Methods for precise acquisition of IC EMC characteristics

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Due to the unpredictable EMC behaviour of ICs, development costs are rising. This trend can be held back by more precise acquisition of an IC's characteristics. The measuring methods suggested in this article have been successfully tested with IC manufacturers.

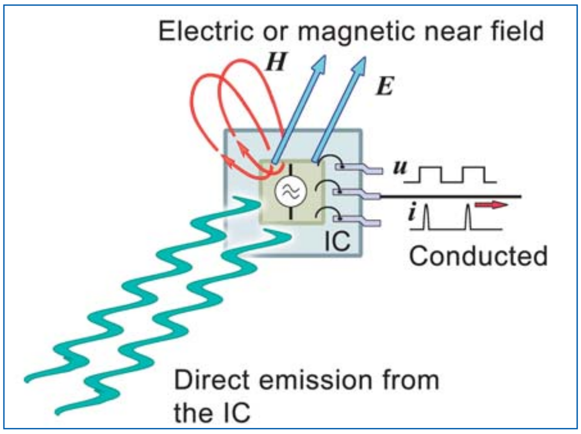

Figure 1. Ways in which disturbances couple out from an IC

■ IC parameters for the board level should give electronic developers and EMC engineers tips for the electrical and mechanical design of a device. The parameters provided by IC manufacturers allow a comparison of ICs and thus facilitate their choice. The IC user, however, has to consider not just the board level but the entire functional EMC chain from the source, i.e. the IC's interior, through the module, right down to the far field. If the IC parameters are tailored to this functional chain, this makes it much easier for the IC user to estimate the time and money needed and make optimum use of the ICs.

The IC user has to deal with three ways in which disturbances couple out from an IC during his work: "coupling out of disturbances via the electrical connections of an IC", "coupling out of disturbances via an electric or magnetic near field" or "direct emission from the IC" (figure 1).

Coupling out of disturbances via the electrical connections of an IC: the RF current and RF voltage on the pin are the corresponding physical quantities. They are theoretically able to stimulate direct emissions from the conducting track that is connected to the driving pin, though this does not occur in practice. Instead, the RF current and RF voltage are transformed by the line nets of the PCB into an H or E field which stimulates emissions from the board's own or neighbouring metal parts. Excitation via the electric field can be implemented by a square-wave voltage (Clk) which is coupled into the lines by the IC. The square-wave voltage generates an electric field in the vicinity of the conducting track. Some of its flux lines end at distant metal parts. These flux lines cause the entire metal system to vibrate.

Magnetic excitation occurs, for example, at particularly high currents in the Vdd-Vss current loops which are led across blocking capacitors and the GND plane outside the IC. The current in the conducting track or IC causes a near field H2 which extends upwards. No emission will occur if the near field H2 does not include any metal system. The return current in the GND plane generates a near field H1 which rotates around the GND plane. This near field H1 induces a voltage in the GND plane through its flux Φ. This excitation voltage is the supply voltage of the "antenna elements" (e.g. cables) that are connected on the left and right of the electronic system. Standing waves $\lambda/2$, $3\,\lambda/2$ etc. can be excited on the antennas.

Coupling out of disturbances via an electric or magnetic near field: this near field is generated by IC internal RF voltages or RF currents. The high frequency field couples into neighbouring or the module's own metal parts and stimulates a disturbance emission. Direct emission from the IC: direct electromagnetic emissions from an IC depend on its electrical and mechanical design. They are possible at an excitation frequency of over 1 GHz. IC-specific physical parameters and measurement systems for their detection can be assigned to these three types of disturbance emissions. It should be remembered that the voltages, currents and fields which occur on the IC depend on the parameters of the connected PCB's line nets. Defined, not simply random measurement setups thus have to be used to detect defined currents, voltages and fields.

