Office de la Propriété
Intellectuelle
du Canada

Un organisme
d'Industrie Canada

Canadian
Intellectual Property
Office

An agency of
Industry Canada

(21) **2 769 965**

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) **A1**

(22) **Date de dépôt/Filing Date:** 2012/02/17

(41) **Mise à la disp. pub./Open to Public Insp.:** 2013/08/17

(51) **Cl.Int./Int.Cl.** *H04L 25/03* (2006.01)

(71) **Demandeur/Applicant:**
VECIMA NETWORKS INC., CA

(72) **Inventeur/Inventor:**
LARIONOV, NIKOLAJ, CA

(74) **Agent:** ADE & COMPANY INC.

(54) **Titre :** MODULATION NUMERIQUE A PLUSIEURS MODES ET COMPLEXITE REDUITE PAR LE BIAIS DU REGROUPEMENT DE DIVERS FILTRES DE TRANSMISSION A MISE EN FORME DE NYQUIST A RACINE CARREE

(54) **Title:** REDUCED-COMPLEXITY MULTIPLE-MODE DIGITAL MODULATION THROUGH CONSOLIDATION OF VARIOUS SQUARE-ROOT NYQUIST SHAPING TRANSMIT FILTER

REDUCED-COMPLEXITY MULTIPLE-MODE DIGITAL MODULATION THROUGH CONSOLIDATION OF VARIOUS SQUARE-ROOT NYQUIST SHAPING TRANSMIT FILTER

This invention relates to the application of one fixed Transmit Shaping Filter to more than one digital modulation scheme's transmission. The performance of the fixed filter is such that the functional and performance requirements of the various digital modulation schemes are simultaneously met.

In ITU-T J.83 standard is disclosed details of the arrangement with which the present invention is concerned. Also in Fred Harris et al, An Improved Square-Root Nyquist Shaping Filter, SDR Forum 2005 is disclosed a prior proposal. The disclosure of both of these documents is incorporated herein by reference, or can be referred to for any details omitted herein.

BACKGROUND OF THE INVENTION

Current digital telecommunication systems operate using band limited channels. Different international standards define the shape of channels' transmit shaping filters for various modulation schemes. A square-root raised cosine (SRRC) filter is one of the most common filters defined for channel shaping. In a digital system, a filter is implemented as a series of coefficients representing the impulse response of the filter. The series of coefficients and a wide-band input data stream are convolved to produce a filtered band-limited output data stream ready for transmission.

In order to have an optimal receiver from channel noise point of view, it is common to have a pair of identical SRRC filters at the transmitter (shaping filter) and receiver (matching filter) such that their cascade response is raised cosine (RC) filter that is known to be an optimal and finite approximation of an infinite ideal filter.

The SRRC filters are usually standardized by defining a template for the amplitude characteristics of the channel shape. The template specifies ripples in the filter pass-band and at the Nyquist frequency, a ~3dB point as well as the out-of-band rejection. The ~3dB point of SRRC frequency response is an important characteristic that is related to the half symbol rate. The SRRC filter frequency response ('H(f)') theoretical function is defined by the following equation:

pass band: H(f) = 1 for |f| <= fn(1-r)

transition band: H(f)=sqrt{0.5+0.5*sin(Pi/2fn [(fn-|f|) / r])} for fn(1-r)<=|f|<=fn(1+r)

stop band: H(f) = 0 for |f|>fn(1+r).. (1)

where 'sqrt' means square root operation, 'f' is frequency, 'r' is the roll-off factor and 'fn' is the Nyquist frequency equal to half the symbol rate 'Rs'.

Therefore the baseband bandwidth ('B') is equal to:

B=(1+r)fn. or B=(1+r)Rs/2..(2)

One of the characteristics of an ideal filter is that its impulse response ('h(mT)') is equal to zero at any symbol time intervals 'mT' except for the center one, i.e.

