BREADBOARD UV PHOTON DETECTION SYSTEM (U)

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BREADBOARD UV PHOTON DETECTION SYSTEM

John G. McCoy
Martin Marietta Aerospace
P.O. Box 179
Denver, Colorado 80201

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US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
Ft. Monmouth, N.J. 07703
A prototype UV digicon-type detector is being developed for possible military application. The system has been breadboarded for demonstration and evaluation purposes. This four channel breadboard system consisting of a digicon detector, power supply, and data handling electronics is described. Results of testing are also presented and discussed.
FOREWORD

This is the final report of work on the development of a Breadboard UV Photon Detection System under contract to the US Army Electronics Research and Development Command, Ft. Monmouth, N.J. on DA Project Ll 62715 A042. Comments, criticisms, or questions concerning this report may be addressed to: Commander, US Army Electronic Warfare Laboratory, ERADCOM, ATTN: DELEW-E (J. Charlton), Ft. Monmouth, N.J. 07703, Telephone: (201) 544-4019.
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1. INTRODUCTION

The proximity focused ultraviolet digicon tube (Ref. 1) is a small, light-weight, rugged, sensitive UV detector having the potential of satisfying a number of military requirements. The purpose of this program has been to design, fabricate and test a breadboard single channel TTL-compatible ultraviolet photon detection system using a UV digicon as the photon sensor and to obtain performance characteristics from this system. These data will be used to provide a first assessment of the potential of digicon detectors for use in passive UV threat warning systems.
2. DISCUSSION

2.1 System design

The breadboard ultraviolet photon detector system consisting of a digicon sensor, high voltage power supply and filter, and signal processing electronics is illustrated in Figure 1. The sensor (Figure 2) is a multi-element digicon based on a design developed for the Air Force Geophysics Laboratory's Multi Spectral Measurements Program (MSMP). The digicon basically consists of a sapphire window with semi-transparent photocathode, a ceramic body and a silicon diode detector array. Electrons liberated from the photocathode by ultraviolet photons are accelerated towards the diode detector under the influence of a static electric field, and lose their energy on striking the silicon diode detector creating electron-hole pairs in the semiconductor material. On the average, one electron-hole pair is generated for each 3.6 eV of energy loss. Energies of between 20 keV and 25 keV are required to produce charge pulses of sufficient amplitude for clean signal-to-noise discrimination.

The detailed design of the digicon tube, driven by the fabrication sequence and the need to stand off 25 kV has remained unchanged from earlier digicons. Since spatial resolution is not required for this application and maximum photometric sensitivity is required, the 10 x 10 diode matrix used in the MSMP imaging detector was replaced with a large area solid state detector. This detector was made from high resistive (9-20,000Ω/cm) N on P silicon in
Figure 1. Block Diagram, Breadboard UV Photon Detection System

Figure 2. Digicon Detector Tube Assembly
the form of a 15.875 mm dia disk divided into quadrants surrounded by a
guard ring (Figure 3). The silicon was overcoated with aluminum for protection
and light opacity and then bonded and wired to the digicon header.
The header was then TIG welded to the digicon body flange. Final fabrica-
tion of the tube was made in a vacuum chamber at approximately $10^{-9}$ torr.
The cesium telluride photocathode was deposited on the sapphire window and
the window then sealed to the digicon body using molten indium (Figure 4).
After preliminary checkout the digicon was potted in its housing using
Silgard 184 for high voltage insulation. (Figure 5)

The charges deposited in the silicon diode detectors are fed into charge
sensitive amplifiers, the first stages of the signal processing electronics
(Figure 6). The resulting pulses are shaped and amplified for level
discrimination. The output of the level discriminator, which is set to
pass pulses equivalent to the 25 keV electron events and discriminate
against amplifier noise, triggers a one shot which is "OR'ed" with the output
of the other three channels' one shots to provide the serial pulse stream
for the TTL interface. A schematic of the signal processing electronics
is presented in Figure 7.

High voltage for electron acceleration is provided by a Spellman FRM25N1500 High
Voltage Power Supply followed by an RCRC filter. This power supply is
capable of providing 25 kV at $500 \mu$A.

The completed Breadboard UV Photon Detector System is illustrated in
Figure 8.
Figure 6
Block Diagram
Signal Processing Electronics
PHOTON COUNTER

NOTES: (UNLESS OTHERWISE SPECIFIED)
1. ALL AMPLIFIERS ARE HA2-2620-70-99
2. ALL RESISTORS ARE RLR305
3. ALL CAPACITORS ARE CKRC6

SELECT IN TEST.
UV PHOTON COUNTER (a)
2.2 Test program

2.2.1 Detector tests

After fabrication the quadrant digicon was tested to determine its basic operational characteristics. A qualitative test of the photocathode produced satisfactory photocurrent measurements when illuminated by a pinhole mercury lamp.

