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THE DESIGNER'S IMAGE

INAUGURAL LECTURE

Delivered at the University College of Swansea
on
21st October, 1975

by

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Department of Electrical
and Electronic Engineering

UNIVERSITY COLLEGE OF SWANSEA
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In preparing an Inaugural Lecture, a newly-appointed Professor has a number of alternatives. He may use the occasion to outline the boundaries of a new subject or Department, diplomatically but firmly staking out a claim to new territory in Academia. Alternatively, he may wish to justify a radical change in teaching an established subject, in the hope of convincing his immediate colleagues and the rest of the College that this is worthwhile. Or yet again he may take the opportunity of explaining his field of research or scholarship to the College and to the public-at-large.

Electrical Engineering is well-established here in Swansea, and in earlier lectures my predecessors have more than adequately justified its place on the academic map. Indeed, the subject is now so wide-ranging that the educator's problem might be seen more as what to leave out rather than what to include. The title for this Lecture will allow me to cover both the remaining alternatives. In the first part I will discuss the significance of *images* in designing objects or systems. Electronic techniques are providing new ways of creating images. I want to show you some of the developments of the past decade and to convince you of their significance for the designer.

But the title "The Designer's Image" has another meaning, and in the second part of the Lecture I will turn to more general questions about design and designers. What is our image of a designer, and in particular, how should he or she be educated ?

We know surprisingly little about mental images and the form in which they are held. People can retain and manipulate complex relationships without resort to external diagrams ; the actual form of representation is a matter for speculation and research. But engineers either individually or collectively need to put images in concrete form at an early stage, and a blackboard or its equivalent is an essential part of an engineering office or laboratory. An engineering student must learn the language of diagrammatic communication for his particular speciality, whether in electronic circuit schematics or mechanical drawings to give just two examples. Graphical communication takes advantage of the combined facilities of the eye and brain for processing spatial information and relating it to internal models.[1] While we may not understand the mechanics involved, the facilities are undoubtedly powerful. It has even been suggested that in the course of evolution, Man's linguistic ability has developed from his advanced visual processing skills, and that understanding a language is related to understanding images.[2]

Diagrams often correspond fairly closely to the physical appearance of the object or system being designed. But some bear little direct resemblance, because they serve to bring relationships or structure which would otherwise be hidden or at least obscured. This latter type are *abstract diagrams* and can be important in solving a problem. A simple example to bring out the contrast would be a photograph of an extended family, say spreading over several generations, along with a diagram of the corresponding family tree. The tree shows relationships which would not be apparent from the photograph.

Another example is that of an electronic circuit. Fig. 1. shows a *schematic* for such a circuit. It uses standard symbols for the components and shows which are connected together. In drawing it, an engineer should observe a number of conventions so that it may easily be understood by other engineers. For example, signals should flow from left to right, positive power supply lines should be at the top of the diagram and negative ones at the bottom. Connection lines should not cross one another and should preferably be either horizontal or vertical. These rules have nothing whatsoever to do with the final appearance of the physical circuit, but they help engineers to communicate more easily. The

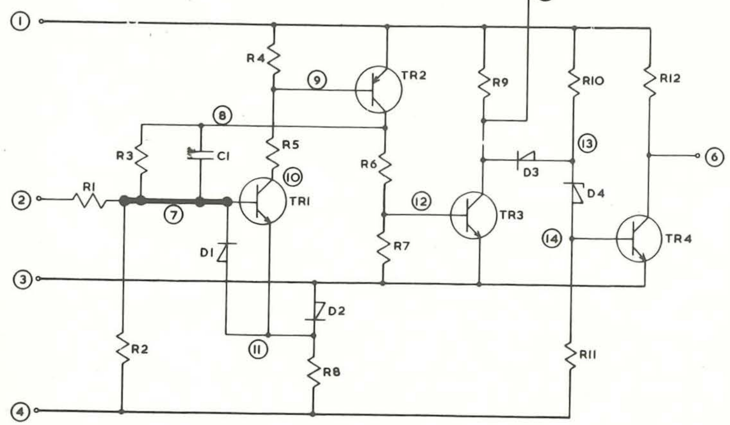

Fig. 1 Electronic circuit schematic

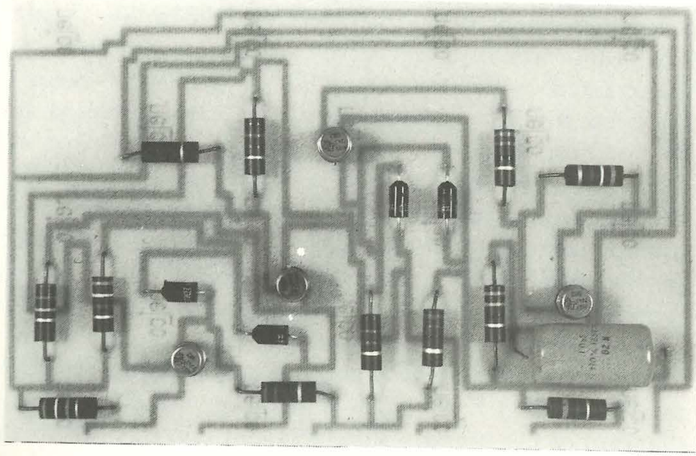

Fig. 2 Printed-circuit board

thick line in the figure identifies a set of components which share a common connection and I will refer to it again shortly.

