Radiation test report

Akash GaN-on-Diamond X-band power amplifier

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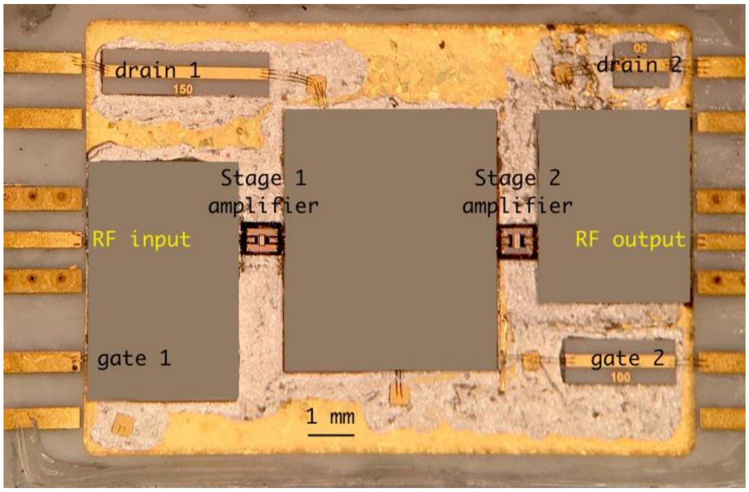
The tested device is a two-stage 5W amplifier operating in the range of 8.0 – 8.4 GHz, with a typical linear gain of 22 dB.
The nominal bias for this device is as follows:

Bias parameter	Nominal value
Gate voltages (Vg)	-2.7 V
Drain voltages (Vd)	28 V
First stage quiescent drain current (Id1)	45 mA
Second stage quiescent drain current (Id2)	90 mA

The total device current at 5W of RF power is about 390 mA at a drain voltage of 28 V.

During the radiation tests described below, the device was biased nominally per the table above and a CW signal at 8.2 GHz of constant level (+10 dBm) was applied at its RF input. The RF output level was measured to be about 32 dBm (1.6 W) after temperature stabilization (steady-state output RF level).



Microphotograph of the X-band amplifier assembly (size: 12 x 8 mm).
First amplifier stage on the left.

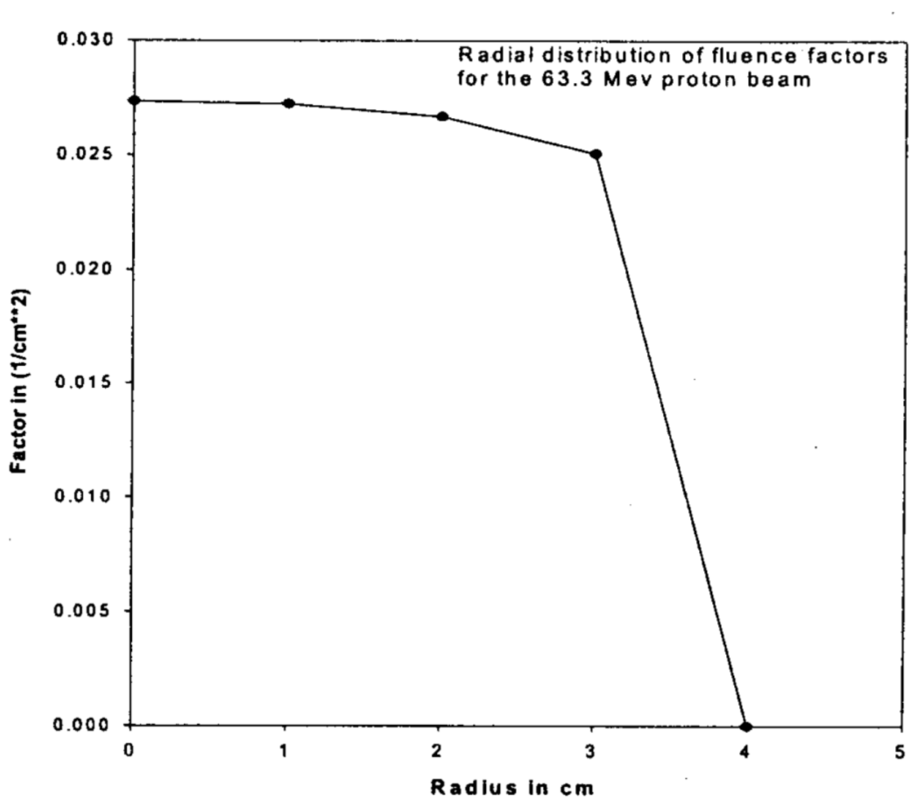
The following parameters were monitored and recorded every 0.5 s:

