DESIGN AND DEVELOPMENT OF 75 MHz 1 kW RF SYSTEM WITH MICRO- CONTROLLER BASED PROTECTION AND CONTROL

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Abstract

A 75 MHz, 1 kW Radio Frequency (RF) system has been successfully tested on a 50 ohm load, along with a microcontroller based protection circuit for protection of the system against the possible problems that may occur during RF power coupling to Radio Frequency Quadrapole (RFQ) load. This paper describes major challenges faced during the development and methods by which they have been overcome. Measurement of the tube anode temperature which is at 4 kV dc and 1 kW RF power is one of these. Confidence provided by these successful experiences has inspired an exploration of possibilities for further enhancement of the present system. These are also discussed in the paper.

INTRODUCTION

Testing of 75 MHz, 1kW Amplifier up to 300 W and its driver up to 200 W on 50 ohm load is reported in [1]. Integration, testing and characterisation of these at 1 kW output power is mentioned in [2]. Due to component heating issues, output matching network was modified and tuned. Older unregulated grid bias supplies were replaced by new regulated ones. ZH-6090H Pre-driver mentioned in [2] was also integrated. The system was tested for 2 hours continuously to observe any temperature related changes. The amplifier provides 1 kW RF power output from signal generator input of 160 mV with 63 dB overall system gain and 51.7% efficiency.

Presently, work is being done for protecting the system during load mismatch conditions. An anode temperature sensing based protection circuit was developed after overcoming various RFI and high voltage issues. This development has introduced additional features and provided valuable experiences for further enhancement of the overall system.

TEMPERATURE SENSING FOR TUBE PROTECTION

In addition to inbuilt protections provided inside the dc bias supplies, special protections need to be incorporated in the RF system when coupling the RF power to a prototype RFQ as large load impedance fluctuations are expected. Circulators are not available to protect the tube from the resulting reflections while operating at such high power and high frequency.

One of the possible results of high reflected power is high power dissipation in the anode resulting in a sudden rise of anode temperature. Tube manufacturers suggest use of temperature sensitive paints to know whether a certain anode temperature is exceeded during operation. This method, however, does not provide online protection. Many attempts were made earlier to sense the anode temperature indirectly, based on temperature of the air flowing out of the anode fins. However, the high voltage (4 kV), high RF (1 kW) environment made this measurement challenging and largely unsuccessful. Recent developments in Infra-Red (IR) sensors and special electronic components designed for RF circuits has made direct anode temperature measurement possible.

A non-contact IR temperature sensor was chosen. Its features include: high IR resolution [3] which allows the sensor to be placed at a reasonably safe distance from the high voltage anode, compactness and ease of mounting, proper grounding and shielding of the transducers and signal conditioning circuits for working in high Radio Frequency Interference (RFI) environment, analog (0-5V) and digital (RS232) outputs, Light Emitting Diode indicators showing operation status, over temperature alarm generation, low cost and ease of availability.

Initially, the 0-5 V analog output of the sensor was monitored. It was observed that conducted RF, entering the signal at the signal conditioning end, introduced a dc shift in the linear amplifier ICs. During measurement, the same temperature corresponded to different voltage levels with and without RF as detailed in [4].

Then, RS232 output of the sensor was connected to a computer and temperature was monitored using LabView software interface. The output had an accuracy of 0.1^oC and no offset in the measurement was observed even when operating at full RF power. Thus, it was clear that this digital signal communication is less prone to errors in RF environment. In order to utilise this digital signal, it was required to introduce a micro-controller based digital circuitry, which uses low voltage levels (3.3V), into a high RF noise environment. This posed the second major challenge especially since there was not much experience available on such a combination.

PROTECTION AND ON-OFF CIRCUIT

Fig. 1 shows block diagram of a successfully tested, in-house developed, protection and on-off circuit based on the above mentioned IR sensor, a 42 MHz, 32 bit ARM7TDMI architecture micro-controller, an RF ON/OFF switch and relays. It was observed that at 1 kW power, temperature of the anode settles at around 65^oC. The microcontroller trips the RF system if this temperature exceeds 80^oC.