The detector was then connected to a single channel amplifier, turned on and biased to 20 kV. We found the dark count to be very high (\( \geq 1000 \text{ sec}^{-1} \)) with pulse heights much larger than we had expected. The second quadrant digicon was tested similarly, producing similar results.

Since our primary objective was to get representative digicon performance data, we fabricated another digicon using a P on N diode array of the type previously used in the MSMP digicons. This tube was tested and performed as predicted producing \(< 10 \text{ counts sec}^{-1} \text{ channel}^{-1} \) dark count. We measured its pulse height distribution and found it to be as expected. The pulse peak varied with applied high voltage between 18 kV and 25 kV as shown in Figure 9 (a), (b), (c). (Notice that as the applied voltage was increased, the separation between signal pulses and amplifier noise increased.) The digicon was installed in the system and tested. In order to insure good signal-to-noise separation, the system discriminators were adjusted to place the low energy cut-off near the trough minimum.
2.2.2 High voltage subsystem tests

The high voltage power supply is provided with a (variable) resistor-controlled voltage trimmer. Tests were made to determine the resistance vs. voltage relationship. The output of the high voltage power supply was connected to a 10,000:1 resistance divider (1 x 10^9 ohms) and the voltage monitored as the control resistance was varied from 0 to 5 x 10^3 ohms. The results of these measurements are given in Table 1.

<table>
<thead>
<tr>
<th>R(KΩ)</th>
<th>E (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25.2</td>
</tr>
<tr>
<td>1</td>
<td>24.3</td>
</tr>
<tr>
<td>2</td>
<td>23.4</td>
</tr>
<tr>
<td>3</td>
<td>22.7</td>
</tr>
<tr>
<td>4</td>
<td>21.9</td>
</tr>
<tr>
<td>5</td>
<td>21.3</td>
</tr>
</tbody>
</table>

Table 1  Output Voltage as a Function of Control Resistance
2.2.3 Signal processing electronics subsystem tests

Tests were performed on the electronics to characterize performance prior to mating with the detector.

2.2.3.1 Noise

Measurements were made of the random amplifier noise for each channel of the system. Since the gain of the charge amplifier is a function of input capacitance, noise measurements were made with input capacitance at 18 pf and 28 pf, which brackets the capacitances expected from the detector. These data are shown in Table 2.

<table>
<thead>
<tr>
<th>Input capacitance = 18 pf</th>
<th>Input capacitance = 28 pf</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH</td>
<td>VRMS</td>
</tr>
<tr>
<td>1</td>
<td>.29</td>
</tr>
<tr>
<td>2</td>
<td>.29</td>
</tr>
<tr>
<td>3</td>
<td>.275</td>
</tr>
<tr>
<td>4</td>
<td>.295</td>
</tr>
</tbody>
</table>

Table 2. Variation of noise with input capacitance
2.2.3.2 Gain

The gain of the charge sensitive amplifiers was designed to be $V/q = 2 \times 10^{15}$, where $q$ is the input charge in coulombs and $V$ the output voltage.

For measurements we inserted a charge of the approximate amplitude anticipated from the diode during normal operation.

$$q = 60 \text{ uV (28 pf)} \Rightarrow 1.68 \times 10^{-15} \text{ coulombs}$$

The output pulse heights were measured for each channel and gain calculated.

<table>
<thead>
<tr>
<th>CH</th>
<th>V</th>
<th>$G = V/q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.85</td>
<td>$1.1 \times 10^{15}$</td>
</tr>
<tr>
<td>2</td>
<td>1.88</td>
<td>$1.1 \times 10^{15}$</td>
</tr>
<tr>
<td>3</td>
<td>1.7</td>
<td>$1.01 \times 10^{15}$</td>
</tr>
<tr>
<td>4</td>
<td>1.8</td>
<td>$1.07 \times 10^{15}$</td>
</tr>
</tbody>
</table>

2.2.3.3 Stability

During this test setup stability was monitored by varying pulse amplitude, rise time, and fall time to 10 times normal levels to try to induce ringing or oscillations. No tendencies toward instability appeared.
2.2.3.4 Count rate linearity

Measurements were made using a random pulse generator to vary the pulse rate input to the charge amplifier of each channel individually, and measuring the TTL output pulse rate.

