EXCITATION AND REFERENCE GENERATOR FOR DUAL FREQUENCY EIT

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Abstract: Construction of a dual frequency generator is presented. The generator is one of main components of the modular dual-frequency impedance tomograph. The generator has been designed using the Direct Digital Synthesis (DDS) method (Figure 2). It provides both, the excitation and the reference signals.

Introduction

Current or voltage generator is one of the main parts of electroimpedance tomograph [1,3]. It directly determines, among others, the quality of images. It should be of high stability, both amplitude and frequency. Moreover, this requirement is more crucial when dual frequency and differential approach is considered. It follows from the conversion of frequency deviation to amplitude variations. This phenomenon is involved when frequency dispersive media are measured. It has been noticed that the frequency instability significantly reduces the overall system accuracy.

A design and parameters of signal generator for dual frequency differential tomography are presented in the paper.

Methods

The idea of measurement is presented in Fig. 1. This technique of measurement can be applied for materials with frequency dependent electrical parameters such as conductivity or permittivity (see Figure 1a). A sum of two excitation patterns of different frequencies is applied to a boundary of examined object (Figure 1b).

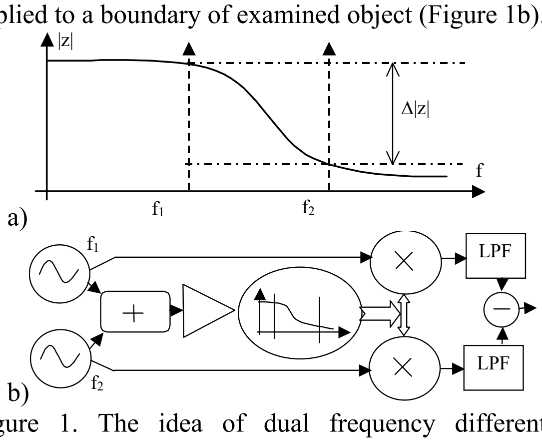

Figure 1. The idea of dual frequency differential measurements

Then, the resulting signals, at two frequencies, are measured simultaneously using two detectors consisting of analogue multipliers (marked ⊗) and low pass filters. Finally, the difference between these two signals is obtained by analogue subtraction, amplified and converted to digital word.

The generator has been designed using the Direct Digital Synthesis (DDS) method (Figure 2). Presented generator consists of four DDS (AD9835 Analog Devices) and is controlled by an AduC812 microconverter (Figure 2) [2]. The AD 9835 is a complete 10-bit DDS system that can work up to 50 MHz. The generator provides both, the excitation and the reference signals. The output signal of the generator can be described by (1) while each of the reference signals is described by (2). A_1 and A_2 are the amplitudes of each independent component of excitation signal while A_{rn} refers to amplitude of reference signal. The amplitude can be adjusted using a software procedure in range of 0-2V_{pp} with 12-bits resolution.

$$U_o(t) = A_1 \cos(\omega_1 t + \varphi_1) + A_2 \cos(\omega_2 t + \varphi_2) \quad (1)$$

$$U_{rn}(t) = A_{rn} \cos(\omega_n t + \varphi_n) \quad n = \{1,2\} \quad (2)$$

The frequency of each component is a fraction of the master clock with 32-bit fraction word. It can be selected within range of 1 Hz to 10 MHz and programmed with 32-bit frequency divisor FWRD:

$$f_{out} = \frac{f_{mclk}}{FWRD * 2^{32}} = \frac{48MHz}{FWRD * 4294967296} \quad (3)$$

$$FWRD = \frac{f_{mclk}}{f_{out} * 2^{32}} = \frac{48MHz}{f_{out} * 4294967296} \quad (4)$$

Where FWRD is a 32-bit frequency divisor word and it can be integer only. Each generator allows presetting the phase shift of its component with 12-bit accuracy:

$$\varphi_{out} = \frac{2\pi}{4096 * PREG} \Rightarrow PREG = \frac{2\pi}{4096 * \varphi_{out}} \quad (5)$$

A complete 48 MHz high stability crystal oscillator has been used as the reference generator for the DDS units. It produces square TTL wave.

