The evolution of ASD™ power integrated functions towards integrated EMC.

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Abstract: **-** For several decades, electronic component manufacturers have marketed power integrated functions on a single chip. There are two complementary technologies, the "smart power" one which generally combines a MOS switch with its control logic and the ASD™ (Application Specifique Discrete) which consists of power components only on a single chip. The integration evolution of the ASD™ depends on the know-how in the manufacturing process. Our team has studied ASD™ applications' reactions to today's EMC (ElectroMagnetic Compatibility) standards. We have focused our attention on the evolution of conducted perturbations produced by a mains chopper , and the operation of a multi-switch ASD™ in an environment polluted by electromagnetic perturbations. After analyzing the results obtained, we have set up several rules concerning the ASD™ design, so that its components satisfy the standard required as soon as they are designed. Eventually, we have two types of products complying with the EMC standard from the start, thus avoiding any further filter.

Key-Words: **-** Power, Integration, ASD™, EMI, EMC.

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1 Introduction

For several decades, electronic component manufacturers have tended to elaborate integrated circuits able to perform more or less complex functions (drivers, demodulators, ...).

In the same way, integrating on a single silicon chip a number of electronic components able to convert energy is an industrial reality which has kept making advances for the past 15 years. Historically, the first approach to power integration was the "smart power" one. More recently, a new approach to functional integration of power components has been developed at STMicroelectronics, and was called « ASD™ » (Application Specific Discrete). A large variety of applications, either in the industrial field (static converters, motor speed control,...) or in home appliances operating on the 220V 50Hz mains can benefit from the advantages brought by the integration of low and medium power converters (the load current ranging from a few mA to approximately 50 A).

Several elementary cells (resistors, diodes, transistors, thyristors,...) have already been developed using the ASD technology. The whole set of the elementary cells thus developed builds up a true « ASD library » for the designer.

We will first give a reminder of the main notions regarding the two approaches to power integration ; then we will dedicate this article to the evolution of the ASD™ integration. Next, we will deal with the EMC aspect ; finally we will consider electromagnetic perturbations in the design of ASD™ cells.

2 The two approaches to power integration

The first approach to power integration was the one called "smart power" : it consists in integrating inside the silicon, next to the power switching element (MOS or bipolar transistor, with horizontal or vertical conduction), the control and protection logic. This logic must be completely insulated from the power part. Presently, the insulation is achieved through junctions : the control of the power part is enclosed in a P-well inside which NMOS, bipolar and CMOS logics are introduced, following more and more complex design rules [1]. The fact that there is such an insulation by junction implies that the vertical power structure must be a 3-layer one (MOS or bipolar transistors) (Fig. 1).

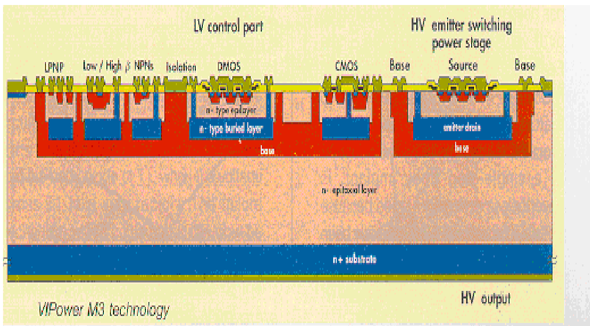

Fig. 1 - Section of a "smart power" structure.

Yet, this technology of logic/power insulation still doesn't allow the integration of thyristor-like 4-layer structures. Recently, the "smart power" technology has been thriving, and is now widely used in industrial electronics (servomotors, current regulators,...) and in the automotive industry (alternator regulator, electronic injection, electrically-controlled side-view mirrors,...) [2].