$h(mT) = 1$ when $m=0$

$h(mT) = 0$ when $m=+/-1,+/-2,+/-3\ldots$ ………………………………………………(3)

where T is the time between symbol transmissions related to the symbol rate of a particular standard. Equation (3) shows that there should be no inter-symbol interference (ISI) between different symbols coming at symbol rate. A realistic SRRC filter is close to satisfying equation (3), however its ISI is never equal to zero due to the finite filter length.

Symbol rate, channel bandwidth and the related SRRC roll-off factor are the unique parameters defined for different modes in different standards for a particular application. The out-of-band emission mask to minimize the interference with adjacent channels is another unique characteristic of a particular standard and application.

Having exactly same SRRC filters at the transmitter and receiver minimizes ISI. If on the other hand SRRC filter at the transmitter was designed for different specifications (i.e. rate, roll-off factor and bandwidth) than matching SRRC filter at the receiver then ISI is increased that significantly degrades the performance of the received signal.

References:

ITU-T J.83

CableLabs DRFI

"An Improved Square-Root Nyquist Shaping Filter" by fred harris

SUMMARY OF THE INVENTION

Method to define and enable the use of a single filter as the transmit filter in for more than one digital modulation schemes and/or international standards for digital communication including:

Method for determining a single coefficient set for a transmit filter.

Transmit filter coefficient set corresponds to a specific amplitude/phase frequency response.

Frequency response of single coefficient set meets or exceeds the functional and performance requirements of one or more modulation schemes and/or international standards.

Modulation scheme and/or international standard specifies the following applicable requirements:

- general transmit filter shape (i.e. RC or SRRC) including:

- pass-band ripple
- 3dB point
- stop-band attenuation

- a minimum modulation-error ratio (MER), relating to ISI performance of the transmit-receive filter pair

- adjacent channel noise performance

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is the ITU-T J.83 template for a Square-Root Raised-Cosine Transmit Filter. It specifies requirements for a square-root raised-cosine filter having a rolloff factor of 'alpha', with passband ripple of less than 0.4dB peak-to-peak, a 3dB point accuracy of 0.4dB, and out-of-band rejection of better than 43dB relative to the nominal passband. The use of these specifications would allow a designer to specify a set of transmit filter coefficients that would meet the requirements of the digital communication system specified by ITU-T J.83.

Figure 2 - Comparison of amplitude responses of various J.83 Transmit Filters with a consolidated Filter

Figure 3 is diagram showing first, second, and third-adjacent channel frequency bands first for a 6MHz channel plan, and in brackets for an 8MHz channel plan. Specifications such as CableLabs DRFI require noise performance in each of these bands to be better than values specific to the digital communication system in use. A transmit filter

Although the design targeted J.83 Annex modes A, B and C [1], the approach can be used in other similar standards.

The channel shaping filter defined for different Annex modes is specified as a Square-Root Raised Cosine (SRRC) filter with an approximate roll-off factor. The latter is related to the symbol rate and the channel bandwidth of a particular annex mode.

Considering different symbol rates in different Annex modes of J.83 and a constant sample rate at the output of the shaping filter, we have developed a shaping filter architecture that oversamples data symbols and then performs a linear interpolation between the adjacent samples. The linear interpolation is controlled by a Digital Phase Lock loop (DPLL) that is beyond the scope of this document.

In developing shaping filter, it is important to match the bandwidth, rate and the template of the half-Nyquist baseband amplitude characteristics specified for SRRC filter in J.83 standard. The latter defines templates for the amplitude characteristics of the channel shaping filter. Annex modes A, B and C of J.83 standard have roll-off factors equal to ~0.12, ~0.13, ~15 and ~0.18 while the channel bandwidth is either 6 or 8 MHz. The pass-band ripple of +/-0.2 dB and the 3 dB point of SRRC filter (6 dB of Nyquist filter) as well as 43 dB point are the other important characteristics of the templates.

We have estimated that a shaping filter of 35 taps is sufficient to satisfy all Annex templates and achieve a relatively good sidelobe attenuation. Considering rate matching issue mentioned above, we had to oversample input data symbols by 64 in order to perform a linear interpolation between the adjacent samples. Therefore, we have developed a multirate shaping filter with a polyphase structure. Each tap of this filter contains 64 coefficients and DPLL determines what coefficients to apply for a particular input data symbol at a particular time.

