Smoothed Symbol Transition Modulation Digital Signal Processing Algorithm

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Abstract

We present a new, patent pending, modulation technique called smoothed symbol transition modulation (SSTM). Smoothed symbol transition modulation removes the rectangular windowing function limitations present in conventional modulation techniques. Conventional modulation is limited by the instantaneous step changes between symbols. In binary frequency shift keying (FSK), for the message {0, 1,}, there is a step change in transitioning from 0 to 1. In quadrature amplitude modulation (QAM), each in-phase, I, and quadrature phase, Q, symbol is transmitted for 1 symbol time. For the symbol transition, $I(n\text{-}1)$ to $I(n)$, assuming $I(n\text{-}1) \neq I(n)$, there is also a step change. The same step changes also occur in the quadrature channel. The embedded rectangular windowing functions present in conventional modulation are from the instantaneous step changes. The step changes always occur at multiples of the symbol time. Conventional modulation is also limited by the modulator's dynamic behavior during a symbol transition.

Smoothed symbol transition modulation replaces the step changes with smooth, zero slope transitions between symbols. For smoothed symbol transition modulation, a symbol transition occurs over 1 symbol time; not an instantaneous step change. Smoothed symbol transition modulation uses half cycle raised cosine waveforms, and zero slope line segments to create a smooth waveform with zero slope symbol transition points. The smooth waveform and zero slope symbol transition points reduce channel bandwidth. SSTM offers opportunities for improved performance under intersymbol interference, multipath signal conditions, dispersive channel conditions (arctic flutter), and timing jitter conditions.

We present simulations comparing conventional FSK and QAM to smoothed symbol transition modulation FSK and QAM respectively. We show considerable improvements in bandwidth and power spectral density. SSTM is a general concept that can be incorporated in any digital modulation system. Potential applications for SSTM include narrow band systems, multi-channel DSL modems, crowded frequency channels, and urban multipath environments.

1. Introduction

SSTM [1-2] basis functions are half cycle raised cosine waveforms, , and zero slope line segments, —. The basis functions form smooth, zero slope transitions between symbols. As we will demonstrate, the half cycle raised cosine provides a smooth waveform similar to a full cycle raised cosine with less bandwidth. Smoothed symbol transition modulation slowly changes over 1 symbol time unlike the step change used in conventional modulation.

Manchester raised cosine modulation is described in Lili, et al. [3]. (1) It uses a full cycle raised cosine waveform; (2) it does not try to minimize the slope over a symbol time; and (3) it does not consider zero slope, smooth symbol transitions. References [4-5] cover overlapped raised cosine modulation.

We will use the { • } notation to identify sequences similar to the (•) notation used for equations. Sequence {1.1} shows serial data stream {1, 0, 0, 1, 1, 1, 0, 1}. The symbol transitions are shown in {1.2}. The start symbol transition is 0* to 1, *where the initial symbol is assumed to be 0.

1	0	0	1	1	1	0	1	serial data	{1.1}

0*→1	1→0	0→0	0→1	1→1	1→1	1→0	0→1	bit transitions	{1.2}

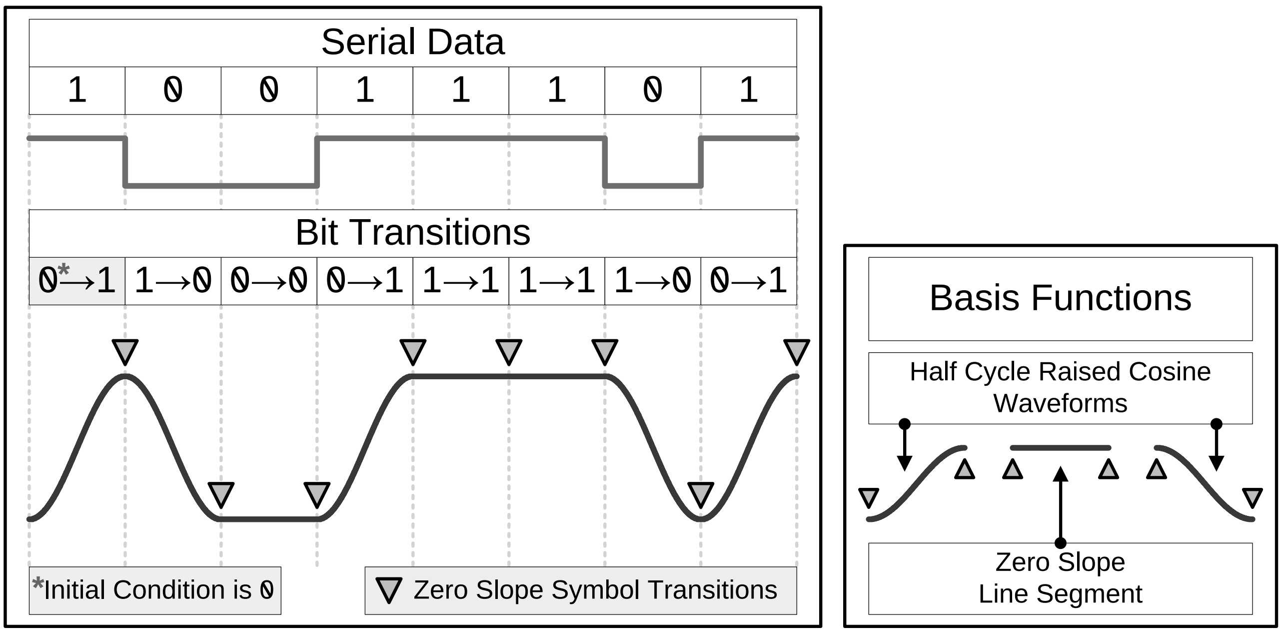


Figure 1.1. Binary Smoothed Symbol Transition Modulation

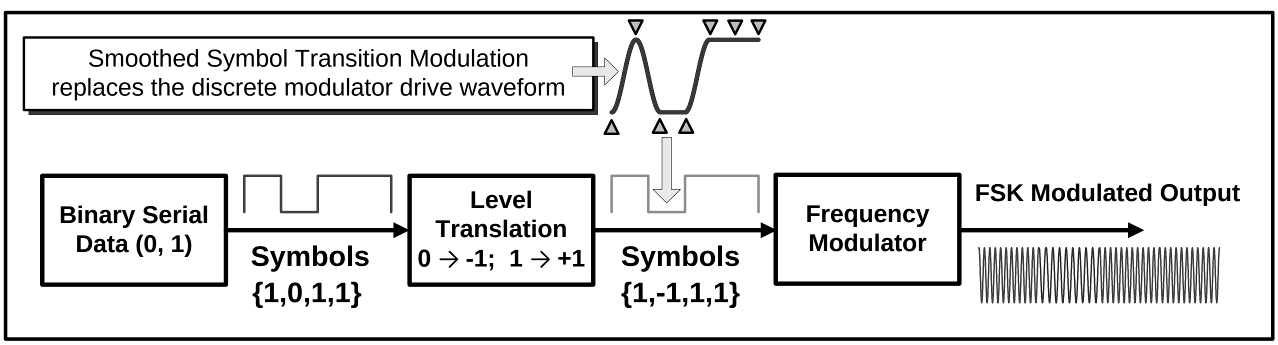


Figure 1.2. Conventional Frequency Shift Keying Modulation

Figure 1.1 illustrates how symbol transitions are mapped to half cycle raised cosine waveforms and zero slope line segments. Smoothed symbol transition modulation basis functions, ⁄, —, and ∖, are also shown. The triangles, ▿, show the smooth, zero slope symbol transition points. Symbol transitions {0 to 0}, and {1 to 1} are mapped to zero slope line segments —. Symbol transitions

{0 to 1} are mapped to positive going half cycle raised cosine waveforms, ⟋, and {1 to 0} transitions are mapped to negative going half cycle raised cosine waveforms ⟍. In summary, smoothed symbol transition modulation waveform is a smooth function with smooth, zero slope transition points.

For mathematicians only, the three basis functions can be represented by a single function with the gain = 1 giving a positive going half cycle raised cosine, ⟋, gain = -1 giving a negative going half cycle raised cosine, ⟍, and gain = 0 giving a zero slope line segment, —.

Figure 1.2 shows a block diagram for conventional, rectangular windowing function limited, FSK. The stepped modulator drive waveform ***embeds*** rectangular windowing functions into conventional modulation. Smoothed symbol transition modulation replaces the conventional stepped modulator drive waveform with a smooth waveform with zero slope symbol transition points.

2.0 Communication Theory Background

In communication theory, a symbol is a character in an alphabet. A message is a string of characters. For example, a simple two symbol (two character) message is ***CQ***. The American Standard Code for Information Interchange (ASCII) code is a standard 7 bit or 8 bit number for representing characters composed of letters (A, B, C ··· Z, and a, b, c, ··· z), symbols (!, @, #, %, ··· *) and control characters.

2.1 Binary and Hexadecimal Symbols

The binary alphabet contains two characters {0, and 1}. A binary symbol is a character in a binary alphabet. A binary symbol only needs 1 binary digit (bit) to represent it. The information contained in each symbol is summarized by the ratio of bits/symbol. A binary symbol contains 1 bit/symbol. The hexadecimal alphabet consists of 16 symbols (characters) {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F}. The hexadecimal alphabet symbols written in binary are {0000, 0001, 0010, 0011, 0100, 0101, 0110, 0111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, and 1111}. Each hexadecimal symbol represents 4 binary digits. There are 4 bits/symbol in the hexadecimal alphabet. We will use the prefix 0x to indicate a hexadecimal number. For example, 0x41 = 65 decimal = A (ASCII code for the letter A).

The message ***CQ*** , in 8 bit ASCII, is 0100 0011, 0101 0001 in binary or 0x43, 0x51 in hexadecimal.

2.2 Quadrature Amplitude Modulation Symbols

A more complex alphabet, 16 quadrature amplitude modulation (QAM) consists of 16 symbols (characters) in its alphabet. QAM symbols can be represented in binary (base 2 numbers) or hexadecimal (base 16 numbers). In binary, the 16 QAM symbols are {0000, 0001, 0010, 0011, 0100, 0101, 0110, 0111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, and 1111}. The QAM symbols are Gray encoded where nearest neighbor symbols only have one bit change between symbols. Figure 2.1 shows the constellation diagram for 16 QAM. For example, the 4 nearest neighbors to QAM symbol 0101, differ in only one bit: 0001, 0111, 0100, and 1101. 16 QAM consists of 16 symbols; 4 binary digits are required to represent the 16 symbols. 16 QAM contains 4 bits/symbol.