The second approach, called « functional integration » [3], is quite new : the first products based on functional integration were introduced by STMicroelectronics 5 years ago, under the name of ASD™ products, [1], [4], [5]. The principle is the following : On one single chip are integrated all the power elements (diodes, transistors, thyristors,) required to achieve either the conversion of energy or the protection. The integration combines in the Si volume various areas having specific features (such as doping, thickness), that are made to interact to perform a global power function identical to the one achieved with all the power components individually mounted on a printed circuit. This approach complies with the coherence principle, in so far as there is combination architectures that are strictly vertical, of the same size, and elaborated in the same technology (Fig. 2).

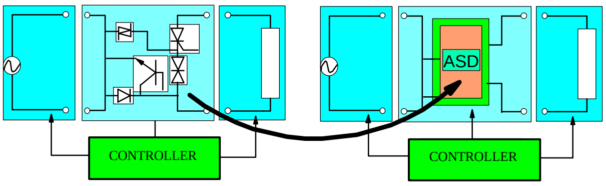

Fig. 2 - ASD™ Approach

The ASD approach contribution is its ability to hold high voltages (DC or AC) as well as high current peaks ; yet its ability to work on signal processing is poor today, unlike the "smart power" approach. As a result both approaches seem to be complementary [6].

3 Evolution of the ASD™ technology

Thanks to the advances and innovations due to its know-how in microelectronics, STMicroelectronics is presently developing and managing the evolution of various generations of functional integration, depending on their increasing complexity [1], [7]. Thus we can notice :

- The first generation (ASD1), featuring 500µm thick silicon wafers with lithography on one side, able to achieve integrated combinations of rectifying diodes (bipolar and schottky), zener diodes, resistors (metallic or by diffusion),
- The second generation (ASD2), featuring 210µm thick wafers with lithography on both sides, able to achieve integrated associations of transistors (NPN and PNP), thyristors, GTO, resistors and diodes. Fig. 3 is an example of vertical integration of a combination of power components.

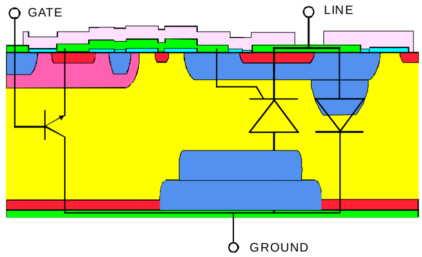

Fig. 3 - Example of vertical integration of power components in the ASD2 generation

In these generations, the technological elementary bricks implemented build up a true ASD library from which the designer can choose the appropriate architecture required to develop a more complex power structure.

Today the basic ASD applications are : line cards protection in telecommunication, computer boards protection, ignition circuit or battery charger in the car industry, lighting of fluorescent tubes. The ASD technology is particularly useful for the integration of circuits operating on the AC mains : indeed these circuits can hold rated voltages when working from 400V to 1500V, and very high densities of pulsating current peaks (100A/mm^2 in 1ms) . Other generations are under study : they are different from one another by the way they combine more and more complex structures : bipolar transistors, thyristors, VDMOS, LDMOS, etc...

4 Electromagnetic interference and electromagnetic compatibility

4.1 Introduction

We have seen the ASD™ applications relate to the protection or to communication on the mains. Regarding protection, it's no use studying electromagnetic perturbations, all the more as some ASD™ sometimes behave as a filter (EMIF for mobile phone). Regarding commutation, power functions have at least one switch which operate on the mains. Therefore, the applications using this type of functions must be comply with EMC standard.

4.2 Definition

ElectroMagnetic Interference (EMI) is unwanted electromagnetic energy polluting our environment. Its propagation via conduction and radiation over system signal and power lines could affect the operation of electrical equipment around the source. On the other hand, ElectroMagnetic Compatibility (EMC) is the ability of a system to function reliably in the presence of significant levels of EMI (immunity) and, at the same time, to limit its internally generated EMI to avoid interference with the operation of other systems around it (emission).
EMI cannot be completely eliminated but it can be reduced to safe level defined in standards. These standards follow the measurement specifications recommended by the International Special Committee on Radio Interference (CISPR) [8]. Most countries, especially in the USA and Europe, have EMC standard according to CISPR recommendations. For

the immunity part and emission part in Europe, the devices or systems are subdivided into three classes:

- Class A is applicable to non-movable units in commercial, industrial and business areas,
- Class B is applicable to stand-alone consumer equipment (electronic typewriters, Personal Computer, switching power supplies…),
- Class C applies to testing instruments.

