Mixed-Signal Yield Improvement, the Human Factor

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ABSTRACT

When I started to write this article I put down on three pages the outline of the subjects I wanted to discuss. Interestingly enough the outline started with a long list of knowledge and skills one should have to be as efficient as possible in mixed-signal yield improvement. Only at the third page did I consider defining what mixed-signal products even were! I guess this set the tone. In this article we will mostly discuss people skills (sorry, techies!). In a high tech world where marketing is oriented towards equipment, machines, device and product performances, etc., we will talk about people. But first, in order to set up the proper background, let me start at the end.

WHAT ARE MIXED-SIGNAL DEVICES?

Mixed-signal is a generic term used to define integrated circuits (IC) with a substantial level of analogue functionality. This definition is rather broad. If one cannot define complete functionality of an IC using binary mathematics then you probably have a mixed signal IC. Of course in the strict sense even a logic NAND gate is an analogue function, but for the purpose of our discussion we will avoid this confusion.

Because of their increased analogue functions, mixed-signal devices are usually manufactured using dedicated CMOS or BiCMOS processes with several features added to the basic standard (Bi)CMOS process. These features typically include double poly-silicon capacitors, some form of linear resistors (usually made with poly-silicon), high-voltage CMOS transistors, maybe EEPROM and a variety of threshold for the basic CMOS transistors. Some other exotic components can be found, but we will exclude them from this discussion.

The "simple" resistors and capacitors used in mixed-signal process are in effect quite complex from a manufacturing and from a performance viewpoint. Resistors have non-ideal matching, size non-linearity, sensitivity to the proximity of other materials/resistors and the obvious resistance non-linearity as well as parasitic capacitance. The latter non-ideal characteristics of this list are easily handled, the first ones are subtler. Capacitors are a little simpler yet can run into unsuspected problems at high frequencies and the parasitic substrate capacitor can also bring some surprises.

The transistors (MOS) used in mixed-signal products are of course very important and in fact are sometimes overlooked. Being often simply taken as is from the digital version of the same process, they can lack desirable characteristics, like good matching, low substrate currents (from avalanche at the drain), threshold voltage control, low level leakage, etc., not to mention appropriate SPICE analogue modelling.

As for bipolar transistors, beside the normal parasitic substrate transistors which have their collector tied to Vdd (for NPNs) or to Vss (for PNPs), designers like to make use of at least one bipolar transistor with a collector which can float between Vdd and Vss. This is usually achieved by adding one base implant and using the proper CMOS drain implant for making an emitter, the well becoming the collector.

All the components above have to be accurately modelled in SPICE to provide the designer with optimum manufacturing. This modelling best includes variability factors to take into account across wafer, wafer to wafer and batch to batch variations as well as matching data.

With such a variety of components on the same silicon, designers can really make area efficient mixed-signal designs; well, at least in theory; in practice, several problems can reduce yield, and the quest for the culprit can be quite challenging!

IS THERE A PROBLEM?

Historically, besides the obvious market demands, companies have often introduced mixed-signal processes into older fabs as a mean to prolong their life. A noble gesture, which has its obvious economical benefits. From a practical point, the usual knock-knock-product-is-ready-do-we-have-a-process-yet situation often arises. Because of the urge to put together something which works for now (the product), we have to cut corners in getting from point A to point B (the process).

Understand me right, this is the nature of the business and often the difference is made in how smart you are at cutting corners. One hidden difficulty is that in such a situation the engineering staff has to do a lot of learning about the physics of both the basic component and the manufacturing of such components. I would like to suggest that developing a good mixed-signal process requires as much effort as developing a good digital process, even if you already have a good digital process.

Typically, good mixed-signal processes run one or two generations behind the digital processes. This interval corresponds to the time required for digital fabs to stop being profitable and to be converted to mixed-signal operations. It also takes some time to put together the analogue options in a mixed-signal process for fabs which only do mixed-signal processes. So, as far as feature size is concerned, mixed-signal processes will always lag behind. Digital processes are put together with emphasis on high density, low defect densities and high manufacturability. Mixed-signal processes are often just put together on top of an existing digital process. Thus the integration engineer is faced with a greater number of fixed boundary conditions, making his task more challenging. Even in the simpler case of adding a few options to an existing mixed-signal process, the challenge is substantial.

Let us summarise what we now understand: The additional components of mixed-signal processes are themselves very complex features. Processes have a swift development cycle. Engineering is in a learning phase. The probability is that we won't get everything right the first time, or maybe even the second time.

"HOUSTON, WE HAVE A PROBLEM"

We now have a product running on a process, or maybe it limps on a process. Because of the history behind mixed-signal processes their yield problems are inherently different from yield problems on digital products. This means fewer of the digital yield problems, i.e. boring particle hunts and so on, but a substantial number of newer problems associated with the newer analogue components or with the demand being put on these components. Basically you get to learn what you did not know the hard way. Believe me, learning is a never-ending process! After a while, digital problems just completely cease being an option.

Let us resume: why are mixed-signal yield problems often subtle?

Because:

a) Mixed-signal processes are usually mature technologies in which the obvious problems have been resolved a while ago.

b) Mixed-signal products are susceptible to problems, which would not affect a digital product.

c) Component characterisation is often incomplete and integration is a very complex matter.

