Evaluation of operational amplifier immunity by means of Weibull distribution

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***Abstract*—The immunity of operational amplifiers is a trend topic for electromagnetic compatibility EMC community. Radiofrequency interference is usually applied to the operation amplifier and the voltage offset is monitored as a parameter to evaluate the EMC degradation. However, this method does not provide enough information to know the probability of failure to electromagnetic interference of the devices. In this paper, an alternative statistical analysis based on the Weibull distribution is used to analyze the electromagnetic immunity performance of operational amplifiers under different frequency interferences and modulation index. The results confirm the feasibility of the Weibull distribution to evaluate the radiofrequency interference RFI behavior.**

***Keywords*—Operational amplifier, electromagnetic interference, Weibull distribution.**

I. INTRODUCTION

Electronic systems are disturbed by radiofrequency interference (RFI) which can potentially disrupt their operation. In fact, the impact of RFI in analog circuits has been deeply investigated and it has been observed that RFI provoke a voltage offset shift due to non-linear behavior of the involved semiconducors [1]. This effect has been taken into account in the design of operational amplifiers (OPAMP) [2-3]. In this context, the modeling and prediction of interference effects play an outstanding role in the electromagnetic compatibility field. Additionally to the offset voltage shift, the non-linearity OPAMP behavior causes an AM demodulation of RF signals at the modulating frequency, f_m, whose amplitude is proportional to the amplitude of the random modulating noise. This signal, falls into the pass band of the OPAMPs and it contributes to a worsening of the signal/noise ratio, *i.e.*, the interference signal cannot be distinguished from the useful signal.

The RFI problems can be addressed as a statistical process [4]. In order to evaluate the RFI performance several samples of the same device are measured and the average and dispersion are used to compare between different devices. However, this methodology does not provide enough information about the differences or improvement in terms of probability of failure in front of RFI. In this work, a recently presented methodology [5] is used in order to evaluate the performance of operational amplifier under different RFI conditions.

This paper is organized as follows. In Section II, the experimental setup and the samples under test are presented. A brief reminder of the Weibull distribution as well as the measurement results are presented and discussed in Section III. Finally, in Section IV, the main conclusions are summarized.

II. EXPERIMENTAL SETUP

The samples under test are a commercial wide bandwidth JFET input operational amplifiers and a follower topology has been selected as a worst RFI case [6]. In Fig.1 the experimental setup is depicted. A RF interference signal has been injected by means of a RF signal generator connected to a directional coupler in order to measure the actual level of injected power, following the standard IEC 62132-4 DPI [7]. The interference consists of an 868MHz or 2.4 GHz carrier with a 10kHz AM modulated frequency and two different modulation index (50% or 25%) in order to quantify its impact. The injected RFI power has been swept and the operational amplifier output has been monitored in order to quantify the modulated frequency in the frequency band of the operational amplifier, instead of DC offset voltage. As can been observed in Fig. 2, due to the non-linearity of the operational amplifier, the modulated frequency is present at the output of the operational amplifier. The peak of this signal has been monitored to evaluate the immunity level. In order to develop the statistical analysis, 20 samples have been characterized for each RFI condition.

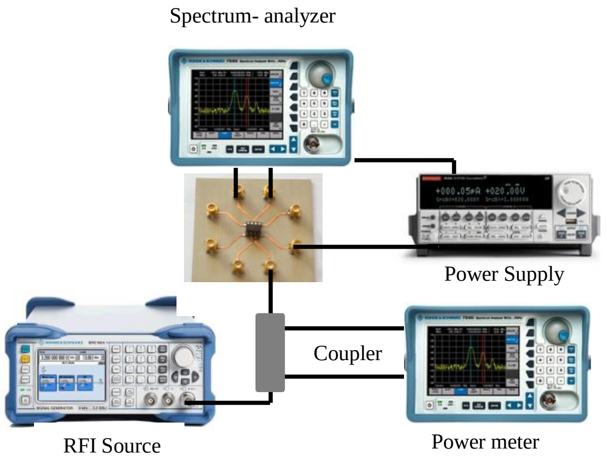

Fig. 1. Experimental setup.

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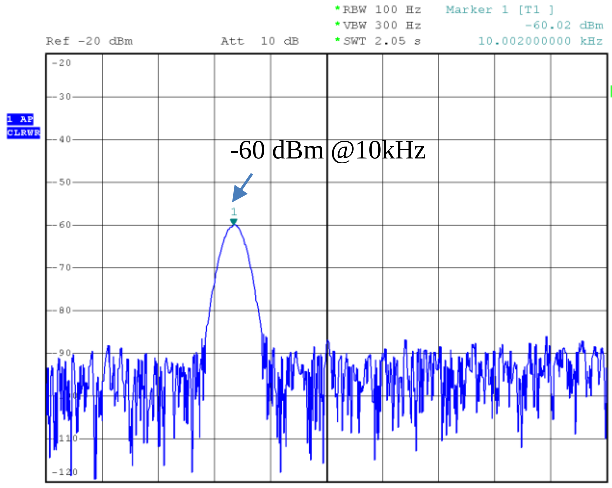


Fig. 2. Experimental demodulation at the opamp output under RFI @2.4GHz with 10kHz AM.

