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# Electronics for ultrasonic vision system

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## Introduction

Semi-autonomous intelligent robots are widely used in manufacturing environments and hazardous environments. For navigation of such robots various machine based vision systems including laser systems, infrared imaging, microwave systems and ultrasonics are used. Ultrasonic systems offer potentially the cheapest and simplest solution, but there are some fundamental and technical limitations which cause serious problems in their successful implementation.

The data acquisition rate in ultrasonic sensors is limited by a finite value of the speed of ultrasonic waves. Large sensing distances are not easy to achieve because of ultrasound attenuation and surrounding noise influence. In this paper we are trying to present the major problems met when developing electronics for ultrasonic vision system, capable to overcome the above mentioned fundamental limitations.

## The system configuration

The generic block diagram of the ultrasonic vision system is presented in Fig.1 [1].

In order to increase the surrounding space scanning rate, ultrasonic signals are transmitted by electronically steered ultrasonic phased arrays [1,2]. Steering of the array is performed using programmable coded sequence generator which has digitally controlled delay of the sequence, which appears at the output. The coded sequence is used as driving signal for power stage amplifiers control, which drive the ultrasonic transducers directly. At different directions different orthogonal coded sequences are transmitted. That also enables to increase the pulse repetition rate and to reduce the influence of a reverberation noise. For transmission and reception of ultrasonic signals the low-cost MURATA piezoelectric transducers are used [3]. To smooth the resulting array field, elements power weighting is applied. The reflected ultrasonic signals are received by receiving transducers and after some amplification and filtering in front-end electronics they are transferred into the main electronics unit. Here, the signals are filtered, amplified, compensated for attenuation and converted into a digital form and supplied into DSP [3]. The information obtained from the parallel DSP's is processed by the master processor, which produces the ultrasonic image of the surrounding environment using tri-aural approach [3]. The measurements are performed at 40 kHz frequency.

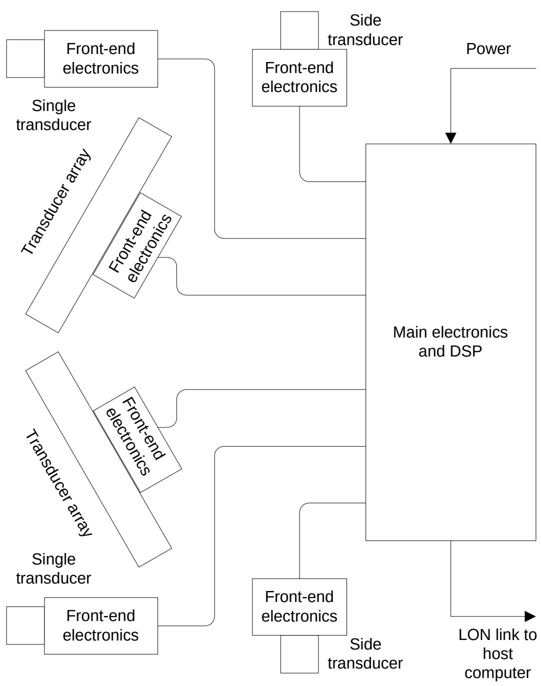


Fig.1. **Construction of ultrasonic vision system**

## Problems

Fig.2 presents the functional block diagram of the ultrasonic vision system [3]. As it was mentioned, in order to obtain a good signal-to-noise ratio, the coded sequences are used [5]. A long sequence allows to increase the transmitted energy. The received signal is processed using correlation processing in order to reduce a noise and improve the temporal resolution. A conventional way of collecting distance data is to transmit the probing pulse and wait for the next transmission a time period necessary for ultrasound to propagate the maximal distance. Acquisition requirements for mobile robots demand the next pulse to be transmitted before the previous pulse arrives from the maximal distance [1]. Using orthogonal sequences for the next transmission allows cancel the reflected signals and multiple reflections from the previous transmission in the received signal [2]. Such an approach enables to reduce the acquisition time. Electronic beam steering allows eliminate the mechanical parts and reduce the time for environment scan [4,5]. The considerations mentioned put specific requirements for the exciting generator. It must be capable to generate the required code sequence with desired delay and switch from one sequence to another very quickly. Using such a generator for the every single array element enable an electronic beam steering. Since the beam steering is performed by change of the delay, special considerations have to be taken about delay setup accuracy, repeatability and tight synchronization with the rest of the system, especially with the A/D conversion.

