Phased arrays of ultrasound emitters controlled by binary signals for acoustic levitation

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Abstract. A phased array of ultrasonic emitters for acoustic levitation has been developed. The array is controlled by a multichannel signal generator. The generator allows you to create 64 channels of independent signals with controlled phase. The possibility of connecting of 4 arrays of emitters, each of the 320 elements. The possibility of providing levitation of foam particles in the field of two oppositely directed arrays was experimentally shown.

1. Introduction
To ensure ultrasonic levitation, it is necessary to control the ultrasound field with high accuracy. Due to the focusing of radiation from a variety of emitters, it is possible to provide high field amplitudes in a given region of space [1–7]. The use of phased arrays of ultrasonic emitters with digital signal generation [1] allows you to control the ultrasonic field and move the levitating particles along a predetermined trajectory. It is advisable to create a system of phased arrays of blocks [2] of the same design. The phase control of each emitter allows you to set the desired field distribution, and varying the values of the amplitudes of the emitters does not significantly affect the final field in the focus area. Such technologies are used for the manipulation of liquids [3]. In works [1–4, 6, 7] for phased arrays, radiators are used at a frequency of 40 kHz of the type MA40S4/S. These radiators are matched with air and allow you to create a pressure of sufficient amplitude for levitation, even water droplets.

In papers [5] and [6], only two signal sources with independently controlled phases are used for single axis movement. In [5], the possibility of levitating an object with dimensions greater than the length of the wave is shown, and the required spatial distribution of the field is set using a vibrating aluminum plate attached to two ultrasonic transducers. Field focusing can be achieved by placing emitters at different depths [6], without the need to use a complex signal control system for each emitter.

In this paper, we propose a system of a 64 channel amplifier with a digital control by a microcontroller for a system of phased arrays, irradiating the region of ultrasonic levitation of particles. The ultrasonic signal is generated by the binary outputs of the microcontroller, in fact, a 64-channel 1-bit DAC is implemented. Binary signals pass through a band-pass filter, which allows you to get almost sinusoidal signals that are fed to amplifiers TDA7297 (32 pieces of dual-channel chips are used). Using a 64-channel signal generator, it is proposed to control 4 flat gratings of radiators, each of which consists of 320 elements. This scheme allows you to control the frequency and phase of the emitted signal, which should be sufficient to maintain levitation.

2. System overview
A multichannel digital-to-analog converter (ADC) requires the transmission of a large data stream, which is not available to low-performance microcontrollers. To control 64 channels of 8-bit ADCs
with a frequency of 100 kHz, a stream of 6.4 MB per second is required. Given that the signal phase is of greater importance in field control, the amplitude of the signal can be set constant. It is proposed to use a 1-bit DAC, or in fact, binary outputs of a microcontroller for setting the signal of a phased array of ultrasonic emitters. It is supposed to use the MA40S4/S ultrasound emitters with a resonant frequency of 40 kHz, which will limit the spectrum of filtered and amplified signal generated by a single-bit DAC. The binary signal from the controller is fed to the low-pass filter and then to the amplifier based on the TDA7297 chip. The amplified signal is fed to the ultrasonic emitters MA40S4/S.

Figure 1 shows a photograph of the developed unit for generating and amplifying 64 ultrasonic signals with controlled phase based on a STM32F407 microcontroller and TDA7297 amplifiers. The radiators of the amplifiers are fixed on the aluminum frame, which ensures sufficient cooling during operation.

![Figure 1. Photo of 64-channel digitally controlled generator with amplifiers.](image)

The microcontroller is controlled in real time via a USB interface from a personal computer. The program provides continuous field control even when receiving data and control signals, which allows you to smoothly move levitating particles. Up to 64 independent ultrasonic emitters can be connected to the signal outputs of the board.

We consider the possibility of controlling particles in three-dimensional space, which is ensured by the use of 4 flat phased arrays consisting of 320 elements (20×16) with independent control of 16 channels (column), placed in rows of 20 elements. In this case, 20 elements placed in column will be controlled by one signal and will be in phase. Arrays are placed in pairs opposite each other. The phase difference between the counter lattices provides the movement of particles horizontally, and the variation of the focusing height of all the lattices ensures the movement of the levitating particle along the vertical axis. Figure 2 shows a photograph of a 64-channel generator connected to two phased arrays of emitters.
Figure 2. 64-channel generator connected to two phased ultrasonic arrays.

Figure 3a shows the signal of one of the channels after passing through the low-pass filter and the amplifier. As a result of amplification, the amplitude of the signal increases and minor distortions appear. However, after emission, the signal becomes harmonic, since the MA40S4 / S emitters have a narrow bandwidth (Figure 3b). The signal in Figure 3b is measured with the help of the ultrasonic receiver MA40S4 / R.

![Graphs](image)

Figure 3. Signal after filtration and amplification (a) and signal after radiation (b).

To test the possibility of levitation of particles in the ultrasound field created by the developed grids, an experiment was conducted on the levitation of foam particles (Figure 4). Two grids were placed at a distance of 16 cm from each other and directed towards (one on top, the other on the bottom), which ensured the formation of standing waves, in the nodes of which the particles levitate. The emitter signals were set to form plane waves with a horizontal phase front. As a result of the interference of counterpropagating plane waves, a standing wave was formed with a step of 4 mm nodes.
3. Conclusions
A control system for phased arrays of radiators for ultrasonic levitation in air has been developed. It is shown that it is enough to use a single-bit digital-analog converter to generate control signals with a predetermined phase. Based on the STM32F407 microcontroller and TDA7297 amplifiers, a 64-channel ultrasound signal generator at a frequency of 40 kHz was created. During the experiments, this generator was connected to two phased arrays of 320 emitters each, which ensured the levitation of foam particles in the air.

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