Development of High Voltage Pulse Power Supply for Microwave Tube Applications

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Abstract - **This paper describes about the design and development of high voltage DC pulse power supply for high power applications. The system has variety of features such as independent control of Pulse Repetition Frequency (PRF), Pulse Duration (T_{on}) and pulse amplitude. PC based wireless module with Graphical User Interface (GUI) having variable/controlled PRF (10Hz-1kHz) and T_{on} (10-100µs) module has been developed for pulse generation. Two sets of -25kV, 10A pulse power supplies are connected in series to achieve -50kV, 10A pulse output voltage. High voltage DC pulse power supply is used for the characterization of high power microwave tube and testing applications. To verify the proposed design, simulation and experimental results on resistive load are presented in this paper.**

Keywords – **Graphical user interface, high voltage pulse power supply, HF transformer, microwave tube devices, pulse switching modules.**

I. INTRODUCTION

The design and development of high voltage DC pulse power supply for microwave tubes (MWT) devices has become very important in recent years due to special requirements of the MWT devices. DC pulse power supply for MWT devices need special design, development and control approach. The frequently used topology for high voltage pulse power generation is based on Pulse Forming Network (PFN) approach. The main drawback of PFN based topology are: output pulse width is load dependant and it is used for only low power applications. High voltage switching using solid state devices directly is reported in some applications. But due to complexity in design, control and voltage balancing across solid state devices its uses are very limited for high power applications [1]. The Cockcroft-Walton generator, or multiplier to generate high DC voltage from a low voltage AC or pulsing DC input is also reported for low power applications [2].

The proposed high voltage pulse power supply system consist pulse switching modules connected in series to generate high voltage, high power output pulse, which is a reliable and robust technique for high power applications. Continuous output pulse voltage variation up to 50kV with Pulse Repetition Frequency (PRF): 10Hz to 1 kHz and Pulse Duration (T_{on}): 10µs to 100 µs has been achieved, with satisfactorily good output over the entire working range. Special pulse generation and control module with utmost precision in PRF and T_{on} control has been incorporated in the system.

II. SYSTEM DESCRIPTIONS

The Block diagram of high voltage pulse power supply is shown in the figure. The basic topology of the block diagram consists of capacitor bank, single phase high frequency square wave inverter, high frequency step up transformer, single phase bridge rectifier, pulse switching modules, pulse generation and control modules.

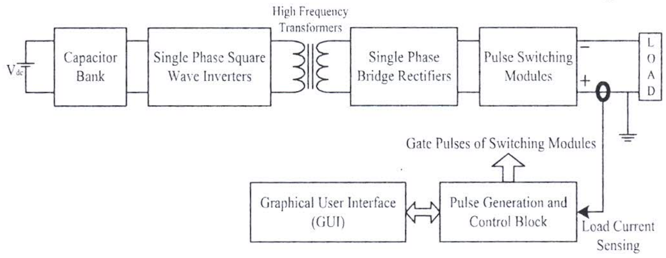

Fig. 1. Block diagram of high voltage pulse power supply

The rectified DC voltage is regulated through capacitor bank at the input side of square wave inverter. Single phase high frequency H-bridge inverter is used for square wave inversion of regulated DC input. High frequency step-up transformer to increase the voltage at required level and providing isolation, rectifier, capacitor to convert and regulate the high voltage transformer output to DC voltage level. Pulse switching modules switches the input regulated DC voltage at required pulse width and pulse repetition rate to generate pulse output voltage. PC based wireless Xbee module with Graphical User Interface (GUI) having variable Pulse Repetition Frequency (PRF) and Pulse Duration (T_{on}) is developed for pulse generation.

Pulse switching module uses high voltage IGBT to switch the voltage and a high voltage diode for free-wheeling the power in the inductive load and also to clamp the IGBT voltage to the input DC voltage. Each pulse switching module has isolated gate drive power supply. Gate control signal is provided through optical fibre cable. Total twenty such modules are connected to form high voltage pulse power supply. Output pulse amplitude is varied by controlling DC bus voltage at the input of square wave inverter. Pulse repetition frequency and pulse width is controlled wirelessly through Xbee module. Overcurrent protection is also incorporated in the systems and it can be seen on the GUI.

