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PHOTOMULTIPLIERS AND GATING CIRCUITS SUITABLE FOR DIFFERENTIAL ABSORPTION LIDARS

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We report briefly on an investigation to identify photomultipliers (PMT's), divider networks and gating circuitry operating in the analog detection mode in an airborne UVDIAL for measuring tropospheric O_3, SO_2 and aerosols. Specific objectives are to hold variations in both signal linearity up to 20mA and signal gain over a 25-μs gate period to less than ±0.1%.

Initial evaluations on 12-stage BeCu dynode-based PMT's, EMI 9817 with an S-20 photocathode (PC) and EMI 9814 with a bialkali PC, encountered a significant signal-induced gain change (SIGC) where a gated PMT exposed to either a pulsed or continuous light source, or an ungated PMT exposed to a pulsed light source both exhibit an apparent increase in gain with time. The SIGC effect, which has been reported previously by Barrick[1] and by Lee et al.[2], appears to be a manifestation of the "rate effect"[3] common to scintillation counting applications where the gain increase varies as the average anode current induced by any combination of repetition rate and light pulse intensity. SIGC for the EMI 9814 PMT, which will be reported on more extensively elsewhere[4], is illustrated by the four magnified traces in the oscillogram of Fig. 1, where the increase in gain per unit time with anode current follows a linear dependence. The gain increase for trace d over 40μs is ~2%. The ramp at the leading edge of each magnified trace that ends after approximately 12μs is an artifact of the digital storage oscilloscope (DSO) and can be ignored.

As PMT's with CsSb dynodes are known to exhibit a much lower rate effect than those with BeCu dynodes[3], it therefore seemed logical to determine whether this observation also held true for the SIGC effect. A new 12-stage PMT with a bialkali PC, EMI 9214, which is essentially identical to the EMI 9814 PMT except that the dynodes are based on CsSb emitter material, was made available for evaluation. The three traces in the oscillogram of Fig. 2 for the 9214 PMT obtained under similar conditions to those for the 9814 PMT shown in Fig. 1, clearly do not manifest any SIGC, at least at the resolution limit of the 10-bit DSO (Lecroy model 9430) used to make these measurements. It is therefore concluded that variations in signal gain for this range of gated signals do not exceed ±0.1%.

Relative PMT linearity measurements were made using the ratio method in which gated PMT anode signals $i^{50\%}$ and $i^{100\%}$ are measured, respectively, with and without a 50% neutral density filter between the PC and a cw blue LED for a range of intensities up to the PMT saturation limit. Linearity plots for the 9214 PMT for four divider networks are shown in Fig. 3, where the voltages across the critical last three stages are the control variables in the form of divider network resistors. The "overlinearity" of the conventionally "tapered" divider networks is due to space charge effects that create a small gain increase due to a disturbance in electron-multiplier focusing near the anode[5] rather than to divider-network voltage fluctuations induced by high signal currents.[6] This conclusion was supported by a number of tests and measurements.[4] The divider network that gives the highest currents (~ 8mA) with variations from linearity of less than ±0.1% is that with the "inverted" taper, where the interstage voltages are progressively reduced towards the anode. Although this circuit reduces the available anode current by nearly an order of magnitude, it eliminates all tendency to overlinearity caused by space charge effects. Linearity measurements over a range of PMT operating voltages from -850 to -1750 V using the inverted-taper network produced a range of similar plots free of overlinearity with a steady increase in the linearity limit for operating voltages up to about -1500V.[4]

Four other related topics have also been investigated[4] and will be discussed. First, a number of different gating circuits have been evaluated including one that maximizes the gate on-to-off signal ratio (~10^6) while minimizing after pulse effects. In addition, features common to all gating circuits ensured full gate turn on to within 0.1% of full amplitude in less than 1µs after initiation. Second, the relationship of the PMT magnetic shield with respect to ground is shown to be a critical factor influencing temporal gain stability (over a 25-µs gate period). Third, bialkali PC linearity data for these PMT's under continuous illumination are presented, and finally, the afterpulse behavior of PMT's with either BeCu or CsSb dynodes are compared for otherwise identical PMT construction and operating conditions.

NOTICE

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development (ORD), prepared this abstract for a proposed oral presentation. It does not necessarily reflect the views of the EPA or ORD.

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Fig. 1 Oscillogram showing SIGC in peak region of four gated signals at 50x magnification for EMI 9814 PMT under continuous blue LED illumination and operating at -1400V with a 3-dynode gate. Horizontal scale: 5μs/div. Vertical scale before magnification: a, 0.1mA/div; b, 0.2mA/div; c, 0.4mA/div; d, 1.0mA/div. Traces a, b, c and d correspond to signals of 0.4, 1.2, 2.4 and 6.5mA, respectively. Each trace is average of ~3×10^4 waveforms obtained at 20Hz.

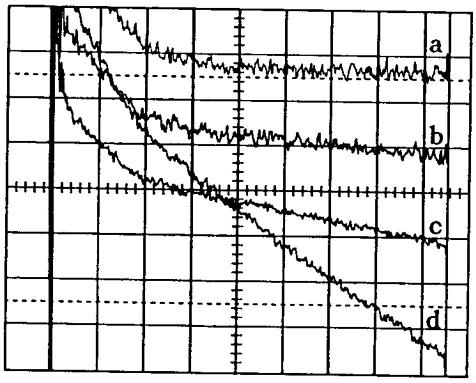

Fig. 2 Oscillogram showing peak region of the gated signal traces at 50x magnification for EMI 9214 PMT, where traces a, b, and c correspond to signals of 1.2, 2.4 and 6.8mA, respectively. Vertical scale before magnification: a, 0.2mA/div; b, 0.4mA/div; c, 1.0mA/div. Other conditions as for Fig. 1. The leading edge ramp due to a DSO antifact is clearly visible in these traces.

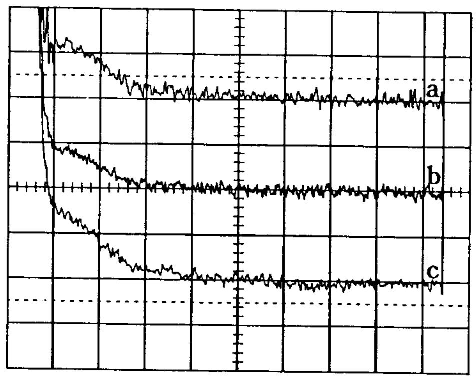

Fig. 3 Signal linearity plots for EMI 9214 PMT operating at -1300V for four divider network voltage distributions, where resistors R_1, R_2 and R_3 control the voltages for dynodes 10, 11 and 12, respectively.