A MICROMINIATURIZED HEART MONITORING SYSTEM FOR ASTRONAUTS

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ABSTRACT

The heart monitoring system used by the astronaut in his space walk from the shuttle used as a portion of the instrumentation, a voltage controlled oscillator and a matching discriminator to encode and decode the heart waveform. In addition to small size, low power, and high reliability, there were additional requirements for greater than normal signal rejection by the input filter of the discriminator and cost reduction by limiting the number of different semiconductors used in order to keep lot qualification costs low. The circuits were fabricated using thick film hybrid techniques. The circuit designs, fabrication techniques and packaging will be described.

INTRODUCTION

Part of the instrumentation built into the suit the astronaut wore during his space walk was a voltage controlled oscillator, VCO, used to encode his heart waveform for transmission to the shuttle. A matching discriminator was in the shuttle to decode the signal. In design and fabrication of the VCO and discriminator there were requirements for small size, low power, and high reliability. The discriminator required greater than normal out-of-band signal rejection. These requirements were met using thick film circuits with surface mounted packaged pretested semiconductors, LIDs. This approach allows relatively low cost, highly reliable hybrid circuits to be custom fabricated. The description here will include discussion of circuits, components, packaging, reliability, and cost considerations of the VCO and discriminator. The frequency used was a standard IRIG 5.4KHz proportional bandwidth channel.

The majority of circuit functions can be realized with a great variety of circuits. The choice of circuit elements, fabrication techniques, and skills of the people involved are of prime consideration in any hardware development. The final circuits are reflections of the many constraints place upon the project by requirements of reliability, cost, schedules, etc. In this case, the need for high reliability and low cost for custom hardware were prime considerations. The VCO had been developed for a satellite program several years ago. At that time, one of the prime constraints imposed was low power requirements. Since its development, several dozen of these VCOs have been used with great success. The advantage of using proven hardware at one point allowed more funds for the development of the discriminator. On this particular program, one of the original constraints on the design was to use a minimum number of different types of components due to the cost of qualifying each component. The circuit for both the VCO and discriminator included the following:

1. Thick film resistors and conductors.
2. NPO capacitor chips.
3. K1200 capacitor chips.
4. Solid tantalum capacitors.
5. One NPN transistor type.
6. One PNP transistor type.
7. An integrated circuit operational amplifier.

These components were the most standard available. The NPN transistor was a 2N930 and the op-amp was a 741.

FABRICATION

The basic thick film process of depositing and firing various inks on an alumina to form resistor conductor network has been used in telemetry for twenty years.

Conductor and resistor pastes or inks are squeeged through a stainless steel mesh containing the desired patterns upon ceramic substrates. These substrates are fired at high temperature best described as dull red. There are many variables in the process, and published literature from the thick film industry is not adequate to describe a total process capable of achieving the resistor stability required for telemetry products. After firing, the resistors are adjusted to desired values by removing resistor material by an abrading process using a microsandblasting technique. This is a low shock process, and if done properly, is superior to more exotic laser trimming which involves extreme localized temperature changes and stresses. After setting resistor values, the substrate is ready to receive the added capacitors and semiconductors.

The semiconductors used here were all prepackaged in ceramic chip carriers, LIDs, and tested before being combined in a functional circuit. These LIDs are one version of the surface mounted devices now being written so much about in the current literature. They have been available for many years and have an excellent history of reliability. The bonding and testing yield is taken before the devices are added to a circuit where individual testing is not possible. In chip and wire assembly, the device yield is taken at the circuit level and borderline devices cannot be found. Reliability should not be tested in but rather should be built into every step. To the best of my knowledge, all telemetry companies use pretested and packaged semiconductors in VCOs as they are one of the more difficult products to produce. The chip and wire approach is used in digital circuits which have less stringent device requirements.

The LIDs and chip capacitors are soldered to the substrates using a solder paste containing appropriate metals and flux. The soldering is done by a patented soldering machine which controls the heating rate, flux activation time, soldering time, and cooling rate. This is a relatively low stress process which allows a major step in the circuit fabrication to be well controlled. Other connections to the substrate are hand soldered by qualified people. The assembled substrates are mounted in the final mechanical package using an epoxy material.

