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THE USE OF SOLID CIRCUITS IN SATELLITE INSTRUMENTATION

by Edgar G. Bush

Goddard Space Flight Center

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SUMMARY

An Optical Aspect Computer for the forthcoming Interplanetary Monitoring Probe has been designed and constructed with SN510 and SN514 solid-circuits used as binary counters, flip-flops, and inhibiting circuits.

The results obtained during the development and testing of the computer indicated that these devices have advantages over other types of logic components and are particularly suitable for spacecraft flight hardware applications.

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INTRODUCTION

Integrated Circuits may be expected to have an increasing impact on all types of future electronic instrumentation. In particular, satellite instrumentation has much to gain from the use of integrated circuits: compact, reliable instrumentation can now be easily built that was beyond the realm of practicability before the event of these components.

This report is in the nature of a progress report on experiences and techniques derived during the development of what will probably be the first NASA unit using integrated circuits to be put into orbit. The integrated circuits to be discussed are Texas Instruments corporation solid circuits.

Many favorable features are offered by the various types of solid circuits, such as small size and weight and significantly fewer external connections needed for assembly on a printed circuit board or welded module as compared to the number required for a comparable transistorized circuit. For example, the assembly of a two transistor binary counter requires at least 22 connections on the board; the same function can be performed by a solid circuit with six. A strong argument for solid circuits is the fact that a complete system can be mounted on one printed circuit card that would require three such cards for conventional transistor circuitry. The elimination of numerous unreliable pressure-type contacts between cards is alone a very desirable feature.

The main *dis*advantage of solid circuits is their greater power drain over comparable transistor circuitry. A less tangible disadvantage is the lack of any precedent to follow in designing flight hardware circuitry using solid circuit devices—and a natural reluctance to substitute new devices for their flight-tested transistor counterparts.

BINARY COUNTERS

During the preliminary work with solid circuit binary counters, some difficulty was encountered in designing a transistorized input circuit. A positive input voltage signal is required by a SN510 binary counter (Figure 1), and triggering occurs when the positive signal voltage drops toward ground potential. Reliable triggering requires that the signal voltage amplitude be somewhat less than the supply voltage, V_{cc}, to the binary. Figure 2 shows input circuitry that has actually been used in

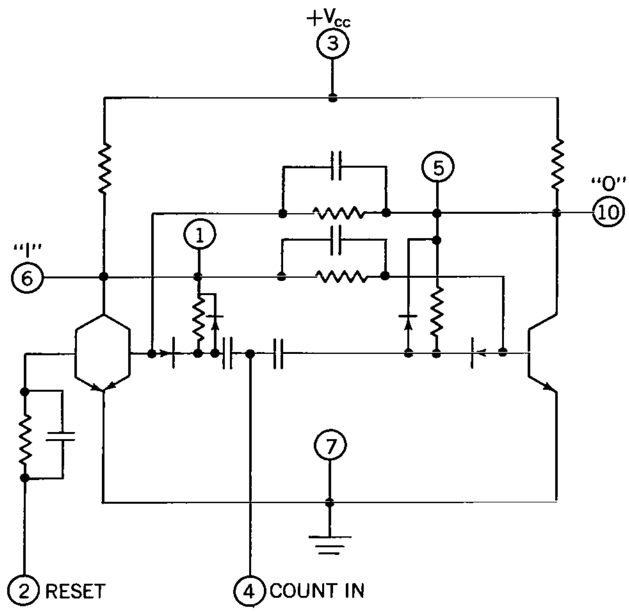


Figure 1—SN510 solid circuit used as a binary counter.

