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DESIGN AND CHARACTERIZATION OF RF CELLS AND ICS USING DIFFERENT TECHNOLOGIES UP TO 6 GHZ

Björn Bieske, Klaus Gille

ABSTRACT

The 2.4 / 5.8 GHz ISM bands and the 868/915 MHz band are well suited for short range data transmission. In addition to proprietary solutions different standards have been established: WLAN, Bluetooth® and Zig-Bee™ [1, 2]. Wireless sensors and networks can be set up easily.

The ever increasing possibilities in computing provide reliable results of simulations of devices and circuits. To extract and verify sets of parameters and models it is necessary to realize measurements in the field of RF up to several GHz.

The performance of analog and RF circuits is increasingly sensitive to sub–micron manufacturing technologies. Standard and primitive devices that are well characterized and modeled are essential to realize stable working designs without silicon iterations.

RFCMOS and embedded analog SOC are rapidly evolving as the low cost process technologies of choice for single chip radio applications. RF performance improvements driven by structure sizes of 0.35 µm and below enable standard CMOS to meet specifications for many RF systems [3].

These measurements can be done on evaluation boards using packaged devices or on wafer using a wafer prober. The DUT can be contacted by impedance controlled RF ACP probes DC needles or test fixtures. Different measurement setups have been established using appropriate measurement equipment according to the kind of RF cells.

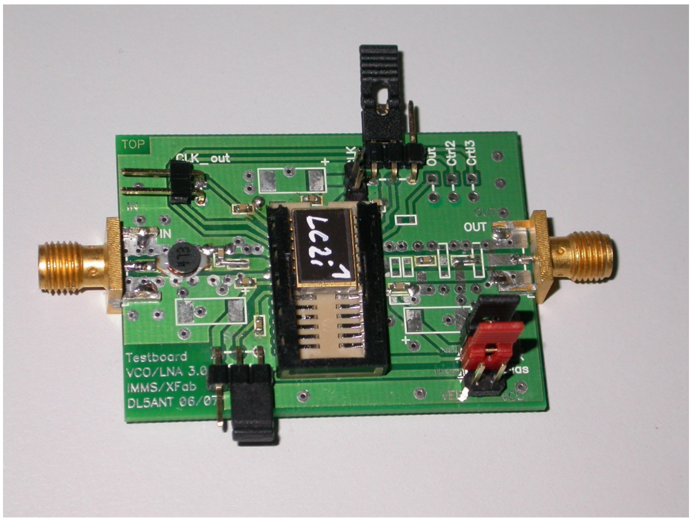

Fig 2: Evaluation Board for VCOs and LNAs using SMD fixture for SOIC-16 packages

Index Terms **–** RF-cell, LNA, VCO, Mixer, S-Parameter, Measurements, Transceiver, PLL, IC-Design

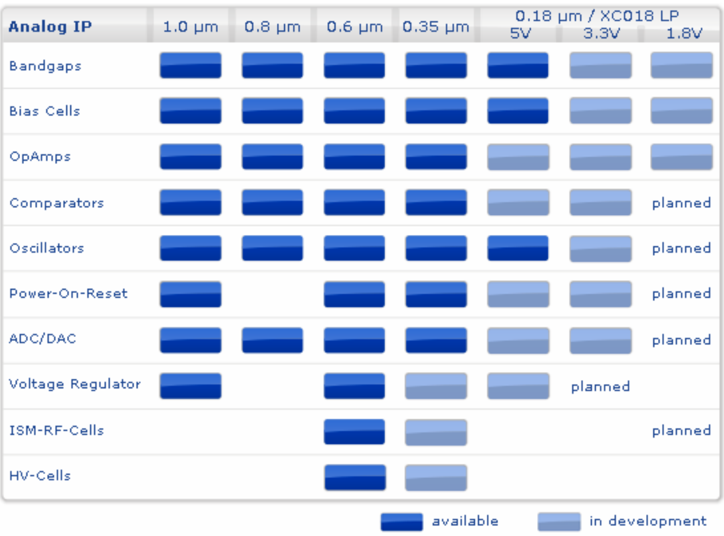

Fig. 1: Broad spectrum of analog IPs offered by X-FAB [4]

1. INTRODUCTION

During the design process of RF transceiver ICs every RF cell inside has to be evaluated and characterized. This can be done for different semiconductor technologies. Especially for automotive applications the devices have to be tested in an extended temperature range.

