In-Situ Total Ionizing Dose Tests of SSPA Components

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Abstract

In-house developed GaAs-based Solid State Power Amplifiers (SSPAs) operating at super high frequencies (SHF) have been tested using a ^{60}Co source to predict the module and its components' response when subjected to its actual space environment. GaAs-based electronic components are considered to be immune against TID. Test results are presented here that quantify residual performance degradations in component specs under various TID and other extreme environmental conditions.

I. Introduction

Electronic components in a working satellite will be exposed to a total ionizing dose (TID) commensurate with its orbit. Solar particles, electrons/protons trapped in the Van Allen belts and galactic cosmic rays (GCRs) are the main sources. TID due to electrons and protons can cause device failures whereas Displacement Damage (DD) and Single Event Effects (SEEs), although problematic, can cause temporary loss of function with lesser possibility of catastrophic failure. Such detrimental events have cumulative effects during the whole mission lifetime of the components and, with well-established techniques it is possible to estimate the time of failure under relevant operating conditions.

SSPA components are chosen as test subjects here as they are key configuration items in any communication satellite. Power Amplifiers (PA) boosts downlink signals in order to compensate for atmospheric path losses. The two primary types of PAs in the market today are: Solid-State Power Amplifiers (SSPAs) and Travelling Wave Tube Amplifiers (TWTAs) [1]. These amplifiers are also critical for space-borne phased-array applications. GaAs-based SSPAs are widely used in aforementioned systems today with GaN-based solutions fast catching up as attractive alternatives due to their inherently even higher power density capabilities [2].

The efforts of manufacturing domestic satellite payload components must be matched by capabilities to carry out standard radiation tests to qualify the resulting equipment for space. Reliability of these components within the space environment can only be guaranteed through ground-based qualification in terms of radiation tests and other widely used environmental tests under varying thermal, vacuum, vibration and shock conditions. Although, the latter set of tests can currently be performed in-house, there is an urgent need to develop the capabilities to carry out the radiation tests locally so as to expedite the qualification of satellite subsystems or components.

II. Total Ionizing Dose Test Plan

A. *Test Techniques and Setup*

At a short driving distance from ASELSAN, there is a radiation testing facility in Ankara; Sarayköy Nuclear Research and Training Center (SANAEM), operated by the Turkish Atomic Energy Agency (TAEK). As dictated by a tight schedule, the construction of the test setup at SANAEM, and the design and manufacturing of the modules were carried out simultaneously to reduce scheduling risks. TID tests are being performed using the ^{60}Co source located at the TAEK SANAEM Gamma Irradiation facility. The source has an activity level of 300 kCi and can deliver a dose rate higher than 30 kRad(Si)/h, which is in compliance with the ESA 22900 standard high dose rate recommendation. A new chamber was designed and built in order to attenuate and deliver the necessary dose rates [3].

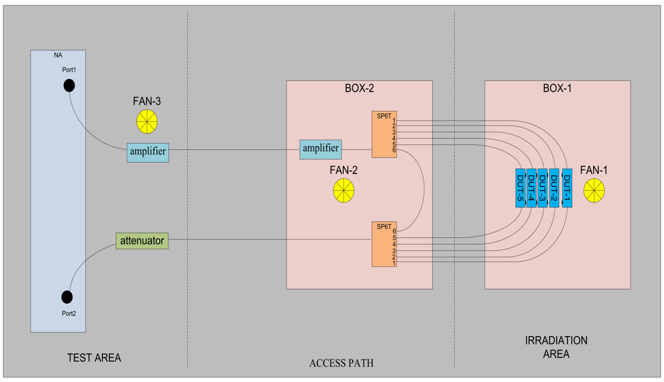

Figure 1: Bird's-eye view of the test facility at SANAEM. The irradiation area and the access path are under strict control for the safety of the personnel.

After careful consideration of the irradiation chamber dimensions, a decision was made to place the measurement devices about 13 meters away from the DUTs. Inevitably, this leads to losses on the RF cables. Thus, amplifiers are used just before the network analyzer and also the RF selection switch. The amplifier before the RF switch is isolated against radiation using thick shielding boxes. Temperature variations during irradiation are also monitored.

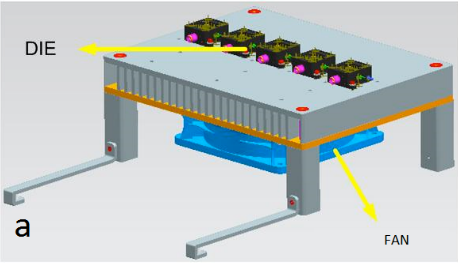

Figure 2. TID test setup for dice

DUTs are placed on an Aluminum slab that is raised off the floor and is cooled by a vertical blowing fan as seen in Error! Reference source not found. **Vertical Al bars acting as legs for the slab are secured on the floor. A picture of the actual setup is given in**
Figure 3.

