11TH INTERNATIONAL SCIENTIFIC CONFERENCE
ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

TEST SETUP FOR QUALIFICATION OF POWER SUPPLY FOR GENIII NIGHT VISION IMAGE INTENSIFIERS

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Abstract: *GenIII image intensifiers have been in use for decades and have undergone continuous improvements in terms of performance. Delicate matching of each individual tube with customized power supply remains workforce intensive and is one of bottlenecks in mass production. With each individual intensifier module having distinctive characteristics, achieving standardized performance in serial production is accomplished by compensating for tube individuality with programmable power supply unit. Since power supply and tube must be enclosed in a sealed package, matching is a one-time operation. For a power supply unit to be capable of matching tube variations in production, it must be capable of wide range of adjustments in polarization voltages. Thus, each power supply must be individually qualified on a dedicated test bench and must satisfy strict requirements for wide adjustment ranges. This paper presents a dedicated, custom made, test bench and its operations for testing power supplies in mass production and qualifying them for tube matching.*

Keywords: *Image intensifiers, power supply, GenIII.*

1. INTRODUCTION

Image intensifiers (II) have for several decades played a key role in night military operations providing the troops with sighting ability and situational awareness as close to daylight conditions as possible. The side enjoying such an advantage is favored in any combat scenario, but one – presence of strong artificial illumination [1]. No military is willing to dispense with this advantage making military night vision goggles (NVG) a regular part of the outfit of most modern armies. A great deal of investment has been provided for research and development of NVG since 1950s, creating at least 3 generation of devices colloquially referred to as GenI, GenII and GenIII night vision systems [2], [3]. A typical NVG assembly consists of an image intensifier, optical components and housing with battery compartment [4]. The image intensifier itself is an encapsulated package containing an image intensifier tube (IIT) and an embedded power supply unit (PSU). The IIT provides optical gain by converting photons to electrons on the photocathode (PC), amplifying the photocurrent in the microchannel plate (MCP) and converting electron current to intensified optical image on the screen (sometimes called anode). The PSU provides required power for PC, MCP and screen in the form of high voltage DC or pulsed sources ranging from -800 V on the PC to over 6 kV on the screen. Standardized IIT sizes include the 25mm and 18mm models.

However, manufacturing IIT on a large scale is a challenging task riddled with technology issues, material quality, process control and quality testing problems of all kinds. Single most important problem yet to be resolved in mass production of the IITs is large tolerance for total optical gain. Since optical gain is a function of all three supply voltages generated by the PSU, the solution to this issue is still a brute force one – the PSU is “matched” to the tube by adjusting the voltages to achieve equal gains of the final II.

In addition, the PSU is tasked with two important functions: automatic brightness control (ABC) and bright screen protection (BSP). Both are implemented with changing the MCP voltage (ABC function) or cathode voltage (BSP function) in response to screen current or cathode current. ABC maintains constant screen current that is set during the matching of the PSU with the tube and BSP operates by reducing the cathode voltage in response to high levels of cathode current. ABC requires quantitative evaluation during test since the ABC is specified as both screen brightness uniformity with cathode illumination change and screen current uniformity with cathode illumination change. BSP is not specified as a PSU parameter but is verified by measuring the cathode voltage change with cathode illumination change.

This approach places a demanding design requirement for the PSU creating and a set of requirements (happily

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DOI: 10.5937/OTEH24119P

expressed in numbers) for adjustment range of voltages and various electrical, mechanical, and other kind of parameters. So instead of evaluating the IITs and classifying them in groups, it is the PSU task to compensate for deficiencies of each individual tube. The reason is purely economic in nature – cost of manufacturing an IIT is an order of magnitude larger than of the PSU, and every single IIT should be used, if possible, to make manufacturing economically viable.

This paper reports on a solution for testing IIT PSU units in mass production with the aim of demonstrating the difficulties associated with PSU design and testing.

2. THE IIT AS AN ELECTRICAL LOAD

The IIT as an electrical load for the PSU can be represented as an illumination dependent current source for the IIT cathode control, voltage dependent resistor for the MCP control (from 70 MΩ up to 150 MΩ) and screen brightness dependent current source for the screen control. This strange combination of active and passive components creates a huge problem for the test environment mainly because of the voltage and current values typical to the PSU as seen in the table below.

Table 1. Voltage numeration

Name	Min value	Max value	Transient condition
Screen voltage	4500V	6000V	Overshoot to 6500V for a part of a second.
MCP voltage	300V	1300V	Varies within range depending on the cathode illumination.
Cathode voltage	-800V	+80V	For auto-gated PSU voltage pulses at frequency of several hundred Hz from -300V to +80V. For non -gated PSU DC voltage increasing with cathode illumination.
Screen current	30nA	400nA	Transient overshoot of several µA during rapid cathode illumination change.
MCP current	2 µA	15 µA	Not tested, irrelevant for operation.
Cathode current	<1nA	30 µA	Pulsed for gated PSU and DC value for non-gated PSU.

