DEVELOPMENT OF A SEVEN CHANNEL TELEMETRY TRANSMITTER

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ABSTRACT

Study of electroencephalograms (EEG) under normal behavior conditions required the development of a small, reliable telemetry system. Here two hybrid ceramic packages were attached face to face to provide a hermetically sealed seven channel telemetry transmitter with glass to metal seals around the seven differential pairs of input leads and the power supply leads. The transmitter's antenna is enclosed in the package by using two loops of gold substrate etched in a pattern around the other circuitry. The package measures .8 x 2.2 x 2.4 cm and weighs 8.5 gms.

Input noise level is below 1 microvolt (rms) and dynamic range is from 1 to 250 microvolts (rms) with a frequency response (6 dB down) of 1 Hz to 150 Hz. Power requirements are 2.1 to 3.6 ma at 2.0 and 3.3 vdc., respectively, with at least 80% (3.3 and 9.5 mw, respectively) going to the radio frequency stage. Data are time multiplexed for pulse position modulation of an 88 to 108 MHz carrier. Maximum measured range of transmission with a 3 volt battery has been 10 m in air.

This transmitter is well suited for the study of any animal large enough to carry the package and a battery. Other biopotentials such as EMG and ECG can be telemetered by increasing multiplexor rates and/or attenuating input signal levels.

INTRODUCTION

Since 1950 a great deal of engineering time has been devoted to the development of multichannel biotelemetry systems. After developing low power consumption stages for preamplification and transmission, engineers then tried to multiplex several signals (representing different biopotentials) into one data stream for transmission on a single radio frequency (RF). Then only one RF receiver/decoder was needed to demodulate and demultiplex the data stream into signals representative of the biopotentials originally sensed by the preamplifiers (preamps). in the early 60's many modulation/demodulation schemes were used and described in the literature (references 1-8). By the late 60's enough integrated circuits were available so that one could implement nearly any of these designs with flat packs soldered to a printed circuit and supplemented with a few discrete components, usually in the input (low noise) and output (high frequency) stages. The 70's have been spent in finding and solving the problems which have reduced the utility of these designs (reference 9). Except for describing a better technique for mechanically connecting the leads between the sensors and the preamps, this paper deals with fabrication techniques or circuit design modifications that improve the reliability of multi-channel biotelemetry transmitters.

DESIGN CRITERIA

The criteria considered in this system's development included (in approximate order of priority) minimum life of six months, seven differential channels with input sensitivity of 1 microvolt (rms), frequency response between 1 Hz and 150 Hz, at least 46 dB of dynamic range (1 to 200 microvolts, rms) power requirements of 3 milliamps or less at 3.0 vdc, transmission frequency in the FM band (88 to 108 MHz), electronics to be protected inside a hermetically sealed case, leads to penetrate the case with glass to metal headers, transmission antenna to be sealed inside a hermetically protected case, dimensions less than 1 x 3 x 3 cm, and weight less than 10 gm. In addition, a technique was needed to stabilize RF transmission against frequency shifts caused by changes in the RF loading surrounding the transmitter. In short, we planned to combine several circuits found to be successful when built with discrete componenets and integrated circuits on printed circuit boards into a single hybrid circuit mounted in a hermetically sealed ceramic package which also contained an RF stabilization circuit and a transmitting antenna.

CRITERIA DISCUSSION

As regards the life of the unit, a hermetically sealed battery pack had already been developed using two parallel connected lithium/thionyl chloride cells, two dropping/interconnect diodes, and a bistable reed switch (Figure 1). It was desired that at any time during the "life" of the transmitter, data could be transmitted by activating the switch so long as the cells had not been expended. Although the cells are advertised to have a 1000 maH of life, our tests show that a fresh cell has 1440 maH between 3.59 and 3.58 vdc, and 360 maH between 3.58 and 3.34 vdc when discharged at a 3 ma rate (Figure 2). Because one cell lasts 600 hours (from 3.6 down to 3.3 vdc), two cells in parallel with series diodes (Figure 1) are expected to provide 3.0 to 2.7 vdc (the battery range for which 3.0 to 2.9 ma are needed) for 1200 hours, or 150 eight hour days. Based upon normal work hours, week, etc., this would be more than six months. Therefore, the shelf "life" implied above is about the same as the life of the battery pack used.