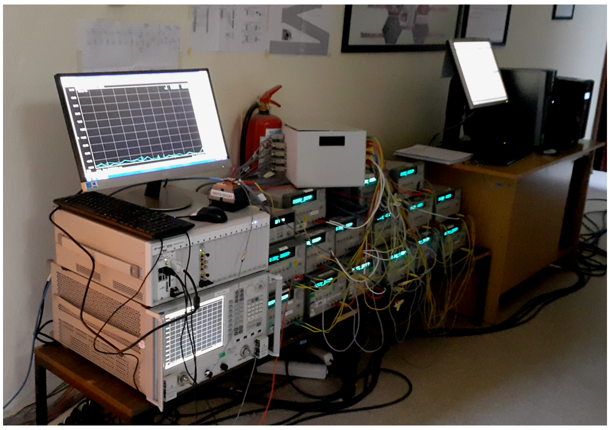

Figure 3. Test Equipment placed outside of the irradiation area.

B. Experimental Conditions

The Aluminum-Lead box attenuates the absorbed dose to the desired levels. The absorbed dose on the DUTs is calibrated using Alanine dosimeters to guarantee dose uniformity. Each one of Alanine dosimeters was placed on the edges of the test board to measure dose uniformity to accuracies better than 1%. The readout mechanism of the dosimeters was based on the procedure of electron spin resonance (ESR) that is capable of measuring dose levels up to 200 kGy.

We also controlled the ambient temperature of the irradiation area to be around 20 ^{0}C during exposure.

Depending on mission specifications, DUTs are expected to absorb around 100 kRad(Si) of total dose during their orbital lifetimes. Here, we use ESA 22900 recommended high level windows to administer a uniform 30 kRad(Si)/h radiation dose rate to reach a total dose of 300 kRad(Si) [4]. This is consistent with a safety factor 3 for the simulated radiation environment that the DUTs are exposed to.

III. RESULTS AND DISCUSSION

As an oxide layer is not present, GaAs MMIC circuits are relatively immune to total ionizing dose effects in contrast to Si-based circuits. In addition, GaAs is a direct bandgap material while Si is an in-direct bandgap material. Thus, minority carrier lifetimes in GaAs are much less than those in Si that means increased immunity against radiation. Finally, due to very high surface state densities of GaAs, Fermi levels are pinned to what is dictated by the surface and hence prevent radiation-induced surface inversion and associated leakage currents [5]. Other studies of the effects of gamma irradiation on GaAs MMIC devices have also shown total dose hardness level near MRad(Si) [6][7][8][9].

Total Ionizing Dose effects were measured through a cascade of a high power amplifier, an attenuator, a power amplifier and a phase shifter within an in-house developed SSPA.

The gamma-ray measurements were performed using ^{60}Co sources providing 30 kRad(Si)/h to achieve 300 kRad(Si) total deposited dose. The DUTs were irradiated under operational bias conditions. Thanks to the fully automated in-situ test setup, all of the components were controlled/monitored and sampled for data, remotely.

Reference output powers for both High Power Amplifiers and Power Amplifiers, reference attenuation levels for attenuators and reference insertion loss levels for phase shifter are derived from components datasheets and pre-irradiation measurements with in-situ test setup.

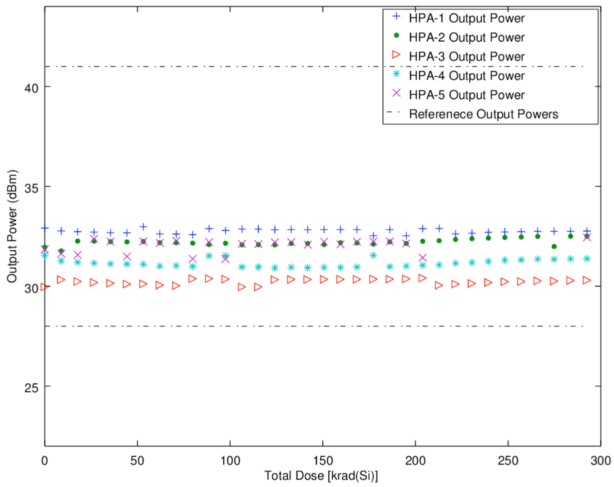

Figure 4. Effects of irradiation on output power characteristics of GaAs High Power Amplifier MMICs.