III. Results

The RFI power has been swept in the setup detailed in Section II and the OPAMP output at 10kHz has been recorded for each sample. In Fig.3 the average and ± 3 times dispersion of 20 samples for both 868MHz and 2.4GHz are shown by applying a 50% modulation index. Although at 2.4GHz the power output at 10kHz is slightly lower, denoting a higher level of immunity with regard to the 868MHz case, it is difficult to quantify the differences between both frequencies. In order to do so, a failure criterion of -50dBm and -60dBm at 10kHz has been fixed and the probability of failure to achieve this criterion has been obtained by means of Weibull distribution. Notice than the failure criterion depend on the application. However, in this case in order to validate the proposed method two different criterion have been used.

The Weibull distribution is a well-known probability function widely used on reliability analysis. In particular it is used in order to evaluate the lifetime of system and electronic devices [8]. The Weibull cumulative distribution function corresponds to (1):

$$F(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \qquad (1)$$

Where β is the shape distribution parameter and α is the scale parameter distribution. These parameters are obtained with a simple linear regression on a Weibull plot (Fig. 4). The obtained parameters for both RFI frequencies are summarized in Table I for two different failures criterion. Once the Weibull parameters have been obtained, it is possible to determine the probability of failure from (1), where x denotes the RFI interference amplitude. In Fig.5 the probability of failure of the same RFI frequencies considered above are shown with a failure criterion of -50dBm and -60dBm at 10 kHz (modulation index, m=50%). After doing the proposal statistical analysis, it can be concluded that the operational amplifier is more robust to 2.4GHz RFI than 868MHz RFI. Specifically, for a failure criterion of -50 dBm, at 2.4GHz the probability of failure is zero up to -2dBm, whereas at 868MHz the probability of failure is zero up to -7dBm, representing a margin of 5dB between both RFI frequencies. For a failure criterion of -60dBm, the probability of failure is zero up to -17dBm at 2.4GHz and up to -11dBm at 868MHz representing a margin of 6dB.

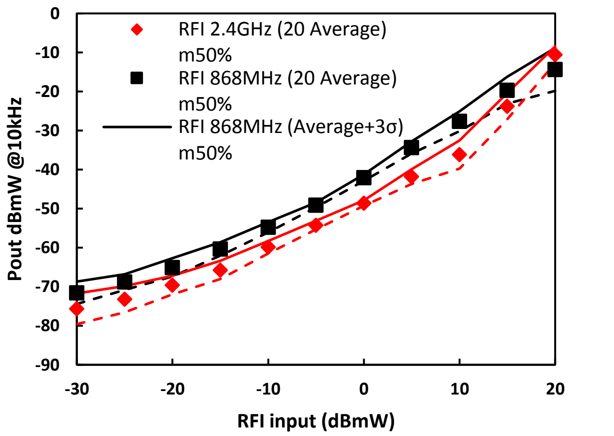
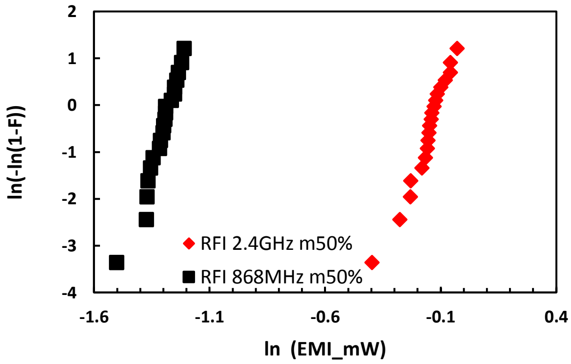
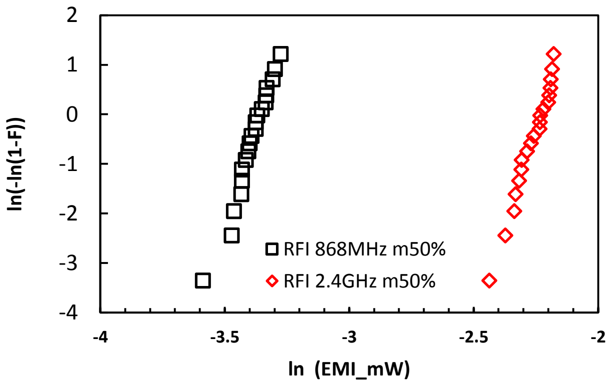