A. High frequency inverter

High frequency (HF) square wave inverter operates in open loop at 30kHz switching frequency with a dead time of 1.8μs-2μs. It is rated for a 560V DC input and output of 560Vrms, 12.5kVA power capacity. Total four such inverters are used in this pulse power supply. The structure for the inverter has been designed such that two H-bridge inverters are accommodated back to back to use a single blower for cooling the heat sinks.

B. Transformer Design

Fabrication of high frequency (HF) step up transformer is done using ferrite core EPCOS U 126/91/20 at operating flux density of 0.3T. To achieve 2.5kV secondary output from 500V primary input, the calculated numbers of primary and secondary turns are Np = 28 turns (14 turns on each limb connected in series) and Ns= 162 turns (81 turns on each limb connected in series) with operating frequency of 30kHz.

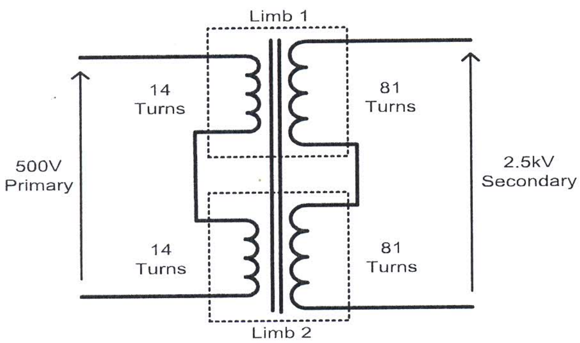

Fig. 2. Winding structure of transformer

The transformer winding is done on custom designed bobbin/former using no-max paper of 2mm thickness.

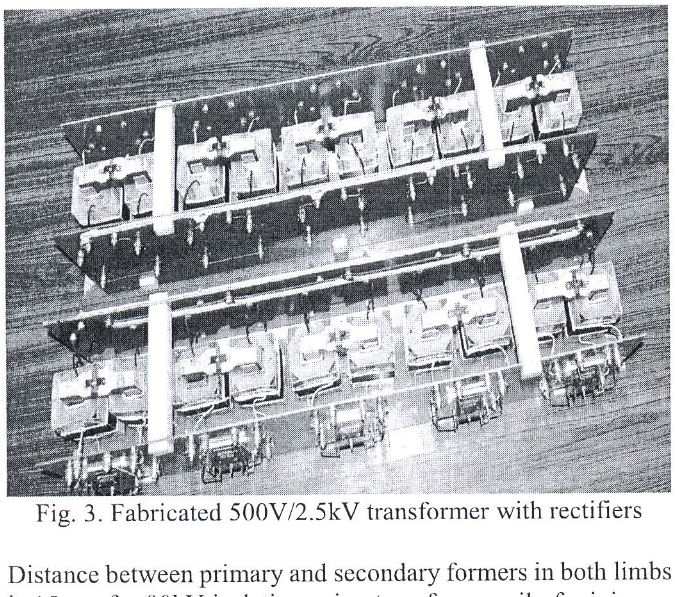

Fig. 3. Fabricated 500V/2.5kV transformer with rectifiers

Distance between primary and secondary formers in both limbs is 15mm for 90kV isolation using transformer oil of minimum 25kV/2.5mm suggested. Total twenty such transformers are fabricated. The transformer assembly is immersed into Servo Electra transformer oil for isolation and cooling purpose.

C. Bridge rectifier

The output of high frequency transformer is connected to high voltage full wave bridge rectifier assembly of 3HVFWB5KDUSF, 5kV/3A with reverse recovery time 40ns. Its output voltage is filtered using set of two non-polar capacitors 32μF/1900V, FFVS6N0326KJE in series, each capacitor having a 3.3MΩ/2W resistance across it for voltage balancing.

D. Pulse switching module

Pulse switching module converts the -2.5kV DC voltage into a -2.5kV pulse output voltage. It has Powerex 4500V/60A, QIS4506002 HV single discrete IGBT for switching -2.5kV DC voltage at the specified pulse width and pulse repetition frequency.

