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Total Ionizing Dose Effect on the Stability and Gain of Linear RF Power Amplifier

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1. Introduction

In the wake of catastrophic incidents at the Chernobyl and Fukushima Daiichi Nuclear Power Plant, the safety and reliability of Nuclear Power Plant have become paramount. To promptly respond to accidents in their initial stages, it is imperative to monitor the Nuclear Power Plants. For monitoring the NPPs, various methods exist i.e. monitoring through drones, monitoring using 3D Modelling and computer vision, and monitoring through wired communication systems [1-3]. However, all of these methods require the maintenance of extensive cable networks, resulting in high maintenance costs and reliability issues. In general, wireless communication systems have undergone significant development and are widely utilized across various industries. Moreover, wireless technologies have been explored for implementation in NPP monitoring, and employing a wireless communication system in NPPs, rather than a wired one, could offer increased reliability, safety, and cost-saving benefits [4]. A mesh of wireless sensor networks can be spread all over the sensitive areas of the NPPs to monitor the sensitive areas [5].

A radio frequency (RF) power amplifier (PA) is an important building block of the transceiver circuit in a wireless sensor network (WSN) which provides the power to transmit/receive the signal. High levels of radiation can cause the ionization of the oxide and insulator inside the metal-oxide-field-effect-transistor (MOSFET) which results in a Total Ionizing Dose (TID) effect. The TID effect can change the threshold voltage of the MOSFET and increase the leakage current. Change in these parameters can cause the PA's linearity issue which is closely related to the stability and gain [6].

In the first part of this paper, we will briefly explain the TID effect, and in the later section, we will show the irradiation test results of a conventional RF Power Amplifier tested in the Cobalt-60 Gamma-ray facility at the Korea Atomic Energy Research Institute (KAERI). Finally, the conclusion and future work are shown.

2. Total Ionizing Dose (TID) Effect on MOSFET

The standard complementary-metal-oxide-semiconductor (CMOS) process is preferred for designing Integrated Circuits as it is cost-effective because a large mesh of sensing nodes is required to closely monitor the sensitive areas of the NPP. However, the high level of radiation causes the ionization of the target material. The high-energy photons (i.e. protons, electrons, or heavy ions) interact with the target material and cause the ionization of the material [7-8]. As a result of this ionization, the electron-hole-pairs (ehps) are created. The energy deposited by the high-energy photon that results in ehps creation is referred to as TID [9]. The generated holes are trapped in the oxide of the MSOFET and cause variation in the threshold voltage (V_{th}) of several millivolts. Moreover, these trapped holes cause the leakage current to flow which degrades the performance of the MOSFET.

3. Irradiation Test Results

The conventional RF PA was tested in the Cobalt-60 source facility as shown in Fig. 1. The operating condition under which the PA was tested is given in table I. The conventional PA IC was exposed to radiation for 23 hours and the total absorbed dose is calculated to be 23 kGy.

When analyzing the s-parameter plots before and during the irradiation test, the primary focus is on understanding how radiation affects the transmission and reflection coefficients of the PA.

(a) (b)

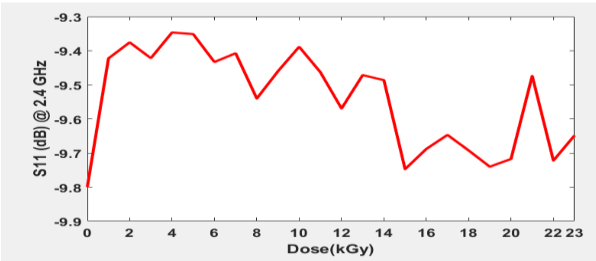
Figure 1: (a) γ–ray irradiation tests environment with Cobalt-60 (b) Experimental test setup

Table 1: Operating Conditions

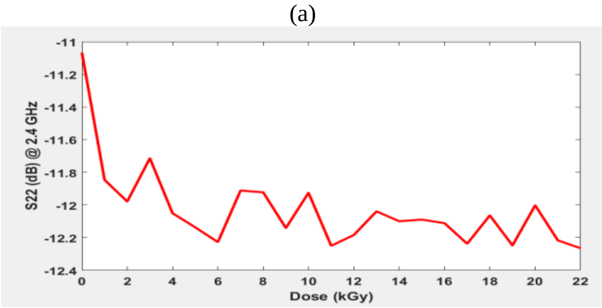
Parameters	Value
DC Supply Voltage	3.2 V
DC Current	20 mA
RF Input Power	-30 dBm
1-dB Compression Point	-40 dBm

Fig. 2 shows the S-parameters of the RF PA for dose level. It can be observed that, at 0 kGy, the gain is 24.55 dB at 2.4 GHz frequency. However, the gain (S21) increased to 25 dB as the absorbed dose increased as evident from Fig. 2(d). But after 14 kGy dose, the gain decreased to 24.85 dB and remained constant. This implies that the PA has eventually become stable as evident from the stability plot explained below.

