DESIGN OF A BROADBAND DOWNCONVERTER / DIGITISER IN A PXI MODULE

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Abstract - **This paper describes the design and implementation of a 6 GHz extension to a 3 GHz RF digitiser in PXI technology. The features of the PXI format that affect the design are considered. The available RF design options are discussed, and the final design solution is presented, with results.**

Introduction

The manufacturing market makes different demands of its equipment than do the development or service markets. As well as the obvious performance and cost targets, high speed is usually very significant. Small size is also valued and, as most manufacturing test equipment finds its way into automatic test systems, a comprehensive front panel changes from being an asset into a liability.

These considerations all push in the direction of modular instrumentation. While VME/VXI has made its way into some military systems, it has not made any significant inroads into commercial systems. PXI is now growing quickly as a modular standard, and proving much more acceptable to commercial users than VXI. Amongst its advantages over VXI are the smaller form factor, lower cost, higher basic speed and being based on a standard PC platform.

PXI features

Designing in any modular format, PXI especially, has both advantages and challenges. Many decisions do not need to be made: what power rails, what size, what software architecture, how to cool. Challenges include fitting everything into the space, and powering it from the available rails.

Apart from the small size, the most serious constraint is the power. As PXI is based on PC power supplies, there is some +12 V, less –12 V, and more +5 V and +3.3 V than you could possibly want. This is a novelty to instrument designers used to running everything from +/-15 V rails. Fortunately, mobiles and micro-basestations have created a huge market that demands low power, low cost, small size components; higher f_T processes and innovative packaging are delivering those parts. As a result, many RF functions can now be performed with a 3 V or 4 V supply, which can be linearly regulated from the rack 5 V. Where a clean 5 V is required, we boost the 5 V supply using a forward converter, which generates far less EMI than a switch-mode converter, to generate 6.5 V for regulation to 5 V.

As PXI is based on compact PCI, the modules are truly PC peripherals. The tight coupling between the modules and the PC afforded by the PCI bus allows for high speed data transfers directly into the top level application, replacing the need for dedicated DSP microprocessors in many cases. The standardised module software interface allows users to modify or replace the supplied top level PC applications with their own custom "instruments". The PC hardware can be upgraded to the latest and fastest.

The specification

The specification was for a 330 MHz to 6 GHz RF digitiser, having the same dynamic range as our existing 3030 3 GHz digitiser, ideally fitting in the same size module. Of course development time and risk, and manufacturing cost should be minimised.

The existing RF digitiser

The RF digitiser consists of a 3030 single stage down-converter and IF digitiser, with the local oscillator provided by a 3010 octave synthesiser. This illustrates one advantage that is available immediately from embracing the concept of modular instrumentation. The 3010 synthesiser is used "as is" on our RF source products. It will also stand alone as a low noise fast switching 3 GHz synthesiser.

The 3030 consists of three cards. The first is a logic card, interfacing with the PXI bus, with a large memory for waveform storage and a large FPGA for real-time DSP. The second comprises the IF amplifier, anti-aliasing filter and digitiser.

Figure 1 – The existing RF digitiser

The third card mixes the RF input down to an IF. It contains the input attenuator and the LO dividers to reduce the octave LO received from the 3010 synthesiser. Rogers 4003 material is used to allow a conventional SMD board construction, this sits within a modified clamshell. This modification allows the pins of the front panel SMA RF sockets to lie on the top surface of the board, to make a good transition onto the microstrip RF tracks.

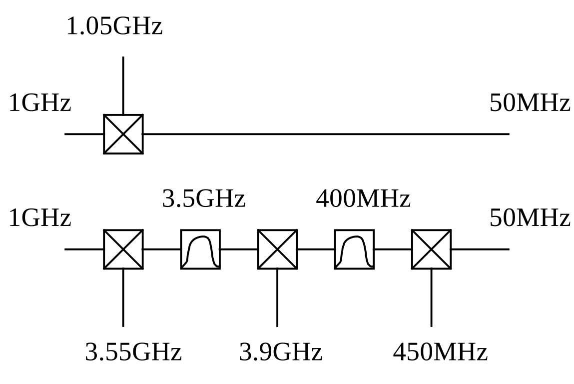

Figure 2 – Single and multiple conversion front ends

The RF down converter uses a single mixer. This architecture was chosen over the perhaps more usual superheterodyne spectrum analyser architecture for a number of reasons. Having only a single stage of mixing instead of multiple stages gives several advantages

a) better level accuracy
b) better dynamic range
c) lower phase noise
d) much smaller form factor
e) more flexible frequency plan

These are exchanged for the obvious disadvantage of the spurious mixing image 2*IF away from the tuned frequency. This architecture is a feature of modulation meters, whose use is well established in manufacturing. Manufacturers understand what they need to do in their well-controlled test environment to avoid problems from this image. The advantages of cost, size and particularly level accuracy that accrue outweigh this disadvantage.

Design options

It made sense to design a new RF card to be compatible with the existing digitiser and logic cards, as these functions would be identical. It would also make sense to at least consider re-using any of the existing down-converter card.

