36th Annual Frequency Control Symposium - 1982

PERFORMANCE CHARACTERISTICS OF CESIUM BEAM TUBE ELECTRON MULTIPLIERS

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Summary

A demountable test system is used to determine operating characteristics of electron multipliers which will be used in cesium beam tubes. Tests are performed using an electron input signal. Multiplier gain and dynode secondary electron emission coefficients are calculated from these test data.

Environmental effects of air exposure and vacuum bake are also determined.

Objective

This work was undertaken as part of a continuing program to develop improved methods for assuring quality in the manufacture of cesium beam tubes.

Background

Device Description

The electron multiplier is used as a linear signal amplifier and is located within the vacuum envelope of the CBT. The multiplier design uses a "box and grid" type of dynode (Figure 1). Each dynode consists of a grid and a housing which is lined with a silver-magnesium alloy. The grid is at the input aperture of each dynode. The output aperture is totally open. The alloy is processed in a manner similar to that described by Wargo, Haxby and Shepherd (1) in order to establish a surface with proper secondary emitting characteristics.

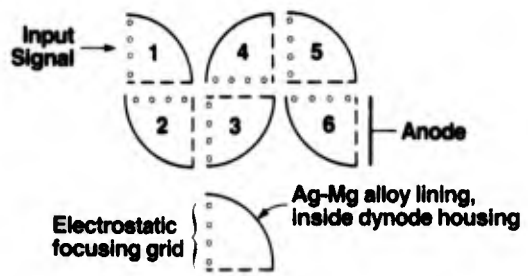

Figure 1. Schematic arrangement of the box and grid multiplier and a single dynode.

Theory of Operation

The input signal consists of a cesium ion beam which is accelerated to the first dynode by some potential difference ($-V_1$) measured with respect to the ionizer. The secondary electrons which are produced at the first dynode are then accelerated to dynode 2 by a potential difference ($+V_2$) measured with respect to dynode 1. The electron current continues to be amplified as it proceeds on to subsequent dynodes until the fully amplified signal is collected at the anode. The inter-dynode potential differences are very nearly the same in our multiplier design to that $V_2 = V_3 = V_4 \ldots$ etc. However, $|V_2| \ll |V_1|$. Since each dynode acts as an amplifier, the net gain G_N of a multiplier with N dynodes may be described in terms of the emission coefficients (δ) of the dynodes and the ion-electron conversion efficiency (η_1) of the first dynode. Then

$$G_N(V) = \eta_1 \delta_2 \delta_3 \cdots \delta_N \qquad (1)$$

where $\eta = \eta_1(-V_1)$

$\delta_N = \delta_N(V_N)$.

The subscripts refer to each dynode number. If we arrange that all inter-dynode voltages are equal and that secondary electron emission coefficients are equal, equation (1) becomes