The circuit may be manufactured in a number of forms, of which a common one today is the *printed circuit board*. Fig. 2 shows such a board, with the components mounted on one side and the printed interconnection pattern on the other. It is obvious that the pattern must lie in a plane, or otherwise some connections would be short-circuited. The board layout was in fact designed automatically by a computer program,[3] which took into account the planarity requirement amongst other factors. Fig. 3 shows the pattern of interconnections, and if we compare it with the original schematic there is little obvious similarity. But if we look more closely we find that the two diagrams are consistent. The set of thicker lines in fact corresponds to the common connection referred to earlier.

In the process of designing the layout, the computer developed what is mathematically known as a *graph*. The family tree is in fact a particular type of graph. For the printed circuit another type is required. Since it must be free of crossings, a *planar graph* is called for. In fact, the situation is more complicated in that the board has two sides, and there is no reason why a connection should not use the space under a component on the opposite side of the board. The graph the computer generated is called a *pseudo-planar graph*, and it can be represented internally by what is known as a *data structure*. The computer has of course no use for a visual representation of the graph, but it helps us to understand how the program works if we draw a diagram. Fig. 4 shows a diagram of the graph. The large dot corresponds to the common connection seen in Figs. 1 and 3. Of the three diagrams, the schematic and the graph are examples of *abstract diagrams* ; that is they bring out relationships not easily seen in the layout.

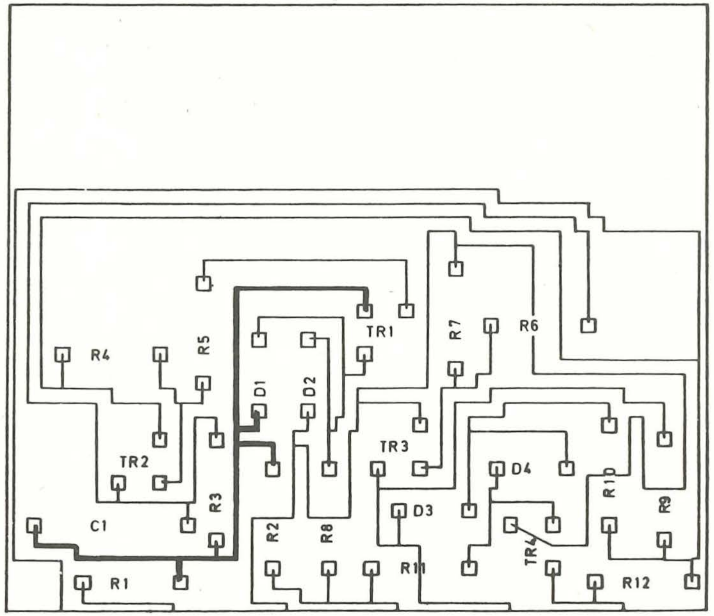

Fig. 3 Interconnection pattern

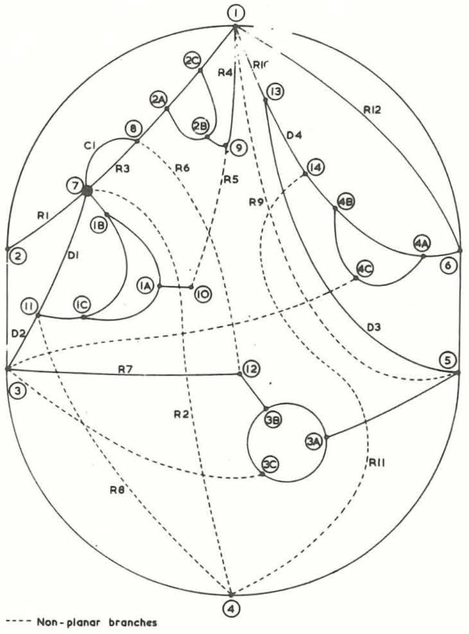

Fig. 4 Abstract graph for circuit

Images then are indispensable in engineering, and for any particular field engineers have built up sets of symbols and conventions, which taken together may be said to constitute a design "language" so to speak, for that field.

Over the last twenty-five years or so, the digital computer has been used to an increasing extent in design, particularly for routine and numerically-tractable aspects. In the mid-1950s, I took part in attempts to automate the design of large power transformers by computer. We are honoured by the presence here tonight of Professor Humphrey Davies, who was my research supervisor at that time. I would like to pay tribute to his foresight and stimulation of work in this and wider fields of power engineering.

The design of power transformers is a complex business, but by considering the detailed logical and numerical steps by which a human designer tackled the problem, it became possible to write down the details and later turn them into a computer program. The procedure was nothing like as straightforward as it might appear. It involved devising explicit methods for dealing with difficulties the designer took in his stride. For example he might have made a poor initial choice of arrangement or assumed a wrong dimension. Again some aspects were better handled by completely new methods for which the computer was particularly suitable and which were out of the question by hand.

The end result was an automatic method of design for a wide range of initial specifications, and a realistic and fairly detailed design could be generated without human intervention.[4] The computer method was particularly useful in preparing tenders for transformers, at which stage it is important to know that a design is feasible and to have a reasonable estimate of its cost.

But there were a number of drawbacks. It was difficult for an automatic method to match the human designer's ingenuity in devising complex geometrical arrangements or in using new materials. A more serious objection to automatic design was that, in the end of the day, responsibility for a design must rest in competent human hands, particularly in situations where the cost of failure is high, as with capital equipment.