Here, we talk only about emission conducted and immunity EMI for power functions used within consumer applications (class B).

4.3 Emission

In Europe, the EMC is very important. Every application must be tested for the conducted and radiated EMI. The application is EMC if the module of each frequency is under the standard value.

For the emission conducted EMI, the European standard is NF EN55014 [9] for our applications [10], [11]. This regulation covers a much wider range of frequencies (between 150kHz and 30MHz). The template of maximum spectrum is shown on Fig. 4.

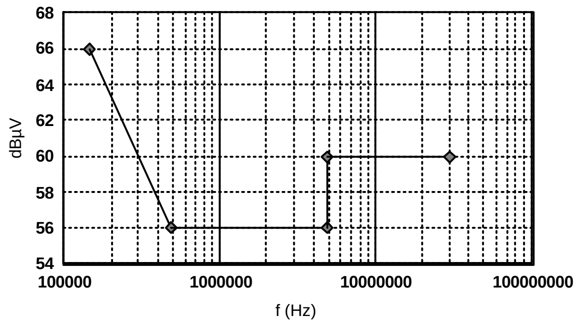

Fig. 4 – Standard EN55014. Template for the emission conducted EMI.

The emission conducted EMI are noise from a system onto the main supply. It usually has a common mode component and a differential mode component. The common mode component appears as a voltage on both line and neutral leads with respect to earth while the differential mode appears between the line and neutral leads.

4.4 Immunity

The applications must functioning in spite of external perturbations. To perform this check test, we submit the tested application to an electromagnetic aggression whose characteristics are defined in standards. We have studied the IEC 1000-4-4 and IEC 1000-4-5 conducted immunity standards

4.4.1 IEC 1000-4-4 standard

The IEC 1000-4-4 standard [12] describes the waveform, the equipment and the operating mode, which allow the burst immunity test. The Electrical Fast Transient (EFT) waveform is shown on Fig. 5. In this test there are some bursts, which are composed of pulses.

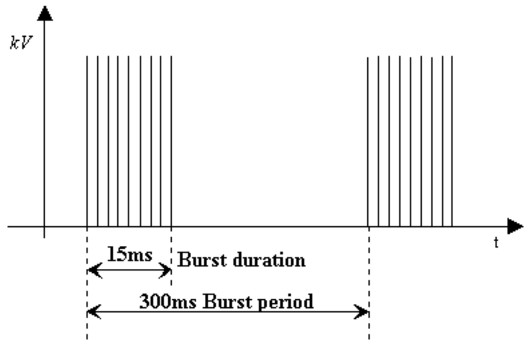

Fig. 5 - Electrical fast transient general waveform.

Fig. 6 represents a real pulse waveform of the generator. These bursts are coupled on the supply and control access. The significant elements of this test are the very short rise time (5ns ±30%), the pulse duration (50ns ±30%), the burst duration (15ms ±20%), the burst period (300ms ±20%), the peak voltage (between 0.5kV and more than 4kV) and the pulse low energy (4mJ per pulse at 2kV).

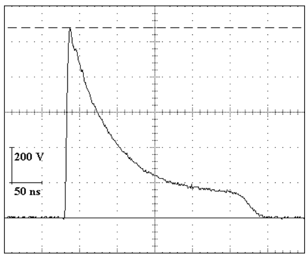

Fig. 6 - The real pulse waveform of the generator.

