VLSI Implementation of 8-PSK/8-QAM/16-QAM Transmitter Circuit in CMOS Technology

Radu Gabriel Bozomitu, Arcadie Cracan, and Gabriel Bonteanu

Faculty of Electronics, Telecommunications and Information Technology,
“Gheorghe Asachi“ Technical University, Iaşi, Romania,
bozomitu@etti.tuiasi.ro

Abstract: *In this paper a VLSI implementation of 8-PSK/8-QAM/16-QAM transmitter using the same circuit architecture in CMOS technology is presented. The circuit is used for transmissions in the ISM radio bands at a carrier frequency of 433 MHz. In order to simplify the circuit implementation, all digital modulations provided by the proposed transmitter present message points that use combinations of only two distinct values of their coordinates. As consequence, the circuit provides the same average transmission power for all modulations and uses the same circuits for all component blocks, except for the number of levels used by the digital modulation and their digital control logic. The operation of the proposed transmitter has been analyzed considering an AWGN communication channel and a receiver circuit model. In the paper the constellation diagram and the signal trajectory of all digital modulations implemented in the transmitter circuit are plotted and the bit error rates have been calculated. The simulations performed in 180 nm CMOS technology confirm the mathematical results.*

1. INTRODUCTION

Communication systems that use digital modulation for high-speed data transmission are widespread nowadays. Due to their high noise immunity, bandwidth and power efficiency, digital modulations are used in many applications, such as: wireless LAN, RFID, Bluetooth, GSM, satellite communications, cable modems, digital television, microwave digital radio, terrestrial microwave, DVB-T, DVB-C, digital video [1-12].

Different implementations of digital modulations are reported in the literature. In [2] a 16-PSK modulator with phase error correction which operates within the IF range between 200 - 400 MHz is presented. The implementation of an *M*-ary PSK and QAM OFDM system via algorithms and simulations is shown in [3].

2. PRINCIPLE OF THE TRANSMITTER CIRCUIT

In Fig. 1 the block diagram of the proposed 8-PSK/8-QAM/16-QAM transmitter (TX) system is presented.

The low frequency blocks of the TX circuit include a serial-to-parallel (SIPO) converter providing three or four bits wide parallel data sequences depending on the digital modulation type, a custom mapping (CustMap) block to drive the two 2-bits digital-to-analog (DAC) converters.

The high frequency blocks are represented by a quadrature oscillator, two mixers placed on the I and Q paths, respectively and an adder circuit where the RF digital modulated signal is built.

In this paper the electrical schematic of the TX circuit is presented.

The operation of the transmitter circuit has been analyzed considering an additive white Gaussian noise (AWGN) communication channel (modeled by authors) and an ideal receiver (RX) circuit implemented at the system level.

The structure of the receiver is identical for all types of modulations, except for the parallel-to-serial converter used at the circuit output, which uses different input bit widths, depending on the type of the modulation.

In order to calculate the probability of error $P(e)$ and the Bit Error Rate (BER) of the proposed transmitter circuit, we use the energy per bit-to-noise power density ratio, given by the following equation [1,4]:

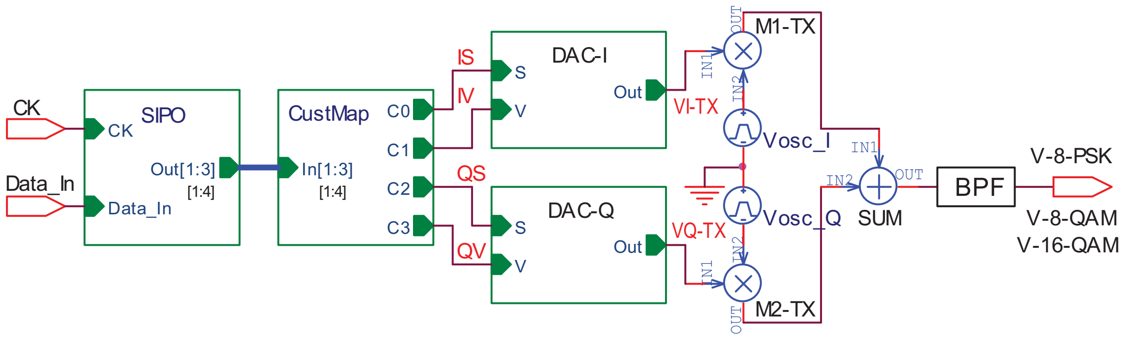

Fig. 1. Block schematic of the 8-PSK/8-QAM/16-QAM transmitter circuit.

$$E_b/N_0 = (C/N)\cdot(B/f_b) \tag{1}$$

where E_b is the energy of a single bit, N_0 is the thermal noise power density, C is the carrier power, f_b is the bit rate per second, and B is the bandwidth of the circuit.

