ntegrated circuits, to a substrate that contains interonnections and passive components, the break-even oint depends on the complexity and the cost of the atachment process. Also, when it is possible to build so nuch circuit complexity into a silicon chip only 50 mils quare, it seems a waste of space to package these ciruits hermetically and separately, since the individual ackages take up so much space. Research is being done n packaging techniques. Within a year or two there will e integrated circuit packages that will not only contain lip-flops, logic gates, or half adders, but also will include ollections of these circuits for the production of funcional items.

At first, the complexity of these future packages will be ept low so that individual packages will contain elenents such as shift registers or binary or decade couners.

In one technique, Fig. 12, that may combine the best eatures of monolithic silicon with those of thin-film echnology, a group of aluminum bonding islands are laced on a glass substrate by photoresistant techniques. These islands are made about one mil thick so that the ilicon chips attached to them will be held above and lear of the substrate. Next, as shown in Fig. 13, thin-film components and interconnections are deposited on the glass substrate. Finally (Fig. 14), monolithic silicon circuits are flipped over onto the bonding islands where an aluminum–aluminum bond is made. In this case, two half adders and two flip-flops are bonded to the thin-film substrate to form one bit of a two-phase shift register. Many functional elements have been made by this promising technique since it offers a compact method for combining the best features of both monolithic silicon and thin-film circuitry.

An example of other packaging techniques being developed is shown in Fig. 15. This assembly contains several six-layer printed-circuit boards that will ultimately hold 16 silicon chips each. Each board has two signal planes and four voltage supply planes. After the boards are assembled with their individual silicon chips, they are stacked very much like the old "tinkertoy" project using vertical pins to make the interconnections between boards as illustrated. Using this technique, we have recently assembled a full parallel–parallel adder with look-ahead logic in a one-inch cube.

Certainly some packaging technique similar to the one just described is needed in order to take full advantage of the size of present-day integrated circuits.

Integrated circuits in military equipment

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The military effect on the progress of integrated circuits has been twofold. First, new technology has developed, some through the direct subsidy of military research and development, and much more through the company-sponsored research stimulated by this support. About $100 million of R & D expenditures escalated from an initial Government expenditure of $2 million. The second effect has been the military agencies' interest not only in using integrated circuits but also in providing the market and the motivation for suppliers to complete the development and establish the production capability to supply this waiting market. Military and space applications accounted for essentially the entire integrated circuits market last year, and will use over 95 per cent of the integrated circuits produced this year. Even in 1970, these applications may well be using as high a proportion as 55 per cent of the circuits produced.

The "Dick Tracy wrist radio" characteristics of integrated circuits are widely known, and there are tremendous size and weight reductions in electronic equipment using these techniques. In many applications, particularly those in which a ton of fuel is required for every pound of payload, these reductions are very important. This is not the only attribute, however, that motivated military agencies to use integrated circuits. Reliability is the most important single factor. We have data on two operating medium-sized computers that use integrated circuits. The first is the Apollo guidance computer, designed by MIT and built by Raytheon. It has accumulated 19 million operating hours on its integrated circuits, in which time two failures have occurred—an initial failure, and the other a failure, external to the package, that was caused by moving the computer. The second system, the MAGIC 1, an airborne computer built by the AC Spark Plug Computer Division, has accumulated $15^{1}/_{4}$ million hours with two failures. Fairchild's in-house life-test program, with 33 million total operating hours, has had a total of eight failures; of these, five accumulated during the first $6^{2}/_{3}$ million hours and only three occurred on more recent units during the last 26 334 982 hours.

These data are not extrapolated from accelerated tests, but are actual, observed operational failure rates, and include early production units in some cases. Considering the complexity of the function performed by these circuits, the integrated circuit equipment today is ten times more reliable than its discrete component counterpart. As new failure modes are identified and eliminated, we may see substantial improvements in the reliability figures.

Today's integrated circuit, with minor exceptions, is just as sensitive to nuclear radiation environments as were yesterday's transistor equivalents. In some military and space applications, this will place a serious limitation on integrated circuits that use conventional transistors for the active elements.

The most liberal way to measure integrated circuit cost is to neglect development expenditures and to consider the total mission—which includes initial cost, maintenance and repair, spare parts logistics, and delivery. For satellite applications, with their premium on weight, integrated circuits are cheaper to use than conventional circuits.

Prices of individual transistors supplied to military contractors range from $3 to $5 in small quantity. In quantities of 50 000 or more, unit prices vary from 75 cents to $2, depending upon transistor type. Tight screening and burn-in for higher reliability will increase these prices.

By comparison, if we consider only the transistors in an integrated circuit, typical prices are about $4 per transistor in small quantities; and in quantitites of over 50 000 prices of $1.50 to $1.75 are average. The reason for this lower cost is that the silicon chip size of a typical 12-transistor circuit can be smaller than that for the 2N1613 transistor.

Performance is another factor, and there are large areas of electronic equipment that cannot be equipped with integrated circuits. In general, the same limitations apply to integrated circuits and transistors. For example, we cannot replace the magnetron in the radar set, and it is difficult to make accurately tuned circuits in integrated form. However, many of the integrated circuit limitations are being overcome rapidly.

In developing any new technology, schedule slippages are expected. As an industry, we have a bad reputation in this area. There are many cases where component manufacturers have committed themselves to a delivery schedule for integrated circuits and have not met the deadline.

But as the range of circuits available as off-the-shelf items is expanded, the designers and manufacturers for the military market will find standard components much more compatible with requirements. And as the components industry gains experience with integrated circuits of special design, manufacturing and delivery schedules will be met on time.

Integrated circuits now satisfy many of the military and space requirements and there will be an increasing use of integrated circuits in military systems. Today, the advanced Minuteman, Apollo, Phoenix, and all new military digital computers use integrated circuits for the major part of their electronics systems. With higher reliability, lower cost, and better performance, many missions once considered too imaginative have become or are becoming both feasible and practical.

Integrated circuits in industrial equipment

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The commercial computer industry accounts for more than half of industrial electronics. Although none of the 1963 production equipment used modular circuits, all manufacturers are exploring their use for high-volume logic applications. The choice of modular circuits or discrete components in new computer design is difficult, and the decision cannot be made by comparing one component approach with another because the alternative circuits seldom have the same characteristics. Therefore, the choice must be made from a total systems standpoint.

Some computer engineers feel that propagation delay times of 5 ns are essential before integrated circuits can be considered at any price level, while others feel that there is a potential price at which today's performance level becomes attractive. A third undercurrent, particularly from some designers of large high-speed systems, pushes hard for propagation delay times of one nanosecond and under.

Forecasts indicate that the price level for semiconductor integrated circuits in the next three years will shift the balance of the performance vs. cost equation. Late 1964 price quotations, for quantities approaching 100 000, are in the unit range of $3 for a three-input AND gate. On a system cost basis, such prices will be lower than for comparable circuits assembled from discrete components. Most people in the industry believe that commercial machines using semiconductor integrated circuits should be available by the end of 1965.

There is even less unanimity of feeling in the computer industry regarding thin-film circuits. Some manufacturers, believing that the long-term cost of thin-film circuits is greater, and their performance less impressive, emphasize semiconductor circuits in their development programs. Others have large internal thin-film development programs. Thin-film circuits will most certainly be applied where lower volume and closer performance tolerances make their use more economical.

Considerable work has been done in very large thin-film magnetic memories in the order of 10^7 bits. Perhaps such assemblies will achieve the "penny-per-bit" cost objective for large-size memories.

The computer data-processing industry consumed over one billion signal-level active and passive components in 1963. Fig. 16(A) expresses that usage in terms of 35