The peak voltage values, which are separated into five level tests (level 1, 2, 3, 4 and special), are chosen according to the appliance. The peak voltages are respectively 0.5, 1, 2, 4 kV or special. For example level 1 is used to test a very protected environment like computer rooms and level 4 is used to test very disturbed environments such as outside appliances which have their own installation rules. In every case the minimum test duration is one minute.

4.4.2 IEC 1000-4-5 standard

The IEC 1000-4-5 standard [13] describes the waveform, the equipment and the operating mode, which allow the surge immunity test. The surge waveform is shown on Fig. 7.

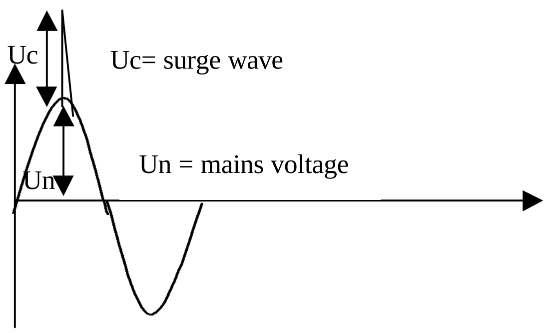

Fig. 7 – Surge general waveform

The significant elements of this surge are the long rise time (1.2µs ±30%), the pulse duration (50µs ±20%) the less surge period (1 minute), the peak voltage (between 0.5kV and more than 4kV) and the pulse high energy.

The peak surge values, which are separated, such as the IEC 1000-4-4, into five level tests (level 1, 2, 3, 4 and special), are chosen according to the appliance. The peak voltages are respectively :

- between line to line,
  no, 0.5, 1, 2kV, or special,
- between line to earth,
  0.5, 0.5, 2, 4kV, or special.

In every case, the minimum test duration is ten minutes.

5 Improvement of ASD™ characteristics

EMC has become a major challenge for switching power supply designers. The EMC challenge has two parts: i) suppression of interference at the source, ii) making devices or systems immune to EMI.

5.1 Reduction of emission "at the source"

Electronic card designers are forced to make some curative EMC with inserting filters not to re-inject the conducted disturbances on the electric network. We put forward a conceptual EMC whose aim is to remove these expensive and thick filters while changing the commutation shapes of the power components to find a compromise between the switching speed and loss by commutation [14], [15], [16].

The ASD™ cell studied in this paper is shown Fig. 8, it commute on a resistive load.

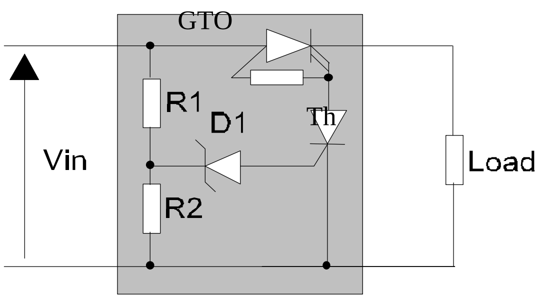

Fig. 8 - Chopper composed of a ASD™ (in gray) commuting on a resistive load.

This cell allows to provide the load with a part of the mains sinusoidal waveform for a period of time given by R1 and R2 resistors and the zener diode D1 : it is a constant phase angle control.

Common and differential mode conducted EMI are presented Fig. 9.
They are compared with the NF EN 55014 standard template.

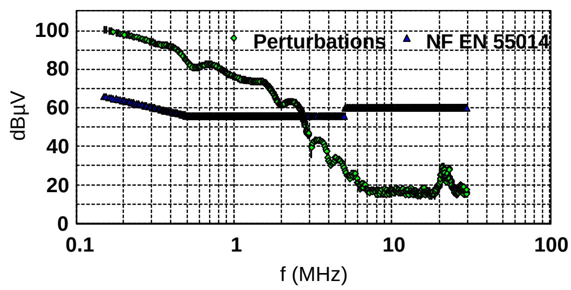

Fig. 9 : Conducted EMI between 150kHz and 30MHz.

