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Investigation of Electromagnetic Interference from a Pulsed Solid State Laser Power Supply

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Abstract

This paper investigates the near field, far field and conducted electromagnetic emissions in a pulsed power supply circuit for a flash lamp pumped solid-state laser amplifier. The power supply consists of a charging circuit, which energizes 300 μF of energy storage capacitor bank to 3 kV. The stored energy is discharged through a flash lamp in the form of pulsed current. It is a single shot event as commonly encountered in large scale high power laser systems. Measurements of the pulsed electromagnetic interference (EMI) are carried out in time domain with the help of a Bi-conical and a Dipole antenna for radiated noise up-to frequency range of 1 GHz, near field E-H probes and a line impedance stabilization network (LISN) for conducted line noise. The post storage time domain transient EMI signals are converted to frequency domain with the help of Welch mean square spectrum estimate in MATLAB. Quantitative measurements and characterization are helpful to understand the noise characteristics in pulsed laser power supplies, to mitigate the noise related issues and to validate them for electromagnetic compatibility (EMC) compliance standards.

Index Terms: EMI, Flash Lamps, Laser power supply

1. Introduction

The basic function of power system in a flash lamp pumped pulsed solid state laser is to extract energy from the power grid, shape and time compress it for delivery to the flashlamps that in turn pump the laser active medium. As shown in the following figure, energy is extracted from power grid over a period of 60 to 120 seconds and converted to capacitor voltage by a charging circuit. After the capacitors are charged to the required voltage, a high voltage and sharp trigger pulse is generated to discharge the stored energy on the capacitor bank into the flash lamp in approximately 600 μs.

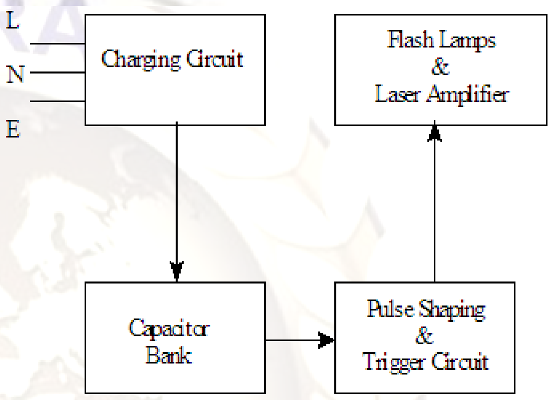

Fig.1. Power conditioning of a flash lamp based laser system

Transfer of energy from capacitor bank to the flash lamp is accomplished using nearly critically damped RLC circuit [1]. The single flash lamp under the present study is energized by 300 μF of energy storage capacitors. There are a number of possible circuit schemes for charging of the capacitor banks and discharging them through flash lamps in controlled manner. These power supplies are pulsed systems, which have potential to generate large electromagnetic fields that can cause interference in other systems and diagnostics. This report presents the measurement results of radiated (near field and far field) and conducted emissions from a flash lamp pumped solid state laser power supply. The noise emission study was conducted on a 280 mm arc length, 16 mm bore diameter xenon filled flash lamp load. Trigger and discharge current loop through the flash lamp network and impedance discontinuity at the interconnects result into conducted and broad band radiated noise. Two different types of far field antennas were used to cover the entire spectrum from 20 MHz to 1 GHz. The AH Systems Bi-conical Antenna, SAS-540 covered the frequency range from 20 MHz to 330 MHz and the Dipole antenna, FCC-4 covered the spectrum from 325 MHz to 1 GHz. HAMEG (HZ-530) E and H probes of bandwidth 1 GHz were used for near field measurements. HAMEG HM6050-2 Line impedance stabilization network (LISN) of bandwidth 30 MHz was used for measurement of line conducted emission.

2. Laser Power supply description

Block diagram of the laser power supply is shown below in figure 2. It consists of a charging circuit, a trigger circuit comprising of the trigger transformer and a control circuit. The control circuit initiates charging of the capacitor bank. On completion of the charging process a high voltage trigger signal is generated which pre-ionizes the flash lamp. This results in flow of pulsed current through the series combination of the capacitor, secondary of the trigger transformer and the flash lamp. The flash lamp discharge cable may be either a single core or a co-axial cable. This work also investigates the effect of a ground image provided by sheath of a coaxial charging cable on the emitted and conducted noise. Length of the discharge cable is 2 m. Photo of a typical charging circuit and the capacitor bank is shown in figure 3.

