High-performance RF design for PXI

By John Wells and Lance Day

PXI presents a significant opportunity for RF instrumentation. It also presents a significant challenge. This compact modular format offers users the opportunity to configure high-performance test solutions in a fraction of the space needed for traditional equipment. John and Lance discuss in this article how Aeroflex met the challenge to design high-performance RF instruments in the PXI format without compromising quality.

Aeroflex made the decision to investigate PXI as a viable platform for modular RF instrumentation because PXI offers significant benefits. It extends well-established electrical and mechanical specifications, offers a rugged and high-speed environment for test system development, and costs a fraction of that of other modular instruments.

Conducting a trial

At the outset of the project, we were uncertain about how best to develop high-performance RF designs within the confines of PXI. Before committing to full development, we conducted a trial using a synthesizer module to see if there were any insurmountable pitfalls. The target specification included a level of performance typical of rack-and-stack signal generators:

- 1 Hz frequency resolution
- –116 dBc/Hz phase noise (20 kHz offset)
- < –150 dBc/Hz noise floor

These specifications embody some severe requirements for signal cleanliness. The prototype was successful and became the Aeroflex 3010 RF Synthesizer module. With this initial success, further development yielded the Aeroflex 3000 series of PXI modules, which are shown in Figure 1:

- 3020 Digital RF Signal Generator
- 3030 RF Digitizer
- 3060 RF Combiner

Instrumentation challenges

Instrumentation has always presented a unique set of design challenges. Unlike the systems they test, instrument system and circuit parameters must be calibrated very accurately. For example, the front end of a receiver merely has to have enough gain; the exact amount is not critical. A similar block in an RF signal generator or measuring receiver has to have exactly the right amount within a fraction of a decibel. Level accuracy of the entire instrument may be only ±0.5 dB over a range of some 125 dB, and any new platform, such as PXI, cannot afford to compromise this accuracy. In addition, the traditional boundary between RF and microwave frequencies is increasing steadily. Today, not many frequencies below 10 GHz meet the definition of microwave, with the possible exception of kitchen appliance frequencies.

In the instrumentation field, RF has always presented difficulties of its own. Issues like ElectroMagnetic Compatibility (EMC) are never far away, and effective screening is a prerequisite. Design of RF instrumentation has traditionally been a conservative discipline. A classical 1980s rack-and-stack signal generator could weigh in excess of 40 lbs, and much of this constituted metal associated with screening. Actually, screening requires a small amount of metal, per se. However, we encounter a vicious circle in which screening adds weight, which requires support, which in turn adds more weight. Add to this a degree of Luddism coupled with the fear of failing to meet EMC specifications, and we have the ideal recipe for an over-engineered product.

By contrast, mobile phone designers have the opposite agenda. A bulky product would not only fail to sell but would also be the subject of ridicule, whereas the public might not notice some specification shortcomings. This is not to

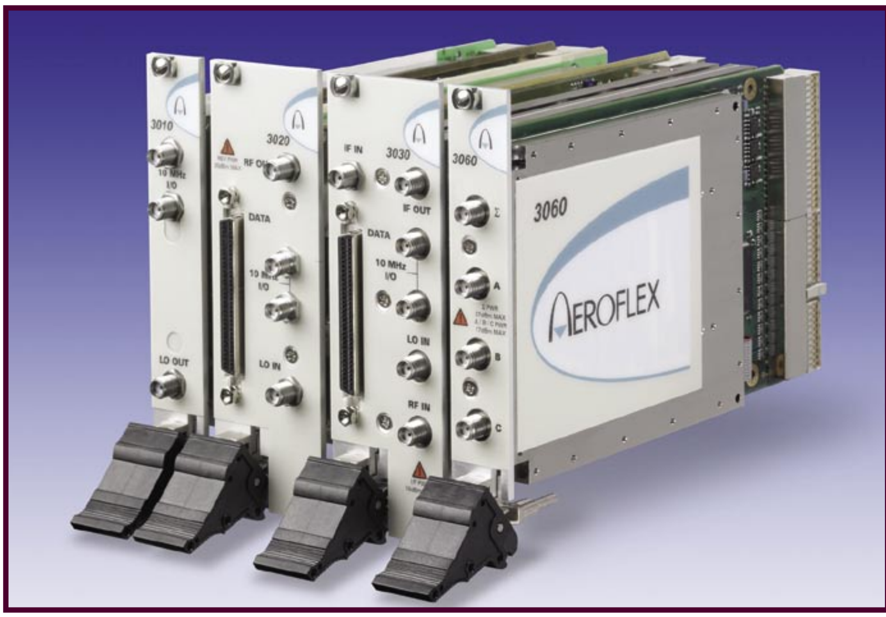

Figure 1

say that such a product is under-engineered, but it is merely subject to a different emphasis. For an RF-based PXI initiative to succeed, it is necessary to dispel the myth that things must be big and heavy to perform accurately. At the same time, we must avoid the risk of shifting the design focus to the point of compromising performance.

