Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (8): 1369-1373, 2005
ISSN 1812-5654

Study on Suppression with Multi-frequency Interference in HFC

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Abstract: QPSK or 16QAM modulation technology is used in upstream channel of HFC bi-direction net. In this study the CMRLS and the CMFTF known as high efficient nonlinear arithmetic are applied in the narrow band interference suppression. After analysis with multi-frequency interference the simulation results are shown that CMFTF performance is the nearly same as the CMRLS algorithm, but less computation, so the CMFTF is considered as the best algorithm.

Key words: 16QAM, narrow band interference suppression, CMRLS, CMFTF, SNR improvement

INTRODUCTION

It is necessary to adopt wideband modulation to realize the transmission of digital signal in HFC (Hybrid Fiber-coax) system. In order to deal with the asymmetry of data transmission flux of the net, the standard of DOCSIS V1.0 recommend that the modulation mode of 64QAM or 256QAM and that of QPSK or 16QAM should be applied in downstream channel and upstream one, respectively. In QPSK, the max input rate applied to the user of HFC is only 5.12Mb/s (S/N>16dB) and it can rise to 8~9Mb/s with same radio-frequency bandwidth on the condition of high SNR (S/N>24dB). It is obvious that the cannel utilization of QAM modulation mode is higher than that of QPSK.

THE STRUCTURE OF 16QAM NARROW BAND INTERFERENCE SUPPRESSER

There are many kinds distributed forms of signal space for 16QAM when the minimal distance of signal space is 2A and the A means certain amplitude related with average power of signal. In them two typical kinds of constellation are the square QAM constellation and the star QAM constellation, the first one is applied in this study. Comparing the two modulated methods, nonlinear suppresser can be structured just as Fig. 1 after splitting the real part and imaginary part of QPSK and 16QAM although they are so different[1].

Let $\rho(\bullet)=\rho_i(\bullet)$, i=1,2 and

$$\rho_1(e_k) = e_k - N + 2\frac{\sum_{l=1}^{N} l\binom{N}{l} e^{-(e_k - N + 2l)^2/2\sigma_k^2}}{\sum_{j=0}^{N}\binom{N}{j} e^{-(e_k - N + 2j)^2/2\sigma_k^2}} \quad (1)$$

$$\rho_2(e_k) = e_k - N + 2d\left(-\frac{e_k - N - 1}{2}\right) \text{ and}$$

$$d(x) = \begin{cases} 0, & [x] \le 0 \\ [x], & 0<[x]<N \\ N, & [x] \ge N \end{cases} \quad (2)$$

For the 16QAM signal N=3

All the parameters are complex number[2] and the received signal is denotation.

$$Z_k = S_k + n_k + I_k \quad (3)$$

and

$$Z_k = Z_{1k} + jz_{2k}$$

$$S_k = s_{1k} + j\hat{s}_{2k} \quad (4)$$

$$n_k = n_{1k} + j\hat{n}_{2k}$$

$$I_k = i_{1k} + j\hat{i}_{2k}$$

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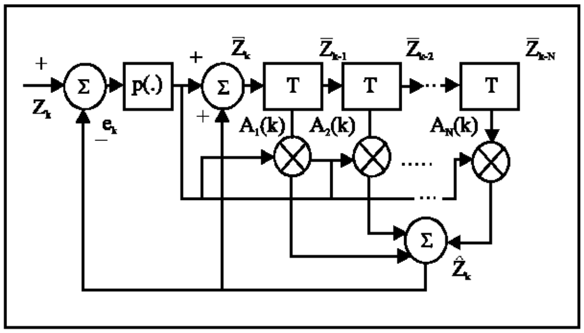

Fig. 1: Structure of nonlinear narrow band interference suppresser

The imaginary part of white noise $\hat{n}_{2k}$ and that of narrow interfere $\hat{i}_{2k}$ come from their real parts n_{lk} and i_{lk} after the Hilbert transform.

$$\hat{n}_2(t) = n_1(t) \otimes \frac{1}{\pi t} = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{n_1(\tau)}{t-\tau}d\tau \qquad (5)$$

$$\hat{i}_2(t) = i_1(t) \otimes \frac{1}{\pi t} = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{i_1(\tau)}{t-\tau}d\tau \qquad (6)$$

NONLINEAR SUPPRESSION ARITHMETIC IN 16QAM

High efficient nonlinear suppression arithmetic MLMS, MRLS, MFTF can be applied in the narrow band interference suppression of 16QAM signal. Since the signal is complex one, it is necessary to modify the MLMS, MRLS, MFTF to complex forms and mark them as CMLMS (Complex MLMS), CMRLS(Complex MRLS) and CMFTF (Complex MFTF).

