# Algorithm for sharpening Raised Cosine Pulse shaping Digital filter and Analysis of Performance of QAM system when subjected to Sharpened Raised Cosine Filter

**Mahua Pal**

Department of Electronics and Communication
Amity University, Lucknow, India

***Abstract-*** This paper proposes an algorithm for sharpening a pulse shaping Raised Cosine filter. Filter sharpening could be used when improved filtering is needed, but insufficient ROM space is available to store more filter coefficients, or as a way to reduce ROM requirements. QAM is one of widely used modulation techniques because of its efficiency in power and bandwidth. In this paper, the coefficients of raised cosine and sharpened raised cosine filter are generated in MATLAB. Utilizing these coefficients the performance of raised cosine filter and sharpened raised cosine filter is observed under different QAM(16QAM, 32QAM and 64QAM) by comparing their error rates and SNR using VSG (vector signal generator) and VSA(vector signal analyser).

***Index Terms***- error vector magnitude, filter sharpening, magnitude error, Phase error , pulseshaping, raised cosine filter, QAM, signal to noise ratio

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## I. INTRODUCTION

In digital telecommunication, pulseshaping is the process of changing the waveform of transmitted pulses. Its purpose is to make the transmitted signal better suited to the communication channel by limiting the effective bandwidth of the transmission and reducing the intersymbol interference (ISI). The raised-cosine filter is a filter frequently used for pulse shaping in digital modulation due to its system[5-6] .Its spectrum exhibits odd symmetry about, 1/2T where *T* is the symbol-period of the communications system. Filter sharpening is a technique for creating a new filter from an old one. When processing data by filters, we often find it necessary to improve the performance of the filter, either by increasing the out-of-band rejection (loss) or by decreasing the error in the passband, or both. A first approach is to process the data by repeated passes through the same filter. Each pass, while increasing the out-of-band loss, also increases the passband error, often to an undesirable level [4]. Improved filtering can also be achieved by increasing the order of a filter. But increasing the order would mean storing more filter coefficients and if insufficient ROM space is available, then definitely one has to go for sharpening technique, which reduces the ROM requirements. In addition, in some hardware filter applications using *application -specific integrated circuits* (ASICs), it may be easier to add additional chips to a filter design than to design a new ASIC. In the late seventies, Kaiser and Hamming described a simple technique for filter sharpening that can be applied to symmetric non-recursive filters with both less passband error and greater out-of-band, or stopband, loss [1]. This technique has been successfully implemented to low pass FIR filter [4] and Window functions [7].

In this paper, the sharpening technique has been generalized into an algorithm which may be applied multiple number of times as long as the digital communication system shows improvement in its performance. Sharpening a pulseshaping filter is a new research area which we have considered in this paper. Since the Raised Cosine filter exhibits symmetric property, we have applied the so designed sharpening algorithm to a Raised cosine filter .

In 16QAM the symbol rate is one fourth of the bit rate. It is more efficient than BPSK (symbol rate is same as bit rate) or QPSK (symbol rate is half of bit rate) or 8PSK (symbol rate is one third of bit rate). Another variation is 32QAM, the symbol rate of which is one fifth of the bit rate. A 64QAM signal that can send six bits per symbol is very spectrally efficient.. A 64QAM system enables the same amount of information to be sent as BPSK using only one sixth of the bandwidth. It is six times more bandwidth efficient. In this paper, QAM system of digital modulation is chosen from the BW efficient point of view using a vector signal generator(VSG). The vector signal generator combines outstanding RF performance and sophisticated baseband generation to deliver calibrated test signals at baseband, IF, and RF frequencies up to 50 MHz. Offering an internal baseband generator with arbitrary waveform and real-time I/Q capabilities the VSG is equipped to test today's complex wireless systems In this paper Raised cosine filter is designed in MATLAB using cut off frequency=250KHz and transition BW = 250KHz and sampling frequency=10MHZ for three successive orders N = 11, 22 and 44 and each time it is sharpened using the sharpening algorithm presented in this paper. For each of these orders the coefficients are calculated in MATLAB for RC filter and sharpened RC filter. The performance of the RC filter and sharpened RC filter is observed in 16, 32 and 64 QAM systems by feeding the coefficients of the so designed RC filter and sharpened RC filter in VSG . To maximize the spectral efficiency we have used premodulation raised Cosine filtering to reduce the occupied bandwidth. To make filtering even more efficient we have sharpened the RC filter prior to filtering using a sharpening algorithm designed in

this paper. Comparative analysis of RC & sharpened RC when fed to 16/32/64 QAM system is presented by taking careful observations in VSA(vector signal analyser) with the help of which we can quickly evaluate and troubleshoot digitally modulated signals with both qualitative displays and quantitative measurements and visualize the system performance rapidly and intuitively with familiar display formats and view the time/frequency spectrum, measure phase error, evm ,magnitude error,SNR [6] or view these for an individual channel in a computer connected to the VSA. Thus the present paper deals with design and computer aided performance analysis of sharpened pulseshaping RC filter for QAM system of communication.