The energy of a single bit, E_b, can be expressed as:

$$E_b = C/f_b \text{ (J/bit)} \tag{2}$$

The frequency bandwidth B provided by 8-PSK/ 8-QAM/16-QAM modulations can be written [1, 4]:

$$B_{\text{8-PSK/8-QAM}} = f_b/3\,;\ B_{\text{16-QAM}} = f_b/4 \tag{3}$$

The communication channel used to analyze the circuit performance has been implemented by using an AWGN source model. The power spectral density (PSD) of this noise source model has been calculated to obtain an imposed value for the E_b/N_0 ratio.

The total output noise power provided by the proposed noise source model can be expresses as:

$$N = PSD_0 \cdot B \tag{4}$$

where PSD_0 is the power spectral density of the noise source model and B is the frequency bandwidth of the circuit depending on the modulation type.

By using the Equation (4) in (1), we obtain the expression of the PSD_0 used in the noise source model:

$$PSD_0 = \frac{C}{f_b}\cdot\frac{1}{E_b/N_0} \tag{5}$$

According to the constellation diagrams of the 8-PSK/8-QAM/16-QAM modulated signal, illustrated in Fig. 2, their message points ($\overline{z}_i$) use combinations of only two distinct values (a, b) of their coordinates:

$$\overline{z}_i = x_i + j\cdot y_i\,,\ i = 1, 2, \ldots, 16 \tag{6}$$

where $x_i = \{\pm a, \pm b\}$; $y_i = \{\pm a, \pm b\}$.

The average transmission power for all types of digital modulations implemented in our system is $C = 10\text{mW}$.

Since the chosen phase shift for the first 8-PSK modulation constellation point is 22.5°, to obtain the required value of the average transmission power, the following values are obtained for the coordinates of the message points:

$$a = 0.03825;\ b = 0.09242 \tag{7}$$

In order to simplify the circuit implementation, we used the same coordinates of the message points to generate all types of digital modulations considered in the proposed TX circuit.

First, the operation of the communication system is implemented and analyzed at the system level, considering ideal models for transmitter and receiver circuits and an AWGN noise source model.

In Fig. 2a the signal trajectory and the constellation diagram obtained at the receiver block for 8-PSK digital modulation, obtained by performing system level simulation of the proposed communication system, are plotted. In this diagram only two (first quadrant) message points are required to generate all the points from the constellation.

Moreover, by taking other possible combinations of these two distinct points coordinates, one can obtain the 16-QAM and 8-QAM modulations, having the constellation diagrams illustrated in Figs. 2b-c, respectively.

The positions of the message points used by all considered modulations (8-PSK/8-QAM/16-QAM) are presented on the same diagram, as shown in Fig. 2d.