IC manufacturers have developed measuring methods for comparing ICs. These methods have in part been adopted in standards (EN 61967). We want to try and determine the extent to which the IC's physical characterization is suitable for IC users for the most important methods. This group of users needs parameters which reveal possible emissions and allow them to deduce countermeasures. Each parameter must indicate how to solve emission problems in connection with the respective application. Example: there should be no structural parts of metal in the vicinity of the IC if this emits particularly high electric fields from its housing. Lack of this information could have fatal consequences in terms of EMC when choosing an IC for a new project such as a car's steering electronics. The high IC near field cou-

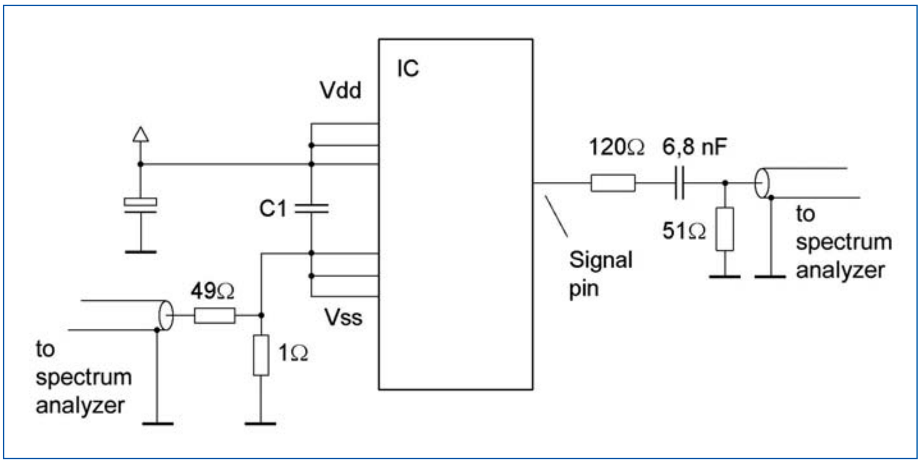

Figure 2. Measuring setup according to EN 61967-4 for measurements on supply and signal pins

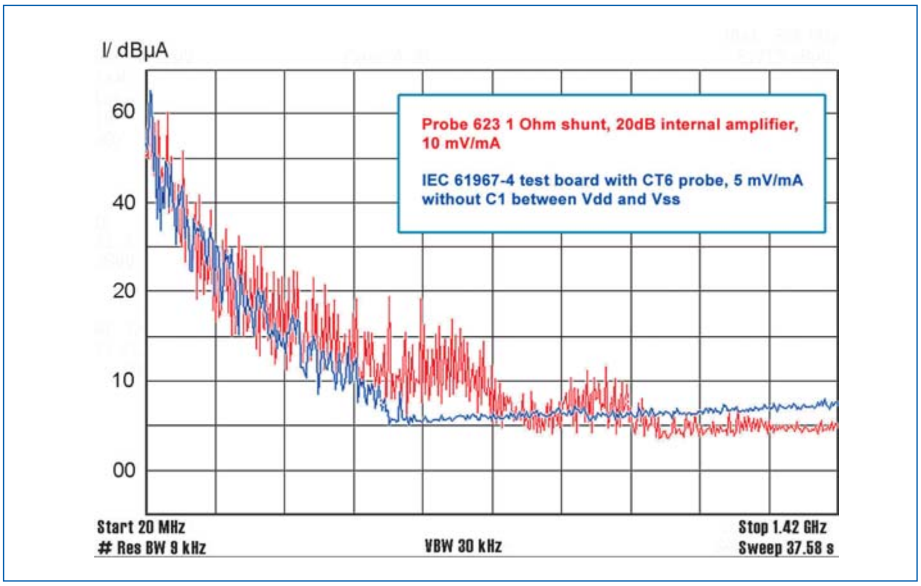

Figure 3. Measurement on an IC in 0.5 µ technology. Comparison between Vss sum current measurement according to IEC 61967-4 and the low-inductance measurement with the 623 probe on the Vss-Cor pin

