of areas where additional effort must be applied. This type of conference offers us the ability to discuss training device technology in a constructive environment. We can focus attention of the technical problems which require resolution as well as report on the results of previously conducted research or engineering effort.

MICROELECTRONICS FOR TRAINING DEVICES

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In an article published in the February 21, 1966 issue of Steel Magazine, B. A. Jacoby of RCA neatly capsuled the case for integrated circuits—"In 1959, integrated circuits meant microscopic electronics—and scientists were interested.

"In 1961, integrated circuits meant more reliable electronics—and the military became excited.

"In 1966, a processing technology that is predictable, reproducible, and economical has made integrated circuits mean low-cost electronics—and an industry revolution is in the making."

The revolution predicted by Mr. Jacoby has indeed occurred—and on an extremely wide front. Today, we find that revolution well underway in the simulator and trainer industry. Goodyear Aerospace's conversion to microelectronics for training devices began around 1963 when the first RTL integrated circuits became available. The movement gathered momentum in early 1966 when the first general-purpose integrated circuit operational amplifier became available. The revolution—at least from the viewpoint of Goodyear Aerospace—will be apparent when we deliver to NTDC in early 1968 a trainer wherein 50 percent of the electronic "make" portion is integrated circuitry and 75 percent of the "buy" portion is integrated circuitry. Designs now in the form of laboratory breadboards indicate that by 1970 more than 90 percent of the electronics content of Goodyear Aerospace trainers will be integrated circuitry. The "why" of this revolution and the rapidity of its growth lie in three words—"low-cost electronics."

If miniaturization were the only point of interest in integrated circuits, their use in simulators and trainers would be limited, since the packaging techniques and size limitations presently requested by the market can be met readily with discrete components. If reliability were the only point of interest in integrated circuits, their use in simulators and trainers would be limited, since reliability requirements can be met readily with discrete designs.

No, the primary attribute of integrated circuits that makes it attractive to the simulator and trainer industry—in spite of obvious miniaturization and proved reliability—is cost reduction.

The cost reduction is not simply one of component prices—it is spread over the total system. But, in order to achieve the total system savings, a company must have first answered these questions—

1. How can integrated circuits be used?

2. What is the timetable for conversion?

3. How rapidly—and how effectively—can we educate and indoctrinate our development engineers?

My talk today will deal with the manner in which Goodyear Aerospace answered these questions and, in addition, will present some observations on the answers.

First, we were fortunate in that our transition to integrated circuits for trainers was based on more than six years of corporate participation in microelectronic device application. Corporate work in microelectronics started in 1961 under a Goodyear Aerospace-funded research and development program. Outside support for our continuing R&D program was obtained in 1962 when we joined the Army micromodule program as a subcontractor of RCA. In 1963 we were awarded the first of a still-continuing series of contracts by Marshall Space Flight Center for the development, fabrication, and test of special-purpose microelectronic circuits. Nineteen sixty-four saw a substantial increase in corporate R&D expenditures and an increased demand from NASA for microelectronic hardware. Also, that year, the company delivered the first of its microelectronic associative memory units to the Navy—an NTDC search memory designed to interface with the AN/USQ-20 computer. Hardware contracts in 1965 included a second-generation associative memory system for Rome Air Development Center, an associative list selector for the same customer, and a nondestruct readout memory, customer and use classified. We are engaged currently in the development of integrated circuitry for the gimbal servo electronics of the Saturn guidance platform.

I note this six-year background of experience as the basis for my opinion that any company only now considering, for the first time, the use of integrated circuits in their equipment might find it best to prepare instead for the entry of large-scale integration.

Goodyear Aerospace is now using integrated circuits in trainers to the maximum extent permitted by technical feasibility and cost effectiveness. Circuits now assembled in-house are 75 percent integrated. Our emphasis on integrated circuits extends even to retrofit and modification programs. The A-6A weapon system trainer is a case in point. This trainer was designed in the early 1960's and is primarily transistorized. As part of our current A-6A update program, we are implementing microelectronics in the retrofit circuits using monolithic analog devices such as operational amplifiers and comparators. Another case in point is our 15C4D radar classroom trainer update program. Here we are increasing the scope of simulation by 25 percent. Yet by providing only 40 percent of the new electronics in the form of integrated circuitry on doublesided boards, we are able to incorporate the additional simulation in the existing cabinets.

Integrated circuits can never be applied in a one-to-one element correspondence with discrete devices in a circuit. In general, the elements of integrated circuit components, active and passive, are unequal in most respects to their discrete counterparts. The basic attributes of integrated circuits are exploited by developing symmetrical circuits in which absolute values are not as critical as their ratios to one another, and by taking advantage of the extremely low cost of mass producing total "active-passive" circuits of compatible elements. This means that circuit designers who have been raised on a philosophy of using low-cost passive devices have difficulty in adjusting themselves to integrated circuit design concepts, which substitute large quantities of very low-cost active devices to perform equivalent functions.

In some cases it is difficult for the individual to retrain himself. At the same time, it is equally difficult for a company to accept the loss of the individual's talents. In recognition of this situation, Goodyear Aerospace embarked on a program of self-help for its technical people. The program includes: eight-week courses on integrated circuit technology for our managerial staff; sixteen-week courses on integrated circuit applications for our line engineers; classes for line engineers to permit personal access to computer-oriented circuit analysis using the electronic circuit analysis program (ECAP) routine; lecturers from universities to present courses in their specialties to our technical staff; and lecturers from our corporate staff to present courses in specialized fields not yet adaptable to a college curriculum.

