ANALYSIS OF A WIDE BANDWIDTH UNDERSAMPLED DIGITALLY HETERODYNED SFGPR

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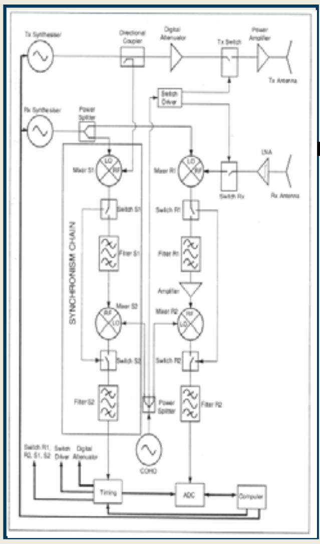
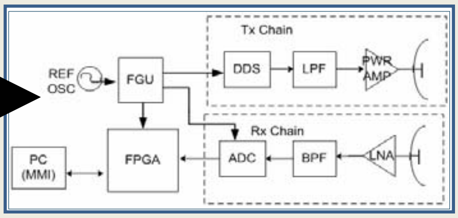
The technical knowledge and field experience achieved during the design of a SFGPR developed in the framework of the ARCHEO project brought to the architecture shown in the figure. This project was funded by the Italian Ministry of the scientific research and industry whose main aim was the development of tools to aid the archaeologists in their field researches.

The purpose of this new design was to develop an architecture that could greatly simplify the radio frequency section of a SFGPR still keeping a wide bandwidth generation capability to achieve a high resolution.

An **heterodyne** architecture was chosen where the **quadrature downconversion** is performed digitally on the undersampled signals. This choice allows to alleviates not only the problems typical of homodyne GPR related to the flicker noise (in that the frequency of the signal to be sampled is always greater than 0 Hz, i.e. 1 MHz) and to the drift of DC values with the temperature but also the problems related to the quadrature demodulation in that it is performed in the digital domain instead of the analog one by direct acquisition of the IF signal.



ARCHEO SFGPR ARCHITECTURE



NEW SFGPR ARCHITECTURE

Transmitting Chain (Tx Chain): the signal to be transmitted is generated by means of a Direct Digital Signal generator (DDS), its output is low pass filtered and amplified prior to be sent to the transmitting antenna. The clock of the DDS is provided by a frequency generation unit.
Receiving Chain (Rx Chain): the signal received by the antenna is amplified by an Low Noise Amplifier (LNA) and provided to a large band ADC; the signal is undersampled with sampling frequencies provided by the FGU. The samples acquired are transferred to an FPGA whose aim is to perform the quadrature downconversion in the digital domain; the local oscillator of this downconverter is chosen according to the frequency of the transmitted signal and to the planned sampling frequency; its phase takes into account the possibility of spectral inversion of undersampled signals also.
Frequency Generation Unit (FGU): aim of this unit is to generate all the frequencies employed in the SFPGR from a very low phase noise master oscillator: DDS and ADC clocks, FPGA reference clock.
The main advantages of the presented architecture are:
- Absence of a synchronism chain, generally used in SFGPR to get a phase reference of the transmitted signal [2];
- Simplified RF front end: both Tx and Rx chains are substantially constituted by an amplifier and a filter; this simplification is allowed by the undersampling of the received echoes; Simplified Frequency Generation Unit;
- Substantial reduction of the power consumption and weight due to the great simplification brought in the RF front end.

In an heterodyne SFGPR to simplify the acquisition of the echoes, they are downconverted to a common intermediate frequency, F_if . This is usually achieved by means of another frequency generator whose tone is at F_if Hz away from the transmitted tone. The idea proposed started from the purpose to eliminate this second frequency generator by direct acquisition of the echoes received and from the consideration that the bandwidth of the tone transmitted during each step is small (at most few kHz). Undersampling was the optimum choice that allow to solve both the problems: the downconversion of the signal is performed automatically (as result of the sampling process) and the signal is sampled optimally without the need to oversample it (in fact the frequencies of the tones transmitted are in the order of 100 MHz – 400 MHz that would require a sampling frequency of 250 MHz – 1 GHz, well above the few kHz needed to acquire the transmitted bandwidth according to the Nyquist criteria for bandlimited signals). Once acquired the echoes are digitally downconverted (quadrature downconversion) to determine their phase. Due to the necessity to adapt the undersampling process to the possible various set of parameters chosen for the SFGPR (*initial frequency, frequency step, number of step*) it may be necessary to modify the sampling frequency on a step by step basis.

The method presented is based upon the "**normalised acceptable bandpass sampling rates**" map. The use of this map allowed also to define a criteria of "best choice", where best means the values that allow to relax the requirements on the anti-alias filters in the analog domain as well as the digital low pass filters following the digital quadrature demodulator.
The aim of the outlined procedure is to find a couple of sampling frequencies with which sample all the SFGPR frequency steps. To reduce the computation effort it takes into account only integer values for the sampling frequencies and the verification is limited to verify which step frequency can be properly acquired by each sampling frequency.
The outputs of this procedure consist of matrices of True/False values, where true means that the corresponding frequency step can be properly acquired. These matrices are important in that they immediately show the combinations of sampling frequencies that can be chosen. Of course the first values that one should take into account are the lowest possible values of the sampling frequencies in that generally they guarantee a lower phase noise.

The figure reports the sampling frequencies (f_ADC) that can be used for each value of the Increment of the Step Frequency to be chosen. The black points represent the useful values (True value). The results shown in this figure must be interpreted as follows: by keeping almost constant the total bandwidth to be transmitted (by acting on the number of step frequencies to be transmitted), for each value are shown all the possible sampling frequencies (black points, if any) that are sufficient to sample all the step frequencies.
This is the first interesting result of the new procedure adopted: by proceeding in this way it is possible to discover the existence of sampling frequencies that alone can be used for suitable operations of the SFGPR proposed.
For what concern the other values of f_ADC (white points, False value) it is not possible from this figure to determine if they can be used or not. To this end other figures are necessary (not shown for sake of clarity). They are obtained by fixing the value and by reporting for each f_ADC value which step frequencies can be acquired in a suitable way.