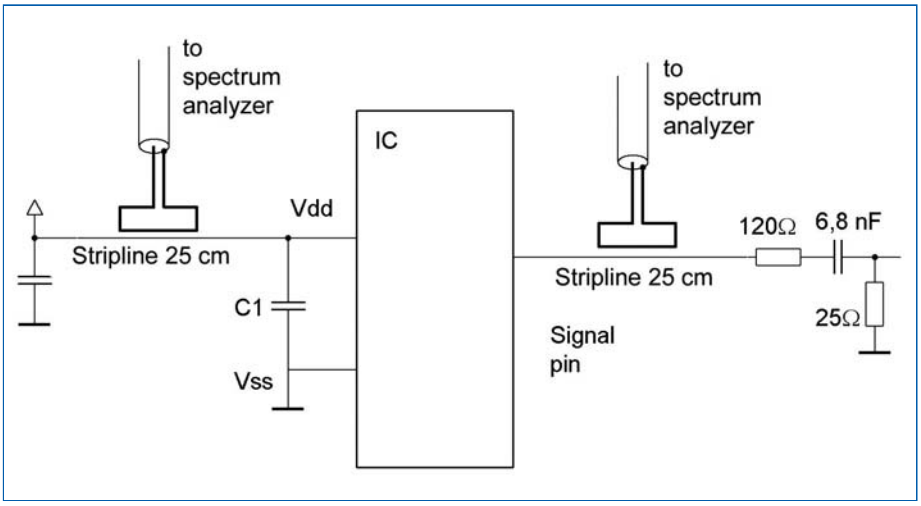

Figure 4. Measuring setup according to EN 61967-6 for measurements on supply and signal pins

ples from the electronic system to the steering column and stimulates disturbance emissions. This example would result in additional costs to ensure EMC.

From the IC user's point of view, it is important that the measured quantities are classified on the basis of their precise place of action (individual pin) and the physical quantity (i, u, H, E). For the IC manufacturer, however, it is sufficient to use global quantities which combine several effects to allow a simple comparison between ICs.

Current and voltage measurement according to EN 61967-4: the sum current in GND is measured with the measuring setup shown in figure 2. This provides a global quantity for comparing ICs. The currents of the individual supply pins, which are of interest for the user, are not measured. A capacitor (C1) is located on the Vdd-Vss pins. This bypasses a considerable share of the sum current around the measuring device. The actual current in the IC loop thus remains unknown. The relatively high line inductivity between the pin and the shunt reduces the current flow and generates a deviation. Figure 3 shows a comparative measurement with a setup that is suitable for RF conditions. The deviation is around 5 dB at 100 MHz and around 20 dB at 500 MHz (measurement already without C1!).

The voltage is measured according to EN 61967-4 with a divider of 120/50 Ω. The IC pins are loaded with 150 Ω to simulate the conducting tracks as transmitting antennas with a load impedance of 150 Ω. Direct electromagnetic emissions from an IC are an exception on the PCB level. Rather, a maximum current generates a maximum H exciter field and a maximum voltage a maximum E exciter field. It is thus much more helpful for the IC user to characterize an IC by a short-circuit or no-load measurement on the pins. The IC's Vss pins are connected to the GND plane via a shunt and lines. The voltage which drops across the inductivity of this short connection is coupled in as a fault in this signal voltage measurement with this measuring setup. The results only allow general comparison between ICs. Higher demands are made for EMC applications.

Current and voltage measurement according to EN 61967-6: the measuring method described above was considerably improved in EN 61967-6 (see figure 4). The IC now has a fixed GND reference. The current is measured with a magnetic field probe. Non-contact measuring on the test board is a real advantage. A great dependence of the probe's position relative to the IC and its frequency dependence are the disadvantages of this current measuring method. The probe's damping increases, for example, to between 60 and 80 dB at low frequencies. Striplines also take up a lot of space. The supply currents of the individual Vdd pins are measurable but not those of the Vss pins. A stripline with an overall line length of 25 mm is necessary to place the magnetic field probe in position. This line's inductivity will reduce the IC current similar to the 1 Ω-method. Practical experience with boards shows that distur-