About twelve years ago, two developments altered the situation very significantly. First it became possible to set up a close relationship between man and computer in which he could control the overall sequence of solving a problem, and supply information to a computer program when required. The concept of *interactive computing* was born. The second development was in *information display*. In view of my earlier remarks on images, it should be clear that if a designer and a computer are to form a working partnership, they should communicate in visual terms. In other words, the computer should be able to draw a diagram for the benefit of the user and also read in a diagram he has prepared for it.

Computer displays had an almost accidental beginning. One of our British pioneers of computing Professor F. C. Williams, invented a method[5] of storing digital information on the screen of a cathode-ray tube, and this method was used for the high-speed store of a number of early British and American computers. The store was intended to be private to the computer, although its contents could be observed by an operator.

Any patterns were in fact accidental, but soon users of the computer realised that the Williams' tube could be used for graphical presentation of results, provided of course that there was still enough room for the program and data as well. One early example which deserves better recognition, was by Grimsdale and Sinclare, who applied the Mark I computer to the design of electricity cable layouts for housing estates.[6] Part of the problem was to divide up the estate into areas of given electrical load and then to find suitable sites for the substations required. Fig. 5 shows a plan of an estate and the appearance of the Williams' tube as the computer divided up the

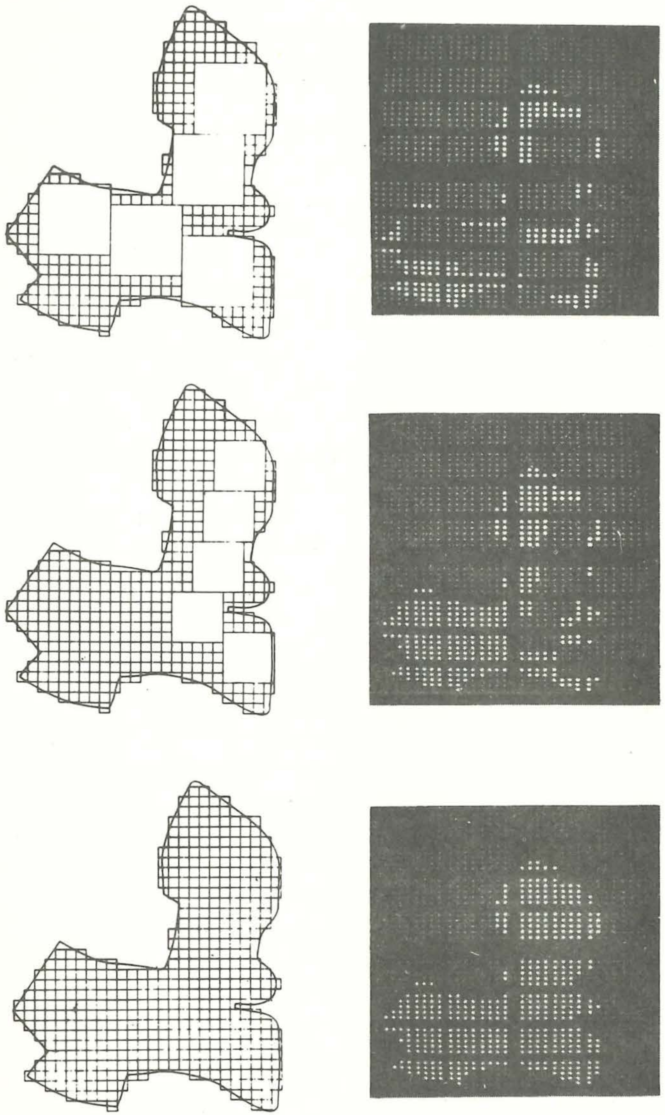

Fig. 5 Williams' Tube applied in housing-estate design (reproduced from Reference 6 by permission of the Institution of Electrical Engineers)

area. The computer worked out sites for substations on a purely mathematical basis, leaving the designer to modify these according to the realities of the estate concerned.

The first really significant combination of displays and interactive computing was made in 1963 by Ivan Sutherland, who carried out research for a Doctorate of the Massachusetts Institute of Technology[7] at one of its laboratories in Lexington Massachusetts. Two hundred years ago this year, a shot fired on the village green of Lexington "rang round the World" in starting the War of Independence. In 1963 an idea from the nearby Laboratory awakened the computer world to new possibilities. I want to recapture something of its impact by showing you a film made at the time.

> At this point the film ' Sketchpad ' (1963) was shown. It illustrated the use of a computer display and light pen in designing a simple bracket and rivet.

In this example and many others, Sutherland showed that a computer display was not merely a substitute for pencil and paper. It offered exciting new possibilities for displaying diagrams dynamically. Not only could diagrams be sketched into the computer—it could improve them as well. He showed that mechanisms could be simulated and even gave an example of bridge stressing.

In retrospect most of these examples were very superficial. As a design exercise the example of the bracket and the rivet is naive, almost to the point of absurdity. But the possibilities of man-machine cooperation had been established.

In fact Sutherland's work stimulated so much activity elsewhere without proper foundations in equipment and software that the inevitable collapse occured. After an initial flush of enthusiasm for a good new idea, serious difficulties became apparent. Investment fell off and ambitious projects were even scrapped. Eventually however basic technical difficulties were overcome, the corner was turned and since then new investment has gone steadily up.

