PACKAGING TECHNIQUES FOR LOW-ALTITUDE VENUS BALLOON BEACON

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Summary

This report presents the results to date of a specific design project in which a microwave beacon is required to operate for a limited time at high temperature ($\sim$325°C) and at high pressure ($\sim$10 bars), in a chemically hostile environment, after surviving large mechanical shock forces (up to 280 gs). One of the most interesting results of this work is the finding that many existing, commercially-available components can be used in such a design with only minor modifications. A further result of some interest is that a crude (and consequently low-cost) testing program can be designed to identify and select promising commercial components.

Symbols

COS	ceramic-oxide-semiconductor
DC	direct current
g	acceleration of gravity
HF	hydrogen fluoride
MHz	megahertz
MOS	metal-oxide-semiconductor
P/P	peak to peak
R-C	resistor-capacitor
RF	radio frequency
V	volt
VBB	Venus balloon beacon

Introduction

The goals of this low-cost design effort are to develop a short-lived microwave beacon which is capable of intermittent operation while suspended from a balloon floating in the atmosphere of Venus, and to do it within a relatively modest budget ($160K). It should be made clear from the start that we are discussing the beacon developmental model, not flight hardware. The flight model has not yet been built and, in view of recent changes in the Venus mission's scope, may not be built for some time. Still, the design exercise is an interesting example of what can be done with limited funds and with existing commercial components, modifying them where necessary, and by using also a bit of that famous American ingenuity.

The low-altitude Venus Balloon Beacon (VBB) was conceived as one approach to studying the winds of Venus. VBB is a small, L-band microwave transmitter to be suspended from a high-pressure French balloon, one-meter diameter, filled with water vapor as flotation gas. The beacon is designed to transmit a series of 1 microsecond, 1% duty cycle pulses which will permit Earth ground stations to track the balloon as it gets blown about by various Venusian atmospheric disturbances.

At the proposed 18-km flight altitude, the expected ambient conditions are 325°C (617°F) and 10 bars (160 psia), with wind velocities as high as 20 meters/sec. The atmosphere is primarily carbon dioxide, with traces of other gases including HF. The forces on the beacon-balloon system during entry into the Venusian atmosphere are calculated at 280 gs for two minutes. The total time of flight of the balloon will be 240 hrs, with the transmitter on during 96 five-minute periods, spaced equally during those ten Earth days.

Discussion

The VBB electronic system comprises batteries, power supply, RF cavity, cavity modulator, timer switch, and antenna (Figure 1). The major problem areas are the power supply (1000 VDC needed to fire the RF cavity), and the cavity modulator (pulse timing accuracy better than 1 part in 10^7 required). The power supply was designed to use reed switches both as input choppers and output rectifiers. The cavity modulator is a large hybrid circuit using an especially cut crystal as the timing element. Both will be discussed in detail shortly, but first a word about the easier parts.

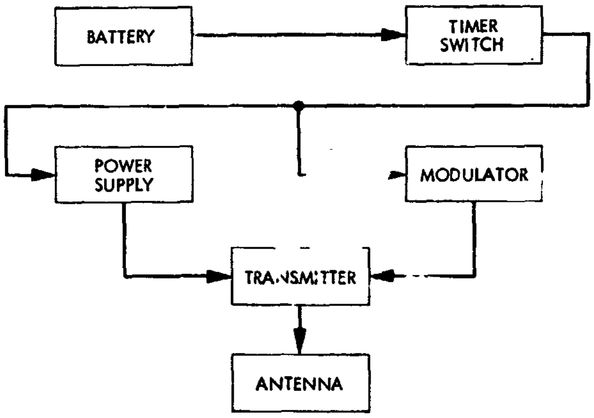


Figure 1. VBB Block Diagram

Batteries

Power is supplied by 1.5 V sodium cells, whose electrolyte melts at $\sim$280°C and can operate in the liquid phase up to $\sim$350°C. These cells hold a charge indefinitely in their solid state and produce 20 watt-hr per cell when in the liquid state (see Figure 2). Since these batteries produce no power when solid, i.e., below 280°C, they become a built-in on-switch for the system, thus eliminating one set of potential headaches including the mass of a main power switch. To get the power needed for 8 hours of operation requires four cells. These use up half of VBB's 2-kg total mass limit.

