Generation of the Narrow Band Digital Modulated Signals Using Quadrature Digital Upconverter

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Abstract. *The paper deals with the modern approach to generation of digital modulated signals at intermediate frequency in digital way. The common digital modulator is based on analogue Quadrature modulator. The modern VLSI integrated circuits enable to implement this signal processing method in digital form. Analog and digital approaches are compared in this document. The measurement of narrow band D8PSK modulation signal generated by Quadrature Digital Upconverter is presented in this paper.*

Keywords

Digital modulation, DSP, DDS, Quadrature Digital Upconverter, VDL.

1. Introduction

The band pass signals are used in radio communication for information transmission. The band pass signal $s(t)$ can be represented by complex envelope $\tilde{s}(t)$ and frequency offset ω_c

$$s(t) = \mathrm{Re}\left[\tilde{s}(t)e^{j\omega_c t}\right]. \quad (1)$$

Easy and common implementation of generation of digital modulated signal is based on generation of the complex envelope. The complex envelope signal is generated in digital modulator as a pair of in-phase I and quadrature-phase Q signals.

1.1 Analog Approach

Complex envelope signal generated in modem is transformed to analog signal that is applied to the quadrature modulator input (Fig. 1.). The digital modulated signal at intermediate frequency is at the output of the modulator.

The important parameters of the quadrature modulator besides operating bandwidth are carrier rejection, sideband rejection, harmonic suppression, and conversion loss. They are influenced by the non-linearity, amplitude and phase un-balance of the quadrature modulator parts.

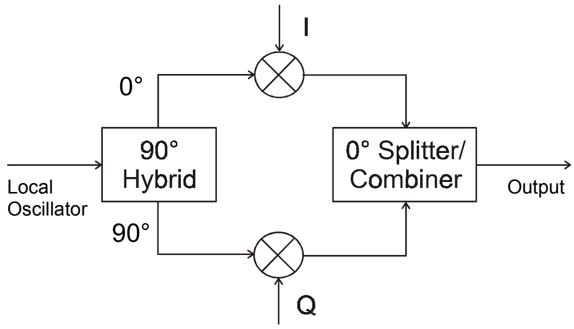

Fig. 1. Analog quadrature modulator

1.2 Digital Approach

Digital quadrature modulator (Fig 2.), which is called Quadrature Digital Upconverter, consists of interpolation filter, DDS (Direct Digital Synthesizer) and complex multiplier. The sine and cosine discrete signals are generated in the DDS. Cosine signal is multiplied by discrete I signal, sine signal is multiplied by discrete Q signal. Both output signals are then added together. This resultant signal is converted to analog signal in D/A converter. Discrete in time analog signal is passed to the low-pass or band-pass filter to be transformed to analogue continuous time signal.

The modem has to generate discrete complex envelope signal with clock frequency equal to clock frequency of the DDS. It is impractical. The discrete interpolation filter with selectable interpolation factor is used to reduce the speed of generation of discrete complex envelope signal.

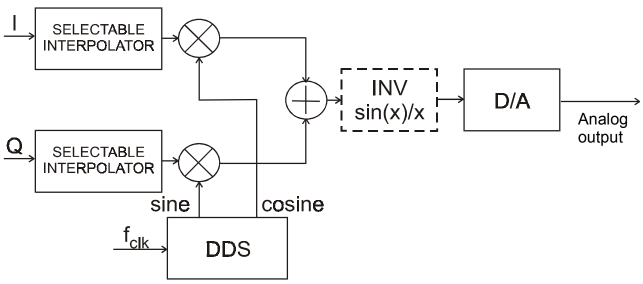

Fig. 2. Quadrature Digital Upconverter

Quadrature Digital Upconverter can by theoretically used for generation of the signal with bandwidth equal to one half of the f_{clk} DDS clock frequency. The level of the output signal depends on its frequency given by this equation

$$\left|H(f)\right| = \left|\frac{f_{clk}\sin\left(\frac{\pi f}{f_{clk}}\right)}{\pi f}\right| \qquad (2)$$

because of the zero order hold function which is intrinsic property of real D/A converter. This reduces usable frequency range of the Quadrature Digital Upconverter to approximately 80% of $f_{clk}/2$.

