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The AC parameters measurement system for ultrasonics

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Abstract
The AC response measurement system is presented. System structure, operation and main units operation are described. The connection setup for a few most common tasks is presented. The obtained results are given. It has been indicated that AC response can be investigated for ultrasonic preamplifier, matching transformer, system filters and ultrasonic transducers. The system is controlled by a personal computer via USB interface.
Keywords: AC response, harmonic waveform excitation, impedance measurement.

Introduction

The AC response is one of the essential parameters of every electronic system. This is also the case in ultrasonics. It is quite useful to have the opportunity to obtain the AC response of the ultrasonic device both during design process and in the operation period. Limited AC response mayinfluence electrical parameters or limit the system performance [1].

In this paper we present the design of the AC parameter measurement system dedicated for ultrasonic equipment evaluation.

The system

The system (Fig.1) contains both the excitation and the receiving units. The excitation channel and the receiving part are connected to the circuit under investigation according to the needed measurement scheme. The driving channel is built using the direct digital synthesizer (DDS) AD9851 from Analog Devices [2]. The DDS technology has significant advantages in many applications and its use will become increasingly common. Using a reference clock and the linear aspect of the phase, the DDS generator can generate very accurate sine waves of almost any frequency completely in the digital domain. This sine wave can be used directly as a highly linear and stable frequency source. The AD9851 contains a unique x6 reference clock multiplier circuit that eliminates the need for a high speed reference oscillator. The AD9851's output waveform is phase-continuous in case of the frequency change from one value to another.

The DDS generator consists of three major components - a phase accumulator, a sine wave lookup table (usually contained in ROM), and a digital to analog converter (DAC). The phase accumulator basically performs an integration function and generates a linear phase "ramp" in proportion to the desired frequency. The sine lookup table converts the linear phase ramp into a sine wave. Even though the AD9851 contains a 32bit frequency control register, a 32bit (2^{32} memory bits) lookup table is not required, as it only has a 10bit DAC. So the sine lookup table does not need to be much more accurate than this, in this case it is only 12bits. This ensures that the accuracy of the signal is determined entirely by the DAC resolution and linearity. The output signal after filtering and amplification can be attenuated by smooth attenuator

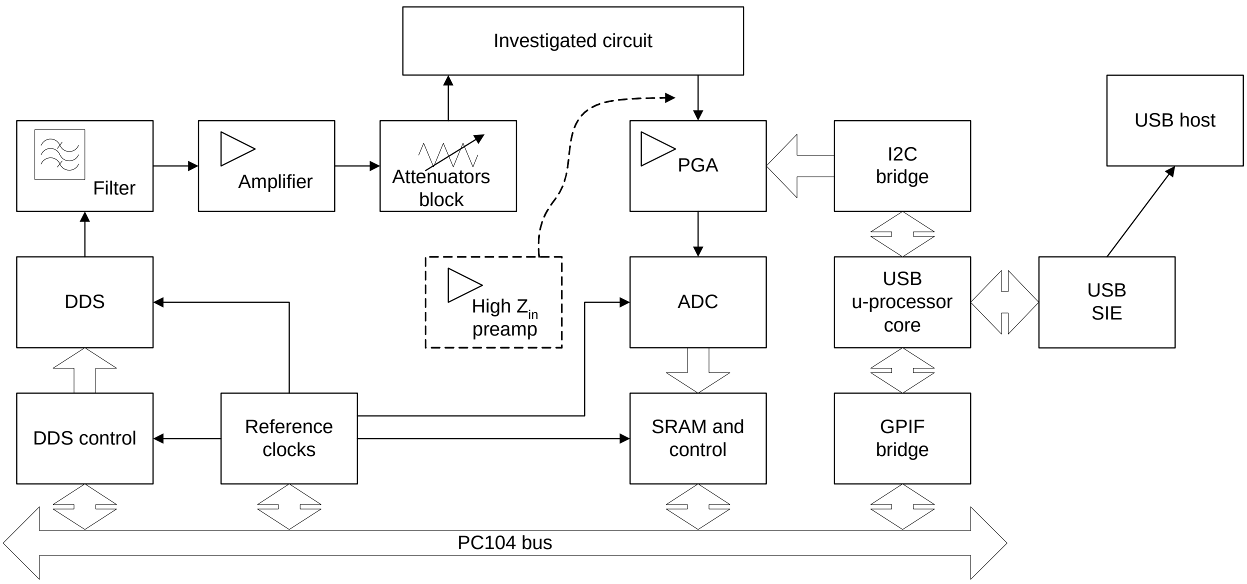

Fig. 1**. System stucture**

or two fixed 20dB attenuation blocks. The DDS control is accomplished by PC via USB interface. The USB interface used possess the high speed general purpose parallel interface (GPIF). The communication bridge is needed to connect the control units and the PC104 bus emulated by USB core GPIF.