Note that the diodes in the battery pack serve two purposes. First, they permit paralleling two cells so that the power pack will supply the voltage produced by the highest voltage cell until it is drained down to the voltage of the other cell, at which time they will share the load. This also provides redundancy should one cell fail. Second, in the event that a direct short develops external to the hermetically sealed battery pack, silicon diodes (.6 vdc drop) will act as either fuses or dropping resistors to prevent a direct short from occuring across the LiSOCl cells. Although the manufacturer of these cells has assured us that the AA size cell will not explode (as have the larger D size cells) when shorted, the diodes give added insurance against overheating.

The frequency response and dynamic range were established by the signal to be measured, EEG in the range of 1 to 200 microvolts (rms). Power drain and transmission frequency were set according to what had worked well in the past to obtain our desired transmission range of 10m in air.

The innovative aspect of this transmitter was the design of an RF antenna as part of the etched circuit inside the ceramic package and a radio frequency stabilization circuit to compensate for RF loading variations in the environment external to the ceramic package. The antenna was fashioned from two complete loops around the perimeter of the circuit etched from the gold substrate used for printing a layout inside the ceramic package. Standard size ceramic hybrid packages, offering glass to metal seals around all penetrations, were used because both coated (with metal) and uncoated mating covers were available. The coated cover was used as a bottom lid for the package and served as a backplane for the transmitter, whereas the uncoated cover was used as a top lid, offering a transparent window to RF transmission. The frequency stabilization circuit was an outgrowth of work done by Weeks, Long and Pauley (reference 10). It uses a frequency doubler/buffer stage and electronic servo loop to maintain constant current in the collector of the output RF transistor. In addition to RF frequency stabilization, this circuit offers the advantage of being able to predict power consumption more accurately than in RF stages that permit current variations to maintain a constant voltage across a varying load.

TRANSMITTER CONSTRUCTION

The "chip and wire" fabrication method (references 11 and 12) was selected as the most economical way to improve upon the reliability of the printed circuit-solder techniques previously used. Pulse position modulation was used because it was compatible with the decoding equipment used for older units. With careful layout, it was possible to include seven differential preamps, pre-multiplexor amplifiers, a multiplexor (mplxr), a postmultiplexor amplifier, a sub-carrier oscillator (SCO), and an RF stage in two packages measuring .4 x 2.2 x 2.4 cm each. The seven pairs of input leads penetrate the same package on the right side before re-entering the left side of the mplxr/RF package via pins that exactly match when packages are mounted face to face. The leads penetrating the right side of the mplxr package were not used and so were cut off close to the package. Power enters the preamp package from the right and the mplxr from the left, via wires which again mate exactly when the packages are glued together with Humiseal (1) under vacuum.

CIRCUIT DESCRIPTION

This circuit (Figure 3) requires 76 resistors, 53 capacitors, 4 integrated circuits, and 36 transistors (three emitter-base junctions of which are used as diodes). The preamp stages (enclosed by "....." in Figure 3) consist of differential-pair transistors (T1, T2) coupled to the input leads by .47 uFd capacitors and very lightly pulled up (for low noise) to ½ of the power supply voltage by 1 megohm resistors. All inputs have 1000 pFd shunts to ground to eliminate any possible RF feedback. Signals leaving the differential stages are low-pass filtered (at 150 Hz) by the 1000 pFd capacitors, buffered by emitter followers (T3) and capacitively coupled into other (buffering) amplifier stages which are direct coupled to the mplxr. Voltage out of the mplxr is amplified and DC restored to approximately 1/2 the power supply voltage (1st op amp of IC2) before driving current through a 220 K resistor to charge a 1000 pFd capacitor in an integrator (2nd op amp of IC3). Voltage occuring at pin 2 which is above 1/2 the power supply voltage will cause voltages at pin 11 and (via a 220K-470K voltage divider) pin 5 to approach ground until the voltage at pin 5 drops below 1/2 the power supply voltage and trips a comparator (3rd op amp of IC2). As the comparator's output (pin 9) is driven from the positive power supply rail toward ground, positive feedback through the voltage divider accelerates the tripping action and diode D1 conducts to discharge the 1000 pFd capacitor. The capacitor is discharged until the voltage at pin 5 (divided between pin 11 and pin 9 via the 220K-470K resistors) returns to 1/2 the power supply voltage, at which time the comparator trips in the opposite direction.