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Each of DDS has serial interface for writing the configuration, frequency and phase programming. Serial interface consists of three lines: FSYNC, SDATA and SCLOCK. The SCLOCK and SDATA lines are used for data transfer while the FSYNC line is used for update of the internal registers in the DDS and it is responsible for initiation of the generators.

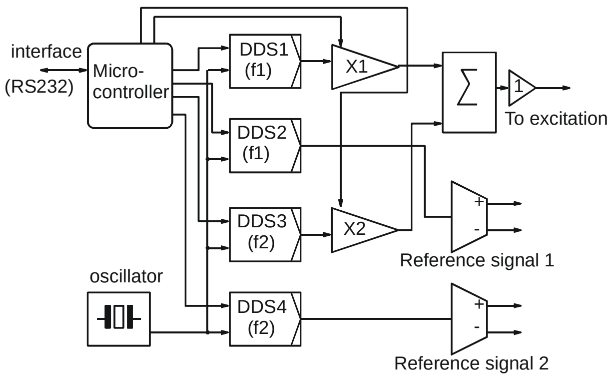

Figure 2. Block diagram of the generator unit

Programming of the four generators demand a method of the synchronisation in order to guarantee the programmed phase shifts between generators. For this purpose the FSYNC line is used. Each FSYNC lines from the four DDS circuits are connected together and controlled from one line of the microcontroller. Also to save the microcontroller ports all SCLOCK lines from DDS1-DDS4 are connected to the same line of the microcontroller (Figure 3).

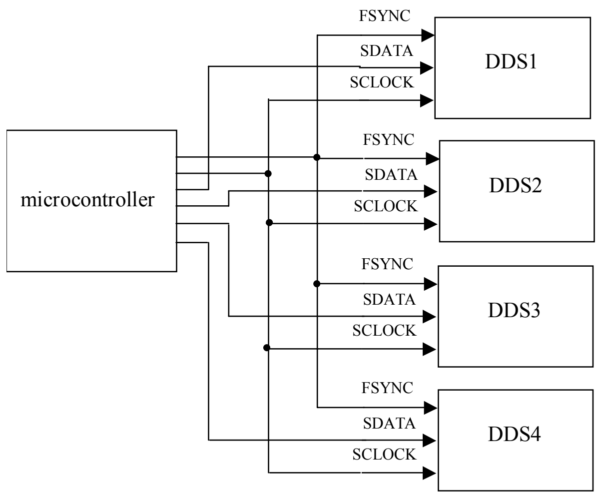

Figure 3. Schematic diagram of the DDS programming interface

During the programming phase the FSYNC line should be held low. During that period all transmission occurs to all the DDS units simultaneously. Usually configuration words of frequency and phase have to be written here. Low to high transition of the FSYNC line initiates the generation for all the DDS.

DDS1 and DDS2 are set to the same frequency of operation similarly DDS3, DDS4 are set to other one. The signals from DDS1 and DDS3 are summed and they are sent to circuit producing excitation pattern. The DDS2 and DDS4 are used for generating of the reference signals for demodulation. The phase shift between DDS1 and DDS3, similarly between DDS2 and DDS4, can be programmed. This enables demodulation of real or imaginary components of the measured signal.

An MC1495 four-quadrant multiplier can adjust the output amplitude of the DDS1 and DDS3. The multiplier is controlled by 12-bit DAC from AduC812 microconverter (Figure 4).

