An Optoelectronic Closed-Loop Control System for RF Amplifiers

STUDENTS: Raymond Huang , Anastasiya Makarevich, Hongming Ping, John Leo Velpugonda

ACCESS LASER
Member of the TRUMPF Group
TRUMPF

RF Driver Protection

- The initial devices of the project are the RF driver and the laser generator. The RF driver generates RF power and transmits it through a cable to drive the laser generator. During plasma initiation inside a laser, the load impedance may be mismatched and cause high amplitude power reflections that can travel back to the RF driver – therefore damaging it.
- The project goal is to develop a VSWR (Voltage Standing Wave Ratio) detector and an optical detector to monitor both the VSWR and the presence of an optical signal to protect the RF driver during the plasma initiation.
- With the circuits detecting the status of the laser and power, the information from the circuits shall be transmitted to the RF driver. The RF driver shall adjust itself according to the information.

Requirements

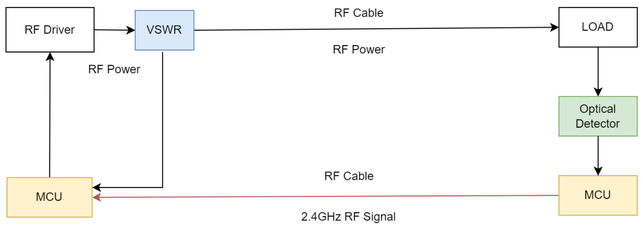

Figure 1: Overall circuit design and interconnections

a) VSWR Detector: Circuit shall couple power from the main line and output a logic high when the VSWR is less than 3:1, low otherwise. It shall be compatible with 45MHz 500W RF driver.
b) Optical Detector: Circuit shall use a 12.5V DC power supply, detect 700-1100nm incident light, have a response time under 0.5us, and be constrained to 2.5cm x 2.5cm x 1cm.
c) MCU: MCU shall process the output of both circuits and transmit to the RF driver, completing the closed loop of the whole system.
d) General: Both circuits shall use SMT components with adequate temperature ratings. Engineering standards such as RoHS and IPC-2221/2222 shall be followed.

MCU

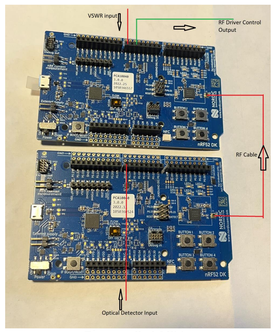

Figure 2: MCUs

Since there are two parts of the whole system – RF driver and laser generator, we use two MCUs on each part, connecting to each circuit. The MCUs are Nordic nRF52832, and this is for RF transmission in 2.4 GHz.

The Optical Detector side MCU (lower MCU) takes the signal from the optical detector circuit. It then transmits the 2.4 GHz RF signal according to the circuit output. The signal is transmitted through the cable in radio frequency (RF signal).

The RF driver side MCU (upper MCU) takes two inputs: RF signal, VSWR circuit's signal. According to this, the RF signal is then transmitted through a cable back to the RF driver.

Optical Detector

The optical detector generates a logic high signal if there is plasma initiation. The schematic is shown in Figure 3 and the stages shown in the block diagram of Figure 4.

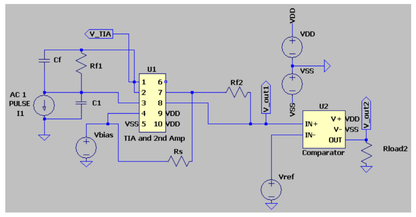

Figure 3: Optical Detector LTspice schematic

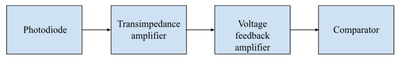

Figure 4: Optical Detector Block Diagram

- Shown in Figure 5, the PCB also includes voltage rails for the various biases done using a regulator and resistive dividers.
- Photodiode is on the back and the output is connected to MCU via BNC.

1) Photodiode: Incident light from the plasma generates a photocurrent in the reverse-biased photodiode.
2) Transimpedance amplifier: The photocurrent is amplified and converted into a voltage signal by the TIA.
3) Voltage feedback amplifier: The TIA output is further amplified in a second stage to preserve bandwidth.
4) Comparator: The output of the second stage is compared to a reference and sent to the MCU. Output high if the laser is on, Output low if the laser is off.