Fig. 3. Experimental opamp output power dependence @ 10kHz in terms of the RFI amplitude. The average and dispersion of 20 samples for 2.4GHz and 868MHz RFI are shown.



a) Failure criterion corresponding to -50dBm @10kHz

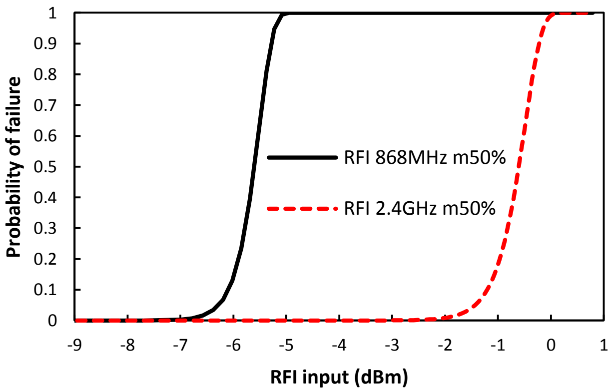


b) Failure criterion corresponding to -60dBm @10kHz

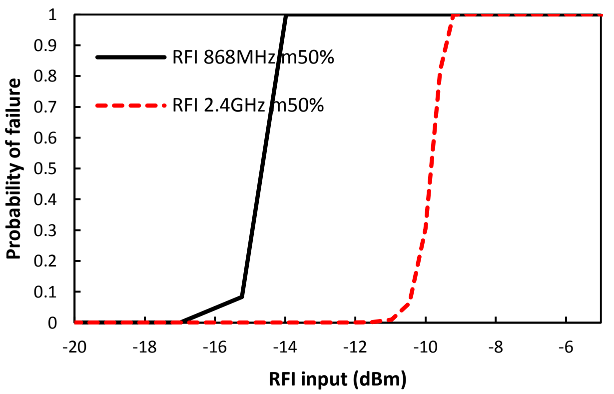
Fig. 4 Line fit of Weibull plot for RFI 868MHz and 2.4GHz.The criterion of failure has been fixed at a) -50dBm @10kHz, b) -60dBm @10kHz.

TABLE I. SHAPE AND SCALE WEIBULL PARAMETERS OBTAINED BY LINEAR FITTING ON WEIBULL PLOT OF FIG.4.

Failure		2.4GHz	868MHz
-50dBm	α	0.89	0.28
	β	13.67	16.77
-60dBm	α	0.11	0.03
	β	16.23	16.11



a) Failure criterion corresponding to -50dBm @10kHz



b) Failure criterion corresponding to -60dBm @10kHz

Fig. 5 Probability of failure of two RFI frequencies. The criterion of failure has been fixed in a) -50dBm @10kHz b) -60dBm @10kHz.

The Weibull method has been also used in order to evaluate the impact of the AM modulation index of interference. In Fig. 6 the operational amplifier power output at 10kHz is shown when an interference of 2.4GHz with a modulation index of 50% and 25% is swept from -30dBm to 20dBm. The average and ± 3 times the dispersion of 20 samples are shown. As expected, the power output at 10kHz is lower if the modulation index is reduced. To quantify the differences, the Weibull plot is applied for both failure criterion (-50dBm and -60dBm) and shown in Fig. 7, the linear regression parameters are obtained and summarized in Table II.

In Fig.8, the probability of failure for both RFI modulation index are represented. As expected, if the modulation index is reduced the probability of failure is lower, in fact, a margin about 4dB is observed between both modulation indexes. These results confirm the feasibility of the Weibull distribution to evaluated and quantify the immunity of operation amplifier to RFI.