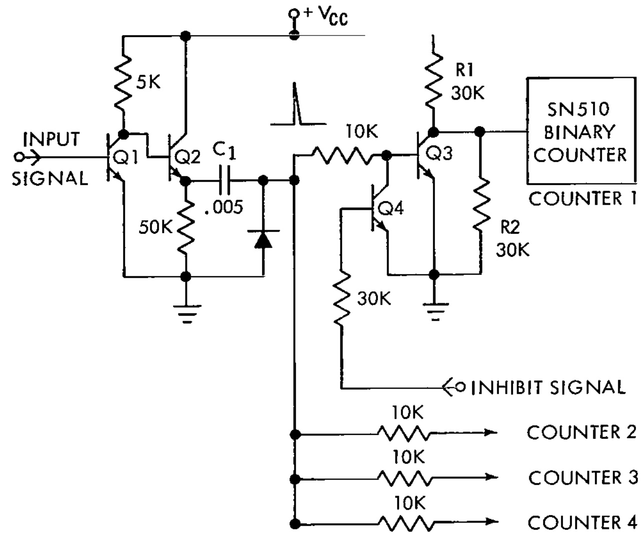


Figure 2—Input circuit to SN510 binary counters.

flight hardware. It can be seen that the signal voltage requirement here is met by the voltage-divider action of R_1 and R_2; the voltage at the collector of Q_3, which is the input signal, can never exceed $V_{cc}/2$.

In Figure 2, transistors Q_1 and Q_2 and capacitor C_1 produce a positive pulse to drive the input transistor to each counter. The purpose of the inhibiting circuit at the base of the input transistor is to stop the count at a time determined by gating signals. Since the collector-to-emitter voltage of the inhibiting transistors is in the order of 0.1 volt when the transistor is biased *on*, and since the offset voltage (the base-to-emitter voltage of the input transistor) is in the order of 0.5 volt, an inhibitor of this type is positive in action.

A unique type of counter shown in Figure 3 requires input circuits to both the first and second stages. The function of this counter is to count at the signal input rate until signal A is received and then count at half that rate until cut off by signal B. Since each input transistor of this counter has two independent inhibiting circuits, a single SN514 solid circuit was used to perform these functions instead of four transistors.

SET-RESET FLIP-FLOPS

A SN514 Texas Instrument solid circuit is shown in Figure 4. This circuit can be set to the "1" or "O" state by the application of a positive voltage to terminal 1 or 5 respectively. The set signal can be effectively gated or inhibited by the external transistor Q_1. Alternatively, the transistor Q_1 can be eliminated and signal inhibition obtained by connecting the inhibiting voltage to terminal 6, if no inhibiting is allowed to occur after a signal pulse has set the flip-flop. If inhibiting *is* allowed during this period, the flip-flop will be returned to the reset state. Both inhibiting modes are useful.