$$G_N(V) = \left[\eta_1(-V_1)\right]\left[\delta(V_2)\right]^{N-1}. \qquad (2)$$

Electron Multiplier Operating Characteristics

Test Apparatus

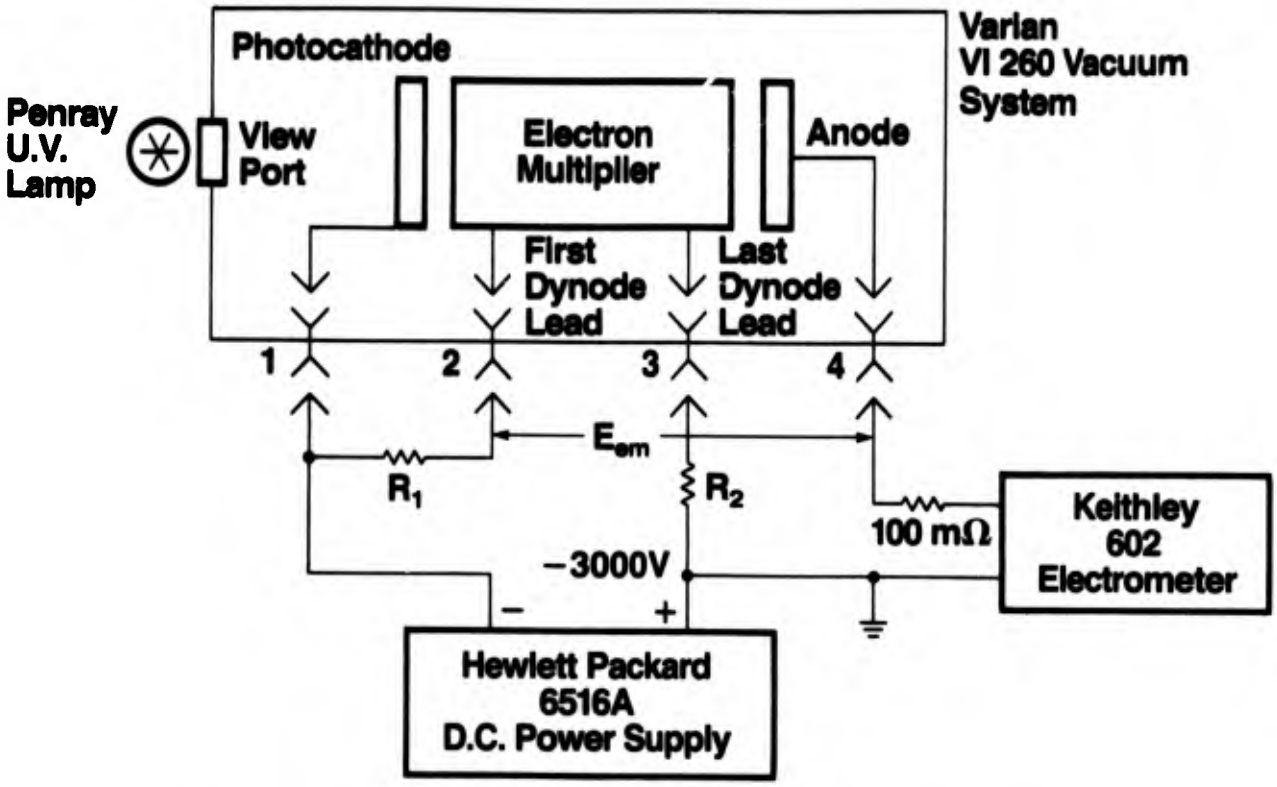

Figure 2. Schematic representation of the electron multiplier test setup. The voltage applied to the multiplier and anode is E_{em}. Output current measurements are obtained with this configuration.

The test apparatus employs an electron input signal rather than cesium ions for reasons that are quite obvious:

1) Once a multiplier is cesiated it cannot be opened to atmosphere without destroying the secondary emitting properties of at least the first dynode. Consequently, the performance would be badly degraded and the multiplier would no longer be useful.
2) Cesium source isolation is needed when the system is open to atmosphere. This requires a more complex arrangement.
3) Cesiation of the test chamber can lead to system maintenance problems over long time periods.

And finally,

4) Since we are really interested in getting a measure of δ, an electron source is quite appropriate, reliable and easy to maintain.

R_1 is chosen so that the cathode to first dynode voltage is the same as the inter-dynode voltage. R_2 is chosen to match the circuitry of the frequency standard. 100MΩ is used at the electrometer input only for protection of the electrometer from inadvertent current spikes. The proximity focused transmission photocathode is an aluminum film on a disk of fused silica. The sapphire view port transmits U.V. radiation to the cathode which, in turn, ejects photoelectrons. U.V. filters are used to vary the input signal level. Signal levels of up to 10^{-10}A. can be achieved. Input signals down to about $5X10^{-14}$A. can be achieved albeit the measurements may be somewhat tedious.

Figure 2 shows the arrangement for making output current measurements. Input current measurements are performed after removing R_1 and R_2 and relocating the electrometer input lead from feedthrough 4 to feedthrough 2.

Experimental Results

General. The determination of multiplier gain characteristics is accomplished solely by means of input current - output current - multiplier voltage (E_{em}) relationships.

