integrated circuits in the UK. Within permanent interconnection technology 2/3rd of the output at sales value is associated with PWBs and 1/3rd with thick/thin film circuits.

2) 29 Immediate time scale R & D problems have been recognized covering all three interconnection technologies.

3) Longer time scale R & D problems will be associated with the continuing decrease in size of add-on electronic components.

4) Solutions to the interconnection technology problems in the longer term cannot be obtained within an environment in which the three permanent interconnection technologies are separated from each other either economically or scientifically.

5) It is suggested that the open market interconnection technology business as a separate entity will increase as time progresses. However, the total need for interconnection technology will increase even more rapidly within the context of the system house or chip manufacturers own business.

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Vice-Chairman	Prof. P. L. Kirby, Welwyn Electric Ltd.
Secretary	Mr. A. N. Pearse, RSRE
Members	Mr. D. Boswell, ITT Components Group
	Dr. H. T. Law, Ferranti/Edinburgh University
	Mr. W. MacLeod-Ross, Plessey/Precision Circuits (Anglia) Ltd.

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Naturally, in any reporting of this nature, there is an inevitable bias due to the views of the authors who must be held responsible for the contents of this paper.

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Appendix

MATERIALS AND EQUIPMENT DATA FOR PWBs, THICK FILM AND THIN FILM CIRCUITS

TABLE A.1.
PWB material data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin (K£)			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A.	U.K.
Laminate									
a) Copper Clad	1495	1557	1608	1683	6343	1388	–	8	4947
b) Paper Phenolic	598	598	649	662	2507	170	–	–	2337
c) Glass Epoxide	480	480	555	567	2082	304	–	8	1770
d) Glass Polyester	68	80	80	80	308	–	–	–	–
e) Glass PTFE[b]	5	15	15	15	50	8	–	42	24
f) Flexible Polyimide[b]	80	80	80	93	333	–	–	309	24
g) Rigid Polyimide	–	5	5	5	15	–	–	15	–
Drills/cutters[a]	129	179	212	344	864	60	–	684	120
Plating Solutions									
a) Electroless Cu.	84	131	164	252	631	–	–	–	595
b) Copper	51	61	74	105	291	–	–	–	291
c) Tin/lead	38	48	61	92	239	–	–	–	239
d) Tin	5	5	5	5	20	–	–	–	20
e) Gold	488	613	633	746	2480	–	–	189	2291
f) Nickel	5	5	5	10	25	–	–	–	25
Dry Film Photo Resists[b]	198	304	361	412	1275	802	–	473	–
Screen Printed Resists	66	99	99	99	363	–	–	53	310
Stencil Materials	53	53	92	92	290	142	–	–	148
Etching sol's	92	105	151	151	499	121	–	72	306
Sensitisers and Conditioners	10	15	28	28	81	–	–	–	81
Fusing Fluids/Fluxes[a]	40	40	53	53	186	–	–	126	60
Solder Alloys	30	30	69	69	198	–	–	20	178
Coding/Marking Inks	30	30	30	43	133	–	–	–	133
Solder Masks									
a) Liquid	40	40	40	66	186	–	–	–	186
b) Dry Film	5	18	28	79	130	–	–	51	79
Tools, Jigs	151	208	258	408	1025	95	–	223	707
TOTALS	4241	4799	5355	6159	20554	3090	–	2309	15155
Percentage of total expenditure						15.0	0	11.2	73.8