An image on a flat screen may give an illusion of reality in several different ways and I would like to show a few examples, both simple and complex.

First the illusion of a *large working area.* A designer is never satisfied with the size of the screen he is offered. He *may* have achieved his most significant creation with nothing more than the back of an envelope, but when asked, he specifies an area the size of a typical drawing board—say, 40″ by 30″. The display designer asks the cathode-ray tube expert and finds that it is difficult to obtain a flat working area more than about 14 inches square due to the danger of the glassware *imploding*—that is the opposite of *exploding*, but equally dangerous. So the best we can do is to make the display appear to be a fourteen-inch square portion of a much larger diagram The illusion is fairly easy to achieve by *computer software*, in which case it takes time, or with *computer hardware* in which case it is expensive.

Although the real world is at least three-dimensional, electrical engineers are fortunate in being able to pretend for the most part that it only has two. For example a typical printed-circuit today would have printed wiring patterns on both sides of the board rather than only one as in my earlier example. The patterns would be joined together at the component pins or by extra holes which are plated with solder. Since the complexity is confined to the two planes we can concentrate on one at a time, and such problems are referred to as "having two and a half dimensions".

Life is less simple for most other engineering disciplines and for the architect, and so I would like to discuss means of producing illusions of *three-dimensional objects.*

The representation of three-dimensional space on a canvas has been a constant preoccupation for the artist from early times.[8] There is a painting by Simone Martini (Fig. 6.) from the 14th Century in which you can sense a struggle going on in the artist's mind between the inportance of the figures and their distance from the

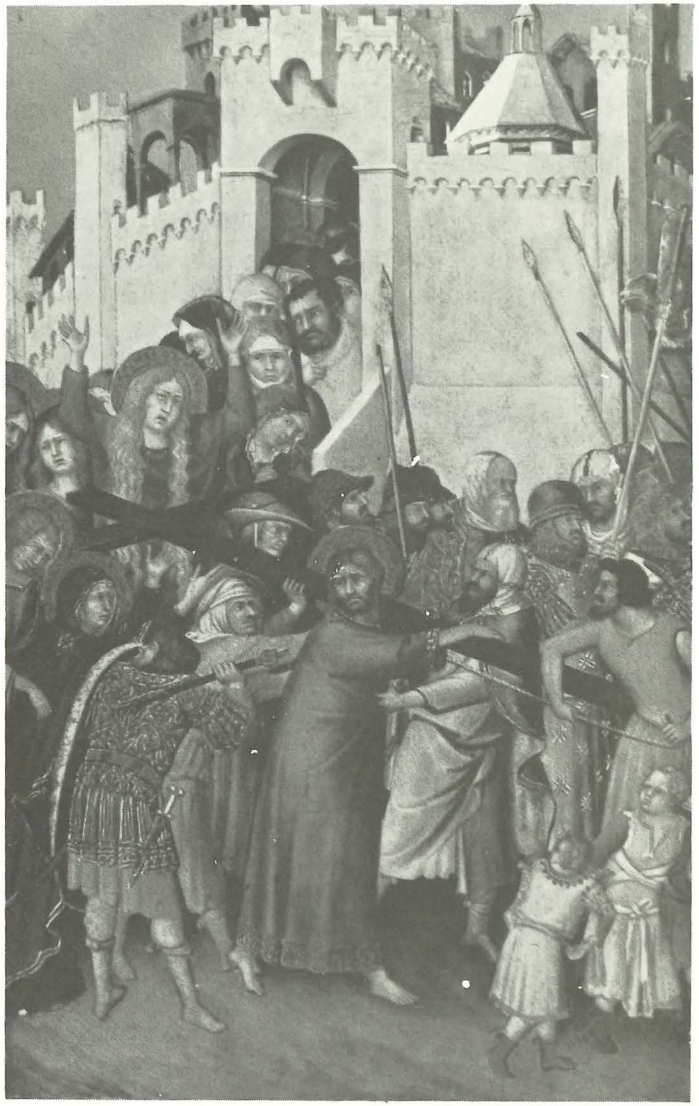

Fig. 6 "The Road to Calvary" Simone Martini c. 1340 (The Louvre)