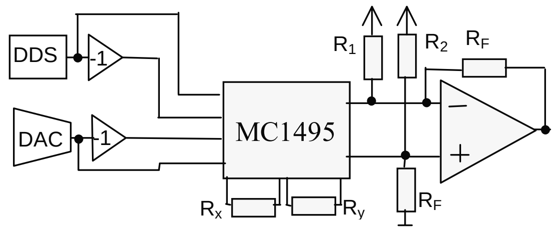

Figure 4. Output signal amplitude control

The reference signals (from DDS2 and DDS4) have value of amplitude set to $50mV_{pp}$. The amplitude can be adjusted internally before the operation and cannot be programmed while in use. Both reference signals have symmetrical output to directly drive the analogue multipliers such as the MC1496. The symmetrical output has been designed with use of high-speed operational amplifiers AD817 made by Analog Devices.

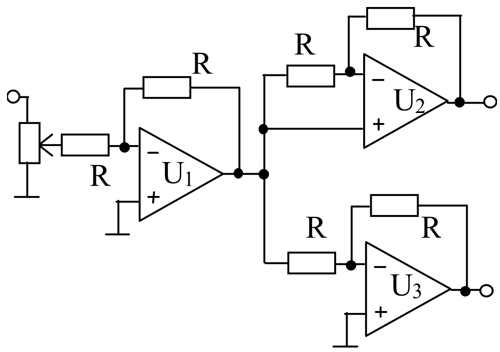

Figure 5. Schematic diagram of the reference signal driving circuit

Analogue demodulation is based on multiplication of the measured and the reference signals and thus it is very sensitive to reference signal quality. The measurement error comes from both, phase mismatch and the noise introduced in the reference signal.

Results

The generator has been manufactured and tested at Biomedical Engineering Department, Gdansk University of Technology. For testing purposes a Windows based application for writing in the frequency and phase registers has been developed (Figure 6). Application allows calculating values of the DDS registers from introduced phase and frequency and in reverse order. Additionally, calculated values of

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registers can be uploaded to generator to produce the desired waveform.

A testing set-up consists of the DDS generator, controlled via RS232 interface, the spectrum analyzer HP8591E (Hewlett Packard), and digital-storage oscilloscope Gould Classic 6000. An additional 20 dB attenuator have been used in front of the spectrum analyzer in order to protect a fragile input of the instrument.

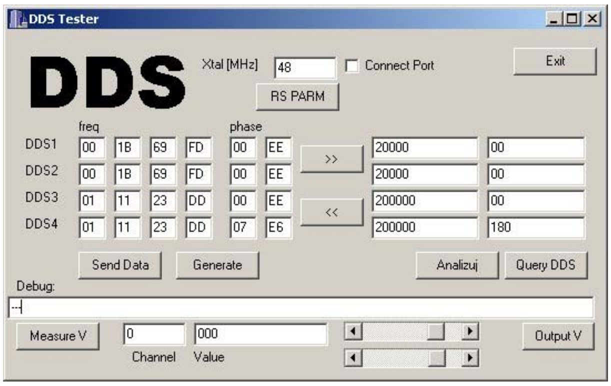

Figure 6: Testing application

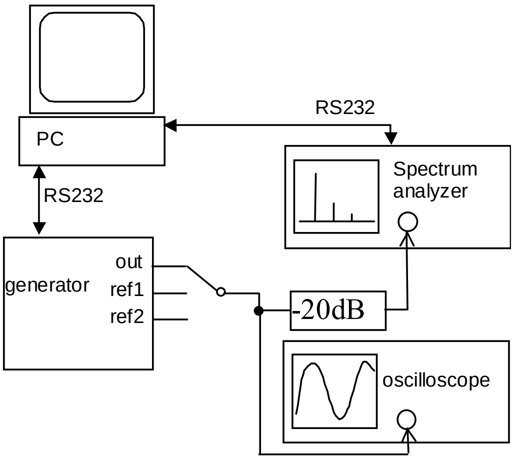

Figure 7: Measurement set-up

First, an output of the generator was connected to input of the spectrum analyzer while the power was disconnected. It allows measuring radio frequency introduced into the band of interest. Result of the measurement is shown in figure 8. It shows that the largest amount of introduced radio frequency was within 0-1 MHz. The largest peak was at the level of about –50 dB. After power-up generator is always set to produce two signals at reference output: 20kHz and 200 kHz. The signal is present at reference outputs only while output of measurement signal is always set to 0. Observing the output of the generator shows presence of several signals: the 48 MHz DDS clock at about –35dB level, and peaks roughly at 22 and 33 MHz. They are second and 3'rd harmonics of the microcontroller clock (11,059 MHz), respectively (Figure 9). The output spectrum of the reference signals is shown in figures 10 and 11, respectively.

