Consumer Microcircuits Limited
COMMUNICATION SEMICONDUCTORS

Application Information

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Using the CMX980A for Non-TETRA Radio Schemes

Introduction

The CMX980A is a truly universal in-phase and quadrature (I/Q) compatible digital radio baseband processor that can used with many types of analogue and digital modulation including AM, FM, SSB, QAM, BPSK, QPSK, FSK, etc. It is a highly integrated system which saves space and cost for the manufacturers producing both analogue and digital radio products. The device allows baseband signals to directly modulate the I/Q carriers for Pi/4DQPSK, or allows direct write access to the I/Q Tx 79-tap filter inputs for use in systems where different modulation schemes are used. The CMX980A already meets the demanding specifications required by TETRA and thus the programmable filters available on-chip are capable of meeting the requirements of any analogue or digital communication system.

The following discussion describes some of the theory behind I & Q modulators, and details how the CMX980A could be used with any modulation scheme:

I/Q Modulation

Any bandpass RF signals can be represented in polar form by:

$$s(t) = A(t) \cos [w_c t + f(t)] \qquad \text{(EQ. 1)}$$

where A(t) is the signal envelope and f(t) is the phase. By using the trigonometric identities, we can represent EQ. 1 in rectangular form by:

$$s(t) = I(t) \cos [w_c t] - Q(t) \sin [w_c t], \qquad \text{(EQ. 2)}$$

$$I(t) = A(t)\cos[f(t)]$$
$$Q(t) = A(t)\sin[f(t)]$$

Since the baseband signals I(t) and Q(t) modulate two exactly 90° out-of-phase carriers $\cos(w_c t)$ and $-\sin(w_c t)$ respectively, we call the system implementing EQ. 2 an in-phase and quadrature (I/Q) modulator. Figure 2 shows the mathematics and hardware implementation of an I/Q modulator.

The local oscillator, usually a VCO within a PLL, generates the carrier and is split into two equal signals. One goes directly into a double-balanced mixer to form the I-channel and the other one goes into the other mixer via a 90° phase shifter (realised by passive elements) to provide the Q-channel. The baseband signals I(t) and Q(t), either analogue or digital in nature, modulate the carrier to produce the I and Q components which are finally combined to form the desired RF transmitting signal. Since any RF signal can be represented in the I/Q form, any modulation scheme can be implemented by an I/Q modulator/filter arrangement.