PXI advantages

Apparently, a fresh look at the design and packaging of RF instrumentation is well overdue, and PXI provides a perfect platform to do just this. Working within the bounds of the PXI standard is useful because it sets strong goals and constraints on engineering. Space and power constraints force the designer to produce power-efficient designs with the minimum number of components from the outset. There is no room for sloppy design, and the amount of mechanical design and reinvention is minimal.

Overriding some limitations

As an envelope, PXI is not ideal. Like all card frames, the mechanical design supports standards engineers established in the 100-percent-leaded component era. Even today, we talk about the component side and the solder side of the board. One such disadvantage is the position of the card within the module slot. The rear of the PCB is only 2 mm from the module separation plane. There is only enough space for low-profile passives and SOCs or screening, but not both. If the PCB slot carries the RF circuitry, it will have to be single-sided. If this is the only board in the module and it requires no bulky topside components, then the remaining slot width is under-utilized. The designer can use this space by adding a mezzanine board within the module, which can also be a good way of segregating control and RF functions.

Another major limiting factor is the front panel. Basically, there isn't enough of it. Required high-frequency RF connections will probably be SMA, which will be adequately durable without being too large. However, accommodating these connections does require some skill. The designer must provide a well-matched transition from connector to PCB, while maintaining an extremely high level of screening integrity around the connector, the board, and the front panel. Interconnection for overall digital control is via the PCI bus. However, in the case of real-time data, such as a digitized baseband signal, it is difficult to avoid adding a dedicated connector. It is imperative that the designer considers the layout of the cables that will mate with these connectors. Otherwise, it will be impossible to make all the connections. Hopefully, these issues are ephemeral with new standards evolving for achieving wideband interconnection in a small space.

The requirement for a high-quality frequency standard throughout the RF test system places additional strain on the front panel. The PXI backplane provides a 10 MHz standard, and a non-controller module, if necessary, can source this. However, the necessity of using a busy multilayer backplane crammed with data and power supplies will almost certainly degrade the standard, making it unacceptable, especially for the purposes of frequency synthesis. We, therefore, need to find front panel space for additional SMA connectors to provide a coherent frequency standard to all parts of our test system.

Power supplies require careful management, which is good because it helps to avoid thermal problems later on. PXI provides copious amounts of power per slot at 5 V and 3.3 V, but only 0.5 A at +12 V and a mere 0.1 A at –12 V. The specification does allow some latitude. For example, a rack manufacturer may elect to provide more current per slot than the statutory minimum. Similarly, a module may consume more than the minimum if the specification clearly states this, although most standards do not encourage such practice. All power rails originate directly from the rack's switch-mode power supply, so they are neither clean nor stable, at least not in instrumentation terms. Some form of sub-regulation is imperative for any rail that directly processes RF. The lack of current at +12 V has not proven to be much of a handicap, as many of the latest RF device families can run at very low voltages. So even with sub-regulation, a +5 V rail is plenty. However, there were one or two instances where a full clean +5 V was unavoidable, and this was provided locally by first boosting the +5 V then using linear regulation.

Finally, there is the issue of the backplane and PCI bus as possible interference sources. In the case of the synthesizer module, using only a single PCB, the approach is to treat the front and rear of the module as two distinctly separate subsystems, providing the analog and digital grounds respectively. Some degree of electrical connection still exists between these two sections but is restricted to filtered power and a medium-speed serial interface between the PCI interface and the core synthesizer controller. The predicted synthesizer switching speed is 200 µs, and the speed of the serial interface is more than adequate to meet this requirement without compromise, while still acting as an RFI filter.

For modules comprising more than one board, such as the 3020 RF Signal Generator, this separation is more straightforward, splitting the unit into two PCBs. Only static (parallel) binary controls, analog baseband (12 MHz in the case of the 3020), leveling control signals, and power supplies link the two PCBs. With the 3030 RF Digitizer, the architecture is split into three PCBs: RF, IF, and digital. It is worth noting that the fully screened RF PCB employs the mezzanine approach, allowing the module to occupy only two PXI slot widths with more efficient use of space.