With these values in mind the test station must measure the voltages and current without loading the PSU appreciably. This is indeed a nasty problem since, for example, measuring the screen voltage requires that no more than about 10nA of current is drawn from the PSU yellow wire implying TΩ value resistor for sensing. Similar issues exist at the cathode with some additional complication of pulsed operation. Measuring µA and nA currents is an issue with its own merits [5], and even more nasty in high voltage case [6] and here additionally complicated since screen and/or cathode current measurement can cause flicker on the screen.

The cathode is a problem of its own, being somewhat of an orphan regarding standards. Standards that existed for GenIII are no longer valid and their predecessor (no longer valid as well) specified the BSP. Although called a “Screen Protection” function, BSP is implemented in the cathode drive circuit. With increased cathode illumination, the cathode voltage rises (it is negative with respect to red wire and ground) and this is deliberately implemented in the PSU to reduce the cathode responsivity and the cathode current. Implementation is usually done with gigaohmic resistor placed in the PSU on the blue wire driver. This means that any test unit measuring cathode voltage must not load the cathode with a resistance of less than about 100 GΩ, otherwise the BSP will be active and cathode voltage cannot be measured.

The problem is complicated even further in auto-gated PSU units that pulses the cathode voltage to PWM modulate the cathode current. Not only they do not implement the BSP function, but at higher cathode illumination (about 1 µA of cathode current) the pulses appear at the blue wire with peak value going into positive with respect to red wire. Given the sharp edges of pulses (around few µs) and large ohmic values of the cathode resistive divider, measuring these pulses is a problem.

Traditional PSU testing uses needle type floating voltmeters and amperemeters that are difficult to read accurately. For this reason, screen current meter has been designed as a separate unit with additional insulation and is not part of the main measuring unit. Insulation is of incredible importance in this setup, since any leakage into yellow or blue wire from nearby components could induce false PSU operation and flicker. Further complication arises from the need to shield sensitive amplifier inputs with faraday cage, which being made of metal, is an excellent conductor. The PSU wires must be insulated perfectly, and the points where they connect to the sensing system (terminals or connectors), require heavy shielding.

Inspite of a rather a bleak outlook, the test unit was successfully designed in the end, by sacrificing volume. If measuring sections for each terminal are separated with a gap large enough to eliminate capacitive coupling and if the terminals are insulated from the metal chassis, then it all works out somehow. Another requirement is that the room moisture is controlled to a level low enough to permit operations. Sometimes, due to leakages on the test modules, the module itself must be immersed in nitrogen. A story beyond the scope of this paper…

Functional PSU testing requires that the operator qualifies the PSU for eventual flicker, i.e., unstable screen brightness with stable cathode illumination. This phenomenon can occur for several reasons, typically if any of the three voltages generated by the PSU exhibit instability. To positively identify the PSU as the culprit, the operator needs to see the waveforms of the voltages, so DC value of the voltages is of limited use. This of course implies that the voltage dividers measuring the high voltages must be carefully compensated and tested for proper pulsed operation [7].

Once voltage and current measurement issues in all operational conditions have been resolved, more complex PSU requirements can be evaluated such as ABC function, BSP function and others.

3. THE BLACK BOX

The heart of the test setup is a dedicated measuring instrument named „The Black Box “(figure 1) out of the lack of inspiration for a name that would describe its function. It is a quad high-voltage passive voltmeter combined with a low voltage voltmeter and amperemeter. This PSU high-voltage side is connected to the PSU under test via top side-colored connectors on the right and measures high voltages on blue, red, black, and yellow wires. The measurement is accomplished via a compensated resistive divider and its output is fed to an ADC inside the box and to a set of analog difference amplifiers.

Figure 1. The black box

Since conventional measurement of the PSU voltage is expressed in relative values (i.e., potential difference between wires) internal analog difference amplifier creates the voltage differences as per table below:

Table 2. Voltage numeration

Name	Vn	Voltage Difference
Screen voltage	V_3	Yellow-Black
MCP voltage	V_2	Black-Red
Cathode voltage	V_1	Red-Blue

These voltage differences are presented on the panel meters with yellow, red, and blue digits, respectively. Additional panel meter with green digits measures the peak voltage in a gated PSU and is not part of the standard setup. ADC inside the unit converts voltage on the four wires with respect to the ground potential (black ground wire), and digital subtraction accomplishes the same result.

The low-voltage PSU side is connected to the left connector set located on the box topside with black as PSU negative battery pin, red as PSU positive battery pin and green wire as EGC input. The dual panel meter on the right top side measures the PSU input voltage on the red wire (red in V) and PSU current consumption (green in mA) through the same red wire.