- First stage gate current (Ig1)
- Second stage gate current (Ig2)
- First stage gate current (Id1)
- Second stage gate current (Id2)
- RF output power level (RFout)

1. Proton beam test

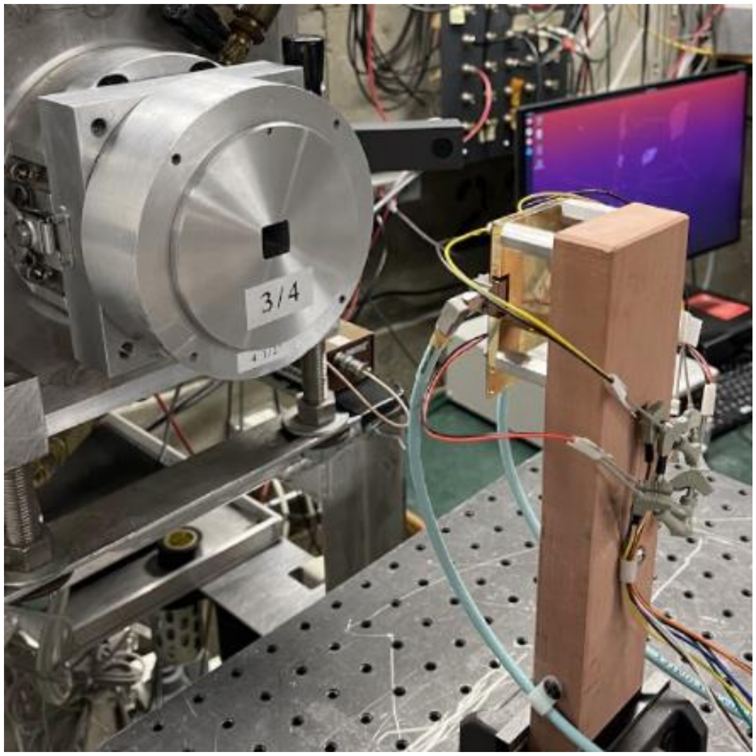
The devices were tested at the Crocker Nuclear Lab at the University of California,Davis.

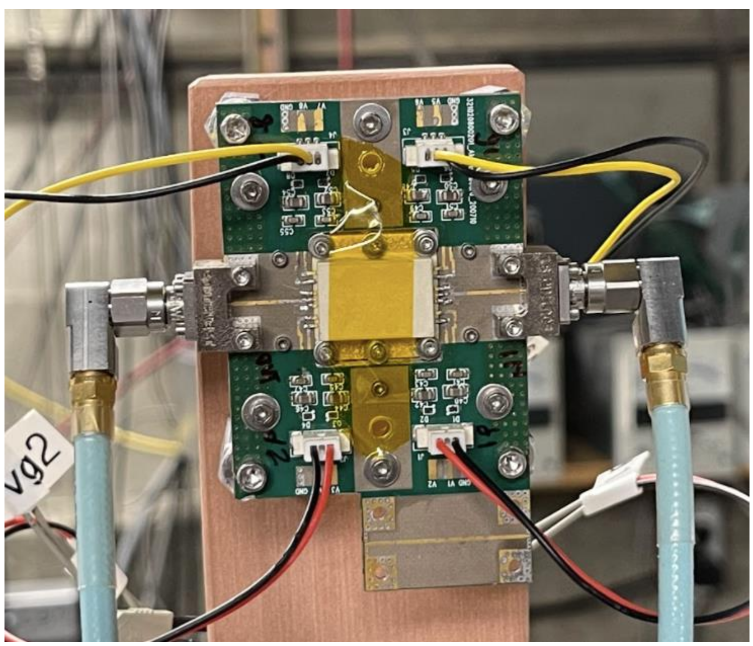
The proton beam source is a Isochronous cyclotron capable of proton energies in the 1 to 68MeV range. The proton energy for this test was set at 64 MeV. The maximum usable beam diameter is 6 cm and its uniformity is shown in the next Figure. The beam size was reduced to 19x19 mm, large enough to cover the active area of the amplifier module. The X-band amplifier device was located in the center of the beam.