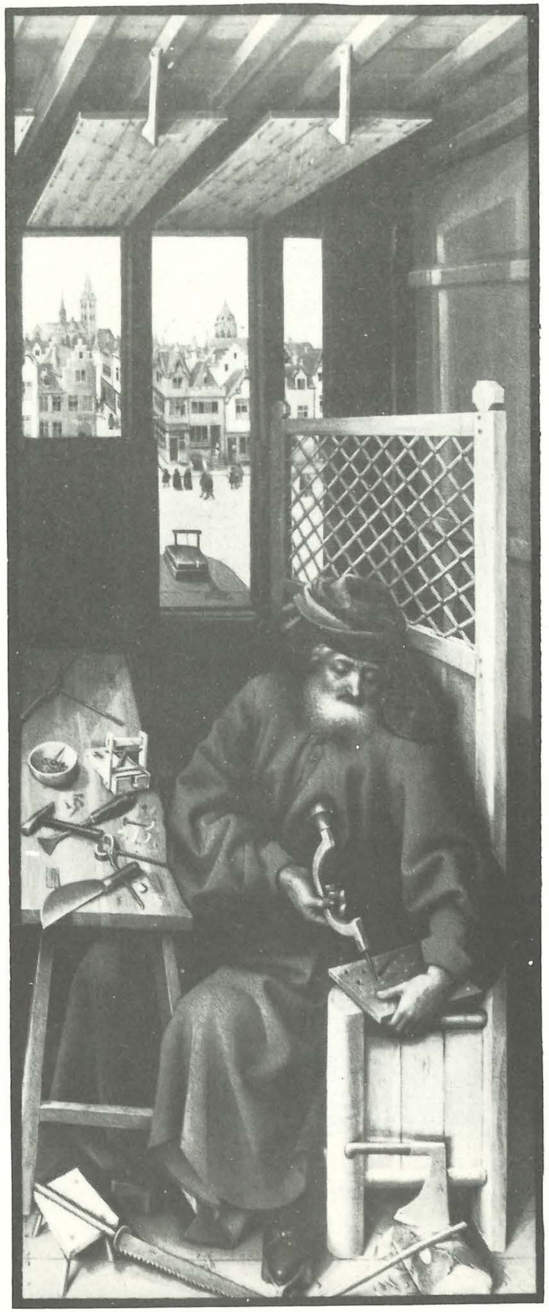

Fig. 7 Merode Altarpiece—right hand panel attributed to Robert Campin c. 1425 (Metropolitan Museum, New York)

viewpoint. We might say that the perspective is wrong somehow—indeed at the time the theory of perspective had still to be discovered. It is hard for us to imagine a world without photographs. About a hundred years later, Robert Campin painted an altar-piece. Fig. 7 is an illustration of the right-hand panel. I am told that the carpenter is at work making a mousetrap for Sin ! The sense of depth is certainly convincing and it is almost as if the artist introduced complexity in order to show off his newly-invented technique !

The theory of perspective makes it straightforward to calculate the coordinates of points in an image by mathematical transformations, and in the 1960s computer displays were set to the task. Fig. 8 shows in the foreground a view of a building as if it were an open wire frame. In the middleground the back lines of the solid building have been eliminated from view, and the result is more convincing. To suppress hidden lines is not as easy as it might seem. Even though the second view is recognisable it may be a poor substitute for a photograph of the real building in that it lacks colour and texture. Fig. 9 shows a textured or grey-scale view, which is even more difficult to compute and display.[9]

For most engineering design situations a set of line drawings is usually sufficient, but sometimes something more elaborate is required. For example, in engine design the shape of the manifolds can significantly affect performance. It has been known for two *different* shapes to be made from the *same* set of line drawings.

Since displays with colour and texture have barely begun to be used in design, I thought it would be better to illustrate the degree of realism that is now possible by taking an example from an entirely different field. It is extremely expensive to train pilots of aircraft and captains of large ships on the real equipment, not to mention the risks involved when abnormal conditions such as fog must be considered. For many years pilots have learned to fly "blind" by means of a trainer cockpit which never

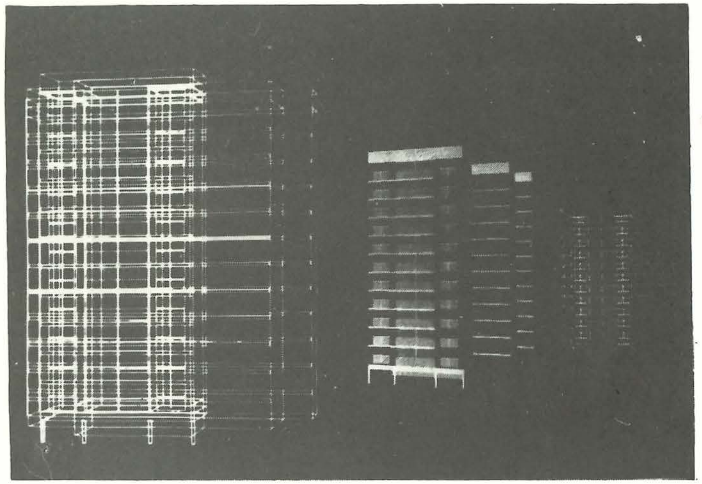

Fig. 8 Three blocks of flats—computer-generated view

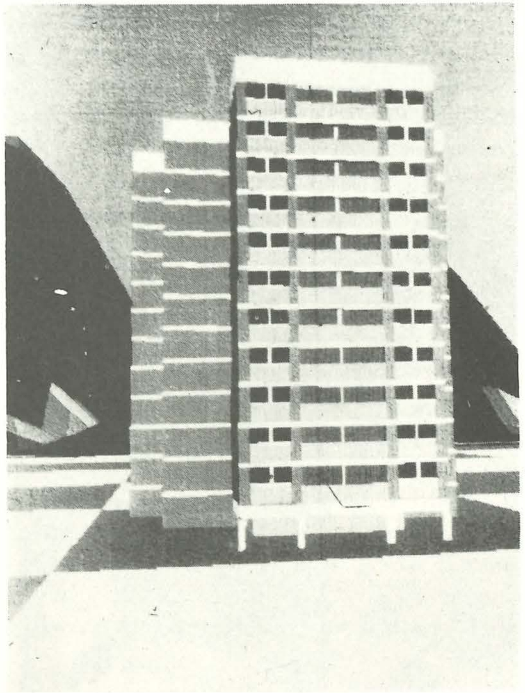

Fig. 9 Block of flats—grey-scale view

leaves the ground. It is fully-instrumented but the windows are blanked out. In landing an aircraft, visual clues are very important, and it has recently become possible to generate realistic views for the trainer windows.[10] The view generator produces a new picture every thirtieth of a second using data supplied by the flight simulation computer.

