DSP Implementation of Interference Cancellation Algorithm for a SIMO System

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***Abstract*—**

This paper presents an implementation on the fixed-point DSP chip of an interference cancellation algorithm containing a linear system. Difficulty in matching the algorithms performance obtained in full precision (IEEE float-point) implementation to those given by a finite precision tends to increase when the algorithms contains one or several linear system to solve.

Gauss and Cholesky methods are implemented. Their performance results are showed and compared. The global implementation margins are discussed.

I. INTRODUCTION

This paper presents the implementation results on the fixed-point DSP chip (TMS 320C6474) [1] of an interference cancellation algorithm based on 2 antennas SIMO system [3]. This implementation is made in the fixed-point 16-bit resolution.

The main aim is to perform the OFDM receiving chain with the interferer cancellation algorithm embedded in a time interval not exceeding the minimum time frame while ensuring a minimum degradation on performances compared to those given by the full precision simulation (IEEE float-point Simulation).

The major difficulty is due to the fact that this algorithm requires a linear system solving. The linear system solving methods differ with respect to their application form or their execution time. Some direct methods require an important execution time such as the QR method. As another example, Cholesky method requires a special form matrix, namely hermitian positive definite matrix.
In practice, Gauss-Jordan method provides a good compromise between the execution time and the complexity of the algorithm.

In this work, the QR method is excluded because of the real time constraint; However the Cholesky and Gauss-Jordan are retained.

In the first section we give an overview of the algorithms that are implemented along with the analytical aspects; in the second section the 16-bits implementation of linear system solving technics are detailed. Finally in the third section, the numerical performance evaluations and the degradation due to the 16-bits resolution are discussed.

II. OFDM RECEIVING CHAIN

Figure 1 illustrates the OFDM receiver. The main parameters of the receiver are taken from TEDS (Tetra Enhanced Data Services) standard [2]:
Frame time = 18ms, OFDM symbol time = 360us, Number of OFDM symbol/frame = 51, FFT length = 32, Guard interval = 1/8, QAM modulation supported: QAM4 and QAM16.

This receiver is identical to a classical OFDM receiver except for two specific parts: channel estimation and channel compensation. These two parts are reserved to perform the interference cancellation algorithm. The next section described them in details.

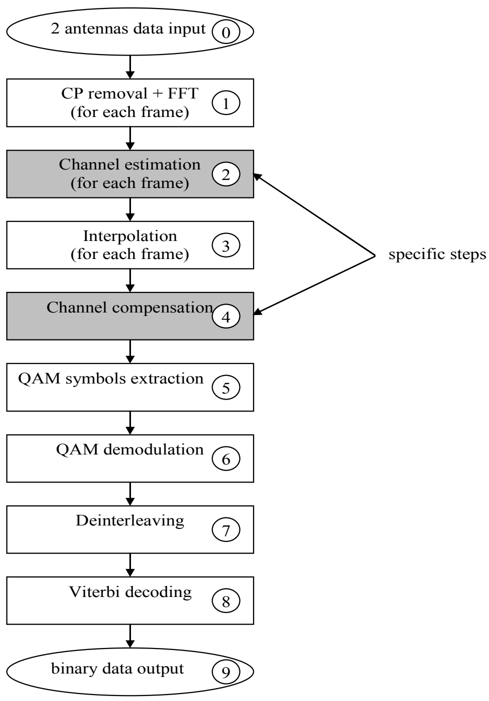

Figure 1. Receiving chain implemented in DSP chip

III. INTERFERENCE CANCELATION ALGORITHM

Figure 2 shows the two parts of the Interference cancellation algorithm (part 2 and 4).

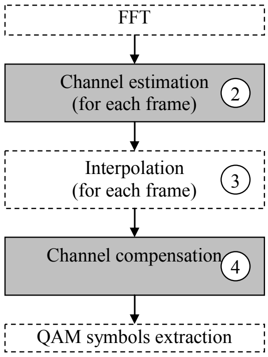

Figure 2. Specific parts where the algorithm is implemented

a. Channel estimation

In Channel estimation part, we proceed by estimating weights w_1, w_2, w_d as depicted in figure 3 and detailed in equations (1), (2) , (3) and (4).

