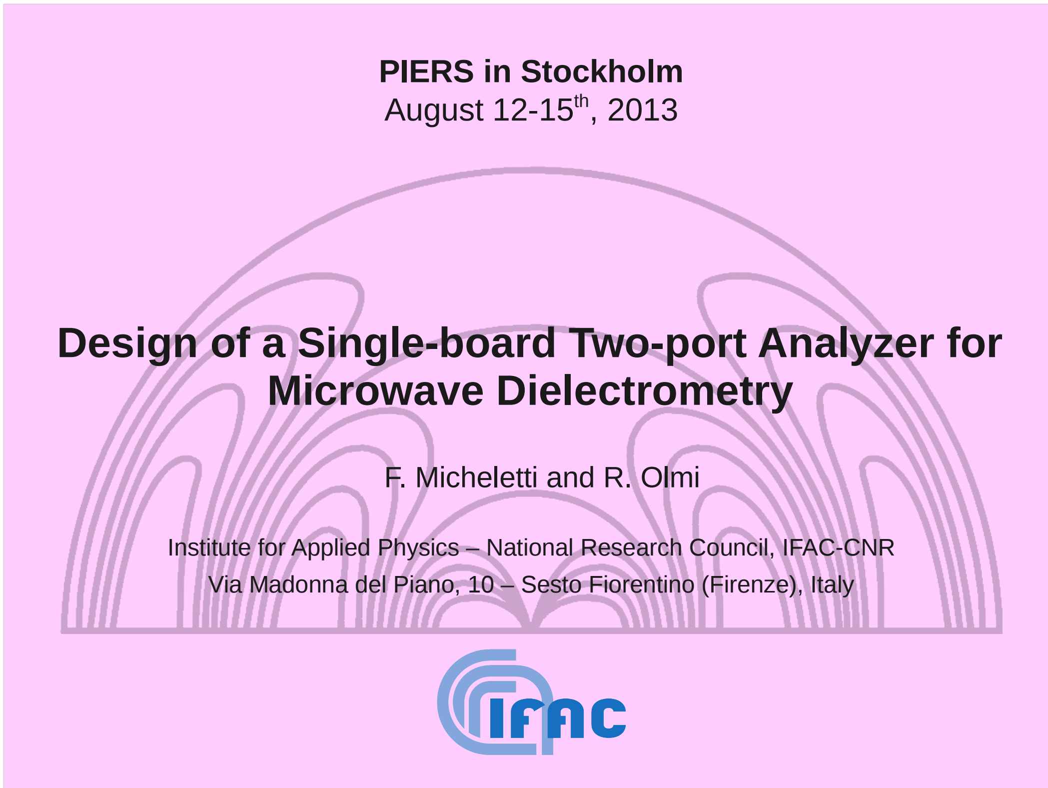
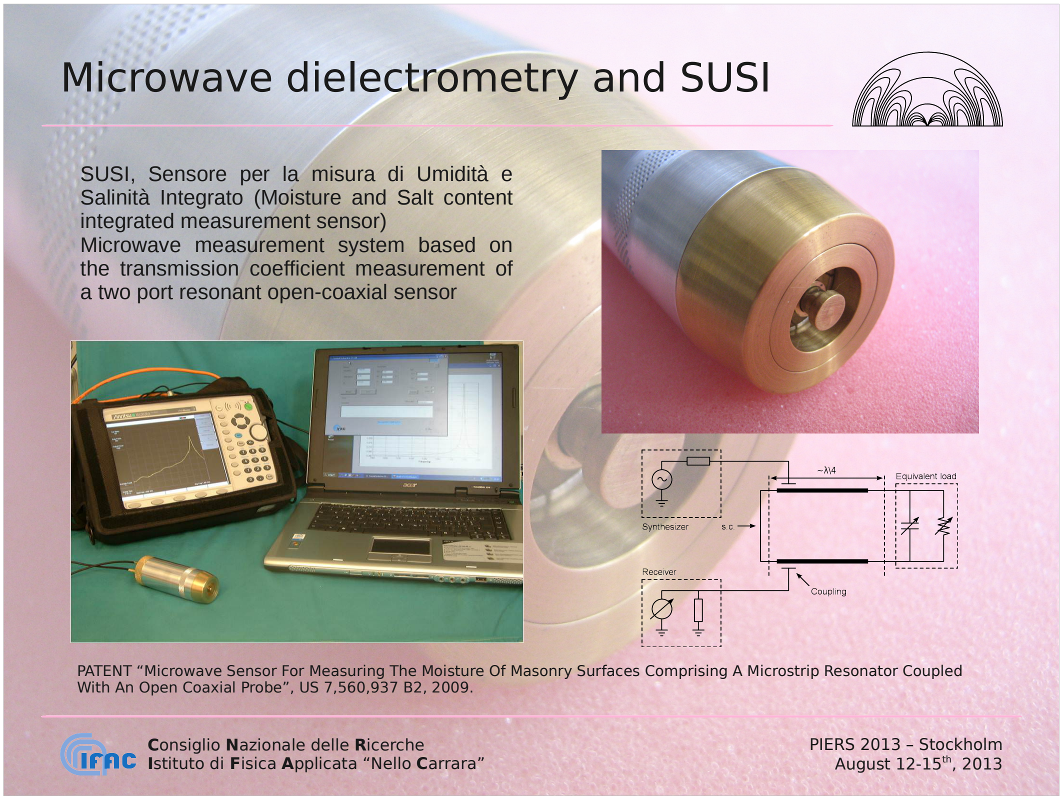


Good morning everybody,
let introduce myself, my name is Filippo Micheletti, I'm a PhD student in Information Engineering at the University of Siena and I work to the Applied Physic Institute Nello Carrara of the Italian National Research Council of Sesto Fiorentino, near Firenze.

In this work I'll talk to you about the design of a single-board two port analyzer for microwave dielectrometry, a part of a project which is in developing on our lab.



So first of all let me spend some words about microwave dielectrometry.

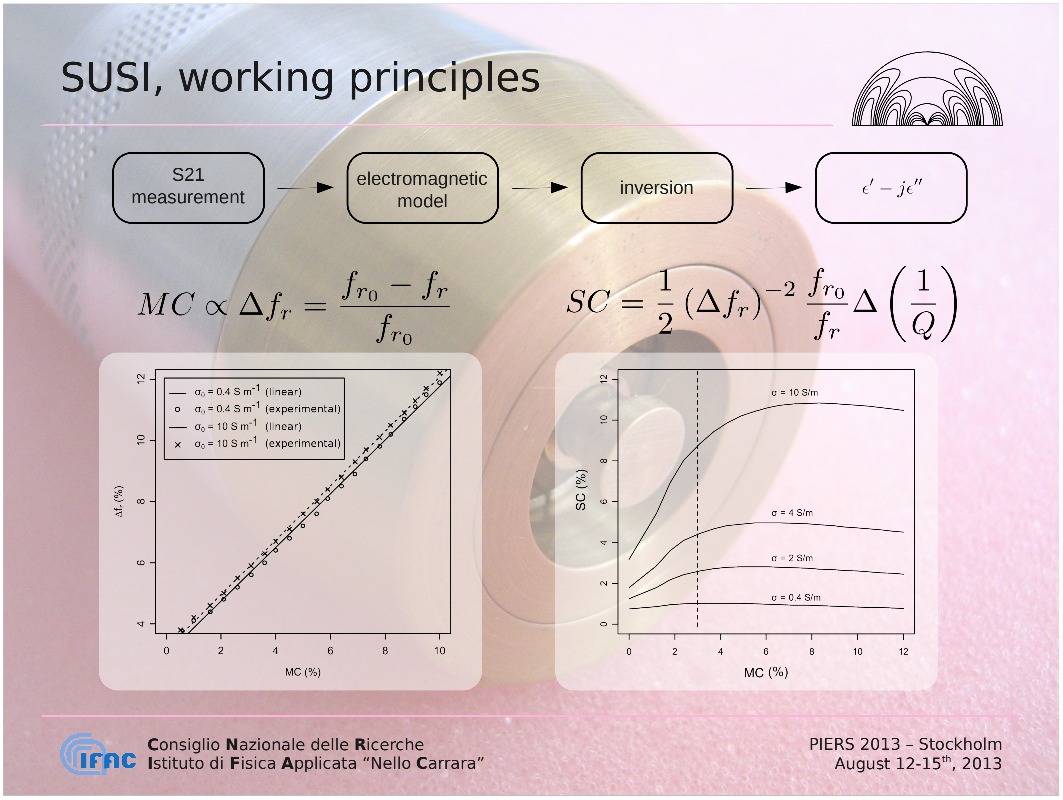
Microwave dielectrometry is a branch of dielectric spectroscopy which use electromagnetic radiation at microwave frequencies to measure the dielectric constant of materials.

In specific in this presentation we'll refer about an instrument developed in our lab in the past few years, called SUSI, that in italian is "sensore per la misura di umidità e salinità integrato", which stay for moisture and salt content integrated measurement sensor and that is an instrument which directly measure the moisture and the salt index in bulk materials.