Figure 4 shows results of the total ionizing dose effects in each GaAs High Power Amplifier MMIC sample irradiated with ^{60}Co under operational bias conditions. The output power remains same levels with increasing radiation dose up to 300 kRad(Si). Similarly, Figure 5 shows output power characteristics of each GaAs Power Amplifier MMIC. Output power remains same levels as in High Power Amplifiers.

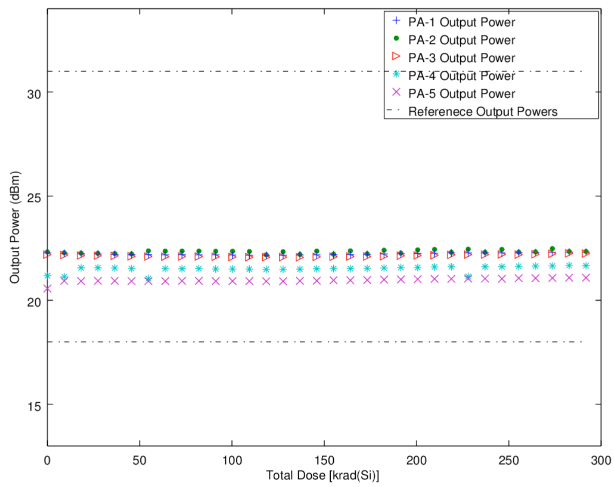

Figure 5. Effects of irradiation on Output Power characteristics of Power Amplifier.

Figure 6 shows the total ionizing dose effects in a GaAs Analog Attenuator MMIC irradiated with ^{60}Co under operational RF bias conditions. Here we focused on first attenuation result. First attenuation exhibits fluctuations around its initial attenuation values with increasing radiation dose.

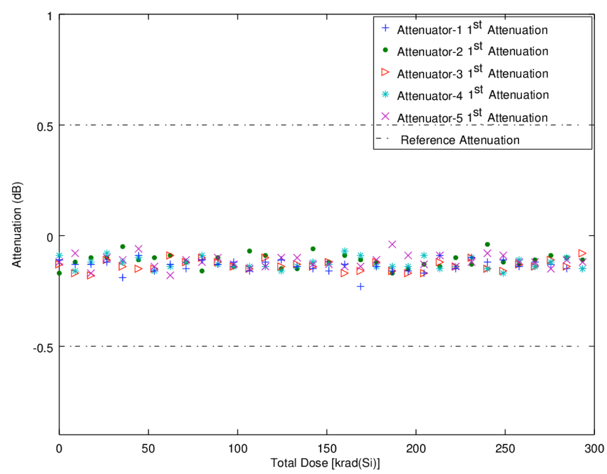

Figure 6. Effects of irradiation on Attenuation characteristic of Analog Attenuator.

Figure 7 shows the total ionizing dose effects in a GaAs Phase Shifter MMIC irradiated with ^{60}Co under operational bias conditions. As seen in Figure 7, insertion loss levels of each phase shifter exhibits monotonic decrease up to 300 kRad(Si) radiation doses.

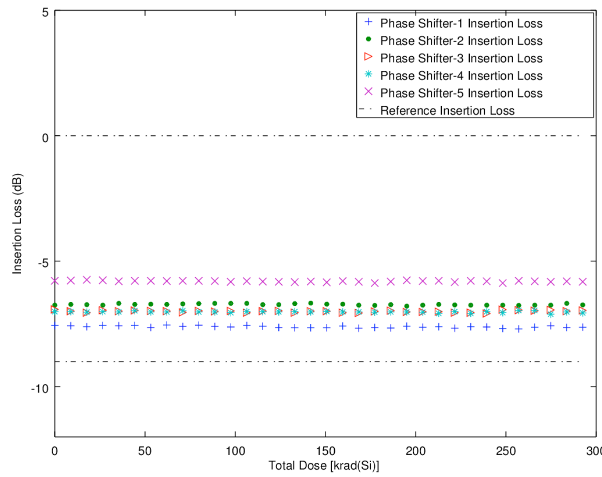

Figure 6 Effects of irradiation on Insertion Loss characteristic of Phase Shifter

IV. CONCLUSION

Radiation hardness of GaAs based components of SSPA under operational bias conditions were investigated. The test results exhibit excellent hardness characteristics under irradiation. The only significant change in the output power of the High Power Amplifier is around 1% below from expected values while it is similar for Power Amplifier. No degradation observed in attenuation characteristics of attenuator. Insertion loss of the Phase Shifter also observed within the expected values with 1% below its characteristics.

These results suggest that components of SSPA will operate successfully against gamma ray irradiation in the space environment.

Although, GaAs MMICs that are components of in-house developed SSPA modules are immune to total ionizing dose effects according to test results, radiation effect studies and tests of SSPA module itself will be investigated to insure its performance in the space environment.

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