CMLMS arithmeti: $E_k = Z_k - \hat{Z}_k$, The nonlinear function is as follow:

$$\underline{\rho}_2(E_k) = E_k - N + 2d(-\frac{E_k - N - 1}{2})$$

$$d(x) = \begin{cases} 0, & [x] \le 0 \\ [x], & 0<[x]<N \\ N, & [x] \ge N \end{cases} \qquad (7)$$

$$\hat{Z}_k = \hat{\underline{X}}_k^T \underline{\Theta}_{k-1} = \sum_{j=1}^{N} A_{j,k-1}\bar{Z}_{k-j} \qquad (8)$$

$$\bar{Z}_k = \hat{Z}_k + \underline{\rho}_2(E_k) \qquad (9)$$

$$\underline{\Theta}_k = \underline{\Theta}_{k-1} + \underline{u}\frac{\varepsilon_k}{R_k}\hat{\underline{X}}_k = \underline{\Theta}_{k-1} + \underline{u}\frac{\underline{\rho}_2(E_k)}{R_k}\hat{\underline{X}}_k \qquad (10)$$

R_k is ascertained by the recursion.

$$R_k = \underline{\beta}R_{k-1} + (1+j-\underline{\beta})\bar{Z}_k^2, \quad (0<|\underline{\beta}|<1))$$

CMRLS arithmetic: Initialization:

$$\underline{W}_N(0) = 0, \underline{C}_{NN}(0) = \sigma I_{NN}, (\sigma >> 1) \qquad (11)$$

Recursion:

$$E(n \mid n-1) = Z(n) - \hat{\underline{X}}_N'(n)\underline{W}_N(n-1) \qquad (12)$$

$$\underline{\mu}(n) = \hat{\underline{X}}_N'(n)\underline{C}_{NN}(n-1)\hat{\underline{X}}_N(n) \qquad (13)$$

$$G_N(n) = \frac{\underline{C}_{NN}(n-1)\hat{\underline{X}}_N(n)}{\underline{\lambda} + \underline{\mu}(n)} \qquad (14)$$

$$\underline{W}_N(n) = \underline{W}_N(n-1) + G_N(n)\underline{\rho}_2(E(n \mid n-1)) \qquad (15)$$

$$\underline{C}_{NN}(n) = \frac{1}{\underline{\lambda}}[\underline{C}_{NN}(n-1) - G_N(n)\hat{\underline{X}}_N'(n)\underline{C}_{NN}(n-1) \qquad (16)$$

$$\hat{\underline{X}}_N = [\bar{Z}_{k-1}, \bar{Z}_{k-2}, \ldots\ldots, \bar{Z}_{k-N}]$$

The nonlinear function is as follow:

$$\underline{\rho}_2(E_k) = E_k - N + 2d\left(-\frac{E_k - N - 1}{2}\right)$$

$$d(x) = \begin{cases} 0, & [x] \le 0 \\ [x], & 0<[x]<N \\ N, & [x] \ge N \end{cases} \qquad (17)$$

CMFTF arithmetic: When the MFTF arithmetic is applied in modulation system of 16QAM the transformation should be change since the input signal now is $\bar{z}(n)$.

$$X(n) = \bar{Z}(n-1) \qquad (18)$$

$$\underline{X}_N^T(n-1) = [\bar{Z}(n-2), \ldots, \bar{Z}(n-2-N+1)] \qquad (19)$$

Put the expecting signal as input signal.

$$X_N^T(n) = [\bar{Z}(n-1), \ldots, \bar{Z}(n-1-N+1)] \qquad (20)$$

The output signal of narrow band interference suppresser is:

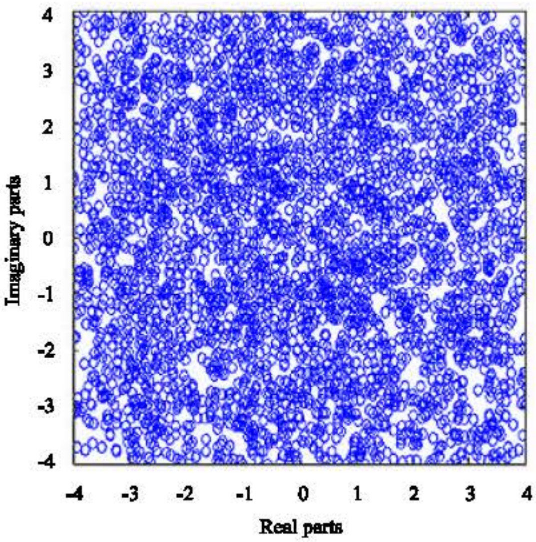

Fig. 2: 16QAM constellation before dealing (average S/J=-10dB, $\sigma_n^2 = 0.01$)