At this point a film was shown to illustrate the potential of computer-generated images in pilot training. It shows take-off and landings at Hancock Field Airport, Syracuse, New York and was generated from computer-stored data. Fig. 10 shows a still.

The degree of realism in the film could mislead one into thinking that the task is simple. To produce views which change instantaneously as the observer alters his viewpoint and which have convincing enough texture and colour, is a severe test for the display engineer. The equipment uses special-purpose digital systems which must operate at high speed. Other contributions come from mathematics, advanced computer programming, cathode-ray tube design and electronic circuits capable of steering an electron beam quickly and accurately over the path required.

Much remains to be done in display engineering, but we have already reached the point where at least one important industry relies on computer-driven displays for the design of its products. I refer to the *integrated-circuit* industry and to the design of medium-scale and large-scale integrated circuits—MSI and LSI in the trade. Fig. 11 shows the mask patterns for an integrated-circuit used in the measurement of flow in pipes. It was designed at Edinburgh University using the computer-aided design facilities for which I was previously responsible. Circuits of this degree of complexity and density can only be designed by the combined efforts of an ingenious human designer and his essential counterpart, the computer display, both of them served by a meticulously-accurate computer system.

Fig. 10 Simulation of aircraft approach to runway
(Note: it has not been possible to reproduce the clarity or colour of the original)

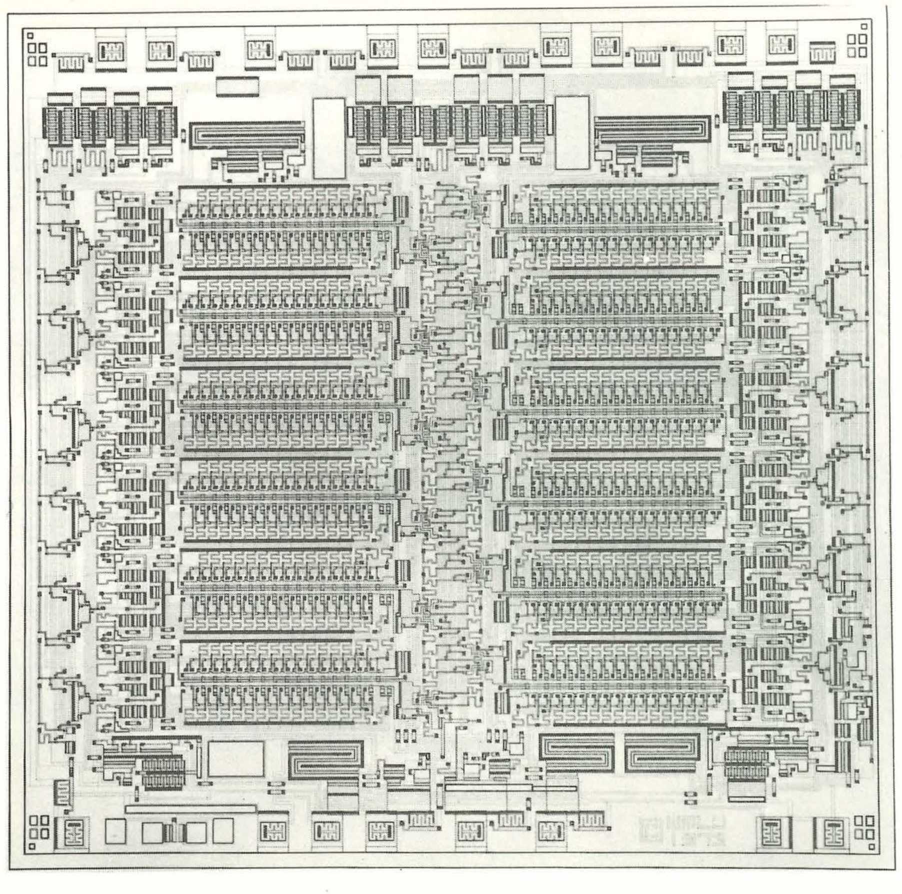

Fig. 11 Superimposed mask patterns for an integrated circuit

It is now time to turn from the high technology of electronic image-making to another interpretation of the title for tonight's lecture : "The Designer's Image".

Let us then consider the designer himself and what he does. What is involved in design as an activity ? What set of qualities is a good designer likely to have ? How can successful designers be trained ? Can they in fact be trained at all ? Where should they learn their craft ?

These are obviously not new questions, and the discussion of them has been going on for two hundred years at the very least. I am conscious of switching at this point from a scientific context in which in general the more *recent* a statement or observation the more likely its value, to a context in which almost the reverse may be true—the older a statement which has been filtered through the fine sand of human experience, the more likely it is to be profound. In the circumstances I wouldn't pretend to have final answers to the questions I have just posed, but I hope to contribute to the ongoing discussion. These questions are *academic* in the best sense of that word, but they are also important ones for our Country. It is commonplace to observe that one of our failings as a Nation is in turning a good research idea into its practical implementation.