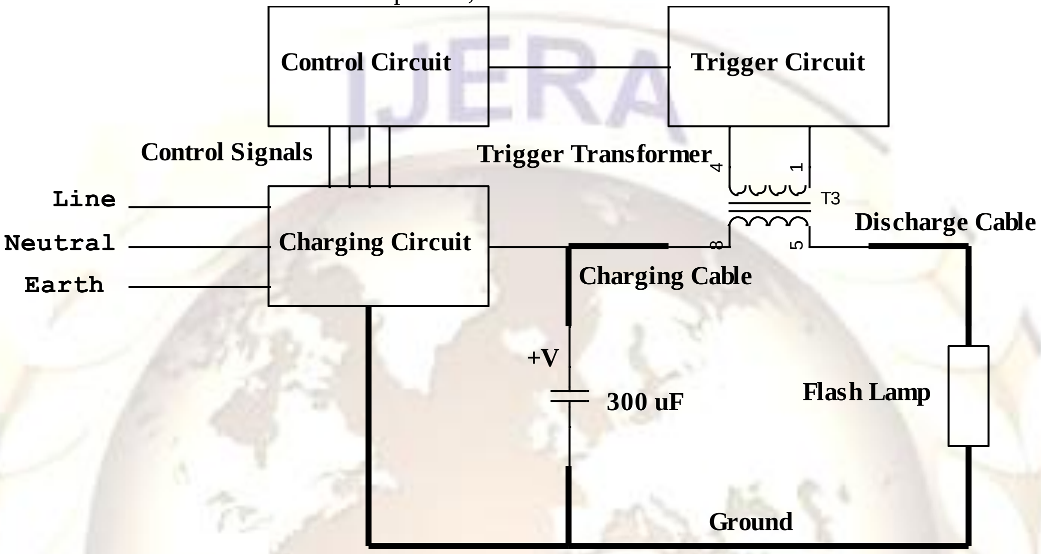

Fig. 2. Experimental setup for the flash lamp power supply

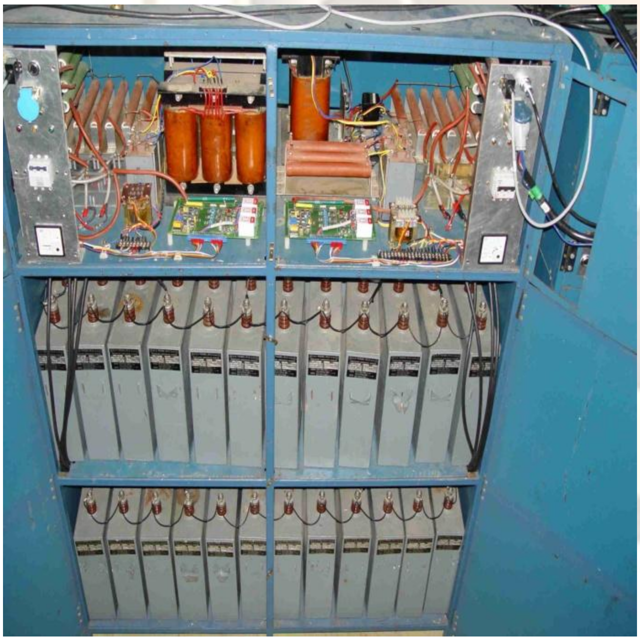

Fig. 3. Power supply capacitor bank

The flash lamp current density varies from 2.5 to 3 kA per cm^2 [2]. Peak of the loop current flowing through the capacitor, trigger transformer and flash lamp depends on the capacitor voltage V_C, circuit impedance Z_0 and flash lamp impedance Z_{FL} as given by the following equation [3],