A slight disturbance in delay setting can result in transmitted ultrasonic field inhomogenity or beam direction angle discrepancy from desired. The coded sequence is converted into phase manipulated signal bursts with fill-in frequency of 40 kHz. Since the final result is formed by all transmission channels, the fill-in frequency phase and stability are of a crucial importance for the resulting signal.

In order to reduce the sidelobes of a beam, weighting of energy, transmitted by an individual array elements, is necessary [1]. For that purpose, the generator power stages should have output power control feature [7].

Also there are few special precautions to be taken at the receiving part of electronics. Despite the noise-robust signals are used, electronics should be protected from a surrounding noise influence, which can jam the useful signal by producing the signal clipping, DC floating and automated gain control distraction. Also, a large ultrasonic signal attenuation has to be compensated by amplification. For reliable reception of signals, which may propagate 10m distance, 80 dB amplification can be necessary. It requires an especially low level of the input electronics noise and the special precautions for signal shielding and transmission into the main block.

## Solutions for signal transmission electronics

Despite the sine wave signal is necessary for transmission, the rectangular signal is used, because it's easier to be generated and allows for power stages heating reduction. Because of resonant properties of transmitting and receiving transducers, rectangular pulses after passing the transducers, become sinusoidal. Generation of the phase manipulated sequences is much easier if the binary excitation is used. Also, less memory is required to store the whole sequence. Design of the power amplifier becomes much easier in such a case, because the logical level output can drive the voltage switch, serving as the output stage. The power control is accomplished by changing the output stages supply voltage. Therefore regulation, of the last stage output power by means of a supply voltage is easier accomplished. Fig.3 presents conversion of the binary sequence into the phase manipulated signal after passing the ultrasonic transducers.

It must be noted that the delay instability requirements are quite tough. In order to deflect the beam by 5°, the 5.5μs phase shift between adjacent 20 mm spaced array elements is required. Roughly, 1% stability of the steering will require 20 ns stability of timing, which ensures 0.5% wave front stability. Taking into account the considerations presented, following requirements for the control block were set. The smallest step of the sequence shift was chosen to be 10 times more then the required stability – 200 ns. Timing stability is obtained by a quarz oscillator.

Employment of binary signals allows to simplify the design of the sequence phase shift circuitry. Fig.4 is presenting the block diagram of the generator, allowing to understand the operation of this unit.

The sequence required is stored in the fast random-access memory (RAM). Extraction of the sequence is done by means of the binary counter, which is the address supplier for RAM. The clock frequency, produced by a

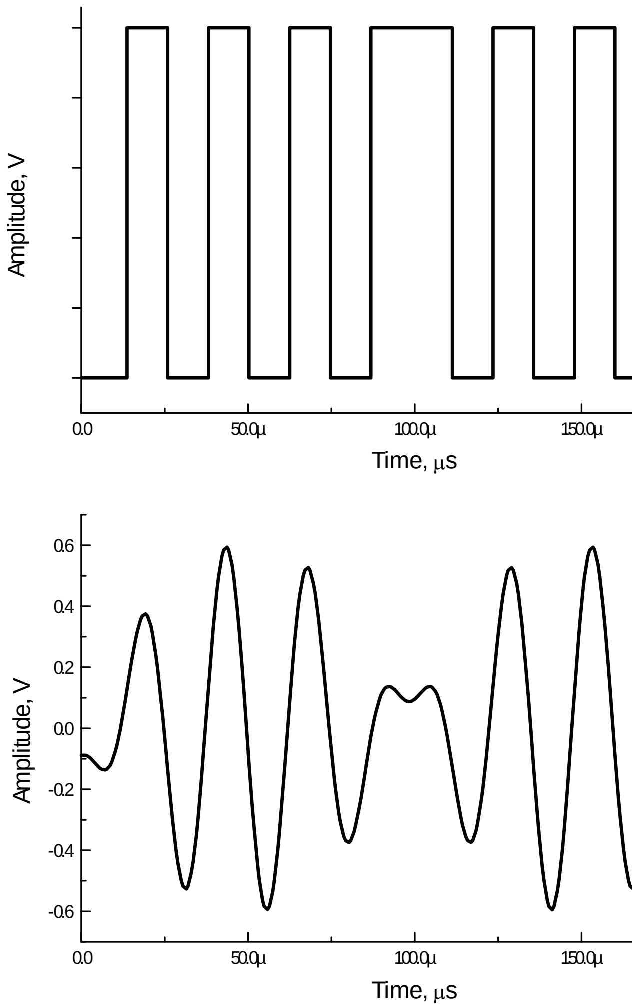


Fig.3. **Binary sequence (top) conversion into phase manipulated sine burst (bottom).**