However, education alone does not provide the means for a company to become competitive in this field of technology. Unless laboratories are provided and special advisory groups are formed, the interest of the newly trained people lags. In recognition of this, Goodyear Aerospace has installed three major facilities for engineering purposes. The first is a clean room with capability to mount and interconnect dice and prototype integrated circuits. This facility fabricates all specialized circuits for the staff, permitting them to quickly evaluate their ideas. The second facility provides the generation of the accurate artwork required for fabrication of multilayer boards. This involves the use of an IBM 360 to program layouts and a computer-controlled Gerber drafting machine. Thirdly, to encourage the use of production-oriented schemes, Goodyear Aerospace has a small multilayer board facility for the engineering staff that complements the production facility for multilayer boards. This facility offers finished multilayer boards on a one-day turn-around basis.

The engineering microelectronics laboratory, the engineering multilayer board facility, and the conventional electronic production facility have been adequate to meet our electronic manufacturing requirements. However, as had been anticipated, the ever-increasing demand for high-density circuit boards to package flat packs, LSI, and cordwood modules with extremely close tolerances forced consideration of the need for expanding manufacturing facilities. After a year of research, planning, and investigation of techniques, equipment, and facilities, Goodyear Aerospace designed and built one of the most modern and functional microelectronic fabrication facilities in the country. This facility is scheduled to go "on-stream" in February of 1968. It is a totally integrated circuit-board fabrication facility including microweld operations and small parts precious-metal plating capabilities.

Production capabilities include standard and precision single-sided, double-sided, through-hole plated, eyeletted, and multilayer printed circuitry. Finished size capability for multilayer board fabrication is 18 inches by 18 inches with a total production capability of 225 square feet per day on a three shift basis.

As may be recalled, the justification for introduction of integrated circuits to trainers was based on cost. However, I do not wish to sweep aside as nonessential the question of reliability. Basically, the reliability of an electronic circuit is determined by the number of active and passive components plus the number of interconnections between the components. Therefore, the monolithic circuit should be and is much more reliable than the equivalent number of discrete components.

The demonstration of the improved reliability in quantitative terms, however, is not easy. Reliability engineers are thoroughly aware of this fact and it would be somewhat redundant for me to list all the problems involved. I propose, instead, to note that the question of reliability preceded the question of cost and to mention our solution.

Three years ago, Goodyear Aerospace formed a Reliability and Components Application Group within the Reliability Engineering Department. They serve as a clearing-house for all integrated circuit data and as a checkpoint for all use of integrated circuits. Their analysis of integrated circuit vendor data, their test of integrated-circuit vendor materials, and their personal survey of integrated-circuit vendor manufacturing facilities and controls are incorporated in a continually updated internal document that rigidly controls the use of integrated circuits within the company.

Now, let me whet your appetite with these observations:

1. The low price of extremely sophisticated integrated circuits permits the "quality" of the simulation itself to be improved. We can show specific examples where—at lower cost—frequency response, gain, stability, and signal-to-noise ratio are improved. More and better simulation can be incorporated at lower or no additional cost.

2. The availability of many versatile integrated circuits has permitted three circuit designers to do the work that previously required ten.

3. The requirement for fewer people doing circuit design has led to more cooperation in information exchanged. This situation leads to fewer interface errors, deletes redundancy between sections, yields more uniform selection of component and power supply requirements, and causes fewer in-process changes in hardware.

4. The different integrated circuits can be purchased in standard identical packages regardless of their circuit function. This reduces the cost of test and mounting fixtures and simplifies the training of inspectors and assemblers.

5. Integrated circuits, for all practical circuits, perform a well-defined function over a specified temperature range. Therefore, the devices can be tested in the final mode of operation with great certainty; they will act accordingly in the circuit. This one test replaces the cost of inspecting, testing, assembling, and circuit evaluating twenty to thirty discrete components.

6. The foresight on the part of the digital integrated-circuit device manufacturers in standardizing on the pin locations for the power supply leads of the dual in-line packages and flat packages has opened the door to the economical use of multilayer boards. The use of a simple multilayer board with buried power supply planes is very attractive. The buried supply and ground planes provide a signal-to-noise improvement through reduced coupling; the board designer now has three degrees of freedom to avoid crossing signal leads by keeping multiple power supply leads which run to each and every package on separate inner planes. In special cases, both outer layers of the board can be kept free for signal leads, permitting use of standard boards that can be prepared and stocked, in advance, requiring only that signal leads be etched when needed. Also, more devices can be located on the same size board, facilitating assembly interconnection and testing of subsystems.

It may be seen from the foregoing that Goodyear Aerospace is firmly committed to maximum use of integrated circuits in training devices. Not so obvious, perhaps, is the impact this technology will have on NTDC specification documents, including 40-1.

In conclusion, I would like to emphasize the following points:

1. Goodyear's interest in, and implementation of, integrated circuits for training devices is based on more than six year, of corporate experience in microelectronic applications.

2. In spite of undeniable advantages in miniaturization and reliability, the primary reason for use of integrated circuitry in trainers is their low cost.

3. The use of integrated circuits in trainers must be accompanied by concurrent monitoring and control of integrated circuit use by an independent reliability engineering group within the company.

4. The use of integrated circuits in trainers offers such undeniable advantages that appropriate steps should be taken by both NTDC and the trainer industry to recognize formally the peculiar nature of this technology and to provide the avenue for its maximum exploitation.

NTDC has shown consistently their ability to lead, guide, and direct the trainer and simulator industry. We look forward to the same degree of leadership during the microelectronics revolution.