When the wideband signal is generated, the frequency dependence can cause some problems, that's why the inverse sin*x/x* filter is added.

Quadrature Digital Upconverter does not suffer from problems like analog quadrature modulator. For example, in analogue quadrature modulator there is problem with low carrier rejection, amplitude and phase unbalance and harmonic suppression. In the case of Quadrature Digital Upconverer these parameters are significantly better.

Unlike in analog circuit, spurious emissions appeare in the spectrum of the signal generated by Quadrature Digital Upconvertor. These spurious emissions are typical for DDS. Level of these emissions depends on the resolution of the build-in arithmetic and on resolution and linearity of the D/A converter.

Another disadvantage of the Quadrature Digital Upconverter in comparison with the analogue one is higher power consumption.

The Quadrature Digital Upconverters is realized as a unique dedicated circuit specially designed for specific application. The programmable logic circuits (FPGA) are mostly applied. The D/A converter is external. Those circuits are optimized for one application.

Nowadays the universal Quadrature Digital Upconverters appear on the market. This integrated circuit is configurable to be used in wide range of applications.

2. Application of the Quadrature Digital Upconverter

The Quadrature Digital Upconverter AD9857 was applied in the modem of the aviation Very high frequency Digital Link (VDL). This digital link is intended to replace existing aviation communication system. These links will be used for digital voice and data communication for both ATM (Air Traffic Management) and non-ATM applications like DGNSS (Differential Global Navigation Satellite System) correction broadcast.

VDL links operate with channel spacing 25 kHz. VDL mode 2 and 3 use Differential 8 state Phase Shift Keying modulation (D8PSK) with Raised Cosine Spectrum modulation pulse. Roll off factor is 0,6. Bit rate is 31,5 kbit/s.

Aviation standards allow very low adjacent channel emission because of payload of the VHF air band. For example, the amount of power from VDL airborne transmitter under all operating condition when measured over the 25 channel bandwidth of the first adjacent channel shell not exceed 0 dBm. When 20 W transmitter power is considered, the power emission to the first adjacent channel shall be 43 dB below carrier. The attenuation of the second adjacent channel should be at least 68 dB.

3. Prototyping Hardware

VDL modulator consists of the DSP for generation of the discrete complex sample of the modulated signal and Quadrature Digital Upconverter that carries out modulation. The 16 bit fix point DSP TMS320C5416 from Texas Instruments is applied. The 14bit Quadrature Digital Upconverter AD9857 from Analog Devices is used.

The Modem generates signal at intermediate frequency 70 MHz. The Quadrature Digital Upconverter clock frequency is 184,8 MHz. This frequency is selected as a multiple of the symbol rate and it satisfies condition that the generated frequency range is 80% of the half of the clock frequency. The interpolation filter is set on the interpolation factor 220. The DSP should generate 840 k sample of the complex envelope per second in this configuration. It means that DSP generates 80 samples per symbol.

Hardware prototype of the VDL modem is based on DSP EWM325C54xx module. The Quadrature Digital Upconverter is designed as extended card.

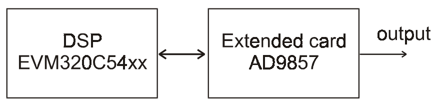

Fig. 3. Prototyping Hardware

4. Software

The algorithm of complex envelope $\tilde{s}$ calculation is very simple (3). The raised cosine spectrum modulation pulse is theoretical infinite. In practical implementation the modulation pulse must be time limited. Our modulation pulse was limited to 5 symbol periods T_s and arisen amplitude discontinuity was eliminated by Kaiser windows function.

$$\tilde{s}_i = I_i + j.Q_i = \sum_k e^{j\Phi_k} h\left(i.T_v - k.T_s\right) \qquad (3)$$

where h modulation pulse, T_s symbol period, T_v sampling period, Φ_k k-symbol phase.

