A Broadband Standing Wave RF Interferometer for Fast and Low-Cost Spectral Analysis

Simon Hemour#1, Florence Podevin#2, and Pascal Xavier#3

#*IMEP-LAHC GRENOBLE, Minatec, INPG*

3 Parvis Louis Néel BP 257, 38016 Grenoble Cedex, FRANCE

1simon.hemour@minatec.inpg.fr

2podevin@minatec.inpg.fr

3pascal.xavier@ujf-grenoble.fr

***Abstract*— A new type of spectrum analyzer (SWIFTS) based on RF interferometry using a low-cost microstrip technology is presented. The acronym SWIFTS was chosen for Stationary Waves Integrated Fourier Transform Spectrometer. The SWIFTS enables both broadband and fast measurements. It consists of a waveguide ended by a short circuit. Power detectors are periodically spaced along the standing wave to sample the signal. The spectrum is obtained with a Fourier transform calculation. A 0.3 – 5 GHz prototype was built to validate the concept. Measurements on a real cellular phone are presented and discussed.**

Index Terms — Quadratic detector, interferometry, Schottky diodes, spectral analysis, UHF spectroscopy

I. INTRODUCTION

Spectral analysis is one of the bases of the radiofrequency characterization. Many instruments already exist, but none of them offers at the same time low-cost, broadband and fast spectrum analysis. However, nowadays, broadband and fast measurements become more and more necessary. For instance, in the field of EMC, it is important to detect unknown frequency of radar emission or electromagnetic impulses [1] ; health care dealing with RF dosimetry needs to measure wideband RF radiations [2], radio-astronomy desires instantaneous GHz spectrometry to follow the evolution of the atmosphere through the water-vapor absorption [3].

As an alternative to available techniques we propose here a new spectrum analyzer based on RF interferometry. Fabricated in a low-cost technology, this spectrometer uses a standing wave to get the spectral information of an unknown signal. With this technique, the instrument offers broadband and fast measurement capabilities. The theoretical principles have already been explained in [4], which dealt only with simulations and modeling for radioastronomy applications at 22 GHz whilst the actual study focuses on the UHF band (0,3–3 GHz) with an operating prototype.

The paper is divided into five sections. Section II mentions shortly the SWIFTS basic principles while section III explains the main steps of its design with a particular focus on the power detectors. Then, in Section IV, first results of the spectrometer operating in a broadband range are shown. Section V is a brief conclusion of the presented aspects.

II. PRINCIPLE AND TECHNOLOGY OF THE SPECTROMETER

The stationary wave spectrometry was first introduced by Lippmann in 1891 [5] for color photography applications. The idea is close to the analog correlation developed by Blum in 1960 [6]. Similarly, in the microwave domain, in 1989, Williams proposed, a sampled-line analyzer for six-port reflectometer applications [7]. More recently, the SWIFTS principle was applied to optics [8] by Le Coarer and Benech.

Compared to Williams's analyzer which characterizes the load, our instrument is loaded by a short circuit and characterizes the input signal (Fig.1).

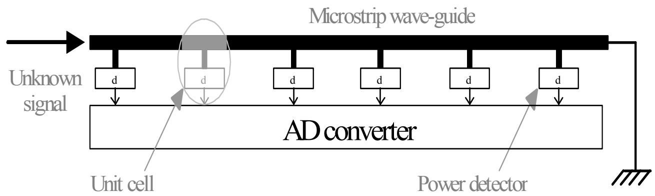

Fig. 1. Conceptual diagram of the SWIFTS.

The unknown signal feeds a microstrip waveguide ended by a short circuit. The microstrip waveguide is etched on a 0.8 mm thick FR4 substrate. This microstrip line is loaded by an array of power detectors and the standing wave is sampled towards a NI 6225 AD Converter which saves the DC voltage for further Fourier transform computation.

For easier design, the sampled line was conceptually divided into unit cells, as shown on Fig. 1. The power detectors are zero-biased Avago HSCH 2850 Schottky diodes that ensure square-law characteristics.

In order to minimize the perturbations of the sampled standing waves, each unit cell has to be carefully designed. In the previous work [4], it has been shown that the spectrometer internal efficiency η_i in Eq. (1) is a function of the coupled amount of energy from the sampled line to the detector, K:

$$\eta_i = 2 \cdot K(1-K)^N \cdot N, \quad (1)$$

where N is the total number of detectors along the waveguide. The maximum efficiency of the spectrometer is reached for a unique value of K depending on N, as shown in the Eq. (2).