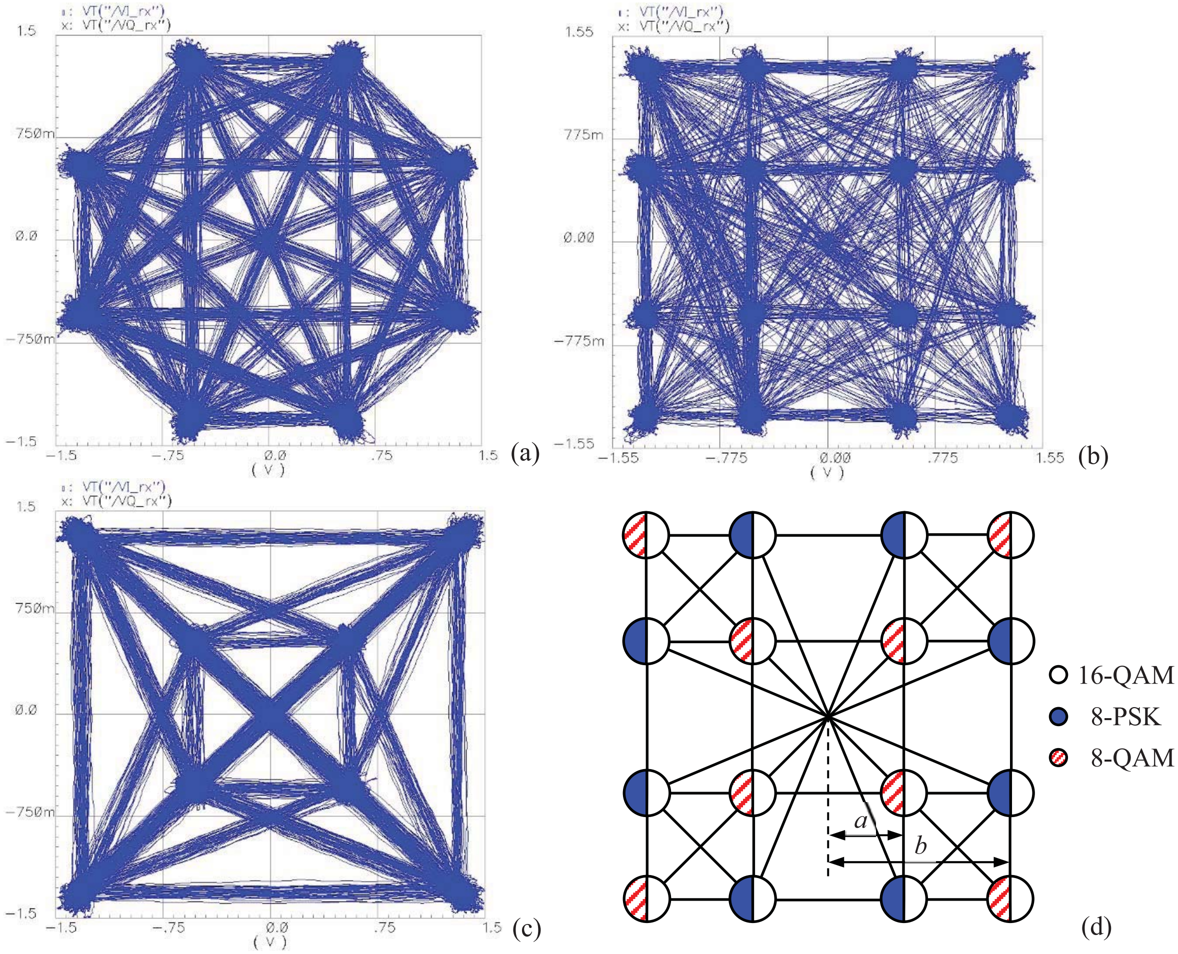

Fig. 2. Signal trajectory and constellations of all modulations obtained at the RX block by system level simulation: (a) 8-PSK; (b) 16-QAM; (c) 8-QAM; (d) positions of message points used by all digital modulations on the same diagram.

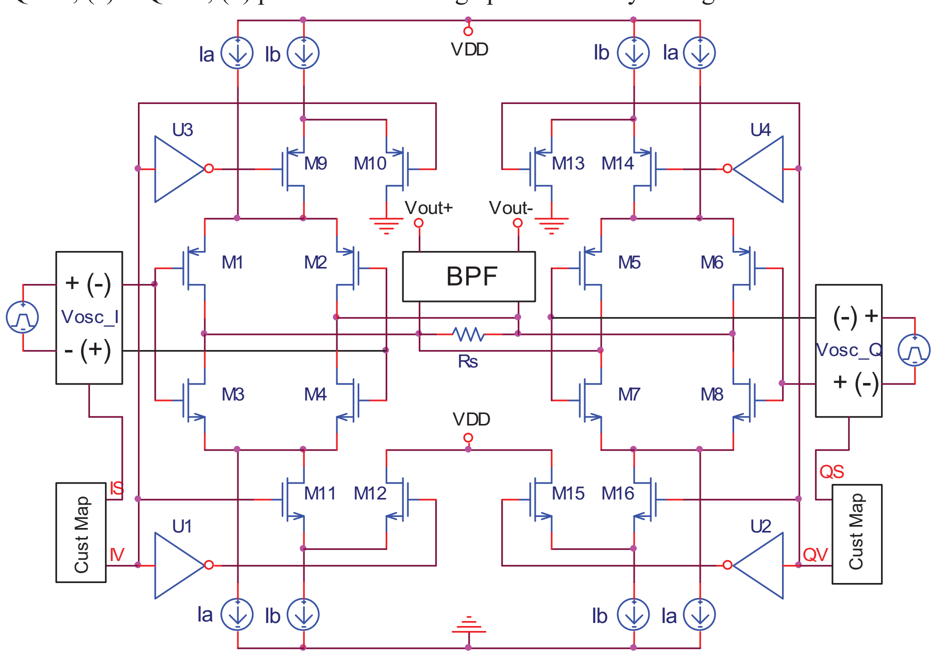

Fig. 3. Electrical schematic of 8-PSK/8-QAM/16-QAM transmitter circuit.

