Selection of test signals and parametric estimation of susceptibility of integrated circuits to electromagnetic conducted disturbances

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Abstract

Some questions related to susceptibility (immunity) of integrated circuits to conducted electromagnetic disturbances are discussed. This includes the selection of test signals, determination of monitoring EMC parameters and proposals of quantitative estimation of integrated circuits susceptibility on the base of measured values of the established parameters and they relative changes under the influence of test signals.

Introduction

Some measurement methods of immunity (susceptibility) of integrated circuits (ICs) to electromagnetic disturbances are already available and even applied in the industry, while some others are the subjects of new standard proposals inside IEC. Generally these methods provide qualitative estimation of the properties of tested devices since they are based on the qualitatively formulated malfunction (failure) criteria and alternative classification of the devices subjected to the influence of tested signals. The aim of this paper is to turn the attention to the questions, which could extend the use of present methods and to introduce new quantitative estimation of ICs susceptibility properties.

Selection of test signals

Measurements of influence of conducted disturbances are performed by applying RF power, voltages or currents to the selected single pin (terminal) or the set of IC pins. Relevant methods actually considered inside IEC include direct RF power injection DPI, bulk current injection BCI and stimulation of IC placed inside workbench Faraday cage (WBFC method) [4]. Transient disturbances are also expected to be taken into account in the future. Up to now direct RF voltage injection (capacitive coupling) is not considered, although its measuring set-up is similar to that used at DPI and BCI methods and direct voltage injection is commonly applied in the investigation of digital noise and coupling mechanisms (through the common substrate) in mixed-signal ICs.

To consider the interfering effects of disturbing signals one should take into account the energy carrying by disturbances as well as the energy distribution as a function of frequency. Up to now the recommended test signals have the form of sinusoidal continuous waves (CW) or amplitude modulated (AM) waves. Nevertheless, as results from the experiments, the penetration of disturbing signals significantly depends on the signal waveform, see Fig. 1 [3]. Penetration of disturbing signal depends of course on the analysed network of the circuit to which the stimulated signal was applied. Generally the tested network is not known in details but can be characterised by a set of terminal parameters.

Some experiments were performed in which random signal (white noise) was used to stimulate the tested devices [2]. Signal bandwidth was carefully controlled with the help of sharp filters to monitor the appearance of circuit malfunction and thus its susceptibility. The relation between the failure threshold and signal bandwidth was clearly pronounced.

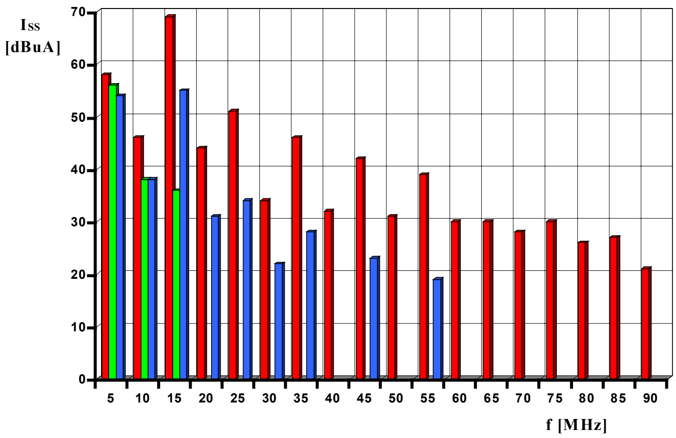

Fig.1 Characteristics of penetration of 5 MHz disturbing signal from RESET terminal to supplying line I_{SS} for microcontroller 80C31 type; green – sinusoidal waveform, red – square waveform, blue – triangular waveform

Monitoring parameters

It can be assumed that regarding electrical function and physical properties of semiconductor devices we are able to specify electrical parameter (or parameters), which could characterize the device behaviour in the presence of electromagnetic disturbances. They will be called EMC or monitoring parameters. Penetration of external or internal electromagnetic disturbances into the tested devices - discrete elements or integrated circuits, causes a change of the determined parameter (s).

Immunity standards proposed inside IEC contain functional status classification that describes the operational status of IC during and after exposure to an electromagnetic disturbance. But the introduced 5 classes (A to E) give only qualitative characterisation of the IC status, e.g.: class A – IC performs all specified functions as designed during and after exposure, class E – IC doesn't perform one or more functions as designed during and after exposure. Beside that mentioned above classes are rather suitable only for digital ICs.

Meanwhile in the practice various effects appearing in the ICs are observed under the influence of electromagnetic disturbances. In case of digital circuits the static failure (malfunction) is observed when the disturbance is of sufficient energy to cause a change of the state. At lower disturbance level a propagation delay is usually introduced.

As far as the analogue circuits are concern the effects of disturbances embrace e.g. changes of amplifier gains, producing of steady state components at the operational amplifiers output, phase shifts etc.

It seems from the above that the susceptibility measurement procedure and conditions as well as acceptance (or rejection) criteria should be individually chosen and specified for each IC functional families and even for individual products e.g. voltage regulator [1].

RF component of power supply current can only be proposed as a sufficiently universal parameter indicating the activity of various circuits under the influence of electromagnetic disturbances. It was proofed by some experimental results obtained mainly for digital circuits and particularly for microcontrollers [3]. Changes in disturbance level and terminal to which disturbing signal was applied found their response in the measured variable component of the supply current I_{DD} or I_{SS}, Fig. 2.

The relative change of the current with respect to the situation without the presence of the disturbances or to the initial value can thus be proposed as the susceptibility measure. On the base of measured and registered samples taken from the supply current its average value, variance and peak-to-peak values can be calculated through the adequate averaging: coherent for the current function in time domain and non coherent – in frequency domain.