The 35 microsecond pulse resulting at pin 9 drives transistor T5 into cutoff and increments the ring counter (IC3). Because the counter is stepped on the back side of this pulse, a similar transistor (T6) will generate a pulse for every 8 incrementing pulses sent to IC3. This serves to produce equal width pulses every time the mplxr selects a successive channel and an extra pulse every time the mplxr starts charging the capacitor from channel 1. Because the time between pulses is proportional to the voltage sensed at each input channel, this SCO appears to be dependent upon signal in order to measure signal. In fact current supplied through the 220K resistor from the power supply to the 1000 pFd capacitor is sufficient ot maintain oscillation independent of input voltage. This is necessary to prevent the erratic SCO operation obtained from sensing over-voltages such as occur when sensor leads break.

The normal and extra pulses are combined via 1.5 m resistors and used to modulate an RF carrier in the RF stage (enclosed by "-----------" in Figure 3). The RF stage consists of a Colpitts oscillator (T7) tuned to 50 MHz and transistor (T8) buffered to drive an output tank circuit tuned to twice the oscillating frequency, causing 100 MHz to be radiated. Current through T8 is converted to a voltage (by the 180 ohm resistor) and fed back via T9 to control the drive from the oscillator. The number of turns and turns ratio of the output transformer were adjusted for peak output (at 100 MHz) into the impedance offered by the two loops of gold substrate used as an antenna inside the package. The miniaturization of this portion of the transmitter has solved several problems at once. First, the near proximity of parts permits the design of transmission characteristics which used to be dominated by random interlead parasitic capacitances; instead of trimming capacitors or bending the antenna for best signal amplitude, frequency, distortion, etc., one can now design tuned tank circuits with sufficient accuracy to match fixed size (impedance) antennas. Second, the small investment in chip real estate required by a few extra parts offers important possibilities such as buffering the oscillator from the transmitting tank and employing frequency doubling techniques. Although these methods have been used in larger transmitter systems, they were usually not used in biotelemetry in an effort to conserve space.

PROBLEMS

The primary problems encountered in thise development appear to have been those of fabrication technique. The conductive epoxy first used (2) was either too old or of a poor composition to the extent that intermittent opens occurred around capacitors after several thermal cyclings of the prototype transmitters. The selection of a different epoxy (3) and the use of an automatic dispenser seem to have solved this problem.

Major circuit redesign was required because large capacitors (18 uFd) require too much room to be included in this package. As a result, a d.c. biasing network had to be developed for the post-mplxr amplifier which previously had been a.c. coupled. The voltage divider (470K-120K-D2) provides the correct d.c. bias to pin 12 of IC2, but we do not consider the inclusion of a trim resistor (R trim) as good practice in any hybrid implementation .... only an expedient solution to the problem.

RESULTS

Prototype transmitters have operated after soaking six months in a saline solution and more time will be required to determine minimum life of the transmitters. but all other design criteria were met or exceeded. Although all circuits are functional over a wide power supply voltage range (2.0 to 3.3 vdc), high signal gain (2000) and dynamic range (1 to 250 microvolts, rms) dictate that the post-mplxr amplifier output have sufficient power supply voltage (2-6 vdc) to provide output signals 1.4 volts in amplitude (2000 x .00025 = .5 vrms = 1.4 vpp).

(1) Type 1B66 sealant is made by Humiseal division of Columbia Tech. Corp., New York.
(2) Uniset C409 Silver filled, one component epoxy by AMICON.
(3) Ablebond 20-1 Silver filled, microelectronics grade. one component epoxy.

The input noise is below our lower limit of measurement at 1 microvolt, rms. The package is smaller (64%) and lighter (15%) than originally required. It contains an internal fixed shape antenna (etched from the gold substrate) and the RF oscillator buffering and current control stabilizes the transmission frequency against variation in loading on the RF output circuit. Those improvements permit the continuous transmission of data on a given frequency under RF loads which shift the carrier frequency (100 NHz) of older transmitters (without buffering or constant current) as much as 2 NHz.