Timer

A timer was needed to spread the power usage out over the 240-hour flight. A mechanical timer (either a motor- or solenoid-driven escapement) was considered, but these had both mass and power-consumption penalties. In view of the high Venus ambient temperature and other higher temperature sources (e.g., the RF cavity operating temperature is on the order of 450°C), a bimetallic switch seemed an attractive solution. Several bimetallic switches of suitable time constant were found avail-

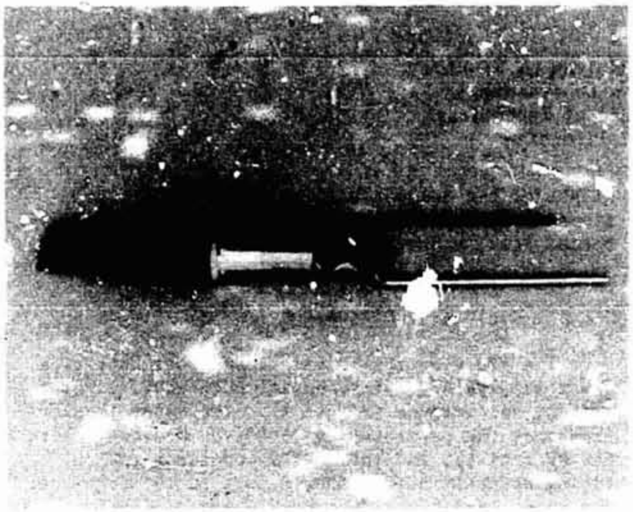


Figure 2. Sodium Battery Cell

able commercially, so this approach was considered the primary solution to the timing problem. The motor- and solenoid-driven escapement were relegated to back-up status.

RF Cavity

The RF cavity used for the development model is a standard aircraft transponder RF cavity, made by General Electric Company, modified by the manufacturer to withstand the 325°C environment. The engineering staff of the GE tube division was interested in the project and made us an offer that, from both schedule and financial standpoints, we could not refuse. In principal the conversion of the standard RF cavity to a high temperature device was not too complicated. The major changes centered around the materials used to make the cavity and the type of soldering/welding used in its assembly. The tube itself was already designed to operate well above 325°C.

Antenna

An antenna with the proper radiation pattern was found and scaled down to operate in L-band. (See Figure 3.) There is no obvious reason why the pattern should change at the high temperatures expected of this project, but the optimum operating frequency will change if dimensions change. Hence, a test antenna was built from solid copper for pattern verification and for frequency-shift evaluation at L-band frequencies and high temperatures. The test model is too massive for flight use; but given additional time and money, the flight unit mass could be reduced greatly, e.g., by designing the flukes hollow, by incorporating the ground plane into the transmitter box, and by using lighter construction materials.

Antenna Cable

One problem which we had to solve that was not so simple as it at first seemed, was conducting the RF signal from the cavity to the antenna. The coax cable industry currently produces high temperature semirigid coax cable that will withstand 325°C for extended periods. This cable uses powered magnesium oxide as the dielectric. Since this material is hygroscopic, both ends of the cable must be sealed. Unfortunately, no commercially available hermetically-sealed connectors could be found, for any temperature range. Hence we decided to do it ourselves.

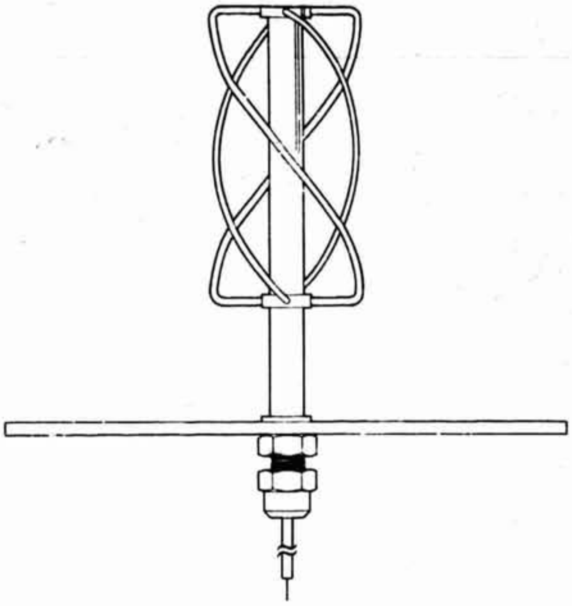


Figure 3. VBB Antenna

It had been noted that the standard type OSM connectors for 0.141 semirigid cable, used for testing some multiplier transistors for a possible oscillator/modulator, were made entirely of metal. Since the connector leaves the cable dielectric exposed, plugs of some material were needed to create seals at both ends of the cable.