All circuits are individually adjusted and temperature compensated. This rugged construction method allows ease of handling and rework is easy if necessary. This process results in essentially a one-hundred percent yield figure.

The final package is a gold plated KOVAR with glassed-in hermetically sealed connecting pins. The hermetic seal is obtained by welding on a cover using a parallel seam welder. Leak rates of less than 2×10^{-8} (atm cc/secHe) are obtained in this matter.

The manufacturing process and reliability of both the voltage controlled oscillator and subcarrier demodulator meet the requirements of MIL-M-38510 for hybrid microcircuits. As per MIL-M-38510, both units pass the qualification tests of MIL-STD-883 Method 5008, Group A, B, C and D tests for Hi-Reliabilty applications. In accordance with MIL-HDBK-217, the reliability prediction analysis for the voltage controlled oscillator shows the MTBF for ground fixed condition exceeds 238,000 hours with a relaibility factor better than .999995 per one hour of operation. This analysis also shows the MTBF for the demodulator exceeds 92,000 hours with a reliability factor better than .99998.

Figure 1 shows the relative size of the miniature discriminator compared with a standard rack mount discriminator.

Figure 2 shows both the VCO, on right, and the discriminator before hermetic sealing.

CIRCUITRY

The circuit functions in the discriminator include an input band-pass filter, a zero crossing detector, a one shot multivibrator, a time averaging circuit with a low-pass output filter, an output amplifier and buffer, output limiting, a voltage regulator with one precision temperature compensated supply, and a dc/dc converter to provide the necessary negative voltages required.

The input band-pass filter required the most design and set-up time. The specification required operation with an input signal amplitude range of 80 to 400mV. The out-of-band rejection required that signals of more than 20 percent from center frequency and up to 800mV must be rejected to below 0.1 percent of full scale output. With a pass band of ±7.5 percent the out-of-band specification calls for rejection 12.5 percent from the bandedge. A rough way to look at this is that the figure of 80dB rejection is required at 12.5 percent from a pass-band. Some of this rejection comes from the low-pass output filter in the form of rejecting the difference signals generated at the nonlinearity of the zero crossing detector by the carrier and the out-of-band signal. This could be a strong 675 Hz signal which is partially rejected by the required three pole 81 Hz output filter. Other strong spurious signals are generated when the out-of-band signal is a rational multiple of the carrier frequency, such as 1/2, 3/2, or 2 times the carrier. Another requirement of the input filter is that the pass-band phase characteristics be a very good approximation of a Bessel response.

The filter had an assymetrical elliptic response. It consisted of five stages. Two stages were band-pass as shown in Figure 3. Two stages contained poles in the pass-band and zeros at the required +20 percent points. These are shown in Figure 4-A with their combined response shown in Figure 4-B. The fifth stage was a low-pass with conjugate zeros at 3/2 times the upper band edge frequency.

The VCO used standard circuitry with one exception. The current through the output filter also passed through the multivibrator. This allowed the total input power to be used to a maximum and resulted in maximum efficiency.

SUMMARY

Thick film circuitry with surface mounted devices is suitable for fabrication of small quantities of specialized circuitry. In the case discussed here, fairly low cost, highly reliable circuits were made using non-exotic components to achieve stringent performance characteristics. The non-recurring engineering time required to develop a thick film hybrid layout is considerably less than that required for a thin film or monolythic chip design.

FIGURE 1Miniature discriminator and standard rack mounted discriminator.