The problem is in software timing. In the case that DSP operates at 100 MHz, the calculation of one sample of the complex envelope (real and imaginary part) should dispose at most 119 cycles. The state diagram of the program function for generation complex envelope is in Fig 4. In the I0, A, C states the real part of the complex envelope is written to the Digital Quadrature Upconverter register. The imaginary part is written in states I1, B, and D. The states I0 and I1 serve for synchronization of the program with hardware. In parenthesis there is a number of DSP clock cycles required for complex envelope sample calculation. The differences between calculation of the 79, 80 and 1- 4, 6 – 9.. samples and 5, 10.. symbols are caused by the data organization in DSP.

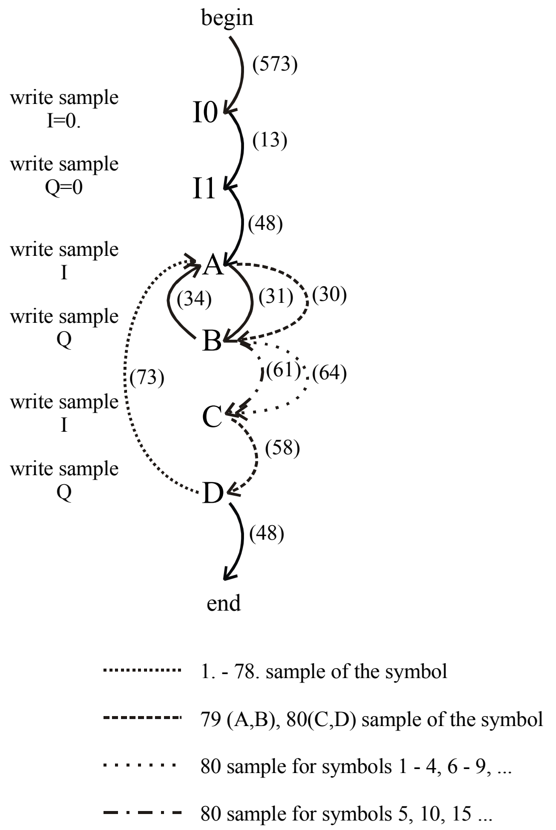

Fig. 4. State diagram of the complex envelope generating function

5. Measurement Results

The spectral property of the modulated signal for random data was investigated. In Fig. 5 there is narrow band spectrum. The figure shows that requirements for radiation to the first and second adjacent channel are satisfied. Fig. 6 demonstrates, that requirement for attenuation of the signal in wider bandwidth is compliance too, but Fig. 7 shows that it is not reached in bandwidth 50MHz. The spurious spectral components are due to limited resolution of the DDS and non-linearity of D/A converter. These spurious components are typical for DDS circuits.

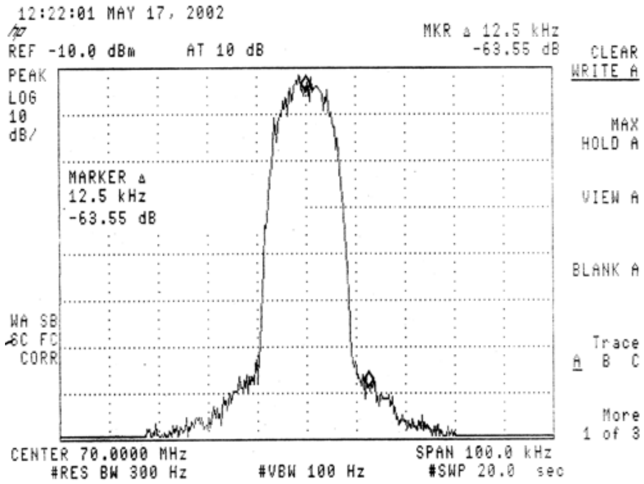

Fig. 5. D8PSK Modulated signal spectrum (span 100 kHz)

