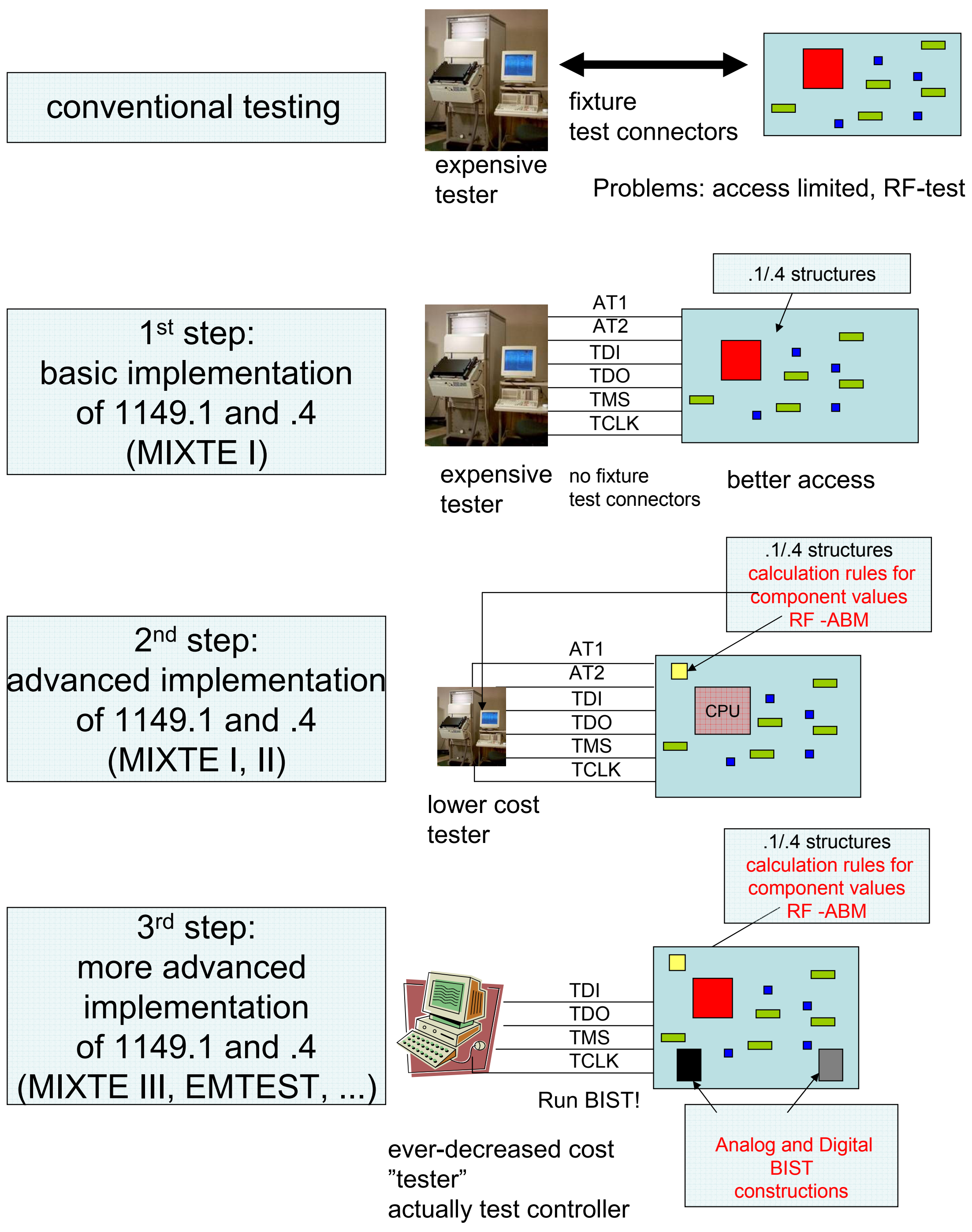
Towards embedded testing

The testing of the mixed-signal circuits has been researched in the University of Oulu in the projects Development of the Testability of Mixed-Signal Circuits (MIXTE) I-III. Nokia and Elektrobit have been the industrial partners of these Tekes projects. The results have been presented in international conferences and workshops (International Test Conference 2004, Board Test Workshop 2003 and 2004, Design, Automation & Test in Europe 2005 and European Test Symposium 2005) [1-6].

