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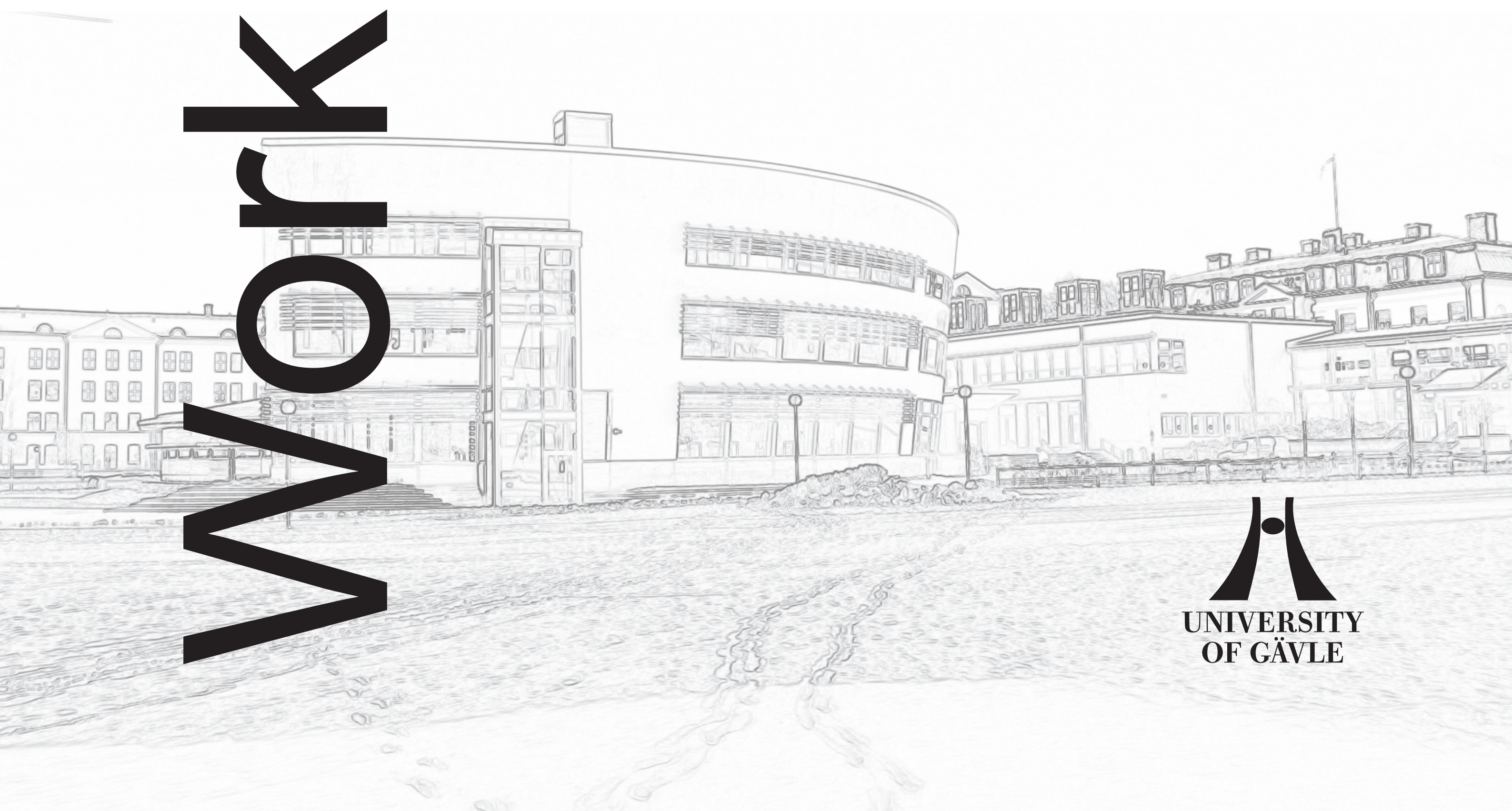
David Wisell, Patrik Stenvard,
Anders Hansebacke, Niclas Keskitalo