## II. DESIGN ISSUES FOR DESIGNING RAISED COSINE FILTER IN MATLAB

The roll-off factor (β) gives a direct measure of the occupied bandwidth of the system and is calculated as *occupied bandwidth = symbol rate* X *(1 +* β*)*.In a perfect world, the occupied bandwidth would be the same as the symbol rate, but this is not practical since β= zero is impossible to implement. The occupied bandwidth (for β =1) = symbol rate X (1 + 1) = 2 X symbol rate. Using β of 0.5, the transmitted bandwidth decreases from 2 times the symbol rate to 1.5 times the symbol rate. This results in a 25% improvement in occupied bandwidth. Hence we chose β=0.5.

The sampling frequency of the digital circuitry (VSG) through which the signal would pass is 10MHz. It has been assumed that the raised cosine filter impulse response to be designed to span five symbols. If a digital filter is used for pulseshaping, then it must operate at a sample rate of at least twice the data rate to span the frequency response characteristic of the raised cosine pulse. That is ,the filter must oversample the data by at least a factor of two. More oversampling yields a more accurate frequency response characteristic. If the filter oversamples by a factor of two (2 samples/symbol) and the desired impulse response duration is five symbols then 10 samples are required (2 x 5 = 10). However, N=11 is chosen to avoid the half-symbol delay associated with an even number of taps. The raised cosine filter will operate at 5MHz. This is well within the specified 50 MHz operating range of the digital circuitry (VSG), so the design is not in jeopardy.

We wish to see the affect of sharpening by increasing the order of the filter, so we have increased N=11 to twice i.e N=22 and four times i.e N=44. For N=22 and 44, the RC filter operates at 2MHz and 1.1MHz respectively which are both within the specified limit of 50MHz and hence again the design is not jeopardized.

The Magnitude response of the Raised Cosine FIR Filter designed in MATLAB for N=11, 22 and 44 using cut-off frequency = 250KHz and transition BW = 250KHz and sampling frequency= 10MHZ, β=0.5 is shown below.

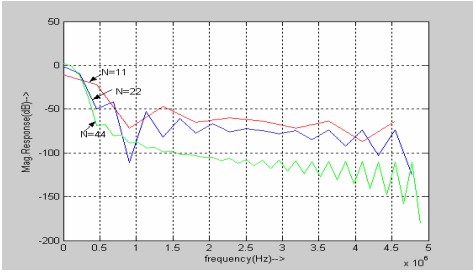



Fig.2.1 Magnitude Response of Raised Cosine Filter (N=11, 22, 44)

## III. DESIGN ISSUES FOR DESIGNING RAISED COSINE FILTER IN MATLAB

If one is given a filter whose transfer function is G(z). Assume that in the passband the frequency response is supposed to be 1 and in the stopband the frequency response is supposed to be 0. Suppose that one has a fillter whose frequency response is moderately close to one throughout the fiter's pass-band and is moderately close to zero throughout the filter's stopband. Suppose one needs a better filter.If one had a function, F(z), that took numbers that were near zero and made them closer to zero that would be a step in the right direction. One would consider the filter defined by F(G(z)) and one would know that its frequency response was better than the frequency response of G(z).The most obvious choice for F(z) is $z^2$ . The function $1+(z-1)^2$ performs a similar task for filters that are near 1 in their passband. The problem with these functions is that the first function improves performance in the stopband but hurts performance in the passband. The second function helps performance in the passband but hurts it in the stopband. We would like to find a function that helps us in both the passband and the stopband. What is needed is a function, F(x),that satisfies four conditions:

1. F(0) = 0
2. F'(0) = 0
3. F(1) = 1
4. F'(1) = 0

If one would like a polynomial to satisfy these four conditions then the polynomial must, at the very least, be cubic(highest order value in polynomial, k=3) any lower order polynomial will not have enough coefficients to allows us to meet all of the conditions.

Algorithm to obtain sharpened transfer function when k=3

Step 1: Find the polynomial: $F(x)=a+bx+cx^2+dx^3$

Step 2: Find derivative of the polynomial: $F'(x)=b+2cx+3dx^2$

Step 3: Assign known values to the polynomial and its derivative

i) At x=0, F(x) =0 and F'(x) =0

ii) At x=1, F(x) =1 and F'(x) =0

Step 4: Substitute values at Step3 for Step1 and Step 2 equations.

i) a=0 and b=0

ii) c+d = 1 and 2c+3d = 0

Step 5: Derive the coefficient values a=0, b=0, c=3, d = -2

Step 6: Find the reduced polynomial: $F(x) =3x^2 - 2x^3$

It is easy to see that any value of x near zero is made smaller by this function and any number near one is made nearer to one by F(x).