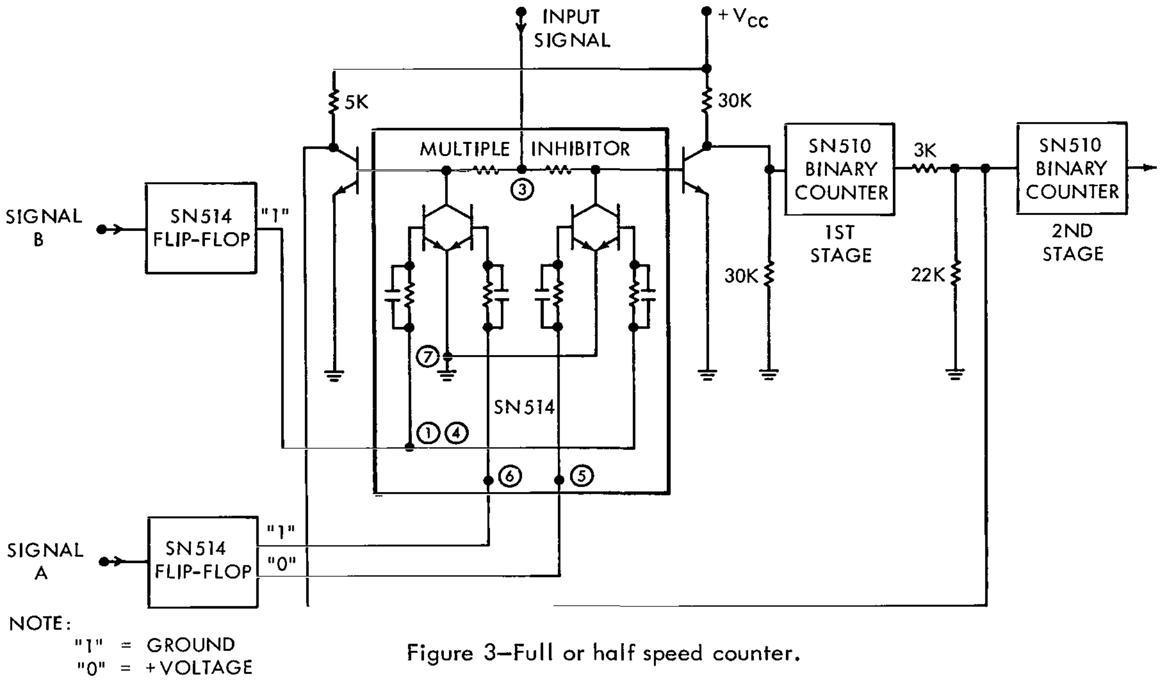


Figure 3—Full or half speed counter.

THERMAL EFFECTS

Figures 5 and 6 show the value of the collector load resistor and the base input resistance respectively of a SN512 solid circuit as a function of temperature.* These diffused resistors have a large positive temperature coefficient, approximately doubling in resistance value from -50°C to 100° C. Therefore, unlike conventional transistor circuitry these components consume more power cold than hot.

Figure 7 is a plot of the power dissipation vs. temperature of a SN510 solid circuit connected as a binary counter. Except for power dissipation, the temperature in the range -50°C to 80°C has little effect on the operation or stability of any of the previously described circuits and in no instance has temperature compensation been necessary.

BREADBOARDING TECHNIQUES

A breadboard circuit using solid circuits can easily be constructed by mounting each

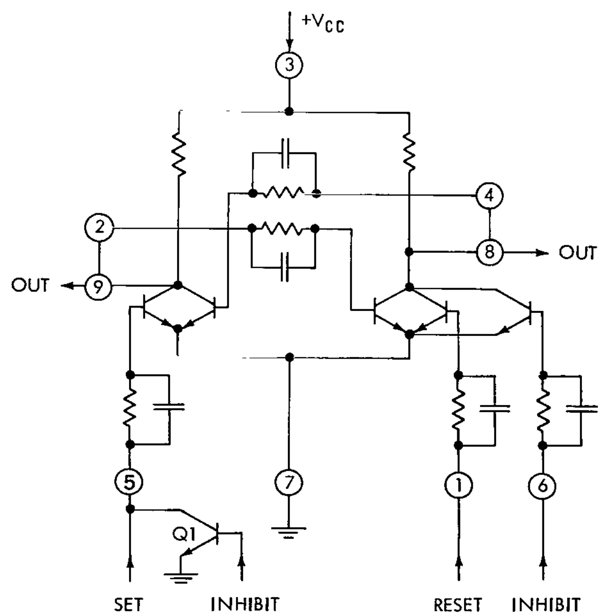


Figure 4—SN514 solid circuit used as a flip-flop.

*These measurements were made by R. Cliff and D. McDermond.