IN NEED OF A SOLUTION

When a yield problem arises in a mixed-signal product it really comes down to people to resolve the problem. There is no machine, or software, which would tell us what the problem is; otherwise this tool should really have been used to prevent the problem. There are tools that can help diagnose the problem, but people must first suspect the problem. These mixed-signal product problems are often linked to components (resistor/capacitors/transistors/etc.) which do not behave as expected.

The essence of this kind (and many others) of problem resolution consists in identifying the nature of the problem itself, understanding how it happens and resolving it. These three steps are really under people control. How fast and how completely people can resolve these technical issues makes a big difference in a team's ability to progress quickly in mixed-signal technologies.

What are the skill sets required to efficiently do this kind of work? I was going to write "The very first skill is teamwork", but actually the first three skills are teamwork, teamwork and teamwork. The fourth skill is intelligence, team intelligence and individual intelligence. Mixed-signal yield problems are basic cases of complex problem resolution; bright people fare well at problem resolution by definition, but because of the complexity of mixed-signal yield problems resolution they must also fare well at teamwork.

The greatest challenge in mixed-signal yield improvement is finding out what is the problem. To achieve this, the team must work its way from the first operation where the problem is noticed back to the operation(s) which cause the problem. This often involves many very specialised fields. In a typical case it could start with verifying wafer test program, testing hardware, ensuring that the problem is really on the wafers! Secondly, identifying the exact component causing the problem (transistor, resistor, etc.). Then understanding what in the process is causing this problem (photolithography, diffusion, design, layout, etch, deposition, etc.), and finally implementing a solution which will ensure that this problem never shows up again; because, we don't want to go through this work again.

Once the problem has been identified, we want to break the "problem chain". The problem chain is the sequence of events rendering a problem possible. The problem chain can be represented by a series of AND-conditions. For example, if a threshold matching problem is caused by doping striation in the substrate (striations are short range ~100 microns doping variations due to oscillations/non-uniformity in the crystal melt during Czochralski growth). The problem chain could be: starting material with striations AND light well doping AND transistor layout AND too small transistor size AND incomplete transistor characterisation AND differential pair input EQUALS our problem.

Preventing any of the conditions in this sequence will prevent this problem from happening again. Of course, one has to carefully choose which is the best way of breaking the problem chain. Failure to do so could cause even more serious problems. The level of complexity in semiconductor manufacturing is very high and one characteristic of this complexity is that manufacturing parameters are closely inter-related. Very often changing one parameter in the problem chain will result in other changes to the manufacturing process. During the effort to reposition the process as close as possible to where it was, except for the problem we are trying to resolve, it is therefore important to be aware of not causing new problems.

TEAM WORK

Why is team work so important when trying to resolve mixed-signal yield problems? Simply put, there is just too much knowledge involved in identifying the problem and in resolving it. It is just impossible for anyone to know all that there is to know in the process resolution exercise. It is, however, important to have people who can "speak" the language of all the various fields involved and maintain optimum levels of communication between team members.

Such people are often natural leaders. They will help maintain focus amongst the team members and always carry the "big picture" with them. As key team members they will focus on positive contributions from other members who are often specialists in their field. The team process is important; it must allow proper dissemination of information to all members. In a sense it is a great learning experience for all team members, with a purpose; solving problem X. As for more junior team members, this experience can be a real booster!

The team process is oriented on information sharing. This is the key. By putting your best people together and giving them an environment where a maximum of information about a problem is available, the solution(s) will often come very easily and rapidly. Not everyone is naturally a good team player, nevertheless, such people hold knowledge which can hold the key to resolving problem X. Let these people participate in the team meeting once in a while, maybe not all the time. They will feel valued and whatever negative aura may surround them will quickly dissipate. Forcing people who are not natural team players to participate in a team process will impose an unnecessary strain on the team, taking energy away from the problem resolution process. Be good to people.

Do you need help from the outside? Bringing in a consultant, either internal or external, can bring new energy. However, as someone coming from the outside, the consultant has to respect a few important rules/qualities:

a) Think of yourself as a catalyst rather that the final solution

b) Be clever, very clever; be modest, very modest

c) Give plenty of credit to the other team members

d) Be able to come from the outside and become a team member in a very short time

e) Do a fair bit of work yourself

f) Don't be afraid to fully expose your knowledge, and limits

g) Ability to think outside the box

h) Have experience, because problems do repeat themselves, and finally

i) The ability to question people about their work without questioning their work!

As an external resource the consultant is expected to gently orient the team towards problem resolution. Of course he may already know the solution and then the team process is somewhat lighter. But in most instances he brings knowledge and positive energy to the table as well as a transmissible desire to learn. His remote position often offers the benefit of being able to judge the end requirement of complex technical situations.

CONCLUSION

Through several years of problem solving I found that knowledge of both device physics and manufacturing physics are the two most important technical assets in doing mixed-signal yield improvement work – after people skills. People skills will get you the technical information required to resolve a problem. Personally, I certainly did a lot of learning in this respect and plan on continuing. It is certainly very challenging to try to know everything about everything, but it is impossible to be a specialist in everything. Of course, to resolve technical problems you need a certain level of problem solving abilities, to be able to differentiate symptoms from problems; a bit of luck and intuition does help as well. But overall, teamwork makes the difference.

ABOUT THE AUTHOR

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