Research has been done to utilize the IEEE 1149.4 Mixed-Signal Test Bus Standard in measurements. The suitability of the test bus has been extended to radio frequencies (up to GHz-range) by building special radio frequency analogue boundary modules (RF-ABMs). With these RF-ABMs it is possible to make basic RF frequency and power measurements. The results of the frequency and power measurements are available as low-frequency/DC signals that are suitable for the low-frequency 1149.4 analogue bus. In the low frequencies, calculation methods have been developed to get the values of the components forming impedances between the 1149.4 compatible ICs' pins. The values are calculated from the measured voltages achieved through the test bus taking the loading effect of the measuring equipment into account, thus enabling the use of low cost instruments. Further, the use of Wheatstone bridge for small resistance measurements for characterizing the ball grid array wear-out has been researched in the 1149.4 environment.


conventional testing
expensive tester
fixture
test connectors
Problems: access limited, RF-test

1st step:
basic implementation
of 1149.1 and .4
(MIXTE I)
expensive tester
no fixture
test connectors
better access
.1/.4 structures

2nd step:
advanced implementation
of 1149.1 and .4
(MIXTE I, II)
lower cost tester
.1/.4 structures
calculation rules for component values
RF -ABM

3rd step:
more advanced
implementation
of 1149.1 and .4
(MIXTE III, EMTEST, ...)
Run BIST!
ever-decreased cost
"tester"
actually test controller
.1/.4 structures
calculation rules for component values
RF -ABM
Analog and Digital
BIST
constructions

Figure 1. Development of mixed-signal testing

Calculation methods

Developing new calculation methods for passive components in 1149.4 environment were one of the main goals in MIXTE projects. The calculating methods give the possibility to measure complex impedances without the need for phase measuring capability or a priori assumptions of the phase angle. The principle of the method is shown in Figure 3. In this method, two sense resistors, Rs1 and Rs2, are used. The stimulus current is first directed through the serial connection of the sense resistors. The voltages between the ground and both ends of the serial connection as well as both ends of Zx are measured. In the second phase, the stimulus is directed through Rs2 only (pin A1 instead of A0) and the voltages between the ground and both ends of Rs2 and Zx are measured. The actual circuit has been realized using STA400s. The STA400 on the left in Figure 3 works in its mission mode, i.e. as a multiplexer (its analog buses, ABs, and analog boundary modules, ABMs, have not been drawn for the sake of clarity). The vector presentations of the impedances and the voltages are shown in Figures 4 and 5. The unknown impedance Zx consists of the real part R and the imaginary part X. [4]

The impedances of measurement equipment have to be taken in to account, which makes the calculations a lot more complex. Also the switch resistances of the 1149.4 compatible component change when different offset voltages are used which also complicates the calculations. The experimental results show that quite accurate (error = ±2 %) results can be achieved when the preconditions are fulfilled, i.e. the right sense resistors and measurement frequency are chosen. On the other hand choosing them wrong can have fatal effect on accuracy. [4]

