# VOR software receiver and decoder with dsPIC

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## 1. Introduction

VOR (VHF Omni-directional Radio range) is a radio navigation system used for civil and military navigation of airplanes. It was originally invented for military but soon after the system was implemented it was used in civil aviation.
Although there is an increasing competition from GPS navigation systems, VOR navigation is still primary aviation navigation in use today and likely stay in use as a backup even after the GPS navigation systems will become primary for navigation.

## *2. VOR operation:*

Navigation information in VOR signal is encoded in two phase-shifted 30Hz signals transmitted from the VOR station. The phase difference between those two signals is directly proportional to the azimuth from the VOR transmitter to the receiver. By decoding signal from one VOR station the observer can determine his bearing to the station. When an observer can receive two VOR station signals, it can triangulate its position on the map.

One of the signals is called reference and the other variable. The reference signal is transmitted omni-directionally from the VOR antenna while the phase of the variable component is electronically rotated around the antenna at the rate of 30Hz. That way when the signal from the VOR is received, it will be dependent on the position of the observer with respect to the VOR station. Figure 1 shows the phase difference between variable and reference signals as a function of the azimuth of the observer from the VOR station.

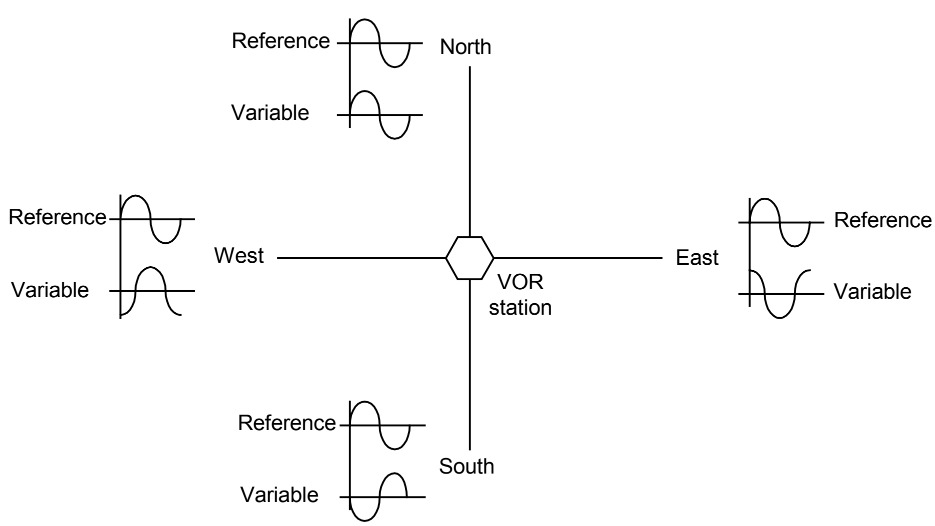


Figure 1. VOR Reference and Variable signal phase around VOR station

### 3. VOR signal:

The VOR signal is transmitted on one of the frequencies in 108.00-117.95MHz frequency band with 50KHz channel spacing. In addition to navigation signals the transmitted signal contains Morse code identification of the VOR station and optional voice component that is used to warn against hazardous weather conditions. The reference signal is frequency modulated to 9960Hz subcarrier and then amplitude modulated together with the variable signal to RF carrier. Figure 2 shows VOR signal in time domain.

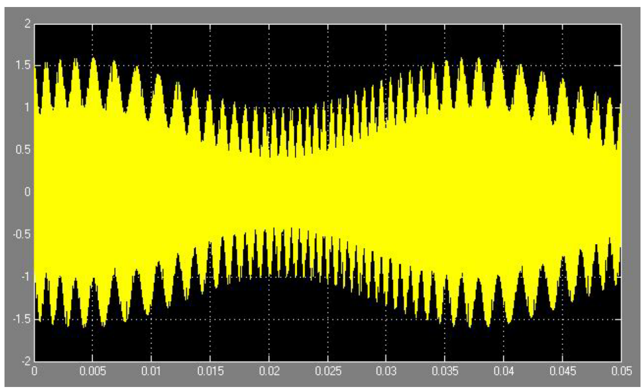

Figure 2. VOR signal in time domain.

Modulation properties:
-30Hz Variable -30%
-9960Hz Subcarrier-30%
-Voice modulation -30%
-Station Ident (Morse code)- 7%

9960 Hz subcarrier
-30Hz Frequency modulation, Modulation Index 16,
+-480 Hz Frequency Deviation

### 4. VOR receiver

VOR receivers are traditionally designed using analog circuits for the reception and signal processing. The performance can be improved by using digital processing of the signal and at the same time the receiver can be simplified by implementing of the receiver in software. Figure 3 shows signal flow in dsPIC based VOR receiver.

The signal received by the antenna is amplified by wideband amplifier and mixed with the signal of the local quadrature oscillator in mixers I and Q. The product of the input signal and 0 deg. Oscillator signal is in-phase (I) signal. The product of input signal and 90 deg. Oscillator signal is quadrature-phase (Q) signal. Both I and Q signals are filtered in low pass anti-aliasing filter before they are digitized in ADC.