The other most important unit is the receiving part. It consists of the high impedance preamplifier (optional) and the programmable gain amplifier (PGA), controlled via I2C interface which in turn is tied to a host PC via USB core. The PGA is AD8367 from Analog Devices [3]. The AD8367 is a high-performance 45 dB variable gain amplifier with a linear-in-dB gain control for use from low frequencies up to several hundred megahertz. The range, flatness and accuracy of the gain response are achieved using Analog Devices' X-AMP architecture, the most recent in a series of powerful proprietary concepts for variable gain applications, which far surpasses what can be achieved using competing techniques. The analog gain-control interface is very simple to use. It is scaled at 20mV/dB, with the control voltage span from 50mV at –2.5dB to 950mV at +42.5dB. This voltage is derived from AD5321 [4]. The AD5321 is a single 12-bit buffered voltage-output DAC that can operate from a single supply, consuming 120μA at 3V. The on-chip output amplifier allows rail-to-rail output swing. The reference for the DAC is derived from the power supply (supplied by AD780 [5]) inputs and thus gives the widest dynamic output range. These parts incorporate a power-on reset circuit, which ensures that the DAC output powers-up to 0V and remains there until a valid control takes place. It uses a 2-wire (I2C compatible) serial interface that is derived from the USB controller core. The rest of control is also accomplished via a host computer, communication via USB interface is by using the GPIF bridge.

The conditioned signal can be supplied either to a root mean square (RMS) detector or dual high speed analog to digital converter (ADC).

The RMS detector core is AD8361 [6]. The AD8361 is a mean-responding power detector for use in high frequency receiver and transmitter signal chains, up to 2.5 GHz. The output is a linear-responding DC voltage with a conversion gain of 7.5V/V rms. An external filter capacitor can be added to increase the averaging time constant. The output is additionally filtered with 100Hz low-pass filter and supplied to serial ADC AD7476 [7]. The AD7476 is 12-bit, high-speed, low-power, successive-approximation ADCs with SPI output. Both parts power is derived from AD1582 [8] for improved stability and accuracy.

The high speed dual channel data acquisition consists of two high speed ADC AD9214 [9]. The AD9214 is a 10-bit monolithic sampling ADC with an on-chip track-and-hold circuit. It operates up to 105MS/s conversion rate with outstanding dynamic performance over its full operating range. The DAC output data is streamed to the high speed SRAM IS61LV25616 [10] from Integrated Silicon Solution, Inc. The ISSI IS61LV25616 is a high-speed, 4Mbit static RAM organized as 256k words by 16 bits. It is fabricated using the ISSI's high-performance CMOS technology. This highly reliable process coupled with innovative circuit design techniques, yields high-performance and low power consumption device. The address access time is 8ns to sustain 100MS/s data transfer rate. All the intermediate latching, synchronization and controlling fast 100MHz clock frequency state machine is organized by 3 Complex Programmable Logic Device (CPLD) chips M4A3-128/64 VC-10 [11] from Lattice. These are 128 macrocells and 64 input/output pins representatives of ispMACH 4A family from Lattice, offering an exceptionally flexible architecture and delivering a superior CPLD solution with in-system programmability through the JTAG interface (IEEE Std. 1149.1). The signal propagation dely for device is 7ns to ensure 100MHz operation. The CPLD also performs the PC104 bridge functions.