quarz oscillator is divided to achieve the required period 187.5ns and fed into the counter. It determines the sequence phase position according to the initial counting instant. Shifting the phase of the counter clock signal allows to create phase shift of the sequence. Hence, the array phase control can be accomplished "upside down" - instead of delaying the sequence at the generator output, the synchronization signal of the sequence is delayed. Organization of the phase shift for a clock is complicated in case the when the shift range is larger than the clock period. Therefore, complex solution was used. The clock for sequence readout was chosen with a period, necessary for the delay minimal step. It is much higher than required for the 40 kHz fill-in frequency sequence. Counter counting is enabled in order to obtain 80 kHz sequence readout period. That ensures very stable ($10^{-6}$) fill-in frequency generation. In such a case it is enough to control the count enable signal start time.

## Solutions for signal acquisition electronics

The ultrasonic array has separate transducers for transmission and reception of the reflected signals. Such an approach allows to avoid the input channels overload by excitation signal and to smooth the beam shape [1]. The

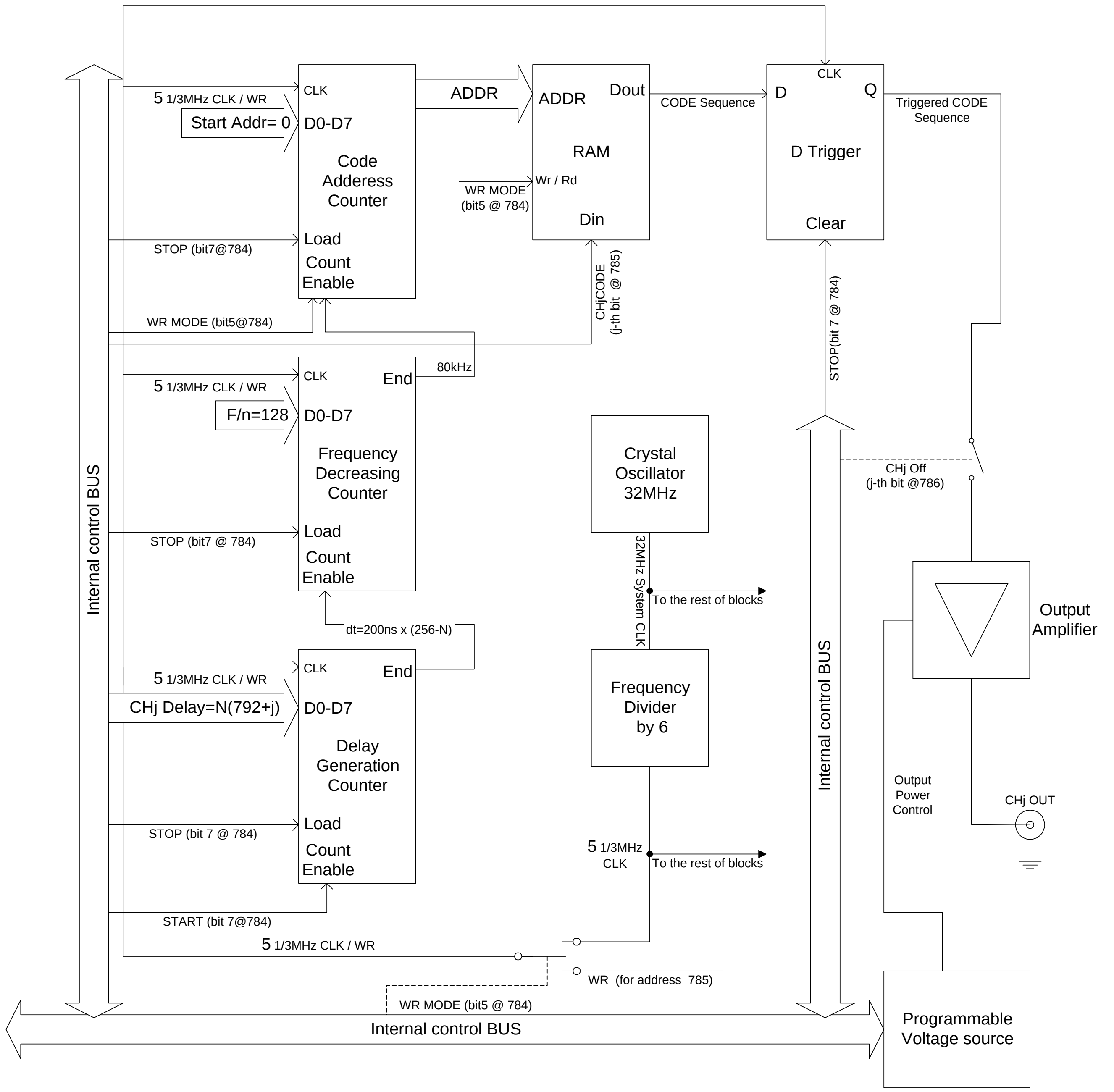


Fig.4. **Generator functional block diagram**

low-cost MURATA piezoelectric transducers are used. Two arrays, placed at 120° angle are used to scan the area in front of the sensor. Also, there are few side looking channels, used to locate the obstacles on sides of the robot [2]. These channels do not require a high accuracy, therefore the same transducer is used for transmission and reception.

All signals received are prefiltered to avoid overload of channel by noise frequency components not falling into the frequency range used for inspection. As it was determined by investigation, majority of noise in a real manufacturing environment is concentrated below 20 kHz range, so 40 kHz frequency was an optimal choice, ensuring the noise separation and the acceptable level of attenuation [3]. In order to separate the ultrasonic signals from a noise, it is necessary to use a filter with a steep frequency response. Because in measurements a phase information is exploited, the filter phase response is required to be linear as much as possible. Therefore, the 4th order Butterworth bandpass filter was used. Such a setup allowed to achieve –30 dB attenuation of noise signals at 20 kHz with respect to the bandpass region. Active RC filter blocks were used in schematics. Amplifiers used in first stages expose 10 nV/√Hz input noise density. Taking