Quadrature amplitude modulation uses both amplitude modulation and phase modulation to encode in-phase, I, and quadrature phase, Q, signals. Equation (2.1) shows the in-phase and quadrature phase channels modulate two carrier signals, cosine and sine, that are 90° out of phase. To encode the ASCII message ***CQ*** in 16 level QAM, the in-phase and quadrature phase values are encoded as (I, Q) as shown in Equation (2.2). Each 16 QAM symbol encodes 4 binary digits (bits) of information. The amplitudes of the I and Q channels create both amplitude and phase modulation. Section 4 describes a conventional 16 QAM modulator.

$$QAM(t) = I(t)cos(2\pi f_c t) + Q(t)sin(2\pi f_c t) \quad \text{where } f_c = \text{carrier (center) frequency} \tag{2.1}$$

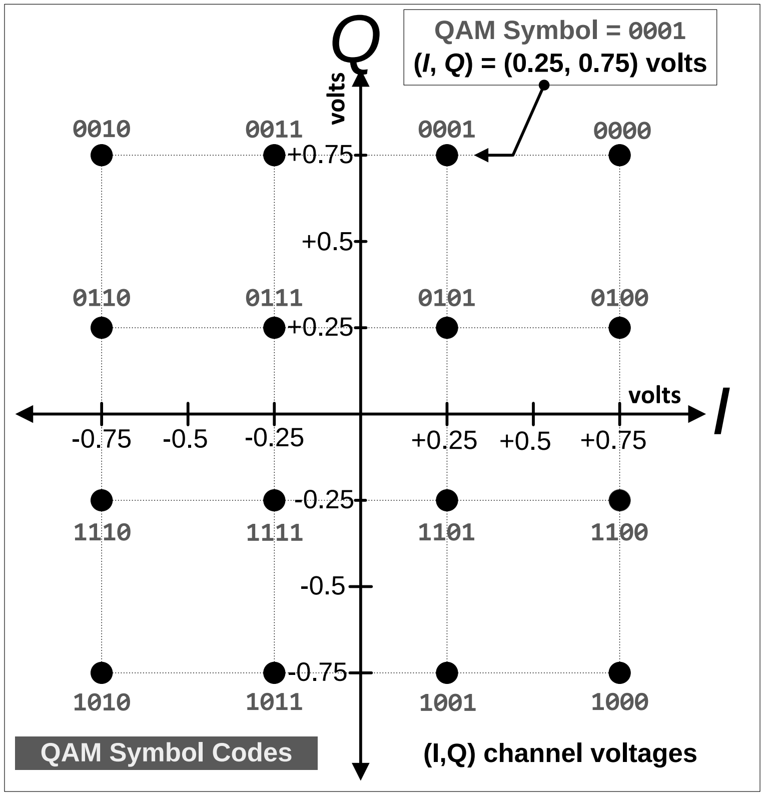


Figure 2.1. 16 QAM Constellation Diagram

	C		Q		message
	0100	0011	0101	0001	QAM symbol
QAM[*I*(*n*), *Q*(*n*)] =	(0.25, -0.25),	(0.75 , 0.75)	(0.25, -0.75),	(0.75, 0.25)	volts
n =	0	1	2	3	integer

(2.2)

3. Windowing Functions

Figure 3.1 compares the time domain graphs of several windowing functions. The rectangular windowing function in (3.1) has two instantaneous step changes from the unit step functions, $u(t)$, at $t = \frac{\pm T}{2}$ points. The raised cosine function in (3.2), with T = 2, and T = 4, forms smooth functions with very smooth derivatives at $t = \frac{\pm T}{2}$ endpoints (e.g. the windowing functions' endpoints, ▽▼). The half cycle raised cosine windowing function in (3.3) has smooth endpoints, ▼, similar to the full cycle raised cosine windowing function. The half cycle raised cosine windowing function has similar properties to the full cycle raised cosine waveform with with *half* the bandwidth, $f_{HC} = \frac{1}{2T}$ Hz compared to $f_{RC} = \frac{1}{T}$ Hz.

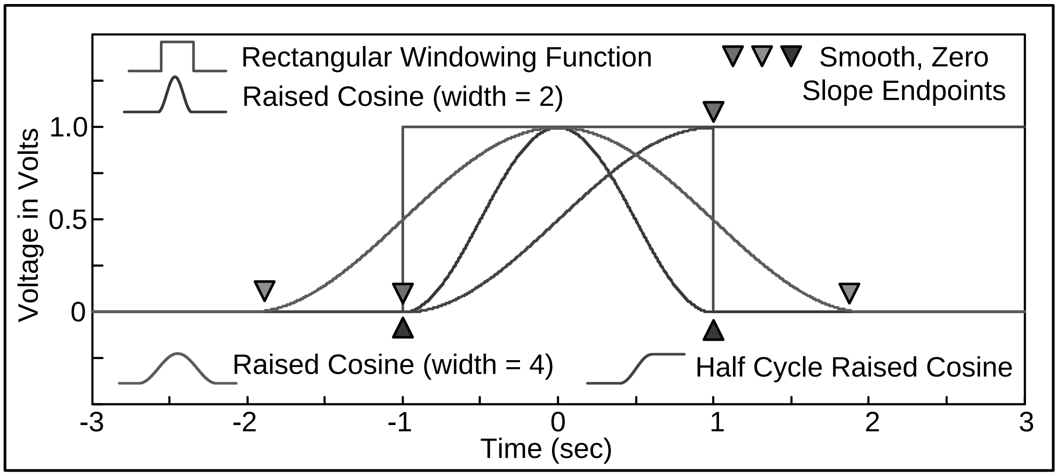
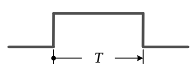
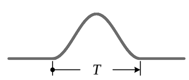


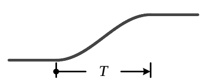
Figure 3.1. Rectangular and Raised Cosine Windowing Functions

$$w_R(t) = \left[u\left(t+\tfrac{T}{2}\right) - u\left(t-\tfrac{T}{2}\right)\right]$$ 

where $u(t)$, ⎽⎸⎺, is the unit step function (3.1)

$$w_{RC}(t) = \begin{cases} \frac{1}{2}\left(1 + cos\frac{2\pi t}{T}\right) & \frac{-T}{2} \le t \le \frac{T}{2} \\ 0 & \text{otherwise} \end{cases}$$ 

raised cosine window (3.2)

$$w_{HC}(t) = \begin{cases} \frac{1}{2}\left[1 + cos\frac{\pi\left(t-\frac{T}{2}\right)}{T}\right] & \frac{-T}{2} \le t \le \frac{T}{2} \\ 0 & \text{otherwise} \end{cases}$$ 

half cycle raised cosine window (3.3)

Figure 3.2 compares the windowing functions' power spectral densities. The power spectral density of the rectangular windowing function has a slow (poor) convergence (slowly approaches linear scale 0.0 W/Hz or $-\infty$ dBm/Hz). The unit dBm/Hz is *shorthand* for the power spectral density in terms of dBm; power in dBm/Hz times bandwidth *does not* give the total power. The raised cosine windowing function with $T = 2$ has a much better convergence. The raised cosine windowing function with $T = 4$ in (3.2) and the half cycle raised cosine windowing function in (3.3) have a similar convergence. The envelope of the power spectral densities for raised cosine windowing function in (3.2) with $T = 4$ and the half cycle raised cosine windowing function in (3.3) are the same. They both have a faster (better) convergence than the raised cosine windowing function with $T = 2$. Figure 3.2 shows the utility of the half cycle raised cosine windowing function. It gives the same convergence as the raised cosine windowing function with $T = 4$, has half the bandwidth of the raised cosine windowing function with $T = 2$, and has the smooth, zero slope transition points required for smoothed symbol transition modulation.

All conventional digital modulators are limited by the rectangular windowing functions embedded in the modulator's output. As shown in Figure 3.2, the rectangular windowing function has a $\sin(2\pi f)/2\pi f$ power spectral density function which has a slow (poor) convergence. The embedded rectangular windowing functions, and non-ideal dynamic switching behavior limit the performance of conventional modulators.

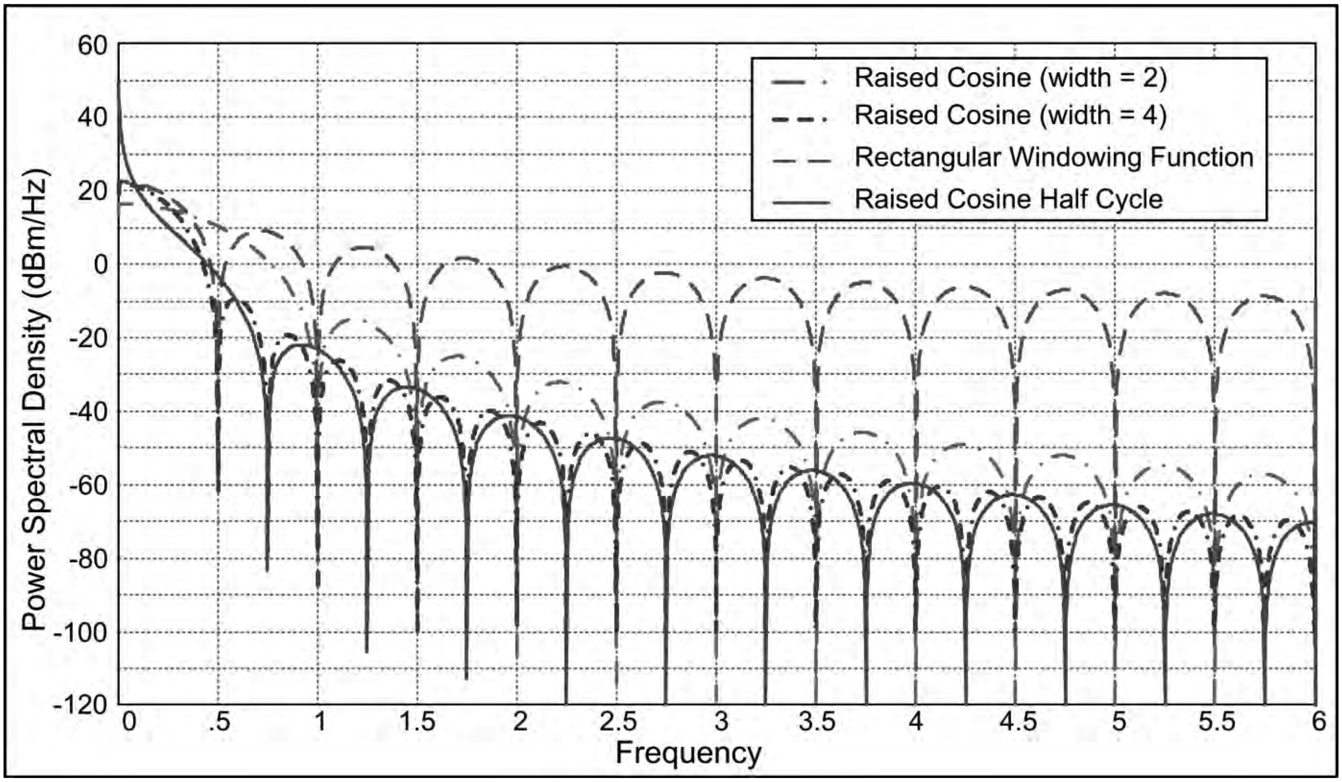


Figure 3.2. Rectangular and Raised Cosine Windowing Functions Power Spectral Density