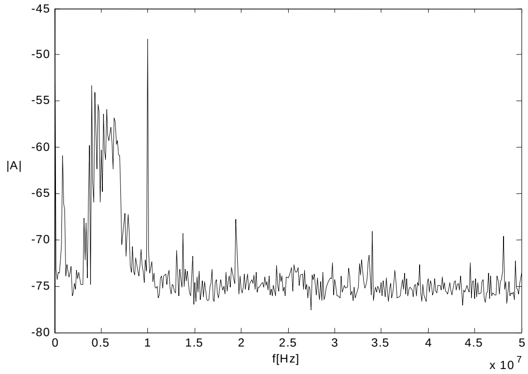

Figure 8: Spectrum of the background noise

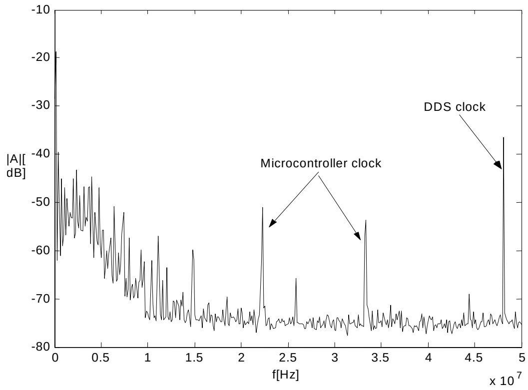

Figure 9: Output signal of the generator after init.