As you can see in the left figure, the SUSI is composed of 3 parts: a scalar network analyzer, a sensor and a personal computer.

The sensor, represented on the right top figure, is the main part of the system and is a particular resonant sensor composed by a resonant cavity opened on a coaxial aperture which can be coupled with the surface of the material to be investigated to perform a measurement based on the so called "open-coaxial" method.

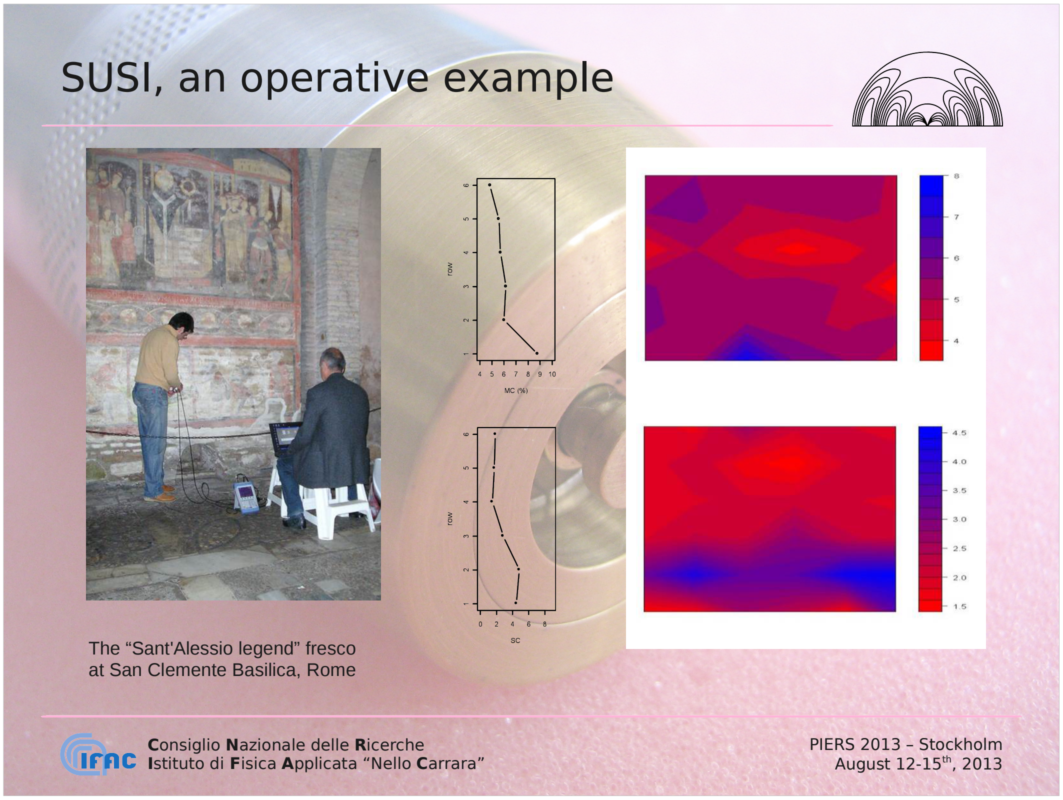
In the left bottom figure you can see a principle diagram of the measurement system which is very simple: a synthesizer feed the sensor which basically is a transmission line with a specific length terminated on an equivalent load which depends on the measured material conditions and so the resonant line is coupled with a receiver and the transmission coefficient through the two ports of the sensor is measured.



Behind the operating principle of the sensor there is a quite complex mathematical study that obviously I have no time to explain here, but in theory the complex dielectric constant of the material would be derived from the inversion of an electromagnetic model based on the coupling of the field on the material and the one on the cavity on the coaxial aperture of the sensor.

In practice however the measured quantities, moisture content and salt index, are deduced directly form the resonance frequency and the quality factor of the sensor through the two quasi-empirical formulas that you can see on the slide.
This is principally because the inversion of the model would be too computationally expensive to be performed at each frequency for a real-time measurement while the detection of the resonant frequency and the measurement of the quality factor can be done almost instantaneously at the end of the span.

As the graphs show these formulas match almost perfectly the measured data and also moisture content and salt index can be separated as two almost independent quantities, at least for our purposes.

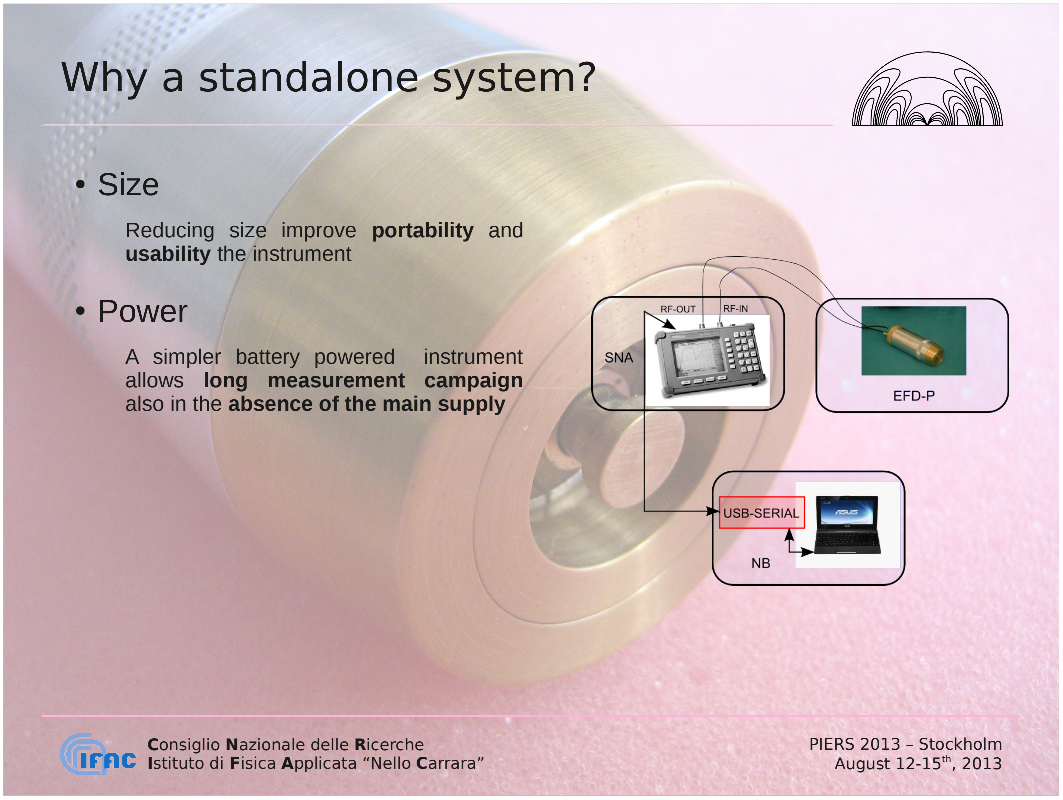


Well in this slide you can see my colleagues Roberto and Cristiano when they are doing some measurements on the Sant'Alessio legend fresco on the Basilica of San Clemente in Rome and you can see how we can extrapolate for example the moisture content and salt index trends on a specific direction or a two dimensional map of these quantities on the surface of the fresco.

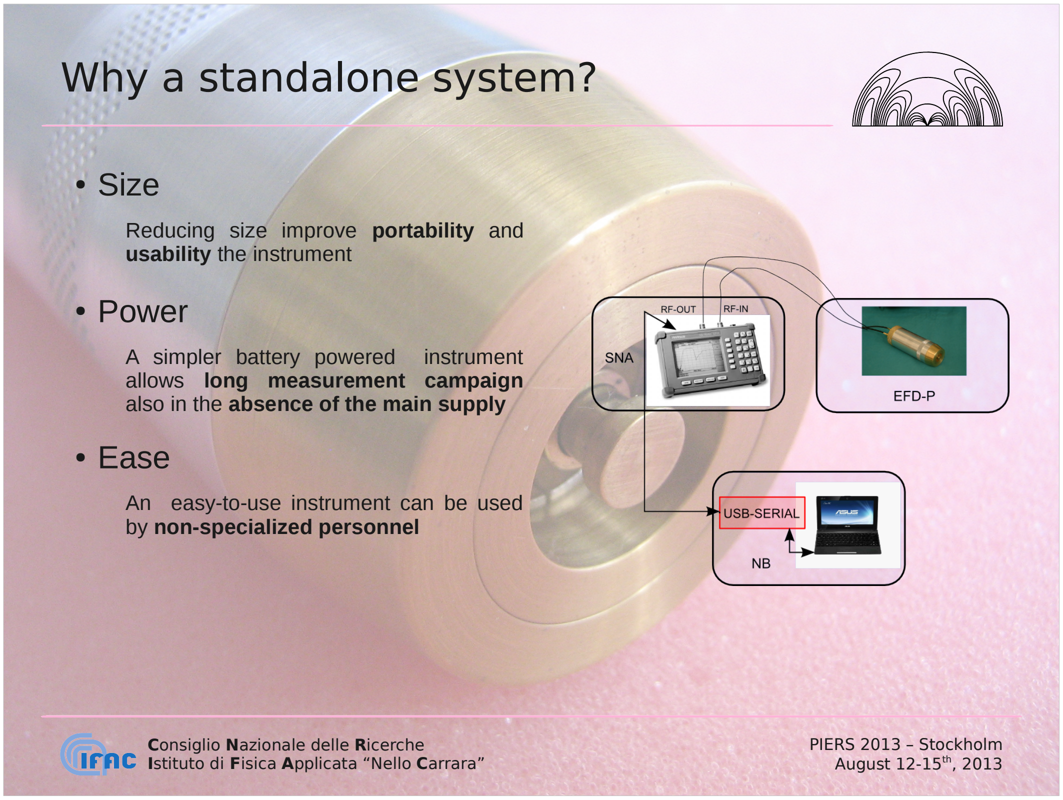
But so: why a standalone system?