Stating this function as sharpened filter Hs (z) in terms of H(z) we have

$Hs(z) = 3H(z)^2 - 2H(z)^3$

H s (z) is called the sharpened version of H (z)

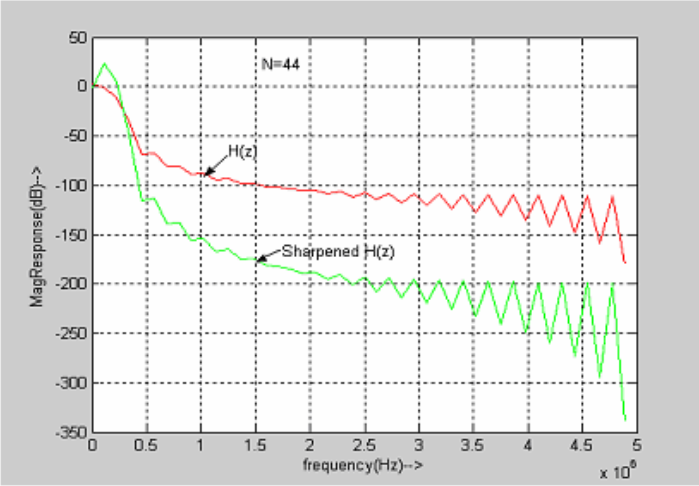



Fig. 3.1 Magnitude Response of Raised cosine and Sharpened Raised cosine filter (N=44))

The technique stated above can be extended to higher orders to obtain still better sharpened filters.

General Algorithm to obtain sharpened transfer function when k>=3

Step 1: Find the polynomial of degree k such that k>=3 degree:

$F(x) = a_0+a_1x+a_2x^2+ - - - - -a_kx^k$

Step 2: Find derivative of the polynomial: $F'(x)= a_1+2a_2x+ - - - - -ka_kx^{k-1}$

Step 3: Assign known values to the polynomial and its derivative

At x=0, F(x) =0 and F'(x) =0

Step 4: Substitute values at Step3 for Step1 and Step 2 equations.

$a_0=0$ and $a_1=0$

Step 5: Find the reduced polynomial after the values of coefficients obtained in Step 4 is substituted in the polynomial equation in Step1 .

$F(x) = a_2x^2+ - - - - -a_kx^k$

Step6: Assign a new constant n =k-3

Step7: Assign coefficients of the first n terms (starting from the lowest power of x) equal to zero in the polynomial obtained from Step5.

Step8: Find the reduced polynomial:

$F(x) =a_{k-1}x^{k-1}+ a_kx^k$

Step9: Assign known values to the polynomial and its derivative

At x=1, F(x) =1 and F'(x) =0

Step10: Substitute values at Step9 for polynomial obtained in step8 and its derivative.

Step 11: Derive the coefficient values of $a_k$ and $a_{k-1}$ .

Step12: Find the reduced polynomial substituting the values obtained in Step 11 in the polynomial obtained in Step 8.

The above algorithm is applied to obtain the transfer function of the sharpened filter with increasing values of k ,the highest order of H(z), starting with k=3., We define a new parameter K called Sharpening parameter which indicates the number of times sharpened. Corresponding to k=3, we have K=1, and both increase as shown in Table3.1.

k=1 implies no sharpening algorithm has been applied to the filter, hence Sharpening parameter K=0.

Table3.1- Sharpened Functions and their stopband attenuation (calculated from the following response curve)

| Highest order of H(z) k | No. of times sharpened K | Function | Stopband attenuation |
|---|---|---|---|
| 1 | 0 | H(z) | 68dB |
| 3 | 1 | $3H(z)^2 - 4H(z)^3$ | 118dB |
| 4 | 2 | $4H(z)^3 - 5H(z)^4$ | 240dB |
| 5 | 3 | $5H(z)^4 - 6H(z)^5$ | 302dB |
| 6 | 4 | $6H(z)^5 - 7H(z)^6$ | 492dB |
| 7 | 5 | $7H(z)^6 - 8H(z)^7$ | 650dB |

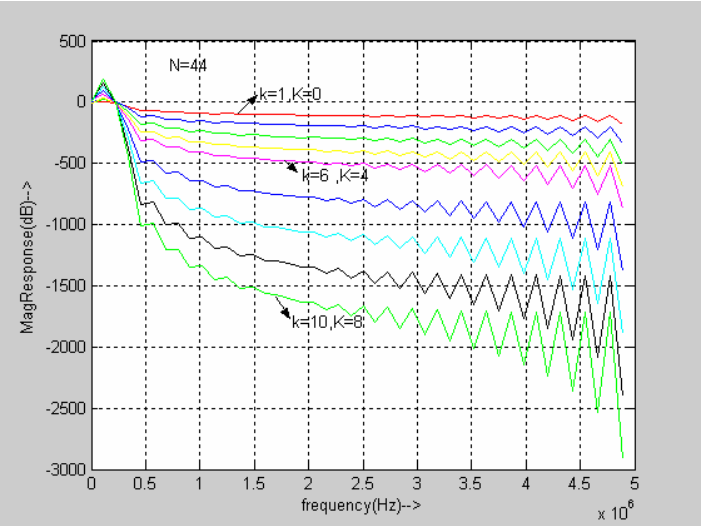



Fig .3.3 Magnitude Response of Sharpened Raised Cosine filter upto 8th sharpening(K=8)