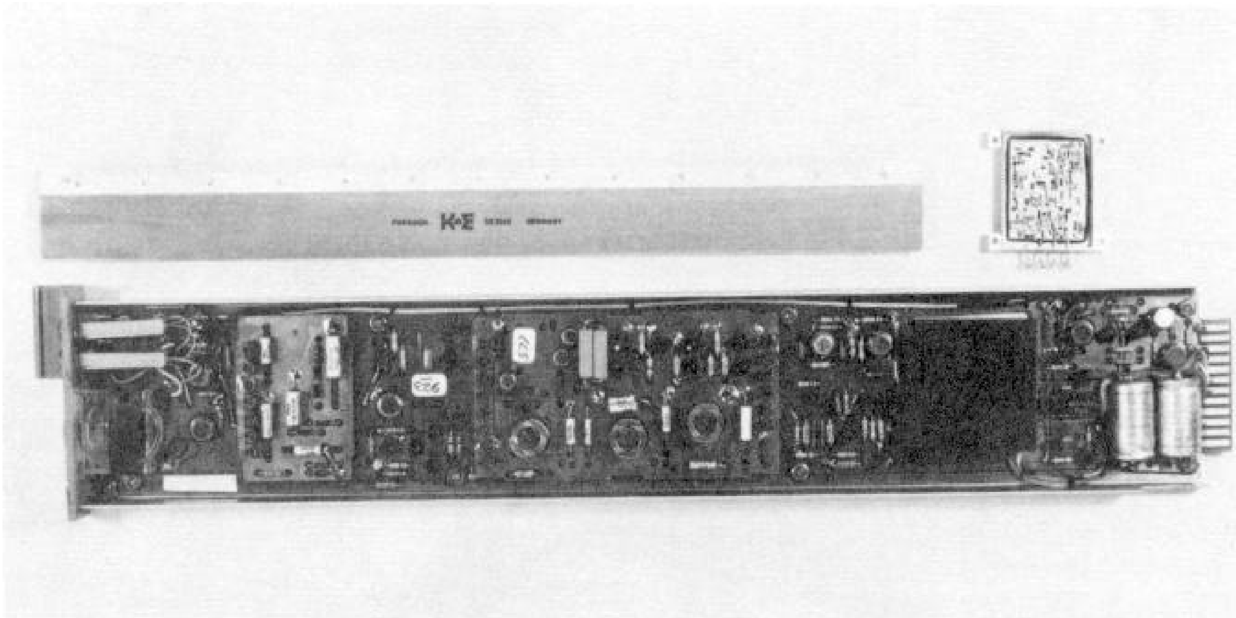
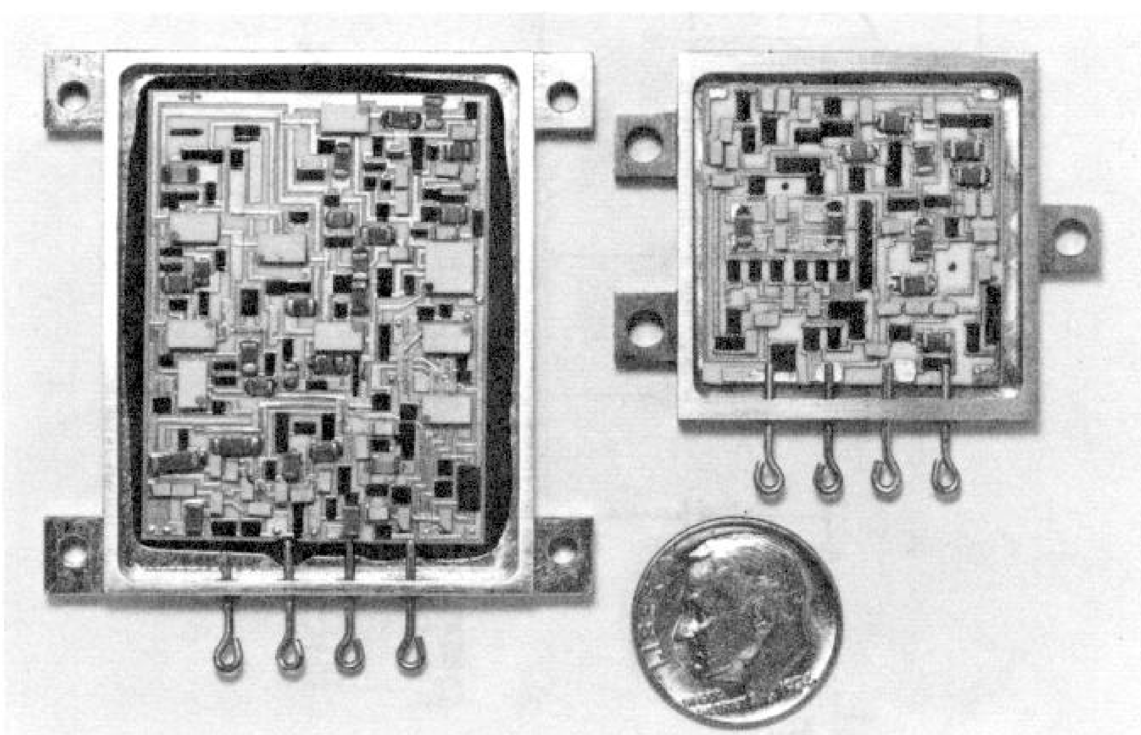