Well, there are several issues related to the traditional measurement system.

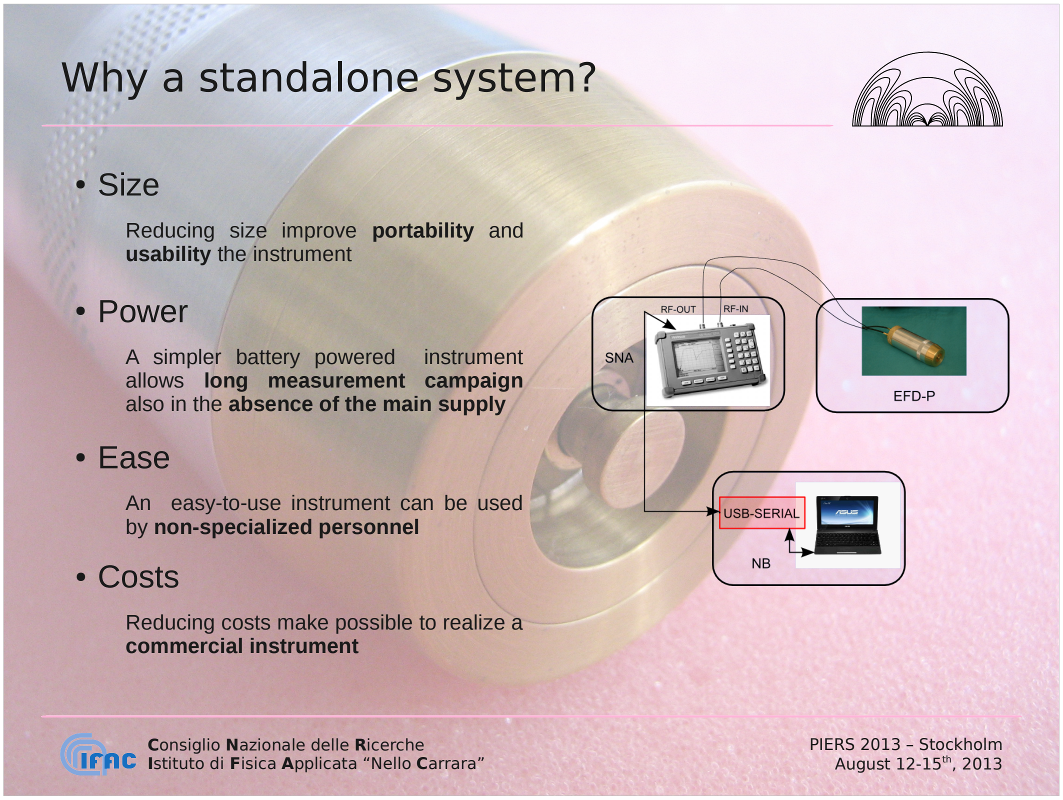
First of all the size of the whole system: we have a scalar network analyzer, and a PC that are not so lightweight.
Also this setup generally needs two operators to perform the measurement.



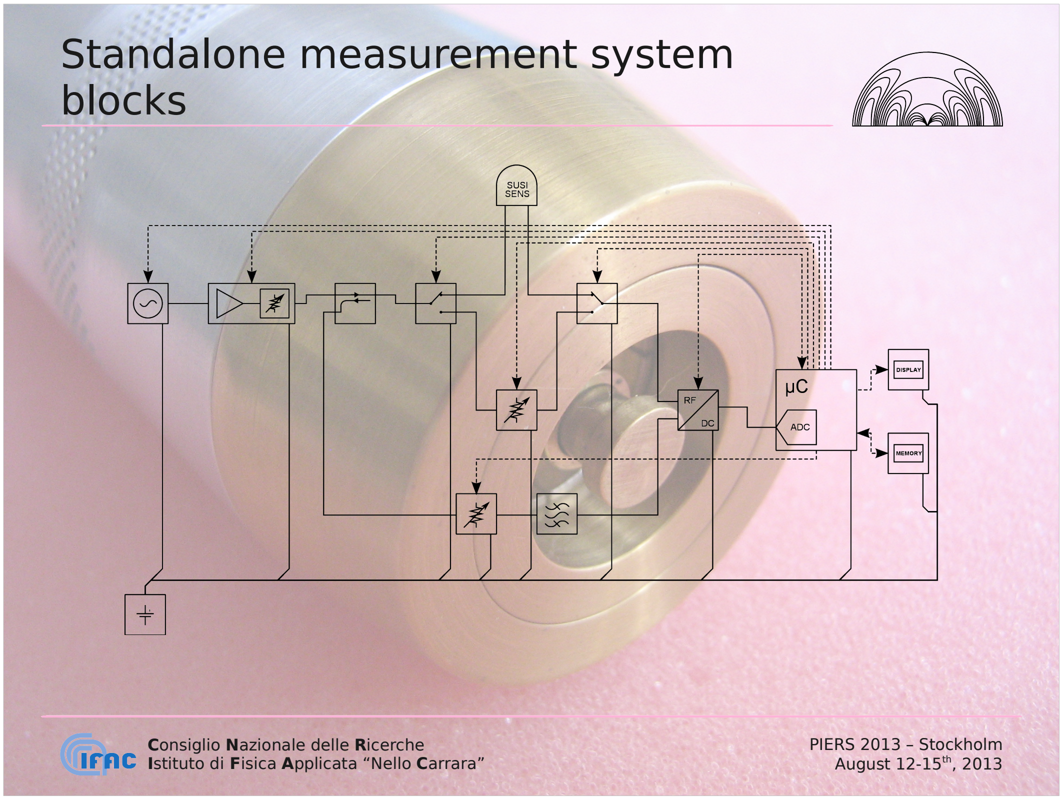
Also the need of electric power is a big limitation on the usage of the instrument because despite both analyzer and PC can be powered by battery the duration of them is quite limited and a measurements campaign can also be quite long.



Another reason is the ease of the instrument because an easy to use instrument which directly returns the desired quantities, moisture content and salt index, allows measurements to be done by non specialized personnel.

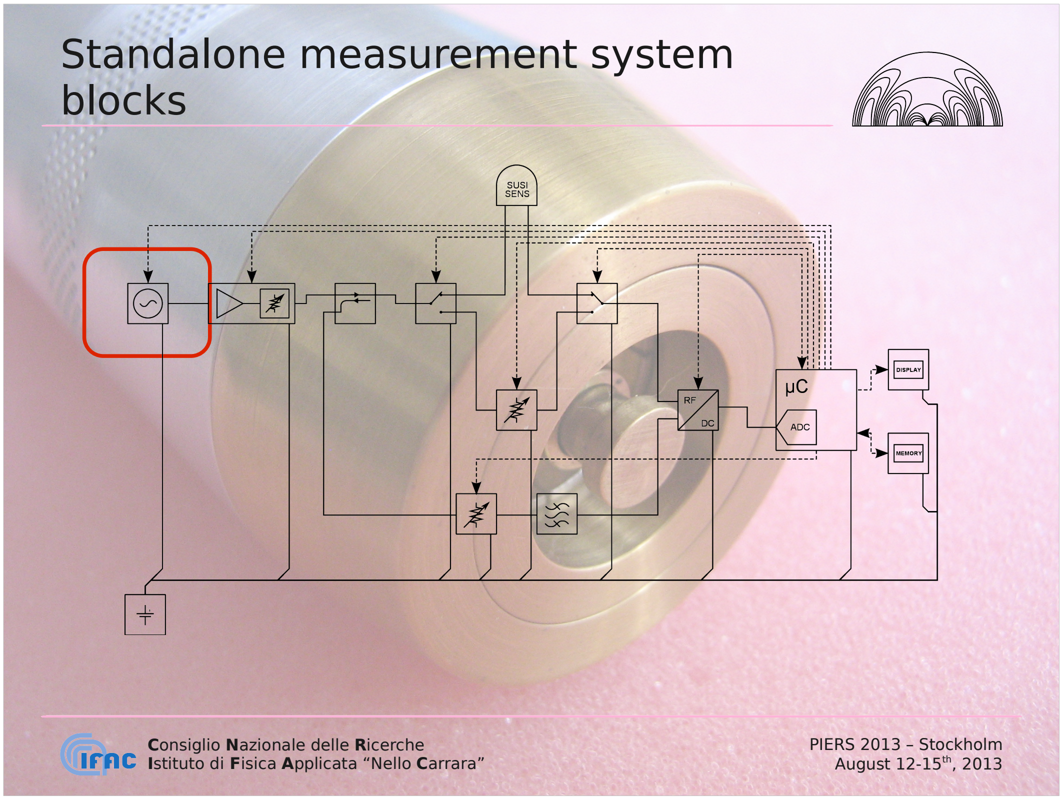


And at last but not the least, the costs, principally of the analyzer especially related to the quite limited use of the instrument for this kind of measurement: reducing costs from some thousands to a few hundred of euros would allow the production of a commercial instrument.