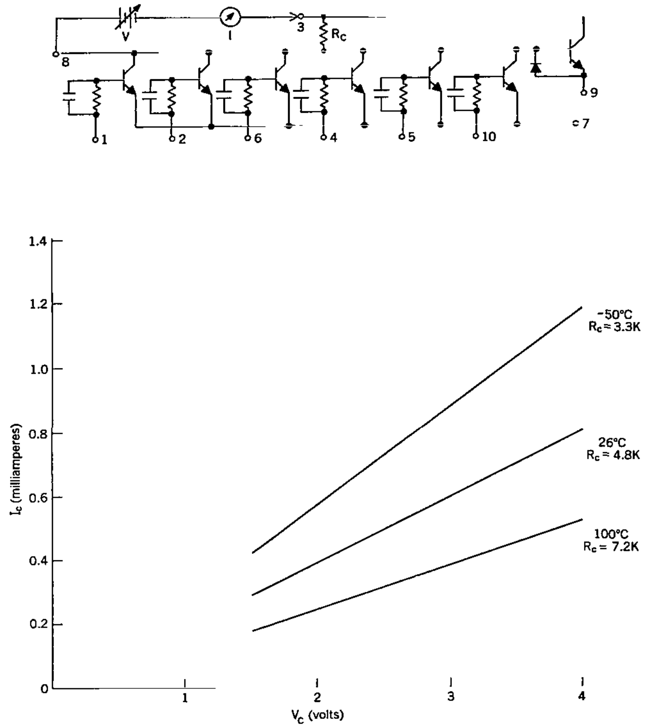


Figure 5—Collector resistance of the SN512 solid circuit.

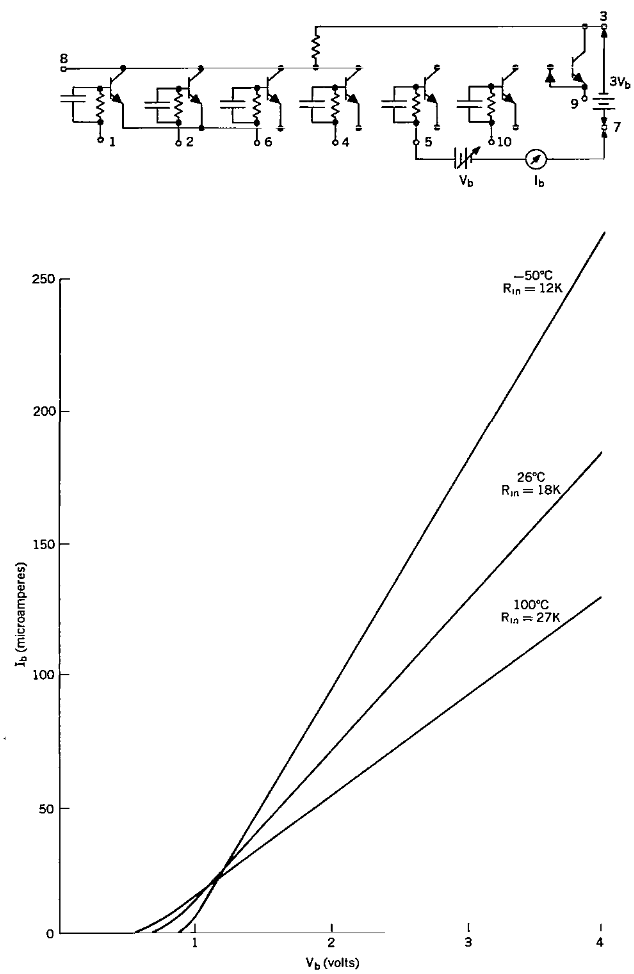


Figure 6—Input resistance of the SN512 solid circuit.

solid circuit on a card supplied by the manufacturer and interconnecting these cards in a conventional manner. No special techniques, skills, or equipment are needed to work with solid circuits and the tabs for external connections will withstand a reasonable amount of flexing and stress. Certain advantages are gained by using solid circuits in circuit development or breadboarding for switching type circuits or logic networks. Since each solid circuit is a complete unit with components such as capacitors, resistors, and diodes diffused on the same silicon slab as the transistors, the assembly of any system which can employ such devices is greatly simplified. A system that would require three breadboards for conventional components can be mounted on one breadboard by using solid circuits, eliminating the need for interconnecting cables. The time required to assemble a circuit with conventional components is in the order of 10 times the period required to assemble the same circuit using solid circuits.

IMP OPTICAL ASPECT COMPUTER

All of the previously described circuits are used in the IMP optical aspect computer system, a block diagram of which is shown in Figure 8. Figure 9 shows the finished printed circuit card. The solid circuit devices are mounted on submodules (Figure 10) which are inserted into Digi-clips on the large printed circuit board; the Digi-clip connections are soldered before potting. This system can operate with a supply voltage tolerance of ±50 per cent from a nominal 3.5 volt supply, an input signal voltage range of ±30 per cent from a nominal 6 volt value, and over the temperature range -20°C to +80°C.