Digitized I and Q signals are passed through low pass filter and detected by calculating the amplitude of the modulating vector from I and Q signals.  The amplitude is then filtered through three filters to separate the components of the VOR signal.
The audio portion of the signal including the Morse code identifier of the station is separated by 300-3000Hz band pass filter. The output of the filter is passed to DA converter that is connected to headphones amplifier.

The Reference signal is separated by bandpass filter 9480 – 10440Hz. The resulting 9660Hz carrier is FM demodulated, for example by using frequency to period conversion and serves as an input for phase comparator together with the Variable signal that was separated by 30 Hz notch filter. Phase difference detected by the phase comparator is the bearing (azimuth) from the VOR station and is displayed on the LCD together with the reciprocal bearing to the station.

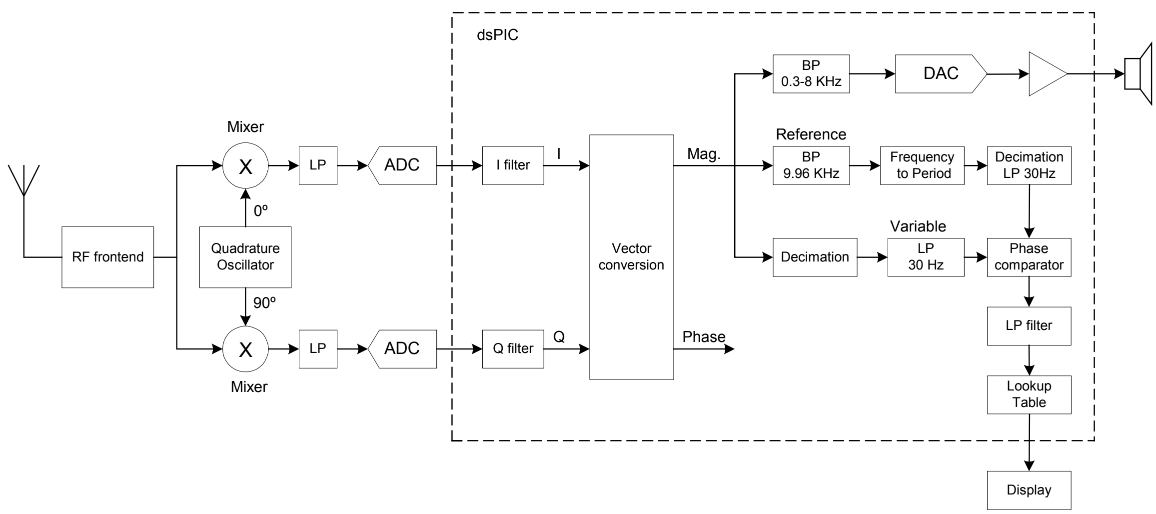


Figure 3. VOR receiver signal flow

## 5. Implementation

Most of the functions of the VOR receiver can be implemented by using Microchip dsPIC Digital Signal Controller. The number of components necessary to design the receiver is greatly reduced by high integration of peripheries in the dsPIC.
Figure 4 shows how the dsPIC based VOR receiver can be implemented.