Considerations when Designing Virtual Instruments



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Considerations when Designing Virtual Instruments

David Wisell, *Member, IEEE*, Patrik Stenvard, Anders Hansebacke, Niclas Keskitalo, *Member, IEEE*

Abstract—**In this paper the software and hardware structure of a virtual instrument measurement system is discussed. The focus is on flexibility, modularity, generality and hardware independence. A software architecture that meets these requirements is proposed and discussed in some detail. The proposed software architecture has a layered structure that makes it suitable for implementation of versatile measurement systems. The measurement functionality is encapsulated in its own, hardware independent layer and communicates with its environment, e.g. physical hardware, through intermediary software components. Finally a measurement system for characterization of power amplifiers that is designed following the proposed software architecture, with software driven measurements, is implemented.**

Index Terms—**software driven measurements, software architecture, synthetic instruments, virtual instruments**.

I. Introduction

The rapid development within the field of measurement methods and techniques and software (SW) design that has taken place over the last years offers new possibilities for designers of measurement systems through the use of virtual instruments (VIs) as building blocks. The concept of VIs is developed within the Interchangeable VI foundation [1]. A closely related term is "synthetic instruments" (SIs), which is often used for essentially the same concept. In this paper we will consistently use the term VI, or VI concept (VIC), but more or less all reasoning and discussions apply to SIs as well.

A VI is here defined as a combination of hardware (HW) and SW into a reusable building block, where the results are presented on a computer screen rather than on a display, with the intention to create maximum flexibility. The idea is that a VI must add some functionality when compared with traditional instrument, not just being cheaper. The first generation of VIs differs from the traditional instruments mainly by being operated from a computer program with a graphical user interface (GUI), rather than from a front panel [2].

The 2nd generation of VIs described here can be used both as standalone instruments or, which is more important, as reusable building blocks in virtual measurement system designs. They are in this respect more like the SIs described in [3]. It should be noted that a 2nd generation standalone VI is not a first generation VI, since a 2nd generation VI may combine functionality from several HW and SW modules while a 1st generation VI is merely a standard instrument controlled from a GUI rather than from a front panel. Since all functionality is implemented in SW we here propose to use the term SW driven measurements (SDMs) for the content or functionality of the VI.

The reasons for using VIs as building blocks when designing measurement systems, rather than traditional instruments, or 1st generation VIs, are several. It makes it possible to combine the functionality of many pieces of HW into one VI having a new functionality that would be difficult to realize if HW parts were used separately. This VI can then be used as a building block to design virtual measurement systems that can do much more than just presenting the functionality of a piece of hardware on a computer screen. Those virtual measurement systems can then be used in an R&D lab or in production testing, communicated with, and connected to a network and operated remotely, for example over the internet, just as traditional instruments.

The use of reusable building blocks gives the system a high degree of flexibility and they can therefore be optimized for the specific application and easily extended or upgraded. It will also be possible to shorten the development time of the measurement system, which is useful in many situations, such as test development for production testing. This could be a vital asset for decreasing time-to-market. Analogous, the design department can benefit from easier and faster measurement system design.

A VI can include traditional instruments as HW building blocks, but usually this leads to a redundancy and/or limited degrees of freedom.

For many applications where the performance requirements are modest, the different pieces of HW that are needed in a system can be fitted into a PC resulting in a small, flexible and versatile measurement system.

For more demanding applications however, like radio frequency (RF) measurements, the HW may be realized with traditional instruments in some cases, but a trend to miniaturization is visible also in this area. High performance solutions both in LXI and PXI standards have started to emerge.

Such a system will also have an increased flexibility since different parts of a traditional instrument will be on separate LXI modules or PXI boards that can easily be changed and upgraded. The HW issues are further discussed in [4] while this paper deals mostly with SW issues.