The word "design" covers a wide range of activities—from the applied Art of the advertising world, where appearance is almost everything to the highly-technical world of integrated-circuit design, where appearance and even elegance count for nothing—for there is virtually nothing to see in the final product. I am sure you would understand my wish to confine the argument to engineering design, and to electrical engineering in particular. In doing so, I don't want to give the impression that engineering design is a dull affair. Far from it—there is plenty of room for individual flair and initiative in the face of technical and economic constraints, not to mention the satisfaction of producing a useful end product. I only wish we could get this particular message over to schools and careers teachers. I suspect that one of the reasons for the shortfall of engineering students is a failure to recognise that engineering is a *creative* as well as an analytical activity.

Design varies so much from one industry to another and from one project to another that it is impossible to give a universal and precise description of the steps involved. But for my purposes this evening I need to give a rough sketch—with a particularly blunt pencil—of a typical design sequence.

First the *OBJECTIVE*. The designer should start by defining the need to be fulfilled, or in other words the overall objective. It is important to pin down any vital details at this stage, and absolutely essential if design is a team effort.

Having an aim, he can proceed to the *CONCEPTUAL DESIGN* stage, in which he should examine the state-of-the-art. Perhaps the requirements are so similar to an earlier project that an existing design may be readily adapted. But this may be to stretch an existing method beyond its limits, and perhaps radically different alternatives must be considered. He is still at the conceptual stage but it is necessary to narrow down the choice to not more than a few alternatives. It simply isn't possible to ' back every horse in the race ' if you'll forgive the racing analogy. But quite often he can predict the performance in a fairly crude way yet sufficient to confirm that it is worth carrying on with one concept, while rejecting another.

The next stage is that of *DETAILED DESIGN*, in which all aspects of a practically-realisable design are worked out. These often include structural arrangements as well as the selection of types of components and their values.

From detailed design he may proceed to the stage of *PERFORMANCE ANALYSIS*. He is now in a position to estimate the performance of a design and to compare the results with the original requirements. Almost inevitably the design doesn't meet them and so he must go back either to detailed design again if the discrepancies are minor, or further back still if the situation is more serious. I must emphasise that in all these stages the design is only on paper.

From now on, it is hard to distinguish design from production but I wouldn't like to underestimate the importance of prototypes, production scheduling, testing and in the end convincing the customer that the design meets his requirements and that he can maintain it.

Let me reiterate that this has been a very rough sketch and it doesn't fit every case by any means. I hope it will be useful in relation to the ideas I am about to discuss.

You may have noticed that different kinds of thinking conceptual and analytical—are required, as well as a good overall strategy. Can we train people to be successful in these activities ? At this point I would like to quote some remarks by Lord Bowden,[11] based on discussions he had had with staff of his Institute :

> "There are a few things upon which all my staff were agreed. First of all, there is a very great shortage of good designers. Furthermore, many of the staff hold, with some heat, that designers are *born* and not made. I pointed out to them that the same sort of complaint is made by the manager of Manchester United about good centre forwards, and that the same complaint has been made to me by people who are trying to get good choristers or good violinists or good people to run anything. The truth is that good men are scarce, and an academic machine cannot create an ability which does not exist, but it can in some way develop and bring out an ability already inborn. A University career can make a man better fitted for a job for which he has some talent. It is extremely important that the university machine should do its best to educate a designer where he *can* be educated, but unless one starts with a good man, one will not make him into a good designer".

At this point two comments need to be added to Lord Bowden's remarks. First, the education of an engineer is incomplete without direct experience of industry. In the Universities we cannot hope to reproduce the realism of an industrial design situation, or to quote Dr. Johnson, "Depend on it Sir, when a man knows he is to be hanged in a fortnight, it concentrates his mind wonderfully". But in a science-based industry, on-the-job training in itself would neither be efficient nor sufficiently general as the basis for a life-long professional career. Second, engineering education is *not only* concerned to produce designers—there are other functions to be fulfilled as well in research, development, sales, operation and management. But I hope you will agree that the design function is the hallmark of *Engineering* as distinct say, from Science.

Having accepted that good designers are born rather than made, how should we set about educating them in Universities ? We ought to be acutely aware that the age range of students is one in which creative talent may flower or fade. It is well-known that unless a mathematician produces a significant paper in his early twenties he is very unlikely to make a major contribution later. You may be surprised to learn that Marconi, Heaviside, Kelvin and Ferranti all made their mark in their early twenties, Ferranti even before he was 20.

During the last decade or more, courses with an emphasis on electrical design have been dropped in favour of more basic scientific topics. Many of the old courses could be criticised for including too much detailed design of well-established equipment, and they do not appear to have been popular with students. It is clearly more important to equip students to meet the problems and possibilities they are likely to face in the next ten to fifteen years rather than to learn intimate details of today's—or more likely, yesterday's technology. Some engineering courses and departments have been re-named "Engineering Science" to emphasise their concentration on fundamentals. I would submit that to teach *only* the constituent scientific topics of electrical engineering to the exclusion of all else ignores both the nature of engineering and the aspirations of students. As someone once said :

> "It is improbable that Mozart would have been a composer at all, let alone the infant prodigy he was, had he been unable to practice his art of composition until he had completed a normal musical education at, say, the age of 22".