In general a large variety of analog IP cells can be considered:

- Bandgaps
- Bias Cells
- OpAmps
- Oscillators
- ADCs/DACs
- Voltage Regulators
- RF Cells

All these bulding blocks are supplied by X-FAB in different technologies to provide a starting point for a customer designed solution (fig. 1).

2. RF CELLS

The RF transceivers can be divided into the following cells with their own specific data:

- LNAs
- Mixer
- Crystal oscillators
- VCOs
- Clock divider
- PLLs
- PAs
- Base band processing

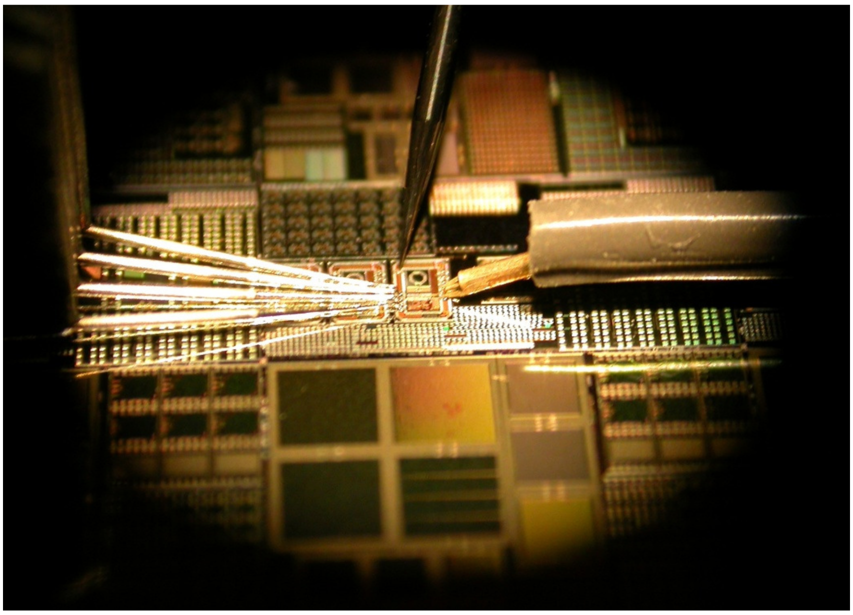

Fig. 3: LC-VCO RF cell contacted on wafer

For every kind of RF cell a special measurement setup is required and a special measurement flow has to be implemented.

Beside the RF cells passive RF devices essential for these bulding blocks were measured:

- Inductors
- Varactors
- ESD structures

As an example the measurements for characterizing different VCO types will be explained more in detail. There are three different topologies for VCOs:

- Ring oscillators
- ECO VCOs
- LC VCOs

Two fully integrated inductor-capacitor-based VCOs are available (fig. 3). Both are based on a cross coupled bipolar transistor pair. The varactors are DC or AC coupled leading to a different tuning range. The layout of these variants was pin compatible and according to a standard evaluation layout set during prior measurements using LNAs. In this way the same hardware platform could be used. The LNAs were designed as wide band as well as narrow band versions for the 868/915 MHz range. Recent projects are working on 2.4 GHz and future target applications between 5 and 10 GHz [5].

3. RF CONTACT SYSTEMS

The majority of these RF cells have a similar pad layout pattern: 2 RF ports and several DC pads. Using standard wafer probing equipment the RF ports should be at the opposite edges of the layout to place ACP RF probes right there. The DC probes can be positioned at the lower and upper edge using south and north positioner or using single DC needles.

The mixer cell needs three RF ports for RF, IF and LO signals. The additional port was placed at the upper edge and the lower edge is available for DC pads (fig. 4).