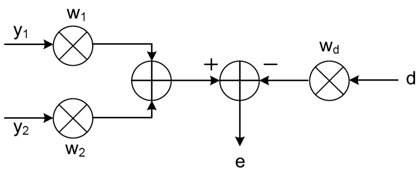

Figure 3. Algorithm's weights estimation

The weights w_1, w_2 *and* w_d are obtained by minimizing the mean square error:

$$\min_{w_1,w_2,w_d} \quad \|e\|^2 \qquad (1)$$

With constraint $\quad w_d^T u = Cste$

$u = [1 \ldots 1\ 1\ 1 \ldots 1]^T$ is unity vector .

The error is defined as follows:

$$e = y_1 w_1 + y_2 w_2 - d w_d = y_1 F_y a_1 + y_2 F_y a_2 - d F_d a_d \qquad (2)$$

With:

y_1 : diagonal matrix whose elements correspond to each OFDM symbol received by antenna 1.

y_2 : diagonal matrix whose elements correspond to each OFDM symbol received by antenna 2.

d : diagonal matrix whose elements correspond to desired QAM data of each transmitted OFDM symbol.

$$\begin{cases} w_1 = F_y a_1 \\ w_2 = F_y a_2 \\ w_d = F_d a_d \end{cases}$$

$F_y = F_{K \times KGI}$ and $F_d = F_{K \times KGI}$ are the truncated Fourier basis,

$$F_L = \begin{bmatrix} 1 & 1 & 1 & & 1 \\ 1 & e^{\frac{-2j\pi}{K}} & e^{\frac{2(-2j\pi)}{K}} & \cdots & e^{\frac{L(-2j\pi)}{K}} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & e^{\frac{-2j14\pi}{K}} & e^{\frac{2(-2j14\pi)}{K}} & \cdots & e^{\frac{L(-2j14\pi)}{K}} \\ 1 & e^{\frac{-2j15\pi}{K}} & e^{\frac{2(-2j15\pi)}{K}} & \cdots & e^{\frac{L(-2j15\pi)}{K}} \end{bmatrix}$$

We assume that:

OFDM symbol length $K = 32$
Guard interval $GI = \frac{1}{8}$

The equation (2) can be rewritten as:

$$e = [y_1\ y_2\ y_d] \begin{bmatrix} F_y & 0 & 0 \\ 0 & F_y & 0 \\ 0 & 0 & F_d \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_d \end{bmatrix} = R\, F_{yd}\, a \qquad (3)$$

With the following concatenations:

$$R = [y_1\ y_2\ y_d],\ F_{yd} = \begin{bmatrix} F_y & 0 & 0 \\ 0 & F_y & 0 \\ 0 & 0 & F_d \end{bmatrix},\ a = \begin{bmatrix} a_1 \\ a_2 \\ a_d \end{bmatrix}$$

Then the solution vector a is obtained by solving the Lagrange multiplier equation corresponding to minimization problem (1) with constraint represented as:

$$w_d^T u = a^T v = Cste$$

While $v = [0 \ldots 0\ 1\ 0 \ldots 0]^T$.

Finally the vector a which minimize (1) is given by:

$$a = \frac{\left(F_{yd}^H R^H R F_{yd}\right)^{-1} v}{v^H \left(F_{yd}^H R^H R F_{yd}\right)^{-1} v} \qquad (4)$$

As can be seen, we have to solve a linear system of equations with a hermitian matrix of dimension $[3KGI \times 3KGI]$.

Several methods are explored and implemented for which a comparative study is done and the results are presented in the next section. In addition it presents the performance results on uncoded BER and compare them to those obtained from the full precision simulation.

a. Channel compensation

As depicted in figure 4, channel compensation is performed and the estimated QAM data is obtained by following the equation (5).

$$\hat{x} = (y_1 w_1 + y_2 w_2)./w_d \qquad (5)$$

With:

$\hat{x}$: estimated QAM data vector.