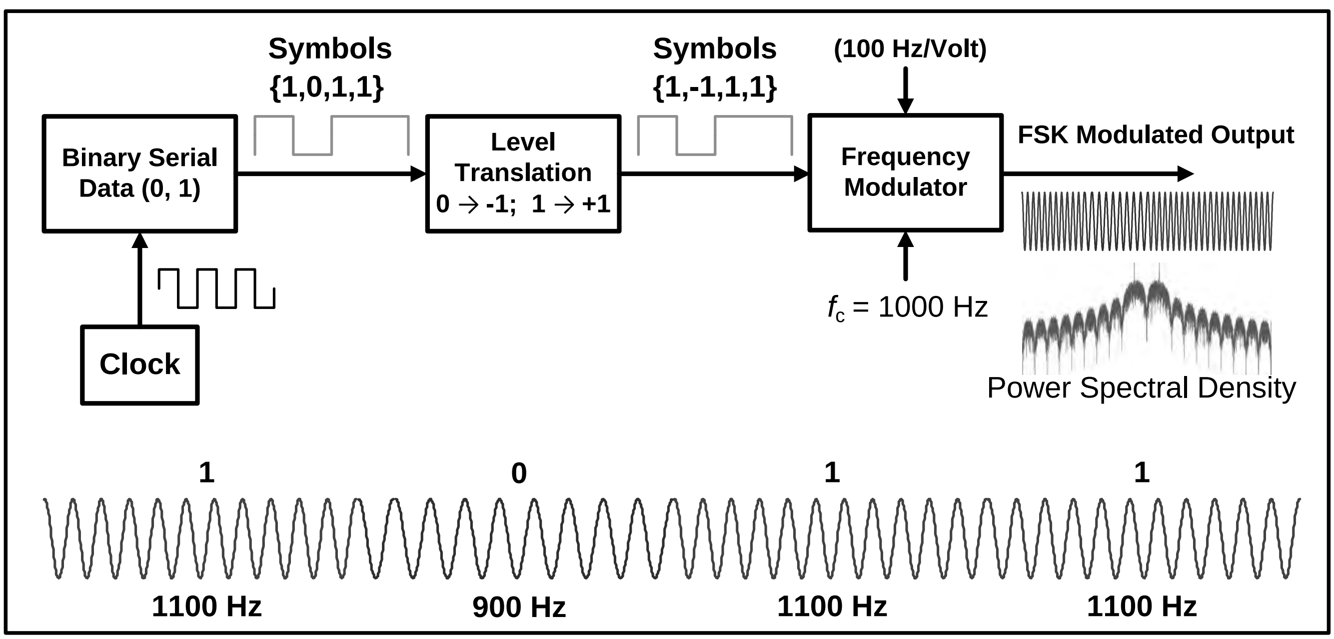


Figure 4.1. Conventional Frequency Shift Keying Modulator.

4. Conventional Rectangular Windowing Function Limited Modulation

Conventional modulators are limited by (1) embedded rectangular windowing functions and (2) the dynamic behavior of the output modulator. A simple, 100 baud (100 bits/second) FSK modulator is shown in Figure 4.1. The carrier frequency is 1000 Hz with a frequency deviation of 100 Hz/Volt. The binary serial data is level converted to +1/-1. The +1/-1 symbols result in a +100 Hz/-100 Hz frequency shift from the 1000 Hz carrier frequency. The output FSK's power spectral density clearly shows the embedded rectangular windowing functions. The dynamic behavior of the FSK modulator also affects the power spectral density. In the time domain, the non-ideal dynamic behavior occurs at the same time as the serial data stream step transitions (the rectangular windowing functions). The cost of the embedded rectangular windowing functions is significant.

A conventional 16 level, quadrature amplitude modulator (QAM) is illustrated in Figure 4.2. The symbol generator creates the same type of stepped waveform as the binary serial data stream in Figure 4.1. The QAM waveforms, in-phase, $I(t)$, and quadrature phase, $Q(t)$, have the same stepped behavior as the FSK modulator. The output waveform from the I/Q complex modulator clearly shows step functions (embedded rectangular windowing functions). Conventional QAM and rectangular windowing functions have the same power spectral density graphs and slow (poor) convergence.

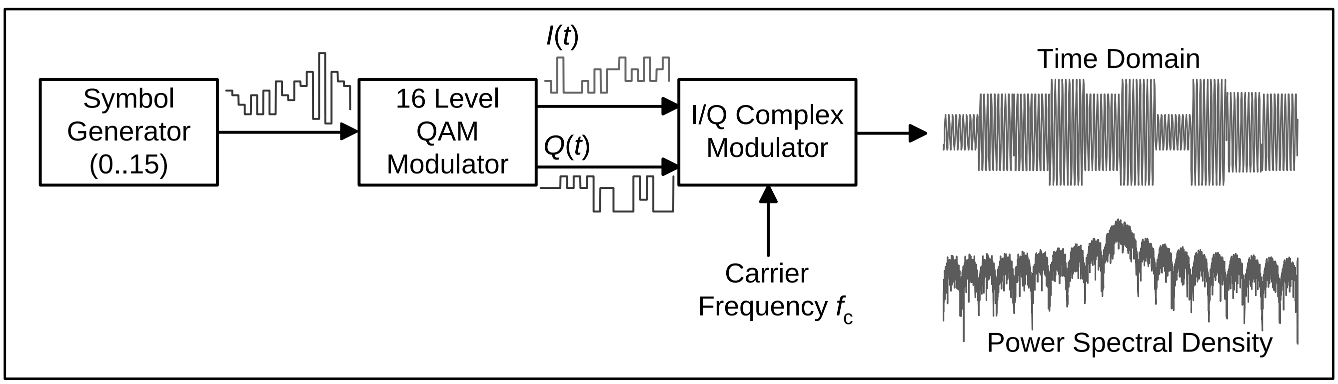


Figure 4.2. Conventional Quadrature Amplitude Modulator.

4.1 Embedded Rectangular Windowing Functions

Figure 4.2 illustrates rectangular windowing functions in 2 dimensional space. A simulated picture of a computer main board is shown. The square shape of the camera's picture elements (pixels) embeds rectangular windowing functions into the output image. Each pixel only contains a constant RGB (red, blue, and green) color value. As shown in the magnified view, the pixels step up and down across the image. The pixels embed rectangular windowing functions into the image. In conventional modulation, the step changes in the serial data stream embed the rectangular windowing functions in the modulated output waveform. Figure 4.4 shows the ideal conventional FSK modulation case, where there is no distortion from the dynamic switching behavior of the modulator (also see Figure 4.1.).

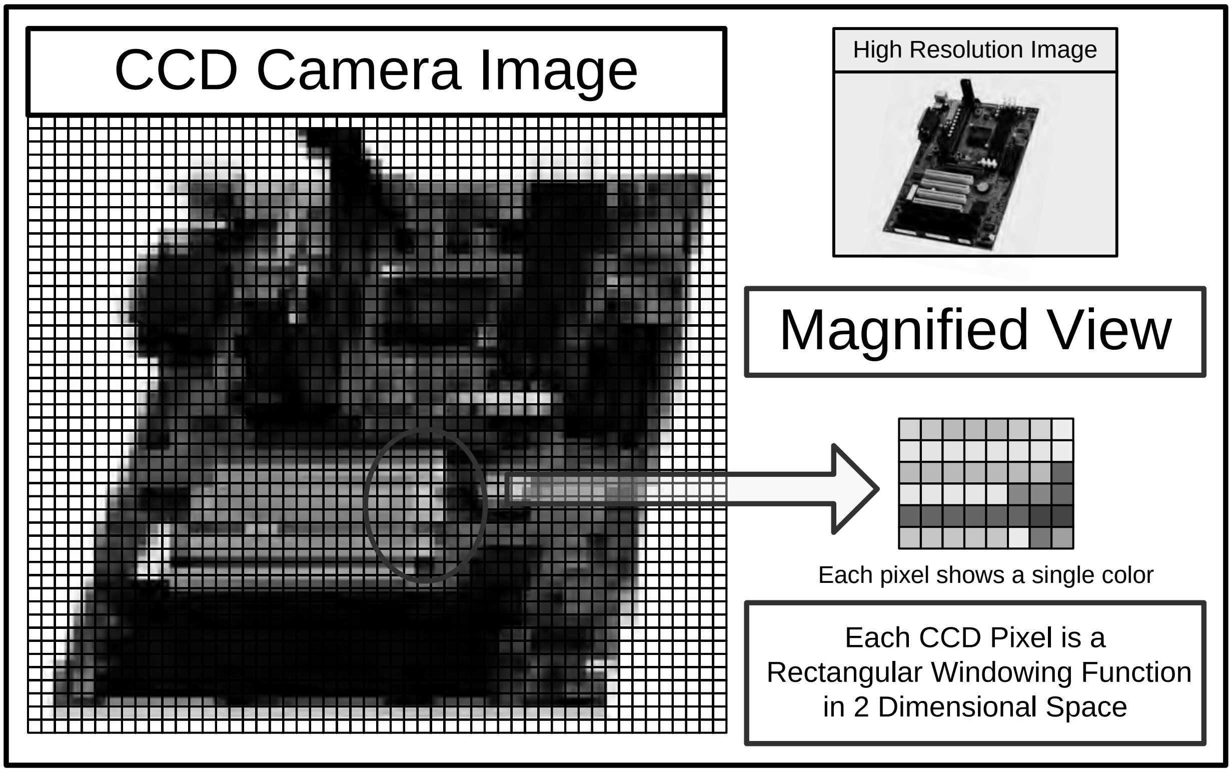


Figure 4.3. Embedded Rectangular Windowing Functions in 2 Dimensional Space.