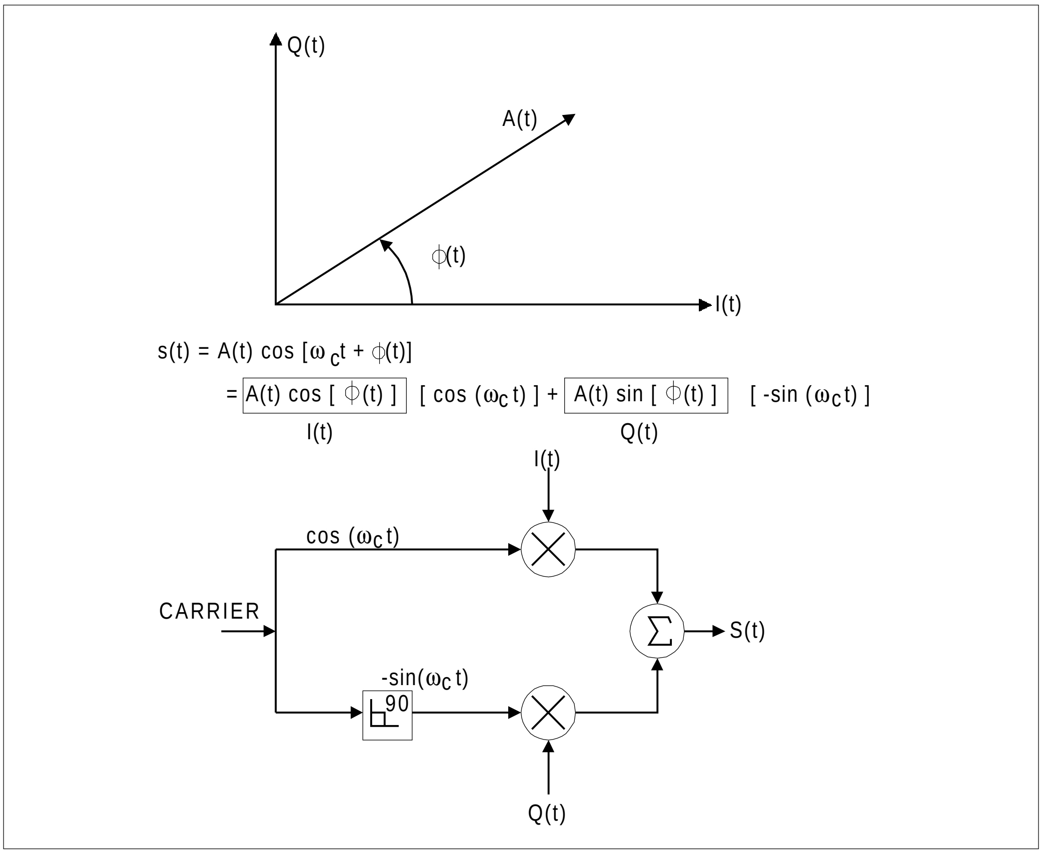

Figure 2 - Mathematical Representation and Hardware Implementation of an I / Q Modulator

Linear Digital Modulation

Linear digital modulation techniques depend on varying the phase and/or magnitude of an analogue carrier according to some digital information: ones and zeros. This digital information can be the output of an analogue-to-digital converter (e.g. voice codec), or it can be digital data in some standard formats (e.g. ASCII). The most popular digital signalling format is non return-to-zero (NRZ), where 1s and 0s are converted into signal with amplitude of 1 and -1, respectively, in a symbol duration. Since the NRZ signal has infinite bandwidth, transmit filters have to be used to limit the spectrum for transmission. To ensure each NRZ symbol does not affect its neighbours due to low-pass filtering and channel distortion causing inter-symbol interference (ISI), the low pass filter has to be a “Nyquist filter”. This class of filters produces a response which will minimise the impact of a symbol on it’s neighbours. One example of this type of filter is the linear phase square-root-raised cosine filter. Together with the same type of filter for receive low-pass filtering, the signal is guaranteed ISI free. One straight-forward technique of transmitting such bandlimited signals through communication channels would be by applying it directly to the mixer of the I-channel to generate the RF signal. This is known as binary phase shift keying (BPSK), where the phase of the carrier is shifted 180° to transmit a data change from 0 to 1 or 1 to 0.

Quadrature or quaternary phase shift keying (QPSK) is a much more common type of modulation scheme used in mobile and satellite communications. It has four possible states (90° apart) and each of them represents two bits of data. Figure 3 shows the baseband generator for QPSK (without the differential phase encoder).

NRZ data bits go through the serial-to-parallel converter (see Figure 4) and are mapped in accordance to some rules to generate I and Q values. The generic rule will be the values of I and Q components are 1 and 1 for the data bits “11” (45°) and -1 and -1 for the data bits “00” (-135°). These discrete signals have to be bandlimited by Nyquist low-pass filters to be ISI free.

A more sophisticated way of mapping results in p/4-DQPSK (D for differential encoding), which is chosen for North America Digital Cellular (IS-54), Personal Digital Cellular (PDC) in Japan, and Personal Handy Phone System (PHS) in Japan. In this scheme, consecutive pairs of bits are encoded into one of the four possible phases: p/4 for “11”, 3p/4 for “01”, -3p/4 for “00”, and -p/4 for “10”. However, unlike the previous case that “11” is always p/4 and “00” is always -3p/4, the encoded phases are the degrees that the carrier has to shift at each sampling instance. Thus, the information is contained in the phase difference (differential) instead of absolute phase for p/4-DQPSK.