During testing, it has been noted that the solid circuit binaries and flip-flops are at least as good as their transistor counterparts with respect to stability in the presence of noise pulses, such as those generated by bench top temperature test chambers.

The majority of the active components used are contained in SN510 and SN514 solid circuit packages. Conventional transistor circuits were employed where it was not convenient to use solid circuits and where, in critical circuits, the question of reliability arose. The excellent quality of the SN510 and SN514 solid circuits is confirmed by the fact that although these components were assembled as received from the manufacturer (without tests), in no instance was it necessary to replace a unit on the prototype card.

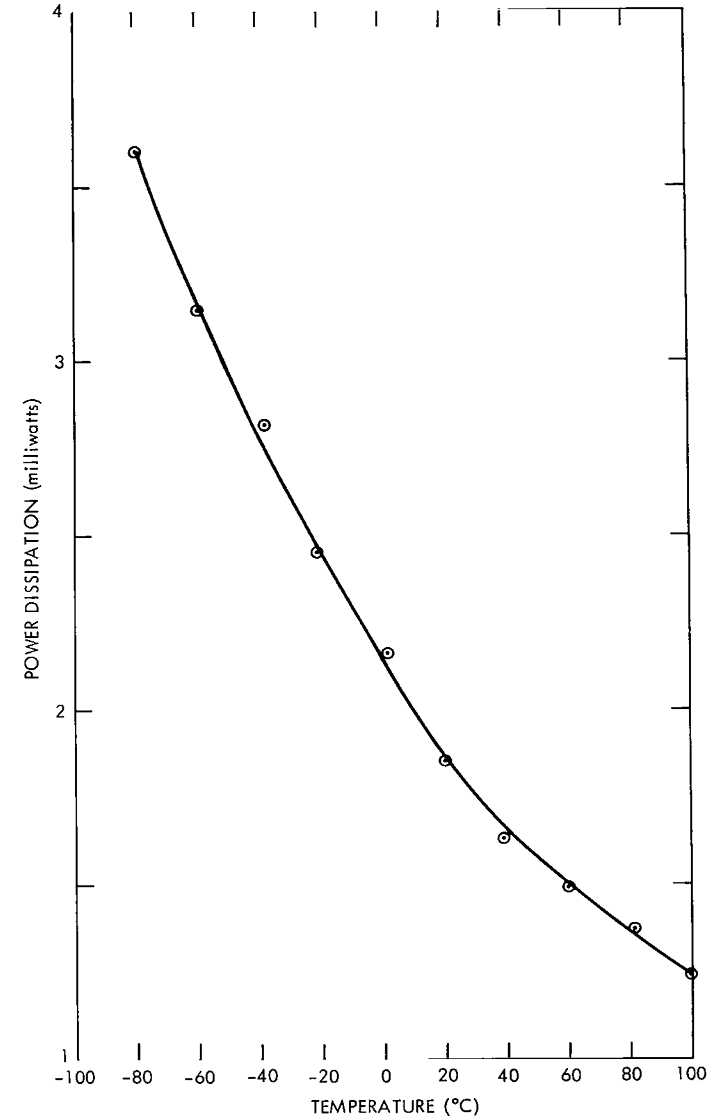


Figure 7—Power dissipation of the SN510 solid circuit connected as a binary counter; V_{cc} = 3 volts.

The fact that both the SN510 and the SN514 units dissipate 2 milliwatts with a 3 volt supply at 25°C as compared to 1/2 milliwatt by their complementary-symmetry transistor counterparts is the main disadvantage in using these devices in flight hardware. In the design of the optical aspect computer a transistor switch disconnects the 3.5 volt supply from all circuits, excepting one flip-flop and two transistors for 4/5 of the time of one sequence of the encoder. This cuts the power drain by a factor of 80 per cent. The peak power dissipated by the system is approximately 150 milliwatts.