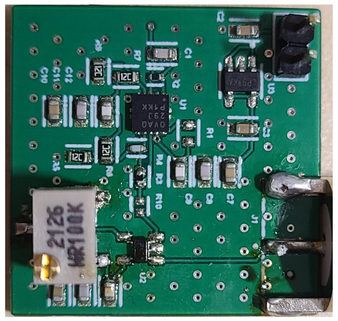

Figure 5: Optical Detector PCB

VSWR Detector

The VSWR detector has 4 subcircuits used to detect the reflections in the main line and outputs a logic LOW signal when a high VSWR (3:1~5:1) is detected.

- Tandem match coupler: The circuit samples the forward and reflected waves from the main line by a factor of –30dB and creates the two distinct outputs respectively.
- Attenuator: The peak detector does not match the characteristic impedance (50 Ohm) of the circuit, causing reflections, therefore detecting a high VSWR falsely. A -10dB π-pad attenuator is placed before the peak detector to reduce the magnitude of the reflected signals.
- Peak detector: The coupled AC signal is converted to a DC signal using a peak detector circuit. This signal is then used to compare the VSWR.
- Comparator: The DC equivalent signals of the reflected and forward waves are compared to each other with a comparator that is adjusted to output low when the ratio between them is greater than 3:1 and output high otherwise.

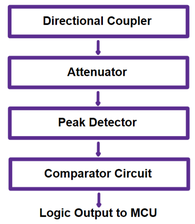

Figure 6: VSWR Detector Block Diagram

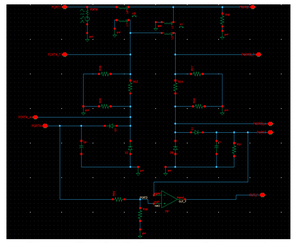

Figure 7: VSWR Detector Schematic

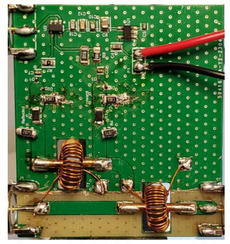

Figure 8: VSWR Detector PCB

Conclusion/Results

Optical Detector:

- Design and layout created in Altium, and components soldered onto PCB.
- Photoemitter used for testing instead of laser (yellow trace)
- Tested all stages of the circuit. Confirmed gain of stages 2 and 3 (green trace and red trace).
- Figure 9 shows output of the comparator in response to the photoemitter input (blue trace).

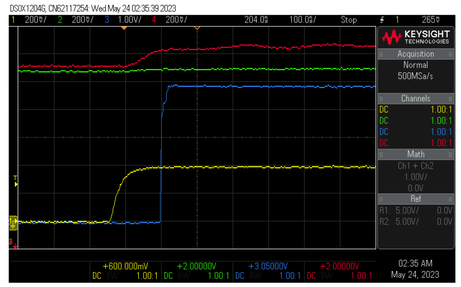

Figure 9: Optical Detector Oscilloscope Results

VSWR Detector:

- Design and layout in Altium.
- Runs 600W at 45 MHz with 5:1 VSWR, meeting the power requirements.
- Triggers around 3~3.3:1 under 45 MHz, 150W testing conditions.
- Figure 10 shows the 3.3:1 VSWR case. Yellow is RF power, blue is forward coupled power, green is reflected coupled signal, and pink is the output signal. The output triggers LOW when a high VSWR is detected.

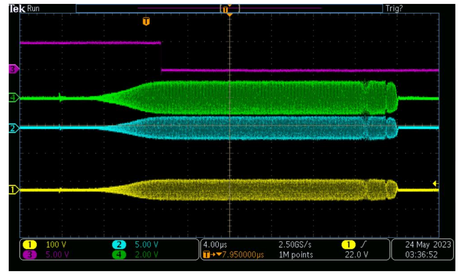

Figure 10: VSWR Detector Oscilloscope Results

MCU:

- Optical Detector Circuit MCU: The firmware of the MCU contains a main function, GPIO interruption handler and radio configuration function coping with RF signal's generation and transmission.
- RF driver MCU: The firmware of the MCU contains a main function continuously polling the RF signal, GPIO interruption handler for VSWR input and GPIO output function to control the RF driver.
- Result: The purpose of the MCU has been achieved - the communication through RF signal, and the interaction with circuits. However, due to the hardware issue, the RF transmission exceeds the time limit.

Future Work

- Further testing the response of both the optical and VSWR detector on site with the laser.
- Testing on the bandwidth and response time of the optical detector.
- Development of the comparator circuit for an adjustable VSWR trigger value.
- The MCU firmware could be optimized to control registers and hardware modules in kernel scope to decrease the processing time.
- The RF transmission could be loaded with more information that might be useful for the interaction between the two parts in the closed loop.
- The MCU could be embedded on the same PCB board together with the circuits.

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ELECTRICAL & COMPUTER ENGINEERING
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