Figure 3 is an example of a set of current transfer characteristics curves.

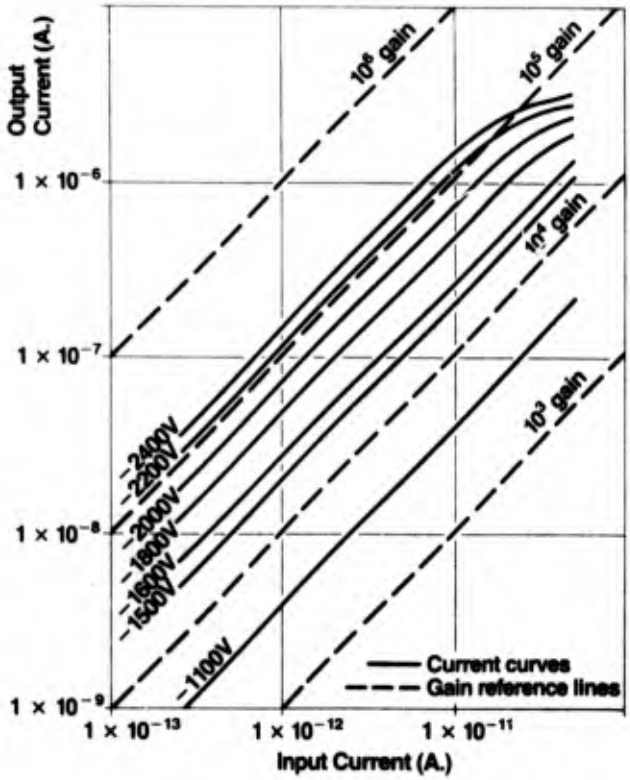

Figure 3. Current transfer characteristics curves for a 6 dynode multiplier. Multiplier voltage (E_{em}) is expressed as 1st dynode potential relative to the multiplier anode.

For all values of E_{em} shown in Figure 3, each output current curve has at least one region of linear response over some input signal range. However as we would expect, as the multiplier becomes saturated, we see that linearity degrades. We may safely say that this specific multiplier will operate in an unsaturated mode for all $E_{em} \geq -2400V$ if the output current does not exceed 1μA.

Another way of looking at the multiplier characteristics is to plot log multiplier gain as a function of E_{em} for various input levels. Figure 4 shows such a curve. Multiplier gain at a given E_{em} is defined as the output current at that voltage divided by the input current. Since we have said that this multiplier will be unsaturated if the output current lies below the upper limit of about 1μA., then the following relationships between gain and saturation can be used for this particular multiplier:

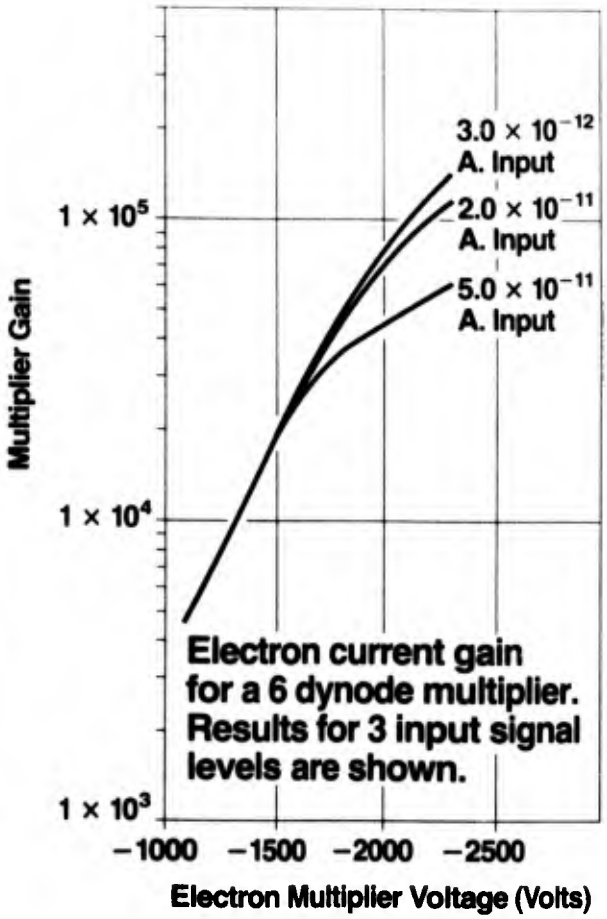

Figure 4. Multiplier gain as a function of multiplier voltage.