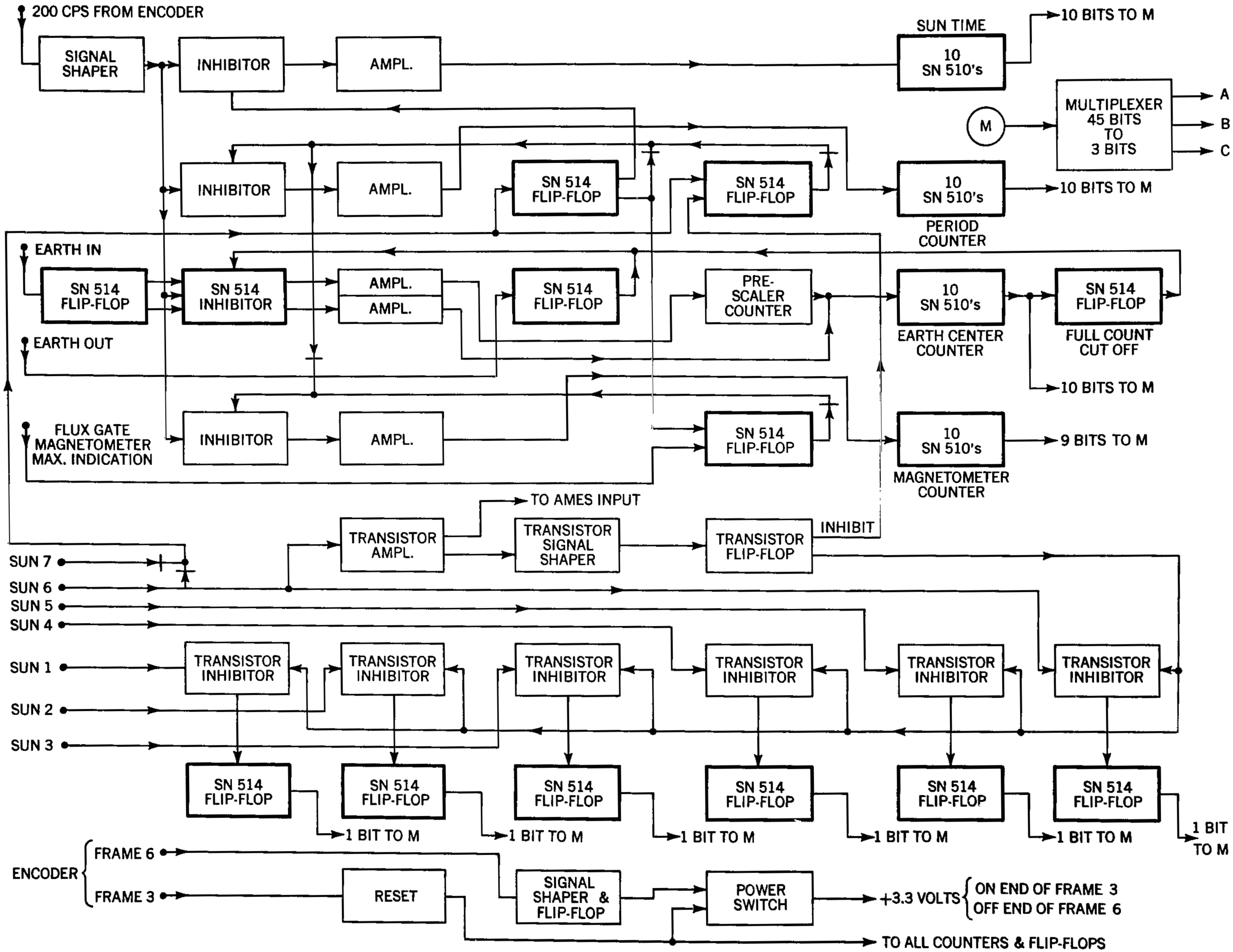