$$I_{peak} = \frac{V_C}{(Z_0 + Z_{FL})} \qquad (2.1)$$

The flash lamp impedance Z_{FL} is dynamic and changes with the flash lamp voltage and current. The circuit impedance Z_0 is given by $\sqrt{(L/C)}$, where L and C represent the trigger transformer secondary inductance and the energy storage capacitance respectively. Thus, the equation 2.1 can be rewritten as,

$$I_{peak} = \frac{V_C}{\left(\sqrt{\frac{L}{C}} + Z_{FL}\right)} \qquad (2.2)$$

The current pulse width is given by,

$$T^2 = \frac{C^3 K_0^4}{2E_0 \alpha^4} \qquad (2.3)$$

Where, K_0 is the flash lamp constant which depends on the flash lamp gas, pressure and the lamp geometry, E_0 is the stored energy on capacitors and α is the circuit damping constant. The laser pulse is generated after occurrence of the peak of the flash lamp current.

3. Measurement set up

For the study of EMI radiated emission in any system the path and loop area of current flow, the current rise time and the peak amplitude are of primary importance. As expressed in equations 2.2 and 2.3 above, the current profile depends non-linearly on a number of variables like capacitor voltage, circuit values and the flash lamp constant. Emission standards for transient current pulses for electrostatic discharge, fast transient and surge are covered by IEC 61000 (4-2, 4-4, 4-5) documentations [4]. As mentioned earlier, two different types of antennas i.e. Bi-conical and Dipole were used to cover the spectrum up to 1 GHz. These are the most popular antennas used for noise measurement in EMC/EMI studies [5, 6]. The antennas were kept at a distance of 1m from the capacitor discharge cable. The near field probes were kept at 20 cm from the discharge cables. Single phase mains power to the flash lamp power supply were drawn through the LISN. The flash lamp current is measured by a LEM (Model: RR6030) make current probe based on Rogowski principle. The noise measurement was carried out by charging the capacitor voltage to 3kV, generating a trigger signal and discharging the stored energy through a flash lamp. The EMI measurement setup is shown in the figure 4. The power supply chassis along with the flash lamp connections are shown in figure 5.

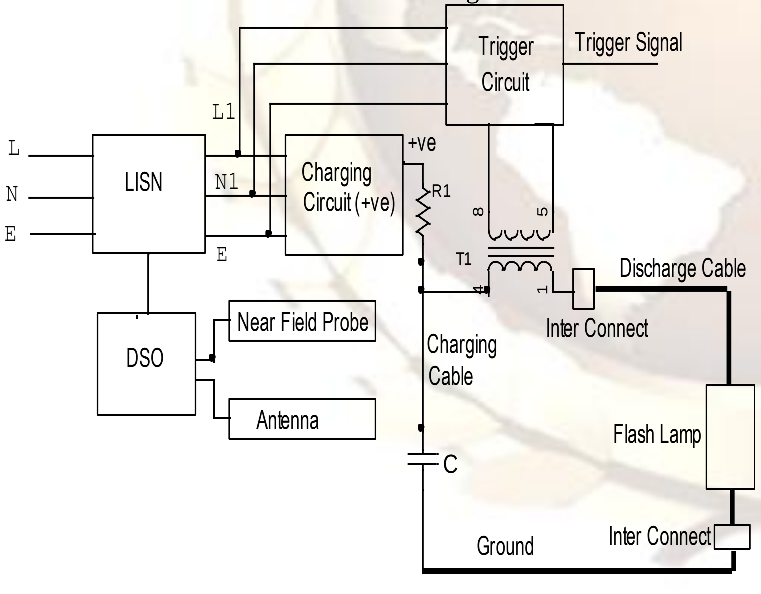

Fig. 4. EMI Measurement setup

Fig. 5. Power supply and flash lamp connection

The flash lamp current and the optical pulse detected with a photodiode is shown below in figure 6. Peak value of the current is 3 kA and the pulse width is nearly 600 µs. A high dI/dt trigger spike is generated at the time of flash lamp pre-ionization and this portion of the flash lamp excitation is the main source of radiated and conducted noise.