Possible modifications to the circuit include the reduction of input sensitivity or the broadening of frequency response in order to transmit larger biopotentials such as ECG or EMG. Resistive attenuation works well for amplitude reduction, and higher frequency response is available by decreasing (or eliminating) the 1000 pFd capacitors on the base of T3 transistors and by decreasing the size of the integration capacitor (1000 pFd) to obtain higher multiplexor rates. The present average sampling rate of 1000 samples per second (sps) for each channel could be increased to 2000 sps with an associated factor of 2 loss in dynamic range. Paralleling the inputs of two channels separated by three intervening channels provides a sampling rate of 4000 sps which would be suitable for most ENIG data requirements.

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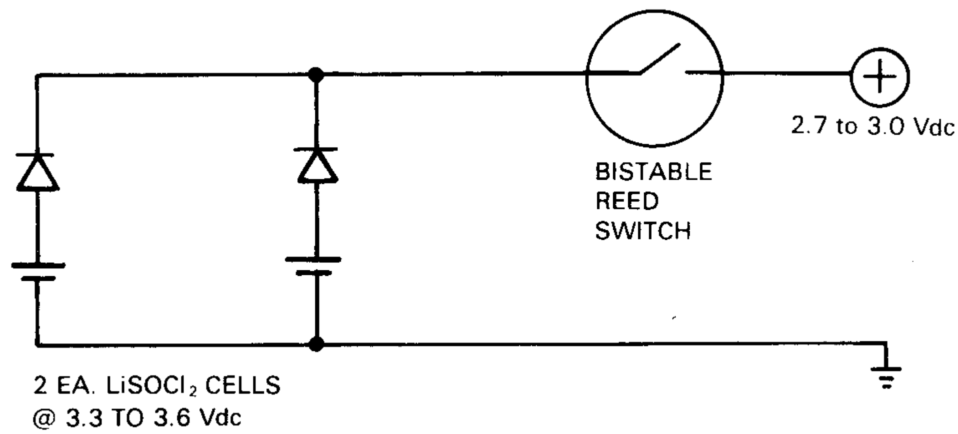

Figure 1. 1 200 hour battery pack.

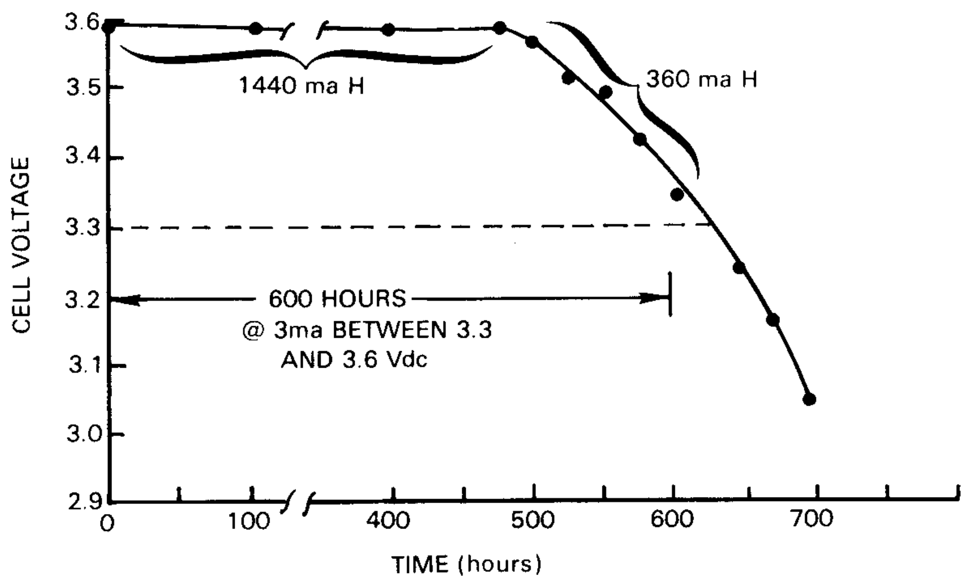

Figure 2. AA size GTE $LiSOCl_2$ cell discharge curve under 3 ma load.