The basic need and requirement is to have a solution (see Fig. 1) that can be reused as an test/measurement equipment between different sites. (i.e. Lab, Verification, Production, and also other)

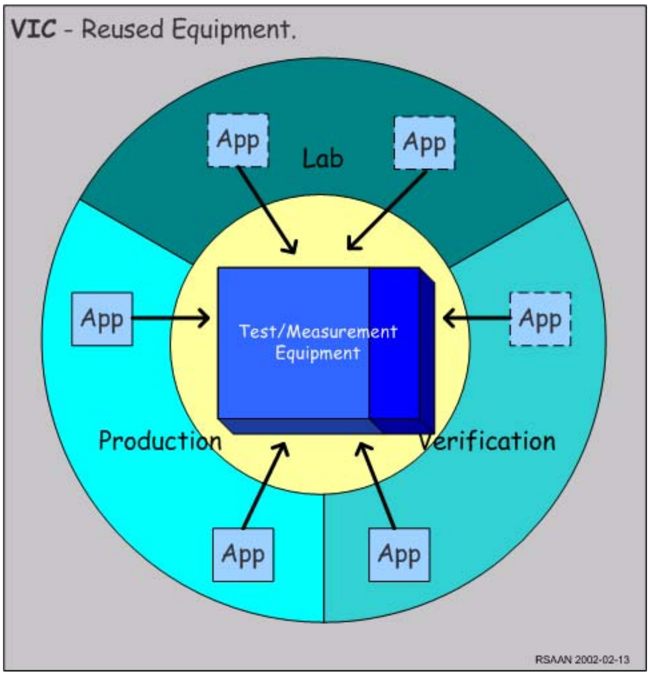

Fig. 1. The concept of reuse. The same HW and VI can be used in many different applications, in the lab, in verification or in production testing.

But also that internally in the VIC have a Software architecture for the VI that also is modular and reusable (as described with the MUL/HAL/HDL/HW structure).

II. Designing a Virtual Instrument Measurement System

The internal design of a VI can be divided into two parts, SW design and HW design.

The SW architecture that should be chosen for a particular VI depends to a large extent of the problem at hand. Words that are central when choosing a SW architecture are generality, flexibility, modularity, and HW independence.

If a system is expected to grow over time, new functionality is expected to be added later, the system is expected to have a long life and it is likely that parts of the system can be reused in similar applications, a high degree of flexibility and modularity is desirable. An example of a flexible SW architecture is shown in Fig. 2. In other situations where none of the above arguments hold a monolithic, inflexible architecture in which all functionality, instrument communication and GUI are compiled into one SW component may be a better choice.

In the flexible solution a component based SW architecture is used, using for example COM or .NET technology [5]. Each component implements a specific interface. It is the interfaces that define the system. The interfaces are independent of the programming language used to implement them. Hence, in principle, any language could be used and different languages can be used to implement different components. The implementation can change, be optimized and so on, while the interface remains fixed. Different replaceable modules can also implement the same interface depending on the application.

In Fig. 2 the measurement functionality of the system has been encapsulated in components that reside in the measurement utility layer (MUL), with one measurement capability in each. The MUL components are HW independent and a MUL component can as well be moved to a simulator environment as connected to HW. Each MUL component is then connected to one or several hardware abstraction layer (HAL) components. The HAL components implement the interface the MUL components need in order to communicate with HW, i.e. set parameters and send and receive data. This implementation can be done in two different ways. Either it can be MUL or HW specific as shown in Fig. 2.