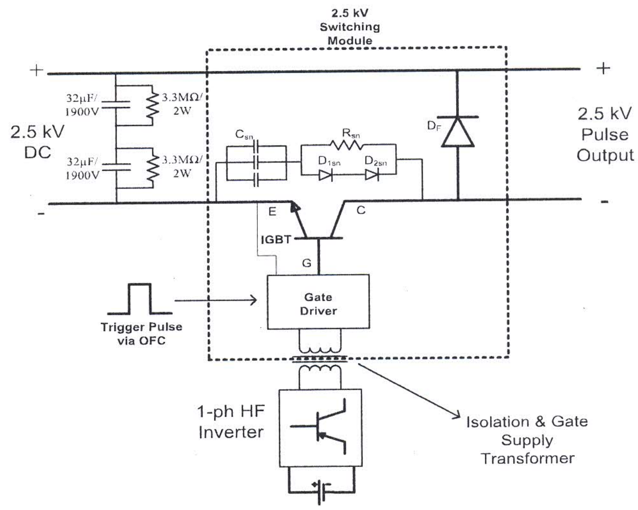

Fig. 4. Circuit diagram of 2.5kV pulse switching module

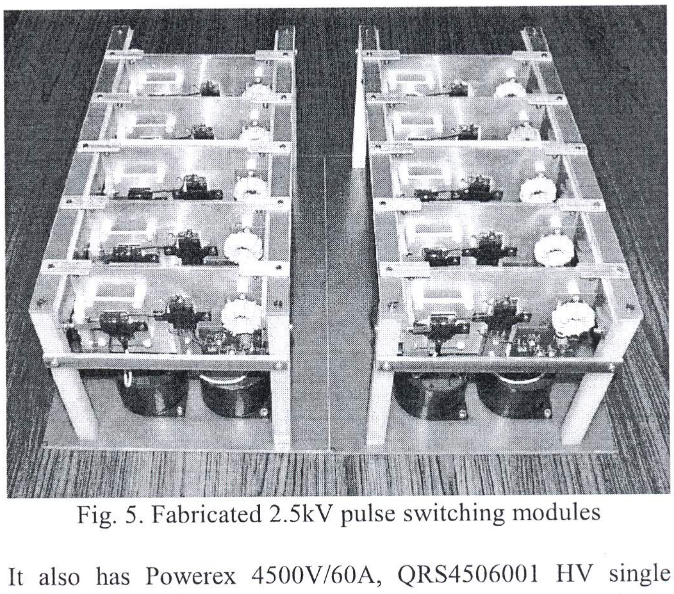

Fig. 5. Fabricated 2.5kV pulse switching modules

It also has Powerex 4500V/60A, QRS4506001 HV single discrete diode (D_F) for free-wheeling the power stored in an inductive load as well as to clamp the IGBT voltage to -2.5kV. The IGBT is mounted on 200mm X 150mm X 5mm heat sink and D_F diode is mounted on 80mm X 60mm X 5mm heat sink.

Pulse switching IGBT is provided with dv/dt protection using RCD snubber circuit. Two series diodes D_{1sn} and D_{2sn}, of 1800V/20A, IXYS DH20-18A, connected in parallel with non-inductive resistor, R_{sn} of 100Ω/25W and it is connected in series with capacitors, C_{sn} of 9.9nF (using parallel combination of three 3.3nF/6.6kV capacitors) making RCD network. The RCD snubber circuit is connected across IGBT as shown in figure 4. The diodes together withstand an instantaneous voltage of 2500V at the beginning of the IGBT turn – ON and facilitate the charging of capacitor, C_{sn} during IGBT turn – OFF. Non-inductive resistor R_{sn} and capacitor C_{sn} are used to control dv/dt during IGBT turn – ON.

PCB with IXDD414YI Ultrafast gate driver circuit, Optical Fiber Cable (OFC) receiver circuit and isolated gate drive power supply is mounted on the pulse switching module. The transmitted pulses from pulse generation block is fed to the gate driver of switching module via OFC cable connected to a receiver R-2521Z mounted on the PCB. The OFC provides a high voltage isolation from the control circuit.