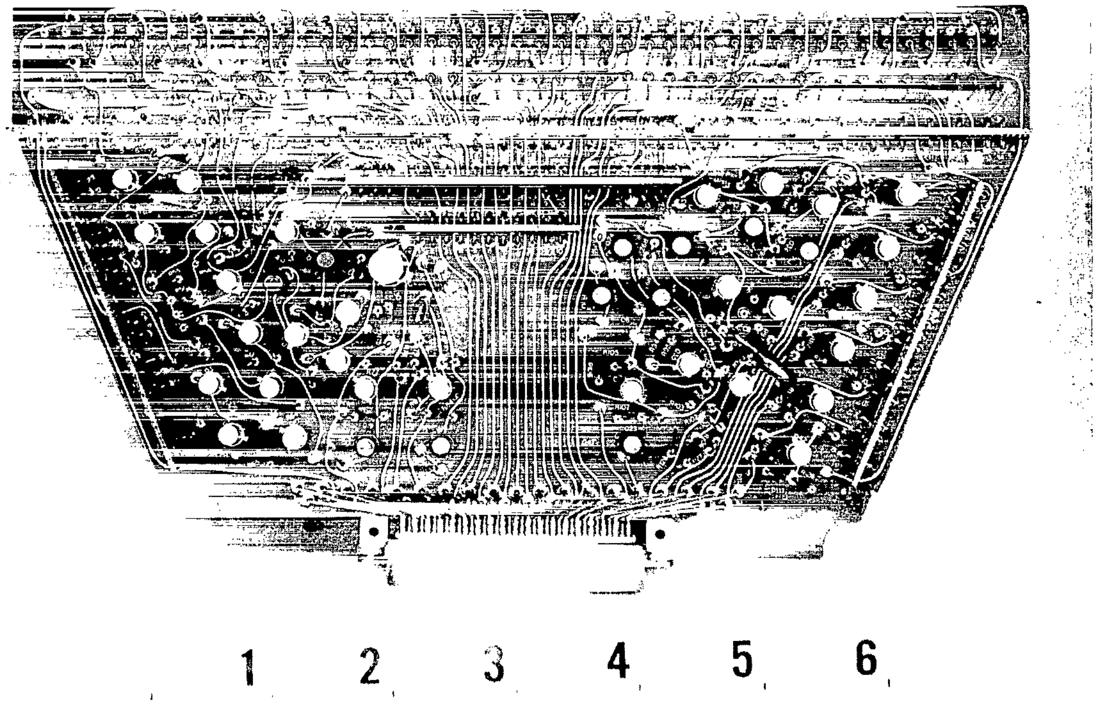