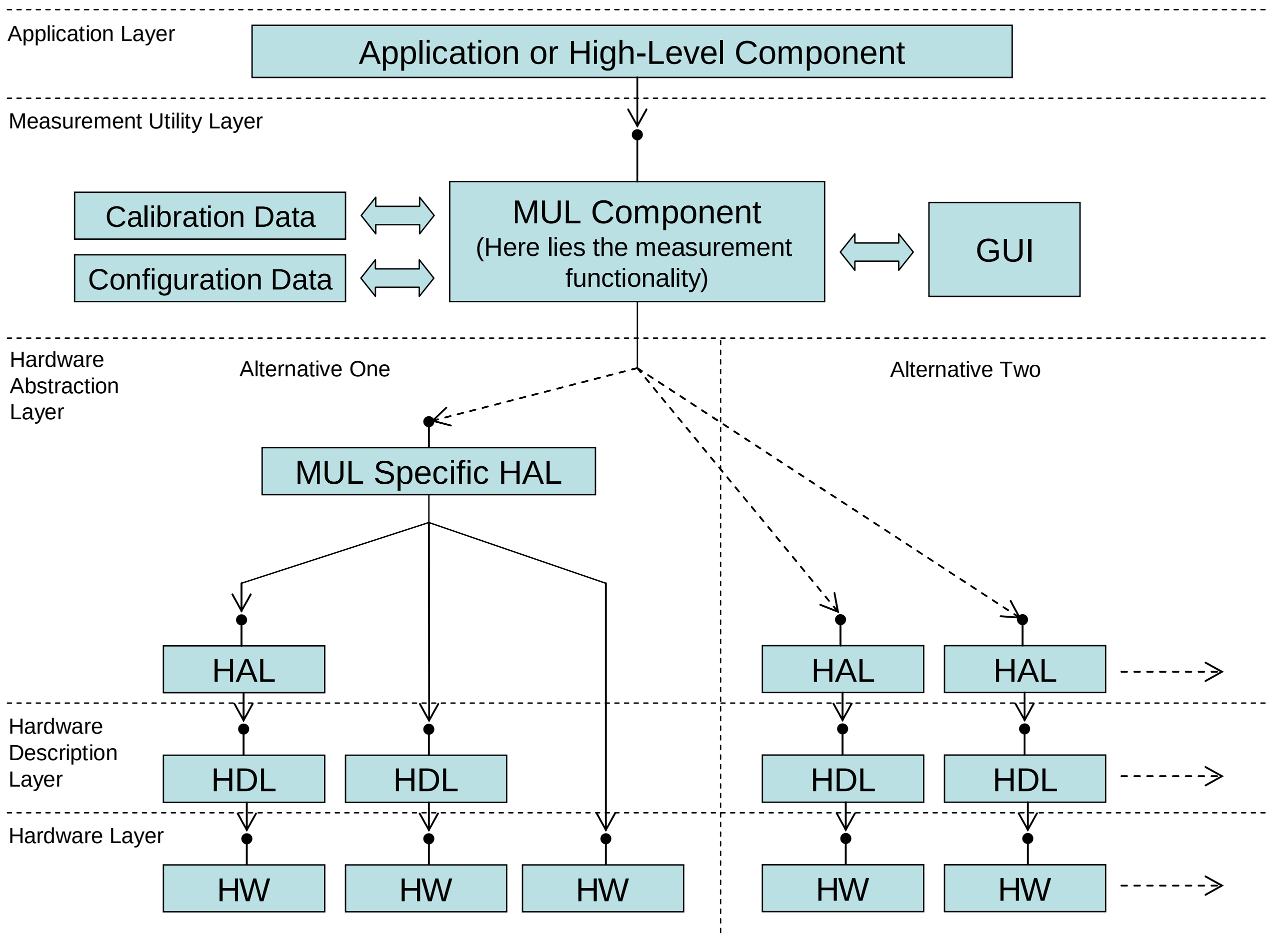

Fig. 2. The proposed SW structure of the VI measurement system. High-level programs, such as test programs, HPVEE, Labview, etc., resides in the Application Layer. The measurement functionality resides in the MUL. The HAL makes the MUL and Application Layer HW agnostic, while the HDL contains HW communication.

The MUL specific HAL component implements the entire interface that a specific MUL component needs and then communicates with one or several HAL components, HW drivers in the hardware description layer (HDL), or directly with a piece of HW using RS232, LAN, GPIB or whatever interface that is available.