	If the input signal level is	then gain saturation occurs at and above gains of
1.	$7.1X10^{-12}A.$	$1.4X10^{5}$
2.	$2.0X10^{-11}A.$	$5.0X10^{4}$
3.	$5.0X10^{-11}A.$	$2.0X10^{4}$

Hence in the range E_{em} = 0 to -2400V where the input signal is $7.1X10^{-12}A.$ or less, an unsaturated curve is shown in Figure 4 as the $3.0X10^{-12}A$ input curve. For higher input levels, saturation begins as the respective curve begins to break away from the unsaturated curve as E_{em} increases. Figure 4 shows that saturation begins at about $2.3X10^{4}$ gain when the input is $5.0X10^{-11}A.$ and at about $5.0X10^{4}$ gain when the input is $2.0X10^{-11}A.$

These data can be useful in monitoring process consistency if one measures gain of multipliers which always have the same nunber of dynodes. However when comparing multipliers which have different numbers of dynodes, it is more convenient to get a measure of single dynode performance. We begin by arranging that all

dynodes in the multiplier have very nearly the same secondary electron yield. We also choose an input signal level which assures us that we avoid gain saturation for the entire range of E_{em}. Then if the ion-electron conversion efficiency (η_i) is replaced by the secondary electron emission coefficient $\delta(V)$, equation (2), becomes

$$\overline{\delta(V)} = \text{Log}^{-1}\left[\frac{\text{Log } G(V)}{N}\right]. \qquad (3)$$

where $\overline{\delta(V)}$ is the calculated mean secondary electron emission ratio,

G(V) is the gain calculated from output and input current measurements

(V) is the inter-dynode voltage

N is the number of dynodes in the multiplier.

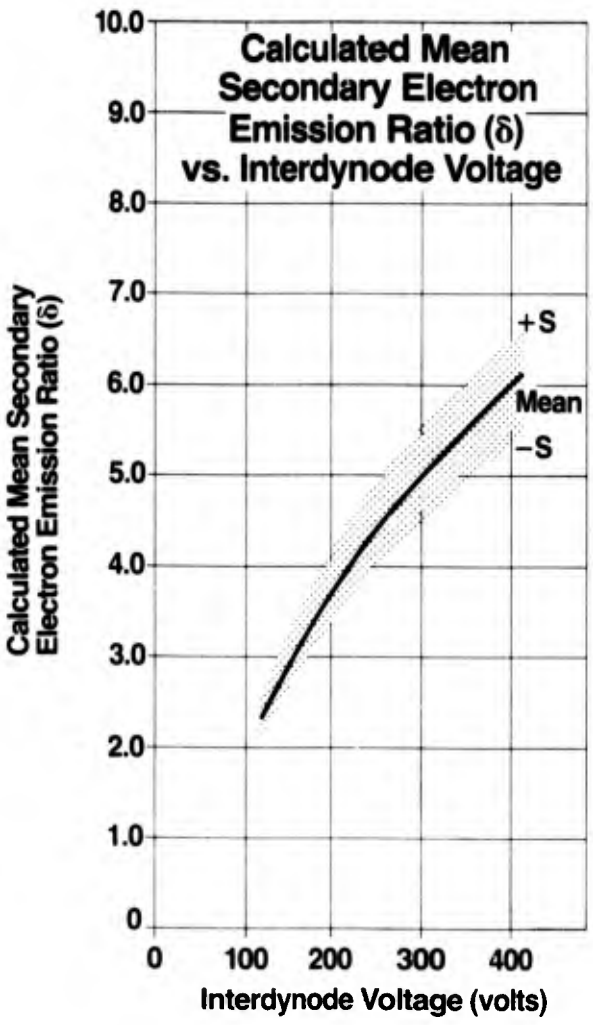

Figure 5. Secondary electron emission ratio as a function of inter-dynode voltage: evaluation of 26 process lots. The width of the band is two standard deviations.