into account that the 35-50 kHz bandwidth is used, 1.20 μV input noise voltage is predicted. After passing an amplifier with 80 dB amplification it will result in the 12.0 mV effective noise voltage at the output. Correspondingly, the noise peak value can be up to 50 mV. At the 8 bit, 2 V range A/D converter input it can create 6 quantisation levels noise. If such a noise is considered to high, a special low noise input circuitry has to be applied. In order to maintain good noise parameters of the amplifier, the main amplifier is followed by the 2-nd order filter. For the same reason, the preamplifier is placed directly at the receiving transducer and the signal is transmitted further only after initial preamplification. The gain of the preamplifier can be controlled remotely in order to get a better dynamic range. Both the preamplifier and the power stages are placed close to the transducers in order to improve sensitivity. The signal is sent into main unit via cable for further amplification, filtering and acquisition. The main amplifier contains time variant gain (TVG) amplifier. This feature can be used for compensation [8] of beam spreading and ultrasound attenuation.

It must be noted here that all components of the system must be synchronized in order to avoid a jittering noise. The synchronization block is designed for elimination of the jittering noise and analog signal sampling control. An A/D converter is included in every DSP processing channel and it is feeding the data directly into DSP's memory.

The DSP are used for processing of the received signals correlation. TMS320C50 type signal processors are used for that purpose. All processors are connected by the same local bus, controlled by the host DSP. For the control of the rest of the equipment, the host DSP is using another bus.

## Conclusions

The use of electronically controlled arrays, separate code sequences for every direction and parallel signal processing allows the sensor to perform environment assessment in real time and to achieve a good noise robustness, which is essential for systems operating in an industrial environment. Specific accuracy and structure requirements have to be satisfied in such systems.

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**Ultragarsinių regos sistemų elektronika**

Reziumė

Ultragarsinių regos sistemų taikymą riboja nepakankamas šio metodo atsparumas trukdžiams ir ribotas erdvės apžvalgos greitis. Šioms problemoms spręsti reikalingas ne tik atitinkamas metodas, bet ir elektroninė aparatūra, atliekanti reikiamas funkcijas. Tokių įrenginių specifika bei sukūrimo problemos ir aptariamos šiame straipsnyje.