An alternative is to let the HAL components correspond to a specific kind of HW, i.e. for example there might be a signal generator HAL interface. All HAL components for different signal generators should then implement this interface.

With this solution it will might be necessary to add a small "helper" component that implements very specific functionality needed by the MUL since that functionality might not be included in the HAL interface for that kind of HW.

It is important to keep in mind that it is the MUL components that hold the functionality of the system. A MUL component can be very general, for example measuring voltage and current or extremely specific, for example measuring a product specific set of parameters in production testing.

A MUL component can also use other MUL components when needed, for example, a high level MUL that encapsulate some complicated measurement functionality may use the simple voltage and current measuring MUL component.

A general MUL component can have a very long life, for example the component that measures voltage and current mentioned above or a component that implements the functionality of a network analyzer (S-parameter measurements), hence outliving several new versions of oscilloscopes or network analyzers. Since the MUL components are HW independent, no changes are needed in them when the HW is changed. Instead any change that is needed is done only in the HAL components. This makes it possible to reuse the measurement capability encapsulated in the MUL component over and over again in different projects at different times and with different HW without having to implement it more than once. This may not be a big advantage in simple applications like the case of measuring voltage and current, but could be a tremendous advantage for complicated measurements.

By combining functionality from different instruments, VIs having new functionality can be designed. Of course, it has always been possible to write a program that communicates with several instruments in order to carry out specific measurements that cannot be done using any individual instrument, but designing a VI for the measurement gives a much higher degree of flexibility and reusability. With the thinking of a packaged and productified VI solution as an complete test/measurement Equipment (VIC), that will as a black-box be similar as a traditional instrument. And thus a VIC can be used from VIs adding new functionality.

Since the MUL contains the functionality of the VI, it will also carry out general calibration routines associated with the VI, for example calibration for S-parameter measurements on a virtual network analyzer. The calibration data are then put somewhere through a calibration interface. The calibration interface can be implemented differently in different cases. In a system having only one VI or in a lab system, a simple component that just saves data to disk could be feasible. In other situations, like production testing, a component that transfers the data to a database may be more suitable. The latter case will also allow several VIs to use the same calibration data.

HW specific calibration, i.e. fixes for specific deficiencies in a particular piece of HW, is best done in the HAL components. The reason is that the MUL should be a general component that should not do different operations depending on the actual HW used. The HAL components on the other hand, know what kind of HW that is used and can then correct for deficiencies in it.

The MUL components are then used by an application. This application could be for example a GUI in the case of R&D, see Fig. 3, which illustrates measurements on a device under test (DUT). The MUL could also be accessed remotely by a GUI or other application residing on a workstation (WS) or PC, Fig. 4, or over the internet, Fig. 5.

A VIC, a complete packaged VI-solution can be used more or less as a traditional instrument, but with some added features:

- Complete local controlled, that will if implemented on an dedicated computer, be as an traditional instrument, turn-key usable.

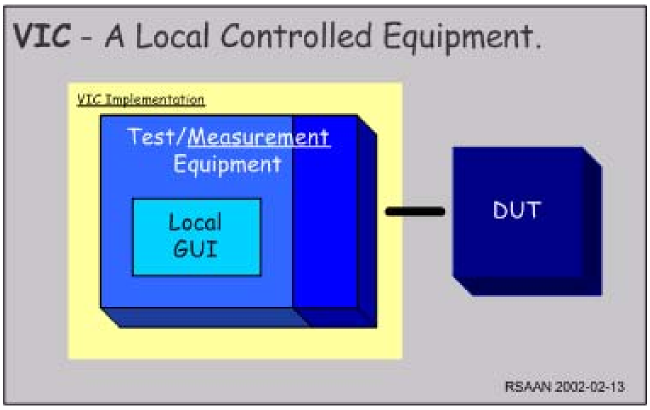

Fig. 3. The VI is operated using a local GUI.

- Having a software interface making it possible to directly communicate with if from other application, for ex. When creating DUT specific test programs.

- Having a specific GUI that can be executed on a stand-alone computer.