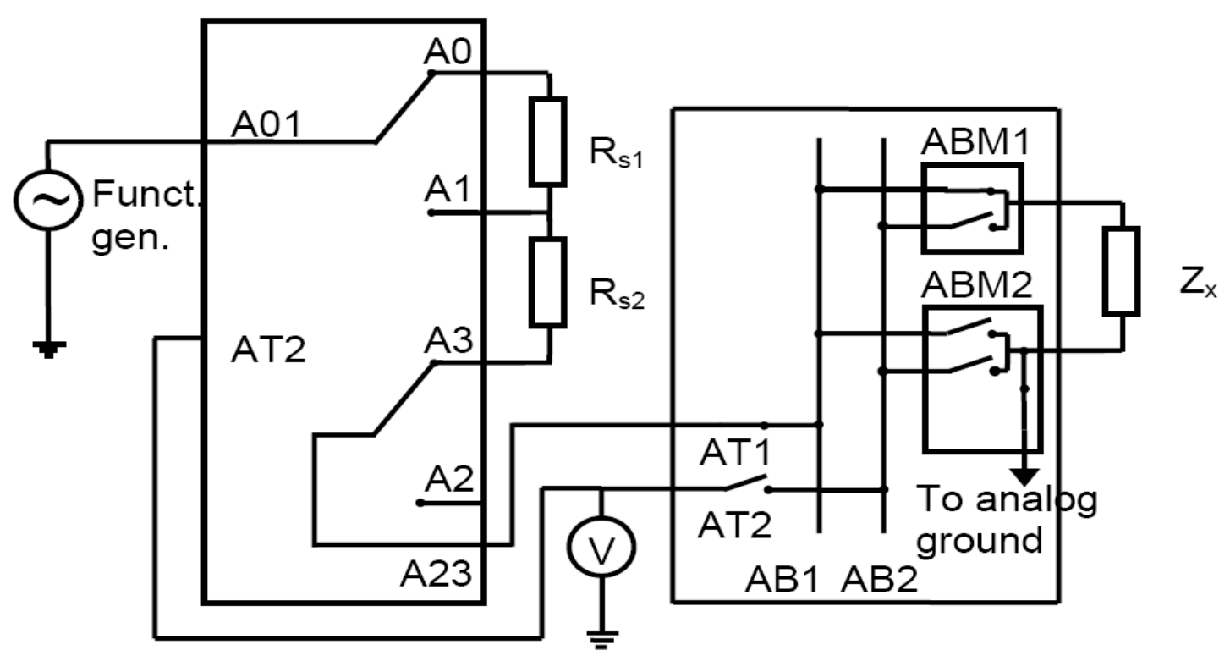


Figure 3. The measurement principle

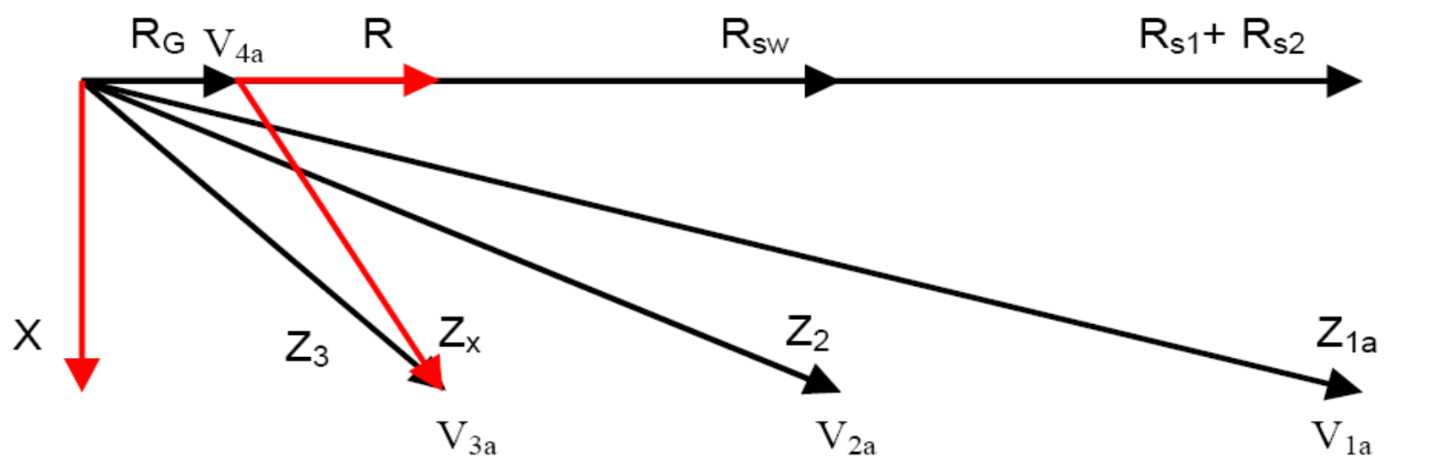