<table>
<thead>
<tr>
<th>Random Pulse Rate (Hz)</th>
<th>Ch 1 (Hz)</th>
<th>Ch 2 (Hz)</th>
<th>Ch 3 (Hz)</th>
<th>Ch 4 (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5335</td>
<td>6700*</td>
<td>5400*</td>
<td>5641*</td>
<td>5862*</td>
</tr>
<tr>
<td>10090</td>
<td>11100</td>
<td>10024</td>
<td>10200</td>
<td>11070</td>
</tr>
<tr>
<td>20360</td>
<td>20100</td>
<td>18950</td>
<td>19000</td>
<td>19500</td>
</tr>
<tr>
<td>29380</td>
<td>27800</td>
<td>27900</td>
<td>28100</td>
<td>27250</td>
</tr>
<tr>
<td>39550</td>
<td>35300</td>
<td>34900</td>
<td>34900</td>
<td>36100</td>
</tr>
<tr>
<td>50700</td>
<td>43600</td>
<td>42400</td>
<td>53500</td>
<td>43500</td>
</tr>
<tr>
<td>71600</td>
<td>59000</td>
<td>55600</td>
<td>57200</td>
<td>58200</td>
</tr>
<tr>
<td>101000</td>
<td>70600</td>
<td>65700</td>
<td>69700</td>
<td>70700</td>
</tr>
</tbody>
</table>

*noise form open front end varied from ~ 150 - 1500 Hz (different with each set up)
2.2.4 System tests

The Breadboard System Tests were performed as outlined in section 3.2 of the technical proposal.

2.2.4.1 Determination of digicon/electronics stabilization time (dark count)

The TTL output of the system was fed into a multichannel analyzer set to accumulate and record the pulses within 511 sequential 1 second integration periods. The analyzer was started and, about 10 seconds later, the detector system turned on: first low voltage (which produced no counts) then high voltage. Tests were run in a dark room. The results of this test are shown in Figure 10. As we expected, the dark count rate had reached a minimum of less than 10 counts/sec/channel by 120 seconds after turn-on. We were surprised to discover that following this minimum, the dark count increased throughout the remainder of the 511 second test period. A long term test was run monitoring the dark count for approximately 4.5 hours. The dark count continued to increase throughout this period and reached 150 counts/sec/channel the end of 267 minutes. We assume that this increase in dark count is caused by charge buildup and discharges from the detector and HV leads (which are not shielded and grounded in this breadboard configuration). Additional testing will be required to firmly determine the source of this noise and eliminate it.
Figure 10

Diode/ Electronics Stabilization
Time After Initial Turn-on
2.2.4.2 Determination of recovery time of digicon/electronics following saturation from a high intensity UV light source

This test was performed using a shuttered high intensity UV source (Hg(A) lamp) to switch from high level illumination to weak UV illumination. The count rate from the TTL output was recorded on a Northern Multi Channel Analyzer sampling at 1 ms intervals. The high intensity lamp was adjusted to produce approximately $1.7 \times 10^5$ counts sec$^{-1}$ and the low intensity rate around 300 counts sec$^{-1}$. The digicon system responded to the illumination as the high level source was shuttered off, reaching the low count rate in $T < .02$ seconds and stabilizing in $T < .1$ sec. (Figure 11). The variation in intensity with lamp on is the detector's response to the AC discharge lamp. The 120 Hz variation is clearly tracked when detector output is observed at high scan rates. The test was run again with a slower (10 ms intervals) MCS scan rate and with the high intensity lamp shuttered both on and off. Results showed the detector system completely stable in less than 0.3 sec following shuttering of the bright lamp.
Figure 11

Digicon Recovery Time Following Saturation (10^{-2} sec/sample)
2.2.4.3 Determination of response/stabilization time of digicon/electronics to changes in UV light intensity

Two UV light sources were set up: one to produce near full count rates from the detector and the other to produce a low count rate. The output was monitored to determine response and stabilization times while the lamps were switched.

- a. both off
- b. high only
- c. both on
- d. high only
- e. both on
- f. low only
- g. both on
- h. both off

Measurements were made with the multichannel scanner integrating for 0.1 second per channel and the count rates approximately

- both off 750 counts/sec (background light)
- low only 4000 counts/sec
- High only 20,000 counts/sec

The responses measured showed response/stabilization times to be (Figure 12).

- a to b .3 sec
- b to c .2 sec
- c to d .2 sec
- d to e .2 sec
- e to f .2 sec
- f to g .4 sec
- g to h .2 sec
Figure 1

Response/Stabilization Time
Changes in tA extension (10 ms/sec/sec 1/2)}
2.2.4.4 Determination of the system's sensitivity to variations in the high voltage source

Count rates were monitored at three levels of light intensity while high voltage was varied by changing the bias resistor between its limits of 5kΩ to 0Ω. The output voltage relates to resistor voltage as shown in section 2.2.2. Results of these tests are given in Table 3.