Figure 8—IMP Optical Aspect Computer.



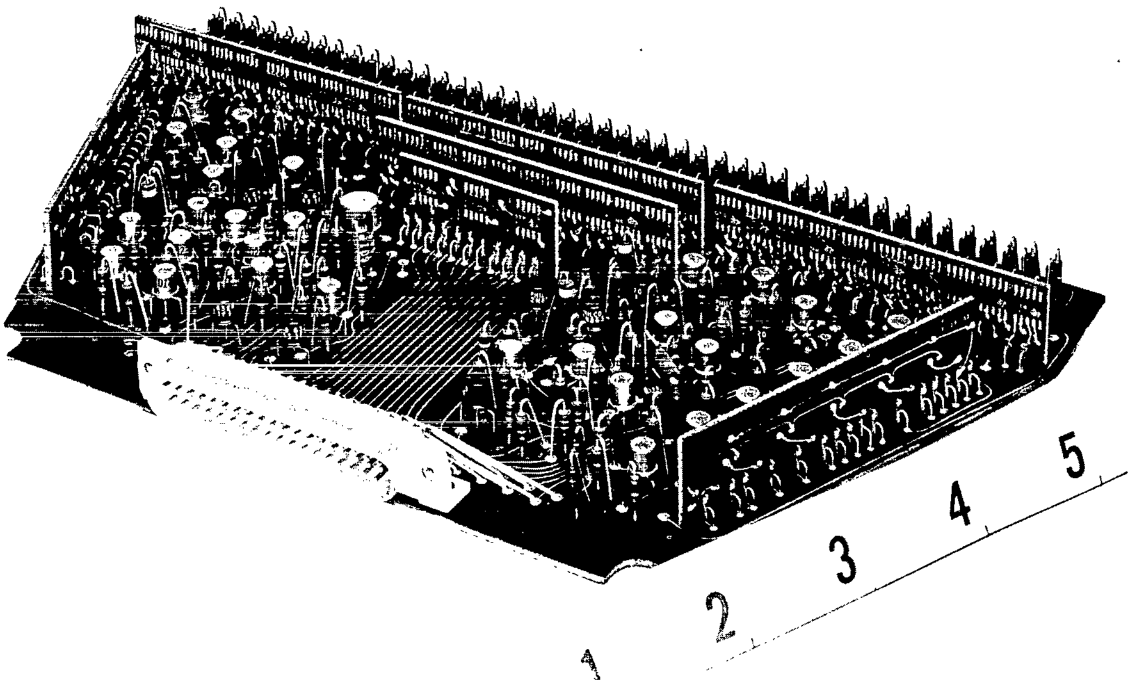


Figure 9—Flight prototype model of the computer card.

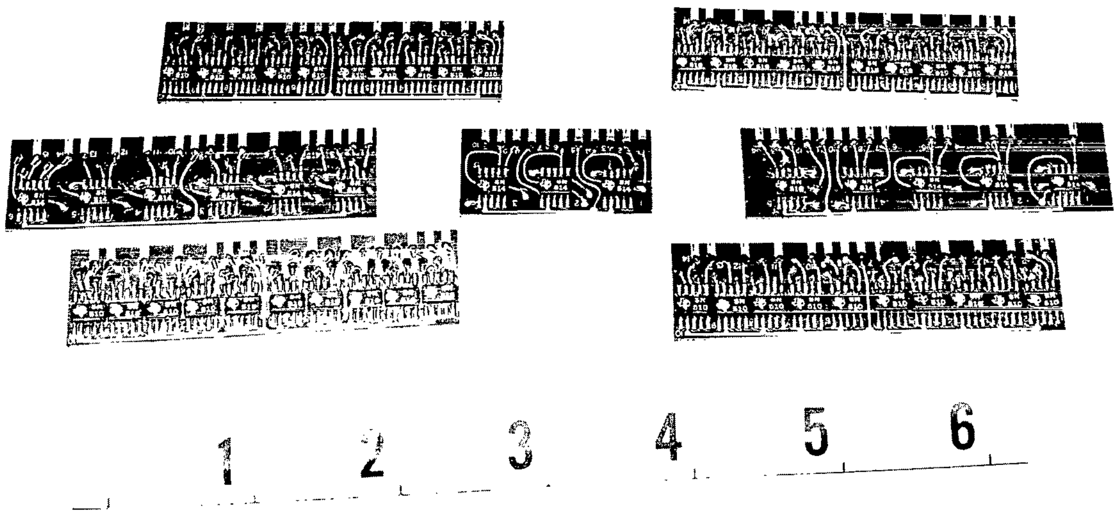


Figure 10—Modules of the flight model computer card.

CONCLUSION

From the information acquired in using these devices and from quality assurance tests it appears that solid circuits are qualified both electrically and mechanically to be used as flight hardware components. The small size and weight of these logic networks should make possible in-flight computations which would not be practical with any other available type of circuitry.

Since this report was written, the IMP satellite was launched (November 27, 1963). The optical aspect computer circuitry described herein was aboard this satellite, thereby, to the best of our knowledge, putting the first integrated circuits into orbit. After four months in orbit all of the circuitry is operating normally.

Since these circuits were designed, a great many new devices have appeared on the market. If the same circuits were designed today undoubtedly the details of the design would be different from those described, both because of these newer devices and because of our present confidence in integrated circuitry. The basic design would, however, remain as described.

NASA-Langley, 1964 G-406

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