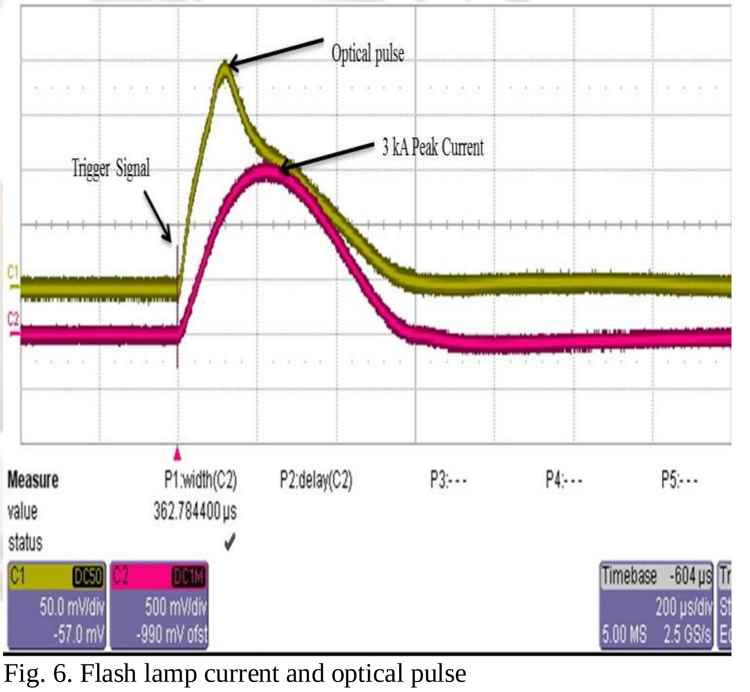

Fig. 6. Flash lamp current and optical pulse

4. Results and discussions

Figures 7 and 8 show the MATLAB generated near field E and H, Welch mean square spectrum [7]. The emissions are shown under the two different conditions i.e. when the capacitor is discharged into flash lamp through a single core cable and secondly through a co-axial cable.