Crocker Nuclear lab proton beam uniformity

The following two pictures show the test fixtures and setup in the irradiation room:





Two different devices were tested:

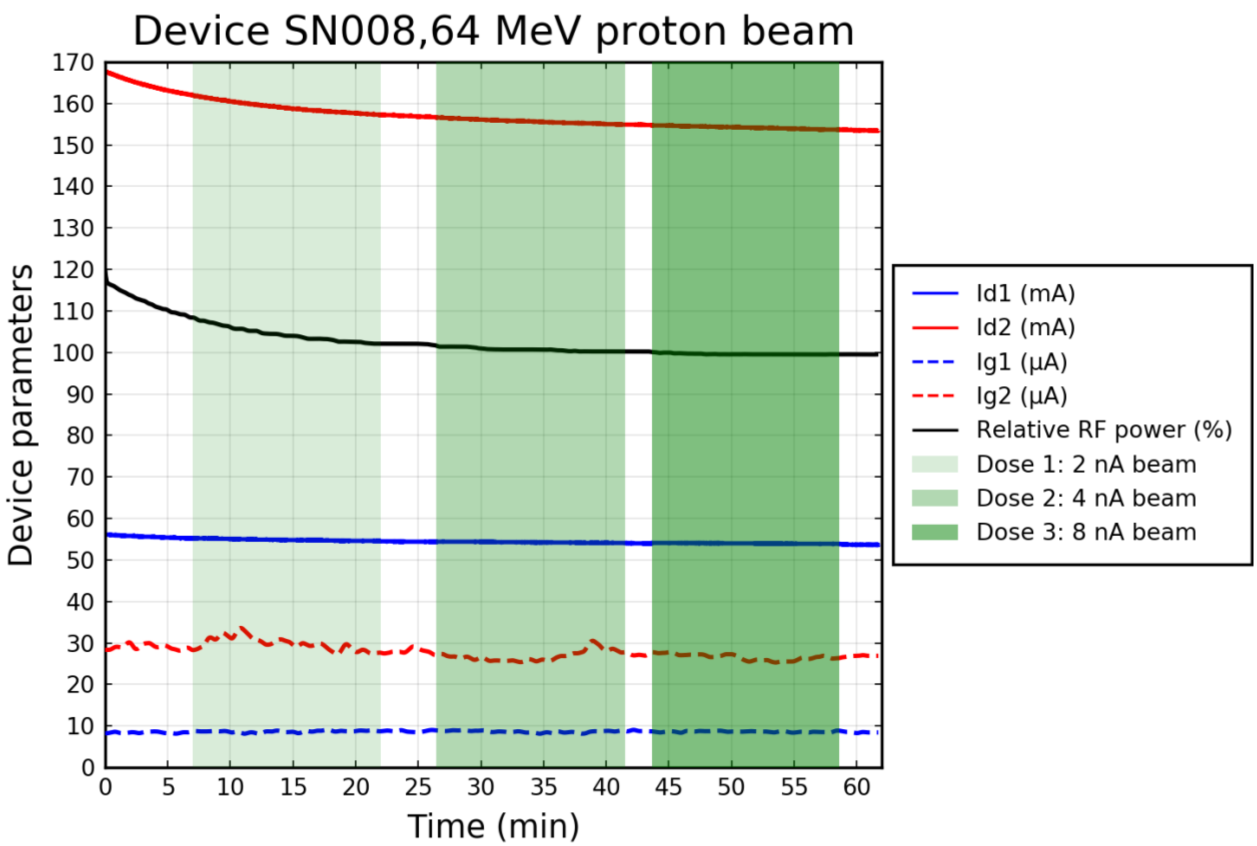
- Device SN008, both stages
- Device SN005, just the first stage tested (second stage was not available at the time of the test)