## IV. QAM SYSTEM APPLIED TO SO DESIGNED RAISED COSINE FILTER

The raised cosine filter and the sharpened raised cosine filter so designed in Matlab for order N=11, 22,44 and the respective coefficients as calculated in MATLAB are each applied to QAM (16, 32, 64) system of communication. The performance of QAM is checked w.r.t EVM (error vector magnitude), magnitude error,

phase error and SNR for both raised cosine and sharpened raised cosine filter.

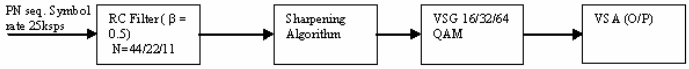



Fig.4a

4.1 QAM system applied to so designed Raised Cosine Filter and Sharpened Raised Cosine Filter of order 44

Table 4.1a Raised Cosine Filter applied to 16QAM (N=44)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 22.7 | 21.2 | 20.8 | 20.0 | 19.5 | 19.0 | 18.7 | 18.9 | 19.0 | 19.2 | 19.8 | 19.7 | 19.8. |
| Magnitude error(% rms)_ | 11.7 | 11.2 | 10.8 | 10.0 | 9.7 | 9.0 | 8.8 | 8.9 | 9.0 | 9.3 | 9.8 | 9.9 | 9.8. |
| Phase Error (deg) | 18.8 | 17.6 | 17.3 | 17.0 | 16.8 | 16.5 | 16.0 | 16.8 | 16.4 | 16.6 | 16.8 | 16.9 | 16.9 |
| SNR | 8.9 | 9.0 | 9.2 | 9.6 | 9.9 | 10.4 | 10.9 | 10.7 | 10.3 | 10.0 | 9.8 | 9.3 | 9.1 |

Table 4.1b Raised Cosine Filter applied to 32QAM (N=44)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 18.3 | 17.8 | 17.5 | 16.8 | 16.3 | 16.0 | 15.8 | 16.0 | 16.2 | 16.4 | 16.2 | 16.0 | 1.2 |
| Magnitude error(% rms)_ | 9.2 | 9.0 | 8.5 | 8.2 | 8.0 | 7.8 | 7.2 | 7.6 | 7.8 | 8.2 | 8.4 | 8.5 | 8.9 |
| Phase Error (deg) | 14.6 | 14.4 | 14.2 | 13.8 | 13.3 | 13.0 | 12.8 | 12.6 | 12.2 | 13.9 | 13.6 | 13.7 | 13.8 |
| SNR | 10.5 | 10.9 | 11.2 | 11.6 | 11.8 | 12.7 | 12.9 | 13.0 | 12.2 | 12.0 | 12.5 | 12.3 | 12.3 |

Table 4.1c Raised Cosine Filter applied to 64QAM (N=44)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 9.6 | 9.0 | 8.5 | 8.2 | 8.0 | 7.6 | 7.2 | 7.6 | 7.8 | 8.1 | 8.4 | 8.5 | 8.4 |
| Magnitude error(% rms)_ | 4.8 | 4.3 | 4.0 | 3.8 | 3.1 | 2.7 | 2.2 | 3.2 | 3.4 | 4.2 | 4.5 | 4.6 | 5.4 |
| Phase Error (deg) | 10.6 | 10.2 | 9.8 | 9.2 | 8.5 | 8.2 | 8.0 | 7.8 | 9.7 | 9.9 | 10.2 | 10.0 | 9.9 |
| SNR | 11.5 | 11.8 | 12.3 | 12.8 | 13.3 | 13.9 | 14.3 | 12.8 | 13.2 | 12.4 | 12.3 | 11.3 | 11.3 |

4.2 QAM system applied to so designed Raised Cosine Filter and Sharpened Raies Cosine Filter of order 22

Table 4.2a Raised Cosine Filter applied to 16QAM (N=22)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 23.0 | 22.4 | 22.0 | 21.6 | 21.3 | 21.0 | 20.8 | 20.4 | 20.2 | 20.0 | 19.8 | 20.0 | 20.2 |
| Magnitude error(% rms)_ | 18.8 | 18.6 | 18.3 | 18.0 | 17.8 | 17.5 | 17.2 | 16.8 | 16.4 | 16.2 | 16.0 | 16.0 | 16.4 |
| Phase Error (deg) | 17.9 | 17.6 | 17.2 | 16.8 | 16.3 | 16.0 | 15.8 | 15.6 | 15.0 | 14.8 | 14.2 | 14.0 | 14.0 |
| SNR | 8.5 | 8.8 | 9.2 | 9.7 | 10.1 | 10.4 | 10.7 | 10.9 | 11.2 | 11.6 | 11.8 | 11.3 | 11.0 |