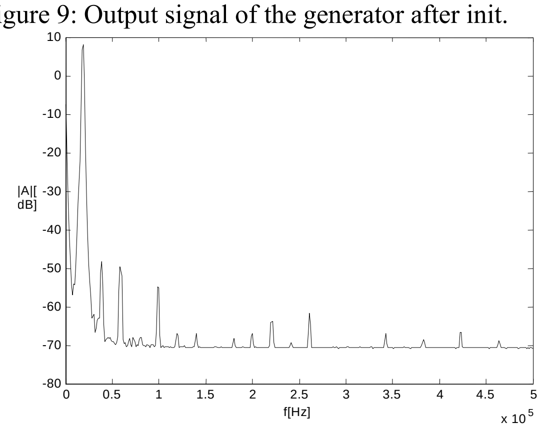

Figure 10: Output spectrum of the reference signal at frequency 20 kHz

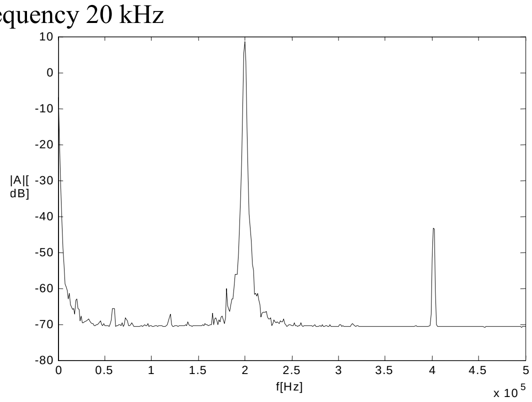

Figure 11: Output spectrum of the reference signal at frequency 200 kHz

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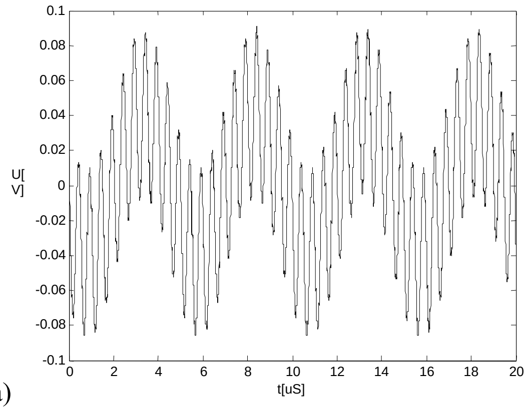
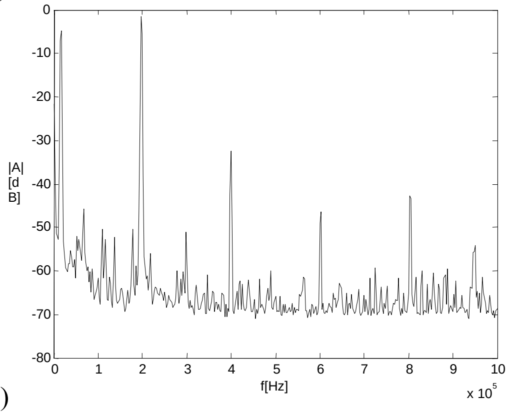


a)



b)

Figure 12: Output DDS signal – two sinusoid 20kHz and 200kHz a) and its spectrum b)

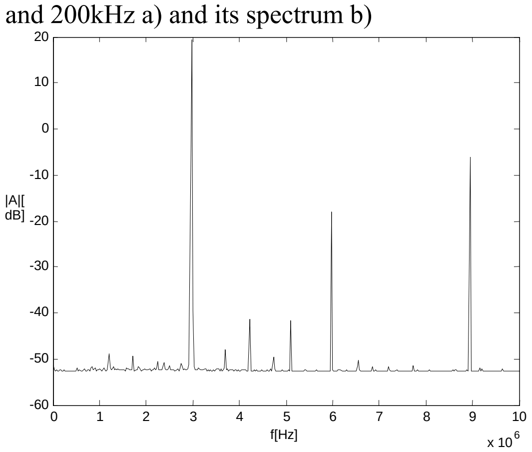


Figure 13: Single 3 MHz output signal

Table 1: Parameters of the generator

Parameter	Value
Frequency range	1Hz – 10MHz for each channel
Resolution of the output signal	10 bit
Output amplitude of excitation	2Vpp max for channel
Output amplitude of reference	100mV pp differential
Frequency stability	+/- 100ppm (temp. 0-50 C)
SNR	50dB (48MHz clock 2MHz out)
THD (thru 6'th harmonic)	<0.25 %

The signal at the output of the generator is consisting of two sinusoids having two different frequency 20 kHz and 200 kHz, respectively is presented in figure 12. The basic parameters of the generator are collected in table 1

Conclusions

The generator, utilizing the DDS approach, has been designed and manufactured at the Biomedical Engineering Department.

The design of the generator demands very careful PCB design. Design has to be modular with good ground and power nets. Major modules of the unit should have separate power nets. Analogue part of the generator should be separated from digital one. A proper protection from cross talks of clock signal is another important problem. A good example of such phenomenon is influence of the crystal resonator on the measurement signal (see Fig. 9). If the resonator is not properly decoupled using small capacitors it may produce harmonics of basic frequency signal. Decoupling reduces these harmonics significantly. Also all power lines supplying all integrated circuits have to be very well decoupled using appropriate capacitors. Good idea is to use both ceramic and electrolytic capacitors in parallel. The latter one should be of low series resistance (low-ESR).

The DDS-based generator is probably the best choice for dual frequency and differential EIT. It can guarantee stability of frequency and amplitude over the measurement time. Also, phase shift between the reference and output channels can be programmed and fixed. The developed generator improved the quality of reconstructed images due to overall noise reduction and its stability. The main disadvantage of the DDS technology is presence of the harmonics in the output spectrum, however careful design, shielding, and signal filtration can minimize this phenomenon.

References

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