Although the ratio of coordinates of the message points (a/b) is different from the value of 1/3 used in the standard square QAM modulations, this solution simplifies the circuit implementation and determines the same average transmission power for all type of digital modulations.

3. VLSI Implementation of the Transmitter Circuit

In Fig. 3 the electrical schematic of the 8-PSK/8-QAM/16-QAM transmitter circuit is illustrated.

The differential pairs (M9, M10), (M11, M12), (M13, M14) and (M15, M16) are used to generate the values (a, b) of the coordinates of the message points for both paths I and Q by using the current sources denoted I_a and I_b in Fig. 3.

The H bridges implemented with transistors (M1 – M4) and (M5 – M8) are used to generate the sign of the coordinates of the message points for both paths I and Q, respectively. The common mode feedback loop was not represented in the Fig. 3.

At the same time these circuits perform the mixing between the coordinates of the message points ($\pm a$, $\pm b$) and the carrier signal at 433 MHz frequency in order to obtain different types of digital modulations, according to the custom mapping implemented in the digital logic of the proposed transmitter circuit.

The differential radiofrequency signal with desired digital modulation is obtained on the load resistor R_S of 50 Ω and it is band-pass filtered for compliance with wireless transmission standards.

The custom mapping used to build the constellation diagrams of the proposed 8-PSK/8-QAM/16-QAM is based on 2-bits only for each signal path.

One of these is the sign bit (IS/QS), and the other is the bit corresponding to the value of the message points (IV/QV). The digital logic that generates these signals (CustMap block in Figs. 1 and 3) is specific to each type of modulation used by the proposed transmitter circuit. All types of digital modulations used in the proposed circuit use the same value for the message points.

4. Simulation Results

According to the rule-of-thumb from [1] a high accuracy BER can be calculated from the simulations that provide at least 100 bit errors. This means that for the accurate estimation of the BER, long time simulations are needed, which are computationally expensive and difficult to implement. Due to the limitations of the hardware computing system, in this paper, BER was estimated considering 4000 bit random data sequences. This means that in our study, the BER has been accurately estimated only for E_b/N_0 ratios less or equal to 7dB.

The operation of the proposed transmitter circuit is studied by using an ideal receiver implemented at the system level, scaled for a received signal power of 1 W.

In Fig. 4 the signal trajectory obtained at the receiver circuit, after demodulation of the RF signal for 8-PSK, 8-QAM and 16-QAM digital modulations are plotted for two cases: (1) by using an ideal communication channel, without noise (Figs. 5a,c,e) and (2) for an AWGN communication channel providing a total noise power, which correspond to an E_b/N_0 ratio of 12 dB (Figs. 5b,d,f).

The performance of the proposed transmitter circuit for all types of digital modulations is analyzed by plotting the BER for different values of the E_b/N_0 ratio.

The BER depending on E_b/N_0 ratio for all types of digital modulations provided by the proposed circuit is presented in Table 1. According to Equation (5), the PSD_0 used by the noise source model depending on E_b/N_0 ratio is also illustrated in Table 1.

Table 1. BER and PSD_0 of the noise source model depending on E_b/N_0 ratio for digital modulations provided by the proposed transmitter circuit.

E_b/N_0 (dB)	PSD_0 (V^2/Hz)	BER		
		8-PSK	8-QAM	16-QAM
0	5.000E-08	0.1325	0.13475	0.1345
2	3.155E-08	0.0935	0.09575	0.0945
4	1.991E-08	0.05575	0.061	0.05675
6	1.256E-08	0.02875	0.03	0.02875
8	7.924E-09	0.01025	0.0125	0.0135
10	5.000E-09	0.002	0.003	0.00375
12	3.155E-09	0.00075	0.0005	0.0015

In Fig. 5 the BER for all types of digital modulations (8-PSK, 8-QAM and 16-QAM) provided by the proposed circuit are plotted. These results are compared on the same graph with the ideal ones (presented in [1,4]), obtained theoretically by mathematical calculation. The difference between the simulation and the theoretically obtained results are mainly due to intersymbol interference (IIS), and the noise produced by electronic devices from the circuit structure.