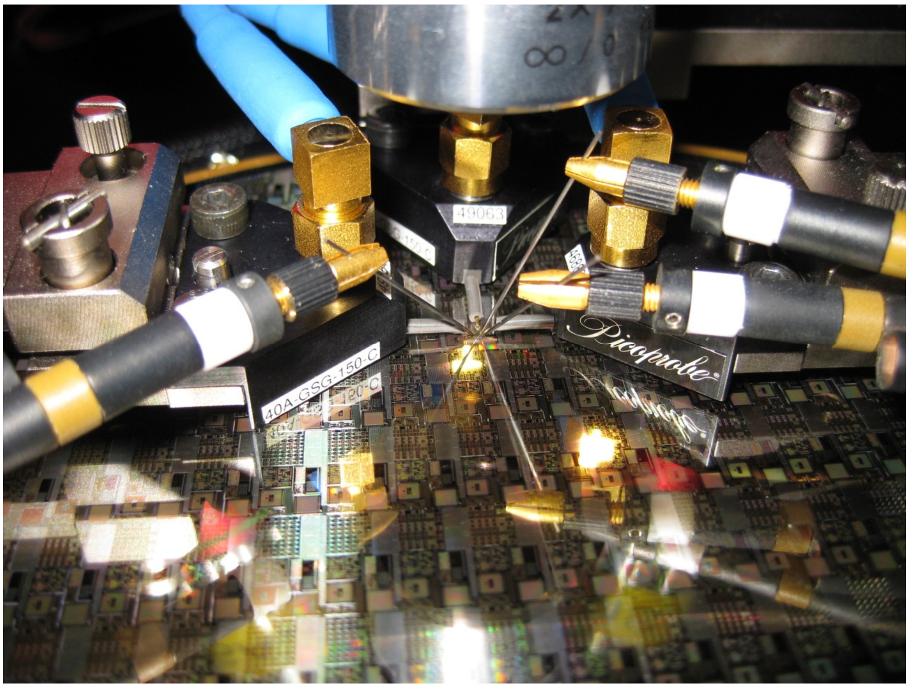

Fig. 4: Mixer cell contacted on wafer using three ACP Probes

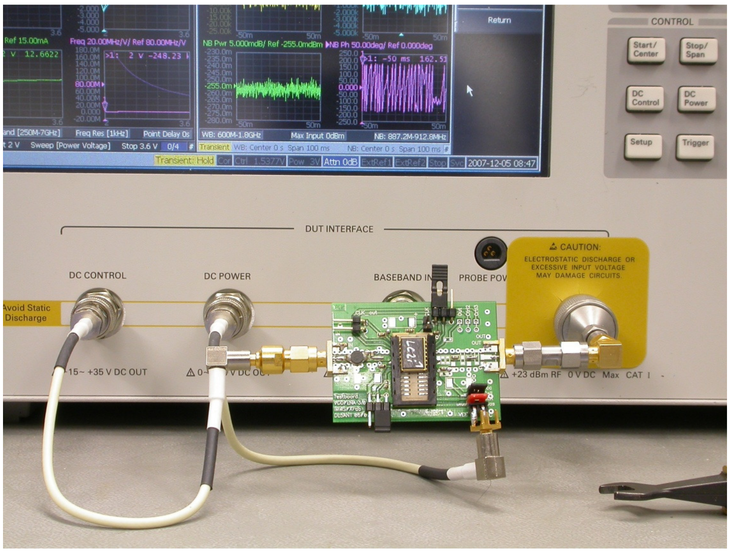

Fig. 5: Measurement setup for measurement of VCO characterization on evaluation board using signal analyzer by Agilent

The same structure was realized on the evaluation PCBs.

For all RF devices up to 1 GHz target frequency range a 16 pin SOIC small outline SMD package is used. Usually the RF pins are two opposite ones. One mutual PCB layout including possibilities for matching elements at input and output path can be used for many different devices (fig. 2).

To measure more devices a SOIC fixture is used. Of course there are parasitics of this fixture, but since there is an input and output matching network needed these are compensated by different values of the external components. So the influence of the fixture is negligible in most cases.

The advantage of this set of hardware is that nearly all kinds of cells could be measured on the same PCB using only different external components. The performance of different devices and different technologies was directly comparable and the costs and time for hardware development could be reduced considerably [6].

For devices above 1 GHz a new packages and fixture with a better RF performance is required. To meet all demands of the specification and to have enough pins available a QFN32 package with the size of 5 x 5 mm was chosen. The solution for test fixtures can be taken from the production test of devices since this is a widely used standard package. The aim is to use a single hardware platform comparable to the devices below 1 GHz.

4. RF MEASUREMENTS

To characterize the devices in detail a set of RF measurements was implemented. These measurements were done by hand for the first investigations and later optimized and programmed for an automated run to characterize ten devices.

The following kind measurements according to the kind of DUT were performed:

- S-parameter measurements
- Spectrum measurements
- Noise measurements
- Transient measurements
- Large Signal measurments
- DC measurements

The DC measurements also include standby current measurements down to the range of pA which is a challenge for the standard measurement equipment.