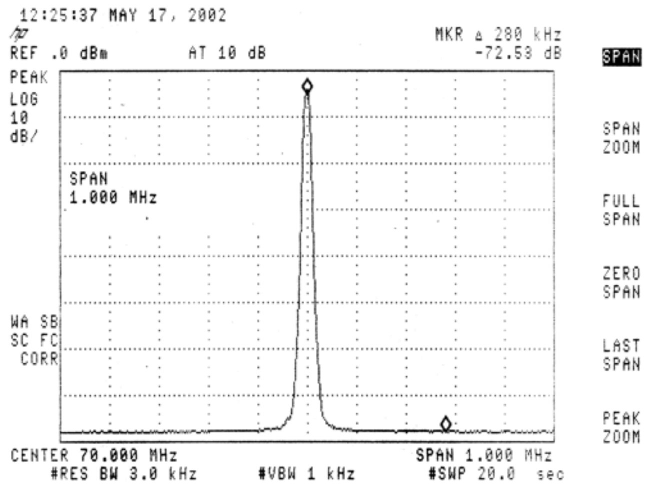

Fig. 6. D8PSK Modulated signal spectrum (span 1 MHz)

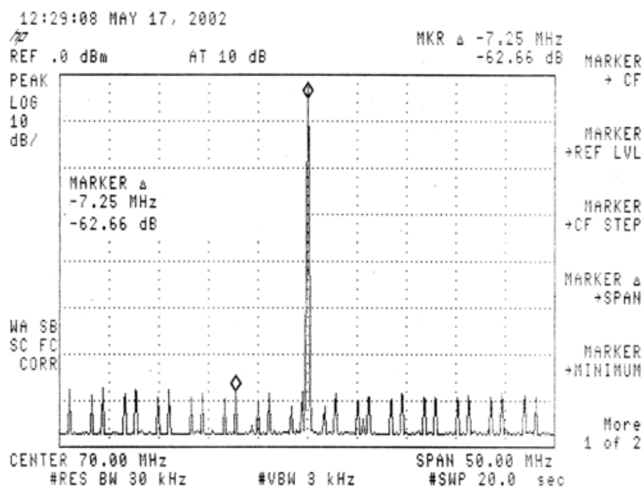

Fig. 7. D8PSK Modulated signal spectrum (span 50 MHz)

In narrow band digital modulated signal this spurious emission can by removed by band pass filter. In the case of wide band system, the band pass filter cannot by generally applied.

6. Conclusion

The paper deals with the Quadrature Digital Upconverter implementation for generation of the narrow band D8PSK modulation. Application of this Quadrature Digital Upconverter eliminates some problems.

Experimental results confirm excellent carrier rejection of the Quadrature Digital Upconverter. No carrier residual is observed. The Harmonic suppression is excellent too. No harmonic components occur in spectrum of the modulated signal. The small phase and amplitude unbalance are guaranteed by principle of operation.

Some disadvantage of Quadrature Digital Upconverter is spurious emissions. These spurious emissions can be removed by band pass filter. In the case of wide band systems the spurious emissions cannot be generally removed.

The Quadrature Digital Upconverter is good choice for narrow band system where power consumption is not critical parameter. The progress in technology probably enables to reduce spurious emissions in the near future.

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Pavel Kovář was born in Uherské Hradiště in 1970. He received Ing. (MSc) and Dr. (Ph.D.) degree from the Czech Technical University in Prague in 1994 and 1998. Since 1997 to 2000 he worked in Mesit přístroje as designer of avionics instruments. Now he is assistant professor at the Faculty of Electrical Engineering, CTU, Prague. His interests are satellite navigation, digital communication, signal processing.