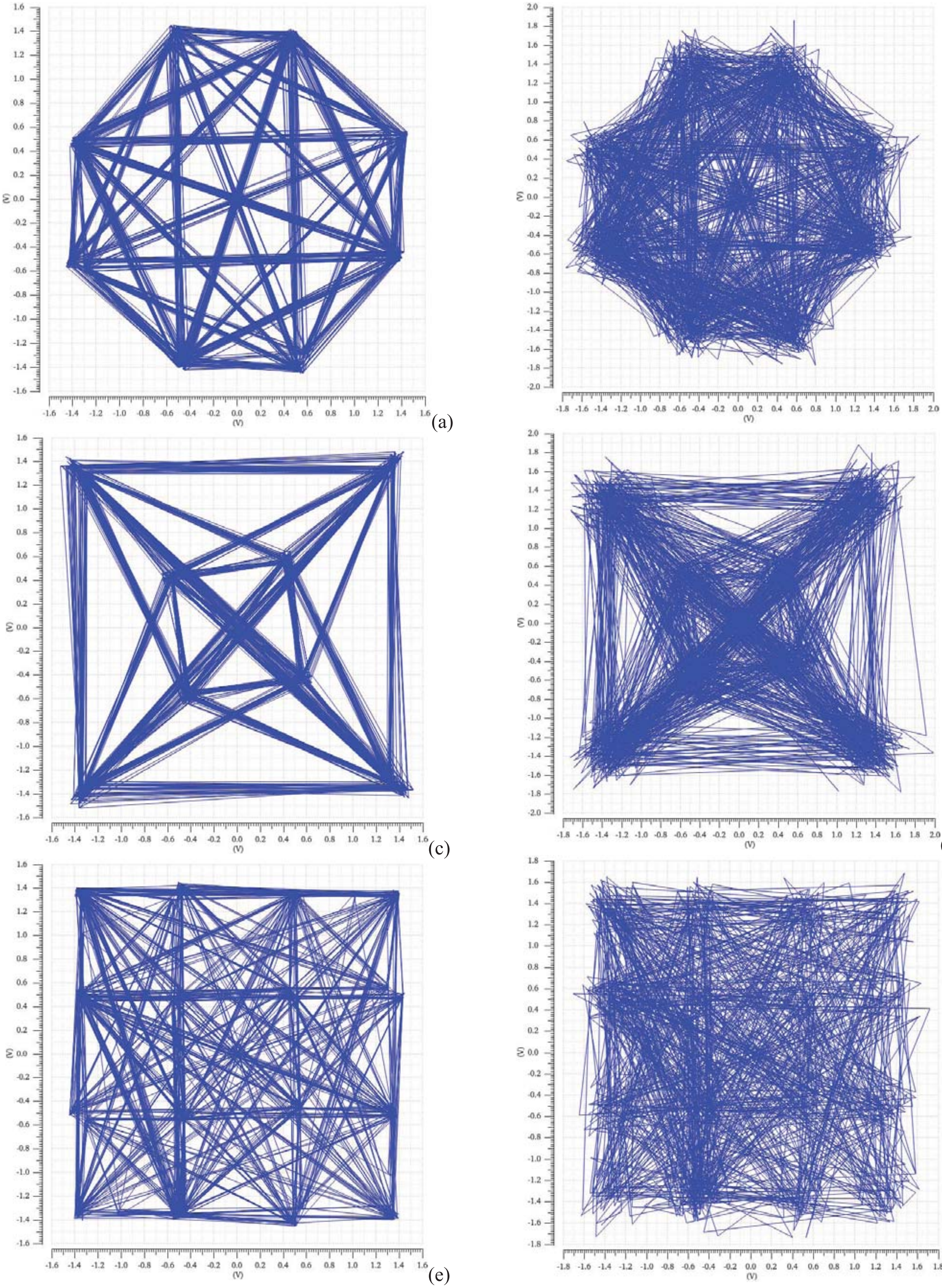

Fig. 4. Signal trajectory at the RX circuit without/with channel noise: (a)-(b) 8-PSK; (c)-(d) 8-QAM; (e)-(f) 16-QAM.