Such configuration ensures that up to 256k samples of analog signal can be captured on two acquisition channels at highest 100Ms/s rate. In order to observe very fast signals, equivalent time sampling (ETS) scheme is introduced. ETS rate under laboratory conditions can reach up to 20Gs/s. The specified acquisition accuracy can be sustained under all circumstances at 5Gs/s ETS. The "heart" of ADC Analog Devices ADC AD9214 is capable of delivering 300MHz bandwidth, so it is intentionally designed for ETS operation, since it's maximal sampling frequency is 105MHz. Usually ETS is accomplished by shifting sampling points to positions between main sampling frequency samples. Since system is intended for use in ultrasonic system with step/spike type excitation, it's more convenient to integrate the generator excitation signal start generator on ADC board and do the shifting on this excitation signal. Such setup allows to use ADC at it's maximal sampling frequency and perform shifting with a single delay generator (AD9501 [12]). The AD9501 is a digitally programmable delay generator which provides programmed time delays of an input pulse. The potential of the delay generator allows for even higher ETS sampling frequency since delay step is set to be 50ps. This would correspond to 20Gs/s but then SINAD and effective number of bits will start degrading, but still are within specified limits. The A/D converter aperture uncertainty (jitter) is 3ps, but AD9501 delay uncertainty (jitter) is 53ps. In order to reduce the jitter influence, ETS delay should be at least 3 times the jitter. This roughly corresponds to 200ps (almost 4 times the jitter) ant turns into 5Gs/s reliable ETS frequency.

Both data acquisition channels (RMS and high speed) are controlled by the host computer via USB interface. The GPIF bridge, mimicking the PC104 bus is used for connection to USB.

All the communication with the host computer is accomplished using the Cypress Semiconductor Corporation's EZ-USB FX2LP IC CY7C68013A [13]. It is a highly integrated, low-power USB2.0 microcontroller. The USB2.0 transceiver, serial interface engine (SIE), enhanced 8051 microcontroller and a programmable peripheral interface are integrated in a single chip. The FX2LP architecture results in data transfer rates of over 53 Mbytes per second, the maximum-allowable USB 2.0 bandwidth, while still using an integrated low-cost 8051 microcontroller. Cypress's smart SIE handles most of the USB protocol in hardware, freeing the embedded microcontroller for application-specific functions.

Application

Using the system various ultrasonic equipment AC responses can be measured. The DDS output voltage is stable over the designed frequency range. Due to phase rounding inherent to the DDS output, the signal has a slight variation in amplitude related to the output frequency [14]. This is only the case at frequencies close to the reference clock half. Also the cables and output impedance introduce the discrepancies in the output amplitude at mismatched loads. For the sake of simplicity all the mentioned factors we can call the system insertion losses. Taking into account the wide frequency range of RMS meter and high linearity at specific amplitude this insertion loss *k(f)* can be obtained by measuring the AC response without device under test (DUT). Then the obtained insertion loss can be stored in a computer memory for compensation of results.

Ultrasonic preamplifier AC response

The easiest application of such AC response measurement system would be measurement of the ultrasonic preamplifier AC response. Refer connections diagram in the Fig.2 for such investigation setup.

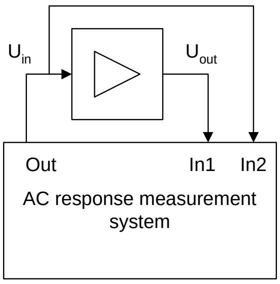

Fig. 2**. Ultrasonic preamplifier AC response measurement setup**

Having the input and the output signal voltages $u_{in}(f)$ and $u_{out}(f)$ the preamplifier response is given by:

$$G(f) = \frac{u_{out}(f)}{u_{in}(f)} \cdot k(f). \qquad (1)$$

Newly developed preamplifier for high frequency ultrasound was inspected. The result is presented in Fig.3.

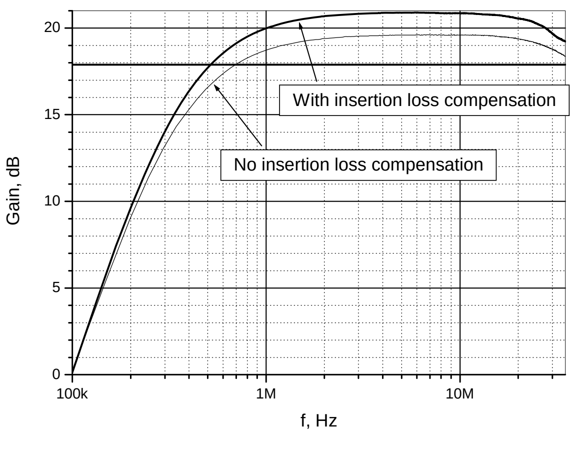

Fig. 3**. Measurement ultrasonic preamplifier AC response**

Note the 1dB difference in the ultrasonic preamplifier AC response when no system insertion loss is used. Fig.4 is presenting the AC response at various design stages of the ultrasonic low noise preamplifier. Obtaining the AC response immediately after some modification is a significant support for the designer.