Figure 5 shows the calculated mean secondary electron ratio as a function of inter-dynode voltage. This curve is based upon test results from 26 separate dynode lots processed in the Hewlett-Packard cesium beam production line. We prefer to use the single dynode performance to monitor process uniformity since the number of dynodes in the multiplier does not complicate comparisons of several multiplier types.

Environmental: Air Exposure. This topic seems to take on renewed interest every so often since low levels of CBT beam siganl have frequently been blamed on multiplier processing and handling during fabrication. Since we qualify batches of multipliers prior to installing them in tubes, it was appropriate to seek a more complete picture by determining the effect on multipliers when exposed to air for a variety of time intervals.

This work was accomplished by exposing the test multiplier to room air which was typically at 70°F and had a nominal relative humidity of 40%. 45 minutes elapsed between the time the dynodes left the dynode processor and the assembled multiplier was first pumped down in the test chamber. Consequently, the exposure interval range is .75 hours to 33.8 hours.

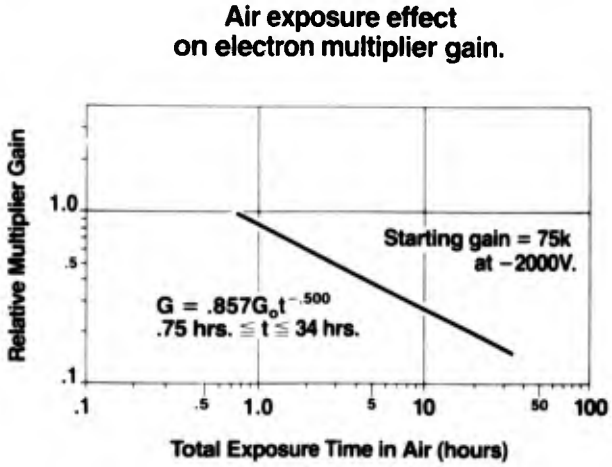

Figure 6. Gain degradation caused by exposure to room air, 70°F, 40% nominal relative humidity. G_o is original gain. t is time of exposure.

Figure 6 shows that the gain has $t^{-\frac{1}{2}}$ dependence where t is exposure time. Note that multiplier gain could be expected to degrade 50% after 3 hours exposure to room air. Proper storage and handling conditions obviously play a major role in maintaining multiplier quality.

Environmental: Tube Exhaust Bake. Also of considerable interest is the effect that tube bake has upon multiplier gain.

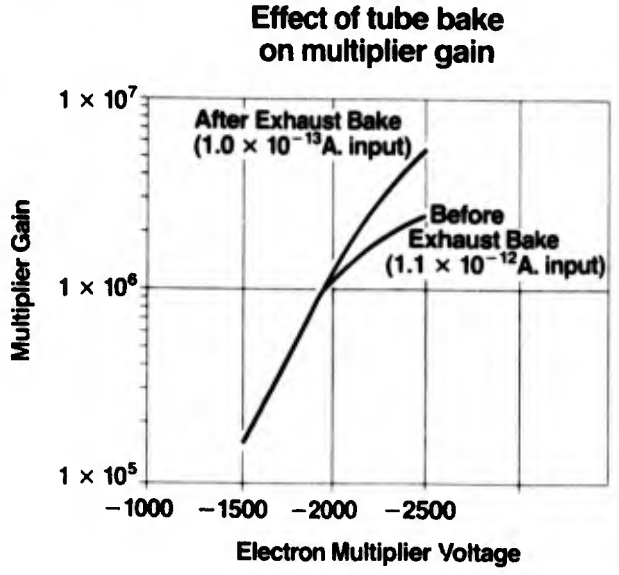

Figure 7. Calculated gain curves before and after tube bake. The unsaturated portions of the curves show excellent agreement thus indicating no gain degradation.

