DVOR NAVIGATION SYSTEM IN THE ACUSTIC MEDIUM

Martin KRCHŇÁK, Ing.
Rampová 7, Košice
krchma@centrum.sk
Ján LABUN, doc. Ing. PhD
Rampová 7, Košice
jan.labun@tuke.sk

Summary. Article discusses the design of the air navigation system DVOR simulator in an acoustic zone that simulates formation of ground system DVOR course information. The article contains a brief description of DVOR system signals that provide a theoretical basis for the design of simulator system. Further, it discusses the mechanical construction which was created based on calculations in theoretical part. Electronic part provides necessary signals in order to keep the principle of DVOR system course information generation.

Keywords: Doppler effect, didactic aid, course, position of the aircraft, angle measurement radio navigation systems, DVOR

1. INTRODUCTION

Today's air navigation uses mainly elements of modern satellite navigation. Older navigation systems, which are slowly being pushed out, are based on ground stations network and broadcasting of radio signals. One of those systems is DVOR (Doppler Very High Frequency Omnidirectional Radio Range). System emits series of signals with different modulations, which may be difficult to understand in some cases. The principle of D-VOR system, which uses radio waves, can be used in in the acoustic environment. Doppler effect occurs in radio and acoustic environment as well.

2. BASIC PRINCIPLES OF DVOR SYSTEM

Because the VOR system's operation is affected by surrounding terrain, this system has been modified. The modified system uses the Doppler effect, which gives it the name Doppler VOR or D-VOR. This system is approximately three times more accurate than VOR and it can be used in terrain, where VOR beacon's serviceability would be limited or impossible. System's resistance to terrain obstacles is achieved by removing the rotation radiation pattern. D-VOR system uses a set of non-directional antennas instead of two pairs of directional antennas, thereby eliminating distortion caused by multiple signal spreading. Signal from D-VOR system can be received on board by the same device as from VOR system in spite of differences in signal processing and emitting.

D-VOR beacon uses the same frequencies as VOR system, therefore works in range of 108-112 MHz, additional signal frequency is 9960Hz, frequency deviation of frequency modulation is 480Hz and non-directional antennas switch at 30Hz. Therefore, to maintain compatibility between D-VOR and VOR, the frequency range of D-VOR is the same as of VOR.

In contrast with VOR, D-VOR uses at least 32 non-directional antennas set on circle and one antenna in the middle. The non-directional antenna in the middle emits sinusoidal, amplitude modulated reference signal of 30Hz. Antennas on circle emit frequency modulated signal with secondary carrier frequency of 9960Hz and frequency of 30Hz. Signal for side antennas is generated in generators of upper and lower sideband, what provides modulation of carrier frequency of 108-

112MHz and with the help of secondary 9960Hzcarrier frequency a phase shift of 0° and 90°. Frequency modulation of 30Hz is created by antenna rotation in place where signal is received. It would be impossible to use one antenna, mechanically rotating at 30Hz, so the antenna rotation is replaced by electronically switching the antennas on circle. Spectrum of DVOR signal is illustrated on Figure 1. Switching control signal is formed in the switching signal generator. The direction of antennas switching rotation is counterclockwise, while in VOR, the radiation pattern rotation is clockwise. The change in a rotation ensures the compatibility between D-VOR and VOR. After demodulation of both signals, same phase relations are created in place where signal is received. The phase shift of demodulated signals corresponds with radial.

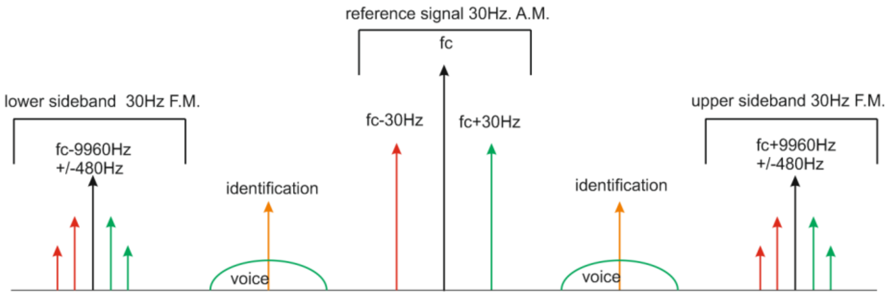

Figure 1 Illustration of DVOR signal spectrum

3. DOPPLER EFFECT IN DVOR SYSTEM

Doppler effect marks frequency changes of acoustic or electromagnetic waves according to object’s movement towards or away from the observer. Moving towards the observer increases the frequency, moving away from the observer decreases it. If a distance of an aircraft is large, angular velocity of antennas when observed from the aircraft is:

$$V_x = V * \sin\phi \tag{1}$$

Where V_x resembles angular velocity towards the aircraft, V resembles angular velocity of a moving antenna and ϕ angle resembles angle relative to the x axis. For Doppler frequency shift for the sources moving at slower speed than the speed of light, we use:

$$\Delta f = \frac{V_x}{\lambda} = \frac{V_x * F_U}{c} = \frac{V * F_U}{c} * sin\varphi \tag{2}$$

In this case, Δf resembles Doppler frequency shift, λ is an emitted frequency wavelenght and c resembles the speed of light. According to this equation, frequency received is modulated by sinusoidal frequency. If the sinusoidal frequency has a period of 1/30 of a second, the signal is modulated by a frequency of 30 Hz. However, ground system D-VOR transmits with two opposite antennas. One antenna runs at F_U=fc+9960Hz signal and the opposite antenna at F_L=fc-9960Hz. Doppler shift received from this antenna is also modulated by sinusoidal signal, but phase-shifted by 180°. When one antenna reaches the maximum negative value of amplitude – the peak, the other one reaches the maximum positive value. For the second antenna, we use:

$$\Delta f = \frac{V_x}{\lambda} = -\frac{V * F_L}{c} * \sin(\phi) \tag{3}$$

Received signal is modulated by frequency of 30 Hz. This means that antennas need to fully rotate 30 times per second. If R stands for radius, the angular velocity of turning antennas is:

$$V = 60 * \pi * R \quad (4)$$

Frequency deviation is set to 480 Hz, therefore:

$$\Delta f = \frac{f_c * V}{c} = 480 = 60 * \pi * R * \frac{f_c}{c} \quad (5)$$

where f_c is carrier frequency. For the radius, we get:

$$R = \frac{8 * c}{\pi * f_c} \quad (6)$$

4. BASIC EQUATIONS OF DVOR SIMULATOR

One of the first things when designing was to transform basic equations of Doppler effect of DVOR system to acoustic environment. Derived equations are valid for signal source moving in a circle. If the signal source is radio waves, it is necessary to use the speed of light in vacuum c = 299 792 458m/s. Acoustic waves, i.e. mechanical vibration, has significantly lower speed, so it is necessary to use the speed of sound v_s = 340m/s in equations. Acoustic transmitter will operate on the same principle as DVOR system, i.e. it will have electronically switched acoustic transducers placed in circle. Switching speed of transducers is calculated from the equation for rotational speed of the mass point in a circle:

$$v = 2\pi f_o r \quad (7)$$

where f_0 is transducers switching frequency and r is a radius of a circle where transducers are placed. Substituting into the equation (5) to calculate the frequency deviation we get:

$$\Delta f = \frac{f_c * v}{v_s} = \frac{2\pi r f_o f_c}{v_s} \quad (8)$$

Where v_s is the speed of sound and f_c is transmission frequency. Frequency deviation – the Doppler frequency depends on three parameters: switching frequency of transducers in circle, radius of the circle and frequency transmitted by transducers. For best demonstration of Doppler effect in DVOR system, it is practical to change every parameter, so different conditions can be simulated and we can point out how does change of any of the parameters influence final frequency deviation. For verification, tables were calculated using MATLAB. One of them is illustrated as Table.1 They show the dependence of the Doppler frequency on rotation speed, radius and transmitted frequency.

