SIMULATION AND SPECTRAL ANALYSIS OF FREQUENCY CONVERTER OF DEVICE FOR 3D MEASUREMENTS OF TURBULENT AIR MOVEMENT

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1. INTRODUCTION

Measurement of air streams movement, particularly speed and direction, always has been a subject of steadfast scientific investigations in all areas of human life and activity. It is especially important to supervise moving of turbulent air when the researches on microwave propagation are carried out. Only when we have full representation in behaviour of the turbulent air and synchronous measured parameters of an electromagnetic wave it is possible to determine the laws of influence of turbulent air moving on parameters of an electromagnetic field.

Investigations in a field of turbulent air movement are not limited by the meteorological one or by the researches in microwave propagation. Local measurements of air movements are especially useful in industry where the bodies of various mechanisms design. In a last case the great attention is paid to aero-dynamic characteristics of mechanisms bodies, taking into consideration possible mechanisms move in different gases or liquids.

Widely used in meteorological supervision mechanical anemometers and instruments for measurement of a wind speed and direction are essentially unsuitable in similar cases. Owing to its inertia, these devices allow to get only integrated values of measured magnitudes [1]. The dynamic range and accuracy of mechanical devices are low. Measurements can be implemented only in a plane, at the best case. At the same time, there is certain interest to supervise the air turbulence which some times can change the value during carrying out of measurements with mechanical devices. Other ways of measurements (radar, optical) are unsuitable for local measurements, as they demand the extended distances [2].

Acoustic method [3] and [4] of measurement of speed and direction of turbulent air movement is well situated for mentioned above measurements. The spectrum analysis of signals and their contribution to the general error of acoustic method of measurements, based on homodyne frequency conversion of ultrasonic signal and described in [5] and [6] is discussed in present paper. This conversion based on frequency shift of initial signal by means of signal's phase shift, described in [7] – [9].

2. SIMULATION AND MEASUREMENTS

According the scheme, described in [6], the 4-Digit Johnson's Counter, Multiplexer and 3-Digit Binary Counter, all of them form the heterodyne signal in device for 3D measurements of turbulent air movement. The controlled phase shifter simulates the operating of mentioned units. The controlling signal of phase shifter results in changing of phase of initial ultrasonic oscillation by 2π over the period *T* of this controlling signal. For simulation this period *T* in 2.5 ms was chosen. The resulting frequency shift F_n will be 400 Hz. The number of steps of controlled phase shifter was chosen equal to 8 for simulation.

The simulation was carried out in environment MathCAD. For simulation we took the initial ultrasonic oscillations with initial phase equal to 0 and the amplitude factor equal to 1.

The law of phase changing of ultrasonic oscillations is described by the following equation:

$$\Phi(t)=180\left\{0.5\,\mathrm{sign}\left[-\sin\left(2\pi F_n t\right)\right]+0.5\right\}+90\left\{0.5\,\mathrm{sign}\left[-\sin\left(4\pi F_n t\right)\right]+0.5\right\}+45\left\{0.5\,\mathrm{sign}\left[-\sin\left(8\pi F_n t\right)\right]+0.5\right\}. \quad (1)$$

This law of phase changing of ultrasonic oscillations is shown in Fig. 1.

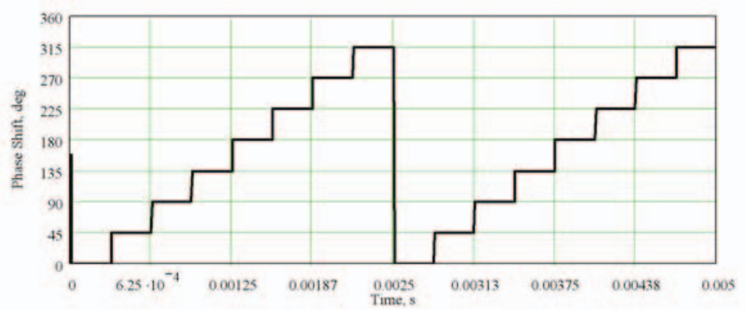

Fig. 1. The law of phase changing of ultrasonic signal

Signal on the output of controlled phase shifter will be:

$$u_{\mathrm{CPHS}}(t)=\sin\left[2\pi f_0 t+\Phi(t)\frac{\pi}{180}\right]. \quad (2)$$

Here the initial phase of controlling signal was accepted equal to 0.

The calculated spectrum of signal (2) is shown in Fig.2.

As we can see from the Fig.2 the ultrasonic oscillations obtain the frequency shift in 400 Hz and the frequency of main harmonica of transformed ultrasonic oscillations on the output of phase shifter is equal to 40.4 kHz.