1.1 Device SN008

This device received three doses at the the following beam current intensities:

- **Dose 1**: beam current of 2nA ($0.25 \cdot 10^9$ protons/cm^2/s) during 900s for a total fluence of $2.3 \cdot 10^{11}$ protons/cm^2 or 30krad(Si)
- **Dose 2**: beam current of 4nA ($0.50 \cdot 10^9$ protons/cm^2/s) during 900s for a total fluence of $4.5 \cdot 10^{11}$ protons/cm^2 or 60krad(Si)
- **Dose 3**: beam current of 8nA ($1.0 \cdot 10^{10}$ protons/cm^2/s) during 900s for a total fluence of $9.0 \cdot 10^{11}$ protons/cm^2 or 120krad(Si)

The device behavior is summarized in the following plot:



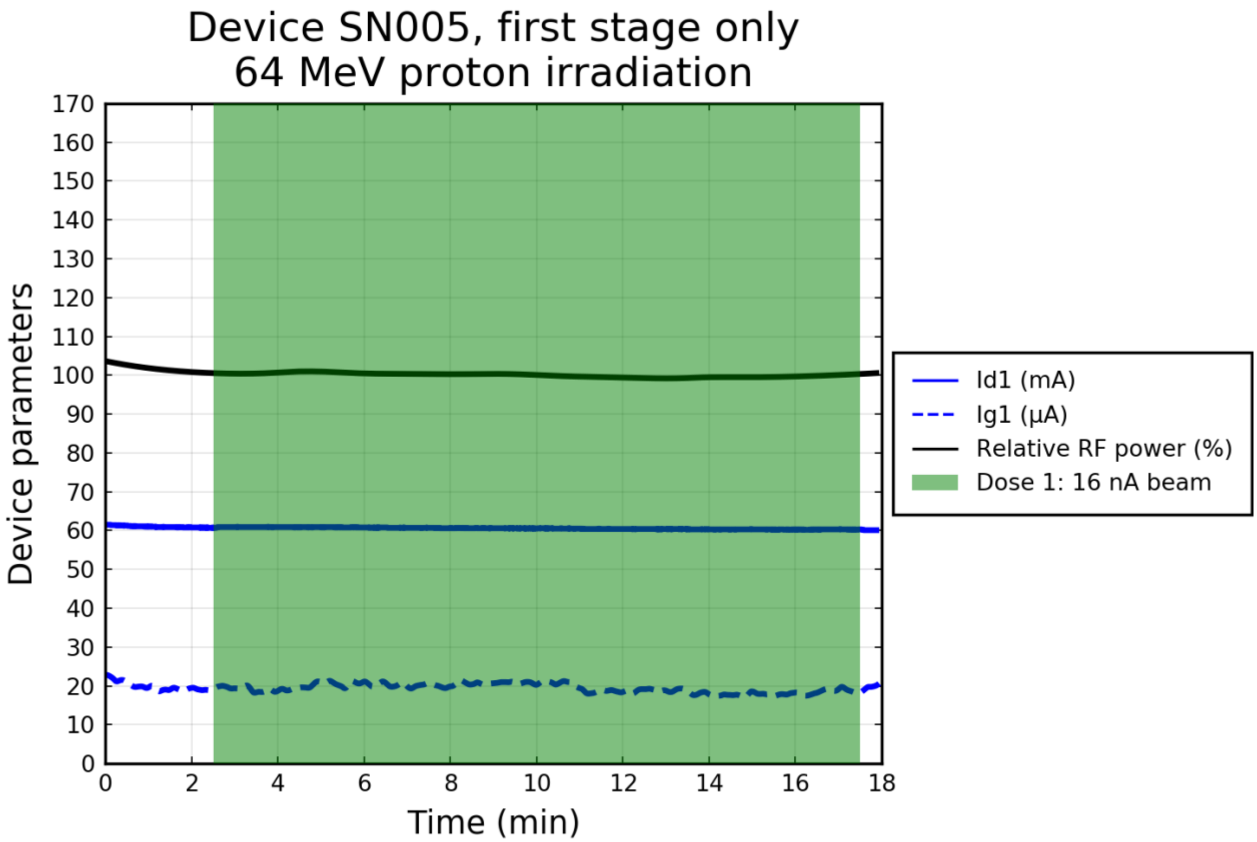
No relevant drifts or upsets were observed for the monitored parameters of this device during the irradiation periods.
The initial observed drift during the first minutes was due to the device not being in full thermal steady state regime (RF output power becomes 100% of the final steady state at about 30 min).