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage

TABLE A.2.
PWB equipment data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A	U.K.
CAD equipment	75	116	173	209	573	–	–	150	423
Artwork generators	36	–	–	90	126	–	–	18	108
Cameras & Accessories	20	25	105	100	250	76	82	–	92
Air condition plant	84	95	76	113	368	14	23	–	239
Cutting equipment	5	28	87	111	231	54	–	74	103
Drills[b]	336	222	540	285	1383	202	–	1082	99
Deburring & clean	56	105	66	128	355	116	–	45	194
Electroless plating	46	105	289	51	491	–	–	–	491
Photo imaging	69	123	128	82	402	166	–	79	157
Screen printing	82	123	92	87	384	191	–	–	192
Electroplating	51	69	377	59	556	–	–	–	556
Resist strip	15	56	100	33	204	42	–	32	130
Etching	72	74	113	112	371	124	–	110	137
Tin lead fusing[a]	10	51	51	54	166	–	–	133	33
Coding[b]	–	18	36	5	59	–	–	59	–
Screen print solder mask	23	28	–	41	92	59	–	–	33
Dry film solder mask[a]	18	28	41	90	177	54	–	123	–
Roller Solder coat	5	15	10	10	40	–	–	–	40
Profiling	46	191	173	80	490	2	–	311	177
Ovens	25	56	48	30	159	–	–	–	159
Multilayer laminate store	10	5	28	10	53	–	–	–	53
Press	36	54	5	59	154	–	–	93	61
Multilayer etch back	–	23	41	10	74	–	–	–	74
Flex coverlay	5	5	5	5	20	–	–	41	–
Microscopes	20	10	15	20	65	20	20	–	25
NDT thickness	20	15	25	20	80	10	–	35	35
Autotest	5	51	121	54	231	16	–	36	179
TOTALS	1170	1691	2781	1953	7595	1146	125	2513	3801
			Percentage of total expenditure			15.1	1.6	33.1	50.2

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage

TABLE A.3.
Thick film materials data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin (K£)			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A.	U.K.
Artwork Mats.	30	48	58	71	207	15	5	56	131
Substrates	356	586	856	1155	2953	198	118	1098	1539
Cermet inks	551	669	919	1594	3733	–	–	2268	1465
Beam lead Chip semi's[a]	203	277	408	550	1438	50	–	998	390
Encap. semi's	206	206	228	276	916	461	33	109	313
Chip caps[a]	250	268	362	357	1237	51	111	826	249
Encap. Caps.	62	67	67	67	263	25	–	35	203
Wires[a]	45	51	39	41	176	22	–	117	37
Solders	79	85	85	136	385	–	–	84	301
Packages[b]	309	493	631	831	2264	454	75	1689	46
Resins & Polymers [a]	43	87	85	111	326	15	5	232	74
Others[a]	80	116	210	210	616	450	–	–	166
Totals	2214	2953	3948	5399	14514	1741	347	7512	4914
	Percentage of total expenditure					12.0	2.4	51.7	33.9

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage
Negligible quantities of add-on resistors were reported.

TABLE A.4.
Thick film equipment data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin (K£)			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A.	U.K.
Clean Rooms	169	210	265	96	740	–	–	3	737
Artwork aids	37	14	11	24	86	–	–	37	–
Substrate Cleaners	5	53	54	52	164	–	–	20	144
Screen printers	82	86	111	150	429	–	–	158	271
Furnaces[a]	74	121	166	139	500	32	–	302	166
Resistor trim[a]	129	367	276	245	1017	20	–	813	184
Scribe[a]	62	57	52	55	226	73	–	142	11
Comp. attach[a]	31	66	158	109	364	18	10	274	62
Wire bonders[b]	80	90	142	96	408	–	–	400	8
Probers[a]	21	37	55	51	164	–	–	120	44
Circuit adjust	43	103	49	103	298	–	–	196	102
Funct'l test eq.[a]	115	308	286	214	923	11	–	603	309
Q.C. eq.	38	58	98	123	317	24	10	149	134
Encaps.	119	96	103	173	491	12	–	181	298
Leak det.	56	28	20	15	119	–	–	41	78
Marking	33	28	50	40	151	–	10	70	71
Others	25	266	209	265	765	33	–	147	585
TOTALS	1119	1988	2105	1950	7162	223	30	3656	3253
	Percentage of total expenditure					3.1	0.4	51.1	45.4