The order of nearest harmonica with essential level is equal to 7, as it was pointed out in [9]. The frequency of this harmonica is equal to 42.8 kHz.

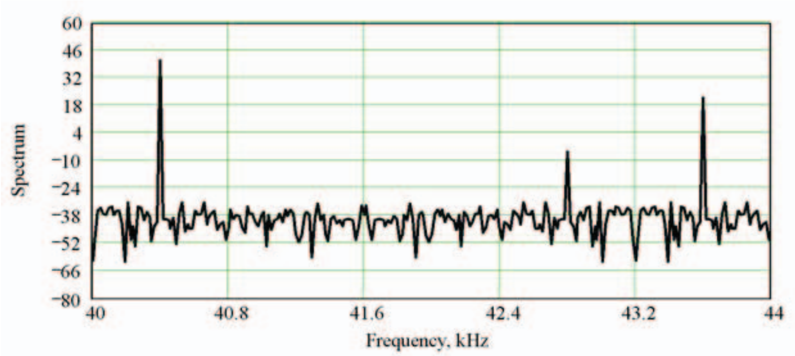

Fig. 2. Calculated spectrum of ultrasonic signal on the output of controlled phase shifter

All of mentioned above simulations were carried out for a case of sinusoidal signal of initial ultrasonic oscillations and for sinusoidal signal on the output of phase shifter with the phase hops. Really, the discussed ultrasonic signal has digital-level nature as the digital multiplexer and digital counters are used in our case.

The spectrum of output multiplexer signal was measured with the digital oscilloscope RIGOL DS1052D. This spectrum of digital-level signal on the output of multiplexer is shown of Fig. 3.

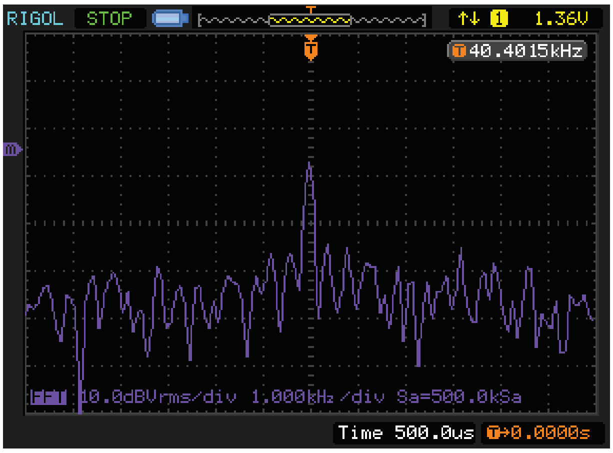

Fig. 3. Measured spectrum of digital-level signal on the output of multiplexer

We must understand the mentioned oscilloscope is not spectrum analyzer. The shown spectrum is a result of Fast Fourier Transformation of sequence under the test. This is the calculated value, caused with some restrictions and assumptions. Often we can watch amazing pictures on screens of similar devices. These pictures can radically overthrow the established views on a problem. Often we can watch on the screen so called “sub-harmonicas” of signals. But in our case, on the output of the multiplexer the signal is present and we watch the well known spectrum, which is well agreed with theoretical knowledge.

3. CONCLUSION

The considered manner of equipment design for 3D measurements of speed and direction of an air stream allows constructing on its basis modern technological measuring instruments which can find application in the industry, meteorological researches, etc. Using a data file of such measuring instruments, it is possible to receive a picture of spatial moving of air in real time. The absence of mobile parts in a considered measuring instrument excludes its mechanical deterioration that favorably distinguishes it from existing analogues with mechanical converters.

Thus, placing of three orthogonal acoustical links with single transmitter and three receivers it can get an accurate account about local 3D air turbulence with high resolution and without any inertia.

Certainly, the amplitude and phase of acoustic wave, which is propagated through air turbulence, change own amounts with relation to turbulence composition. The turbulence composition depends on meteorological parameters (temperature, pressure and so on) and on the presenting in atmosphere of various gases, dust and other capacity distributed turbulences. All of them must be taken into account by the measurements.

Discussed device for supervising the turbulent air movement consists of not expensive equipment, which is ended by the microcontroller. Such device can be stand-alone one as well as a part of more complicated equipment. Several local turbulent air measuring instruments we can joint into a distributed digital system of measurement as each device has anyone digital interface according to the accepted definition. Such system let us supervise the large scale turbulences of air and predict such natural disasters as tornado and so on.

4. REFERENCES

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