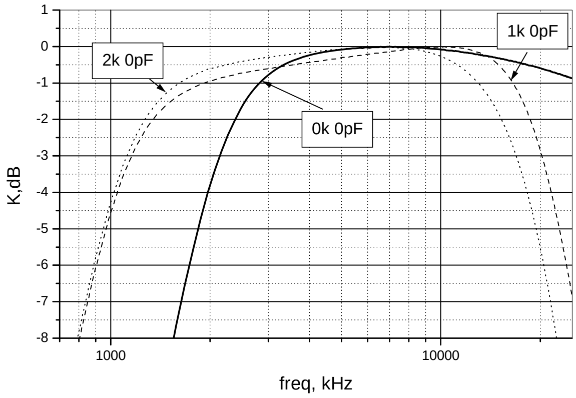

Fig. 4**. Low noise preamplifier AC response at various design stages**

Ultrasonic transducer AC response

Transmission response of two ultrasonic transducers can be obtained. This can be done by applying the excitation signal to the transmitting transducer and measuring the signal voltage at the receiving transducer terminals. Refer to Fig.5 for such measurement setup. In the case of high output impedance of the receiving transducer the optional high impedance preamplifier can be used [15] (refer Fig.1 – the dashed lines block).

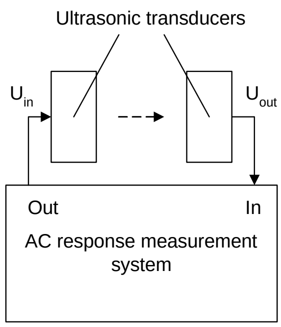

Fig. 5**. Transmission AC response measurement setup**

After modifying the transducers orientation or the coupling layers the transmission AC response situation can be immediately obtained. Refer to Fig.6 for a transmission response of two air coupled transducers.

With the available transducer excitation voltage $u_{tr}(f)$ and the flowing current $i_{tr}(f)$, the transducer impedance magnitude can be calculated:

$$|Z_{tr}|(f) = \frac{u_{tr}(f)}{i_{tr}(f)} \cdot k(f) = \frac{R \cdot u_{out}(f)}{u_I(f)} \cdot k(f), \qquad (2)$$

where $u_{out}(f)$ is the output (excitation) signal voltage and the $u_I(f)$ is the current sensing resistor of value R voltage. Refer to Fig.7 for such measurement setup.

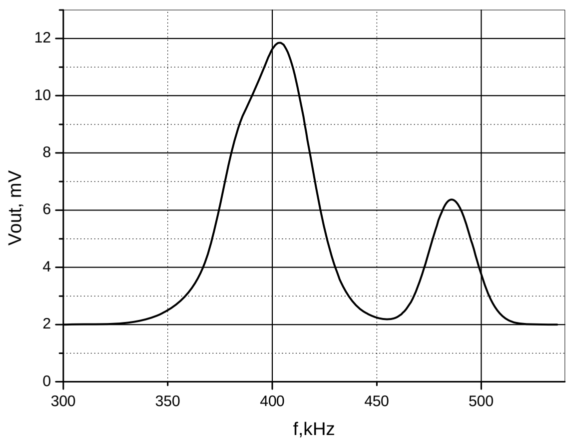

Fig. 6. **Air coupled transducers pair transmission AC response**

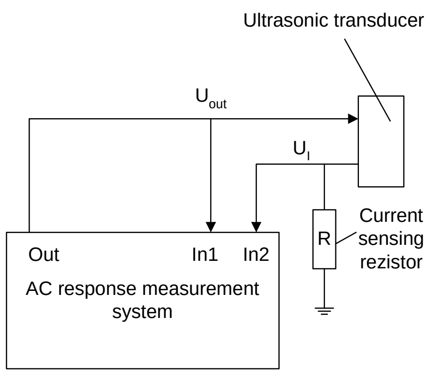

Fig. 7. **Transducer impedance AC response measurement setup**

The experimental investigation on air coupled 500kHz ultrasonic transducer has been carried out. The obtained impedance magnitude AC response is presented in Fig.8.