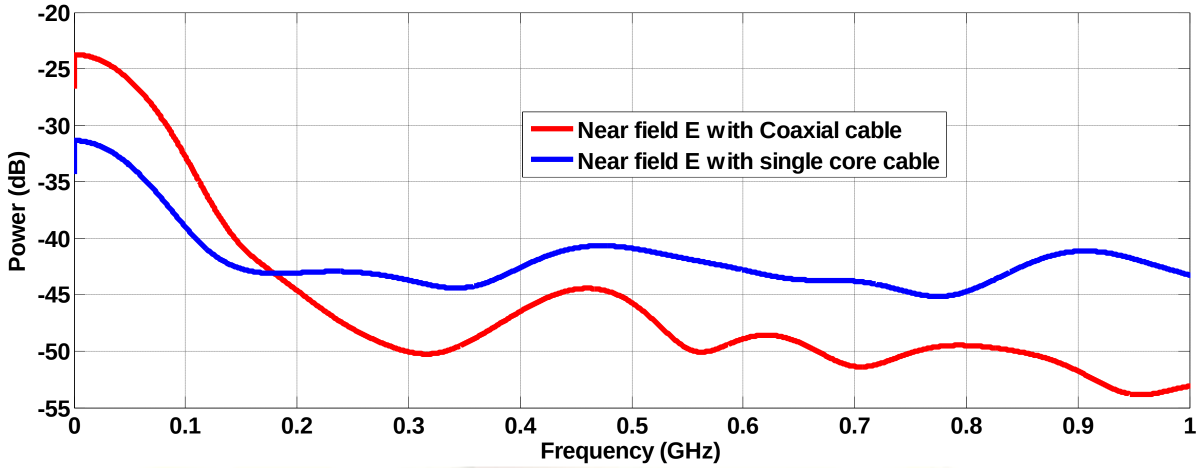

Fig. 7. Near field E spectrum

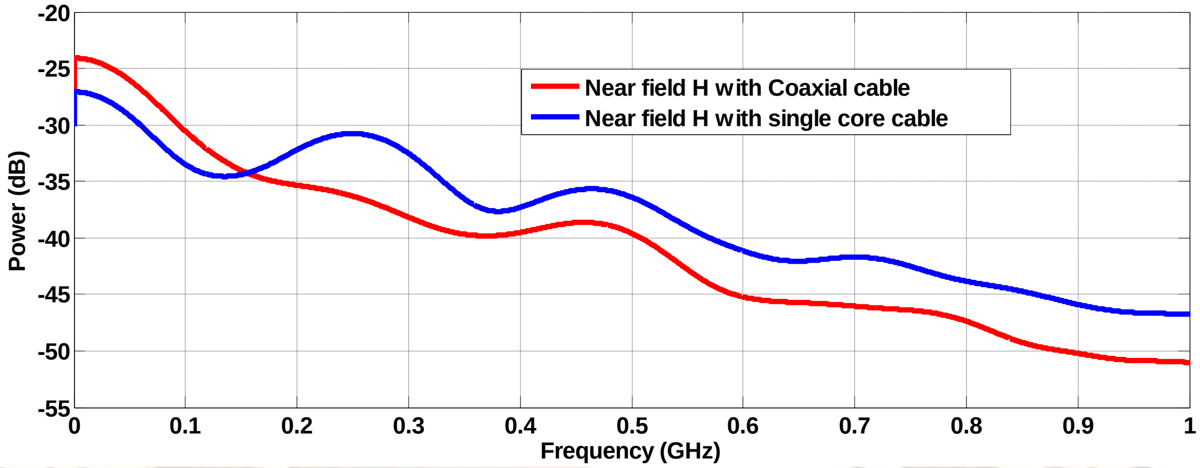

Fig. 8. Near field H spectrum

In the low frequency range (less than 200 MHz) the near field shielding effectiveness of the coaxial cable is smaller. At frequencies greater than 200 MHz the average attenuation of the RG8 co-axial is 3 dB more than a single core cable. The far field emission measured with a bi-conical antenna is shown in figure 9. The antenna is kept at a distance of 1m from the radiating cable. The emission measured with a dipole antenna for a frequency rage up-to 1 GHz is shown in the figure 10.