1.2 Device SN005

This device received one single dose at the the following beam current intensity:

- **Single dose**: beam current of 16 nA (2.0•10^9 protons/cm^2/s) during 900 s for a total fluence of 1.8•10^{12} protons/cm^2 or 240 krad(Si)

The device behavior is summarized in the following plot:



This device also did not show any drift or upsets during the irradiation session

1.3 Notes on the results

1.3.1 Device accumulated radiation dose

Two GaN-on-Diamond devices were irradiated by 64 MeV protons up to a total fluence of 1.6•10^{12} protons/cm^2 (device SN008) and 1.8•10^{12} protons/cm^2 (device SN005). The conversion of these fluences to total dose can be computed from the proton LET (Linear Energy Transfer) in the specific material (GaN) by:

$$\text{Total dose (TID)} = \text{Fluence} \cdot \text{LET}(64 \text{ MeV } p^+, \text{GaN}) \cdot 1.6 \cdot 10^{-5} \quad \text{in rads(GaN)}$$

The LET for GaN can be derived from the LET for Si for proton energies in the 10 – 100 MeV range by [1]:

$$\text{LET}(10 - 100 \text{ MeV } p^+, \text{GaN}) = 0.85 \cdot \text{LET}(10 - 100 \text{ MeV } p^+, \text{Si})$$

A very similar conversion factor is found for GaAs devices, of about 0.80.

The LET for 64 MeV in Si can be found from multiple sources such as the one in [2]:

$$\text{LET}(64 \text{ MeV } p^+, \text{Si}) = 0.0082 \text{ MeV-cm}^2/\text{mg}$$

The total doses can now be determined for each tested device:

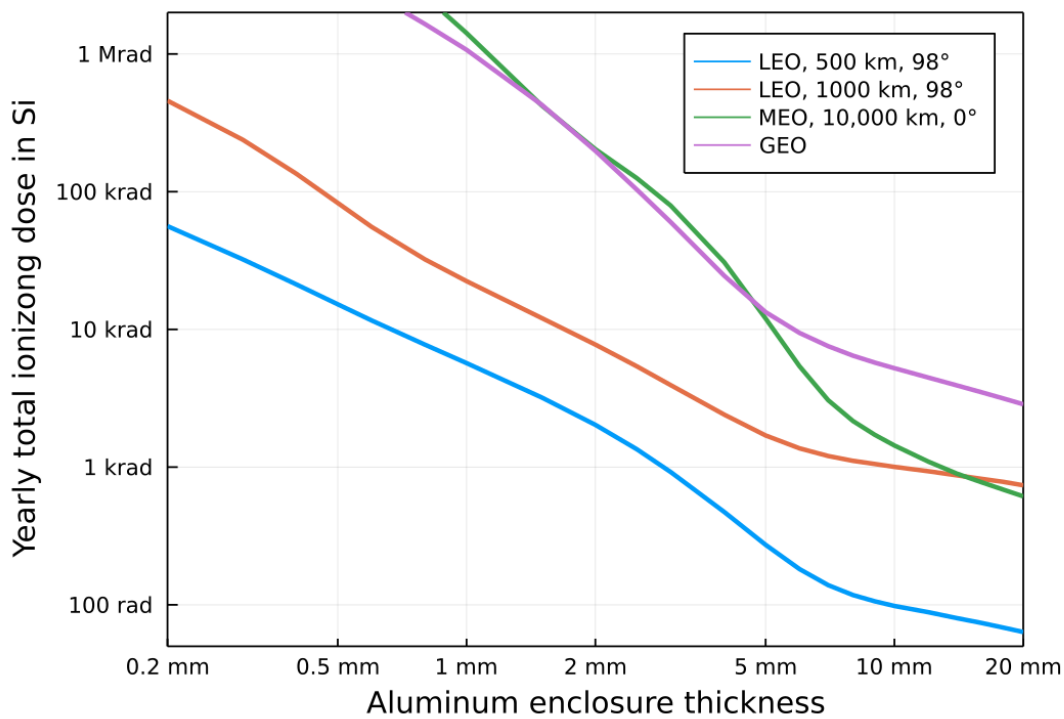
- Device SN008
  $TID = 1.6 \cdot 10^{12}\ p^+/cm^2 \cdot 0.0082\ MeV\text{-}cm^2/mg \cdot 0.85 \cdot 1.6 \cdot 10^{-5} = 178\ krad(GaN)$
- Device SN005
  $TID = 1.8 \cdot 10^{12}\ p^+/cm^2 \cdot 0.0082\ MeV\text{-}cm^2/mg \cdot 0.85 \cdot 1.6 \cdot 10^{-5} = 201\ krad(GaN)$

1.3.2 Expected doses for satellite missions

The total yearly predicted dose for several satellite orbit types is represented in the following plot. (protons and electrons dominate the particles responsible for the total accumulated dose in devices). The plot shows the accumulated dose in Si material, being the doses for GaAs or GaN just slightly lower. This plot was generated from the data provided by SPENVIS - ESA's SPace ENVironment Information System [4]

The TID in devices is highly dependent on the protective aluminum shielding up to a thickness of about 10mm, beyond which there is no additional significant dose reduction.

Considering a total shielding thickness in the 2-5 mm, the devices under test show exceptional tolerance for many years in LEO orbits.
These devices are also suitable for at least a few years in MEO or GEO orbits; in this case a more careful selection of the shielding thickness is needed as well as testing these devices to larger TID dose levels for adequate radiation protection margin.



2.0 References

1. S. J. Pearton et al, "Review—Ionizing Radiation Damage Effects on GaN Devices", 2016 ECS J. Solid State Sci. Technol. 5 Q35. https://www.researchgate.net/publication/284706214
2. Stopping power and range tables for protons in various materials https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html
3. SPace ENVironment Information System https://www.spenvis.oma.be/

Other general references:

4. Paul W. Marshall, "Proton effects and test issues for Satellite designers", 1999 NSREC Short Course https://ntrs.nasa.gov/api/citations/19990110691/downloads/19990110691.pdf
5. Stephen Buchner, Paul Marshall, Scott Kniffin and Ken LaBel, "Proton Test Guideline Development – Lessons Learned", NASA/Goddard Space Flight Center, 2002 https://radhome.gsfc.nasa.gov/radhome/papers/proton_testing_guidelines_2002.pdf