Table 4.2b Raised Cosine Filter applied to 32QAM (N=22)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 15.3 | 14.8 | 13.5 | 13.1 | 12.8 | 12.4 | 12.0 | 11.8 | 11.6 | 11.7 | 11.2 | 11.0 | 11.2 |
| Magnitude error(% rms)_ | 10.2 | 9.75 | 9.5 | 9.2 | 8.8 | 8.5 | 8.2 | 8.0 | 7.8 | 7.6 | 8.2 | 8.4 | 8.4 |
| Phase Error | 16.8 | 16.6 | 16.2 | 15.8 | 15.3 | 15.0 | 14.8 | 14.6 | 14.2 | 13.9 | 13.5 | 13.5 | 13.5 |

| (deg) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SNR | 11.5 | 12.4 | 12.8 | 13.2 | 13.8 | 13.7 | 13.9 | 14.0 | 14.2 | 14.0 | 13.5 | 13.3 | 13.3 |

Table 4.2c Raised Cosine Filter applied to 64QAM (N=22)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 11.2 | 11.0 | 10.8 | 10.7 | 10.3 | 10.2 | 10.0 | 9.8 | 9.6 | 9.1 | 8.8 | 9.2 | 9.4 |
| Magnitude error(% rms)_ | 6.8 | 6.3 | 6.1 | 6.0 | 5.8 | 5.6 | 5.4 | 5.2 | 5.0 | 4.8 | 4.5 | 5.3 | 5.4 |
| Phase Error (deg) | 6.3 | 6.0 | 5.9 | 5.7 | 5.5 | 5.3 | 5.1 | 5.0 | 4.8 | 4.7 | 4.3 | 5.3 | 5.4 |
| SNR | 13.8 | 13.6 | 13.2 | 12.8 | 12.6 | 12.2 | 12.0 | 11.8 | 11.7 | 11.9 | 12.2 | 12.0 | 12.2 |

4.3 QAM system applied to so design Raised Cosine Filter and Sharpened Raised Cosine Filter of order 11.

Table 4.3a Raised Cosine Filter applied to 16QAM (N=11)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 21.6 | 21.0 | 20.6 | 19.8 | 19.3 | 18.8 | 18.0 | 17.7 | 17.2 | 16.8 | 16.2 | 16.0 | 15.8 | 16.0 | 16.2 |
| Magnitude error(% rms)_ | 17.2 | 17.0 | 16.8 | 16.2 | 16.0 | 15.8 | 15.2 | 15.0 | 14.8 | 14.3 | 14.0 | 13.7 | 13.1 | 13.4 | 14.0 |
| Phase Error (deg) | 15.7 | 15.2 | 15.0 | 14.3 | 14.0 | 13.7 | 13.2 | 13.0 | 12.6 | 12.2 | 11.8 | 11.2 | 11.0 | 11.4 | 11.8 |
| SNR | 7.8 | 8.2 | 8.8 | 9.2 | 9.6 | 10.1 | 10.3 | 10.9 | 11.5 | 11.8 | 12.2 | 12.5 | 12.9 | 12.2 | 11.7 |

Table 4.3b Raised Cosine Filter applied to 32QAM (N=11)

| No. of times sharpened(K) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 17.8 | 17.3 | 17.0 | 16.5 | 16.0 | 15.6 | 15.0 | 14.7 | 14.2 | 13.8 | 13.0 | 12.7 | 12.2 | 13.0 | 13.2 |
| Magnitude error(% rms)_ | 15.2 | 15.0 | 14.6 | 14.2 | 13.8 | 13.2 | 12.7 | 12.3 | 12.0 | 11.7 | 11.2 | 10.7 | 10.1 | 11.4 | 12.0 |
| Phase Error (deg) | 12.7 | 12.2 | 11.8 | 11.1 | 10.7 | 10.1 | 9.7 | 9.2 | 8.6 | 8.2 | 7.8 | 7.2 | 6.8 | 7.4 | 7.8 |
| SNR | 10.6 | 10.9 | 11.2 | 11.8 | 12.3 | 12.9 | 13.4 | 13.8 | 14.3 | 14.8 | 15.3 | 15.7 | 16.3 | 16.2 | 15.7 |