Figure 4. Impedances and voltage in phase 1

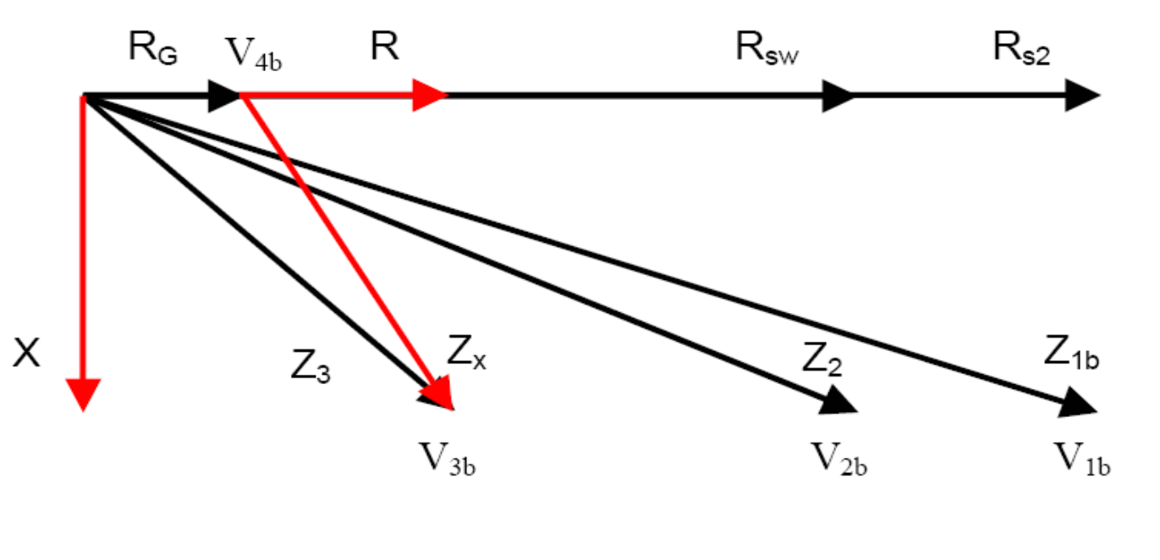
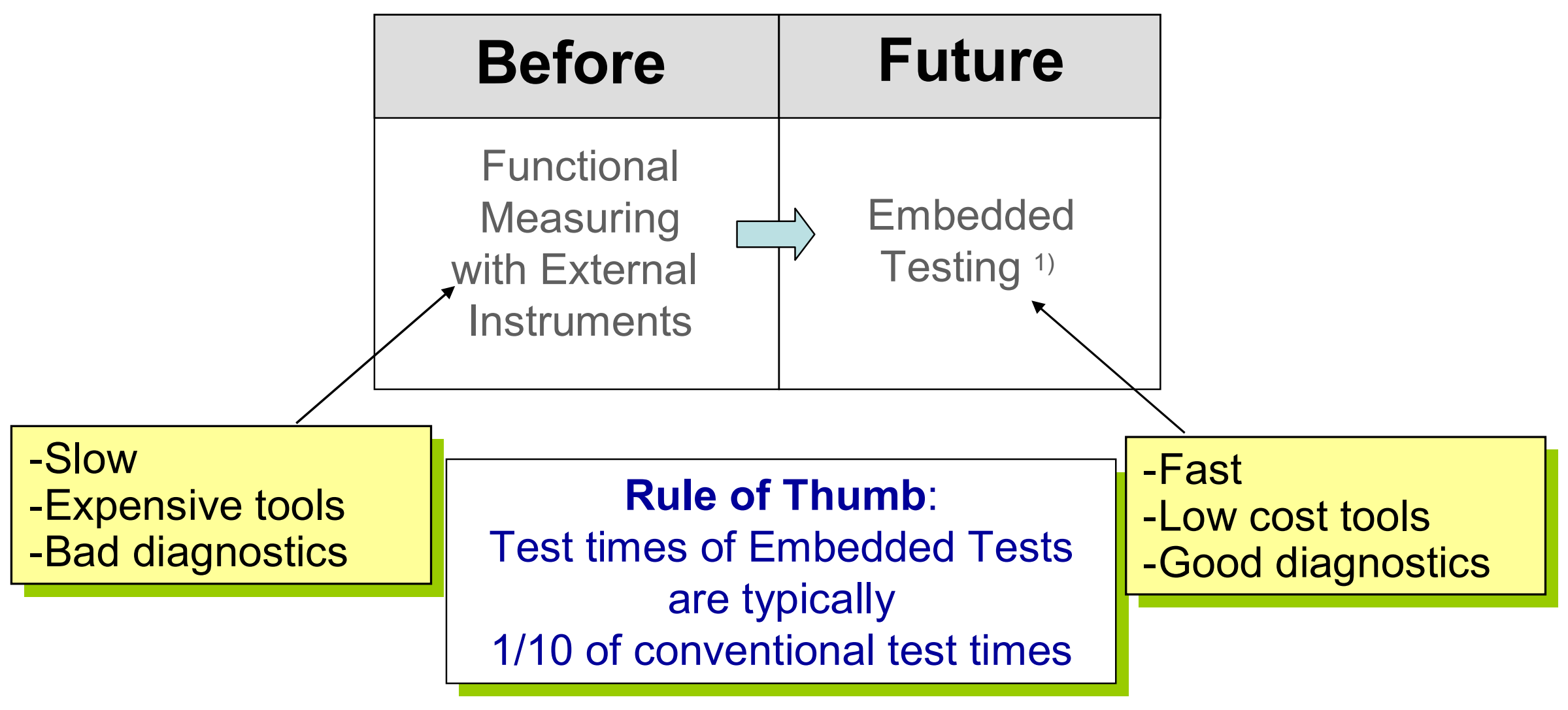