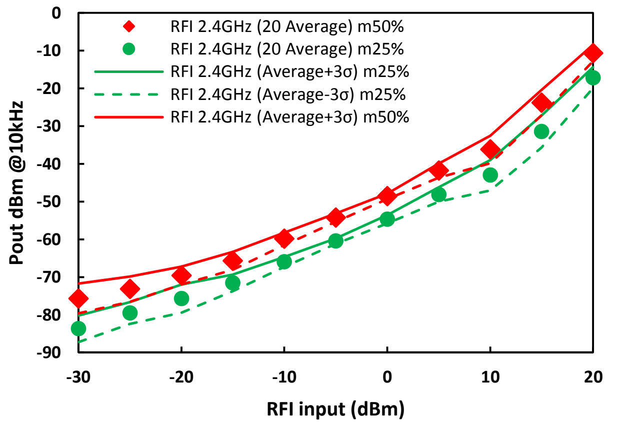
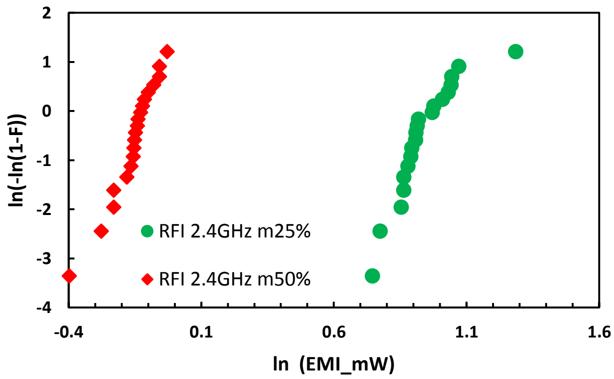
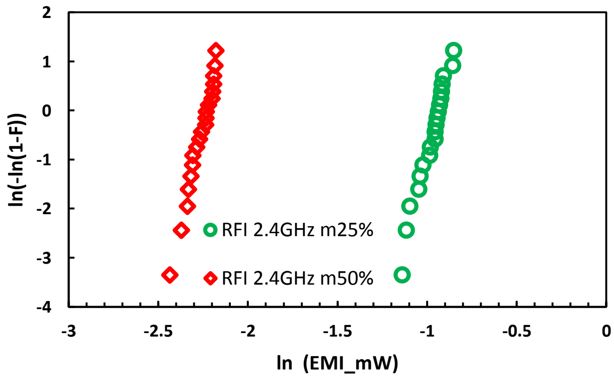


Fig. 6. Experimental opamp output power dependence @ 10kHz in terms of the RFI amplitude with two different modulation index, m=25% m=50%.



a) Failure criterion corresponding to -50dBm @10kHz

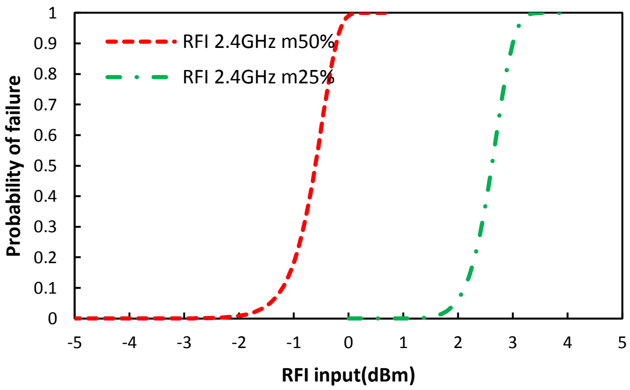


b) Failure criterion corresponding to -60dBm @10kHz

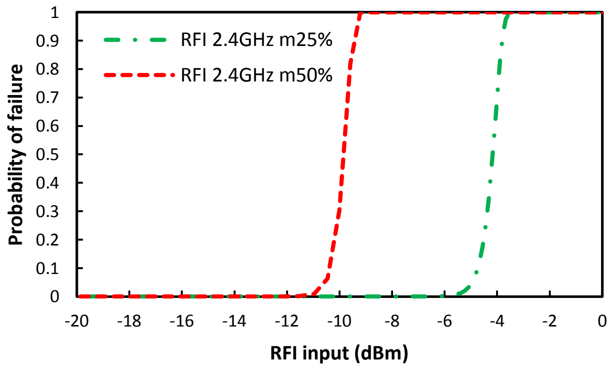
Fig. 7 Line fit of Weibull plot The criterion of failure has been fixed at a) -50dBm @10kHz, b) -60dBm @10kHz.

TABLE II. SHAPE AND SCALE WEIBULL PARAMETERS OBTAINED BY LINEAR FITTING ON WEIBULL PLOT OF FIG.7.

Failure		**m 50%**	**m 25%**
-50dBm	α	0.89	2.73
	β	13.67	8.88
-60dBm	α	0.11	0.39
	β	16.23	14.45



a) Failure criterion corresponding to -50dBm @10kHz



b) Failure criterion corresponding to -60dBm @10kHz

Fig. 8. Probability of failure for RFI modulation index of 50% and 25%. The criterion of failure has been fixed at a) -50dBm @10kHz, b) -60dBm @10kHz.

IV. CONCLUSIONS

In this paper, the immunity of the operational amplifier has been evaluated under different RFI frequencies and modulation index. The immunity has been evaluated with a statistical analysis based on Weibull distribution. The used method allows to quantify the immunity and to obtain the probability of failure of a device under RFI environment. This methodology is highly efficient to compare the immunity of different operational amplifier and/or the immunity under different RFI conditions. The obtained results showed that the used device is more sensitive to RFI at 868MHz than at 2.4GHz, with a margin higher than 5dB in all cases. However, in order to generalize the proposed methodology, a deeply investigation with different distributions and different devices should be evaluated which is the target of the authors for the near future.

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