Table 4.3c Raised Cosine Filter applied to 64QAM (N=11)

| No. of times sharpened(K), | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVM(% rms) | 10.3 | 10.0 | 9.6 | 9.2 | 8.8 | 8.2 | 7.6 | 7.2 | 6.8 | 6.2 | 5.5 | 5.2 | 5.0 | 5.2 | 5.4 |
| Magnitude error(% rms)_ | 13.2 | 13.0 | 12.8 | 12.2 | 12.0 | 11.8 | 11.2 | 11.0 | 10.8 | 10.3 | 10.0 | 9.8 | 9.1 | 10.0 | 10.3 |
| Phase Error (deg) | 11.7 | 11.4 | 11.0 | 10.7 | 10.0 | 9.7 | 9.2 | 9.0 | 8.6 | 8.2 | 7.5 | 7.2 | 7.0 | 8.2 | 8.8 |
| SNR | 11.8 | 12.2 | 12.8 | 13.2 | 13.6 | 14.1 | 14.3 | 14.9 | 15.5 | 15.8 | 16.2 | 16.5 | 16.9 | 16.2 | 16.0 |

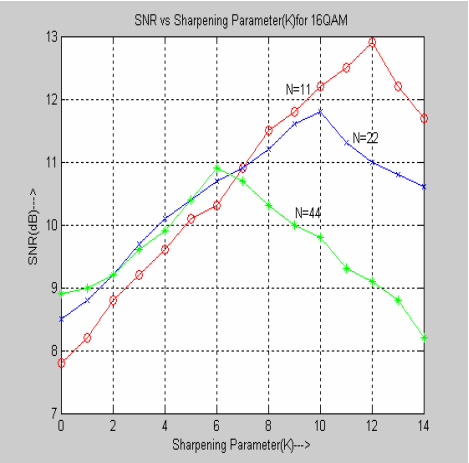



Fig. 4c

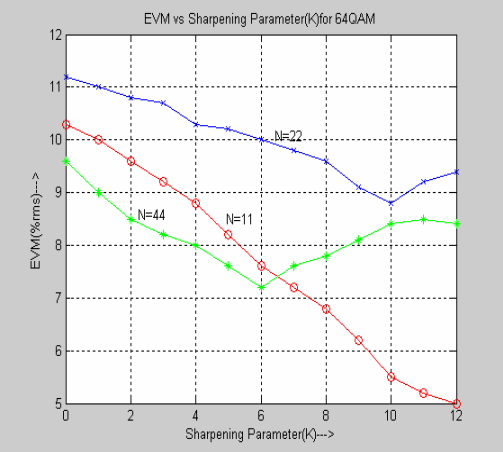



Fig. 4d

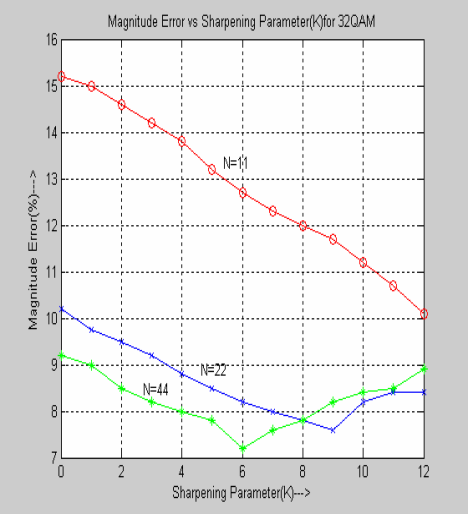



Fig.4e

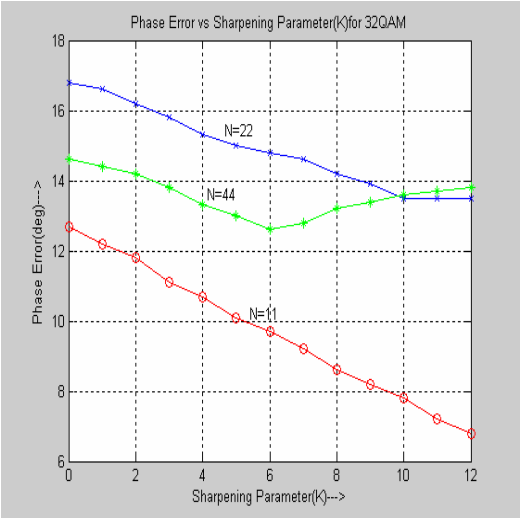



Fig.4f

## V. RESULT AND DISCUSSION

From this response curve Fig.2.1 it can be seen that as the order of the RC filter is increased the filter response curve becomes sharper. Increasing the order of filter implies increasing the design complexities and hence increasing the cost, so this is avoided.

As can be seen from Fig.3.3 the sharpening increases with increasing values of both k and K. From the response curve Fig.3.3 and the table 3.1 it is clear that the sharpening algorithm increases the stopband attenuation which is highly desirable.

The effect of sharpening pulseshaping RC filter under QAM (16/32/64) system can be observed from each of the observation tables (4.1, 4.2, and 4.3). When K=0 i.e. when there is no sharpening used in the raised cosine filter, the values of EVM, magnitude error and phase error are greater than the successive values of EVM, magnitude error and phase error when sharpening has been used i.e K=1, K=2, K=3 etc.