Various types of epoxies were considered, but were found too vulnerable to water. Previous experience with hybrid construction suggested using ceramics. After some investigation Macor, a machinable ceramic manufactured by Corning Glass Works, was selected and machined into several thick-walled washers. Inner and outer wall surfaces then were coated with low frit gold and fired at 650°C to create solderable surfaces. These surfaces next will be coated with a gold germanium solder, the washer placed in the end of the cable, and the cable end heated above 360°C to complete the solder joint. Post-soldering helium leak tests will be performed to assure that no detectable leaks larger than 10^{-9} cc/sec are present. Given that no surprises develop from soldering plug and connector simultaneously, this problem is solved.

Power Supply

Figure 4 is a schematic of the power supply-chopper-rectifier-driver circuit. The principal component of the circuit, the transformer, proved to be the simplest to find. In the literature study at the beginning of the work, a reliable supplier of high temperature transformers (General Magnetics) was located. The test transformers procured from this source have functioned without problems in all testing performed to date.

The tougher problem has been posed by the chopper/rectifier requirements. When first considered, it was thought that the only practical solution to this problem lay in the reed switch approach. Since the reed switches were large and relatively heavy, we were motivated to look for other possibilities.

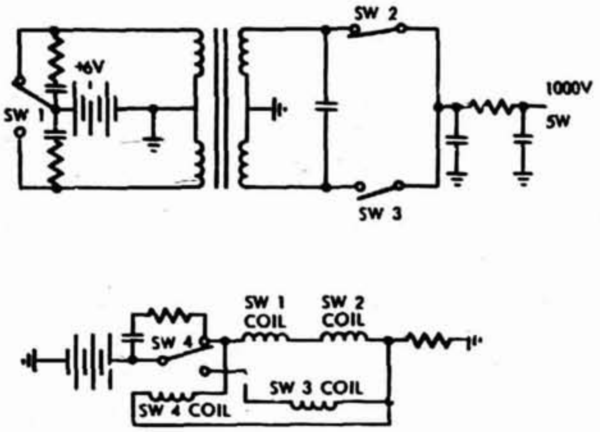


Figure 4. Schematic Circuitry

One of those led us to test some very small (TO-5 can) relays to get an idea of their useful life and voltage-switching capability. When run as self drivers at room temperature and 9 volts. these relays ran for 23 days at ~350 Hz with no apparent degradation. At about 700 V, however, the contacts were burnt at a few microamps. Since they worked so well at their rated winding voltage of 9 volts, it was felt that they might suit the low-voltage side of the chopper/rectifier circuitry.

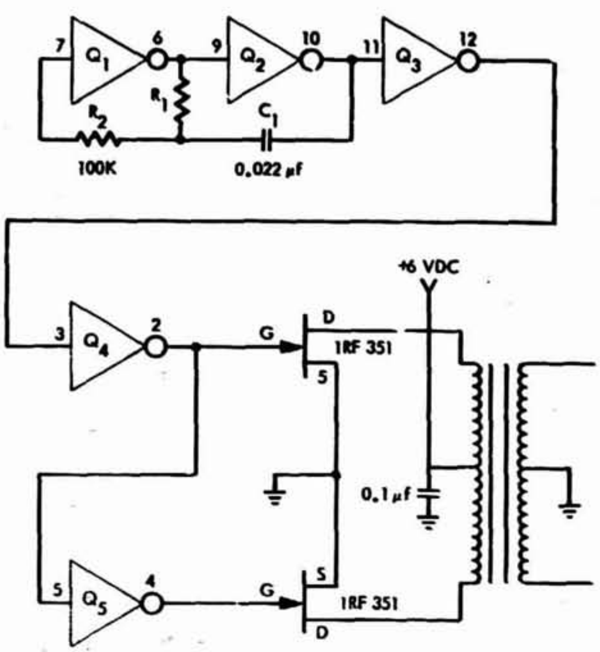
Accordingly, one of these devices was dissected and examined to determine what modifications they would need to survive at 325°C. These modifications, which consisted mostly of substituting high temperature wire insulation and structural components for their existing counterparts, would have required procedural changes during manufacture, rather than post-assembly retrofits. The changes were modest enough to be quite feasible for typical development projects, but were not feasible within the time and cost limits available for VBB. Consequently, we feel that this approach is worth stating for consideration in future high-temperature projects, even though we could not use it in our case.

Another approach explored was based on the use of semiconductor devices as low-voltage switches. The chief advantage of such an approach would be a significant simplification of the chopper/rectifier synchronization problem.