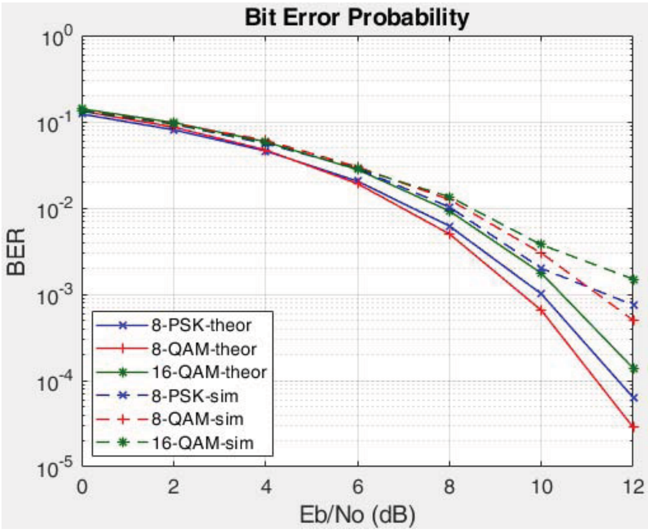

Fig. 5. BER of the proposed/ideal transmitter circuit for 8-PSK, 8-QAM, 16-QAM digital modulations.

Another small dissimilarity from the ideal values of the BER is due to the difference of the non-square 8-QAM and 16-QAM modulations used in our TX circuit from the standard ones with square symmetry.

On the other hand, to simplify the circuit implementation, a custom mapping, different from standard Gray mapping has been considered in our system design.

The only external noise source considered in the analysis of the proposed circuit operation is the channel noise, modeled with an AWGN source.

5. Conclusion

In this paper a new transmitter circuit which provides the 8-PSK/8-QAM/16-QAM digital modulations has been implemented in a 180 nm CMOS technology. All types of digital modulations are generated by using the same circuit configuration, except for the digital logic which control the hardware component of the circuit.

In order to implement the AWGN transmission channel a new noise source model has been developed.

The circuit performances have been analyzed by computing the BER for all types of digital modulations provided by the proposed transmitter circuit.

In the paper the 8-QAM/16-QAM modulations have been obtained by using the message points of the 8-PSK modulation, providing the same average transmission power and very close BER.

The accuracy of the results depends on the length of the input data sequence. The simulation results are close to the theoretical values of the BER for E_b/N_0 ratios less or equal to 7dB and confirm that the proposed circuit is suitable for practical applications.

References

[1] Dayan Adionel Guimarães, *"Digital Transmission A Simulation-Aided Introduction with VisSim/Comm"*, Springer-Verlag Berlin Heidelberg 2009;

[2] B. Wupperman, B. Fox, R. Walker, S. Atkinson, D. Budin, C. Lanzi, S. Bleiweiss, "A 16-PSK modulator with phase error correction", In *1993 IEEE International Solid-State Circuits Conference Digest of Technical Papers*, pp. 138-139, February, 1993;

[3] H. Yeh and V. R. Ramirez, "Implementation and Performance of a M-ary PSK and QAM-OFDM System in a TMS320VC5416 Digital Signal Processor", *2007 Second International Conference on Digital Telecommunications (ICDT'07)*, San Jose, CA, 2007, pp. 19-19;

[4] Digital Modulation - Chapter 2, http://ee.eng.usm.my/eeacad/mandeep/EEE436/CHAPTER2.pdf;

[5] Leon W. Couch, II, *"Digital and Analog Communication Systems"*, Eighth Edition, Pearson Education, Inc., publishing as Prentice Hall, New Jersey 07458, 2013;

[6] Simon Haykin, Michael Moher, *"Introduction to Analog and Digital Communications"*, Second Edition, John Wiley & Sons, Inc., 2007;

[7] Simon Haykin, *"Digital Communications"*, John Wiley & Sons, Inc., 1988;

[8] M. K. Simon, and M.-S. Alouini, *"Digital Communications over Fading Channels"*, 2nd Ed. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2005;

[9] Walter Fischer, *"Digital Video and Audio Broadcasting Technology"*, Springer-Verlag Berlin Heidelberg, 2008;

[10] Behzad Razavi, *"RF Microelectronics"*, Second Edition, Pearson Education, Inc., New Jersey 07458, 2012;

[11] S. Benedetto and E. Biglieri, *"Principles of Digital Transmission with Wireless Applications"*, New York, USA: Kluwer Academic and Plenum Publishers, 1999;

[12] E. A. Lee and D. G. Messerschmitt, *"Digital Communication"*, 2nd Ed. Boston, USA, Kluwer Academic Publishers, 1994/1999.