When examining Fig. 9, we can see that the interference generated are far superior to the standard template (from 35dB to 150kHz), in spite of the low current interrupted (1A). Therefore, no application can use this circuit without modifying it. The solution usually chosen to reduce conducted EMI, consist in using a filter before the perturbing circuit, between its terminals and the mains. But this filter is more bulky and expensive than the integrated function itself.

That's why we tried to reduces current variations during GTO commutations. Thus, EMI is reduced not only before the application, but in the design of the circuit.

To achieve this, the switch can't work like a normal one, that is to say it can't commute abruptly between ON and OFF states ; on contrary it must show a linear operation between these two states.

Observing this leads to the basic structure of the commutation cell presented Fig. 10.

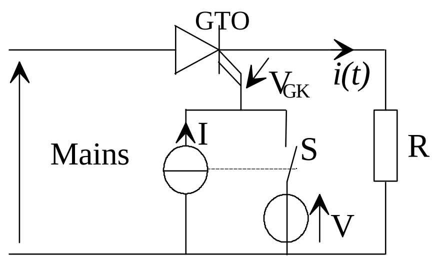

Fig. 10 - Theoretical structure of the EMC cell offering linear commutation.

The current generator controls the ON/OFF state and it actuates the voltage generator. The latter enables to control the consumed current during the GTO commutation.
Good results are achieved with a quasi-sinusoidal current waveform at switch off (Fig. 11).

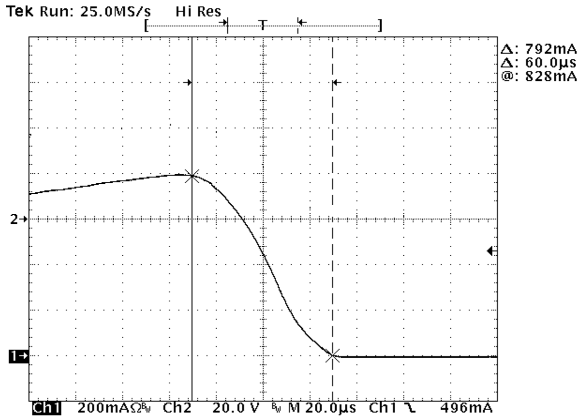

Fig. 11 – Real waveform of our EMC cell.

The conducted electromagnetic perturbations generated by this cell are shown Fig. 12.

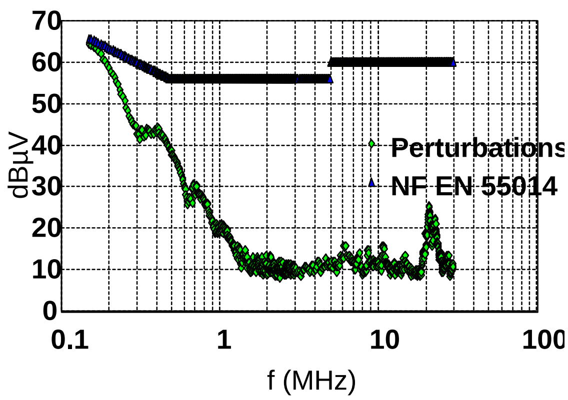

Fig. 12 – Conducted EMI generated by the EMC cell.

We can observe the aim is reached, as interference are at the highest of the standard template and this, for low frequencies.

5.2 Improvement of immunity.

We work with several configurations of a new ASD cells consisting of several devices for the same function. For example, the ACS 402 cell is an AC line switch array that is to say it has just four AC Switches inside, with an independent control circuit, but one common anode.

Fig. 13 shows the functional diagram of the ACS402, and Fig. 14 represents voltage-current characteristic.