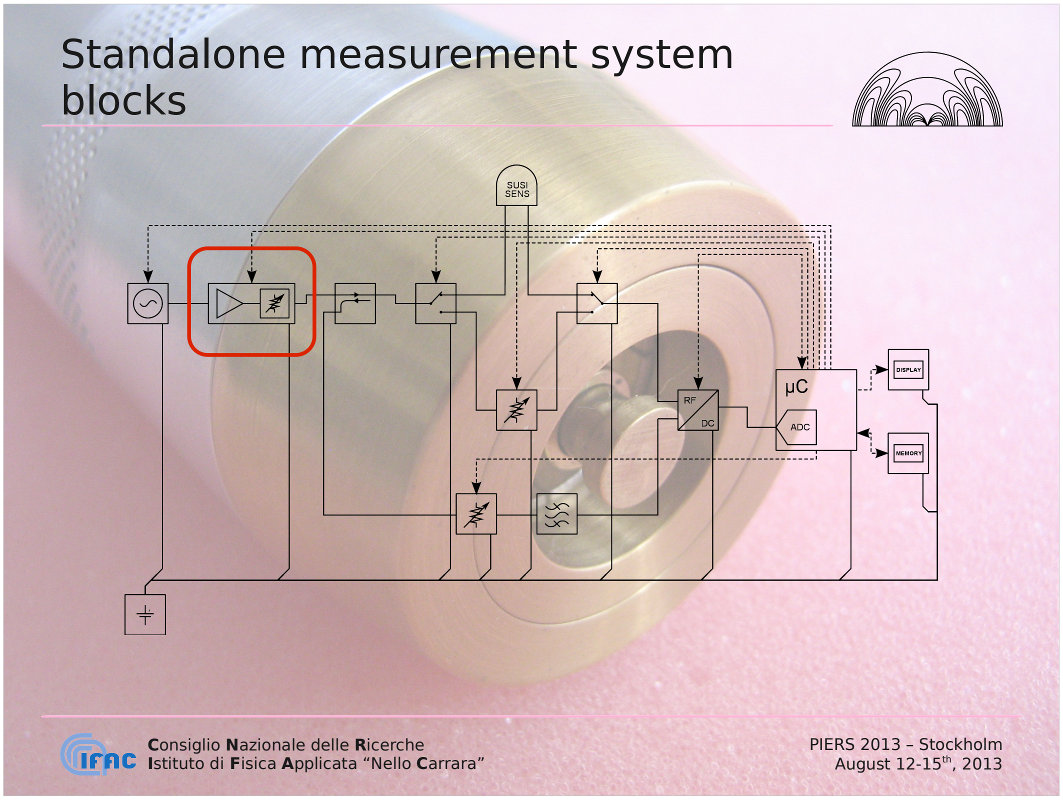


So, let's see some spots of the design of the standalone system.

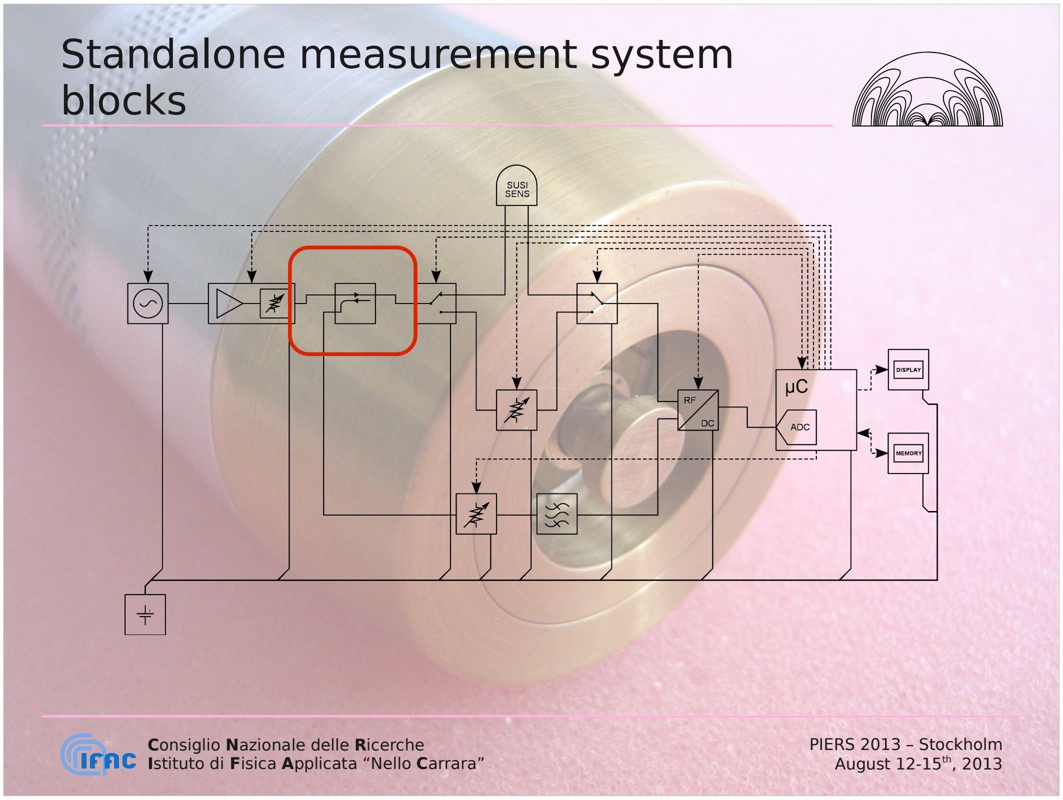
Here we have a principle block scheme of the system.



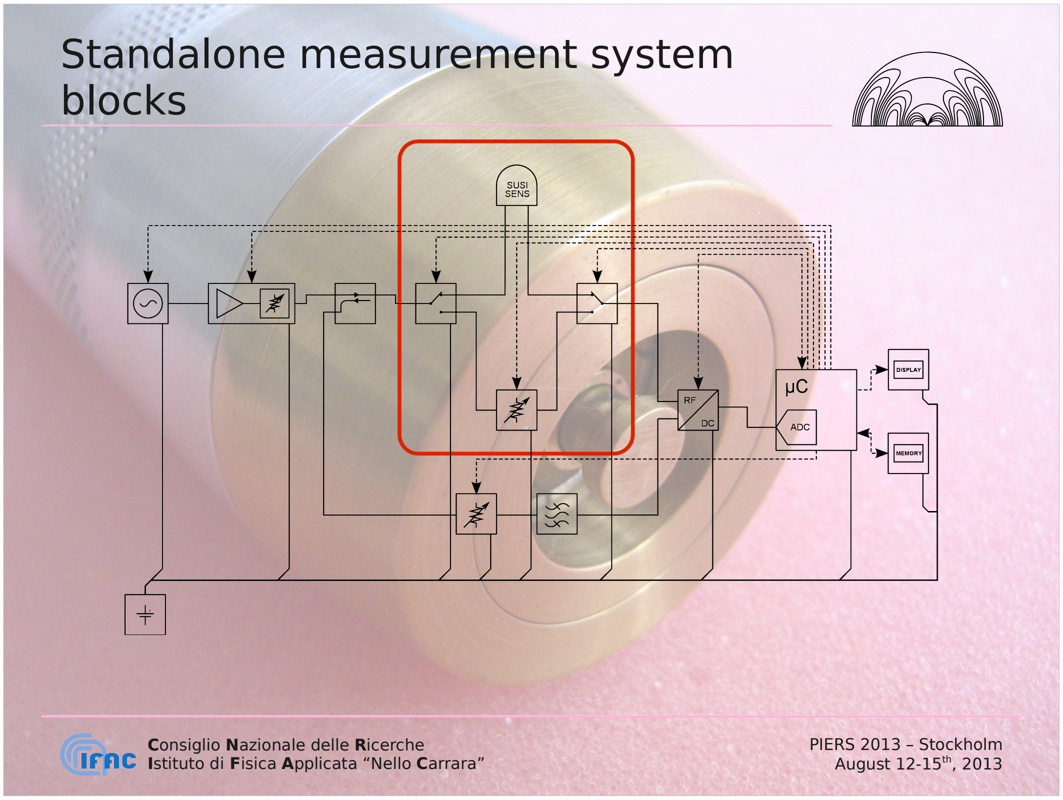
We have a synthesizer with the task to feed the sensor.