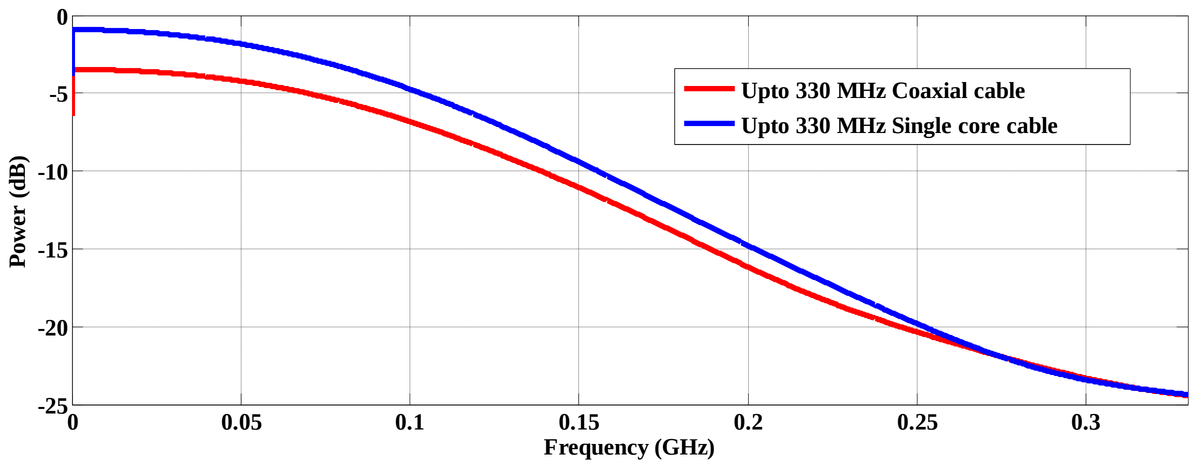

Fig. 9. Radiated spectrum up-to 330 MHz

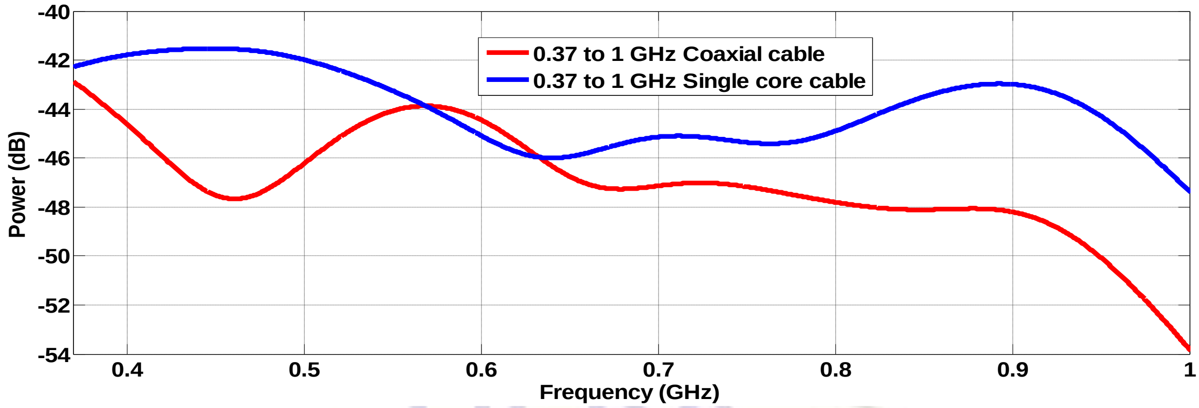

Fig. 10. Radiated emission up-to 1 GHz

The co-axial cable far field shielding shows resonance and deterioration at around 600 MHz. The line conducted noise measured with a LISN is shown in figure 11. The average reduction of the line conducted noise because of co-axial cable is of the order of 2 dB.

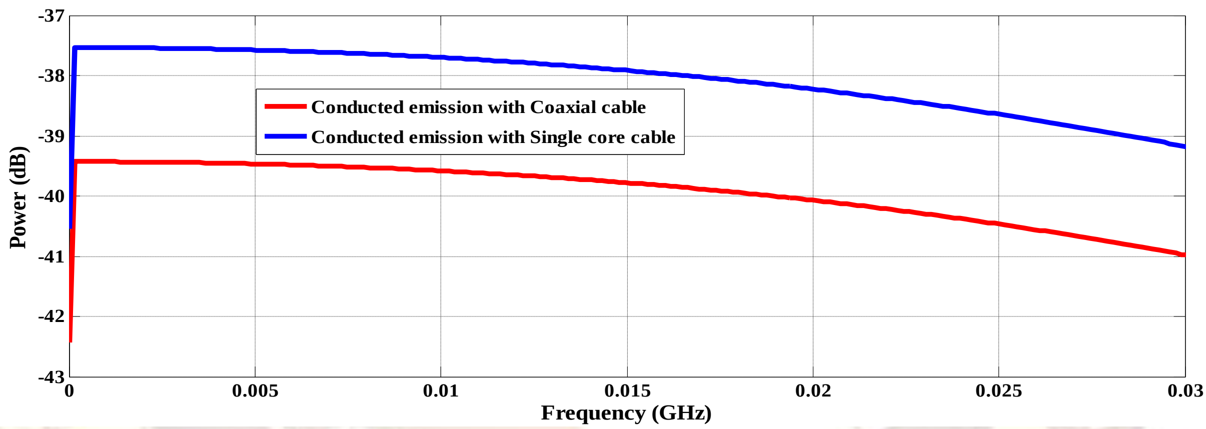

Fig. 11. Line conducted noise spectrum

5. Conclusion

This paper describes the measurements and characterizations of radiated (near and far) fields and conducted emission in a pulsed power supply circuit for a flash lamp load. The power supply consists of a 300 uF capacitor bank which is charged to 3 kV. A high voltage trigger signal results into controlled discharge of the capacitor bank through a flash lamp. The flash lamp discharge current peak is 3 kA and the pulse width is 600 µs. The main discharge current is preceded by a high voltage flash lamp trigger pulse. Trigger voltage, main discharge pulse and the interconnect impedance discontinuities result into radiated and conducted EMI. Compared with a single core cable, a co-axial cable shows narrow band resonance effects at certain frequencies where the sheath shielding effect deteriorates and EMI increases, however, it helps in reducing the overall radiated and conducted EMI as compared to a single core cable.

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