The presented solution with VI's and VIC also give us further possibilities to even more distribute the solution, out to more mobile terminals and so on.

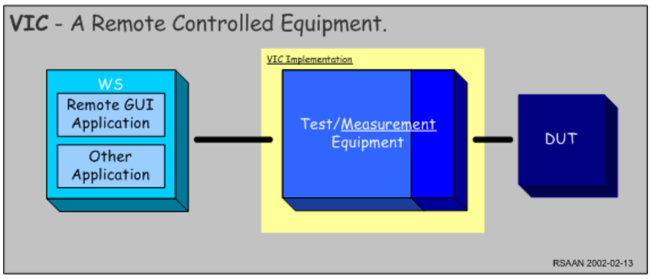

Fig. 4. Remote operation of the VI.

- Possibility to have a WEB-solution where the GUI is operated in a standard WEB-explorer.

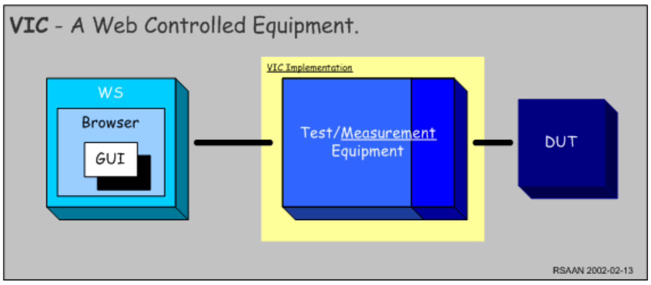

Fig. 5. The VI may be operated over the internet.

- Solutions were the VIC is controlled from different sources at the same time.

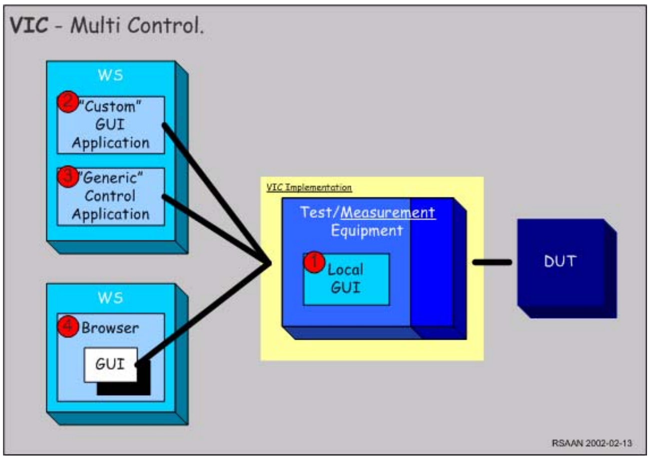

Fig. 6. The concept of multi control. The VIC supports the simultaneous access from several different applications.

It shall here be stressed that the idea is to reuse the same VI, and especially the HW, in many different situations and applications, i.e. the same VI and HW may be used in the R&D lab or in production testing. The concept of reuse is illustrated in **Fel! Hittar inte referenskälla.** and is a basic foundation of the VIC.

Another possible feature of the VIC is the concept of multi control, see Fig. 6. By multi control the access methods of Fig. 3 (local GUI), Fig. 4 (remote) and Fig. 5 (internet) are combined. The interface of the VI can handle the multiple simultaneous access from many applications. The data in each application is continuously updated and all the applications can control the VI. To have numerous applications that simultaneously controls the VI may be impractical and a more common situation is probably that one application actually controls the VI while the others just listens. This could be suitable in e.g. teaching situations in which the "teacher" controls while the students listen.

In the case of a very specific MUL, there is probably no need for the instrument HAL since it is likely to be a one time implementation. Then the MUL specific HAL can communicate directly with the HDL component or the HW, Fig. 2.

The same principles hold for the HW architecture as well. The parameters that should be considered are HW dependence, modularity, flexibility – standardization, and of course performance.