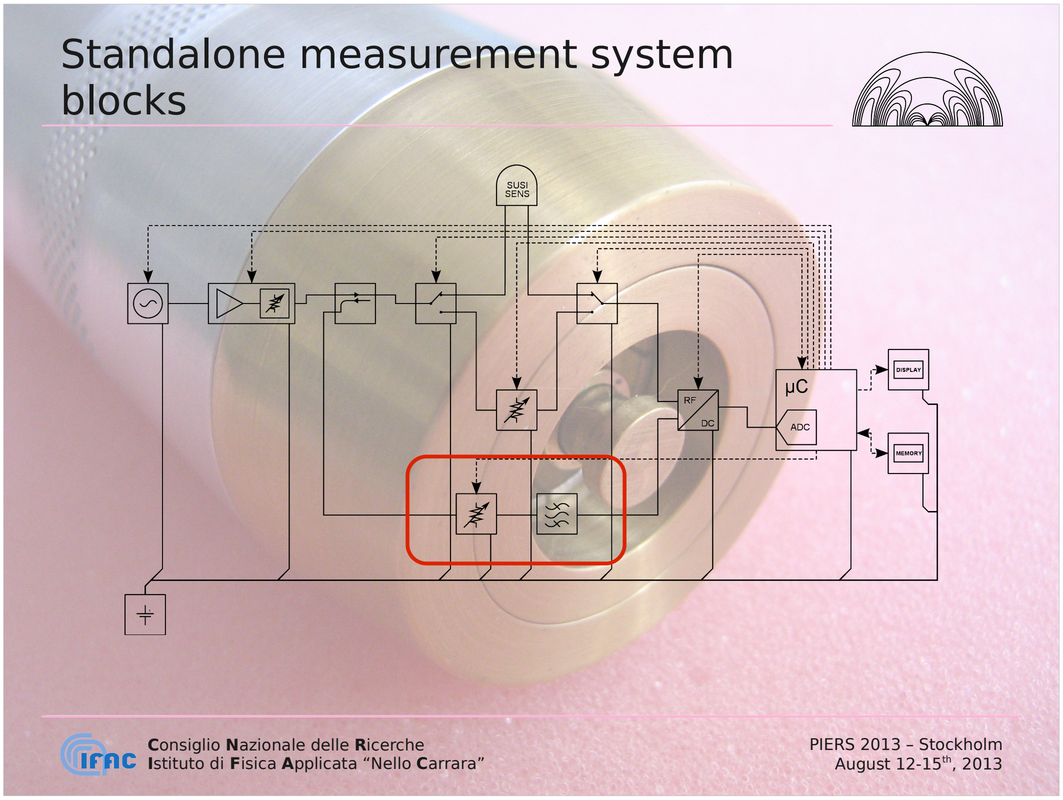
Then we have a block composed by an amplifier followed by an attenuator that act as radio frequency buffer, we will talk in more detail about this block on the follow.



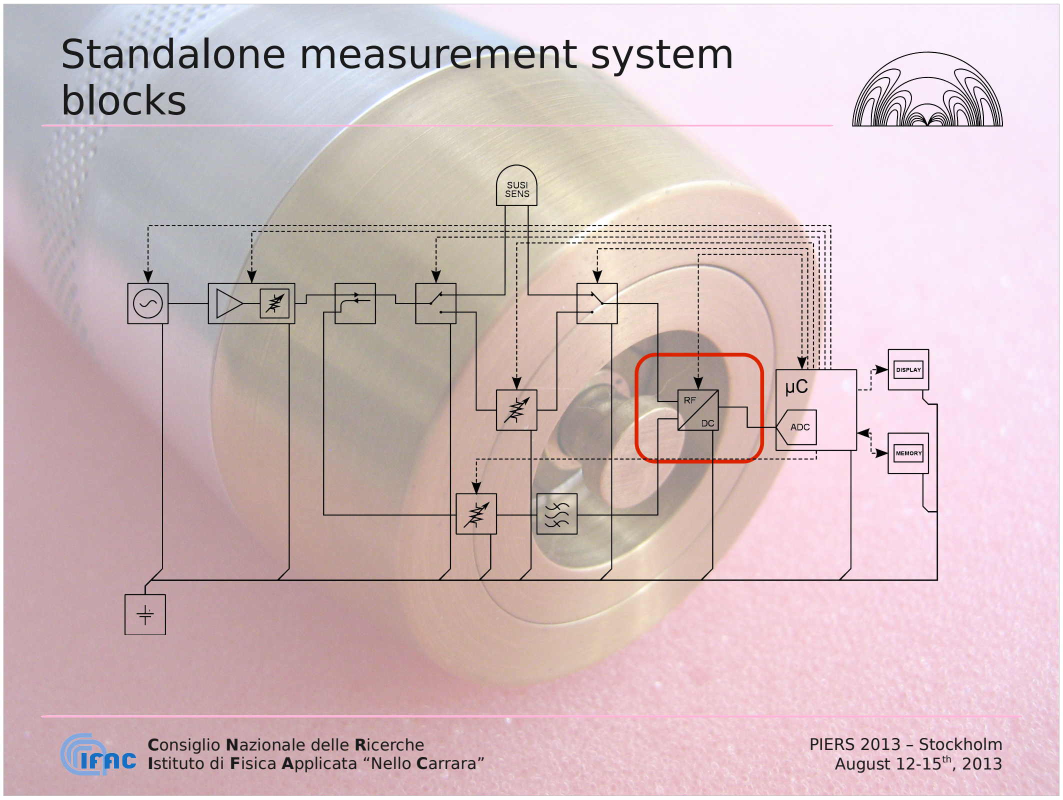
After the RF buffer we have a directional coupler, its purpose is to extract a small portion of the signal produced by the synthesizer to use it as a reference for the measurement of the transmission coefficient.



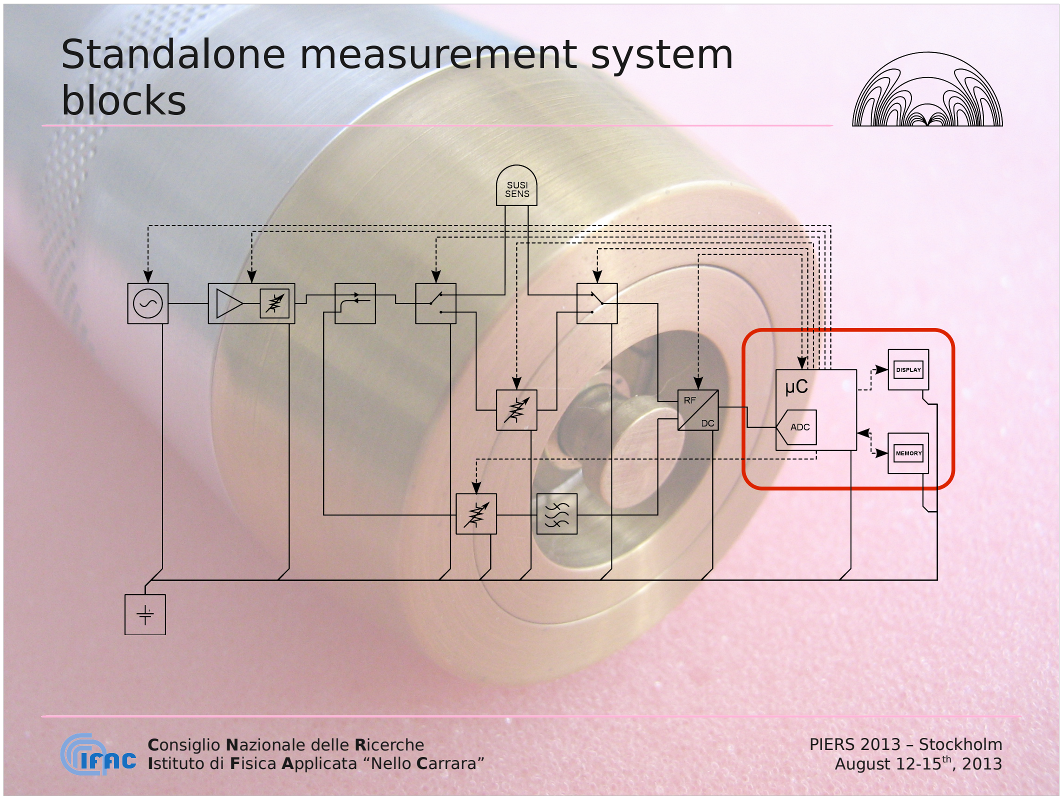
From the main line of the coupler, we go to the sensor, which can be by-passed with an attenuator using two single-pole double through RF switches to perform a sort of calibration of the system.