Also SNR values with no sharpening (K=0) is lower than the successive SNR values with sharpening (K=1, 2, 3 etc.) in RC filter

From these observation tables it is also clear that 64QAM works better than 32QAM which in turn performs better than 16QAM when subjected to Raised cosine and sharpened Raised Cosine filter. As the sharpening parameter K is increased performance of QAM (16,32, 64) all improve as the EVM,. Magnitude Error and Phase Error each decrease and SNR increase with increasing value of K.

Different error mechanisms will affect a signal in different ways, perhaps in magnitude only, phase only, or both simultaneously. Knowing the relative amounts of each type of error can quickly confirm or rule out certain types of problems. Thus, the first diagnostic step is to compare the relative sizes of the phase error and the magnitude error.

When the average phase error (in degrees) is larger than the average magnitude error (in percent) by a factor of about five or more as can be seen in Table 4.1a(16QAM, N=44), Table 4.1b(32QAM, N=44), Table 4.1c(64QAM, N=44),Table 4.2b(32QAM, N=22), this indicates that some sort of unwanted phase modulation is the dominant error mode. In such cases one

should proceed with further measurements to look for noise, spurs, or cross-coupling problems in the frequency reference, phase-locked loops, or other frequency-generating stages. Residual AM is evidenced by magnitude errors that are significantly larger than the phase angle errors as can be seen in Table 4.3a(16QAM, N=11), 4.3b(32QAM,N=11),4.3c(64QAM,N=11).In many cases, the magnitude and phase errors will be roughly equal as can be seen in Table 4.2c(64 QAM, N=22). This indicates a broad category of other potential problems including compression, clipping, and zero- crossing non-linearities.

Large error vectors, both at the symbol points and at the transitions between symbols, can be caused by problems at the base- band, IF or RF sections of the transmitter. In-channel spurious cause interference in the modulation. A single spur combines with the modulated signal. We see that by using the sharpening algorithm, %rms value of EVM decreases, which means decrease in spurious signals.

From the Tables 4.1a, 4.1b, 4.1c we see that sharpening improves performance of QAM (16/32/64) for N=44, till K=6(no. of times sharpened =6), after which the performance of QAM degrades.

From the Tables 4.2a, 4.2b, 4.2c we see that sharpening improves performance of QAM (16/32/64) for N=22, till K=10(no. of times sharpened =10), after which the performance of QAM degrades.

From the Tables 4.3a, 4.3b, 4.3c we see that sharpening improves performance of QAM(16/32/64) for N=11, till K=12(no. of times sharpened =12), after which the performance of QAM degrades.

These verifications can be observed clearly from the Graphs as shown in Fig. 4c, 4d, 4e& 4f.

Thus we can say order of Raised Cosine filter (N) is inversely proportional to the sharpening parameter K upto which QAM improves i.e. **N ά 1/K**

N= order of Raised Cosine filter

K= sharpening parameter (upto which QAM improves).

## VI. CONCLUSION

The main goal of this paper was to sharpen a pulseshaping raised cosine filter and observing the effect of sharpening on QAM system, of communication. The RC filter designed in MATLAB is sharpened by applying the sharpening algorithm. Each time the RC filter is sharpened by the sharpening algorithm, its stopband attenuation increases as shown in Table 3.1.The coefficients of these sharpened RC filter is calculated in MATLAB. These coefficients are then fed to QAM system in VSG to see the effect of sharpening on QAM system. The outputs checked in the computer connected to VSA verifies that QAM system shows improved performance till twelfth sharpening when order of the filter is 11 i.e .N=11; till tenth sharpening when order of filter is 22 i.e. N=22, and till sixth sharpening when order of the filter is 44,i.e N=44. Thus if an engineer wishes to improve the performance of QAM system of communication without increasing the order of the RC filter, he may do so by sharpening the RC filter. In this paper the order of the RC filter is chosen as N=11, 22 &44 without jeopardizing the design.

For each of these orders N it is proved that firstly performance of QAM system improves by sharpening the RC filter and using it prior to modulation; secondly 64QAM performs better than 32QAM which in turn performs better than 16QAM and thirdly QAM(16/32/64) system shows improvement by sharpening the RC filter K (sharpening parameter) times where K is found to be inversely proportional to the order N of the RC and sharpened RC filter.

## APPENDIX

### *A. Error Vector Magnitude (EVM), Magnitude error and Phase Error*

The error vector magnitude or EVM is a measure used to quantify the performance of a digital radio transmitter or receiver. A signal sent by an ideal transmitter or received by a receiver would have all constellation points precisely at the ideal locations, however various imperfections in the implementation (such as carrier leakage, low image rejection ratio, phase noise etc.) cause the actual constellation points to deviate from the ideal locations. Informally, EVM is a measure of how far the points are from the ideal locations. An error vector is a vector in the I-Q plane between the ideal constellation point and the point received by the receiver. In other words, it is the difference between actual received symbols and ideal symbols. The average power of the error vector, normalized to signal power, is the EVM. For the percentage format, root mean square (RMS) average is used.The error vector magnitude is equal to the ratio of the power of the error vector to the root mean square (RMS) power of the reference. It is defined in dB as