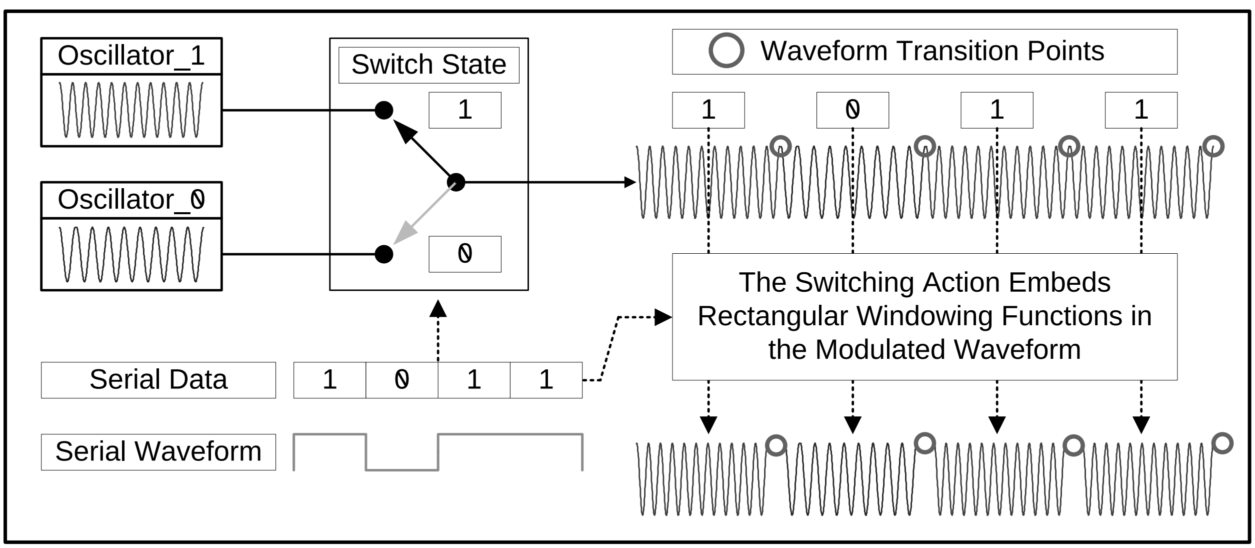


Figure 4.4. Embedded Rectangular Windows in Conventional Modulation

4.2 Non-Ideal Modulator Behavior

Figure 4.5 and Figure 4.6 show examples of non-ideal dynamic modulator switching behavior. Figure 4.5 shows a modulator output transient or glitch occurring as the input serial data step changes from 0 to 1. Figure 4.6 shows a serial data step change from 1 to 0. For the 0º phase angle difference between the modulator tones, there is a slope mismatch at the symbol transition. For the worst case of 180º phase difference, there is a sharp transient. Since the glitches occur at the symbol transition points, this makes having a smooth transition between symbols even more important.

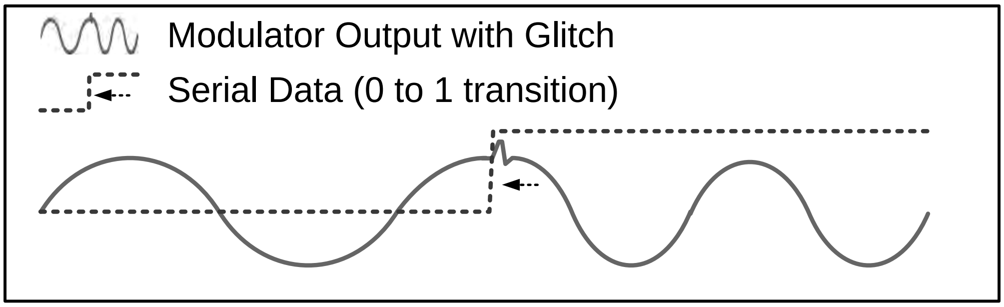


Figure 4.5. Modulator Switching Transient or Glitch

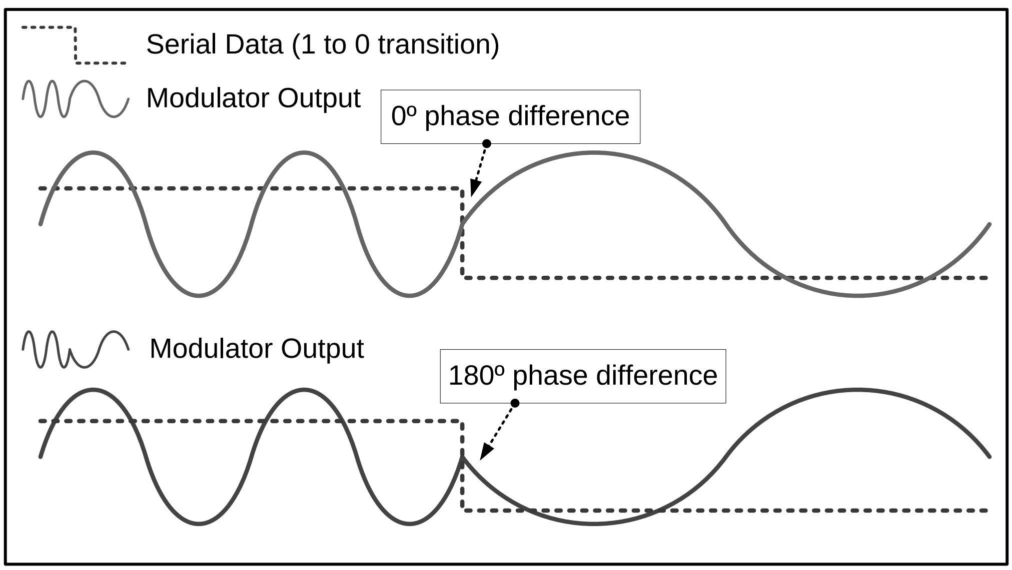


Figure 4.6. Phase Difference in Modulator Frequencies

4.3. Windowing Functions and Power Spectral Density Convergence

Figure 4.7 shows example drive waveforms for a 100 baud (bits/second), 1000 Hz carrier frequency, frequency shift keying (FSK) modulator. Conventional FSK drive waveform is a binary serial data stream showing step changes in the waveform. The 0.1 symbol, 0.5 symbol, and 1.0 symbol rise and fall times show how limiting the rise and fall times, or limiting the bandwidth of the serial data stream, affects the FSK power spectral density. Figure 4.8 compares conventional serial data to rise/fall time limited serial data. As the rise/fall times increase from conventional 0.0 ms (0.0 symbol time) , 1.0 ms (0.1 symbol time) , 2.0 ms (0.2 symbol time), 5.0 ms (0.5 symbol time)

, 7.0 ms (0.7 symbol time), and 10.0 ms (1.0 symbol time) , the embedded windowing functions change from rectangular, trapezoidal, to triangular. Figure 4.9 compares conventional rectangular windowing function, triangular windowing function, and half cycle raised cosine windowing function modulator drive waveforms. The triangular windowing function is a coarse approximation to the half cycle raised cosine windowing function. The main difference is the discontinuities at the endpoints.

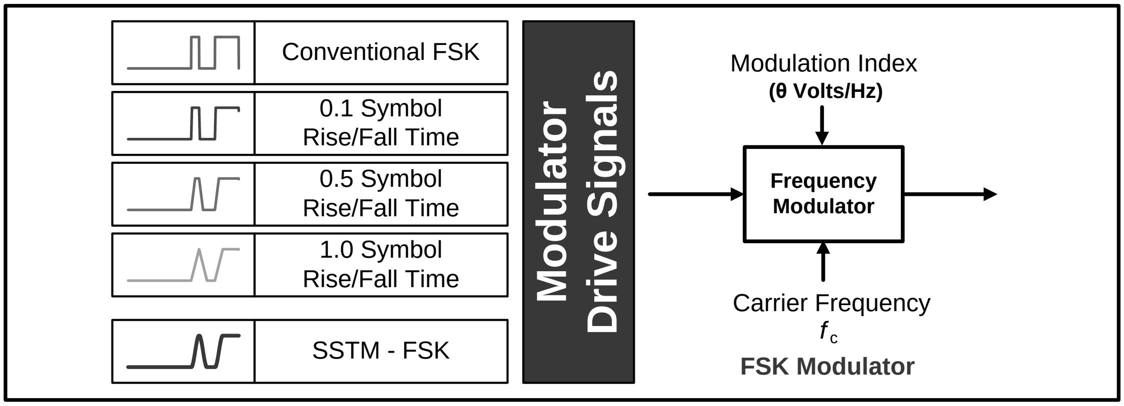


Figure 4.7. Example FSK Modulator Drive Signals.