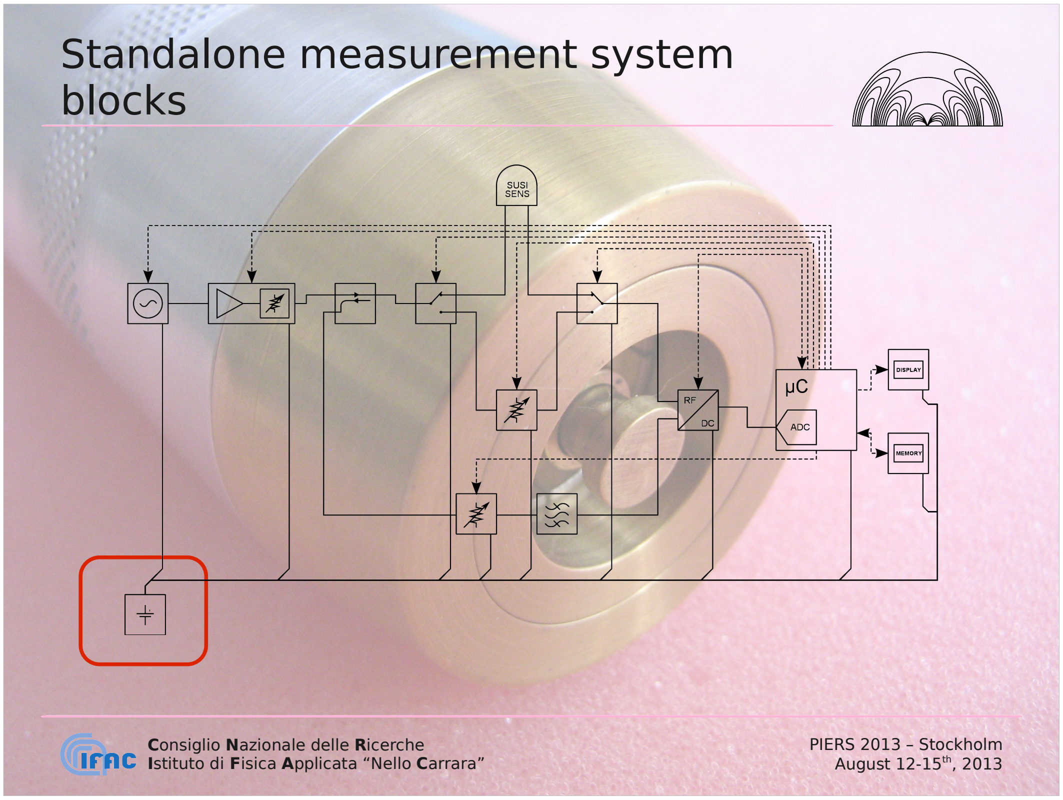
From the coupled line of the coupler instad we go to an attenuator used to reduce the power level of the reference signal to let the receiver to work in its best conditions as we'll see in a moment.



Then the main and the reference lines go to an RF differential receiver which measure the ratio between the power level of the 2 signal and give an analogue DC output.

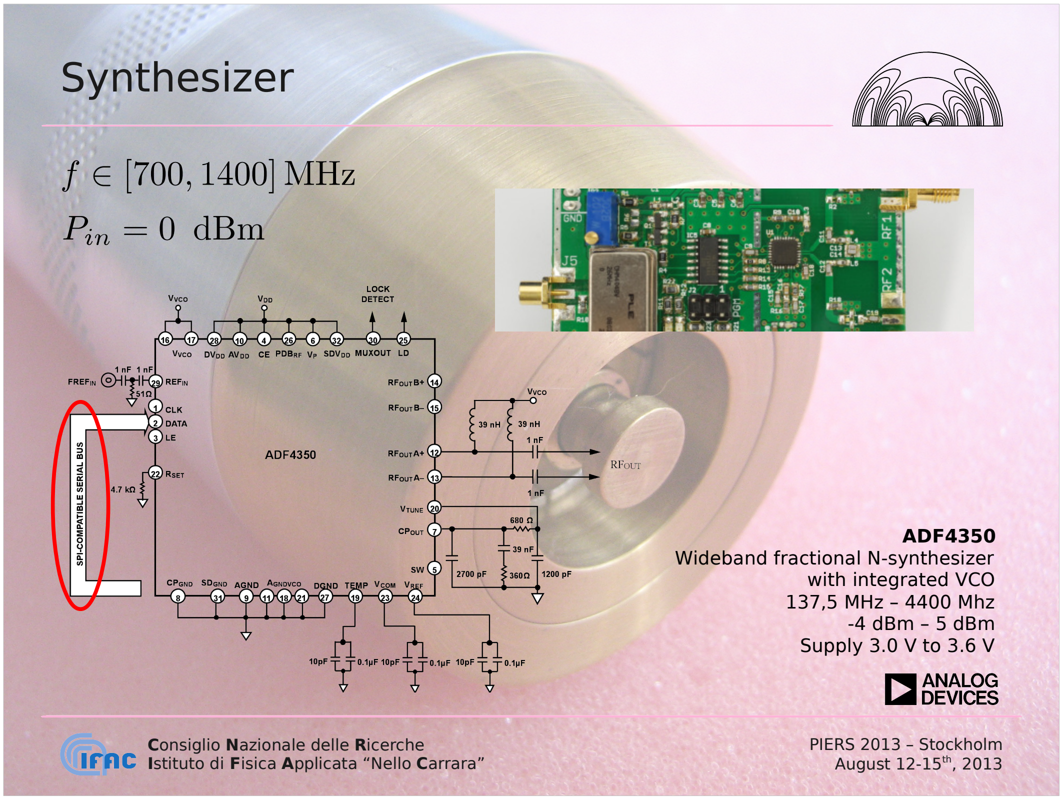


We also have a microcontroller which converts the measured signal, controls the whole system, in particular the synthesizer to perform a frequency span, and then detect the resonant frequency and measure the 3 dB band to obtain the moisture content and the salt index which can be stored in a memory and displayed on a simple LCD screen.



Obviously the whole system is powered by a battery.

Ok, I don't want to annoying you with the design rules of each system blocks, for the most of them you have just to respect some specifications relative to the operating frequency band, the tolerate power level, the flatness of parameters or to resolve some simpler algebraic equations for choosing the value of some of each parameters, but what I want is to focus on the parts which require some particular attention.

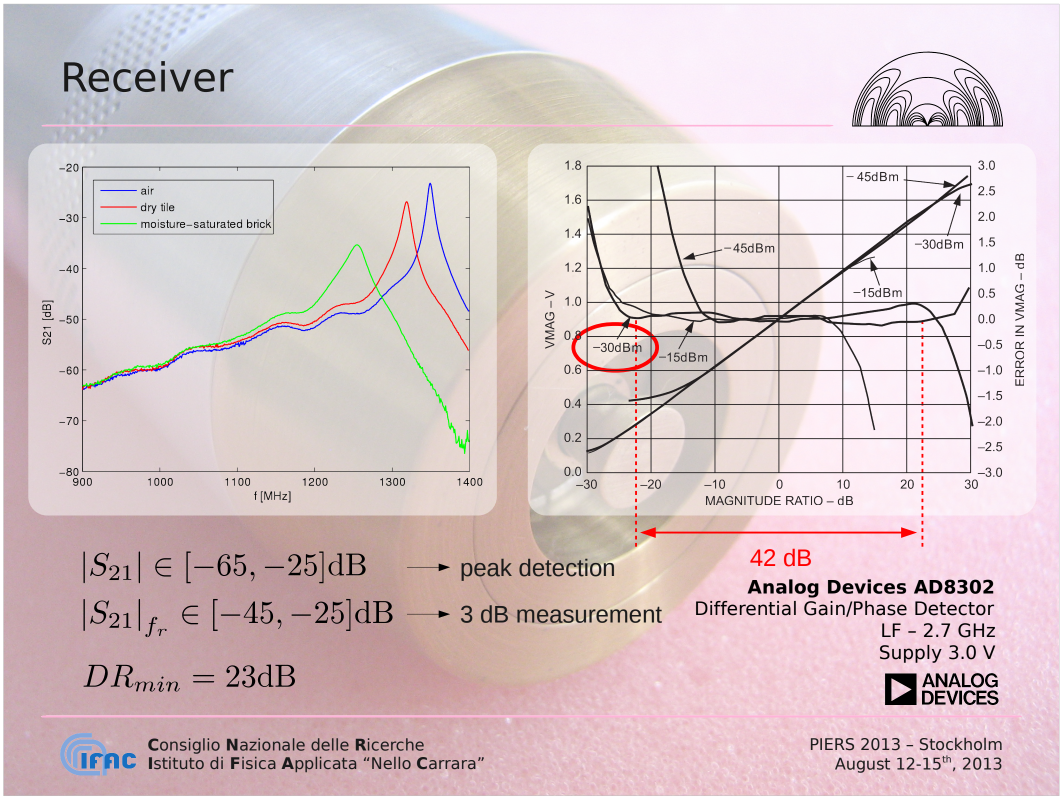


First let's take a look to the synthesizer.

