Fast, Space Qualified 3000 V Modulator for a Cloud Profiling Radar

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Abstract
Cloudsat’s Cloud Profiling Radar (CPR) delivers a 2 kW of RF pulse using an extended Interaction Klystron (EIK). To drive such an EIK, it was necessary to develop a -16.3 kV High Voltage Power Supply (HVPS) and a Focus Electrode Modulator (FEM), floating at Cathode potential to turn the EIK’s Beam on and off -45V to -3kV with respect to the Cathode. This paper describes the design approach for the FEM and its performance at EM and Flight Configuration. In author’s opinion it a simple but universal approach which allow designer to achieve greater flexibility and freedom in designing high swinging space qualifiable FEM.

Introduction
This paper described the development of a fast 3000 V Focus Electrode Modulator (FEM) to drive a 2 kW, pulsed Extended Interaction Klystron as part of a High Power Amplifier (HPA), see figure 1, used in the Cloudsat Profiling Radar (CPR) due to launch in June of 2005. This will be the first Radar instrument to fly in space at this power, operating voltage and high speed 3000V FEM (rise and fall time of less then 200 nanoseconds). The EIK was developed by Communication & Power Industries of Canada (CPI) and has been published (ref 1, 2)

The Modulator floats at a cathode potential of -16.3 kV and the modulator, when in cut-off, is -3.0 kV with respect to cathode. FEM output is at -45V with respect to Cathode when the beam-on state.

Figure1: Cloudsat High Power Amplifier

Therefore the challenge was the containment of extreme high voltage (-20 kV) and as well as high slew rate of modulator voltage and retain the rise and fall times without any special screening of any part

There are many ways is achieving the performance, but JPL selected a push-pull arrangement using four (4) appropriately de-rated high voltage FETs
in series in each of the Push/pull stage (referred to as a four stage Modulator).

For the Flight units, the design had to be modified to a 10 stage configuration (10 each in each for pull and 10 each for the push stage) due to orbit-dictated radiation environment and tests of flight FETs. Both four stages and ten stages Modulator completed there environmental and thermal vacuum test and met all the performance requirements.

**Basic Electrical Design**

Figure 2 below shows a generic Block Diagram for the Focus Electrode Modulator (FEM). The A5 and A6 Block each contain four or ten series FETs.

![Figure 2: Generic Block Diagram (4 or 10 Stages)](image)

Basic Top level Layout (not to scale) of the FEMs elements are shown in figure 3.

The A5 stages are designed such that in absence of Pulse Command the output FETs are biased negative with respect to their sources. The A6 stages are biased on. Each stage (switch) has its own driver commanded driven by a four (4) or ten (10) secondary transformer. A5 Pulse transformer (A) is out of phase with A6 pulse transformer (B).

The pulse transformers are designed to minimize capacitance to primary winding and equalize capacitance between secondary windings and maximize coupling to the primary.

![Figure 3: Basic FEM layout for Flight Units](image)

<table>
<thead>
<tr>
<th>Temperature, C</th>
<th>-20</th>
<th>25</th>
<th>55</th>
<th>70</th>
<th>Req.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid On Volts</td>
<td>-5.8</td>
<td>-34.8</td>
<td>-35.1</td>
<td>-35.4</td>
<td></td>
</tr>
<tr>
<td>Grid cuttof Volts</td>
<td>-2839</td>
<td>-2845</td>
<td>-2807</td>
<td>-2809</td>
<td></td>
</tr>
<tr>
<td>Grid Dela nano sec</td>
<td>500</td>
<td>525</td>
<td>552</td>
<td>544</td>
<td></td>
</tr>
<tr>
<td>Grid Rise nano sec</td>
<td>170</td>
<td>147</td>
<td>178</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>Grid Stab nano sec</td>
<td>750</td>
<td>800</td>
<td>854</td>
<td>889</td>
<td></td>
</tr>
<tr>
<td>Grid Fall nano sec</td>
<td>50</td>
<td>73</td>
<td>72</td>
<td>41</td>
<td>200</td>
</tr>
</tbody>
</table>
The delay is caused by the pulse shaper on the lower deck.

*Note:* Breadboard and EM utilized a four (4) stage and Flight unit utilized a ten (10) stage design.

Figure 4: The Grid Rise, fall and delay

**Containment of High voltage and high slew rate.**

High voltage designer are fully cognizant of the dangers of high electric stress, presence of corona and temperature. In this design care was taken to insure that the assemblies were corona free at or above the operating voltages and electrical stress, corona and temperatures were consistent with the 12 year design life.

Figure 5 shows the flight configuration of the FEM. There are six cards for A5 and five cards for A6. The 6th in A5 card is dedicated to the Focus electrode ON voltage. Each of the cards in A5 and A6 contain two stages. Therefore the maximum potential between any two cards is less than 600 Vdc.

The uniqueness of the design is that the back side of the assembly is at a uniform potential, but are separated by 600 V (worst case). It also important to note that A5 and A6 components are pointing inwards so that the end assemblies sit at

Figure 5: Flight Configuration of FEM

-20 kV or -16.3 kV, except A5’s outside card always remains -16.35 kV (Focus electrode -45 plus Cathode potential). In addition the edges are rounded as it can be seen in figure 5 and 6, to minimize edge effects. Figure 6, shows the voltage

Figure 6: Voltage distribution across FEM
distribution, Individual Assemblies and final assembly is corona free at operating voltages. Further, it was important to maintain reasonable temperature rise and profile and the results are shown in figure 7.

![Figure 7: Temperature rise profile](image)

**Test Data.**

Testing to date including a large number of deliberate and accidental shorts at ambient pressure and vacuum, with and without the EIK (Extended Interaction Klystron). The FEM did not experience failure and the performance remained within requirements as shown in Table 2 and figure 9.

**Table 2: Flight HPA 101, FEM data**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>HVPS/EIK Deg</th>
<th>RF Delay nana sec</th>
<th>RF Rise Nano sec</th>
<th>RF Storage Microsec</th>
<th>RF Fall time Nano Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/50</td>
<td>920.0</td>
<td>62.0</td>
<td>1.050</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>25/35</td>
<td>980.0</td>
<td>57.0</td>
<td>1.080</td>
<td>22.0</td>
<td></td>
</tr>
<tr>
<td>0/20</td>
<td>922.0</td>
<td>50.0</td>
<td>1.029</td>
<td>28.0</td>
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<tr>
<td>20/-15</td>
<td>910.0</td>
<td>49.0</td>
<td>0.950</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>715/5</td>
<td>902.0</td>
<td>52.0</td>
<td>1.004</td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>10/15</td>
<td>920.0</td>
<td>54.5</td>
<td>1.039</td>
<td>22.0</td>
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<tr>
<td>2525</td>
<td>848.0</td>
<td>59.0</td>
<td>1.084</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>2523</td>
<td>888.0</td>
<td>52.0</td>
<td>1.000</td>
<td>22.8</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 9: FEM Command, RF output and Spectrum in TV**

**Conclusion.**

It is clear that EIK’s requirement of 200 nanoseconds for rise time and fall times has been met over the specified environment. And Data collected is within the CPR requirement and performance is very satisfactory. When launched, it will be the first such instrument in orbit to deliver 2 kW of RF power in with such a fast FEM. In author's opinion this approach to the design, is adaptable to any range of voltage swings (excursions) if attention is paid to the pulse transformer design, selection of FETs.

**References**