For a 32 detectors spectrometer, the best coupling factor is equal to -15dB (3%).

$$K = \frac{1}{1+N} \quad (2)$$

III. Design Optimization

Since the spectrometer may be seen as 32 adjacent cells, the design study has been limited to only one of them. In order to validate this approximation, the single cell S11 parameter has to be small enough to lower the perturbation from one cell to another. In such a way, the first design specification is S11<-30dB. Moreover, as explained in the previous section, the percentage of coupled energy must be equal to 3% (-15dB in the Fig. 2). In order to get a broadband behavior, the design must limit the frequency dependence of S11 and K.

In the previous work [4], the cell design was based on a $\lambda/4$ length probe followed by a zero biased Schottky diode loaded with a printed capacitor. This configuration presented two drawbacks: cross-talk between two different probes and moreover, a narrow-band transfer characteristic which is due to the stub matching of the diode.

In order to solve both issues, in this design the Schottky diode is directly inserted in the microstrip waveguide. The matching network consists here in a SMC resistor of 1.9 kΩ connected to the HSCH 2850 diode in order to reach the 3% coupling. Furthermore, such a configuration of the SMC resistor also prevents the diode from ESD. A thin wire brings the diode output voltage to the AD Converter. Since the wire presents high impedance at radio frequencies, only the DC component of the signal is transmitted.

The unit cell was designed with the use of Agilent's *Advanced Design System* circuit simulator. Fig. 2 shows the coupling factor K and the reflection coefficient S11 of the cell for different frequencies. The cell exhibits a very good coupling factor increasing from -20 dB to -10 dB; from 0.3 GHz to 5 GHz. This rather flat behavior suggests a broadband operation range.

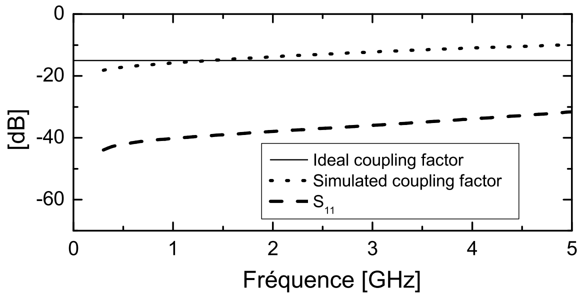

Fig. 2. Reflection coefficient S11 of the unit cell (dashed line) and energy coupled from the microstrip to the detector (dotted line). The maximum of efficiency is obtained at -15dB (solid line).

The S11 parameter is kept under -30 dB in order to improve standing wave ratio. With the fulfillment of the specifications, the complete spectrometer was implemented via an array of 32 detecting unit cells. The final circuit is shown in Fig. 3.

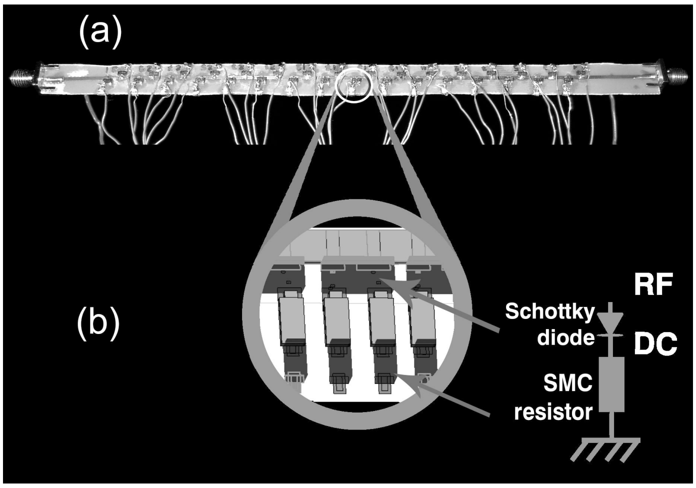

Fig. 3. (a) Photograph of the full spectrometer built with 32 unit cells. (b) 3D view (zoom) and diagram showing details of the cell (diode and resistor).

IV. Experimental Results

A. *Characterization of the single cell*

Measurement has been performed using an Anritsu 68367C synthesized signal generator and a LeCroy 424 WaveSurfer Oscilloscope. In Fig. 4 the output DC voltage from the power detector is plotted versus the input RF power at different frequencies.

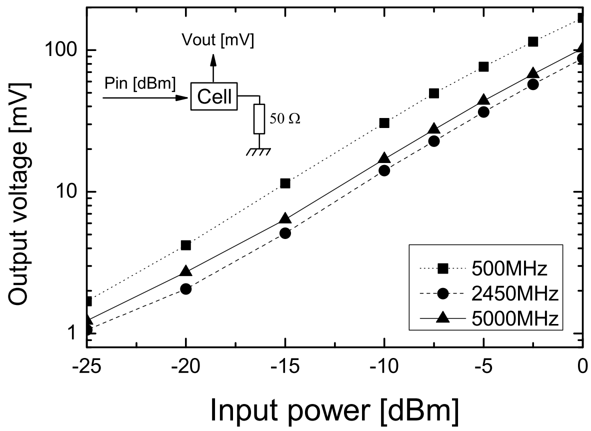

Fig. 4. Detected voltage versus input power in a single detector at 500 MHz (doted line), 2450 MHz (dashed line) and 5 GHz (solid line).

