WAVEGUIDE TRANSFER SWITCH DRIVER MULTICHIP MODULE

FOR CASSINI SPACECRAFT'S TELEMETRY CONTROL UNIT
THIN FILM TECHNOLOGY RADIATION HARDENED MCM

VICTOR BOYADZHYAN

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, California 91109-8099
Mail Stop 303-300

Tel. (818) 354 7226
FAX (818) 393 4272

e-mail Vardkes.Boyadzhyan@jpl.nasa.gov

Abstract-This paper summarizes and reports a radiation hardened Spacecraft Integrated Circuit Technology to be flown on board the Cassini spacecraft in 1997 A.D. The Multichip Module has been designed to have an operating life of fifteen (15) years with appropriate derating guidelines for high reliability.

1. Introduction

The Cassini Spacecraft's Telemetry Control Unit Waveguide Transfer Switch(WTS) Driver Multichip Module (MCM) is part of Cassini Spacecraft's Bay 5 (five) Electronics which includes the spacecraft's radio. The function of the WTS Driver MCM is to provide a 250 millisecond long pulse to the spacecraft's Waveguide Transfer Switch which acts as a "door" control between the Low Gain and High Gain Antenna Waveguides. The schematic diagram of the MCM is depicted in Figure 1 on the next page. It ensures reliable closure of one microwave path while the other sends or receives signal from or to the spacecraft.

2. WTS Driver Multichip Module

The WTS Driver Multichip Module is a custom Radiation Hardened Electronics Switching circuit. In case of a single point failure WTS driver electronics will fail as a single unit. The circuit will be replaced by its redundant unit on-board the Cassini spacecraft upon ground command from the earth. The Block Diagram of the Waveguide Transfer Switch Driver MCM is depicted in Fig. 2 on the next page.