		Radius (m)												
		0,3	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**	**1,1**	**1,2**	**1,3**	**1,4**	**1,5**
Frequency of switching (Hz)	**1**	1.66	2.22	2.77	3.33	3.88	4.44	4.99	5.54	6.10	6.65	7.21	7.76	8.32
	1,5	2.49	3.33	4.16	4.99	5.82	6.65	7.48	8.32	9.15	9.98	10.81	11.64	12.47
	2	3.33	4.44	5.54	6.65	7.76	8.87	9.98	11.9	12.20	13.31	14.41	15.52	16.63
	2,5	4.16	5.54	6.93	8.32	9.70	11.9	12.47	13.86	15.25	16.63	18.2	19.40	20.79
	3	4.99	6.65	8.32	9.98	11.64	13.31	14.97	16.63	18.30	19.96	21.62	23.28	24.95
	3,5	5.82	7.76	9.70	11.64	13.58	15.52	17.46	19.40	21.34	23.28	25.23	27.17	29.11
	4	6.65	8.87	11.9	13.31	15.52	17.74	19.96	22.18	24.39	26.61	28.83	31.5	33.26
	4,5	7.48	9.98	12.47	14.97	17.46	19.96	22.45	24.95	27.44	29.94	32.43	34.93	37.42
	5	8.32	11.9	13.86	16.63	19.40	22.18	24.95	27.72	30.49	33.26	36.04	38.81	41.58
	5,5	9.15	12.20	15.25	18.30	21.34	24.39	27.44	30.49	33.54	36.59	39.64	42.69	45.74
	6	9.98	13.31	16.63	19.96	23.28	26.61	29.94	33.26	36.59	39.92	43.24	46.57	49.90
	6,5	10.81	14.41	18.2	21.62	25.23	28.83	32.43	36.04	39.64	43.24	46.85	50.45	54.05
	7	11.64	15.52	19.40	23.28	27.17	31.5	34.93	38.81	42.69	46.57	50.45	54.33	58.21
		Frequency shift (Hz)												

Table 1 Doppler shift frequency table

5. DESCRIPTION OF MECHANICAL PART

Based on the calculation it can be concluded that the radius of the circle on which the transducers are arranged must vary between 0,3 and 1,5 meters. Transmitting frequency of transducers has to be in acoustic zone. It is necessary to use a frequency applicable to listen. It is predicted that the most applicable frequency to transmit would be 300Hz to 900 Hz. At this frequency, high revolution of transducer switching will not be needed and frequency deviation will be high enough to be noticeable. Lower frequency of switching will make it possible to hear the modulation frequency of central transmitter of reference signal, which will appear as fluctuating signal strength.

Transducers have to transmit in wide frequency range, from 300Hz to maximum 1500Hz. Low-frequency transducers transmit to approx. 100Hz, high-frequency transducers transmit from approx. 1500Hz. For this particular use, the best transducers are wide-range, which are available to transmit from approx. 100Hz to several kHz. Existing requirements describe how the transmitter of the simulator should look. Complete mechanical part is shown on Figure.3.

- 16 transducers placed on circle
- variable circle radius in range of 0,3 to 1,5m
- wide-range transducers working from 300Hz to 1500Hz placed on a ceiling.
- transducer in center of circle for transmitting the reference signal
- control panel with control electronics

Figure.1 Photo of mechanical part

6. DESCRIPTION OF ELECTRONIC

Control electronic has to ensure the creation, processing and reproduction of the signal. Shape and processing of the signal shall be similar to the signal of DVOR. Main block diagram is on Figure 4. Electronics provides:

- carrier wave of reference signal
- modulation wave of reference signal
- amplitude modulation for the creation of a reference signal
- generate a variable signal
- synchronized switching of transducers with modulating wave of reference signal
- power amplification of all signal and their reproduction
- elements of system parameter control
- elements of parameter display