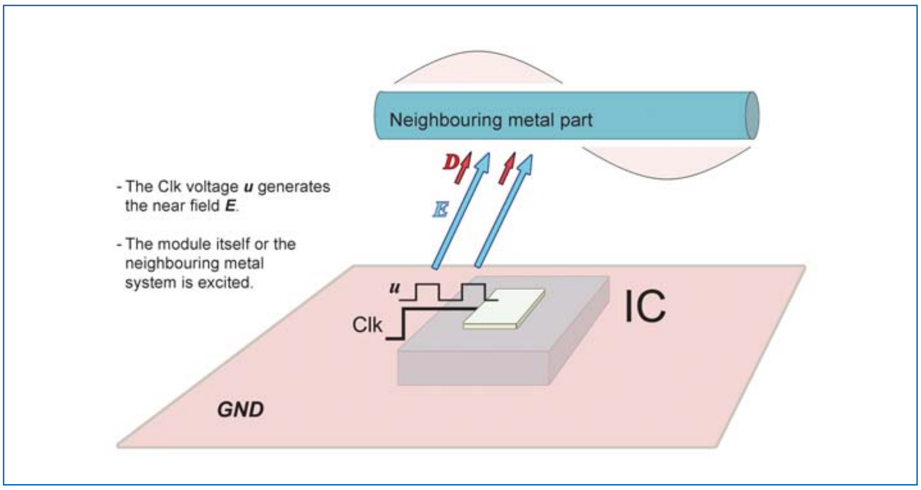

Figure 5. Mechanism of direct E field emission from an IC to neighbouring metal parts

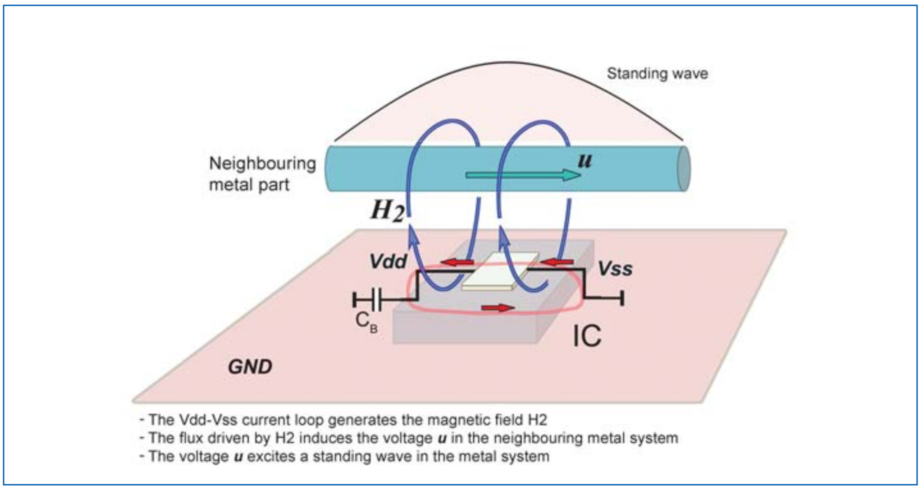

Figure 6. Mechanism of direct H field emission (H2) from an IC and the counter-induction in neighbouring metal parts

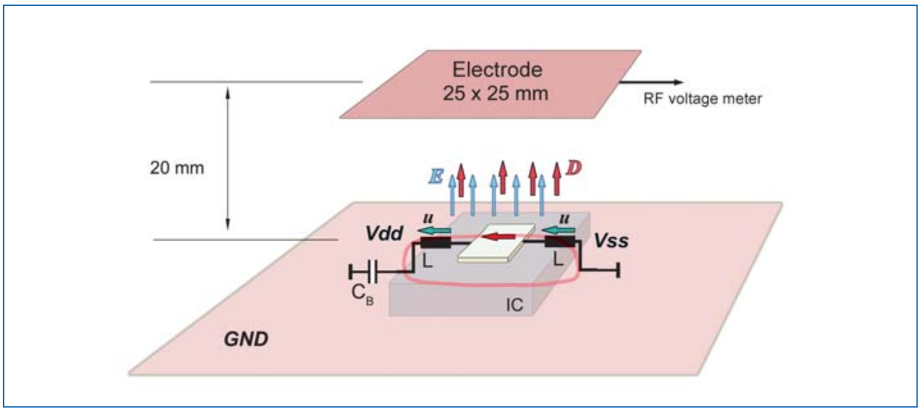

Figure 7. Measuring setup for detecting direct E field emissions from the IC

bance emissions can be reduced to 10 dB if the line is extended by 10 to 20 mm from the Vdd pin to the first blocking capacitor. The information obtained would be as unsuitable for IC users as if a capacitor C1 were to be inserted between the Vdd and Vss pin as in the 1 Ω method.