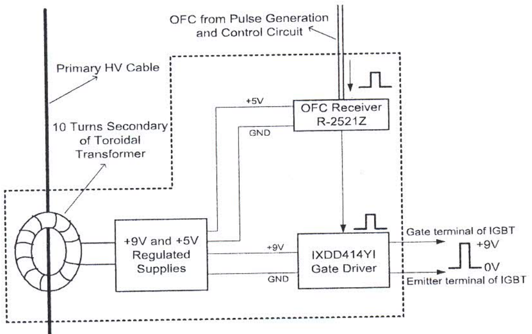

Fig. 6. Schematic diagram of gate drive circuit

For floating gate drive power supply, high voltage insulated wire passed through toroid transformer and acts as primary winding. The toroid based transformer is designed with an isolation of 90kV between primary and secondary. Its primary side is excited by 16V, 40kHz H-bridge square wave inverter. The secondary voltage is rectified and regulated to generate isolated gate drive supply for each pulse switching module.

E. Pulse Generation and Control Unit

Pulse power supply for high power applications requires utmost precision in pulse repetition frequency and pulse width control. PC based wireless pulse generation unit with its graphical user interface having variable PRF: 10Hz-1kHz and T_{on}: 10μs-100μs is developed. The developed module enables the user to control the frequency and pulse width of high voltage pulse power supply through a wireless network.

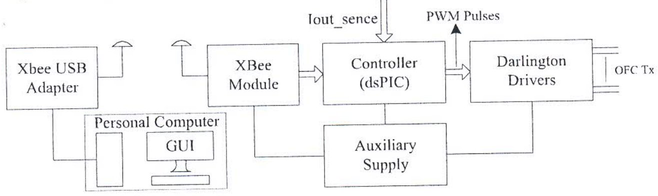

Fig. 7. Schematic diagram of pulse generation and control

III. SIMULATION MODEL

The proposed high voltage pulse power supply is simulated in MATLAB/Simulink model. For simulation purpose the input voltage is taken as 500V constant DC. Simulation model consist two sets of -25kV, 10A module, connected in series to form -50kV, 10A pulse output system. At ratted power of 50kW, with PRF: 1kHz and T_{on}: 100μs, a resistive load of 5kΩ is connected across the output terminal.

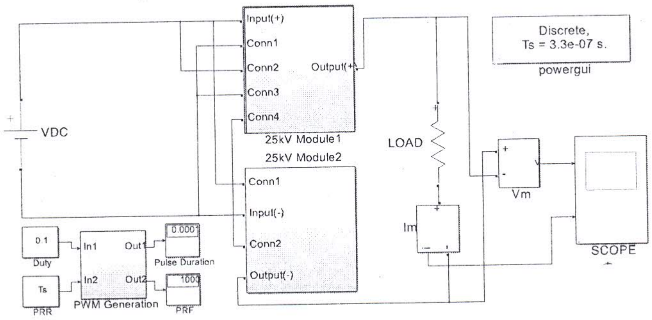

Fig. 8. Simulink model of pulse power supply

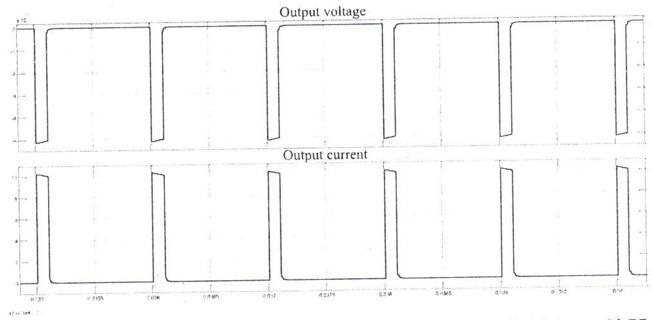

Fig. 9. -51.5kV, 10.2A pulse output waveform @100μs, 1kHz
Scale: X axis 1 unit=500μs; Y axis 1 unit=10kV and 2A

IV. HARDWARE DEVELOPMENT

Two sets of -25kV, 10A pulse power supply units have been fabricated. Each set consists ten sets of pulse switching modules, rectifier modules, HF transformers, HF square wave inverters, cooling arrangements and other related circuitry.