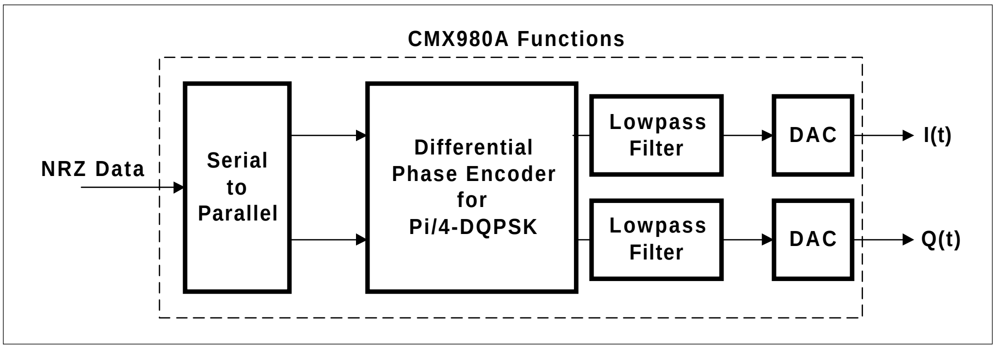

Figure 3. QPSK and Pi/4-DQPSK Baseband Generator

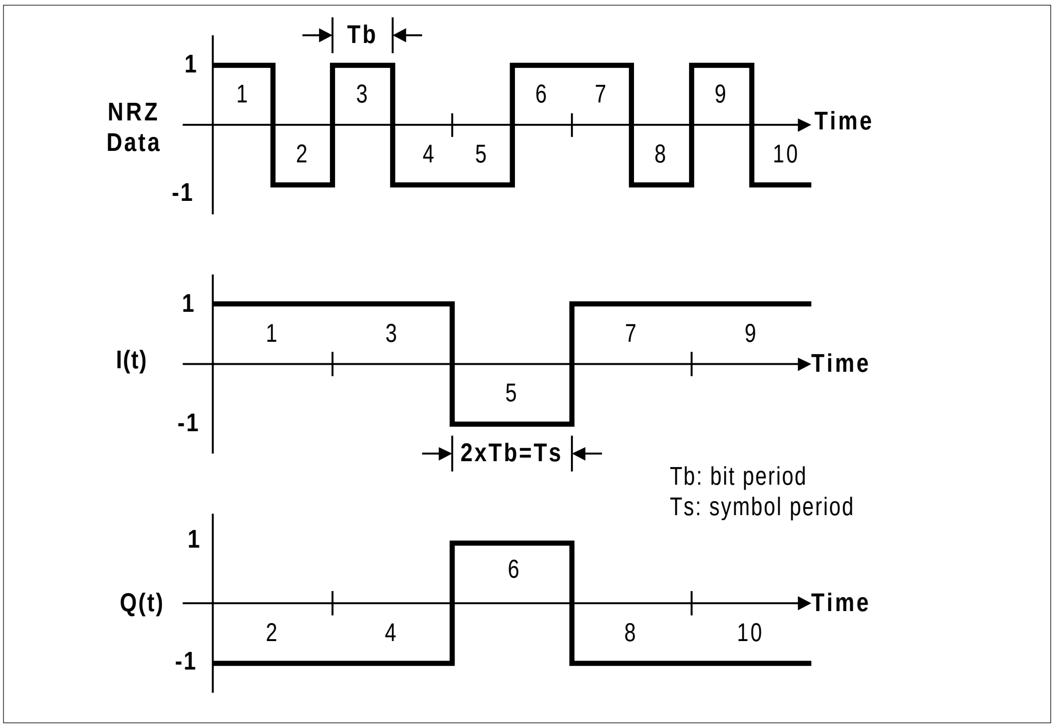

Fig.4. Serial-to-Parallel Conversion

A better way to tell the difference between QPSK and p/4-DQPSK is by looking at the signal constellation diagram, shown in Figure 5, which displays the possible values of I and Q vectors and change of states. The constellation diagram is also known as the phase diagram because it shows the phase of the carrier at the sampling point. Notice that the phases of QPSK are assigned for every two bits of data; therefore, it can transmit twice as much information as BPSK in a given bandwidth, i.e., more bandwidth efficient. 8-PSK is another type of modulation used for high efficiency requirements. It maps three bits into 8 phases, 45° apart, in the constellation. More spectral efficient modulation can be created by mapping more bits into one phase at each sampling point. However, as you put more dots in the signal constellation, the signal susceptibility to noise is lower because the decision distance is shorter (dots are closer). Then, it requires higher carrier-to-noise (C/N) ratio to maintain the same bit error rate (BER).

One common misconception is that since p/4-DQPSK has 8 states in the constellation, it is just another type of 8-PSK. Notice that at every sampling instant, the carrier of p/4-DQPSK is only allowed to switch to one of the 4 possible states (see Figure 5). So, we still have two data bits which get encoded into 4 phases. Thus, it has the same spectral efficiency as QPSK for the same carrier power. The reason for using this modulation scheme is twofold. First, the envelope fluctuation, which causes spectral spreading due to non-linearity of transmitter and amplifier, is reduced because the maximum phase shift is 135° instead of 180°. Second, the signal can be demodulated non-coherently which simplifies the receiver circuitry by eliminating the need for carrier recovery.