Preliminary tests indicated that the Harris CD 4009D Ceramic Pack COS/MOS inverter and the IRF 351 HEXFET power transistor would function at temperatures above 250°C. A DC/DC converter was designed, using the CD 4009D as the oscillator and driver of a pair of the 351's (see Figure 5).

For the converter tests, the 1 kV secondary was rectified by off-the-shelf diodes (not shown in Figure 5). These diodes functioned satisfactorily up to about 200°C, at which point they were removed from the oven and operated at room temperature for the higher temperature part of the tests.

The test converter (see Figure 6) functioned for 50 hours at 250°C. Efficiency dropped from 93% at room temperature (20°C) to 73% at 250°C. In view of the limitations on power available in the VBB mission, this approach was rejected. For cases not so limited, however, this approach should be quite useful.



NOTE: Q_1 - Q_5 CD4009D
+6V ON PIN 1 AND 16
GND ON PIN 8

Figure 5. Solid State Chopper

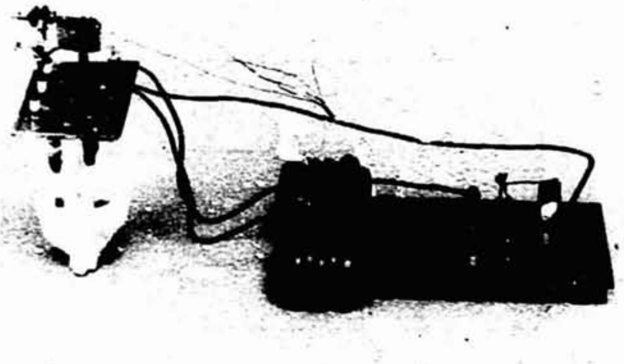


Figure 6. VBB Test Converter Unit

The approach finally selected for VBB uses reed switches supplied by Gordos Corporation. These high-voltage switches are packaged with driver coils similar to one of their standard lines. The contact bounce on these switches was markedly less severe than some others tested, and are capable of switching the 1 kV secondary without difficulty.

We found in our testing that improper synchronization can result in destruction of the switches, but that if a very precise R-C circuit is employed contact burnout on the 1 kV side of the circuitry can be avoided. We have found also that type C switches (i.e., SPDT, see Figure 4) can be used on the low-voltage side and in the driver circuit, but the standard type A (i.e., SPST) switches are required in the secondary side to survive the 1 kV.

Hybrid Modulator

Earth station tracking of VBB requires the timing accuracy of the transmitted pulses to be at least as good as 1 part in 10^7. This requirement precluded the self-blocking mode of tube operation, and imposed a need for some sort of modulator. A high-temperature test program at JPL several years ago had established that properly cut crystals were capable of maintaining the required accuracy. Three crystals (3 MHz, 5 MHz, and 10 MHz, respectively) cut for minimum drift at 325°C, have been acquired from a commercial supplier. As of this writing, these crystals are being tested at temperature to verify turnover points and drifts.

The crystal control circuit designed as a result of the above considerations is shown in Figure 7. A breadboard model of this circuit, shown in Figure 8, was fabricated from materials known to function satisfactorily at high temperatures. The principal testing goal was to evaluate the 2N5911 dual JFET's operations and to determine what would be required to keep it operating satisfactorily at high temperature.