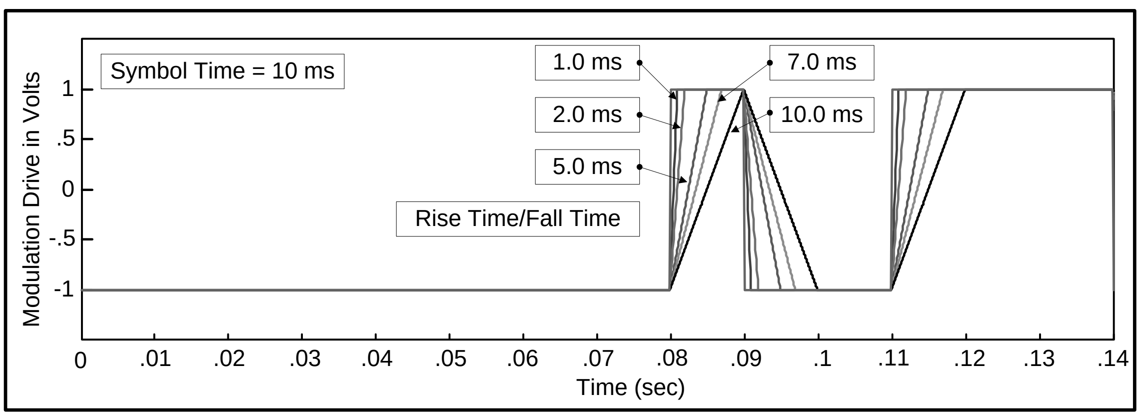


Figure 4.8. Modulator Drive Rise Time Examples

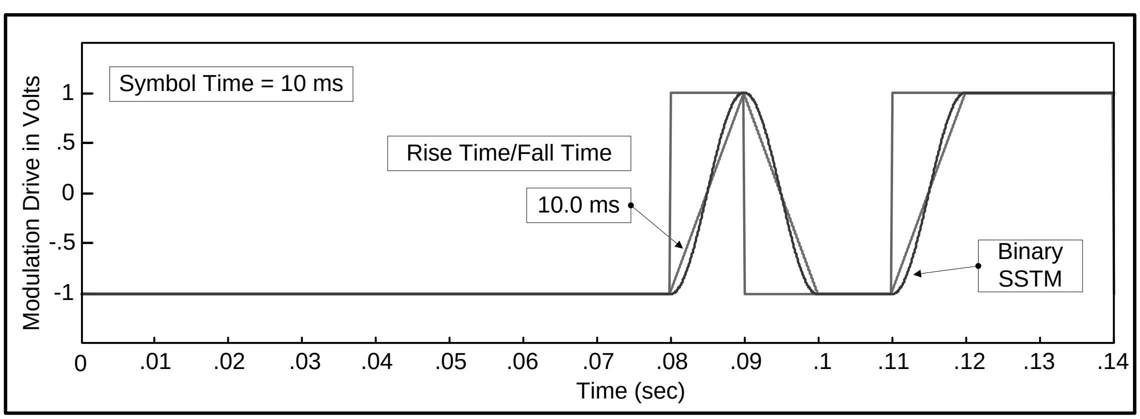


Figure 4.9. 1 Symbol Time Rise/Fall Time and SSTM Comparison

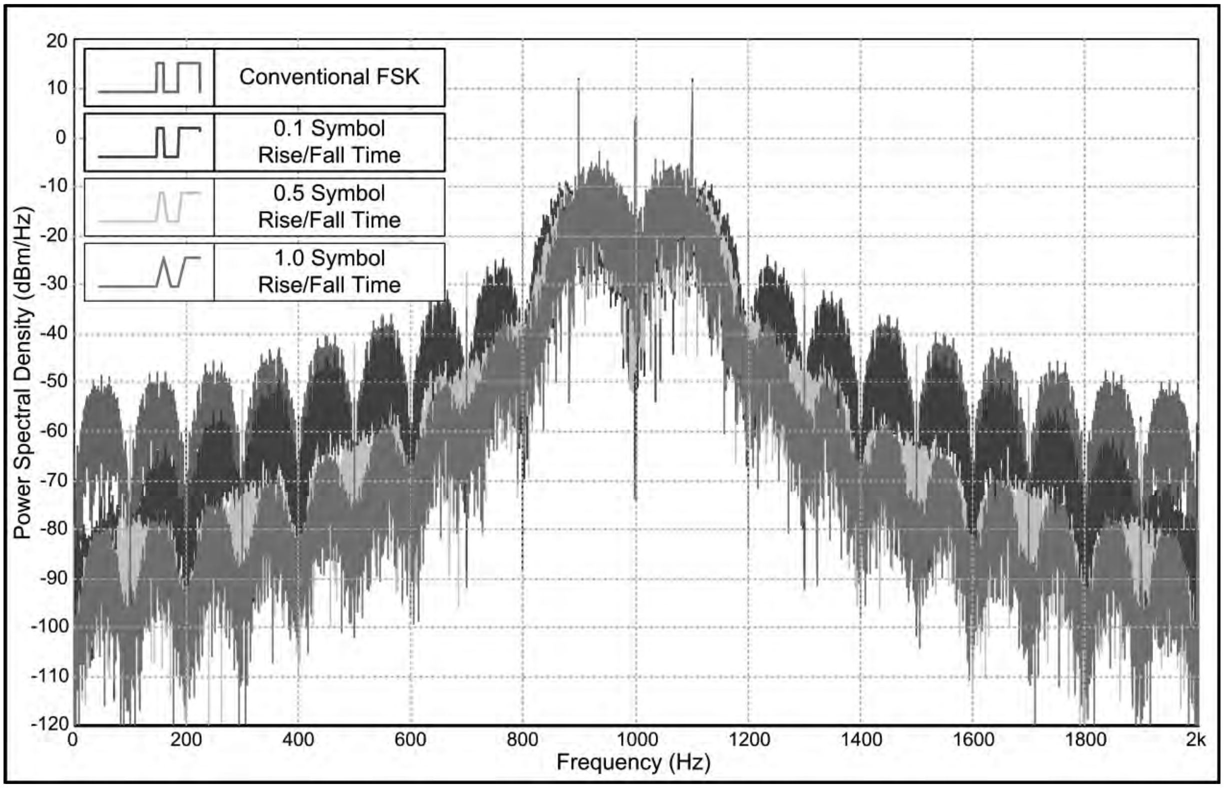


Figure 4.10. Symbol Time Rise/Fall FSK Power Spectral Density Comparison

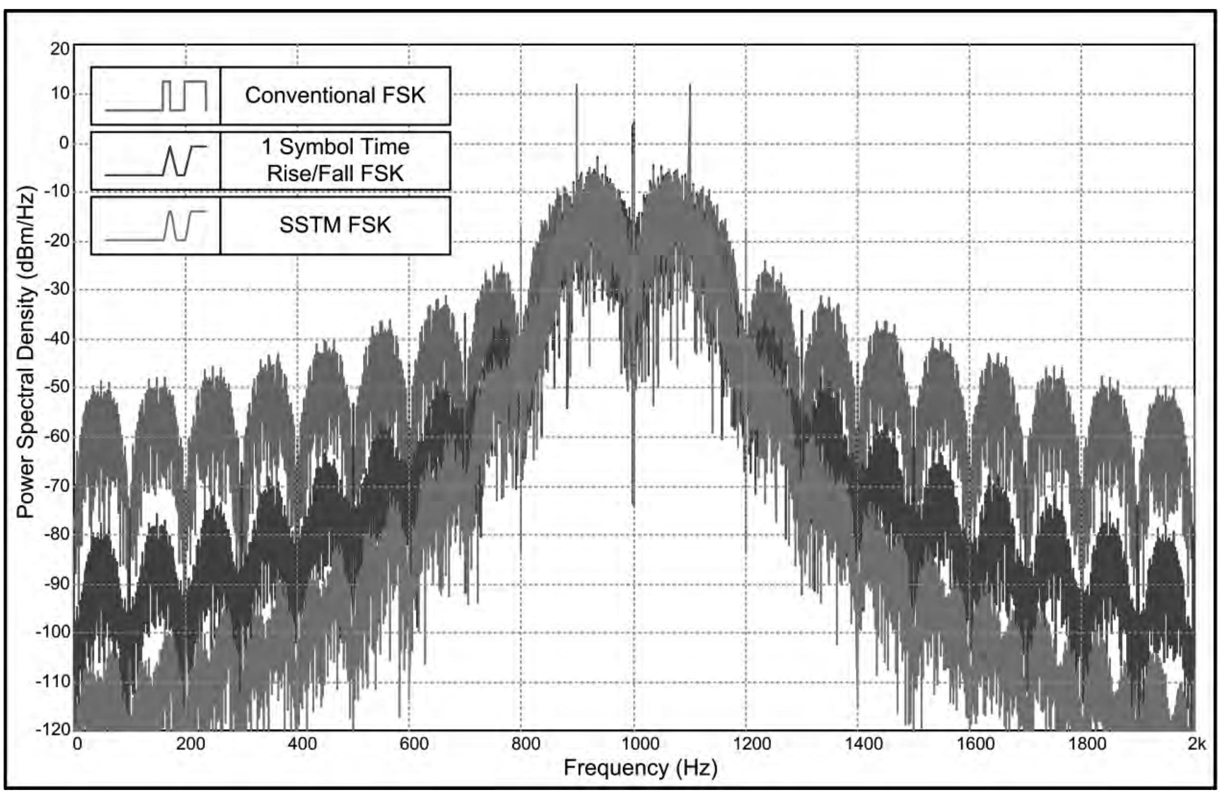


Figure 4.11. Conventional, 1 Symbol Rise/Fall Time, and SSTM PSD Comparison

Figures 4.10 and 4.11 are for simulated FSK modulators with 100 baud (100 bits/second) and a 1000 Hz carrier frequency. Figure 4.10 illustrates how the rise/fall times, for conventional rectangular, trapezoid, and triangular windowing functions, affect FSK's power spectral density. As the rise/fall times increase, the derivatives of the serial data waveforms decrease, the bandwidths decrease, and the power spectral density graphs converge faster. Figure 4.11 compares conventional, 1 symbol rise/fall time, and smoothed symbol transition modulation FSK's power spectral densities. The main lobes for 1 symbol rise/fall time and SSTM FSK are similar. The convergence for SSTM is much faster. The power spectral density plots in Figures 4.10 and 4.11, clearly show how the rise/fall times affect the bandwidth and convergence. The rectangular windowing function limited waveforms are a poor choice for bandwidth and convergence.