TEM cell method according to EN 61967-2: the TEM cell measurement takes up the idea of combining the fields generated by the IC in one global measuring quantity. Electric and magnetic fields are measured together. From the IC user's point of view, however, the electric and magnetic fields have to be measured separately. This requirement is based on the functional disturbance emission chains that have been described and the IC user's goal of preventing possible disturbance emissions during the mechanical and electrical design of the device from the very outset. However, the TEM cell cannot differentiate between electric and magnetic fields so that the measurement results are only of limited use.

A two-terminal network is characterised by a no-load voltage and short-circuit current. A maximum disturbance emission is initiated by a maximum voltage (generates a maximum E-field) or a maximum current (generates a maximum H-field). An RF no-load voltage and RF short-circuit current measurement is thus useful for IC characterization.

High demands are made on the RF current meter. The frequency range for its measuring band width is between 10 kHz and 3 GHz. 1 Ω shunts are sufficient for many applications though 0.1 Ω may become necessary, for example, if Vdd is less than 5 V. Furthermore, it can be concluded that the current meter's inner inductivity must be less than the IC's loop inductivity. It thus follows that the inductivity of the current meter should be 1 to 2 nH assuming that an IC's loop inductivity is 10 nH. If several supply pins of an IC are internally connected through parasitic components for RF conditions, the RF current can switch to other pins when the current meter is inserted with too high inductivity and the impedance increases in this connection. The current path of the whole measuring setup must thus have an extremely low inductance.

The measuring setup must be arranged over a short electrical distance to avoid measuring on standing current and voltage waves. The wave length at 3 GHz is around 10 cm. The IC and the measuring setup share an accordingly shorter length. This may not leave much scope for the measuring setup. The measurement results at a frequency of 3 GHz should thus be evaluated extremely critically. The emission mechanism based on the excitation of neighbouring metal parts through an E or H field is only effective at a distance of less than λ/2.

Measuring the near field that is emitted directly from the IC: the mechanism of a direct near field emission is clearly recognizable in figures 5 and 6. The measuring method is shown in such a way that the real emission from the board is simulated. The type of field is decisive for the countermeasures that have to be taken. The electric and magnetic near fields must be measured separately. Two meters are thus needed. The respective information for the IC user can be acquired with the following measuring setups.

E field measurement (see figure 7): a field electrode of 25 x 25 mm should be positioned at a distance of 20 mm from the IC. This field electrode is connected to an RF voltage meter. RF