$EVM(dB) = 10 \log_{10} (P_{error} / P_{reference})$

where $P_{error}$ is the RMS power of the error vector. For single carrier modulations, $P_{reference}$ is, by convention, the power of the outermost (highest power) point in the reference signal constellation. EVM, as conventionally defined for single carrier modulations, is a ratio. as a percentage of the square root of the mean power of the ideal signal,( as a percentage of the square root of the average symbol) to the peak signal level, usually defined by the constellation's corner states. The EVM value depends on the peak and means signal power is dependent on constellation geometry, different constellation types (e.g. 16-QAM and 64-QAM), subject to the same mean level of interference, will report different EVM values.

The error vector is the vector difference at a given time between the ideal reference signal and the measured signal. Expressed another way, it is the residual noise and distortion remaining after an ideal version of the signal has been stripped away. EVM is the root-mean-square (RMS) value of the error vector over time at the instants of the symbol (or chip) clock transitions.

While the error vector has a phase value associated with it, this angle generally turns out to be random, because it is a function of both the error itself (which may or may not be random) and the position of the data symbol on the constellation (which, for all practical purposes, is random). A more useful angle is measured between the actual and ideal phasors (I-Q error phase or phase error), which contains information useful in troubleshooting signal problems. Likewise, I-Q error magnitude, or magnitude error, shows the magnitude difference between the actual and ideal signals. The magnitude of the error vector versus time

measurement shows the error vector magnitude variations as a signal changes over time—that is, at and between symbol decision timing points.

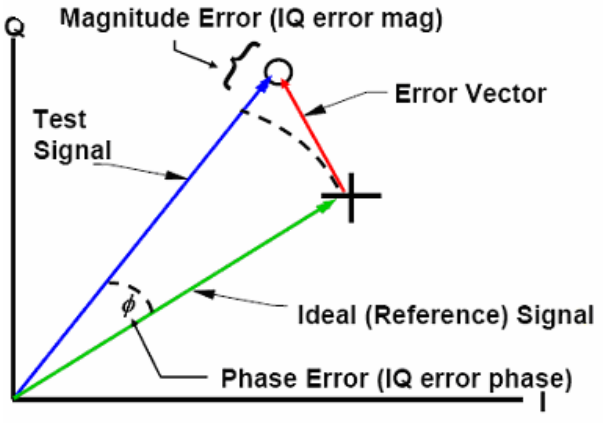



Fig.4b

*B. Signal-to-noise ratio (often abbreviated SNR or S/N)*

It is a measure used in science and engineering to quantify how much a signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal. A ratio higher than 1:1 indicates more signal than noise. In less technical terms, signal-to-noise ratio compares the level of a desired signal (such as music) to the level of background noiseSNRs are often expressed using the logarithmic decibel scale. In decibels, the SNR is defined as :

$SNR(dB) = 10 \log_{10} (P_{signal} / P_{noise})$

*C.Vector Signal Generator*

The vector signal generator combines outstanding RF performance and sophisticated baseband generation to deliver calibrated test signals at baseband, IF, and RF frequencies up to 3 GHz. Offering an internal baseband generator with arbitrary waveform and real-time I/Q capabilities, ample waveform playback and storage memory, and a wide RF modulation bandwidth, the VSG is equipped to test today's complex wireless systems. .

The VSG is an adaptable platform with optional capabilities to customize the instrument for baseband and RF test applications ranging from simple distortion test and general purpose troubleshooting to baseband coding algorithm development, advanced transceiver design verification, and high volume manufacturing.

The Coefficients of Raised Cosine filter and sharpened Raised Cosine filter designed in Matlab is fed in VSG when the filter chosen in VSG is user- defined (FIR). The modulation chosen in VSG is QAM (16/32/64)

*D.Vector Signal Analyserr*

The vector signal analyzer (VSA) facilitates faster and easier communication system design from initial design simulation to final hardware prototype. It offers 36 MHz bandwidth capacity for measuring signals such as cellular and satellite communications, digital video, wireless LAN (WLAN), and local multipoint distribution service (LMDS).

It offers digital demodulation and has facility of IQ measurement.

We can quickly evaluate and troubleshoot digitally modulated signals with both qualitative displays and quantitative measurements and visualize the system performance rapidly and intuitively with familiar display formats and view composite measurements of the code domain power (CDP), time, spectrum, phase error, evm and magnitude error. or view these for an individual channel.

In addition, a new code domain error measurement provides a histogram of error vector magnitude (EVM) versus channel. We can display our results in constellation, eye, trellis, or spectrum diagrams. In VSA we can detect intersymbol interference, quadrature balance and error, and spurious responses.

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**First Author** – Mahua Pal , M.Tech. (Radiophysics and Electronics, Calcutta Univ,) Faculty in Amity University Lucknow, mahuapal@yahoo.com