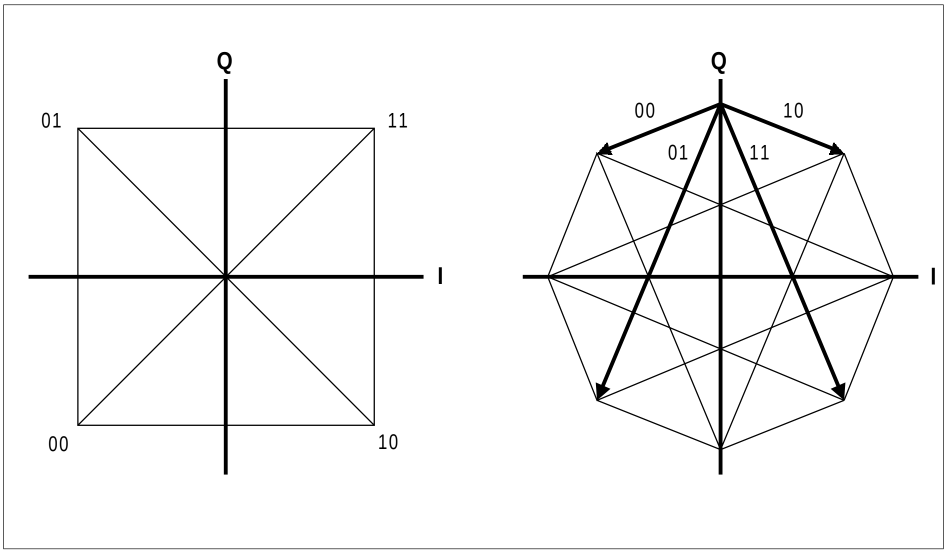

Figure 5 - Signal Constallation of QPSK and Pi/4-DQPSK

Digital FM

Another family of digital modulation is categorised by frequency change of the carrier instead of phase and/or amplitude change. One of them is frequency shift keying (FSK), where the carrier switches between two frequencies. FSK is also known as digital FM because it can be generated by feeding the NRZ data stream into an analogue VCO. FSK appears as a unit circle in the signal constellation because the RF signal envelope is constant and the phase is continuous. Baseband filtering is usually applied for FSK to limit the RF bandwidth of the signal so that more channels can fit into a given frequency band.

One common modulation of this type is known as Gaussian minimum shift keying (GMSK), which is used for GSM and some other wireless applications. GMSK can be generated by following its definition: bandlimit the NRZ data stream by a Gaussian low-pass filter, then modulate a VCO with modulation index (2 x frequency deviation/bit rate) set to 0.5. In other words, the single-sided frequency deviation is one fourth of the bit rate (Df = R/4).

Another way of generating GMSK is by I/Q modulator. Referring back to EQ. 2, any RF signal can be split into I and Q components. Unlike the QPSK mentioned before, baseband I(t) and Q(t) are not discrete points for FM signals; rather, they are continuous functions of time. The way to produce FM is shown in Figure 6. We first store all the possible values of cos[f(t)] and sin[f(t)] in a ROM lookup table, which will be addressed by the incoming data to generate the I and Q samples. The output data from the ROM is then applied to D/A converters, after low-pass filtering for signal smoothing, to produce the analogue baseband I and Q signals. This method guarantees the modulation index to be exactly 0.5, which is required for coherent detection of GMSK (e.g. GSM system).

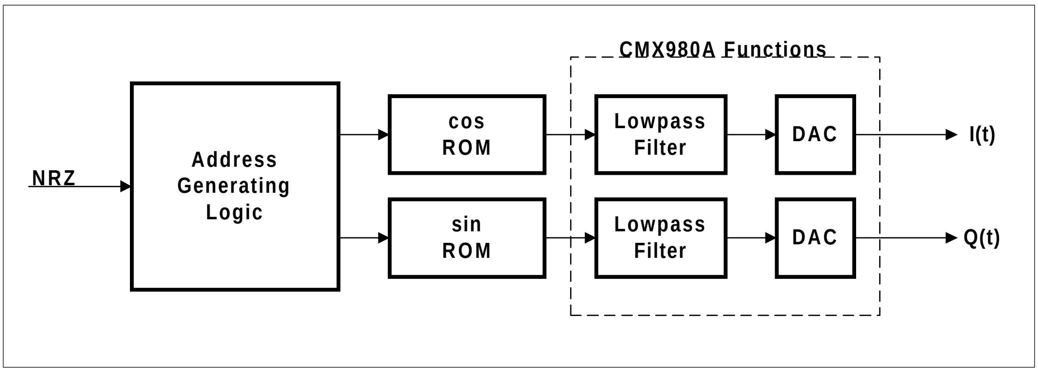

Fig.6. Digital FM (e.g. GMSK) Baseband I/Q Generator

Analogue FM

The I/Q principle previously described for Digital FM, can also be applied to generating analogue FM signals. Again the I(t) and Q(t) values are not discrete points for analogue FM signals; but are continuous functions of time (see figure 7 - (It should be noted from the constellation diagram, that GMSK and Analogue FM are strictly frequency modulation: there is no amplitude modulation. Note also the points at either side of the X & Y axes in the GMSK constellation diagram, indicating the extent of the intersymbol interference)). The way to produce analogue FM is similar to that shown in figure 6. All the possible values of cos[f(t)] and sin[f(t)] are stored in a ROM lookup table, which will then be addressed by the incoming data to generate the I and Q samples. The output data from the ROM is then applied to D/A converters, after low-pass (brick-wall) filtering for signal smoothing and band limiting, to produce the analogue baseband I and Q signals.