<table>
<thead>
<tr>
<th>Resistance (kΩ)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage (kV)</td>
<td>25.2</td>
<td>24.3</td>
<td>23.4</td>
<td>22.7</td>
<td>21.9</td>
<td>21.3</td>
</tr>
<tr>
<td>High level output (sec⁻¹)</td>
<td>2.5x10⁴</td>
<td>2.3x10⁴</td>
<td>2.2x10⁴</td>
<td>1.9x10⁴</td>
<td>1.7x10⁴</td>
<td>1.5x10⁴</td>
</tr>
<tr>
<td>Medium level output (sec⁻¹)</td>
<td>6.4x10³</td>
<td>5.4x10³</td>
<td>4.4x10³</td>
<td>3.6x10³</td>
<td>3.0x10³</td>
<td>2.7x10³</td>
</tr>
<tr>
<td>Low level output (sec⁻¹)</td>
<td>2800</td>
<td>2000</td>
<td>1400</td>
<td>900</td>
<td>650</td>
<td>550</td>
</tr>
</tbody>
</table>

Table 3 Variation of Digicon System Count Rate to changes in High Voltage.
This test was performed by connecting the high voltage to the grid while the high voltage was turned off. The current voltage channel analyzer was set to 50 milliseconds and the voltage was turned on for 6 seconds. After the high voltage had been turned off, the current and voltage were recorded and the current and voltage had recovered from their initial state (Figure 3).
2.2.3.6 Determination of short term stability following bright transients

This test was performed by operating the breadboard multiplier system using a moderate intensity source ($\approx 30,000$ sec$^{-1}$) and superimposing a bright source ($\approx 300,000$ sec$^{-1}$) of short duration. The recovery time was monitored using the multichannel analyzer set at a slow integration time. The system was pulsed with the bright light source approximately one second to three times and allowed to settle for about 30 seconds between transients. We found the system to have recovered and stabilized within 15 seconds in each case. (Figure 1.)
3. CONCLUSIONS

The digicon-based Breadboard Photon Detection System has been shown to be a very highly responsive system for the measurement of low levels of ultraviolet radiation. In all cases tested, the system responded to and recovered from both minor and extreme changes in incident UV light levels very rapidly (worse case less than 400 ms). Similar times were measured for the recovery from both light and high voltage transients. The system's settling/stabilization time following initial turn-on was found to be less than 60 seconds.

In only one area the system tests gave results less than desired: that relating to noise. We found that after initial settling of the detector, the background count increased with time from less than 10 counts sec\(^{-1}\) channel\(^{-1}\) to around 100 counts sec\(^{-1}\) channel\(^{-1}\) at 2500 sec (\(\sim 40\) min) to around 150 counts sec\(^{-1}\) channel\(^{-1}\) at 16000 sec (\(\sim 4.5\) hours). This problem was also exhibited in the high voltage stability test (section 2.4.4.4) since due to this noise the discriminator levels were moved closer to the pulse peak than optimum, causing the system to be more sensitive to changes in high voltage than it would have been with more optimized settings.

We assume that this increase in background noise is caused by charge buildup and leakage and that it can be eliminated by improved grounding and shielding in the detector and high voltage cables.
4. RECOMMENDATIONS

It has been shown that a UV photon detection system using a digicon type photon detector potentially offers many advantages over conventional UV detectors (pm tubes) for application in passive UV threat warning systems.

We recommend that the program which began with this breadboard sensor evaluation be continued through the development of a flyable prototype sensor to permit flight evaluation of the digicon detector in this configuration. This will require some additional investigation into the source of background noise and the elimination of this problem. Additionally it will require repackaging of the data handling electronics and high voltage supply.
5. REFERENCES

DISTRIBUTION LIST

Commander
Hanscom AFB
ATTN: AFGL/LKO (Dr. R. E. Huffman)
Massachusetts 01731

Commander
Naval Weapons Center
ATTN: W. R. McBride, Code 3854
China Lake, CA 93555

Commander
Pacific Missile Test Center
ATTN: D. E. Papcke, Code 1233
Point Mugu, CA 93042

Commander
Naval Research Laboratory
ATTN: R. A. Patten, Code 5530
Washington, D.C. 20375

Mr. David M. Reilly
Honeywell Electro-Optics Center
2 Forbes Road
Lexington, MA 02173

Dr. M. Rome
EMR Photoelectric
Box 44
Princeton, N.J. 08540

Prof. W. E. Spicer
Stanford Electronic Laboratories
McCullough Bldg 228
Stanford, CA 94305

Commander
Naval Air Systems Command
ATTN: W. K. Whiting AIR 53322C
Washington, D.C. 20361

Director, Electronic Warfare Laboratory
ERADCOM
ATTN: DELEW-E(J. Charlton)
DELEW-P(E. Newsom)
Ft. Monmouth, N.J. 07703