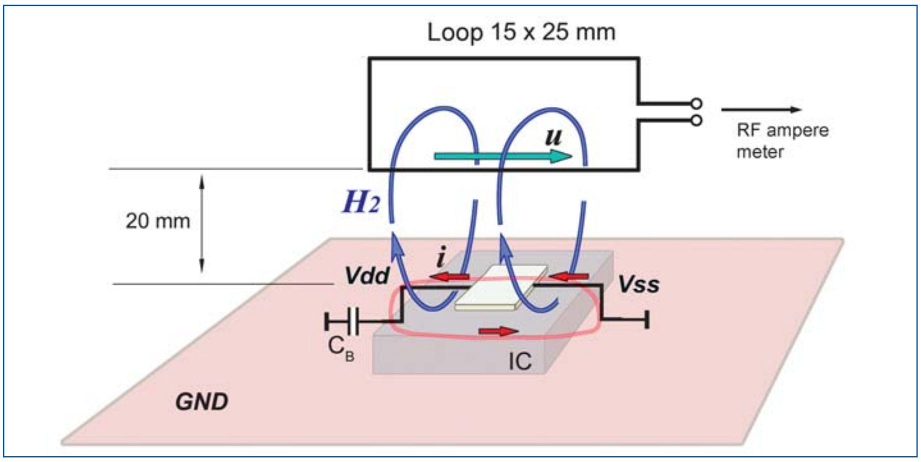

Figure 8. Measuring setup for detecting direct H field emissions from the IC

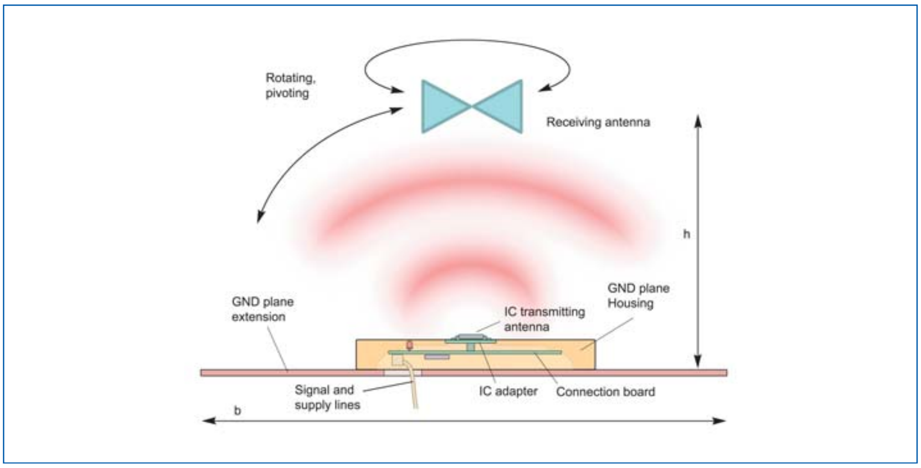

Figure 9. Measuring setup for detecting direct emissions from the IC

voltage versus frequency is the measuring quantity.

H field measurement (see figure 8): a rectangular induction loop of 15 x 25 mm is positioned at a distance of 20 mm. An RF current meter is connected to the induction loop. RF current versus frequency is the measuring quantity.

Measuring the IC's direct emission: an IC is around 2 cm in size. Assuming a wave length of $\lambda/2$ on the IC's metallic parts this corresponds to a frequency of around 8 GHz. A resonance excitation of the IC with a length of 2 cm is not possible below 3 GHz. However, it can also act as a shortened antenna and thus enable a direct emission. Particularly large IC dimensions are between 5 and 10 cm. 5 cm corresponds to $\lambda/2$ at 3 GHz. Resonance excitation becomes likely as a limit case for particularly large housings. We suggest using the measuring setup shown in figure 9 for measuring direct emissions. The IC is attached to a ground plane whose mechanical dimensions are the multiple of the largest wave length to be expected (edge length (b) of around 2 m x 2 m). A distance (h) of the receiving antenna of 1 m is sufficient. The receiving antenna should be able to be rotated and pivoted.

Design of the IC test board: an IC test board is used to implement the measuring methods that were suggested to determine an IC's physical parameters. This board allows the following measurements in connection with special probes:

1. RF short-circuit current
2. RF no-load voltage
3. E field at a distance of 20 mm
4. H field at a distance of 20 mm
5. RF inflow
6. EFT coupling
7. Near field measurement on the IC surface

The IC test board ensures that the measurement can be taken under conditions that are suitable for RF. The introductory picture shows the design of the IC test board. It consists of a metallic GND plane into which an adapter PCB is inserted together with the EUT. The IC is surrounded by a contact surface for different measuring probes. The adapter PCB (IC adapter) closes the GND plane of the metal plate through its own GND. The IC is thus attached to a continuous GND plane. The IC adapter bears the filters and the defined IC loading variants for no-load and short-circuit measurements. The supplies and signals are led to the connection board via plug-and-socket connectors. The RF probes are placed on the metallic GND plane. They can be moved to any position and thus reach each pin. During current or voltage measurements, the respective pin is electrically connected to the probe via the pin contact for a short time.

An EFT generator is available for coupling in EFT. Its burst pulses are controlled by a PC and led to the respective IC pin via a probe. When RF is coupled in, this is fed into the IC pin via the probe's pin contact. RF current and voltage are measured in the probe. Probes that are equipped for field detection are used for field measurements. A field probe is placed on the GND plane with a micro-manipulator to measure the near field on the IC (IEC 61967-3). The test board is fixed on a large metal plate and a receiving antenna is mounted above this to measure direct emissions from the IC. ■