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Interferences Cancellation Theories and Applications

- Communication is recovery of Originality rather than Orthogonality of Receive Signals –

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Human Network for Better 21 Century

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Abstract

Interferences among signals from different sources are universal problems in communication networks. The author proposed a signal space theory as an analysis means of the interferences cancellation systems [1]. A fundamental limit of Least Mean Square Error (LMSE) method was clarified by the signal space concept and how to eliminate the limit was shown. The method is essentially elimination of the desired signal component from the output before correlation measurement of the main path and auxiliary paths signals for control of the adaptive weights. The method applies to wide ranges of interferences cancellation systems, one of which is the decision-feedback equalizer widely used in digital signal transmissions.

It is important to discriminate the difference between orthogonality and originality of the signals. The original signals from different sources are mutually orthogonal but the converse is not always true. The conventional multiple-input-multiple-output (MIMO) systems implemented at antenna subsystems are based on creating orthogonal sets of signals from the receive signals. The orthogonalization of the receive signals is merely rearrangement of the transmission paths coefficients and does not always improve the Signal to Interferences Ratio (SIR) of the receive signals. In this paper the author proposes MIMO systems that can separate the original signals by improved LMSE algorithm. The point of the method is in regeneration of the desired signals replicas at the receiver for more accurate correlation measurements based on which the adaptive weights of the interferences cancellation loops are controlled. The essence of the method is utilization of the small signal suppression effect in non-linear devices, such as demodulation or hard limiting. Note a pri-ori knowledge about the desired signal is used for regeneration of the desired signal. The method proposed in this paper can be applied to wide ranges of communications and control systems.

Keywords

Interferences, LMSE, Decision Feedback, Antenna Side-lobe, Correlation, Uncorrelated, Orthogonality, Originality,

Hard limiter, small signal suppression effects non-linear devices

1. Originality and Orthogonality of Signals

In communication systems the signals carry information from the senders to the receivers. The signals from different senders are uncorrelated because they are modulated by independent series of symbols. The originality of the signals means that the signals from different origins are uncorrelated and are orthogonal in the signal space. But the converse is not true; orthogonal signals are not always from different sources..

The objective of communication is to regenerate the original signals from the sender at the receiver.

2. External Signals and Thermal Noises

Suppose we have a desired signal Sd to receive by a main path receiver X. The receive signal X also contains other signals S1,S2,,,,Sm generated by different sources that leak into the receive circuit . In order to cancel those interferences, we set a number of auxiliary receivers Y1,Y2,,,Yn.

The auxiliary paths signals may contain external signals S(m+1),S(m+2),,,S(m') which are not contained in the main path signal X.

Each receiver also contains thermal noise originated at the receiver antenna temperature and the front head Low Noise Amplifiers (LNA).

The main path and auxiliary paths signals are now expressed as follows;

X = M・Sd + I1・S1 + I2・S2 +,,,,+ Im・Sm + Nx

Yi = Di・Sd + Li1・S1+Li2・S2 +,,,, + Lim・Sm
+L(i, m+1)・S(m+1) + ,,,+ L(i,m')・Sm' + Ni
(i = 1,2,,,,,n)

where Sd and {Sj ; j = 1,2,,,m,,,m'} are original signals. Without loss of generality we assume the norms of original signals are normalized: ||S||=1.

The {Ii, Lij: i=1,2,,,n, j=1,2,,,,m,,,m'} are transmit coefficients of the communication paths.

The Nx and Ni (i=1,2,,,,n) are thermal noises.

3. Limits of LMSE Method

In order to cancel the interferences into the main path signal X, we subtract the auxiliary path signals Yi multiplied with adaptive weights Wi (i=1,2,,,n) from X to get signal Z.

Z = X – [i=1,n] Σ Wi・Yi
= (M- [i=1,n] Σ Wi・Di)・Sd
+ [k=1,m] Σ (Ik− [i=1,n] Σ Wi・Lik)・Sk
+ [k'=m+1, m'] Σ [i=1,n] Σ Wi・Lik'・Sk'
+ Nx - [i=1,n] Σ Wi・Ni

The adaptive weights Wi are controlled to minimize the norm of the output signal Z by setting

∂ ‖ Z ‖ ˆ2 / ∂ Wi* = 0

which tells;

(Z, Yi) = 0 (i= 1, 2, , , , n)

The output signal Z is made to be orthogonal to each auxiliary path signal Yi(i=1, 2, , , , n).

The adaptive weights {Wi;i=1, 2, , , n} are solutions of the following equation;

[(Yi, Yk)][Wi> = [(X, Yk)>
(i, K = 1, 2, , , , n)

where

(Yi, Yk) is the correlation of signal Yi and Yk.