FIGURE 2   Discriminator, left, and VCO, right, before sealing.



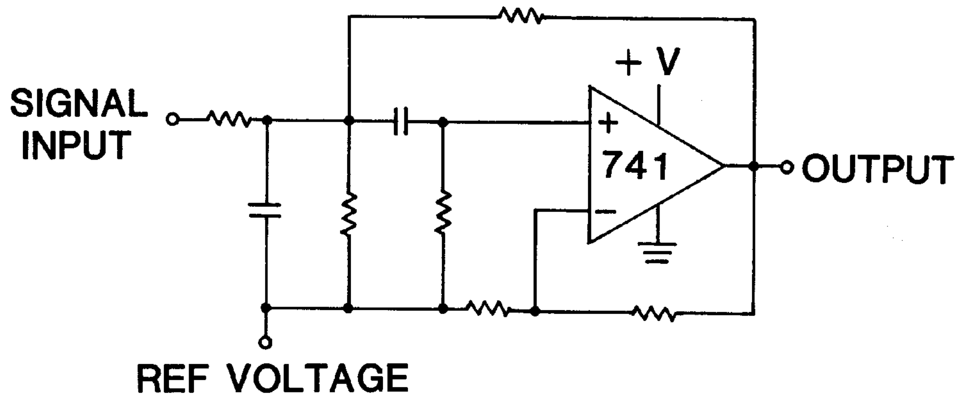


FIGURE 3 Band pass filter stage.

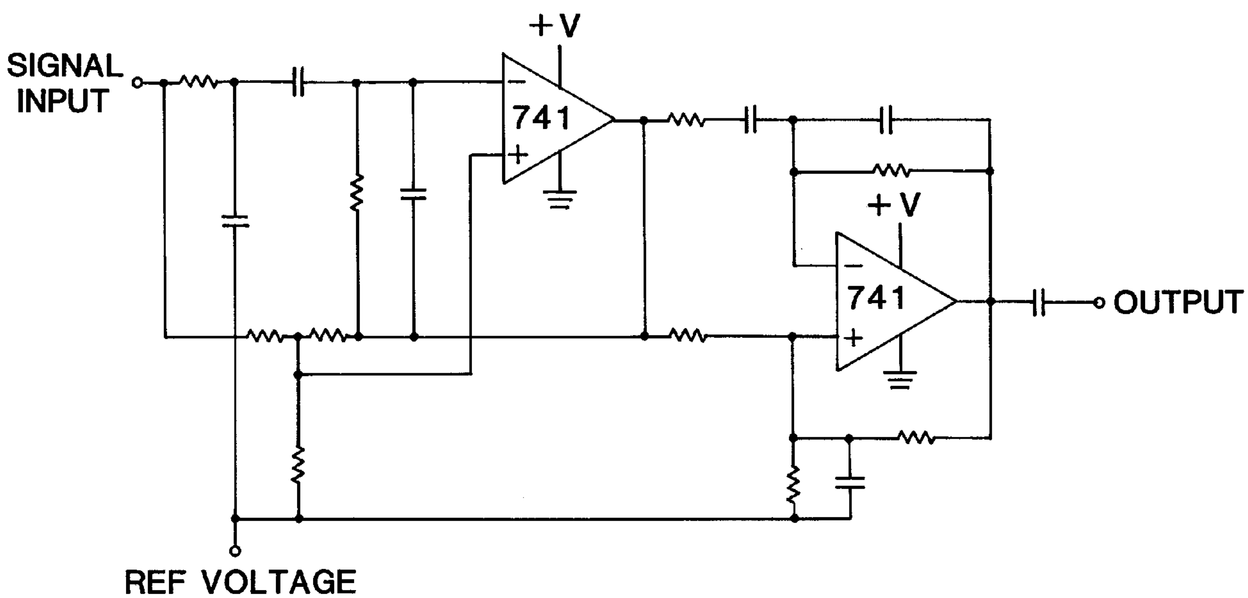


FIGURE 4A Notch filter stages.