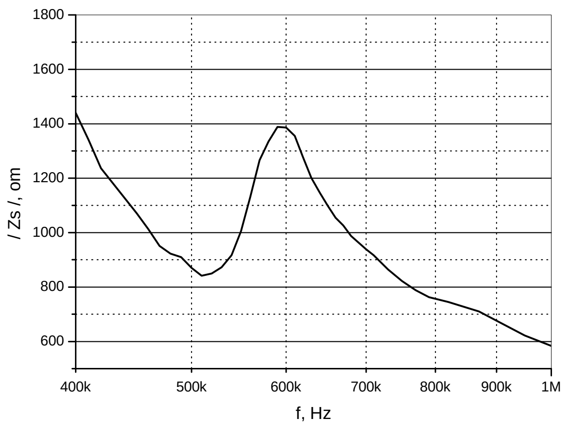

Fig. 8. **Transducer impedance magnitude AC response**

Ultrasonic generator AC response

The high voltage ultrasonic generator output AC response can be evaluated using the system output to drive the generator and oscilloscope probe set at 1:100 division. Fig.9. is a reproduction from source [16] where a linear MOSFET generator for ultrasound applications was investigated.

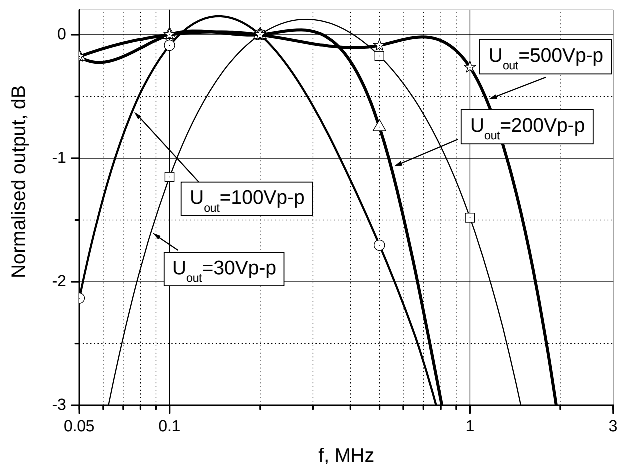

Fig. 9. **Frequency response for IRFZ34N configuration**

In publication [17] the RF transformer application in an ultrasonic transducer impedance matching has been studied. The results presented in Fig.10 are the excerpt from the paper, showing the voltage AC response at the transducer terminals at different exciting generator output levels.

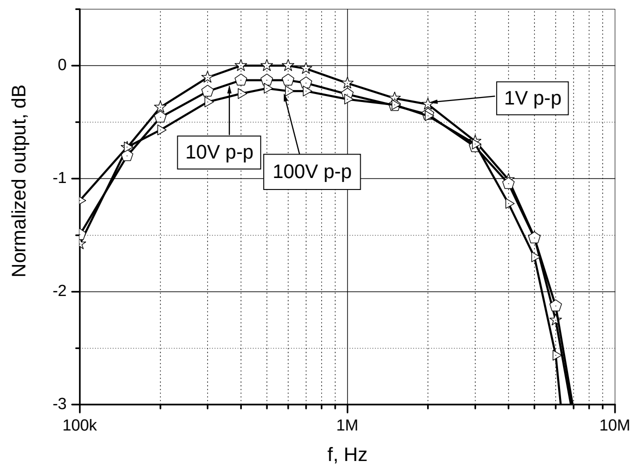

Fig. 10. **Normalized output voltage frequency response**

The results obtained indicate there is some slight reduction in the bandwidth at high signal level in high frequency region. Designer has the immediate indication of the influence of parameters on a device performance.

Conclusions

The presented system for AC parameters investigation has proved being useful for ultrasonic equipment AC response evaluation. The demonstrated application list is not exhaustive - system can be used for material properties inspection, complex impedance measurement and as calibration unit for ultrasonic NDT systems.

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Ultragarso įrangos dažninių charakteristikų matavimo sistema

Reziumė

Pateiktoji dažninių charakteristikų matavimo sistema skirta ultragarsinės įrangos tyrimams. Aptarta sistemos struktūra, veikimas, pagrindinių elementų aprašymas. Nurodytos sujungimo schemos ir pateikti rezultatai keletui plačiausiai paplitusių uždavinių. Parodyta, kad gali būti tiriamos pradinių stiprintuvų, derinimo transformatorių, sistemų filtrų ir ultragarsinių keitiklių dažnio charakteristikos. Sistema valdoma iš asmeninio kompiuterio, naudojant USB2 sąsają.

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