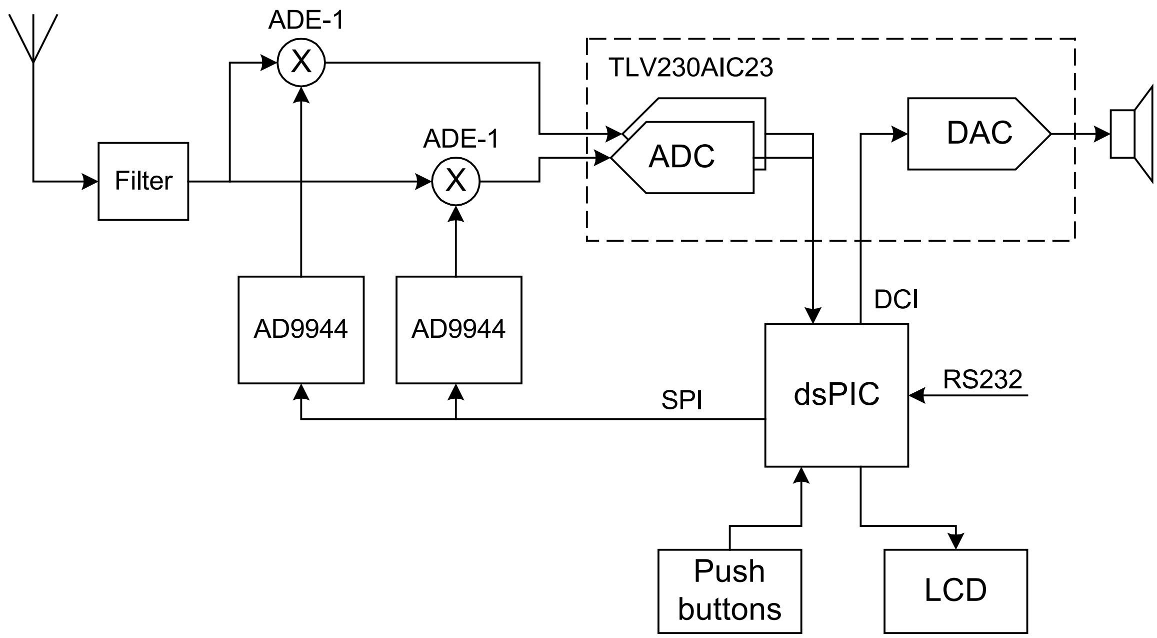


Figure 4. dsPIC based VOR receiver

Input RF signal passed through LC Band pass filter and mixed with the quadrature oscillator signal in two mixers to produce I and Q signals. There are many mixers available with good performance, for example SA602 or Mini Circuits ADE-1.

Critical element in processing of the input RF signal is a good local quadrature oscillator signal. There are few ways how to do it with good performance. We can use passive LC phase shifting network but that approach does not work well over the range of frequencies.
Classic approach is to generate oscillator signal with four times of the receive frequency and passing it through Dual Flip-Flop circuit to produce quadrature signals. This approach however does not scale well since it requires the logic circuit to run on very high frequency. In this case that the maximum oscillator frequency that would be required is close to 500MHz.
Better way to design quadrature oscillator is to use direct digital synthesis (DDS). Recently several integrated DDS circuits capable of generating frequencies in required range came out. One of them is Analog Devices AD9954. It can generate sinusoidal

signals up to 160MHz with great performance. To generate quadrature signals we can use two AD9954 connected to the same source clock signal and synchronized in master – slave configuration. By programming the phase via SPI compatible serial interface we can generate desired output 90° phase shifted quadrature signals.
There is another interesting DDS integrated circuit from Analog Devices. The AD9854 is capable of generating two output signals with phase shift controlled by software. Unfortunately the maximum frequency generated by the AD9854 is 100MHz.

The signal from the mixer has to be filtered by anti-aliasing low pass filter before it is converted into digital signal.
The codec that will digitize signal from the mixers should have at least 16 bit resolution and software selectable sampling rate. Good example is Texas Instruments TLV320AIC23 codec. It is dual 16 bit codec with sampling rate up to 96KHz. It also has other important features such as digital filter, integrated headphone amplifier and programmable gain amplifiers that can be used for controlling input gain and output volume.

Sampling rate of the ADC has great impact on the load of the DSP and should be carefully selected. The sampling frequency has to be at least twice the highest frequency of the sampled signal in order to be able to recover the transmitted information [1]. In case of VOR the highest frequency in the received signal is in the FM modulated 9960Kz subcarrier. Frequency deviation is 480Hz so the highest frequency is 10440Hz. Minimum sampling frequency is then 20.88Khz or more commonly used 22 or 24 KHz.

The heart of the receiver is dsPIC Digital Signal Controller. It connects and configures the DDS and codec via SPI compatible serial interface. It also receives the high-speed data stream of converted input signals from the codec. Microchip currently offers several Signal Controllers that have DCI interface. For example dsPIC30F4013 in small package or higher pin count dsPIC30F5013 and dsPIC30F6014.
The DCI interface on dsPIC has several modes that are supported by most of the codecs. In the receiver we need to process both I and Q input signals with minimum delay. The best for that is Multi-channel Frame Synchronous Serial DCI mode. The other DCI modes that are supported by dsPIC receive each channel individually at double of the sampling rate. That will also generate twice more interrupts which will decrease the time that we have available for DSP processing.

After dsPIC receives the data it does the signal processing. The audio signal is output back to codec to DAC. With the headphone amplifier built in we can connect headphones directly to codec output.
The bearing to the VOR station is calculated by the dsPIC and displayed on the LCD display connected to the SPI port of the dsPIC.

Small keypad can be connected to general purpose input lines of the dsPIC. User can input desired receiver frequency on the keypad. The frequency is converted into control word for the DDS circuit and sent over SPI interface.

## *6. Conclusion*

The article shows that dsPIC is can be used as a core building block for software receiver. It is powerful enough to do necessary DSP processing of the received signal.
With small software changes using the same hardware, it is possible to design receiver operating in amateur radio band. Flexibility of the DDS signal generation allows for covering many amateur radio bands with just one receiver. By adding additional circuitry for transmitter, it is possible to design transceiver using the dsPIC to generate SSB signals by phasing method.
It is also likely that soon the dsPIC will be available running on higher clock frequency that will allow for FM signal processing and for designing dsPIC based FM radio receiver. Then the dsPIC solution will be suitable as a platform for GNU Software radio project.

Literature:

[1] Oppenheim Alan V., Schafer Ronald W., "Discrete-Time Signal Processing", published by Prentice Hall Inc., 1989.
[2] Sanjit K. Mitra, “Digital Signal Processing”, published by McGraw-Hill Ltd. 2001
[3] Microchip website www.microchip.com