This circuit contains five Analog to Digital Converters (ADCs) of which one, ADC0 is used for self diagnostics; ADC1 is connected to an analog multiplexing board making a total of eleven external analog signals inputs. It has four DACs. It has 14 General Purpose Input/Output

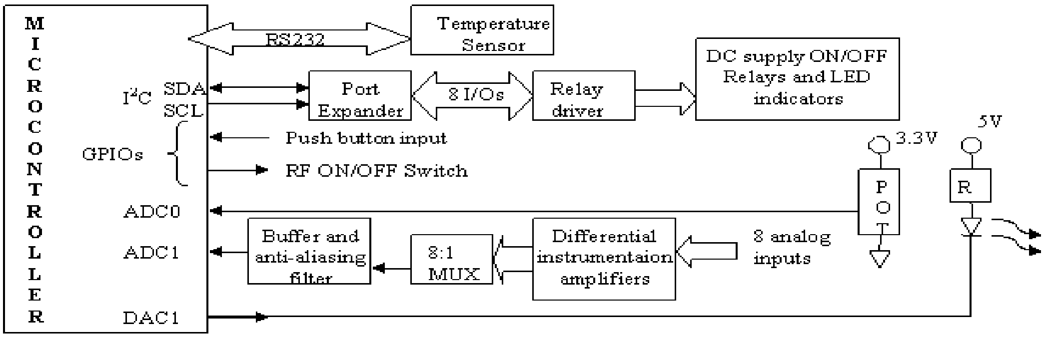

Figure 1: Block diagram of Prototype Protection circuit tested with 75 MHz, 1 kW RF system.

(GPIO) pins of which two have been used to interface with an Inter-Integrated Circuits (I^2C) port expander board to control various relays. Thus this circuit can easily accommodate a large number of parameter sensing and control requirements. RF output power signal (0 to 43 mV) from a directional coupler was monitored online and results of this measurement are given in [4].

Introduction of a micro–controller system has added automatic on/off, self diagnostic capabilities and remote operation features into the system along with possibility of monitoring, logging and control of various parameters of the system which is being explored experimentally.

ISSUES FACED, SOLUTIONS AND NEED FOR FURTHER IMPROVEMENT

It was observed that any attempt for I^2C communication during RF operation leads to temporary failure of related ICs. This presented the third challenge while designing the protection circuit. The system had to be designed such that all communication during RF operation is done using direct GPIO pins of the micro-controller. Also the software has been specially developed such that any temporary communication failure due to entry of RF noise in the signal level does not hamper the working of the system or hang the software. Timeouts, error checks and fallback strategies [5] have been introduced in all communications to peripherals for this purpose.

Use of differential signalling interfaces such as Control Area Network (CAN) bus is important in future designs to overcome this issue. During RF operation it was observed that the sensing points at switches/relays must be connected to relevant voltages or ground and not left unconnected; actions based on zero voltage level sensing rather than high voltage level sensing is less prone to RFI errors; and as expected twisted cables reduces RFI entering low frequency signals.

The sensed temperature was used to control the output of one of the Digital to Analog Converters (DACs) to which an LED was connected. It was observed that there is a shift of 0.3 V in this voltage during RF operation. Thus steady voltage outputs are prone to errors in the presence of RF. Instead, outputs based on Pulse Width Modulation (PWM) and current converters would provide more effective analog control outputs.

Electro-magnetic interference (EMI) filter modules are available for various frequencies, voltage/current levels and source/load impedances which must be introduced at every low to high frequency interface [4]. Conducted noise can pass into nearby filtered channels through radiated emissions at such high frequencies. Hence filters must be mounted such that all inputs and outputs are separated by metallic shielded enclosures.

Buffers based on normal Op-amps introduce a dc offset in the signal output corresponding to RF at the inputs. Thus, often the output goes into saturation. Less than a year back special EMI hardened op-amps have come into production to overcome this issue [4]. These have very high 'EMIRR' or electromagnetic interference rejection ratio which makes it very useful in such applications.

Various other such special components are becoming available because of the increased research in RF devices for the mobile and wireless industry. Most of these are surface mount devices. Hence, a well designed digital processing based general purpose board using such components can be developed with provision for protection, monitoring and control in such a manner that it may be easily used on a large variety of RF systems without major hardware modifications. With further study and understanding, modern control systems, filters, sensors and actuators may be used to design advanced RF power amplifiers such that highly stable, precisely controllable and safe RF power may be provided even in fluctuating load conditions.

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