Traditionally, all HW of an instrument have been fitted into a box with little possibility for the end user to get access to the internal architecture of the instrument. An alternative could be to split the traditional instrument into, for example, a number of LXI modules and put them in a rack, or a number of PXI boards fitted into a PXI rack. Some manufacturers are taking this approach while others have an internal architecture that looks somewhat like this. This modularity makes it easier to replace a certain part of the instrument. It is also important that the manufacturers agree upon what standards to use so those pieces of HW from different manufacturers can operate together. Such a standardization would substantially increase the flexibility of the system and open up for the possibility for the end users to add their own boards to the measurement system. Some high performance instruments can may not at present be divided in such a way, while some simpler measurements can be done by boards fitted into a PC.

High performance instruments, especially for general purpose and many other applications, have a very large need for internal optimization and corrections that require very high competence and large experience to design, i.e. it is best done by an experienced instrument supplier as a traditional instrument. However, for a specific application it is easier to optimize, correct and obtain signal integrity by using separate modules for a high performance solution.

With the flexible SW architecture discussed above, however, all possible HW solutions can be combined into the same measurement system and at the same time maintaining flexibility, reusability and the possibility to upgrade the system.

The ideal HW architecture for RF measurements, provided that the performance requirements can be met, would probably be similar to the one shown in Fig. 2 (simplified sketch). This is also the architecture promoted by the SI community [6], [7]. All signals are generated by the digital-to-analog converter (DAC) and up-converted to RF. The response of the DUT is down-converted and then sampled by the analog-to-digital converter (ADC).

In addition to everything said above, price is always a factor that should be considered. The initial cost of development of a general and flexible system is always higher than for a dedicated one. The long term cost could, however, prove to be substantially lower. Thus, tradeoffs have to be made.

III. Using a Virtual Instrument Measurement System

A VI system may be used in a design or R&D lab as well as in production testing. Dependent on the application, the focus may shift on how the system is accessed by the user. The user could be, for example, a test program or a standalone GUI. Note here, that the GUI is not in general a part of the VI system, but a user of this system.

To support the design of systems of VIs, it is desirable that a modular sub-GUI, using for example ActiveX technology, is tied to each VI, see again Fig. 2. Then a system GUI for different systems can be built using these sub-GUIs. This may result in one R&D system GUI and one production testing GUI for the same set of VIs and HW. The sub-GUIs, even though they are tied to the VIs should be independent components.

In the design department, the VI system is likely to be operated from a GUI, but in production testing, the system will be operated remotely from a test program.

IV. Example of a Virtual Instrument Measurement System

A measurement system for measurement of dynamic, but also other, properties of power amplifiers (PAs) has been designed and built according to the principles of flexible SW design that has been outlined above. The system comprises a number of VIs.

Dynamic characterization of amplifiers means, in short, to measure the non-linear frequency response of the amplifier. This differs from traditional methods which use a network analyzer to measure the non-linear response at a certain frequency by sweeping the amplitude of a sine wave and the linear response by sweeping a sine wave over frequency. The idea behind this system is that all the necessary measurements can be carried out using sampled digital data. This significantly reduces the cost of the system since several “traditional” instruments can be replaced by VIs and some measurements that have previously been carried out using complicated set-ups or “home-built” solutions can now be done using VIs designed specifically for them. The system is designed for lab use, but can be reconfigured for use in a production environment, basically by changing the application layer components. A more in-depth presentation of dynamic characterization and modeling of PAs can be found in [8].

The basic HW set-up is shown in Fig. 8. As used here, this is in principle an implementation of the HW architecture in Fig. 2. It consists of a vector signal generator (VSG) that produces a modulated signal at a carrier frequency and a vector signal analyzer (VSA) that down-converts and samples the RF signals. Both the input and output signals of the amplifier can be measured.

In the actual implementation an FSQ from Rohde & Schwarz and an SMU 200A also from Rohde & Schwarz are used as VSA and VSG, respectively.