(Yi, Yk)= ∫ Yi・Yk* dω/2π

and [(Yi, Yk)] is the matrix whose (i, k) element is (Yi, Yk).

[Wi> is the column vector whose i-th element is Wi. The adjoined row vector <Wi]=(W1, , , Wn).

We now check the contents of (Z, Yj) = 0

(M- [i=1,n] Σ Wi・Di)・Dj*・ ‖ Sd ‖ ˆ2
+
[k=1,m] Σ (Ik− [i=1,n] Σ Wi・Lik)・Ljk*・ ‖ Sk ‖ ˆ2
+
[k'=m+1, m'] Σ [i=1,n] Σ Wi・Lik'・Ljk'*・ ‖ Sk' ‖ ˆ2
+
Wj・ ‖ Ni ‖ ˆ2
= 0

Ideally the second term in the above equation should be zero;

[k=1,m] Σ (Ik− [i=1,n] Σ Wi・Lik)・Ljk* = 0

or

[LL(i,j)]・[Wi> = [ILj>

where

LL(i,j) = [k=1,m] Σ Lik・Ljk*
ILj = [k=1,m] Σ Ik・Ljk*
(i, j = 1, 2, , , n)

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Or more simply

$[L_{ik}][W_i\rangle = [I_k\rangle$

Unluckily those transmission coefficients as Lij, Ik and m; the number of interference signals are unknown at the receiver. The only available signals are X and {Yi} (i=1,2,,,n). Thus we conduct the LMSE processing at the receiver believing the output Z= X-<W][Y> will have the minimum power if the interference signals are cancelled.

Generalized thermal noise

We first consider the nature of the signals in the system. The main path signal X includes the desired signal Sd and the interfering signals S1, S2,,, Sm. The auxiliary paths signals Y1,Y2,,,Yn includes those signals in the main path and additionally, those extra signals S(m+1),S(m+2),,,S(m') and the thermal noise Ny.

The above extra signals are external to the signal space of the main path hence their nature in the system is similar to that of the thermal noise. Therefore they will be included in the thermal noise Ny in the following analysis.

Space of the auxiliary paths signals

The signal space we are interested in here consists of the original desired signal Sd and the interfering signals {Si; i= 1,2,,,,m}.

The auxiliary paths signals {Yi; i=1,2,,,,n} form vectors in the signal space {Sd, {Si}}.

Two vectors Yi and Yj span a plane in the signal space by a linear combination;

$\alpha \cdot Y_i + \beta \cdot Y_j$

where α, β are arbitrary complex numbers.

The spanned plane is represented by the vector

$Y(i,j) = \alpha \cdot Y_i + \beta \cdot Y_j$

which maximizes the power ratio of the Sd component to that of the {Si} components[1].

The above process is repeated to get the vector Y(1,2,,,n) which represents the signal space formed by the auxiliary path signals.

The auxiliary paths signals are now represented by the vector Y= Y(1,2,,,n);

$Y = D_y \cdot S_d + S_y + N_y$

where Sy is interference signals composed in the subspace {Si; i=1,2,,,m} and Ny all the other external signals and thermal noise.

As Sy and Ny are mutually orthogonal, the angle θY between Y and Sd is;

$\tan^2(\theta Y) = |D_y|^2 / (\|S_I\|^2 + \|N_y\|^2)$

Limits of LMSE method

In the previous analysis the output Z of the interference cancellation circuit is so controlled as to form it orthogonal to all the auxiliary signals, namely the subspace spanned by those signals, which tells;

$(Z, Y) = 0$

If we express the output Z as follows,

$Z = M_z \cdot S_d + S_z + N_z$

and define the angle θZ by

$\tan^2(\theta Z)$

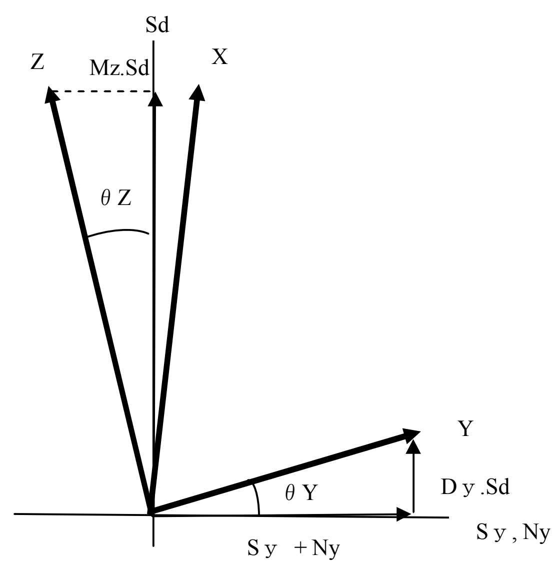
$= (\|S_z\|^2 + \|N_z\|^2) / |M_z|^2$

Then the LMSE processing gives the result [1];

$\theta Z = \theta Y$

The vectors relationship is depicted in the following figure.