5. Smoothed Symbol Transition Modulation

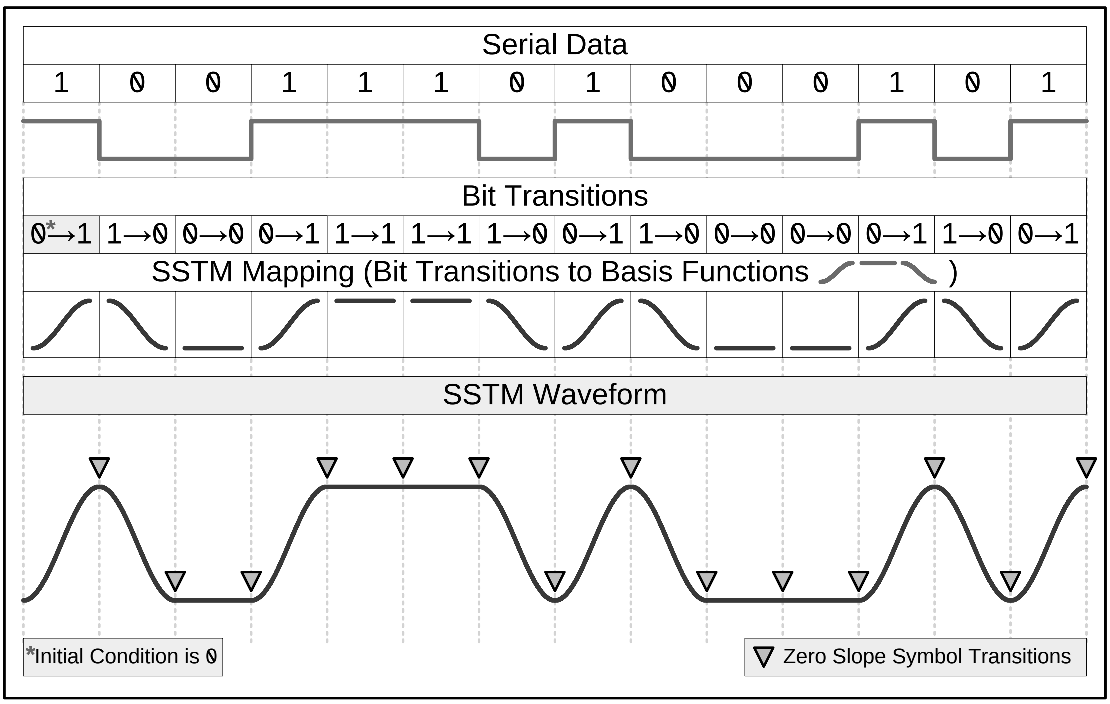


Figure 5.1. Binary Smoothed Symbol Transition Waveform

Figure 1.1 introduces binary smoothed symbol transition modulation. The basis functions for smoothed symbol transition modulation are , —, and . The triangles, ▿, show the smooth, zero slope symbol transition points. Figure 5.1 illustrates the steps to convert from binary serial data to smoothed symbol transition modulation. The initial symbol (initial condition) is assumed to be 0 for this example. The bit transitions $\{0 \rightarrow 0\}$, and $\{1 \rightarrow 1\}$ are mapped to zero slope line segments, —. The bit transition $\{0 \rightarrow 1\}$ is mapped to a positive going half cycle raised cosine waveform . The bit transition $\{1 \rightarrow 0\}$ is mapped to a negative going half cycle raised cosine waveform . The bit transitions to basis function mappings result in a smooth waveform with zero slope points at each symbol transition, ▿. As described in section 3, the serial data transition points have a large affect on the bandwidth. The resulting SSTM waveform resembles raised cosine windowing functions and Tukey windowing functions (also called the tapered cosine windowing function).

The basis functions are chosen to form smooth, zero slope transition points between symbols. The half cycle raised cosine provides excellent power spectral density characteristics as described in section 3. Other windowing functions, including wavelets that have similar properties to the smoothed symbol transition modulation basis functions may also be used.

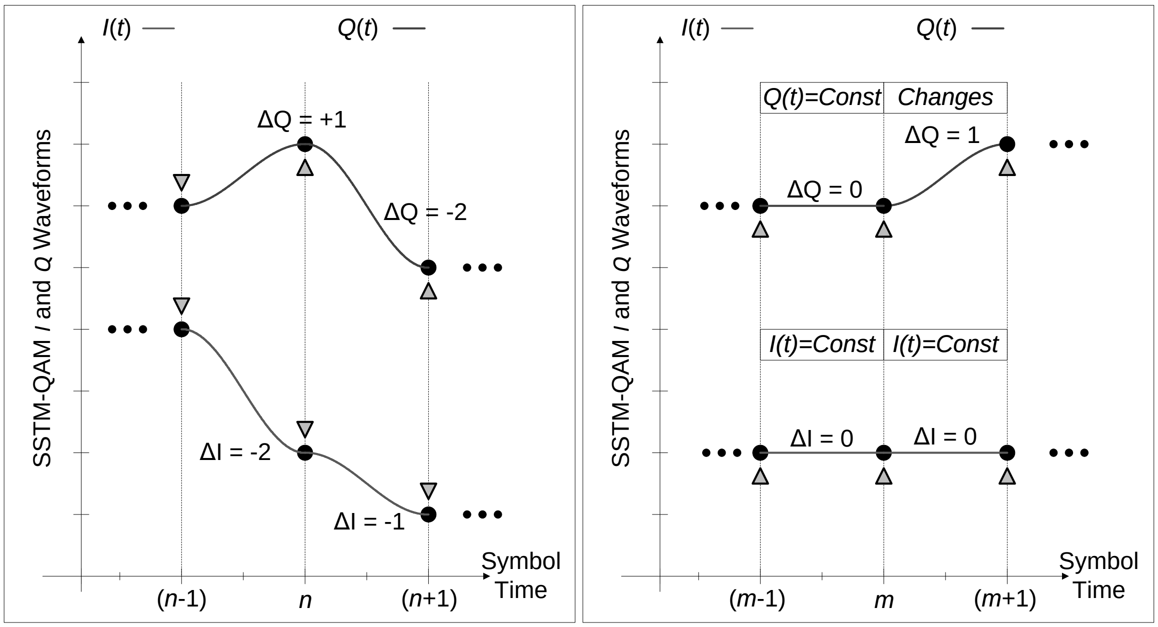


Figure 5.2. SSTM QAM Symbol Transitions

Smoothed Symbol Transition Modulation Quadrature Amplitude Modulation (SSTM-QAM) is introduced in Figure 5.2. The same basis functions are used to connect conventional I and Q stepped waveforms together. The half cycle raised cosine functions are weighted by the height of the step change. For example, for a change of ΔI = -2, the half cycle raised cosine waveform is multiplied by -2. For a ΔQ = +1, the half cycle raised cosine is multiplied by +1. For a constant, ΔI = 0, or ΔQ = 0, conventional QAM is mapped to a zero slope line segment. SSTM-QAM is simply a “gain scaled” version of binary SSTM. Conventional and SSTM modulators were simulated using [6]. Section 6 describes the block diagrams (algorithms) for binary, and QAM smoothed symbol transition modulation.

5.1 Binary Smoothed Symbol Transition Modulation Simulation

A 100 baud (100 bits/second), 1000 Hz carrier frequency, smoothed symbol transition modulation FSK modulator block diagram and simulation are shown in Figure 5.3. A conventional FSK modulator is simulated in Figure 1.2. By adding the SSTM mapping block before the frequency modulator in Figure 1.2, the conventional FSK modulator is converted into SSTM FSK modulator. Figure 5.4 shows the mapping of binary serial data {5.1} to SSTM. Smooth, zero slope symbol transitions are shown by ∇.

Figure 5.5 compares the power spectral densities, for simulated conventional and SSTM, 100 baud (100 bits/second), 1000 Hz carrier frequency, FSK modulators. The conventional FSK modulator and rectangular windowing function have the same power spectral density graph (compare Figure 3.2 to Figure 5.5). The SSTM FSK power spectral density follows the power spectral density of a raised cosine windowing function. One limitation of SSTM is the line spectra at multiples of the bit rate (100 bits/second or 100 Hz).

0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	0	1	1	1	0	0	0	1	0	1	0	0	1	1	{5.1}