$(./)$: point wise division.

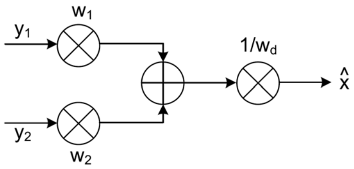

Figure 4. Interference cancellation and channel compensation

b. Linear system solving algorithms

The most important difficulty to implement this algorithm resides on the linear system solving. We have implemented Gauss-Jordan elimination and Cholesky method.

The choice of Gauss-Jordan method here is due to its quick execution and the fact that it does not need any particular form of matrix, unlike Cholesky method. As we know the Cholesky method is robust but it requires having a hermitian positive definite matrix. Unfortunately errors accumulation in the previous stages of the receiving chain leads the matrix to loss its positive definite property. Hence we must avoid this case by adding σI to the original matrix $\left(F_{yd}^H R^H R F_{yd}\right)$ [10]. σ is a positive scalar chosen so that the expected performance is not degraded (more details in the next paragraph).

c. Ill-conditioned matrix problem

This problem occurs when the matrix F_{yd} is over dimensioned. In [3], the weights w_1, w_2 have an impulse response length equal to that of the propagation channels, while w_d impulse response length is twice more long. The optimal solution according to the proposed algorithm is the one obtained when the rank of F_{yd} is equal to the sum lengths of (w_1, w_2, w_d) impulse response's. But in practice, the rank of F_{yd} is constant and set to $3KGI$. This forces matrix $\left(F_{yd}^H R^H R F_{yd}\right)$ to be singular when the channel impulse response is less than KGI. This problem is solved by regularization.
The two most popular regularization methods are Tikhonov and *TSVD* methods [9].

The Tikhonov regularization ignores the element of the solution which is corresponding to the small singular values of the matrix $\left(F_{yd}^H R^H R F_{yd}\right)$ to be inversed.

The equation (4) before regularization is $a = \frac{\left(F_{yd}^H R^H R F_{yd}\right)^{-1} v}{v^H \left(F_{yd}^H R^H R F_{yd}\right)^{-1} v}$

By *SVD* decomposition, we have $F_{yd}^H R^H R F_{yd} = PSP^H$, where, P and S are respectively the Eigen vectors and the Eigen values matrices of the $\left(F_{yd}^H R^H R F_{yd}\right)$.Then the equation (4) can be rewritten as:

$$a = \frac{\sum_{i=0}^{3KGI} \frac{1}{s_i} p_i^H v p_i}{v^H \sum_{i=0}^{3KGI} \frac{1}{s_i} p_i^H v p_i v} \quad (6)$$

It can be easily verified that a is sensitive to errors when s_i becomes small.
The regularization is achieved by adding σI to $\left(F_{yd}^H R^H R F_{yd}\right)$. We obtain:

$$a = \frac{\sum_{i=0}^{3KGI} \frac{s_i}{s_i+\sigma} \frac{1}{s_i} p_i^H v p_i}{v^H \sum_{i=0}^{3KGI} \frac{s_i}{s_i+\sigma} \frac{1}{s_i} p_i^H v p_i v} \quad (7)$$

This regularization reconfigure the minimum value of s_i to be $s_i + \sigma$.
If σ is carefully chosen, we improve the robustness against errors without any performance loss.
The second method we can apply is called *TSVD* (*Truncated SVD*). This method is performed by truncating the singular values for $L < 3KGI$. L is the equivalent regularization parameter .
Then the equation (6), is modified to be :

$$a = \frac{\sum_{i=0}^{L} \frac{1}{s_i} p_i^H v p_i}{v^H \sum_{i=0}^{L} \frac{1}{s_i} p_i^H v p_i v} \quad (8)$$

IV. Numerical Results

The numerical results are obtained by simulating an QAM4-OFDM transmission through a propagation channel in *TU*50 (typical urban with 50Km/h velocity) and *HT* (typical urban with 200Km/h velocity) [4], using Jakes model [5][6]. The frames are transmitted via RTDx link (Direct receive/transmit link) [1] from PC where the transmitted frame is generated with full precision calculation to the DSP. DSP returns the demodulated data via the same link to the PC where the SER (symbol QAM error rate) is calculated.