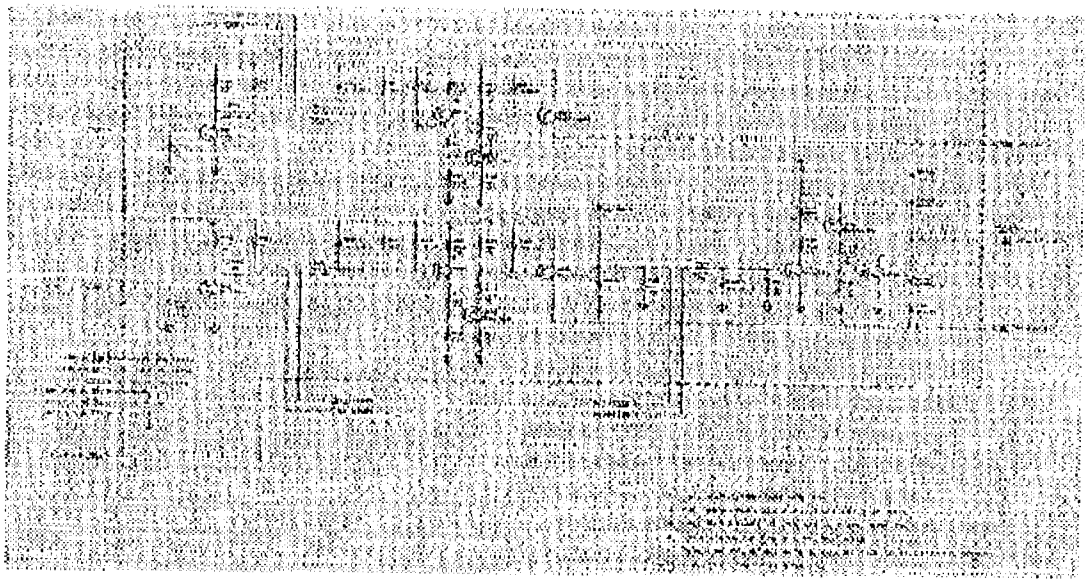

Figure 1 Schematic Diagram of WTS Driver MCM

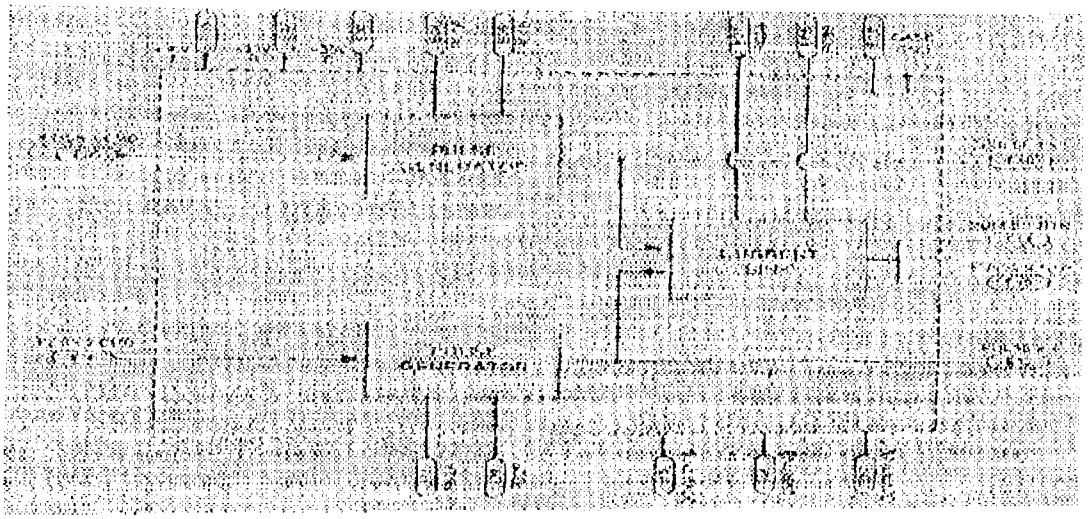

Figure 2 Block Diagram of WTS Driver MCM

The WTS driver MCM is composed of pulse generator circuits and a current sink circuit to be connected to the WTS Coils. The Integrated Circuit MCM provides two switches on both the High and Low sides of the load (pins E18 and E14; also pins E12 and E13). This guarantees that during any single point failure the high side of the power bus will not be shorted to spacecraft ground

The pulse width timing circuit components have been chosen to be placed outside the MCM. This allows modifications to the pulse widths as necessary to meet spacecraft requirements [4]. These are done through pins E04 & E06-- E07 & E08 for one pulse processing path. Power and return to the WTS Multichip Module are through three (3) pins, ensuring reliability of power connections. The traces are designed to carry up to

5 Amps of current. The current driving capability of the WTS driver MCM provides to its load is 0.6 amperes for 250 msec to the load.

The layout of the Flight Electronics has been done using AutoCad utilizing high reliability layout guidelines. Both of the pulse generator circuits are laid out as congruent pieces at the top and at the bottom of the substrate with the common sink circuit in the middle [2] (see Fig. 3). The footprint dimensions of the package is 1.295 X 1.900 inches.

The Electronics and its packaging have been designed with other flight hardware projects in mind in order to make the MCM universal enough to be used on-board other spacecraft.

Prior to layout and packaging, the substrate area was estimated using the MCM Parts List. The Parts List included all discrete devices, (i.e. transistors, diodes, chip capacitors, and chip resistors) device sizes, their value tolerances and power dissipation. Calculations were summed for each circuit element and then multiplied by ten (10)