Figure 5. Impedances and voltages in phase 2

General Testing Trend in Future


Before
Functional Measuring with External Instruments
-Slow
-Expensive tools
-Bad diagnostics

Future
Embedded Testing 1)
-Fast
-Low cost tools
-Good diagnostics

Rule of Thumb:
Test times of Embedded Tests are typically
1/10 of conventional test times

1) Embedded Testing means e.g. any self tests, self tunings, internal test loops

Figure 2. General testing trend in future
(original source Jukka Antila)

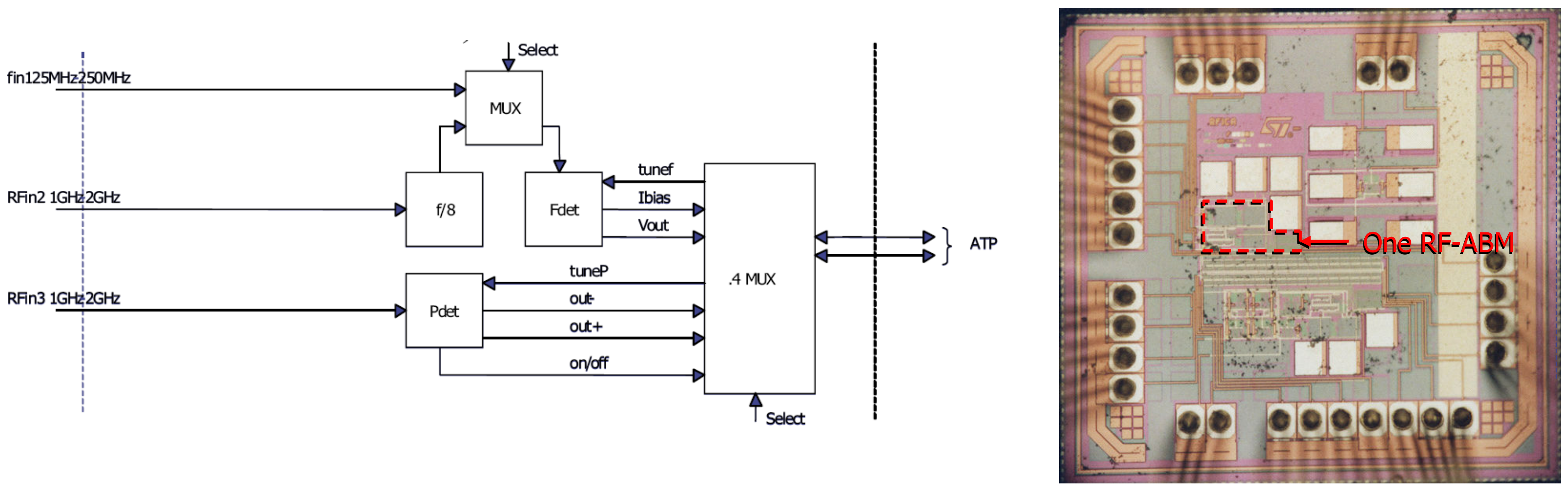
Extending the IEEE 1149.4 to RF

Other main goal of MIXTE projects was to extend the low-frequency 1149.4 test access to higher frequencies. The extension of the basic low-frequency 1149.4 test access to RF is made possible by the RF-ABM ASICs developed by one of the authors [5]. These circuits act as RF-to-LF translators, which provide at the output pins of the ASIC DC signals, the level of which is proportional to the frequency or the power of the input RF power or frequency. The ASIC output can be directly connected to the 1149.4 analogue test bus and the functionality of the ASIC controlled by connecting the ASIC in series to the STA400 control bus. I.e. the ASIC is directly accessible as part of the normal 1149.4 control architecture via the common JTAG type connector, which makes the use of the RF section of the test architecture easy from the test software point of view.

The main parts of the RF-ABM of Fig. 6. (a) are frequency and power detectors which extract DC quantities relative to the input signal power and frequency, respectively. Because of the frequency limitations due to the used circuit process, the frequency of the input signal had to be divided by 8 before the actual frequency detection. Measurement results (Vout, out- and out+) from and tuning inputs (tunef and tuneP) to the detectors themselves can be connected to the IEEE 1149.4 type analogue test port (ATP) using a programmable switch matrix (1149.4 MUX).