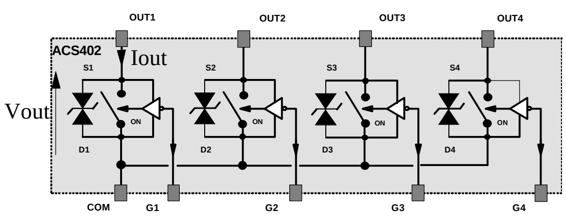

Fig. 13 - Functional diagram of the ACS402, 4 AC Switches with an independent control circuit and one common point.

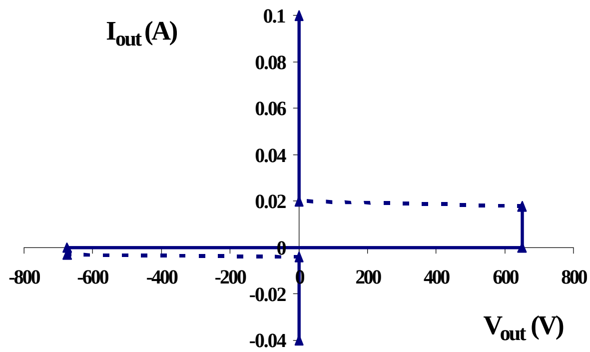

Fig. 14 - Voltage-current static characteristic.

5.2.1 IEC 1000-4-5 behavior

In case of over voltage higher than the voltage breakdown, the device turn on (*Fig. 14*). The structure is designed to operate in this condition, with a high level of peak power.

5.2.2 IEC 1000-4-4 test

In applications, for example household appliances (washing machine valve, pump and fan) the four AC Switches can work at the same time. Moreover, if a disturbance appears all the switches must stay in the state they were in.

In presence of 4 switches in the same case, new problems due to coupling and interactions appear.

For these reasons, we must test the immunity for the ACS402 with the EFT from the IEC 1000-4-4 standard.

We have tested three batches, which have different structures but realize the same function [17]. Over 1000V, the three structures triggered off whereas they weren't controlled by the gate, which is not a satisfying result (
Table 1).

Voltage	V out sign	batch 1	batch 2	Batch 3
700	> 0	NF	NF	F
	< 0	NF	NF	F
1000	> 0	F	NF	F
	< 0	F	NF	F
2000	> 0	F	F	F
	> 0	F	F	F

Table 1 - Results of immunity control tests for 3 batches of ACS402. With NF = Not Firing, F = Firing.

Numerous design rules have been deduced from these tests. They can deal with the silicon layout as well as with the pin connections.

Two new cell, the ACS402 and ACS 108, have been built up following these new design rules ; the results are very satisfying as regards the IEC 1000-4-4 standard. Results are shown in Table 2 for these two AC Switches.

Voltage	V_{out} sign	ACS108-5SA	ACS402-5SB4
500	> 0	NF	NF
	< 0	NF	NF
1000	> 0	NF	NF
	< 0	NF	NF
2000	> 0	NF	NF
	< 0	NF	NF

Table 2 - Results of immunity control tests for the two final batches of AC Switch according to the IEC 1000-4-4 standard. With NF = Not Firing.

6 Conclusion

Power integration on a single chip is today a reality. It is found under the name of "smart power" or ASD™.

The ASD™ technology has an increasing component integration thanks to the advance in performances in microelectronics, particularly in lithographies.

In parallel these improvements, we focused our attention on electromagnetic pollution. We studied conducted EMI generated by these functions and how they react in a polluted environment.

Our purpose was to i) obtain, at the design stage, a switch with EMI inferior to the EMI accepted the the standard, ii) make immune to external interference a function composed of several common anode switches.

Today, we have :

- A mains switch whose conducted EMI comply with the NF EN 55014 standard, without a mains filter. Its main applications are light dimmers and DC power supplies from the mains without transformer,
- Switch array with a common anode that works in an electromagnetic environment described by the IEC 1000-4-4 standard.

Thanks to these cells, applications are smaller and cheaper, as they don't require any filter or any other protection.

Consequently, today improving power integration implies advances in manufacturing processes, but also the integration of the requirements of the EMI standards as soon as the component is designed.

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