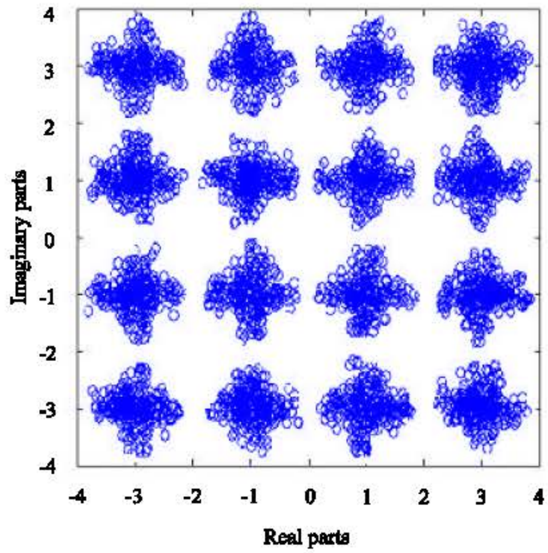

Fig. 4: Constellation after the CMRLS (average S/J=-10dB, $\sigma_n^2 = 0.01$)

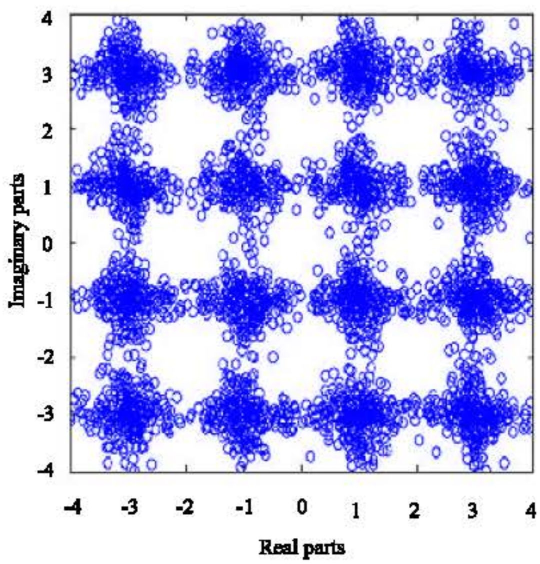

Fig. 3: 16QAM constellation after the CMLMS (average S/J=-10dB, $\sigma_n^2 = 0.01$)

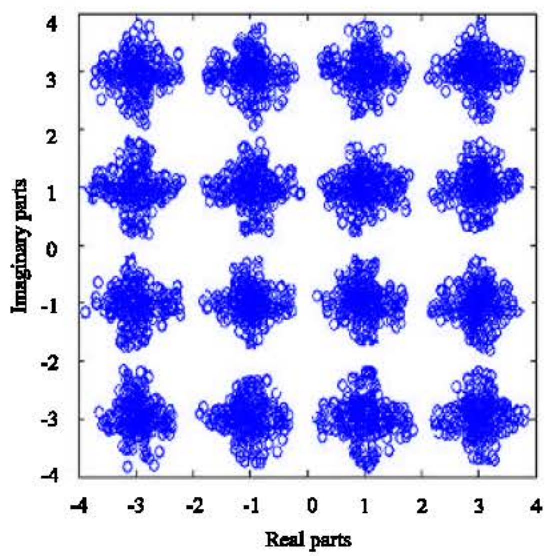

Fig. 5: 16QAM constellation after the CMFTF (average S/J=-10dB, $\sigma_n^2 = 0.01$)

$$E(n \mid n-1) = Z(n) - \underline{X}_N^T(n) W_N(n-1) \quad (21)$$

$$\rho_2(E(n \mid n-1)) = E(n \mid n-1) - N + 2d\left(-\frac{E(n \mid n-1) - N - 1}{2}\right) \quad (22)$$

$$d(x) = \begin{cases} 0, & [x] \le 0 \\ [x], & 0<[x]<N \\ N, & [x] \ge N \end{cases} \quad (23)$$

The update equation of $\overline{z}(n)$ is:

$$\overline{Z}(n) = \rho_2(E(n \mid n-1)) + \underline{X}_N^T(n) \underline{W}_N(n-1) \quad (24)$$

RESULTS

Since the emission signal and the received one are complex number, the SNR in simulation is defined as follow:

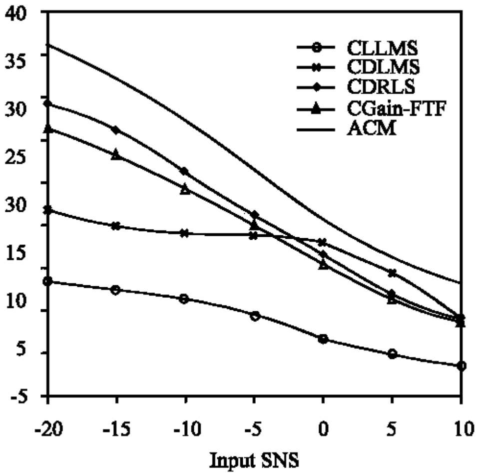

Fig. 6: Improvement curves of SNR ($\sigma_n^2 = 0.01$ five interference sources)

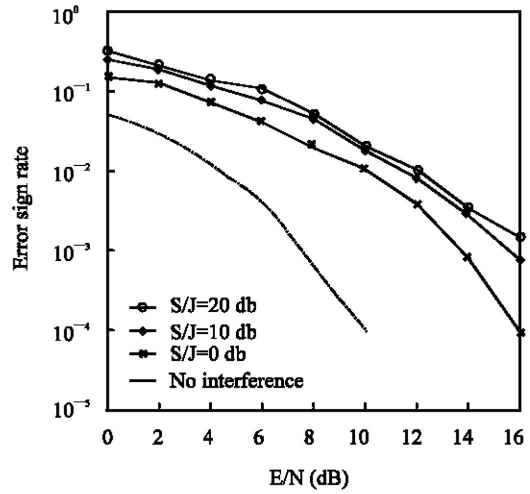

Fig. 8: Error sign rate in different interference (CMRLS, five interference sources)

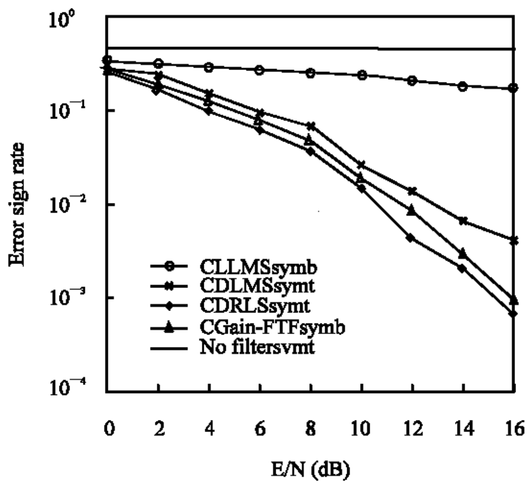

Fig. 7: Curves of error sign rate (S/J = -10dB, five interference sources)

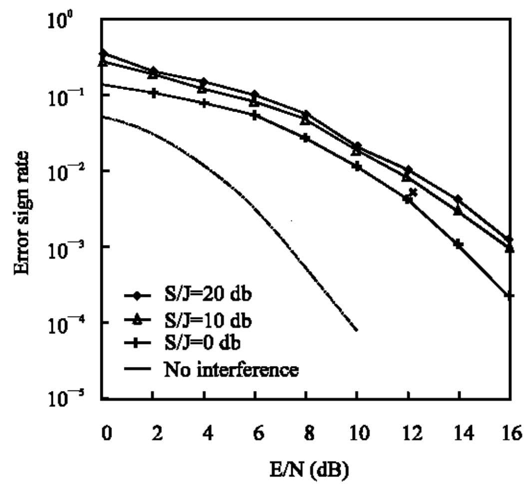

Fig. 9: Error sign rate in different interference (CMFTF, five interference sources)

The suppression input SNR is defined as:

$$\mathrm{SNR} = \frac{E\{[\mathrm{abs}(S_k)]^2\}}{E\{[\mathrm{abs}(Z_k - S_k)]^2\}} \tag{25}$$

The suppression output SNR is defined as:

$$\mathrm{SNR} = \frac{E\{[\mathrm{abs}(S_k)]^2\}}{E\{[\mathrm{abs}(E_k - S_k)]^2\}} \tag{26}$$

The improvement quality of SNR is defined as:

$$\mathrm{SNR} = \frac{E\{[\mathrm{abs}(Z_k - S_k)]^2\}}{E\{[\mathrm{abs}(E_k - S_k)]^2)} \tag{27}$$

In these expressions, abs(·) means calculating modular.

