process. At each stage, the scope for errors is large, and the failure rate at the quality assurance and testing stage is very high indeed. The more complex the microcircuit and the more densely packed the wafer, the more wastage occurs.

The first stage in testing calls for the entire wafer, with its many hundreds of identical integrated circuits, to be fitted into a computer-controlled rig that tests each circuit.

Nine chip-sized locations on the wafer are often reserved for testing purposes.

The test rig not only marks each reject with an ink spot, but also extracts information on failure rates for each wafer, locating failures within both the wafer and the individual chip and identifying specific faults.

Wafers are then cut into individual chips, and the rejects are extracted manually. The remaining chips are mounted on miniature metal stampings.

Connecting pins on the chip are hooked up to the stamping with very fine wires — again in a process controlled by computer — and the whole is sealed into a plastic or ceramic carrier, from which connecting pins protrude when it goes for final and more exhaustive testing.

Currently, the limit on the degree of miniaturisation, which lies in the photo-lithographic stage of manufacture, is the wavelength of light — around a two-millionth of a metre (20 millionths of an inch). Recent advances are centred on the use of X-rays, which will allow perhaps a 50-fold reduction in the size of microelectronic circuits.

Almost all aspects of chip manufacturing, from the design stage through prototyping, to mass production and final testing, are so complex as to be practically impossible without the use of the very devices that are being produced – a remarkable paradox!

The application of computers to the design process, for instance, allows sub-sections to be pre-defined and called up from memory each time they are needed.

Take the case of a random access memory (RAM) chip, where each individual bit is held in a single-transistor storage cell. To store 2 Kbytes the chip will need to contain an array of 16,384 identical cells. It is a simple matter for the designer to define the structure of a 'master' just once and then instruct the design computer to repeat it 16,384 times.

The use of computers in the design department is not limited to this useful but quite simple trick. Draughtsmen now work, not at drawing boards, but at Visual Display Terminals, and use light pens to 'draw' directly on to the monitor screen. The finished drawing is prepared by the design computer directly using a multi-colour plotter.

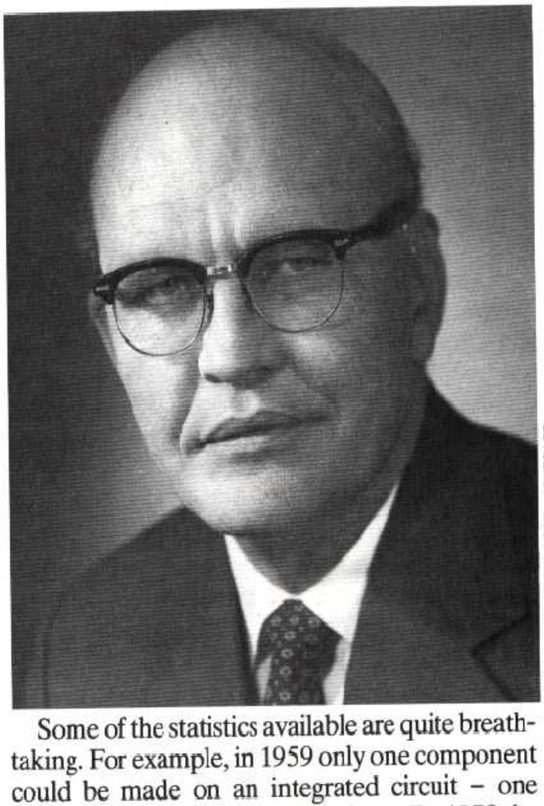
It's not only the graphic design process that is improved by mechanisation. On page 103 we describe the creation of a computerised model of an oil production field. This same modelling technique can be applied to circuit design, also, allowing the designer to try out a variety of different solutions before committing himself to a costly manufacturing process. By this method much of the very expensive trial and error prototyping can be avoided.

When we speak of the 'microelectronics revolution', we are talking about quantum jumps in speed and cost- and size-reduction. Perhaps, at this point it would be worth recalling the characteristics of a valve based computer:

Large physical size
Slow processing speed
High power requirement
Limited memory and instruction set
High cost

All these factors were affected by the discovery of the transistor (see page 46), but in terms of the manufacturing process, the computer industry was still a very labour-intensive, and hence, costly, business. Discrete components still had to be assembled onto Printed Circuit Boards.

It was the discovery of the integrated circuit – and more especially of the microprocessor – that allowed the industry to take full advantage of the advances in computer-controlled manufacture and processing.



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A Microelectronics Revolutionary
Jack Kilby is generally credited with the discovery of the integrated circuit while working at Texas Instruments in 1958. He constructed a single package, half an inch by a quarter that contained a number of transistors. Modern electronic circuits contain hundreds of thousands of devices in the same space

Some of the statistics available are quite breath-taking. For example, in 1959 only one component could be made on an integrated circuit – one diode, for instance, or one transistor. By 1978 the densest of Large Scale Integrated Circuits (LSI) had more than a quarter of a million components on a single chip. Over an even shorter period, 1973 to 1983, the cost per bit of computer memory has declined by a factor of twenty, and the use of electronics components of every type, world-wide has increased by a factor of one thousand. And these trends are likely to continue into the foreseeable future. It has been estimated that the number of devices used every year will increase one hundred-fold over the next three years.