In order to keep a homogeneous sensitivity of the spectrometer over a wide operating range, the diodes should exhibit a similar behavior, whatever the frequency is. Results shown in Fig. 4 display a good behavior with a satisfactory variation (a maximum ratio of 2 over a decade). This is due to the coupling factor and the frequency diode limitation. The low-pass behavior of the diode [9] explains the fact that the DC voltage reached at 500 MHz is higher than the one raised at 2.45 GHz or 5 GHz at a given input power. However, as the coupling factor increases slightly with frequency, the output voltage reaches a minimum in the vicinity of 2.5 GHz. Obviously, calibrating the detector for different frequencies would improve the accuracy of the power measurement.

B. Characterization of the spectrometer

In the setup for RF interferometry depicted in fig 5, the Anritsu 68367C synthesized signal generator feeds the instrument with a single tone signal. The reflection is achieved by an SMA connected to a coaxial cable plugged at the output of the spectrometer. The spectrometer is 15.7 cm long and the 32 detectors are spaced every 4.9 mm. From each detector, a thin wire is connecting the DC output to the NI 6225 AD Converter. During the measurements, the system is attached not to move. To be able to access easily to the output of the SWIFTS without moving the spectrometer, an RG 58 coaxial cable is connected between the spectrometer and the short circuit.

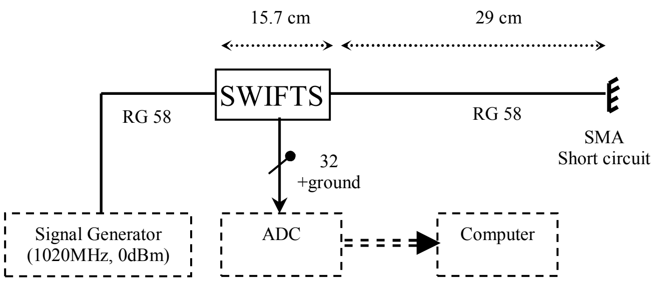

Fig. 5. Measurement setup for RF interferometry using the SWIFTS.

Figure 6 shows the voltage on each of the 32 detectors for an input signal of 1020 MHz / 0dBm. The upper x-axis represents diode number of the sampled point and the lower x-axis gives information of the distance from the short circuit.

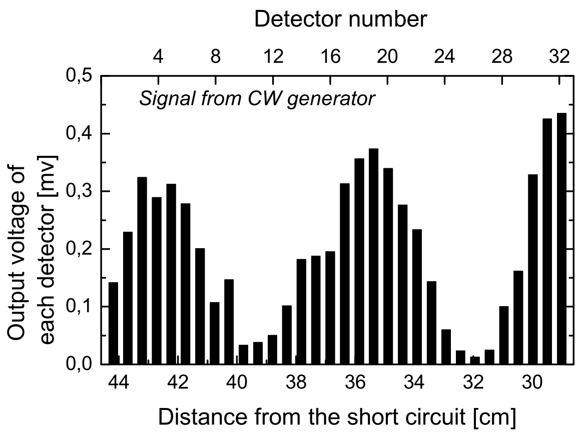

Fig. 6. DC voltage measured on the 32 power detectors placed along the standing wave.

The standing wave is clearly seen, even if the spectrometer should be calibrated to get better accuracy. Calculating the effective dielectric constant ε_{eff} from the period of the standing wave leads to a value of almost 5 while the expected value for this microstrip line should be about 3. This is due to a slowering effect on the wave along the periodically loaded transmission line that has already been shown in other works [10].

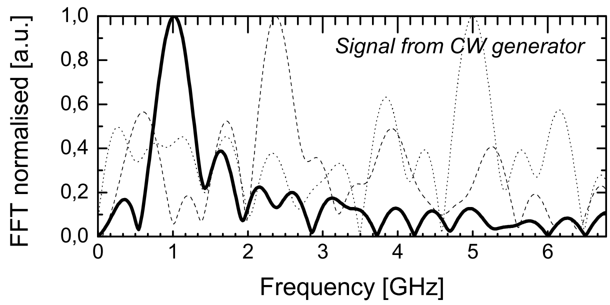

Fig. 7. Fast Fourier Transform (FFT) of the 1 GHz standing wave shown in Fig. 6 (bold line) together with similar results at 2.45 GHz (dashed line) and 5 GHz (dotted lines).