We've used an on-chip synthesizer from the Analog Devices , the ADF4350 model, with an integrated VCO and PLL; we've chosen this particular chip because it perfectly match our frequency and power requirements, in fact our sensor works in about an octave between 700 MHz and 1.4 GHz, and it is designed to be feed with a 100 mW signal.

This particular chip also include a power front end, has a very low power consumption and needs a low-voltage power supply.

In this slide you can see a schematic of the typical usage of the chip which can be controlled with a SPI-compatible protocol.



Here we have the receiver.

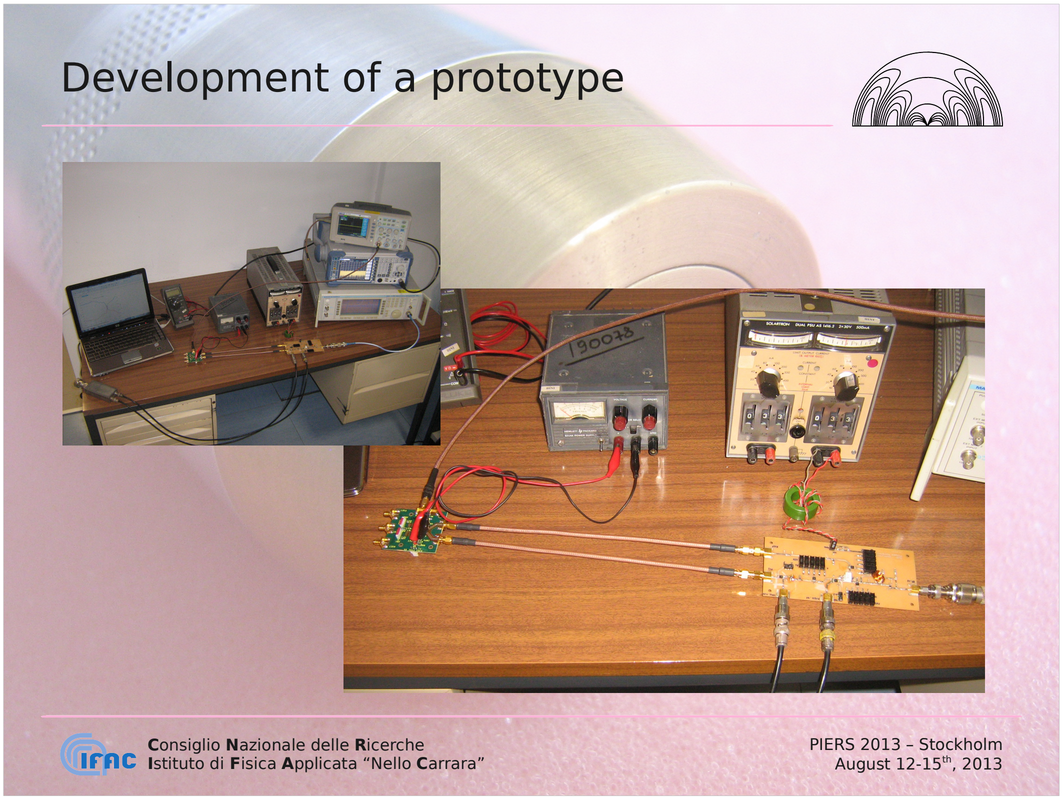
Choosing an appropriate receiver means to take in account the working frequency of course, but principally the required dynamic range of the component.

If you look at the figure on the left of the slide you can see the measured transmission coefficient through the two ports of the sensor in three different conditions: the blue line refers to a measurement on air, the red one is done with the sensor coupled with a dry tile and green one is done using a moisture-saturated brick.

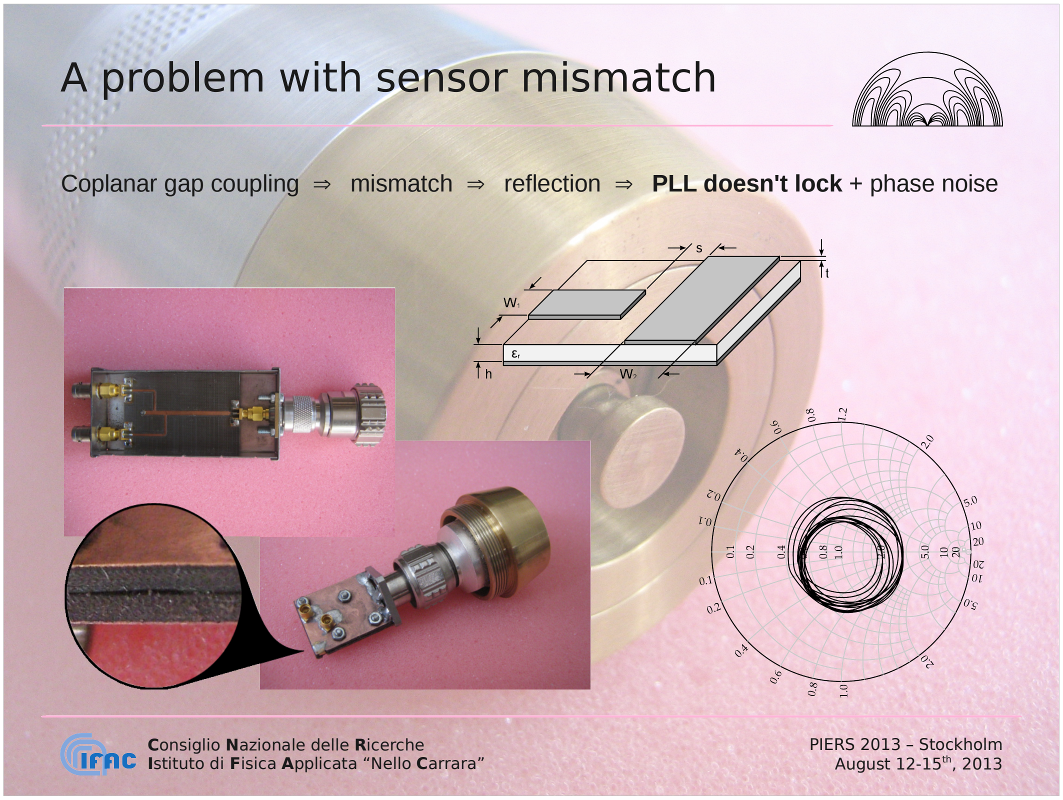
Well, as you can see the peak of the S21 parameter has different amplitudes depending on the measurement conditions and taking into account the most different ones, which are from one side on air which involves low losses, and on the other side on moisture-saturated material with salts which involves high losses, we have that the value of this parameter is always comprised between -25 and -65 dB (the lower level is imposed by noise).

Also the peak is always comprised between -25 and -45 dB so, due to the fact that we want to measure the 3 dB band to determine the quality factor of the sensor, the minimum required dynamic range is about of 23 dB.

Taking into account this consideration we've chosen the integrated receiver AD8320, from Analog Devices again, which is a fantastic differential gain and phase detector with a quite high dynamic range: at least 42 dB remaining in an error range of 0.5 dB, in the condition of -30 dBm as reference signal (and this is the reason we have an attenuator on the reference line of the measurement system).



Here we have some photos of a prototype we built some time ago, on the bottom you can see the setup where the synthesizer is substituted with a lab synthesized signal generator, and a particular of two parts of the system, a board containing the RF section and another one with the receiver.



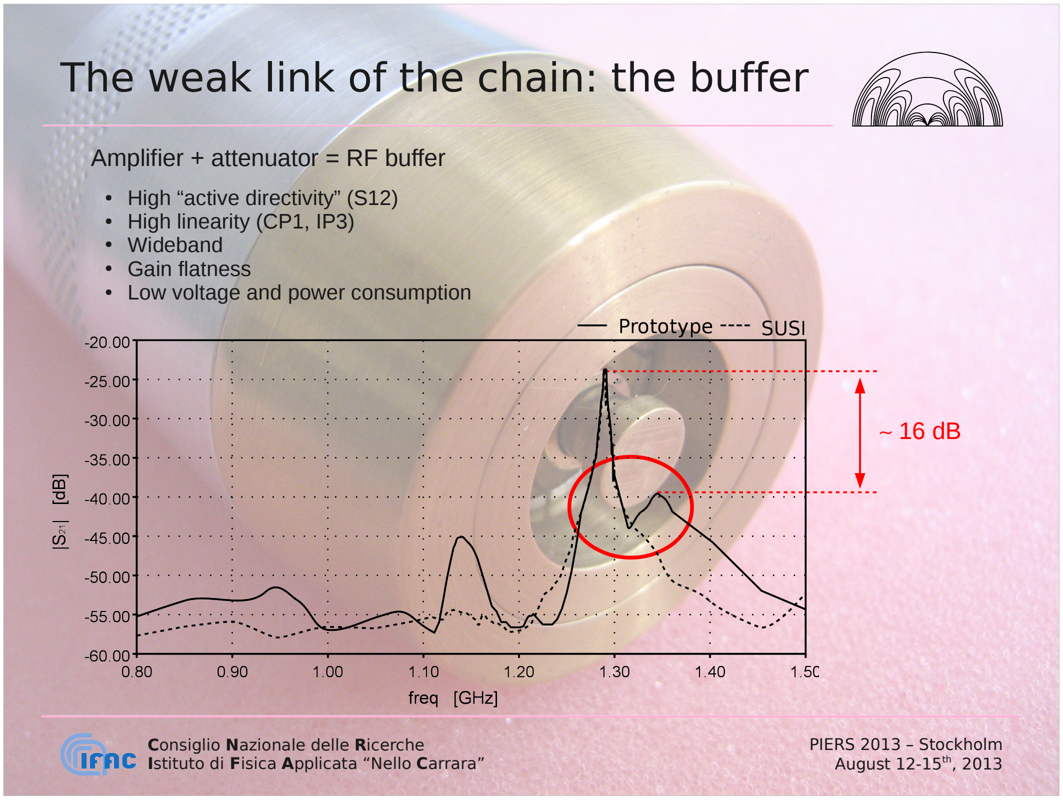
Ok, so all seems to be fine untill now but we have some problem related to the sensor.