Considering that data symbols of any Annex mode are represented as I and Q values of maximum 4 bits (i.e. 256-QAM), we were able to eliminate multiplications at the shaping filter taps by storing all possible 2^4=16 combinations of multiplication of I (Q) and each coefficient. To eliminate multipliers, each tap is implemented as a block RAM in FPGA, where the input address consists of upper 6 bits of symbol phase from DPLL and lower 4 bits of input data symbols (I or Q). Thus, block RAMs at each tap store not the coefficients but rather products of multiplication of coefficients and input data symbols.

Considering dual-port block RAM structure of Xilinx FPGA, we are able to process I and Q data simultaneously. The outputs of the block RAMs are then added in the adder tree and linearly interpolated. This architecture eliminates multipliers and any additional fractional delay filters e.g. Farrow filter. However, one of the challenges of this approach is a significant time to reload all the block RAMs of the shaping filter switching between Annex modes on the fly. Considering 2^6*2^4 addresses, the total data storage reaches 35 block RAMs of size 1Kx18 bits each.

Thus, it was important to eliminate block RAM reloading while switching between different Annex modes.

Following the above Fred Harris paper on Nyquist filter design approximation, we have developed a new approach to shaping filter design that can be applied not to a single filter of a particular Annex mode, but to all of them. The developed Annex-agile shaping filter approximates not a single SRRC filter (like in Harris), but all SRRC filters of Annex modes A, B and C.

The SRRC approximation is based on a typical Parks-McClellan (remez) algorithm for designing linear phase FIR filters. Considering an approximated SRRC at the transmitter and a typical (presumably ideal) SRRC at the receiver, it is important to estimate Inter-Symbol Interference (ISI) between the two. In [2], it was already shown that this ISI is on the level of SRRC filter itself. We have stepped further than this and developed a shaping filter that has relatively low ISI between itself and different SRRC filters dedicated to a particular annex mode.

The search for this filter is performed through an iterative process. We were able to iteratively modify parameters in Parks-McClellan algorithm to develop a filter with frequency response that matches all the templates of any mode. The main modification (tuning) in Parks-McClellan algorithm is performed with transition bandwidth. As long as we satisfy a 3 dB point, we are relatively free to modify the transition bandwidth. This slightly modifies the roll-off factor in each Annex mode within the template boundaries. At each iteration we evaluate ISI of the developed shaping filter with all SRRC filters of every mode. The major trade off here is between the steep fall of the transition band of the mode with ~0.12 roll-off factor and ISI of the mode with ~0.18 roll-off factor. The iterative search is considered completed when ISI of all Annex modes is approximately at the same level and all the templates are satisfied.

Apart from the theoretical shaping filter evaluation (with e.g. Matlab), we performed hardware testing of the implemented filter. The modulation error rate (MER), bit error rate (BER) as well as adjacent channel noise (ACP) measurements with Agilent PSA\VSA and Rohde & Schwarz EFA tools were the ultimate evaluation of the designed shaping filter. It was expected to see the dependency between the estimated low ISI and measured high MER.

We were able to lock demodulator and achieve unequalized MER of more than 42 dB (equalized >47 dB) with PSA\VSA in any Annex mode having one approximated shaping filter. (For comparison, the original SRRC filter of the same length had unequalized SRRC of less than 40 dB.) This approach eliminates block RAM reloading time while switching between different Annex modes.

As an alternative technique, we have also developed a shaping filter with a dual set of block Rams. One set of block RAMs was dedicated to Annex modes with roll-off factors of ~0.12 and ~0.13 while the other one was dedicated to ~0.15 and ~0.18. The appropriate set of block RAMs is selected based on the requested Annex mode with the corresponding roll-off factor. The switching between the sets is performed on the fly eliminating block RAM reloading. This approach doubles the number of memory blocks but gives a more precise transition roll-off as well as 43 dB point. It also lowers the ISI, and thus the measured MER then improved to more than 46 dB without equalizer and more than 50 dB with an equalizer of PSA\VSA.