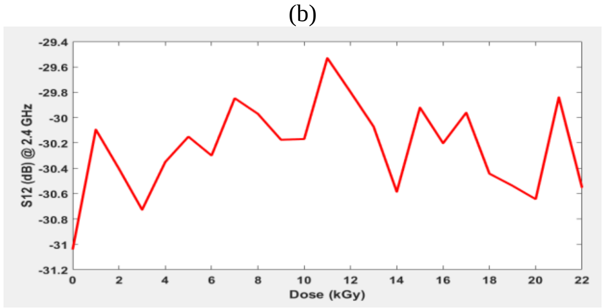
Fig. 3(a) shows the pre-irradiation stability plot of the RF PA for frequency and it is clear that the PA is stable at all frequencies and maximum power is transferred to the loads. After irradiation, the circuit is stable for all frequencies because the stability factor is larger than 1, however, the factor slightly decreases from 1.12 to 1.04 until the absorbed dose of 13 kGy as plotted in Fig. 3(b). Interestingly, after the 18 kGy, the stability factor is improved due to the gain (S21) of PA. Thus, the improvement in gain and S11 results in the overall improved stability of the circuit.



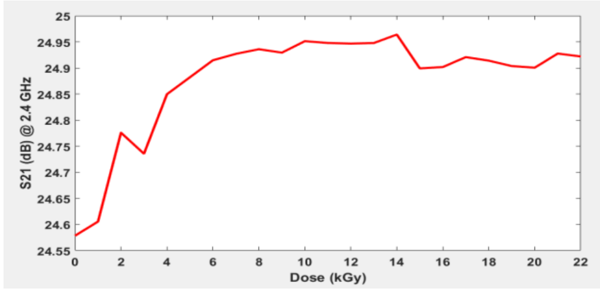
(a)



(b)

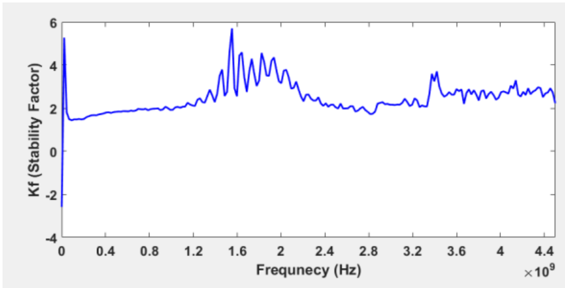


(c)

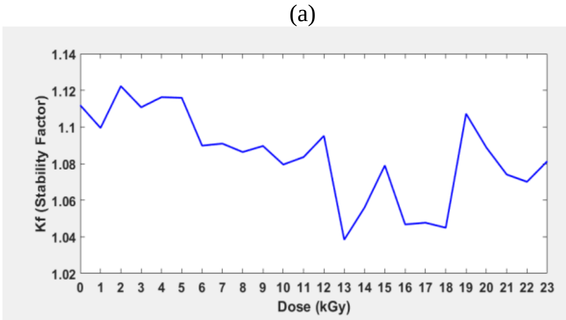


(d)

Fig. 2. The change in the S-parameters due to TID upto 23 kGy, (a) S_{11}, (b) S_{22}, (c) S_{12}, (d) S_{21}



(a)



(b)

Figure 3: The degradation in the K_f due to TID (a) Pre-Irradiation, (b) Irradiation upto 23 kGy

3. Conclusions

The TID effect on the stability and gain of conventional RF PA is studied in this paper. The gain increases as the absorbed dose increases but the stability decreases which implies that the PA has reached its 1-dB Compression point and the PA has become non-linear. The linearity is closely related to the power consumption. At higher dose levels, the PA becomes unstable, and the power consumption increases which reduces the gain (S21). The gain increased from 24.55 dB to 25 dB and the stability factor (K_f) decreased from 1.12 to 1.04. The reverse transmission coefficient (S12) is also increased which implies that a portion of the input power is reflected to the source. More detailed results will be presented at the conference.

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