Figure 7 shows the vacuum bake did not degrade the performance of this multiplier. The difference in the two curves is due only to the fact that this 9-dynode multiplier saturates easily and too high an input signal level was used in the first test. The unsaturated section of the before-bake curve perfectly matches the same portion of the after-bake curve. Our conclusion is that the multiplier is very compatible with the tube exhaust bake.

Development Process Results. Having established a reliable method for evaluating dynode performance and then gathering statistics on the production process we have undertaken efforts to develop improved dynodes. Dynodes which exhibit higher gain and greater long term stability will allow us to operate multipliers at lower voltages thereby extending first dynode lifetime. Figure 8 shows the improved performance of recent development dynodes. The comparison is made against the mean of 26 production process runs, presented earlier in Figure 5 and against one of the higher quality production runs. At 250 volts we observe $\bar{\delta}$ = 5.9 for the development process, $\bar{\delta}$ = 5.0 for the better production run and $\bar{\delta}$ = 4.4 for the mean of the production runs. If we were to use these improved dynodes in 6 dynode multipliers and operate at -1500V. the respective electron current gains would be $42X10^4$, $16X10^4$ and $7.3X10^3$. We have neglected the fact that in the cesium tube we must consider the

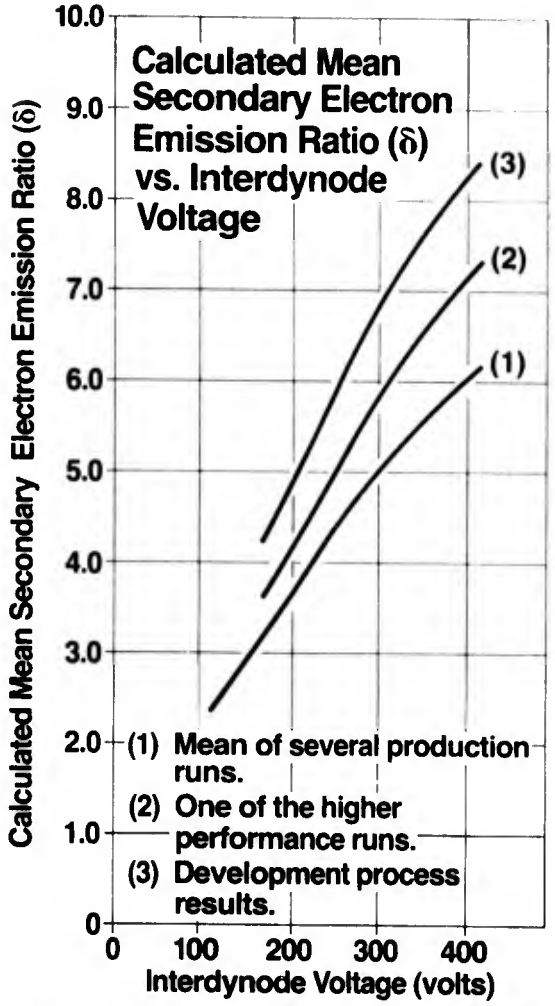

Figure 8. Comparison of development dynode process results with production process results.

first dynode conversion efficiency for the cesium ion. Still, the development process shows nearly a six fold gain improvement at this voltage.

Conclusion

The equipment and methods used to evaluate electron multiplier performance and process consistency have proved worthwhile since they provide a means to qualify electron multipliers prior to installing the multipliers in tubes. Test results continue to provide us with a high confidence level in dynode process reliability and in multiplier fabrication standards as well as handling and storage methods.

The production data are useful in establishing meaningful reference points for determining environmental effects and for determining the effects of process variations.

Acknowledgements

The author extends sincerest appreciation to Jerry Amaral, Adelaide Hamilton and Troy L. Payne for the support they provided for this work.

Bibliography

1. P. Wargo, B.V. Haxby and W.G. Shepherd, "Preparation and Properties of Thin Film MgO Secondary Emitters," J.Appl. Phys. 27, 11, (Nov. 1956) P.1311-1316.