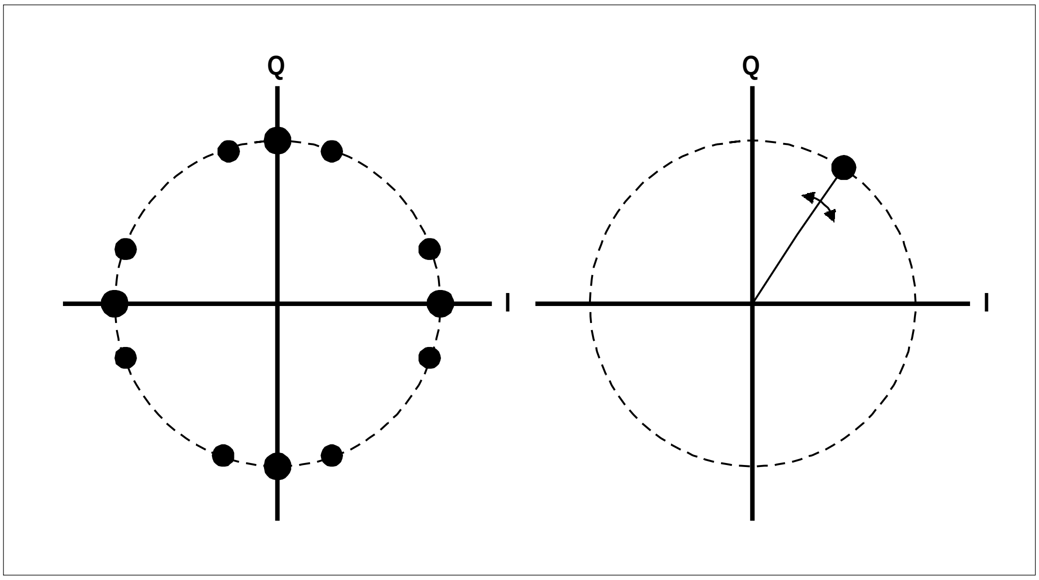

Fig.7. Signal Constallation of GMSK and Analogue FM

Single Sideband AM (SSB-AM)

AM signals can be divided into 3 types: the conventional AM, double sideband suppressed carrier AM (DSB-AM) and Single Sideband Suppressed Carrier AM (SSB-AM). The first type is not attractive because for 100% modulation, two-thirds of the transmit signal power appears in the carrier, which itself conveys no information at all. By using a balanced modulator, one can generate DSB-AM, where the carrier is totally suppressed and only the upper and lower sidebands are present. However, this is still not the best because the information is transmitted twice, once in each sideband. To further increase the efficiency of transmission, only one sideband is needed to deliver the information. SSB-AM can be generated by an I/Q modulator with the baseband information feeding the modulator (by quadrature), as shown in Figure 8. This modulation technique can greatly reduce the bandwidth of the signal and allows more signals to be transmitted in a given frequency band.

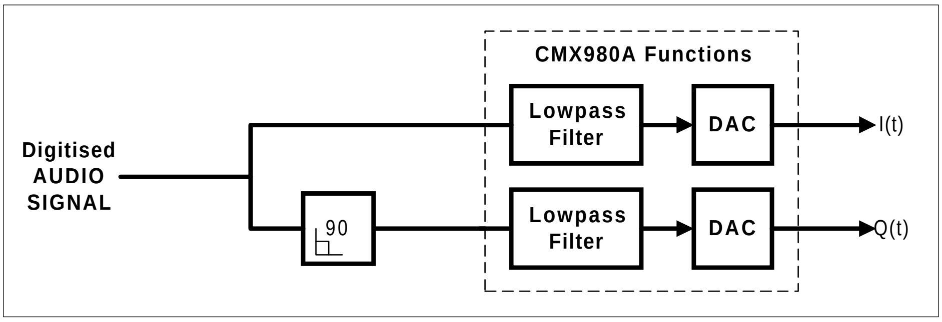

Figure 8 - Baseband Processing for SSB-AM

In Conclusion
The examples discussed in this document, are just a small demonstration of the CMX980A's versatility and the systems in which it could be used. For detailed system specific information, please contact CML's technical support team for assistance.

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