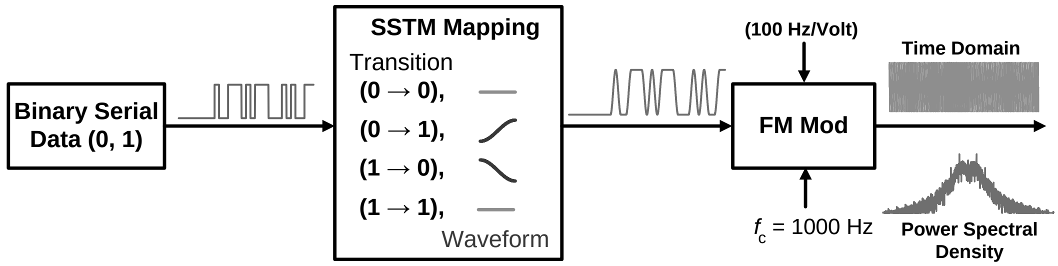


Figure 5.3. Example 100 bits/second, 1000 SSTM FSK Modulator

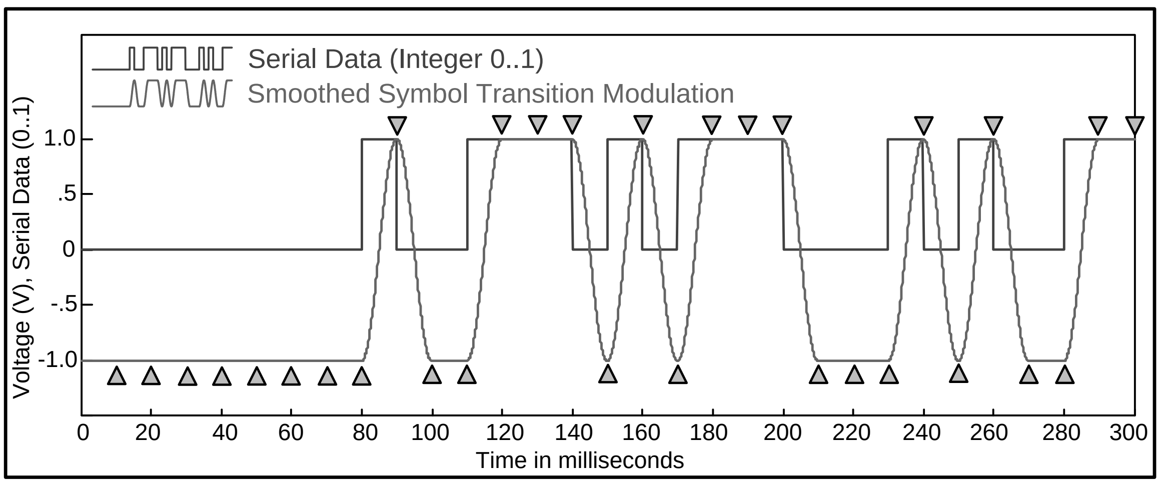


Figure 5.4. Binary Smoothed Symbol Transition Modulation

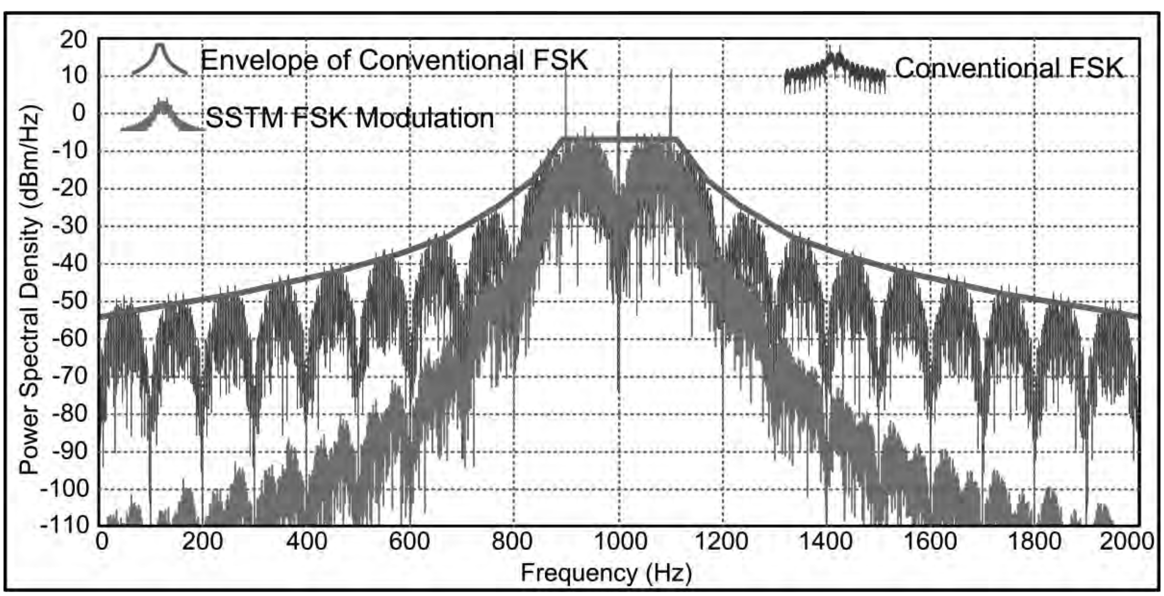


Figure 5.5. Conventional and SSTM FSK Power Spectral Density Comparison

5.2 QAM Smoothed Symbol Transition Modulation

Conventional QAM block diagram was introduced in Figure 4.2. The constellation diagram for 16 level QAM is shown in Figure 2.1. Conventional QAM in-phase, $I(t)$, and quadrature phase, $Q(t)$, waveforms have the same stepped behavior as the FSK modulator in Figure 1.2. The in-phase and quadrature phase stepped changes embed rectangular windowing functions. The I/Q complex modulator waveform clearly shows the embedded rectangular windowing functions. Conventional QAM's power spectral density clearly has the same slow convergence as the rectangular windowing function's power spectral density illustrated in Figure 3.1. Conventional and SSTM QAM block diagrams are compared in Figure 5.6. SSTM QAM simply adds an I/Q SSTM block before the conventional QAM's I/Q modulator block.

The time domain waveforms, for a simulated 100 symbol/second, 1000 Hz carrier frequency conventional QAM modulator and SSTM QAM modulator, are compared in Figure 5.6. The SSTM modulator converts the conventional I and Q channels to smoothed symbol transition modulation. The SSTM I and Q waveforms are smooth functions with zero slope symbol transition points. Figure 5.7 compares the power spectral density for conventional QAM to SSTM QAM. Conventional QAM shows a rectangular windowing function power spectral density. SSTM QAM shows a raised cosine power spectral density function.

For a 20 % frequency shift from the 1000 Hz carrier frequency, SSTM QAM power spectral density envelope has better than 25 dB lower power spectral density (Table 5.1). The convergence for the SSTM QAM power spectral density is much better than conventional rectangular windowing function limited modulation. SSTM QAM does not have line spectra at multiples of the symbol rate (100 symbols/second).

SSTM QAM does not have the rectangular windowing function limitations present in conventional QAM. The PSD also packs more information/bandwidth, than conventional 16 QAM or a conventional FSK modulator's power spectral density from Figure 1.2. SSTM QAM clearly offers higher performance than conventional QAM.

SSTM offers opportunities for improved performance under intersymbol interference, multipath signal conditions, dispersive channel conditions (arctic flutter), and timing jitter conditions. The rapid convergence of SSTM QAM offers improved performance for multi-channel (128, 256, etc.) DSL modem applications.

Table 5.1. Conventional to SSTM QAM Power Spectral Density Envelope Comparison (100 symbol/second, 1000 Hz carrier frequency)

20 % Bandwidth Points	Conventional PSD in dBm/Hz	SSTM PSD in dBm/Hz
800 Hz	-25	-52
1200 Hz	-25	-53

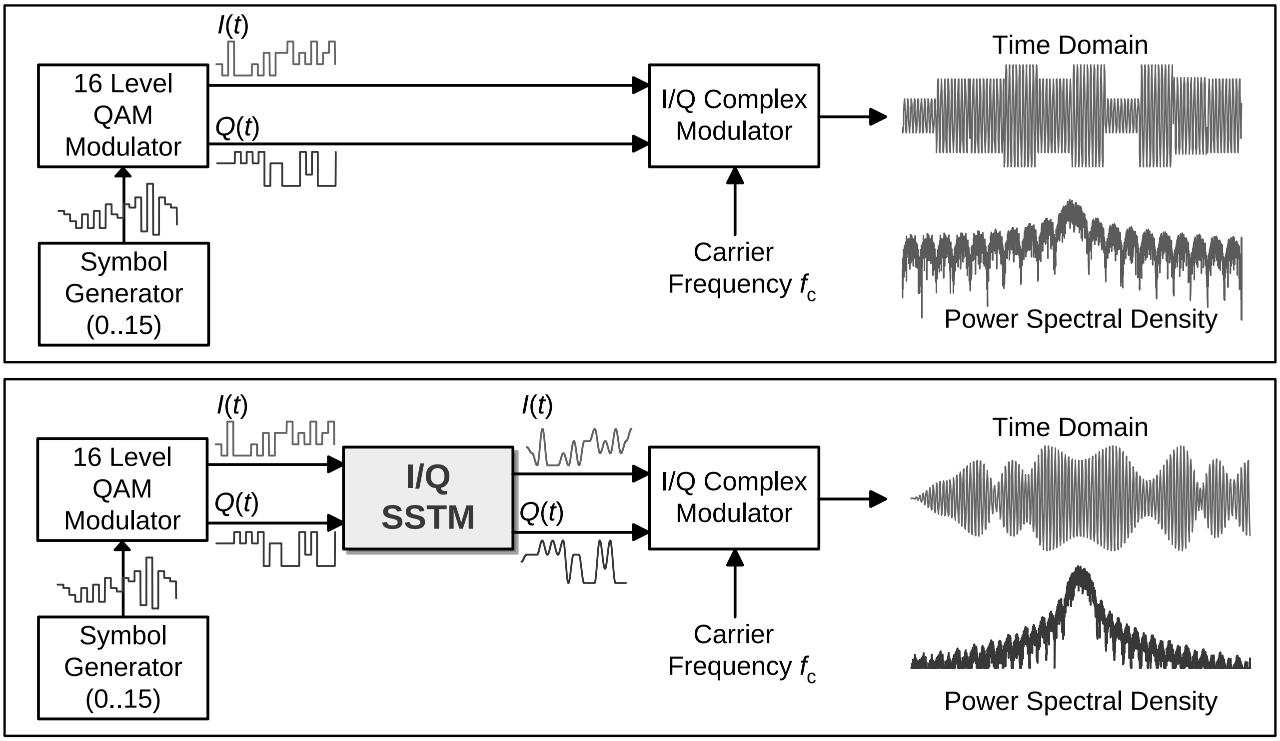


Figure 5.6. Conventional and SSTM QAM Block Diagrams

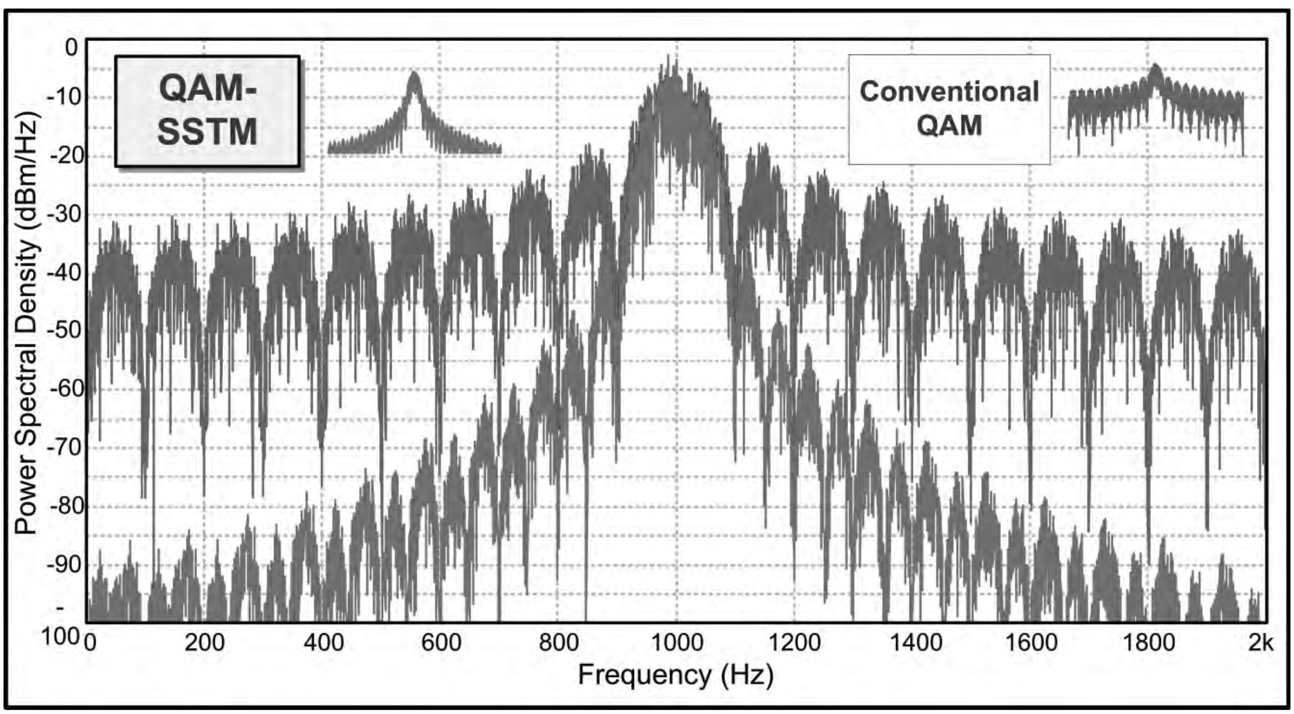


Figure 5.7. Conventional and SSTM QAM Power Spectral Density Comparison

6. Smoothed Symbol Transition Modulation Algorithm

We present block diagrams for binary and QAM smoothed symbol transition modulation. SSTM-QAM is simply a gain scaled version of binary SSTM.