The MUL contains several components needed for characterization of power amplifiers such as signal generation, network analyzer, dynamic characterization, two-tone sweep, complementary cumulative density function (ccdf), etc. These are connected with the instruments through the HAL and HDL in different ways.

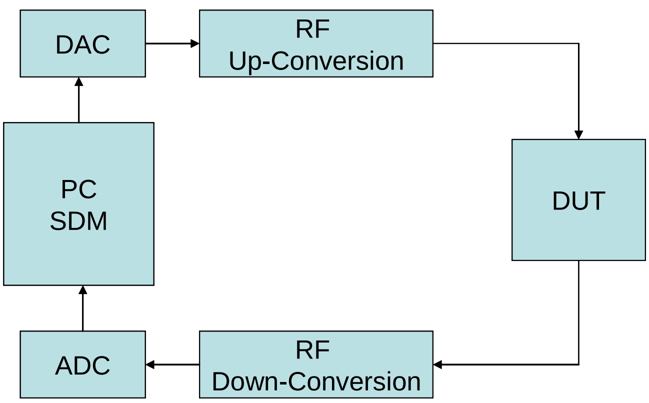

Fig. 7. Principle for the general HW set-up for RF measurements.

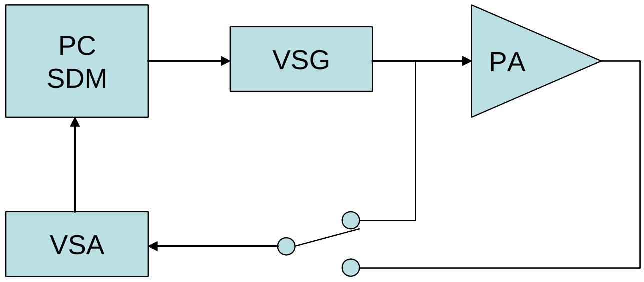

Fig. 8. The HW set-up of the implemented VI measurement system.

V. Discussion and Conclusion

It has been shown that by careful choice of the HW and SW architecture a flexible and modular VI system can be designed. The system makes it easy to move complex measurement functionality from one HW measurement system to another as long as the general HW structure in Fig. 7 is supported. This has the advantage that price and performance trade-offs for the physical HW can made for specific applications while maintaining the same measurement functionality.

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References

[1] http://www.ivifoundation.org/.

[2] P. Bilski and W. Winiecki, "Virtual Spectrum Analyzer Based on Data Acquisition Card," *IEEE Trans. Instrum. Meas.*, vol. 51, pp. 82 - 87, 2001.

[3] C. Nadovich, *Synthetic Instruments: Concepts and Applications*: Newnes, 2004.

[4] J. Fleagle, "Tradeoffs in Synthetic Instrument Design and Application," presented at Autotestcon 2005, Orlando, FL, 2005.

[5] http://www.microsoft.com/net/default.mspx.

[6] http://zone.ni.com/devzone/conceptd.nsf/webmain/7B38CE253B8D928C862571BE007BBF3C.

[7] http://www.evaluationengineering.com/archive/articles/0405/0405synthetic_instruments.asp.

[8] M. Isaksson, D. Wisell, and D. Rönnow, "A Comparative Analysis of Behavioral Models for RF Power Amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 54, pp. 348-359, 2006.

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32. Klingberg T, Kågström J: Samordnade sopor. Om avfallshantering i praktiken. En studie på uppdrag av Forskningsstiftelsen Gästrikeregionens Miljö. Department of Business Administration 2005.

33. Rönnow D: Software for determining the third order Volterra kernels of radio frequency power amplifiers. Department of Technology and Built Environment 2005.

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40. Fregidou-Malama M, Jakobsson S: Etablering av regional yrkeshögskoleutbildning i Hofors och Sandviken. Department of Business Administration 2008.

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UNIVERSITY
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Postal address: SE-801 76 Gävle, Sweden
Visiting address: Kungsbäcksvägen 47
Telephone: +46 26 64 85 00 Fax: +46 26 64 86 86
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