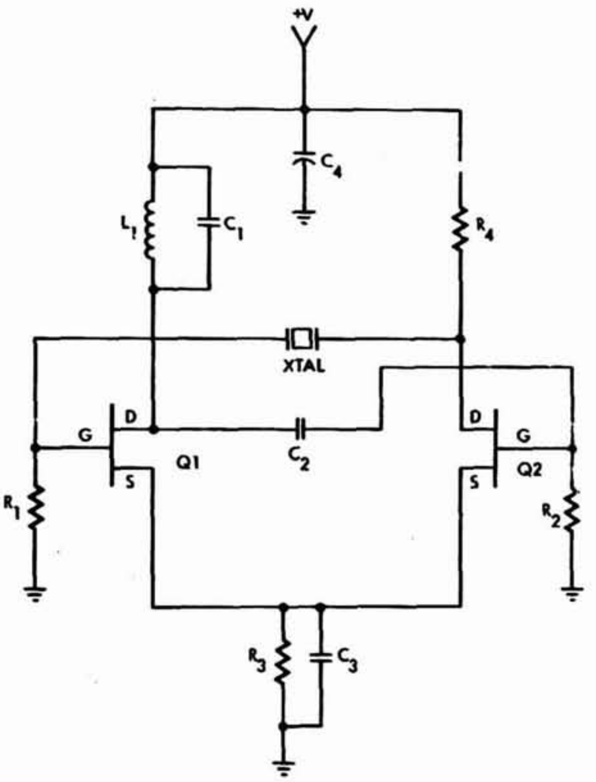


Figure 7. Crystal Control Circuit

Testing showed that a tuned circuit feeding Q1 (as shown in Figure 7) was required for satisfactory operation. The results of operating the test circuit at 280°C for 100+ hours, which produced no failures, are shown in Figure 9. It will be noted from these data that increasing the temperature reduces the output amplitude. If the rate at which the output drops remains fixed, a second tuned circuit, feeding Q2, will have to be added to achieve satisfactory performance at 325°C. This presents no obvious problems.

It should be noted in passing that it was not absolutely necessary for all materials in the test circuit to be high-temperature substances. Low temperature solder, for example, melted at the test temperature, but remained in puddles around the component leads and performed its electrical functions satisfactorily.

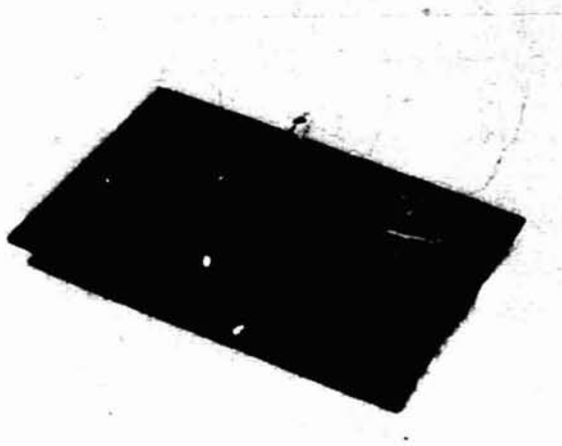


Figure 8. Breadboard Model

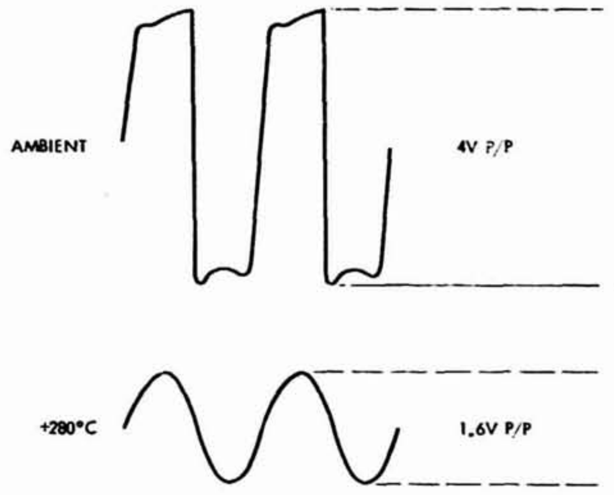


Figure 9. Output Wave Forms

As of this writing, a refined test circuit has been laid out on a 2 in x 2 1/2 in, 96% alumina core substrate. Thanks to extensive testing of hybrid inks for high temperature service conducted previously by Sandia Laboratories, a satisfactory ink (Du Pont 9910) was found easily. Gold-germanium solder has been chosen for connecting discrete component leads to substrate inks. The high temperature epoxies and/or potting compounds for bonding the discretes to the substrate have not yet been chosen.

The refined test will be conducted using all discrete components. For later tests and flight hardware, 2N5911 and 2N3821 dies have been ordered, along with chip resistors rated for 325°C operation. It is anticipated that the complete circuit will fit on a much smaller substrate.

Conclusions

The principal conclusion to be drawn from the work reported here is that many ordinary components, designed for operation under Earth-normal conditions, may be used in extreme environments -- either "as is," or with minor-to-moderate changes in their construction. A catalog of such extendabilities was started by previous researchers, and has been augmented by the present work.

In addition, a great deal of useful extendability information pertinent to a particular project may be gained at relatively low cost, by employing "rough and dirty" test procedures, custom-designed to fit the needs of that project. In our case, even though the development model has not yet been tested as a complete system, the prospects for a positive, within-budget outcome of the May-June time-frame development-system tests (schedule dependent upon receipt of the final-design cavity, reed switches, etc.), appear quite bright. At that time, our principal problem will become meeting the 2-kg mass limit. Given the results to date, it appears that the only section requiring extensive redesign here will be the antenna, and this does not appear to pose any significant problems.

Acknowledgment

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