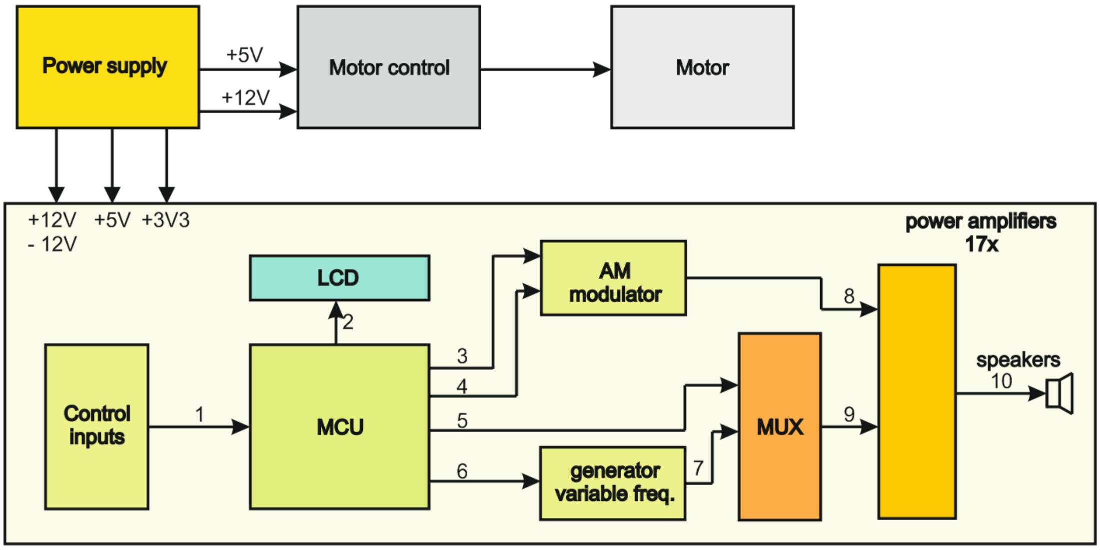

Figure.4 Block diagram of control electronic

1. Microcontroller - MSP430F5338, receives input signals from control elements and generates frequencies based on requirements. Integrated DAC transducers are used to generate signals. Data for transducer are generated on the principle of direct digital synthesis – table and a control word. At the same time, the microcontroller controls the multiplex switching synchronously with the modulation frequency.
2. Control elements – allows the user to change the parameters. It is advised to use rotation encoders and buttons to ensure simple control.
3. LCD display – allows to display the set parameters.
4. AM modulator – ensures amplitude modulation for the speaker in the centre of the device, which simulates non-directional antenna. Transconductance amplifier LM13700 is used as the modulator.
5. Generator 1 – circuit ensuring creation of requested transmission frequency working on the principle of direct digital synthesis. Because of the simplicity and output signal quality, the AD9850 module was used as it contains every required element to create and filter the signal.
6. MUX – digitally controlled analog multiplex 74HC4067 which ensures electronic signal switching for power amplifiers. Transmission frequency generator is connected to the common input and individual outputs are connected to the inputs of power amplifiers.
7. Power amplifier – provides the necessary power on inputs to speaker excitation. 17 channels from integrated circuits TPA1517 are used, which provide 3,5W/4Ω with 1% THD.
8. Speaker – transforms the electric energy from power amplifiers into sound waves. MONACOR SPS7-4SQ is used.
9. Power supply – provides the necessary voltages with sufficient margin for each individual circuit. 3.3V voltage is required for all digital circuits, 12V sub-circuit supplies power amplifiers and amplitude modulator, 5V voltage with large current capacity is used to power the engine.
10. Motor control - control with reversing rotation by switches and relays
11. Motor – two-directional motor providing arm lifting.

7. CONCLUSION

The main purpose was to create an electronic system for DVOR simulator. The system should provide the output signals based on an analysis of DVOR system. One of those signals is amplitude-modulated signal, whose carrier frequency is tunable in range from 300Hz to 700Hz. Modulation frequency has a range from 0,5Hz to 20Hz. The second signal is frequency modulated, but is created in receiving place by rotation of signal source. Rotation is created by electronic switching of transmitters – speakers. Transmitting frequency can be tuned in range from 300Hz to 1kHz. Switching frequency can be modified depending on modulating frequency in the same range. This ensures their synchronization, which is necessary for determination of information. Because of the modern microcontroller used, the system has a software part as well, which is composed of many service functions and variables needed to operate peripherals and tuning. The software part is not included in this work.

Outputs were checked by measurement. It was proven that the system provides requested signals in sufficient quality and range. The result of the work is a device that fulfills the specified aim.

Continuation of the work could be a design and implementation of mechanical structure based on DVOR system. That would create a complete simulator, which would copy the DVOR system in its appearance and functions.

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