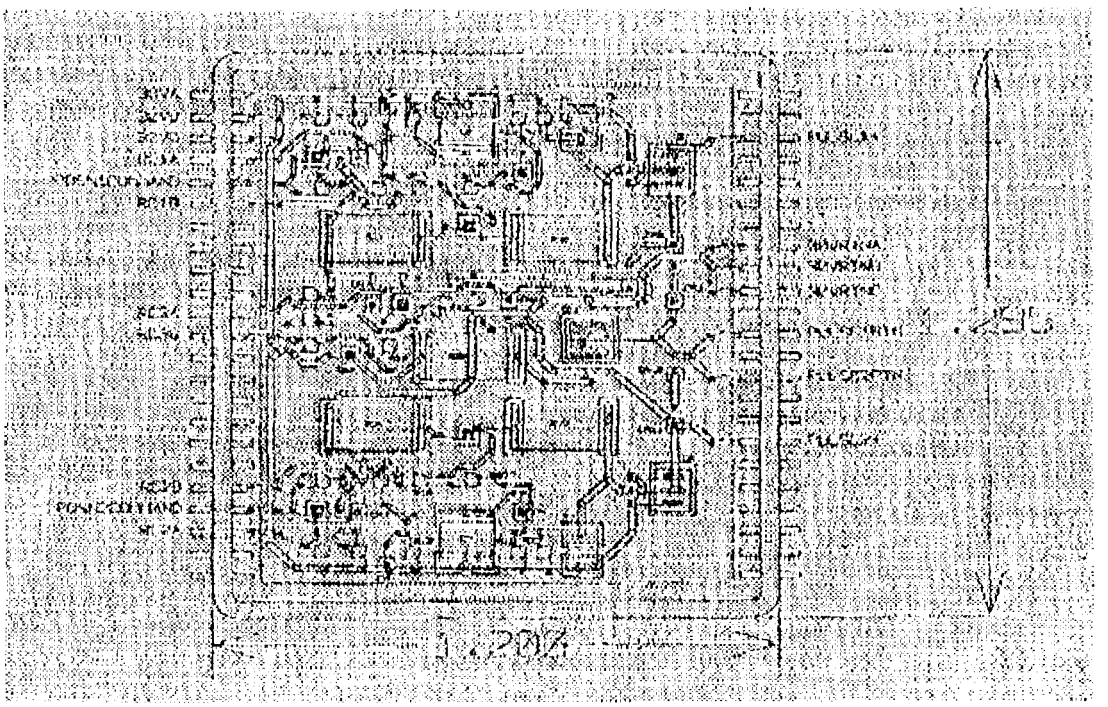

Figure 3. WTS Driver MCM Substrate Level Layout

2.0 Testing

Pre-testing of semiconductor die (transistors and diodes) has been essential for producing MCM circuits with initial high yields. Defective die have been identified and replaced in the early stages of the MCM assembly. Calculations for initial yields and first rework yield are :

Initial Hybrid Yield (Fo)--Assuming 20 devices (M=20 devices) each having 10% (Industry average) probability of failure (P):[1]

$$Fo = (1-P)\exp(M) \qquad (1)$$

$$Fo = (1-0.1)\exp 20 = 0.9\exp 20 = 12.2\%$$

First Rework Yield (F1)

$$F1 = (1-Fo)(1-P)\exp M1 \qquad (2)$$

where M1 is the average number of failures per rework

$$M1 = (M*P)/(1-Fo)$$

$$1-Fo = -0.112 = 0.878$$

$$M1 = 20(0.1)/0.878 = 2.28 \text{ average rework failure, therefore}$$

$$F1 = 0.878(1-0.1)\exp 2.28 = 69\ \%$$

Burn-in consisted of applying power to the circuit while maintaining an elevated temperature for an extended period of time. Raising the ambient temperature and applying power to the circuit, stresses the critical connections and components while accelerating the life cycle of the Multichip Module.

Burn-in has been a critical step in the screening of WTS Driver MCMs since it has established electrical and thermal conditions that approximate actual operation in a compressed time frame (i.e. burn-in of 160 hours at 125 degrees Celsius is equivalent to a full year of operation at ambient temperatures). Ion migration is the most common failure mechanism. Chloride or sodium ions are two prevalent forms of ionic contamination. Positively charged sodium ions under the temperature and bias conditions readily migrate to N doped regions causing high leakage current and even shorts. Chloride ions tend to migrate to the P-doped material and may cause emitter to collector shorts in NPN transistors. These defects may not be discernible for many months, but the combination of high temperature and power that is provided by burn in accelerates the ionic migration without effecting the normal failure rate or the wear-out rate.[1]

The WTS MCM also passed MIL-STD-883D test inspections with ten different test methods. It includes 11 transistors, 4 capacitors, 33 resistors and 11 diodes with 59 total number of parts. The radiation hardness of the assembly is 100 Krad (Si). The WTS MCM has been tested over military temperature range of -55 degrees Celsius to +125 degrees Celsius and passed full functional and performance tests. The total power consumption is 2.25 Joules during 250 msec of operation.

Conclusions

A newly developed spacecraft Integrated Circuit [100 Krad (Si)] Technology is presented in this paper. The WTS driver MCM technology opened possibilities to fly high reliability electronics with low mass and volume. Future spacecraft electronic technologies will rely on developments described in this paper to play on low mass, low volume (i.e. DS1 and DS2) missions.

Acknowledgement

This work has been performed at Jet Propulsion Laboratory, California Institute of Technology with Cassini Flight Program under a contract with National Aeronautic and Space Administration.

References

[1] James J. Licari and Leonard R. Bulow. Hybrid Microcircuit Technology Handbook: Materials, Processes, Design, Testing and Production. Noyes Publications, 1988.

[2] Paul E. Gray and Campbell L. Searle Electronic Principals Physics, Models, and Circuits. John Wiley & Sons, Inc., 1966.

[3] Millman & Taub. Pulse, Digital, and switching waveforms. McGraw-Hill, Inc. 1965