Let us examine the set of fundamental subjects at this point. At first sight these might appear to be fixed, but I believe that in the long-term the list is subject to change as the scope of the profession changes, and also the relative importance of the subjects themselves may vary. Electrical Engineering has continually widened its boundaries as new principles and applications have been discovered or invented. Our senior professional Institution stems from the Society of Telegraph Engineers, founded in 1871. It added "Electricians" to its title two years later, before becoming the "Institution of Electrical Engineers" in 1888. Its Royal Charter does not have any more precise definition of its subject than "electrical science and engineering and their applications".

Every student needs a basic understanding of the *phenomena* of electrical science and their underlying physical laws. He needs to know the laws governing the networks of electrical engineering and how to predict their behaviour. A few years back, the term ' network ' would have been understood as covering electrical or electronic circuits, with passive devices such as resistors and capacitors, along with active devices such as transistors and valves. Also power system networks would have been included as a rather special case. But now a new type of network has become prominent—that comprising elements which have only a finite number of recognisable states, often only two. I will refer to such

networks as *digital systems*. In one sense they are no different from electronic circuits and the underlying physical laws of operation are the same. But if we try to analyse them by the established methods of circuit analysis we soon become lost in a mass of detail, not to mention the enormity of the task. Instead, we can pretend for the most part that the elements are ideal and predict their performance accordingly. At another level of abstraction we may think of a particular digital system as a computer and use *algorithms* to describe what it does. As well as networks of digital elements, we may have networks of computer processors and related units. While all these networks are subject to the laws governing electronic circuits, we need to model and analyse them in different ways. Determining the laws of operation, or even *imposing* them on a digital system is an active research field, and one in which Professor Aspinall and his colleagues are at work. I wouldn't like to be caught poaching on his preserve, but the essential point I want to put across is that digital systems are now central to Electrical Engineering and must be considered when we try to determine what subjects are fundamental.

In case anyone sees this as special pleading for the computer industry, I want to give you some idea of current trends in major branches of electrical engineering, in particular instrumentation, communications and control, where digital systems are replacing older methods.

The Chief Engineer of the Independent Broadcasting Authority recently predicted that[12] in the next ten years practically *all* television signals will be in digital form, from their generation in the studio camera, through transmission networks, to the early stages of the broadcast transmitter itself. Already, remote station control and waveform monitoring are accomplished by substantially-digital systems.

Digital methods are revolutionising the telecommunication industry and this is now regarded as inevitable even for an existing telephone network such as ours, with its massive investment in analogue equipment. Another example is the microprocessor—the integrated-circuit form of a computer processor. It was recently estimated that the World market in microprocessors alone would be of the order of £70 million per year before 1980. This is not to count the remainder of each system in which a microprocessor plays a part.

Some of our recent graduates are already applying microprocessors and the pace is accelerating. Up till now complexity has implied cost. But with integrated-circuit technology this is no longer inevitable. For example the flow measurement chip I mentioned earlier is based on statistical operations which would have been far too expensive to implement with standard components, even standard integrated circuits. But now if sufficient numbers are required, a special-purpose integrated circuit may be feasible.

Apart from digital systems, I believe that an increasing proportion of our future graduates are likely to be concerned with *systems* than with individual devices. In well-established industries such as power distribution and telecommunications they may be concerned in improving the efficiency of operation or planning additional capacity at minimum cost. Most engineers should be aware of the social context to which large-scale engineering developments relate. I think it would be an advantage if engineering students could gain some experience of non-engineering but related disciplines and the ways in which their practitioners formulate and solve problems. Society increasingly wishes to know the likely effects of large-scale developments at the proposal stage, rather than afterwards.

We could usefully review the list of fundamental subjects to take account of both changes in technology and also techniques for analysing, and to a limited extent, for synthesising large-scale systems.[13] It will be particularly difficult to achieve these aims in the current situation of Universities, with few if any new staff and so little

interchange of staff with industry. This is all the more reason why Universities should try to be involved more in post-experience training in cooperation with industry, and re-training in particular. Perhaps we should consider the question of re-training University staff as well ?

I have interpreted the title of my lecture in two ways and now in this final section I would like to tie several ideas together. In my sketch of the design process I deliberately didn't mention the possibility of computer assistance. I wished to emphasise that creative design is very much an activity for human beings rather than computers. But there are aspects in which the computer can help, both in the design process itself and in the education of designers.

While a computer is no match for the flair of a good designer I believe it could be used more in giving him insight about the basic phenomena he wants to exploit. This is particularly important in electrical engineering. The computer display has an obvious role and I would like to see it used in the calculation and display of field phenomena of various kinds. The visual display could be more useful in this case than direct measurement in the laboratory.

At this point a film was shown illustrating the generation of ultrasonic pressure waves from a submerged electromagnetic transducer. It was made by Dr. H. N. Christiansen at the University of Utah and employed a finite element method for solving the underlying partial differential equations. The results were shown in three dimensions using colour to represent intensity.

If insight is what we are after, we must be careful to see that details of computer programming and operation do not stand in the student's way. Modern computer systems can help us to achieve this aim. We ought to explore the significance of visual design in engineering much further.

There are more obvious aids to the designer in the *detailed design* and *performance analysis* stages I mentioned earlier. Students could experience these aspects for relatively simple problems, and I believe that such techniques can be taught and experienced without over-attention to technological details. Moreover, students seem to enjoy the experience !

I hope in this Lecture to have given you a better image of the designer and a glimpse of new possibilities which are already with us or lie ahead.

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