Monitoring parameters can also be determined by using system simulators, if we are able to adequately model the tested IC [1].

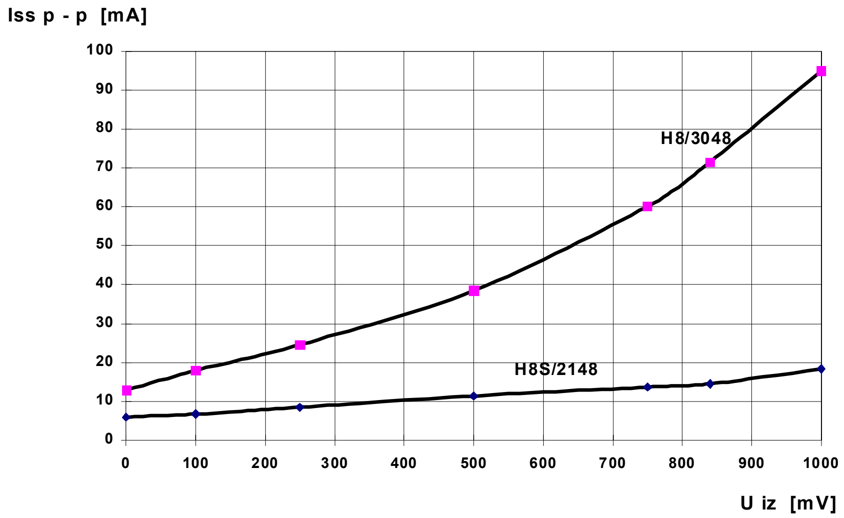

Fig. 2 Peak-to peak values of supplying current I_{SS} as a function of disturbing voltage U_{iz} applied to circuits input for two types of Hitachi microcontrollers

Basic relations for characterization of relative changes

During the test we can use controlled disturbing signal sources to provide the regulation of disturbance level in continuous or step-by-step manner.

Resulting change of established X parameter could be expressed in the form

$$\psi(t) = x(u)/x(u = 0) = x(u)/x(0) \tag{1}$$

in which $x(0)$ and $x(u)$ – the values of X parameter of tested device without the presence of disturbances and after the coupling of some disturbances $u > 0$, respectively.

If we test n devices then we can find n continuous functions

$$\psi_i(t) = x_i(u)/x_i(0) \quad \text{for } i = 1,2,...,n \tag{2}$$

which represent the realizations of random function of relative changes $\Psi(u)$ of X parameter such that $P(\Psi(0) = 1) = 1$. When the disturbing test signal is changed in step-by-step manner then we will deal with the function $\Psi_i(u_j)$

$$\Psi_i(u_j) = x_i(u_j)/x_i(0) \qquad \text{for } i = 1,2,...,n; \quad j = 1,2,...,k \tag{3}$$

The calculated values are the observed (experimental) values of random variable $\Psi(u_j)$ representing the instantaneous state of the random function of relative changes $\Psi(u)$ for $u = u_j$.

The distribution of random function $\Psi(u_j)$ can be approximated by normal (Gaussian) distribution, as the result of elimination of the influence of unknown initial distribution of the X parameter, obtained through the dividing process. Since that we can assume in practice that nearly all values of random variable $\Psi(u_j)$ are located inside the interval $E[\Psi(u_j)] \pm 3\sigma[\Psi(u_j)]$ at which $E[\Psi(u_j)]$ means the expected value and $\sigma(\Psi(u_j))$ – standard deviation of random variable $\Psi(u_j)$.

Quantitative (parametric) estimation of the device susceptibility (immunity) to electromagnetic disturbances can be done if we would recognize the observed changes of determined EMC parameter as an evidence of partial failure of the tested device.

Since the values of X parameter are always positive for any u_j, the following condition is fulfilled

$$P[X(u_j) \geq 0] = P[\Psi(u_j) \geq 0] = 1 \tag{4}$$

We can choose an auxiliary function

$$\varphi_i(u_j) = \varphi(\psi_i(u_j)) \tag{5}$$

which has the values located inside the interval [0,1].
The values of 0 and 1 can be ascribed to the ultimate states of the tested device, respectively, when it works properly without the presence of any disturbances and when it passes to the malfunction (failure) state.

Further simplification in the calculation procedure can be obtained if we assume that raising the disturbance level $u > 0$ causes only increase of the value of monitoring parameter X.

$$\varphi_i(t) = 1 - 1/\psi_i(t) \tag{6}$$

This equation can be useful if we would like e.g. to use combine coefficient embracing more than one monitoring parameter of the tested device.

As an example the data used to design figure 2 can be taken for calculation. Disturbing signal of 1000 mV caused the increase of I_{SS} peak-to-peak value for H8/3048 device from initial 14 mA to 95 mA. Hence the relative increase is about 6.8. For improved and disturbance "hardened" microcontrollers H8S/2148 the I_{SS} is generally significantly smaller and increases only about 3.16 times. From (6) the values of φ function are: 0.853 for H8/3048 and 0.684 for H8S/2148.

Since the interfering effects depend on the energy and frequency of disturbances, the susceptibility features of the IC, determined on the base of relative changes of monitoring parameters, can be represented as a surface in 3D space.

Conclusion

Any attempt toward generalization of the susceptibility (immunity) determination of different ICs meets many obstacles resulting mainly from the various types of possible disturbances and their levels (reflected by the test severity) as well as from various acceptance or rejection criteria of the tested ICs. Parametric estimation of susceptibility properties of ICs, especially at lower disturbance levels, can be performed by the selection and analysis of some monitoring EMC parameters of the ICs.

References

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