Figure 5 and 6, compare the performance achieved by the two methods of linear system solving (Gauss and Cholesky) to those obtained by the full precision calculation (Matlab simulation). In these figures, we compare the *SER* vs $E_b N_0$ (signal to noise ratio) when the interferer power is assumed to be negligible compared to that of the noise.

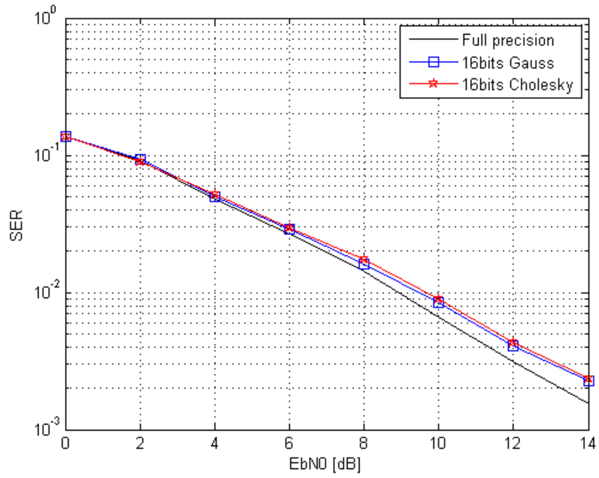

Figure 5. ***SER*** **vs.** $E_b N_0$ **for TU50 Channel without interferer**

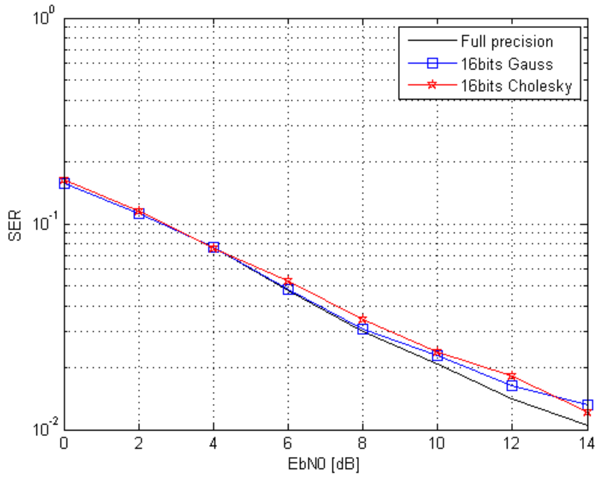

Figure 6. ***SER*** **vs.** E_bN_0 **for** ***HT*****200 Channel without interferer**

The figure 7 and 8, compare the values of *SER* vs *CIR* (carrier to interference ratio) when using a propagation channel with interferer at $E_bN_0 = 12dB$.

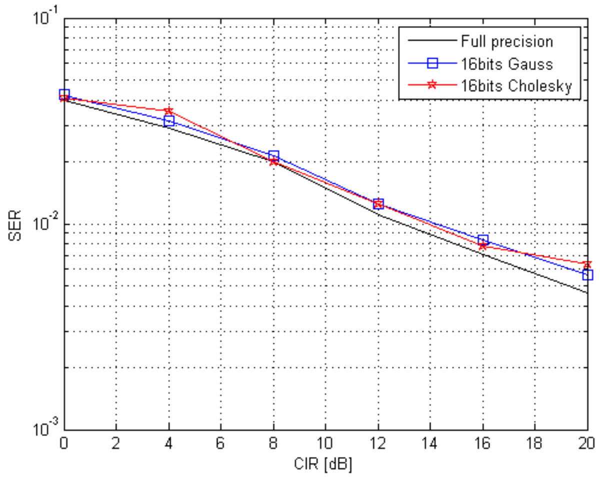

Figure 7. ***SER*** **vs.** ***CIR*** **for** ***TU*****50 Channel at** $E_bN_0 = 12dB$