The fabricated RF-ABM ASIC was extensively tested as reported in [5]. After DC-calibration the power measurement uncertainty caused by the temperature, supply voltage and process variations is roughly 2 dB and the frequency measurement uncertainty is 0.1 GHz, respectively. If the error caused by the process variation is ignored, i.e. a wafer specific calibration is performed, the power measurement uncertainty decreases to 1 dB and the frequency measurement uncertainty to 0.05 GHz, respectively. The rise time of the power detector for a 20 dBm power step is 3.4 μs and that of the frequency detector for a 0.6 GHz frequency step is 13.2 μs.

The above described RF-ABM ASICs were used in a 1 GHz direct-conversion transmitter to demonstrate the PCA-level design and implementation of the 1149.4 RF extension. This demo transmitter, which allows the evaluation of the whole 1149.4 test architecture in a modern and relevant application, combines in a novel way the LF signal and component measurements with the new RF measurement capabilities. It also brings together the different 1149.4 related research topics covered by the MIXTE projects.



(a)

(b)

Figure 6. (a) The basic RF-ABM and (b) dice photograph of the RF-ABM ASIC

[1] J.Hakkinen, P.Syri, J-V. Voutilainen, M.Moilanen, "A Frequency Mixing and Subsampling Based RF-measurement Apparatus for IEEE 1149.4", Proceedings of IEEE International Test Conference, 2004

[2] J.Hakkinen, P.Syri, M.Moilanen, "A Frequency Mixing and Subsampling Based RF-measurement Apparatus for IEEE 1149.4", 2nd IEEE International Board Test Workshop, 2003

[3] T.Saikkonen, J.Voutilainen, M.Moilanen, "Some Methods to Calculate the Values of Passive Components from the Measurements Made with an 1149.4 Compliant Device", 2nd IEEE International Board Test Workshop, 2003

[4] T.Saikkonen, J.Voutilainen, M.Moilanen, "Calculating the Values of Passive Components in 1149.4 Environment", 3rd IEEE International Board Test Workshop, 2004

[5] P.Syri, J.Hakkinen, M.Moilanen, "IEEE 1149.4 Compatible ABMs for Basic RF Measurements", Design, Automation & Test in Europe 2005

[6] J-V. Voutilainen, M.Moilanen, "Embedded Characterization Technique for BGA Solder Joint Wear-Out with 1149.4 Mixed-Signal Test Bus Architecture", IEEE European Test Symposium 2005