As we told on the beginning of this presentation indeed this sensor is a particular resonant cavity coupled with a feed line and another line to extract a signal and perform the measurement of the transmission parameter between the two ports.

As you can see on the right figure on this slide the cavity is realized with a microstrip line, to be precise the first model of the sensor was realized using microstrip, but the recently used one is realized in stripline technology, anyway the coupling between coupled lines and the resonant one is realized in a simple way by using a coplanar gap, as illustrated in the figure on the middle.

This kind of coupling is equivalent to a sort of open circuit of the coupled line and a capacity between the two coupled line relative to the gap so we cannot avoid the mismatch of the sensor ports.

The figure on the bottom left reports the measurement of the reflection coefficient at the port 1 of the sensor and as you can see this is quite mismatched.



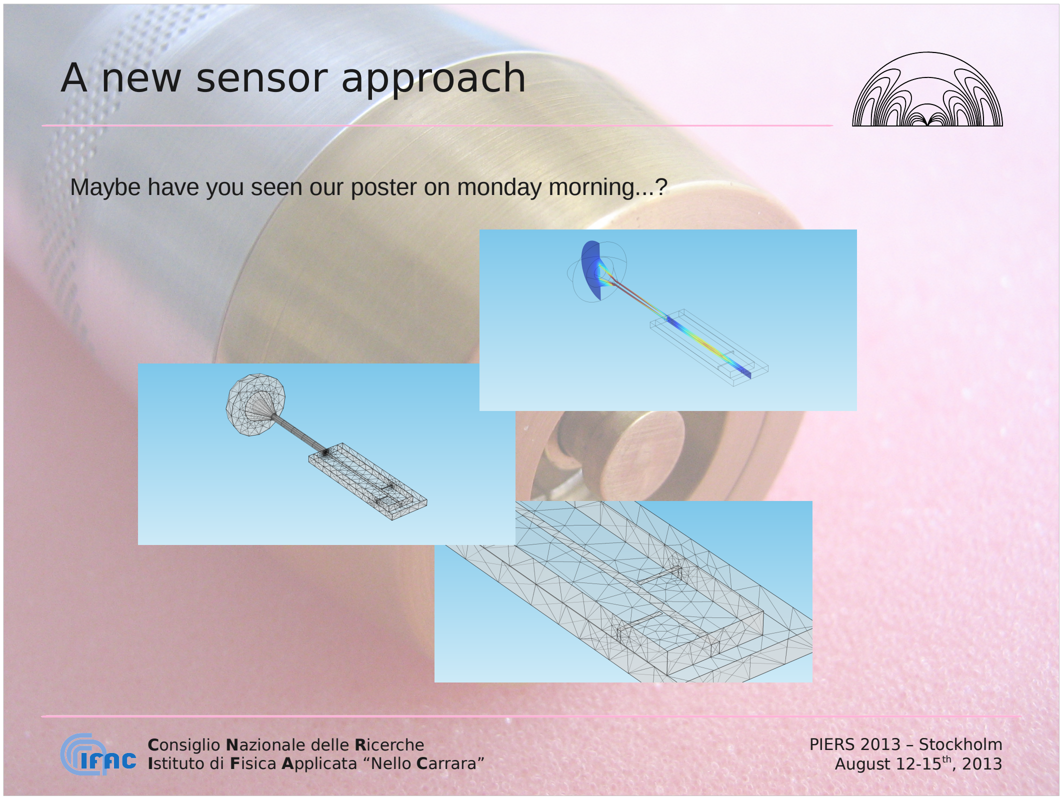
So let me spend some words about the amplifier.

As I told just some slide ago the amplifier followed by the attenuator is just a common way to realize an RF buffer.

This buffer is needed to protect the synthesizer from the reflected signal due to the sensor mismatch: indeed the back coupling of this signal with the synthesizer involves an increase of the phase noise that is not a particular problem on this kind of measurement, but it involves also a more difficult or impossible phase lock of the internal PLL which can slow down the measurement or make it impossible.

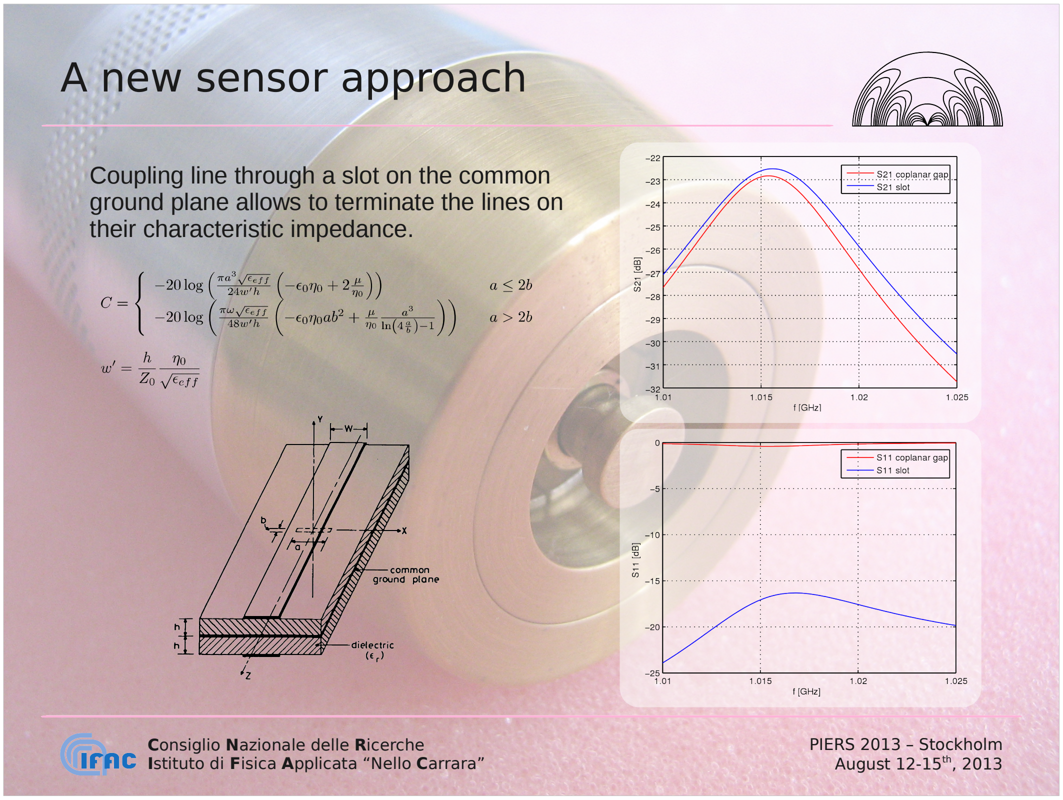
Dimensioning the amplifier is also a little bit tricky because of some specifications like the required linearity, the need of a low power consumption and a low voltage supply, the wide-band, the gain flatness and especially the so called “active directivity” that is a sort of S12 parameters for active devices.

The figure shows a comparison between a measurement on air performed with the existent instrument and another one performed with the prototype realized and as we can see there are also some spurious peak introduced by the variation of the amplifier gain on the scanned frequency band.



So what we want to do is basically to eliminate the amplifier from the system chain, and to do this we have to match the sensor, so our efforts have been moved on the last months on the re-design of the sensor.

We started from modeling the currently used sensor to analyze more in detail the electromagnetic behavior of the coupling and, as we shown in a poster on the poster session of monday morning, we designed a new sensor with the same characteristic of the older one, but with a different coupling method based on a slot on a common ground plane between the coupled lines.



This approach is based on some works that we have rearranged for our purposes that also bring to an approximated formula that link the coupling factor of the aperture with its dimensions and anyway the result at the moment is a full-wave model of the new sensor which allows us to terminate the lines on their characteristic impedance having the same reply of the past sensor but without the problems due to the mismatch.

Well, I think that's all, I would like to thank my PhD advisor Professor Lorenzo Capineri to be here and my colleague, boss and friend Roberto Olmi who allows me to take part to this great conference.

Thank you all for your attention.