The EGC function is evaluated with a potentiometer placed left to the black connector. The potentiometer value is 100kΩ. There are several combinations of the EGC functionality of the PSU varying with the manufacturer and the product. The EGC resistance (set by the said potentiometer) can be connected to ground (black wire) or battery positive (red wire). The green switch to the potentiometer left is used to switch between these two options so that all PSU models can be evaluated.

The switch to the far left applies the power to the PSU and the potentiometer below that switch is used to set the PSU input voltage from 1.7V up to 3.7V. The PSU itself is positioned on the holder between the connectors for convenient adjustment via its integrated potentiometers.

The remaining assets on the black box topside are used for special PSU model adjustments.

The right side of the black box contains a set of four 4mm round receptacles colored in the high-voltage side colors. The IIT tube (without its PSU) is connected to the black box via double isolated white wires and module's own set of colored connectors mounted on the module holder (black recessed tube to the right). In this way all PSU can be evaluated using the same quality intensifier module and qualified.

The setup uses separate microammeter for measuring the screen current on the yellow wire that is connected between the black box right side yellow connector and image intensifier module yellow wire.

During testing it is possible to disconnect the module from the black box right side connectors and a set of fixed resistors can be connected in its place. These tests are part of the PSU procedure for evaluation.

The black box back side contains power on/off switch and DE15 connector for connection to the oscilloscope. The analog difference amplifier outputs, PSU input voltage and current consumption are available for observation on the oscilloscope.

4. SETUP

The black box is positioned in the middle of the test table, as seen in figure below (figure 2). The module holder is enbedded in the table to the right. Tha transformer placed to the table far right side powers the bulbs in the illumination setup that is below the table and will be discussed later. Since PSU qualification requires careful testing for possible flicker and screen brightness issues, a microscope is required and it is located behind the module holder on a swing arm. Typical test requires eye observation of the module screen without and with microscope, so a convenient microscope mount is very useful. Table top contains an oscilloscope (almost any 4 channel model would do) for observation of voltages and a luxmeter (model Digilux 9500). The luxmeter has it measurement head connected via a gray cable, and the head can be moved around the table and placed on the module when needed. Due to strict screen brightness uniformity requirements, human eye cannot discern the level on nonuniformity that disqualifies the PSU. So a lux meter is necessary for screen brightness tests. The paper table strapped to the table top contains a list of transformer voltages measured on the AC voltmeter atop the transformer and respective illumination levels of the cathode.

Figure 2. Test table topside setup

The black box unit contains a Raspberry PI computer that acquires the ADC data and presents the voltage waveforms on the monitor (figure 3). Important values such as average voltages, peak-to-peak voltages and other values are calculated and shown on monitor for ease of use. This duplicates the oscilloscope function since occasional flicker can be traced to PSU voltage instabilities. Given that 0.1% of variation of the MCP voltage is visible by human eye in close contact with the screen, oscilloscope with 8 bit ADC cannot detect the cause of the flicker. The ADC module inside the black box uses 16 bit ADCs and can resolve these small variations on the 2K monitors, which is an important aspect of the PSU control. Simply put, observing the voltages on the oscilloscope does not guarantee that PSU voltages are stable to the required level.

Figure 3. PSU waveforms

Below the table there is a set of incadescent lamps (figure 4) that illuminate the cathode from below the table via a lens placed on the module holder bottom mount (not visible). The illumination surface (a diffuser) also contains a target for module resolution qualification so that resolution of the IIT in low-light and high-light conditions can be easily tested. The illumination can be covered via a hinged door to the right (barely visible) in order to prevent external light from entering the lens and illuminating the cathode. In this way a controllable cathode illumination is possible from 10^{-4} Lux up to 200 Lux.

Figure 4. Test table bottom-side setup

The illumination setup contains cooling fan that is also powered by the same transformer so that it generates fan noise at high illumination levels only. Since the module cathodes degenerate quickly at the levels of illumination, testing is short, so noise is not a big problem.

Table 3. PSU Evaluation Tests

Test Type
PSU High voltage measurement in all operational conditions.
Screen current measurement in all operational conditions.
Battery Voltage compliance.
Current consumption from battery in all operational conditions.
Screen brightness uniformity change with cathode illumination change.
Screen current uniformity change with cathode illumination change.
ABC function verification.
MCP voltage step response.
Rise-on time evaluation.
Response-time evaluation.
MCP voltage change with various resistive loads.
Cathode voltage change with various resistive loads.

5. CONCLUSION

A solution for II PSU evaluation in mass production has been presented in this paper. The solution fits inside a 3 m^2 room with all instruments placed within hands reach. All the tests required for PSU qualification can be performed on this test bench within about 10 minutes. This setup eliminates one of bottlenecks in PSU production allowing for more units of equal quality to be produced.

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