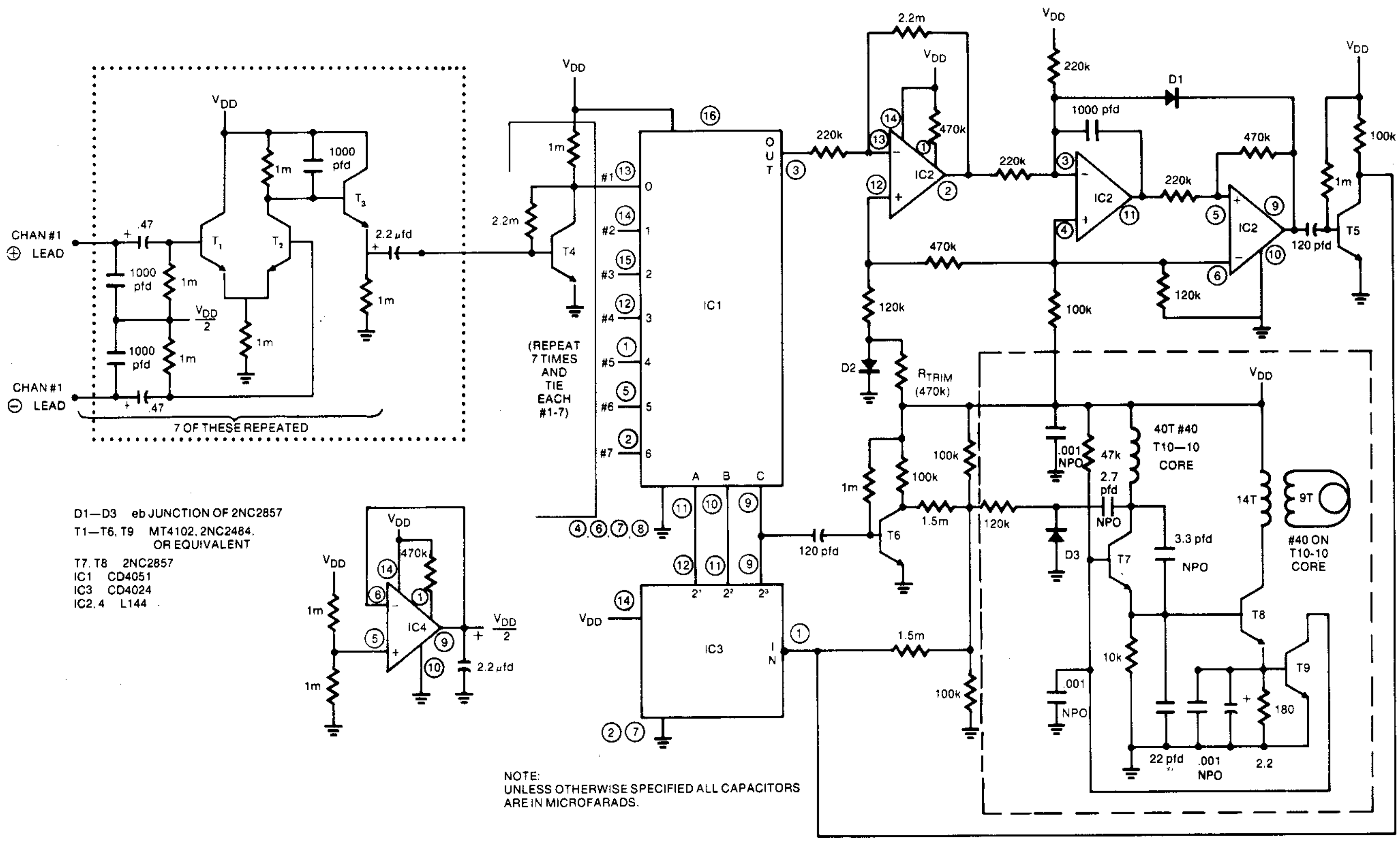

Figure 3. Seven channel hybrid telemetry transmitter.