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage

TABLE A.5.
Thin film materials data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin (K£)			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A.	U.K.
Artwork Materials	11	11	11	16	49	–	–	25	24
Substrates[b]	33	53	53	66	205	–	–	205	–
Evap'n. sources	11	24	29	28	92	–	–	–	92
Pre-coated substrates[c]	98	98	118	168	482	449	–	33	–
Photoresist and developers[c]	21	21	21	25	88	20	–	68	–
Chemical etchants	20	15	15	15	65	–	–	–	65
Photomask Plates	11	11	11	15	48	–	–	20	28
Chip semiconductors	61	168	368	468	1065	–	–	780	285
Chip caps[a]	38	51	84	141	314	133	–	126	55
Other discrete applique devices	48	61	74	94	277	–	–	138	139
Bonding wire[c]	15	28	28	48	119	–	–	119	–
Epoxy	16	16	16	29	77	–	–	39	38
Solder Preforms[a]	10	23	23	43	99	–	–	79	20
Solder wire	6	6	6	6	24	–	–	4	20
Sub-carriers for s/c dice[a]	10	23	43	85	161	–	–	141	20
Packages[b]	103	198	248	373	922	–	–	856	66
Cleaning Solvents	38	38	38	58	172	20	–	–	152
Wire bond tools[a]	15	28	28	48	119	–	–	99	20
Expendable hand tools	21	21	21	21	84	28	–	8	48
Other tools[b]	11	11	24	24	70	–	–	66	4
TOTALS †	597	905	1259	1771	4532	650	–	2806	1076
Corrected TOTALS	398	604	840	1181	3023	434	–	1872	718
			Percentage of total expenditure			15.1		59.3	25.6

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage
[c]Items for which import level is 100% of total usage

Due to the lack of sensitivity of the Working Party's questionnaire in the range 1K – 10K£ the small number of replies received and the preponderance of replies in the 1K –10K£ range, the total material expenditures will appear high. The experience of the Working Party has lead to the correcting of these figures by applying a multiplication factor of 2/3 to the totals and these corrected figures have been used in the presentation (e.g. Table VII. Figure 7)

TABLE A.6.
Thin film equipment data

	Expenditure (K£)					Total Expenditure in terms of Country of Origin (K£)			
	1977	1978	1979	1980	Total	Europe	Japan	U.S.A.	U.K.
Installation clean rooms	211	47	161	119	538	–	–	5	533
Artwork materials	11	11	11	11	44	–	–	20	24
Layout aids	24	6	11	11	52	–	–	10	42
Photo red'n cameras	11	6	23	19	59	–	–	–	59
Cleaning systems	48	28	23	46	145	–	–	94	51
Driers and ovens	20	10	28	38	96	–	–	–	96
Loaders	10	10	10	28	58	–	–	10	48
Photoresist coaters	29	6	29	23	87	–	–	29	58
Exposure systems[a]	23	23	28	18	92	82	–	–	10
Resist developers	10	5	18	36	69	–	–	46	23
Selective etching[a]	10	10	18	18	56	–	–	46	10
Substrate holders[b]	10	10	16	11	47	–	–	47	–
Substrate scribe and cut	10	10	62	19	101	–	–	2	99
Resistor trim	223	218	243	38	722	–	–	300	422
Wire bonders	33	15	33	23	104	–	–	76	28
Eutectic die bonders	5	7	5	25	42	–	–	9	33
Component attch.m/c	33	28	20	15	96	–	–	51	45
Electroplate m/c	10	5	–	–	15	–	–	–	15
Measurement equip. & probes	43	61	29	43	176	1	1	116	58
Test equipment	103	98	136	155	492	40	–	39	413
Insp. devices & microscopes[a]	29	53	62	29	173	2	87	34	50
Environmental test	54	28	34	19	135	–	–	–	135
Package sealing[a]	24	28	44	39	135	–	–	119	16
Leak test equipment[a]	16	16	10	6	48	8	–	35	5
Package marking	11	10	6	6	33	–	–	10	23
TOTALS	1011	749	1060	795	3615	133	88	1098	2296
Percentage of total expenditure						3.7	2.4	30.4	63.5

[a]Items for which import level is >66% of total usage
[b]Items for which import level is >90% of total usage

In order to relate the figures in the above Tables A.1–A.6, to Figure 7 and Table VII, the following multiplication factors should be noted:

i) Ratio of received replies to total U.K. business
PWB 1 : 4
Thick film 1 : 1.7
Thin film 1 : 2

ii) Ratio of materials spent to output at sales value
PWB 1 : 3
Thick film 1 : 4
Thin film 1 : 3.6