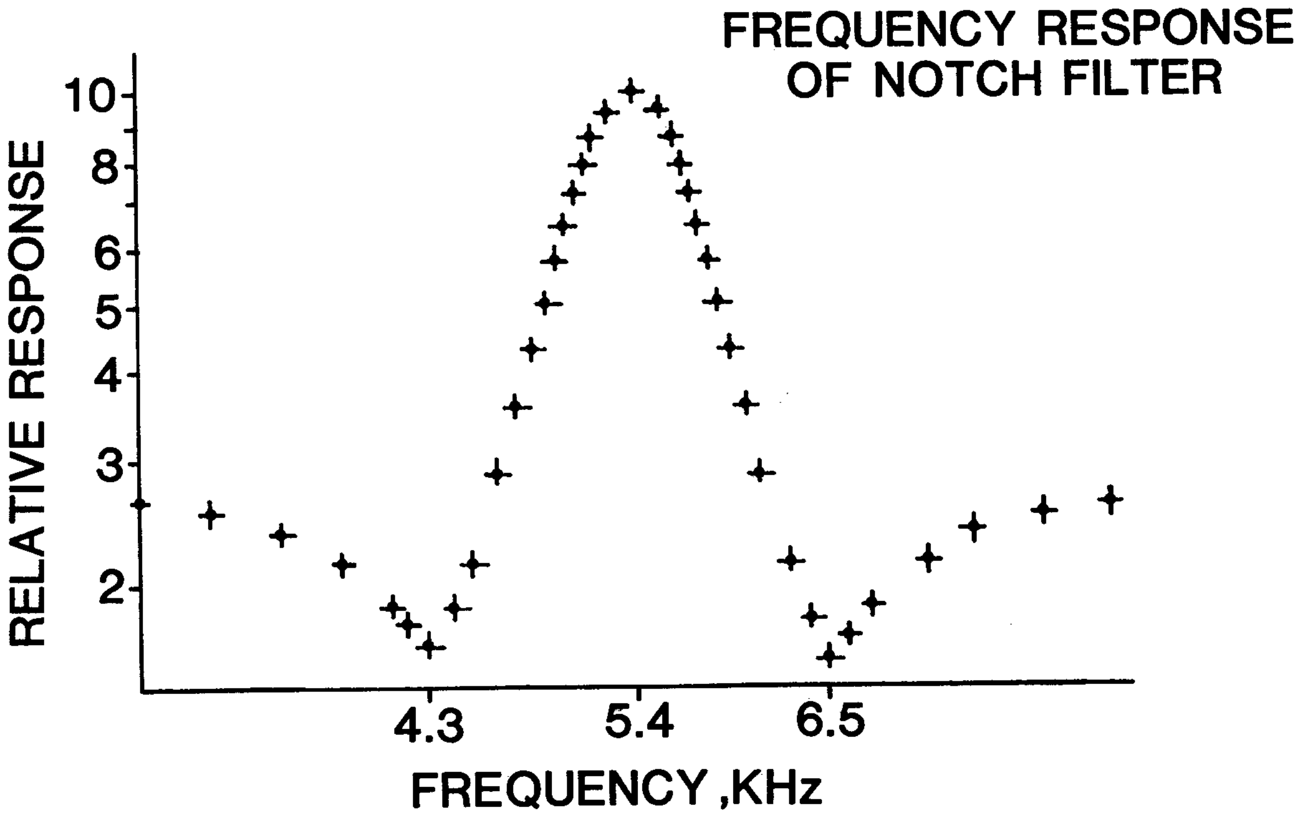


FIGURE 4B Notch filter response.