The first option that was considered briefly was to use block down-conversion in front of the existing 3 GHz mixer. This has the advantage that the existing 3 GHz path is unchanged. Stacked against this route are the requirements for another local oscillator (albeit just a few fixed frequencies) and a second stage of mixing with the degradation in dynamic range and level accuracy that would ensue.

The next option was to replace all of the 3 GHz components in the down-converter path with ones that were good to 6 GHz, and to double the existing 3 GHz LO up to 6 GHz.

Amplifiers and attenuators that did not exist only a few years ago were now readily available as catalogue items from companies like M/A-Com and Watkins Johnson. However, mixers were more of a problem. Nothing was available that was specified to operate down to 300 MHz as well as up to 6 GHz. Some mixers came close, but those that did were usually physically large, or low drive level with small dynamic range, or very expensive, or a combination of all of those.

One route to a solution to the mixer problem was to have one developed, either by an existing mixer supplier, or in house as a development of our IQ modulator technology (see A. Jones, ARMMS November 2004). This route would increase the development risk and timescale, so was not the leading choice.

The final option, and the one that was eventually chosen, was to use a second mixer to cover the 3 GHz to 6 GHz frequency range, operating from a doubled local oscillator, and converting down to the same IF. This option had a number of advantages. The dynamic range and level accuracy advantages of single stage down conversion were retained. Many mixers were available in the 3 GHz to 6 GHz band. Having separate mixers allowed the RF and LO paths to be banded, easing the flatness requirements of each.

Modification to the existing board

The SMA input transition required a little retuning for best VSWR to 6 GHz. The RF input attenuator was replaced with a 6 GHz component. A new 6 GHz amplifier was followed by a switch to route the signal to either mixer. The 3 GHz path is essentially unchanged from the 3030, apart from a more thrifty use of board area.

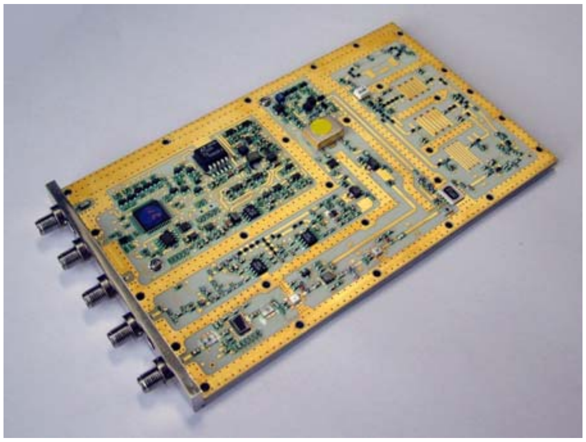

Figure 3 – The 6 GHz RF downconvertor board

The most significant function in terms of area on the new board is the LO doubler. This is based on the HMC158 integrated doubler from Hittite. Conventionally, one would fit a balun transformer and a schottky diode quad. However, once the matching and assembly of these has been considered, the single purchased part wins on design time, assembled cost and size. The drive level for this doubler was +17 dBm, conveniently the same as the LO drive level for the 3 GHz mixer. This enabled the same signal to be switched to either the 3 GHz mixer, or to the doubler. In a rack and stack instrument, each of these functions might be given their own drive amplifier, however in PXI one is always on the lookout for ways to save space and power.

The performance of any doubler becomes unpredictable if fed from a source with significant second harmonic. The doubler was therefore preceded by two half-octave low pass filters, covering 1500 MHz-2100 MHz, and 2100 MHz to 3 GHz. These use printed inductors, and discrete and printed capacitors, and are switched by PIN diodes.

The performance of any mixer degrades, usually shown as increased levels of intermodulation distortion and spurious responses, if the LO contains sub-harmonics. The doubler was therefore followed by three printed inter-digital third-octave bandpass filters, covering 3 GHz to 3800 MHz, 3800 MHz to 4800 MHz, and 4800 MHz to 6 GHz. Again the filters are switched by PIN diodes.

The mixer is provided with a +17 dBm LO from a MGA-82563 amplifier. This is a recently available low voltage component ideal for PXI, able to produce +20 dBm output power from a 3 V supply.

Results

An RF Digitiser covering 330 MHz to 6 GHz
Occupying 3 slots in 3U PXI
Typical 0.3 dB level accuracy
75 dB spurious free dynamic range
75 dB intermodulation free dynamic range
Noise spectral density < -145 dBm/Hz
20 kHz offset phase noise typically
  –116 dBc/Hz at 2 GHz and
  –108 dBc/Hz at 5 GHz
3GPP ACLR of 68 dB (uplink)
3GPP ACLR of 63 dB (downlink, test model 1)
1024-pt FFT typically 1 ms in a 2 GHz P4

Conclusions

This paper has presented the design and implementation of a 6 GHz extension to a 3 GHz RF digitiser in PXI technology. The available design options were discussed. Examples were given of the way the PXI format affects the design, and some new components and novel methods for working with these.