In both approximated Annex-agile filters with single or dual-set of block RAMs, we were able to significantly improve ACP as well. The Adjacent Channel Power of the most challenging regions of 750 KHz skirt and 5.25 (7.25) MHz band improved to ~70 dBc versus ~60 dBc of the SRRC filter of the same length.

Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made within the spirit and scope of the claims without department from such spirit and scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

CLAIMS

1. A shaping filter for a digital telecommunication system comprising:

a square-root raised cosine (SRRC) filter;

where the SRRC approximation is based on a typical Parks-McClellan (remez) algorithm for designing linear phase FIR filters.

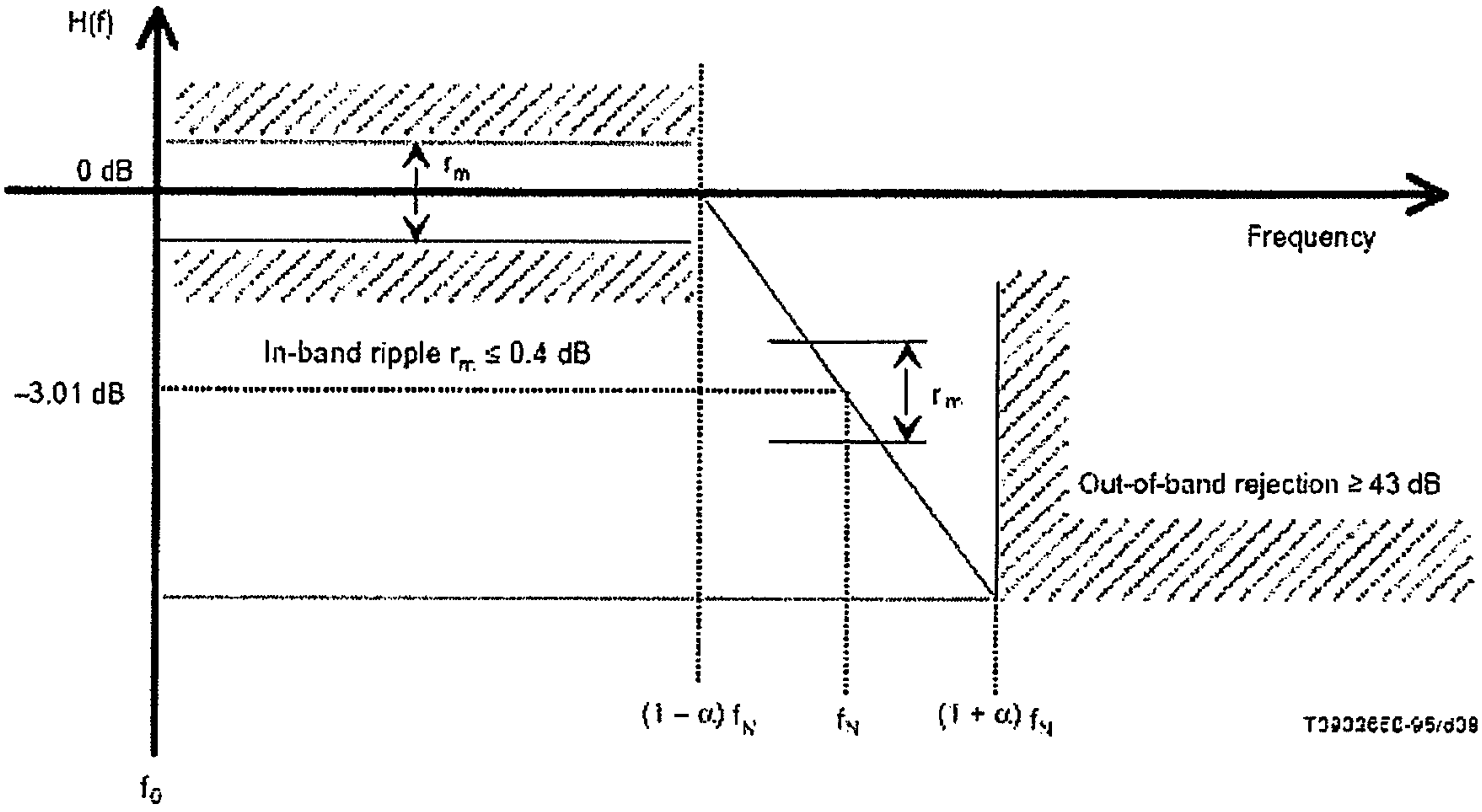
2. The filter of claim 1 which has relatively low ISI between itself and different SRRC filters dedicated to a particular annex mode.