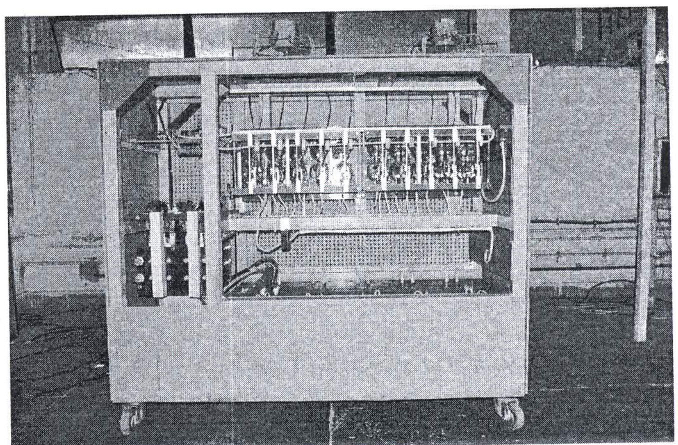

Fig. 10. Fabricated pulse power supply -25kV,10A unit-I

Two sets of -25kV, 10A pulse power supply has been integrated to achieve -50kV, 10A pulse output voltage and current respectively.

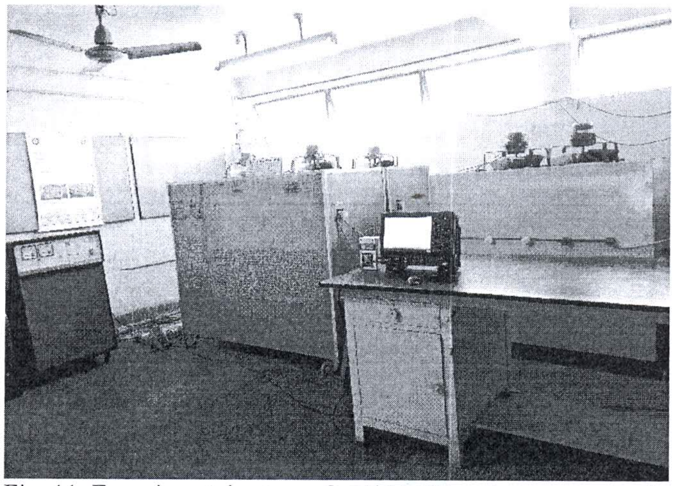

Fig. 11. Experimental set up of -50kV,10A pulse power supply

V. EXPERIMENTAL RESULTS

In order to verify the study analysis and simulation experimentally, two sets laboratory prototype of proposed pulse power supply has been fabricated as shown in figure 10. Individual testing of pulse switching module has been done on resistive dummy load for maximum rated pulse output current and pulse output voltage of -2.5kV and 10A respectively, over the entire range of PRF: 10Hz to 1kHz and T_{on}: 10μs to 100μs. Similarly, both fabricated set has been tested on resitive dummy load for rated pulse output current and pulse output voltage of -26kV, over the entire range of pulse repetition frequency and puse width. Test results of -25kV, 10A, 25kW pulse power supply modules are presented in figures 12-13. The testing was done for more than 15 minutes with fast rising time of output pulse waveform, satisfactory flat output pulse shape and slower turn – OFF with a tail. To avoid any damage, output current protection is incorporated. The developed pulse power supply system has high flexibility of output voltage variation with respect to the pulse repetition frequency and pulse width.

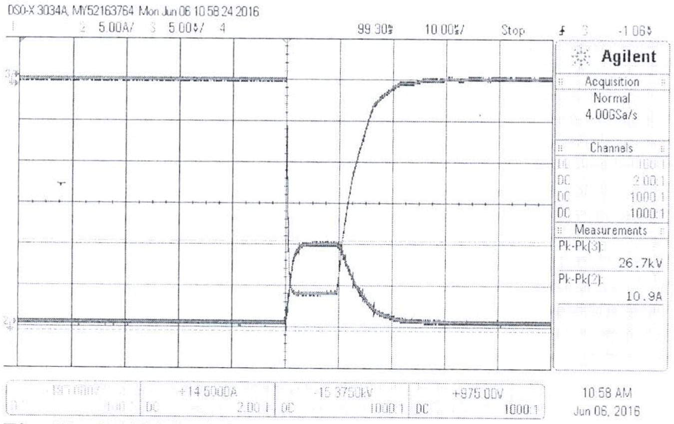

Fig. 12. -26.7kV, 10.9A pulse output waveform @10μs, 100Hz
Scale: X axis 1 unit=100μs; Y axis 1 unit=5kV and 5A