The results of the Fig. 6 were saved on computer and the DC component suppressed. A classical Fast Fourier Transform interpolation (rectangular window + additionnal zeros) was used to recover the spectrum. Fig. 7 displays, in bold solid line, the FFT of the data shown on Fig. 6. It is clearly seen that even with a low number of detectors, thanks to signal processing, most of the spectral energy is recovered at 1020 MHz. The spectral resolution, limited by the total length of the spectrometer will be improved in further work

Fig. 6 also displays results at 2.45 GHz and 5 GHz in dashed and dotted lines. It is noticeable that the 5GHz response is not as good as the 1020MHz one. It can be explained similarly to the Fig. 4 remark: at high frequencies, more current comes through the parasitic capacitance of the diode and less through the junction. Thus, at high frequency DC voltage outgoing of the quadratic detector is less and the signal-to-noise ratio is lower.

In further work, smaller SMC will be used, reducing in this way the parasitic capacitance. It will result in the increase of the signal-to-noise ratio and the operating frequency.

C. Measurement of the emission of a mobile phone

In order to illustrate the potentiality of the presented instrument, a measurement of a 900MHz-band cell phone emission is attempted in free space. The set up looks like the one shown in Fig. 5, but here the spectrometer is fed by a $\lambda/4$ wire antenna. The emission from the cell phone placed at a distance of 30 cm is measured whilst communicating. The ADC samples the DC voltage from the power detectors every 128µs. Fig. 8 shows the pulses of energy emitted by the phone.The chosen unit is the Volt. In fact, each pulse corresponds to the sum of the 32 DC voltages, each one being itself the image of the average power detected by the diodes. Between energy and average power the unique factor is the constant time duration of the pulse. As for Fig. 9, it details the stationnary wave corresponding to one pulse. The figure shows the same comportment of the spectrometer that was seen on Fig. 6.

Finally, Fig. 10 gives the spectral information of this particular pulse with interpolation.

Such measurements, even if the post processing of the measurement remains primitive, demonstrate the fast measurement ability of the proposed instrument in comparison to today's heterodyne broadband spectrum analyzers.

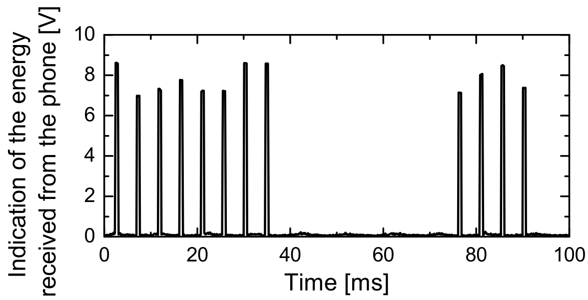

Fig. 8 Measurement of the temporal spikes emitted by a cell phone

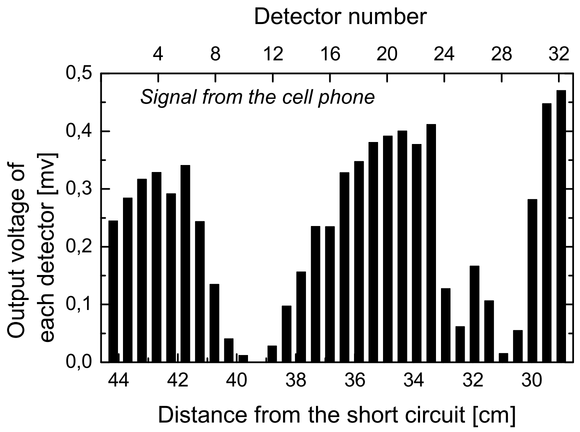

Fig 9 Standing wave corresponding to the first spike shown in Fig 8

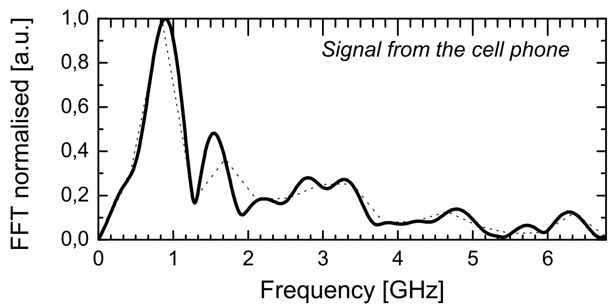

Fig. 10. FFT of the standing wave shown in fig. 8 with interpolation (solid line) and without interpolation (dotted line)

V. CONCLUSION

A new spectrometer (SWIFTS) has been successfully fabricated and measured. It is designed for fast, broadband and low cost measurements. The SWIFTS uses a set of power detectors directly placed along the way of a standing wave. By using this structure, the spectrometer has a broadband operation range and covers the whole UHF band. The performances of this fast and broadband spectrometer have been established with the measurements of a real cellular phone.

VI. ACKNOWLEDGEMENT

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