3. The filter of claim 1 which enables the use of a single filter as the transmit filter in for more than one digital modulation schemes.

4. The filter of claim 1 which comprises a Square-Root Raised Cosine (SRRC) filter with an approximate roll-off factor.

5. The filter of claim 1 wherein the roll-off factor is related to the symbol rate and the channel bandwidth of a particular annex mode.

Drawings



f_N Nyquist frequency

Figure 1 (pulled from ITU-T J.83 Annex A) - Example template for Square-Root Raised-Cosine Transmit Filter

<need to create figure 2. Placeholder below>

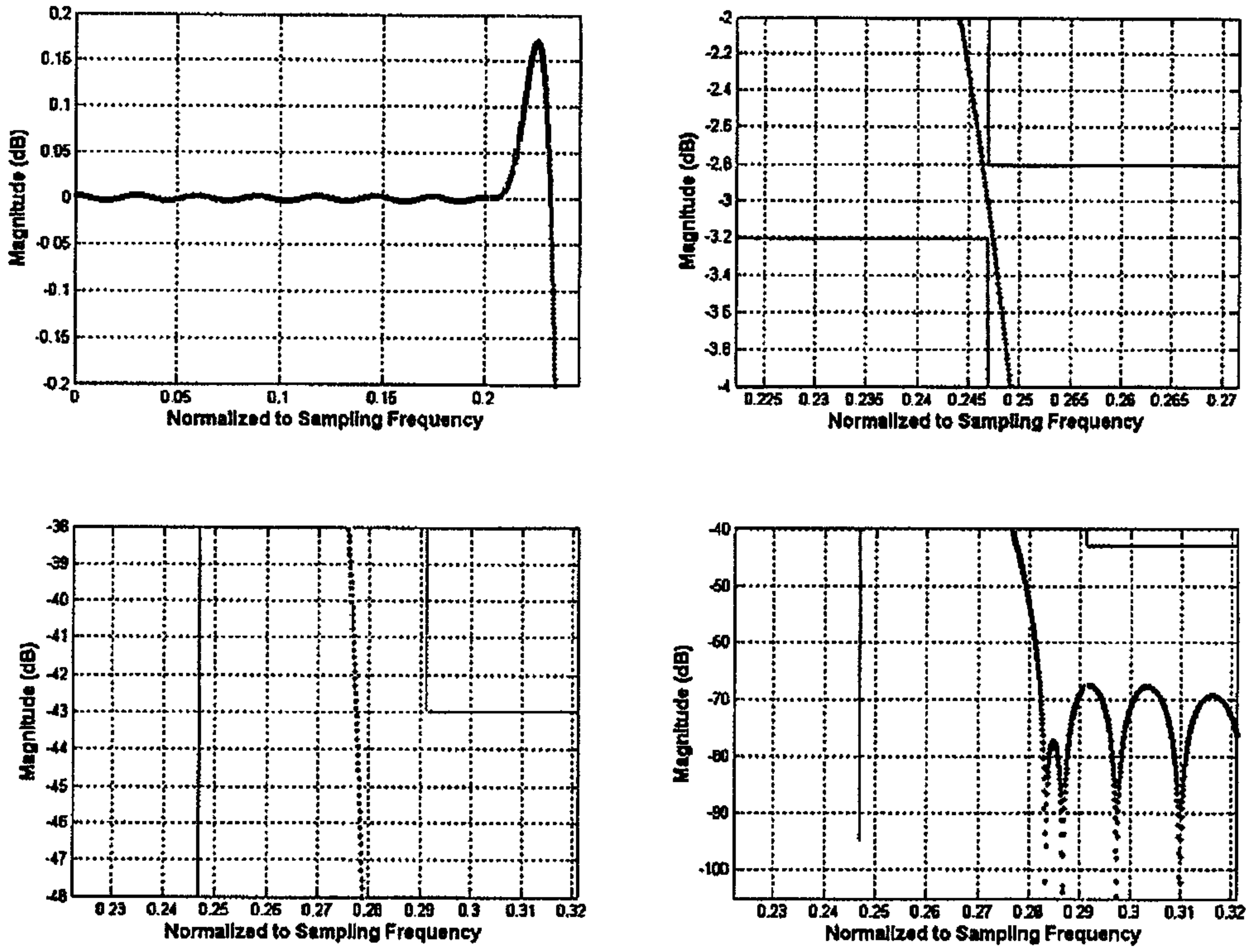


Figure 2 - Comparison of amplitude responses of various J.83 Transmit Filters with a consolidated Filter

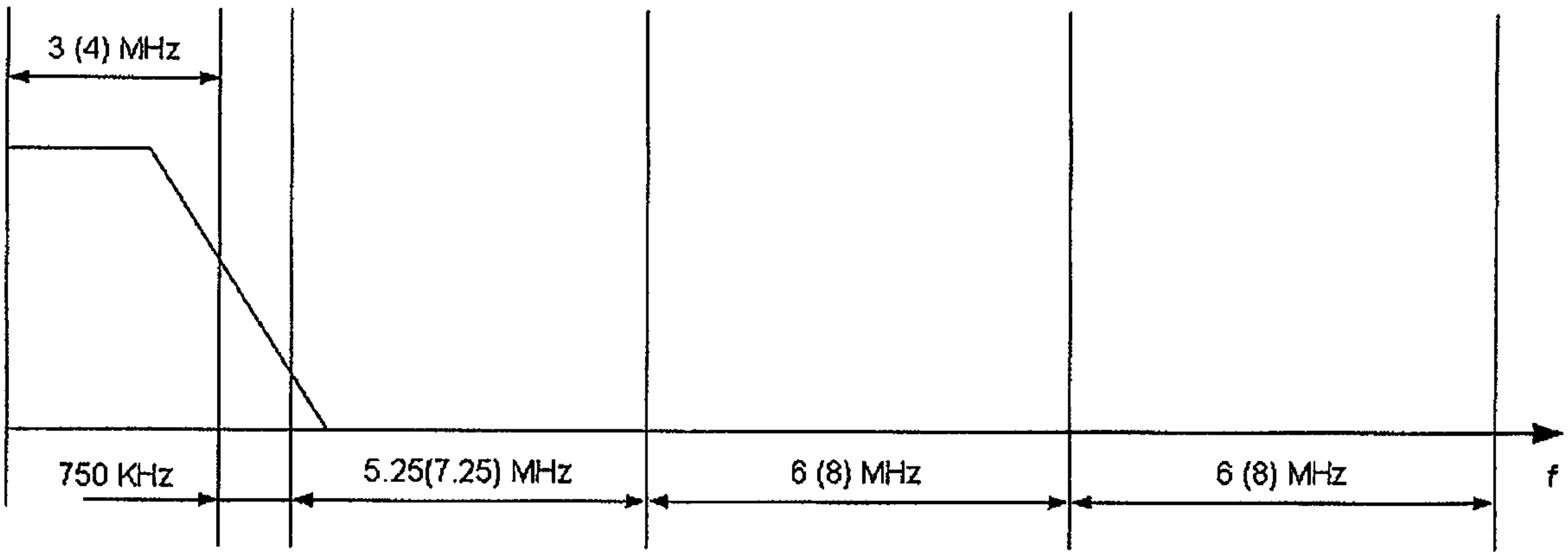


Figure 3 - Adjacent frequency bands for 6 (or 8) MHz QAM channels as per DRFI