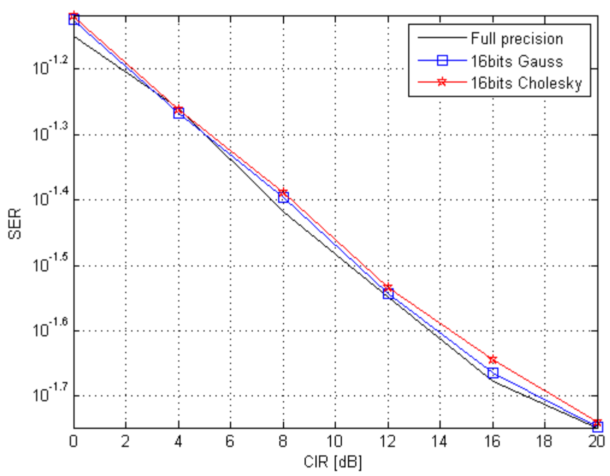

Figure 8. ***SER*** **vs.** ***CIR*** **for** ***HT*****200 Channel at** $E_bN_0 = 12dB$

According to figures shown above, we can conclude that the performance (in *SER*) of Cholesky method are close to those of Gauss. We have also a small difference between the DSP and Matlab (Full precision) performance (Matlab slightly better than DSP), this is due to the ill-conditioned matrix when *CIR* or E_bN_0 becomes high. This phenomenon is more apparent in *TU* mode because the channel impulse response is shorter than in *HT* mode. In the fixed-point format, this problem may force the matrix to be non-positive definite. Therefore, we have added σI to the matrix in order to be able to perform Cholesky method. The same operation is done with Gauss to get an exact comparison.

In addition this operation is comparable to the Thikonov regularization [7][9][10] which limits the sensitivity to error when the matrix is ill-conditioned. This often occurs when dealing with such filters [8].

Now we proceed to study the execution times of the different blocks of the receiver chain.

Table 1 shows that the Gauss method takes a bit more time (14 us) than the Cholesky. But compared to total duration of the reception chain (8036 us), this difference is insignificant.

As for the memory use, Gauss seems better and use less memory (860 bytes) than Cholesky, this difference is neglected compared to the total memory used.

n°	step	memory used [bytes]	DSP cycle count	execution time (µs)
2	Channel estimation (with Gauss)	2348	1859684	1860
2a	Gauss (with pre scaling)	420	84770 (97205)	84
2b	Cholesky (with pre scaling)	1280	70306 (83777)	70
3	modified interpolation	58752	913911	914
4	Channel compensation	28	458725	458
0 to 9	common + specific parts	232980	4836065	4836

Table 1. memory used and execution time

Table 2 summarizes the comparison between the two linear system solving methods.

In this study we can conclude that the performance of Gauss method is still close to those of Cholesky. The conclusion of robustness given in Table 2 takes its origin from the calculation errors occurred in the different stages of the receiving chain before the linear system solving bloc. These errors can impose the Cholesky algorithm a non-positive definite matrix. This drawback does not affect the Gauss-Jordan method.

	Gauss elimination	Cholesky decomposition
speed	faster if size < 8x8	faster if size > 8x8
memory used	lowest	2 or 3 times higher, but memory usage is still low
precision	tie	tie
robustness	good	good

Table 2. Linear system solving methods comparison

V. CONCLUSION

In this paper, we have studied the implementation in a 16-bits fixe-point DSP chip of an OFDM receiving chain including the interference cancellation algorithm. We have explored the Gauss-Jordan and Cholesky methods of linear system solving.

The implementation is successfully done. The performances seem acceptable for the two methods. The real time constraint is respected.

VI. REFERENCES

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