At first the VCOs were measured using source meters, and a spectrum analyzer controlled by an Agilent Vee or ICCAP program. To improve the measurement capabilities and speed a signal analyzer e.g. SSA [7] by Agilent (fig. 5) or FSUP [8] by Rohde & Schwarz including dedicated routines for VCO and PLL measurements was used later. This equipment offers excellent capabilities for measuring the phase noise of free running VCOs.

The noise measurements were realized on wafer using a noise parameter test system including electronic tuner by ATN microwave and on PCB by Firmware extensions of the spectrum analyzer. Due to the small amount of devices to test there always is a trade-off between small test programs and the use of automated tester equipment [9,10].

The next step is to measure devices with differential RF ports [11].

5. MEASUREMENT RESULTS

As an example the tuning characteristics of three different topologies of VCO are shown in fig. 6. The LC-VCO offers the best data but this type needs a large chip area compared to the other types. Evaluating the complete data sheet the customer has the choice to select the right VCO which can meet all the requirements of his application.

The LNAs were designed in different variants using external tank circuits and integrated resonant circuits. All devices without internal frequency selective components were measured broad band at 50 Ohm load resistance. This could be done on wafer and on PCBs in the same way. The results are compared in fig. 7 and the target frequency for maximum gain of LNA3 was 868 MHz.

To complete the data sheets of LNAs the following measurements were done:

- S-Parameters
- IP3
- Noise figure
- 1 dB compression
- Power supply rejection Ratio (PSRR)

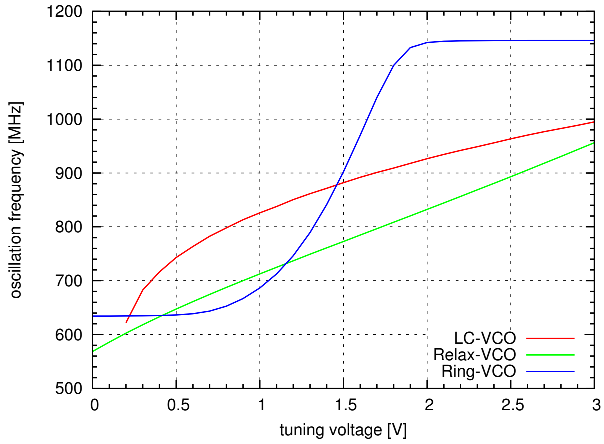

Fig. 6: Tuning characteristic of different topologies of VCOs (Note: LC-VCO: starting at 0.3V, Ring-VCO: 1 to 1.7V usable)

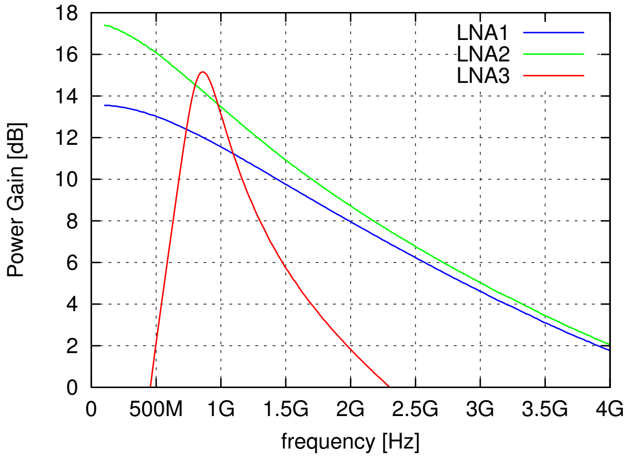

Fig. 7: Gain of different LNA topologies

LNA1 is a fully integrated LNA based on an emitter stage with feedback resistor between base and collector to achieve good input and output matching. No external matching elements are needed.

LNA2 is based on a bipolar cascode configuration with an on chip load resistor of 50 Ohm. Thus the output is well matched but the input needs a matching network depending on the package.

LNA3 is also based on a bipolar cascode with an on-chip LC-tank circuit to compensate for the parasitic capacitors at the output node. This allows higher gain at lower supply current compared to the resistively loaded LNAs mentioned before. The output matching is good in the vicinity of 868 MHz but the input has to be matched like LNA2.

6. CONCLUSION

A platform for design and characterization of RF cells as well as measurements on wafer and on PCB has been developed. Using these standard cells can improve and speed up the design process for customer applications.

Different technologies can be compared directly by using the same evaluation hardware and measurement setups. The measurement flow can be automated to get repeatable results due to constant measurement conditions.

These standard RF cells can be used to monitor the process parameters and their influence on the stability of the design. All RF cells can be put together to realize a complete RF transceiver.

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