There are several narrow interference with different frequency distribute in HFC upstream cannel in fact. The capability of the CMLMS, the CMRLS and the CMFTF on the condition of multi-interference are compared simulation by five-frequency interference $i(k) = \sum_{j=1}^{5} \sqrt{2J_j} \sin(k\Omega_j T_c + \theta_j)$. Parameters can be selected as the list: Frequency deviation $\Omega_j T_c$=0.25, 1.0, 1.5, 2.5, 3.0, average SNR S/J = -10dB, WGN variance $\sigma_n^2 = 0.01$ and filter module is 12. CMLMS convergence coefficient μ=0.002, in the CMRLS oblivion factor λ=0.99, initial parameter σ=10, in the CMFTF initial parameter σ=50. 3000 code elements are applied in constellations.

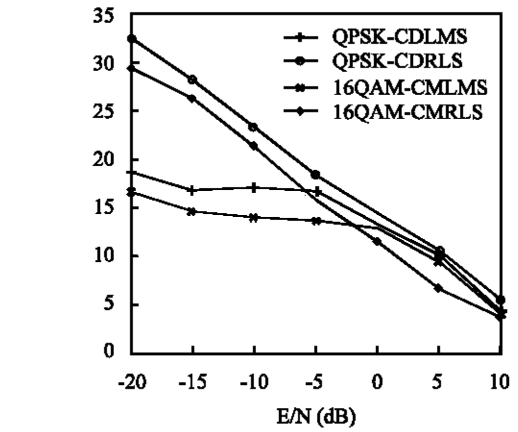

Fig.10: SNR improvement capability compare 16QAM and QPSK (five interference sources)

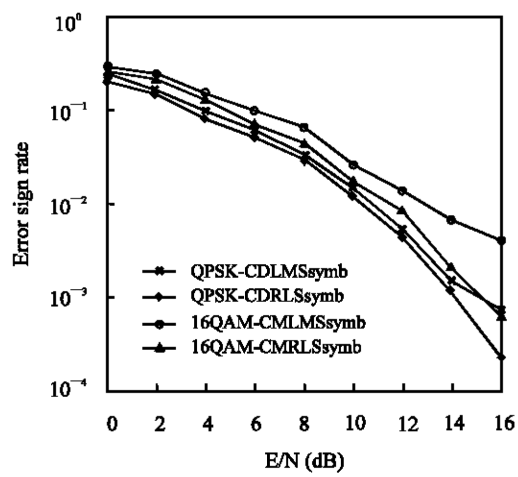

Fig.11: Error sign rate capability compared between 16QAM and QPSK (five interference sources)

In Fig. 2, the constellation distribution of 16QAM signal is so disordered interfered by five lines of frequency that the original signal cannot be identified. In Fig. 3, the clustering effect is not good and the error is large yet though it is better than before. In Fig. 4 and 5 original signal can be identified with good clustering.

The CMRLS is the best one, the next is the CMFTF and the CMLMS is bad in Fig. 6. The same conclusion can be drawn from the error sign curves. (Fig. 7) The CMFTF has nearly same good result as the CMRLS in which the error sign is less than 10^{-3}. But CMFTF has less account than the CMRLS. It is 3N2+5N+1 = 493 times of multiply or division and 2.5N2+1.5N = 378 times of addition or subtraction needs when the level of filter is N=12. On the same condition, the respective times are only 7N=84 and 10N=120 for the CMFTF. So the computation of CMFTF is more less than the CMRLS.

The error sign rate curves of the CMRLS and the CMFTF in different interference are shown in Fig. 8 and 9. The difference of error sign rate between them is little and those curves also show that the two kinds of arithmetic have good robustness. So the CMFTF arithmetic is the best one in multiple frequency interference.

The SNR improvement of QPSK is better than 16QAM from Fig. 10 when they are interfered by several kinds of frequency. In Fig. 11, the error sign rate of QPSK is lower than the other too. In this way, the anti-interference capability of QPSK is a little better than 16QAM under the same input SNR, but the difference can be shorten by narrow band interference suppression.

CONCLUSIONS

Severe noise and interference on the upstream channel in the HFC system and noise funneling effects are very hard. These noise and interference abstract as narrowband interference and take a nonlinear suppression measure from the point of signal processing. Simulative results are shown that CMFTF performance is the nearly same as the CMRLS algorithm, but less computation, so the CMFTF is considered as the best algorithm.

ACKNOWLEDGEMENTS

The authors are indebted to the former graduate students Yidan Jin. This study was supported by Natural science foundation of Guangxi, P.R. China. (0229053).

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