6.1 Binary SSTM Block Diagram

Figure 6.1 presents the block diagram for binary smoothed symbol transition modulation. QAM is simply a gain scaled version of Figure 6.1. The level translation block converts serial data 1/0 to +1/-1 as illustrated in {6.1}. *D*(*n*) is serial data waveform (+1/-1). *D*(*n*-1) is serial data delayed by 1 symbol (here 1 bit). The initial symbol (initial value) for *D*(-1) is assumed to be 0. The *Gain*(*n*) is the height of the half cycle raised cosine waveform. If *Gain*(*n*)=0, then we have a zero slope line segment. The "DC Offset" is the starting point for SSTM symbol(*n*). DC_Offset = *D*(*n*-1). The unit raised cosine half cycle generator provides unit half cycle raised cosine waveforms as shown in Figure 6.1. Gain(*n*) sets the peek-to-peek amplitude of the half cycle raised cosine waveform. DC_Offset is the initial value for the half cycle raised cosine waveform. SSTM_Output(*t*) = DC_Offset(*n*) + Gain(*n*)·HC(*t*) where HC(*t*) is the unit half cycle raised cosine.

serial data	1	0	0	1	1	1	0	1	0	0	0	1	0	1
level shifted	+1	-1	-1	+1	-1	+1	-1	+1	-1	-1	-1	+1	-1	1

{6.1}

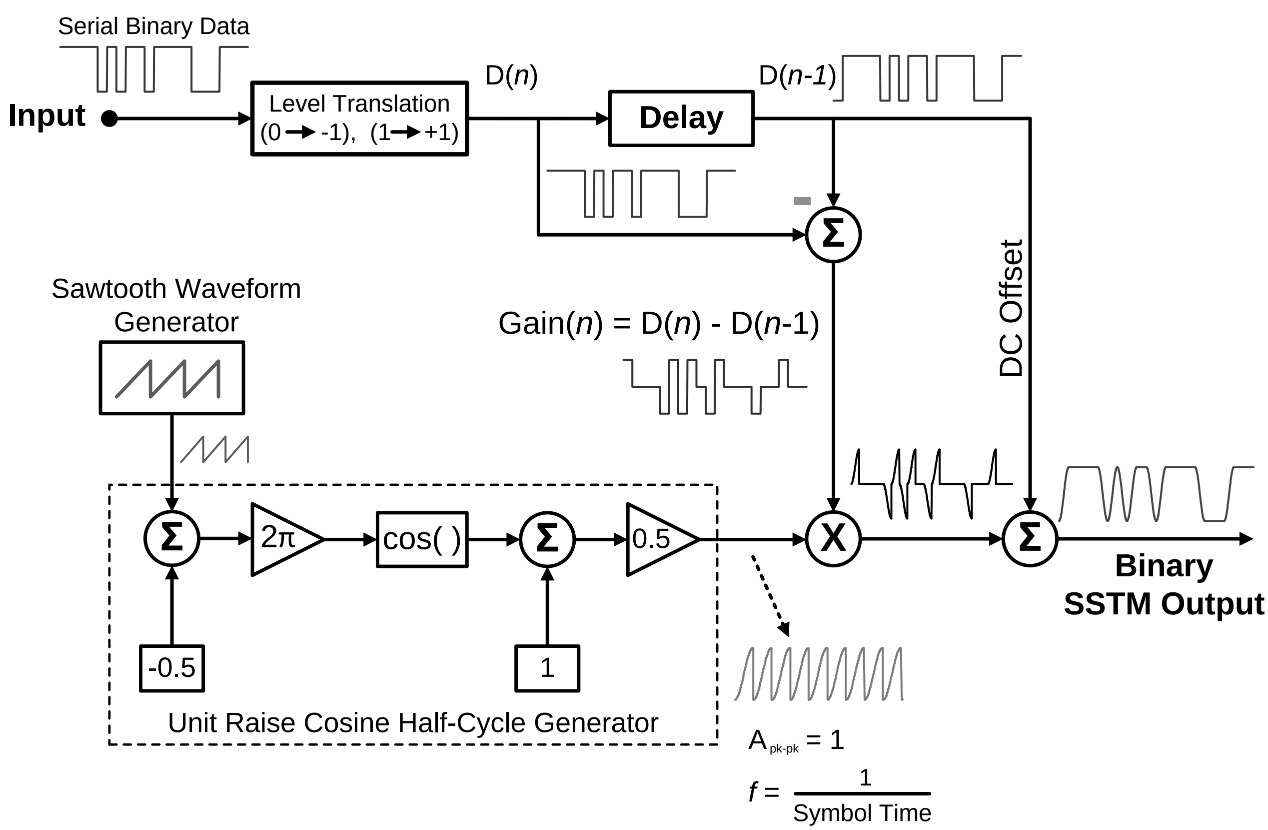


Figure 6.1. Binary SSTM Modulation Block Diagram (Algorithm)

6.2 SSTM-QAM

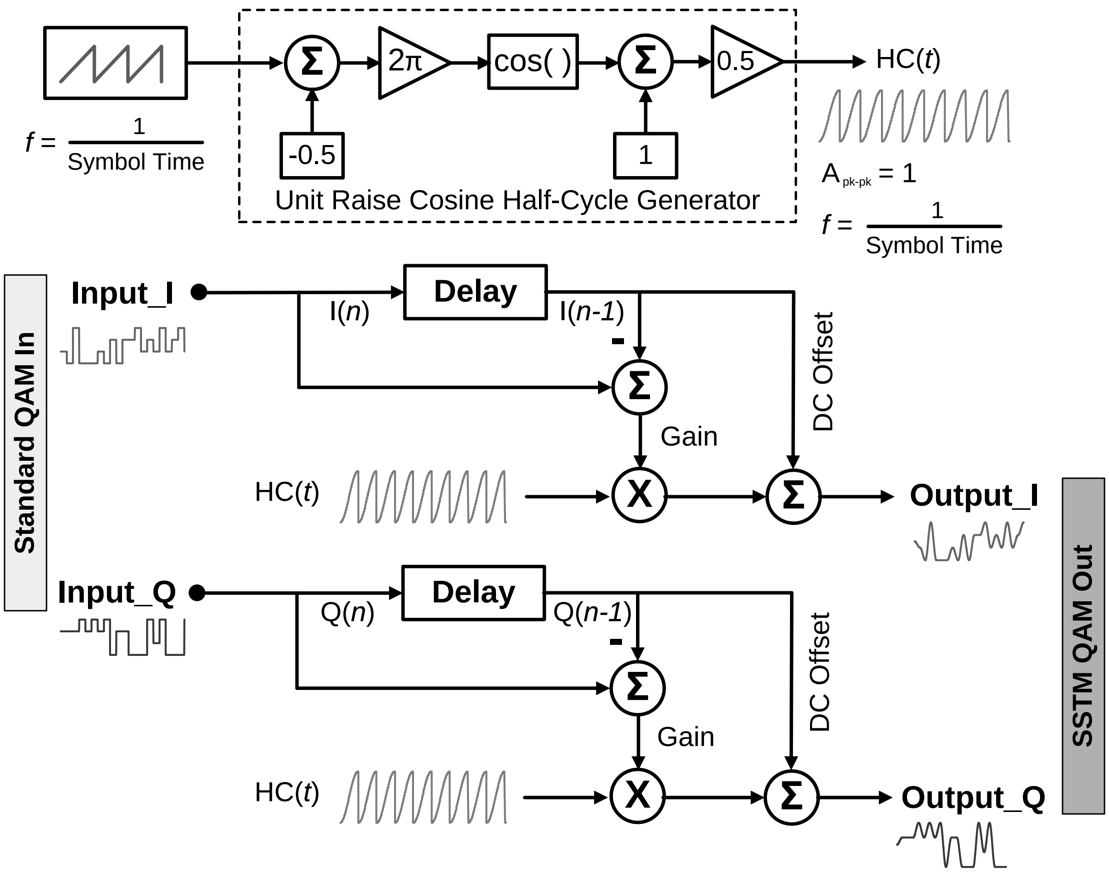


Figure 6.2. Smoothed Symbol Transition Modulation QAM Block Diagram (Algorithm)

The binary smoothed symbol transition modulation block diagram in Figure 6.1 is extended to SSTM-QAM in Figure 6.2. SSTM-QAM uses two channels: *I* and *Q*. The *I* and *Q* channels work just like the binary SSTM from Figure 6.1. The only difference is the gains for the I and Q channels are larger. For 16 QAM, there are 4 values for I and 4 values for Q instead of +1/-1 for serial SSTM in Figure 5.1.

6.3 SSTM Modulation Applications

SSTM algorithm can be used in any digital modulation system. As shown in Figure 5.3 and Figure 5.6, the SSTM block is simply placed before the conventional modulator: FSK, QAM, etc.

7. Conclusion

Smoothed symbol transition modulation, solves the limitations of rectangular function limited conventional modulation. Table 7.1 summarizes conventional rectangular windowing function limited modulation.

Smoothed symbol transition modulation consists of half cycle raised cosine waveform and zero slope line segment basis functions. The basis functions form smooth, zero slope transitions between SSTM symbols. SSTM uses a half cycle raised cosine over 1 symbol time which has less bandwidth than a full cycle as illustrated in Figure 3.2.

Binary SSTM and 16 level SSTM-QAM simulations demonstrate the utility of the concept. Smoothed symbol transition modulation simply adds one more block before the output (final) modulation stage. SSTM offers opportunities for improved performance under intersymbol interference, multipath signal conditions, dispersive channel conditions (arctic flutter), and timing jitter conditions. In terms of digital signal processing, SSTM is low cost, and offers significant performance improvements over conventional rectangular windowing function limited modulators.

Table 7.1. Summary of Conventional Modulation Limitations

- The binary, QAM, et al. symbol transitions are step changes. The step changes embed rectangular windowing functions in the output modulated waveform.
- Rectangular windowing functions have a slow (poor) convergence.
- A conventional modulator's output is not a smooth, slowly varying function.
- The slope of the modulator's output is not continuous across a symbol transition
- The slope at each symbol transition is not zero.
- The embedded rectangular windowing functions, and modulator's dynamic behavior makes compensating for multipath interference, channel dispersion, and time varying delays more difficult.

8. Acknowledgement

The author wishes to thank RDECOM community for the opportunity to develop Smoothed Symbol Transition Modulation.

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