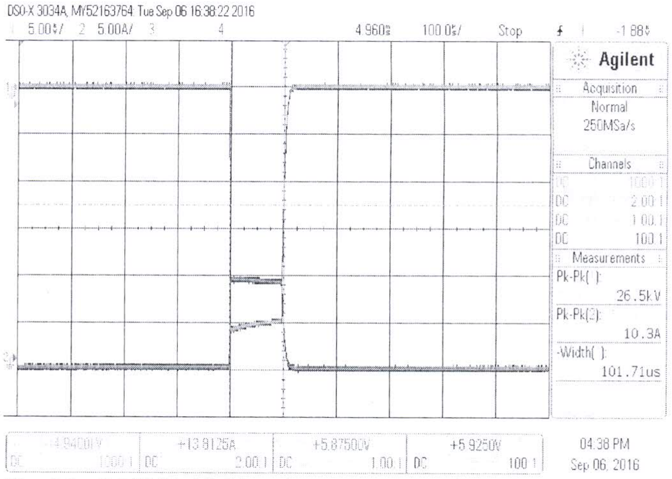

Fig. 13. -26.5kV, 10.3A pulse output waveform @100μs, 1kHz
Scale: X axis 1 unit=100μs; Y axis 1 unit=5kV and 5A

Test results of -50kV, 10A pulse power supply with PRF: 100Hz, 200Hz and T_{on}: 10μs, 20μs on resistive dummy load are presented in figures 14-15.

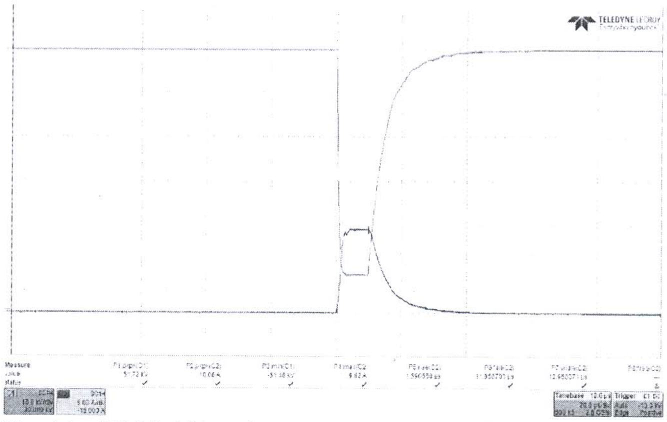

Fig. 14. -52kV, 10A pulse output waveform @10μs, 100Hz
Scale: X axis 1 unit=20μs; Y axis 1 unit=10kV and 10A

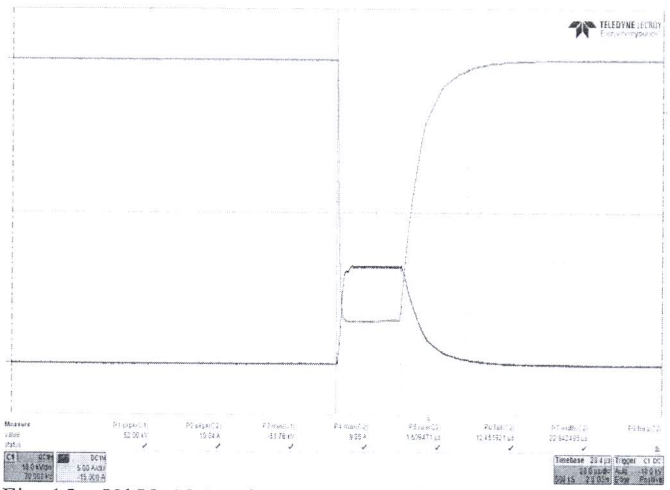

Fig. 15. -52kV, 10A pulse output waveform @20μs, 200Hz
Scale: X axis 1 unit=20μs; Y axis 1 unit=10kV and 5A

VI. CONCLUSION

The proposed high voltage pulse power supply has been designed, simulated, fabricated and tested on resistive load up to output pulse voltage of -52kV and pulse output current of 10Apk with wide range of pulse repetition frequency and pulse duration. The output pulse voltage has fast rising time and flat output pulse voltage shape over a large range of pulse width and pulse repetition frequency. The fabricated system has the advantages of high efficiency, reliability and output voltage variation flexibility with respect to pulse repetition frequency and pulse width. Testing of -50kV, 10A high voltage DC pulse power supply on Klystron (5GHz) load at rated power level is in process.

VII. REFERENCES

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