IP solutions

All PXI modules require an interface to the PCI bus. A great many interface devices are available off-the-shelf, all of which strive to offer a comprehensive solution. This setup typically entails a wide local bus I/O system coupled with various serial bus solutions and all manner of bells and whistles. This configuration can lead to a large pin-count, which is fine for BGA-capable PCBs, but for a single PCB it is preferable to keep copper layers to a minimum for high-performance RF design. Coupled with the inevitable glue-logic of any digital RF interface, this configuration can lead to physical sprawl in digital designs that will ultimately limit the space available for RF circuitry. Fortunately, a number of IP solutions are available for configurable logic that enable integration of fully compliant PCI interfaces into devices such as Field Programmable Gate Arrays (FPGAs). Not only do these solutions allow the same physical device to absorb all back-end logic, but they also allow designers to opt for the package that is just big enough for their pin-count needs and no more.

Device implementation and packaging tools

Throughout the eighties and much of the nineties, RF device technology appeared stagnant. New devices were slow to appear and circuit functions like IQ modulation were especially difficult to implement. In the case of instrumentation, it was very difficult to simplify and integrate the RF parts of the design without sacrificing performance to an unacceptable degree. By contrast, integrated circuit platforms have been developing steadily, and digital applications have always been the first to benefit. However, the dam has now burst with all manner of RF functions appearing in integrated form, fuelled by the demands of mobile communications. Two other factors have undoubtedly played a part. One is device packaging, and the other is the creative input from the fabless design houses. They have the freedom to innovate and adapt processes to applications far removed from their original aim. Not all of this innovation is readily applicable to instrumentation; the circuit functions are often too highly specialized. Nevertheless, designers can leverage a lot of it.

While component technology has greatly assisted engineering of PXI, modern design tools have not. CAE packages aim toward big-concept, top-down design, and the environment they engender can be quite intimidating. The doctrine, if followed fully, is to do system design and behavioral modeling, partitioning and generation of requirements specifications, followed by circuit design and tolerance and yield analysis, all within the CAE envelope. Traditionally, designers would build test pieces to evaluate actual circuits. Only then would anyone start to think about the overall mechanical design and layout within the product. This approach is all very fine if the designer has plenty of time and money for CAE licences, and a spare corporate division at their disposal. Even printed circuit layout tools can be infuriating when trying to optimize an RF layout. Modern packages are heading towards auto-everything, and insist that engineers meet every design rule at every stage as they edit and manipulate the layout, which can make getting from A to B a nightmare. Perhaps RF engineers can take some comfort in the knowledge that machines simply cannot replace them, at least as of yet.

Our design approach

The design approach Aeroflex has taken is hard to define rigorously, which is good. A design team should be flexible at the outset. First, we assessed the latest and most promising useful components and building blocks. Components had to be easy to pick and place, and there had to be a very good reason for doing anything that required special assembly techniques. This constraint also tempered the target specification. Next, we evaluated system designs while simultaneously appraising their impact on layout. While considering the impact on the layout, we designed detailed circuits. Where necessary, utilizing unconventional circuit topologies, we completely redesigned circuits, such as filters, to achieve a different aspect ratio to suit the evolving layout. In this respect, low-level linear simulation was invaluable. Final layout and prototyping of the full design came next, skipping the subcircuit prototyping step. Pushing on with the whole design was considered more important than ironing out wrinkles in individual circuits, only to be caught by unforeseen layout interactions later. Where necessary, sub-circuits were tested in situ without the need to make any special test-pieces.

Testing is extremely important. To facilitate initial work, we constructed dedicated test jigs that eliminated the need to have the unit under test mounted in a rack. These comprised a frame with a small backplane and interface that we could use with a desktop PC. These test jigs resembled *pinball machines,* as we so nicknamed them. Additionally, we made provision in the designs for a reasonable degree of in-circuit testing without unduly compromising the designs. However, we avoided early implementation of this provision. In-circuit testing generates a considerable amount of baggage in the form of dedicated fixtures and test programs, which discourages subsequent design improvement or any other beneficial change. Flexibility remains paramount.

Successful migration to PXI

The results of these practices and general way of thinking have been remarkably successful at Aeroflex. While designers today would scoff at the mantra of "get it right the first time," we kept all iterations in our design to very manageable levels. By applying this reasoning, we were able to migrate high-performance RF instruments to the PXI platform. For the Aeroflex 3000 product series, the resulting specifications compare favorably with their larger cousins, proving that high performance no longer means big and heavy.

__John Wells__ is chief RF technologist and __Lance Day__ is a principal design engineer with Aeroflex, Stevenage,

England division. Both are involved with PXI product design and development at the company.

For more information, contact Aeroflex directly.

Aeroflex Inc.
35 South Service Road
Plainview, NY 11803-4193
Tel: 516-694-6700
Fax: 516-694-4823
E-mail: info-test@aeroflex.com
Web site: www.aeroflex.com