,



The tan^2(θ Y) is inversely proportional to the desired to interferences signals power ratio of the subspace Y (SIY). The tan^2(θ Y) gets larger as the number of the auxiliary paths increases [1]. Besides the SIR of the auxiliary paths will be generally worse than that of the main path, thus the interference cancellation based on LMSE methods will degrade rather than improve the SIR of the output Z.

4. Improved LMSE

The above analysis has shown the shortcoming of the LMSE method is caused by the correlation of the desired signal components in the auxiliary paths signals {Yi} and the output Z of the circuit.

We are to regenerate the desired signal Sd from the output signal Z. If the regenerated signal Sd' is a faithful replica of the desired signal, by removing it from Z, we can eliminate the ill effects caused by the leakage of the desired signal Sd into the auxiliary paths signals {Yi}.

Let

$$Sd - Sd' = \varepsilon \cdot Sd \qquad (|\varepsilon| \ll 1)$$

We apply an LMSE operation to Z by Sd';

$$Z' = Z - V \cdot Sd'$$
$$= Dz \cdot Sd + Sz + Nz - V \cdot Sd'$$

By LMSE method we achieve

$$(Z', Sd') = 0,$$

by adaptive control of V to get

$$Z' = \varepsilon \cdot Dz \cdot Sd + Sz + Nz$$

Correlation measurements

Instead of correlation measurements between Z and Yi (i= 1,2,,,n) we conduct the measurement between Z' and Yi.

The {Yi} are composed of the components;

$$Yi = Di \cdot Sd + Syi + Ni$$
$$(i = 1,2,,,,n)$$

where

$$Syi = [j=1, m] \Sigma Lij \cdot Sj$$

From the above relations the following equivalence holds;

$$(Z', Yi) = (Z, Yi') = 0$$

where the Yi' is;

$$Yi' = \varepsilon \cdot Di \cdot Sd + Syi + Ni$$
$$(i=1,2,,,n)$$

Since the factor ε is common among all Yi, the resultant subspace of the auxiliary path signals becomes;

$$Y' = \varepsilon \cdot Dy \cdot Sd + Sy + Ny$$

And the angle θY between Y and Sd is;

$$\tan^2(\theta Y')$$
$$= \varepsilon^2 \cdot |Dy|^2 / (\|Sy\|^2 + \|Ny\|^2)$$
$$= \varepsilon^2 \cdot \tan^2(\theta Y)$$

By the orthogonality condition;

$$(Z', Yi) = (Z, Yi') = 0$$

we get the output Z which is controlled to meet the following relation in the signal space; θZ = θY'

or

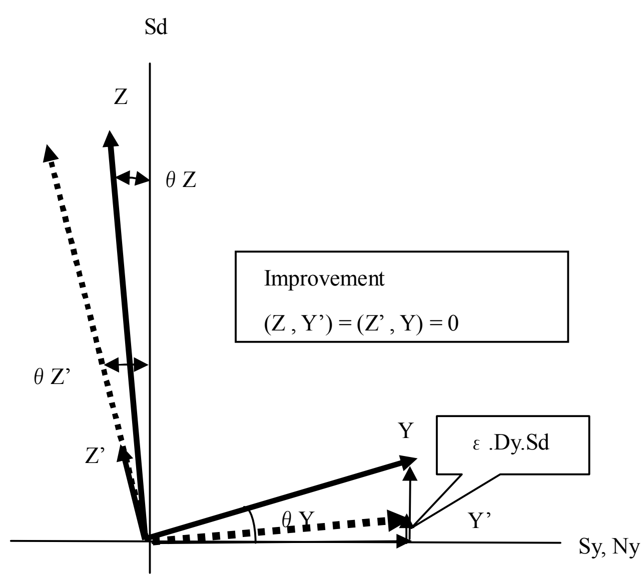
$$\tan^2(\theta Z) = \tan^2(\theta Y')$$
$$= \varepsilon^2 \cdot \tan^2(\theta Y)$$

As

$$\tan^2(\theta Z)$$
$$= (\|Sz\|^2 + \|Nz\|^2) / (|Mz|^2)$$
$$= 1/SIZ + 1/SNZ$$

where SIZ and SNZ are respectively the signal to interferences and noise power ratios of signal Z, the above analysis tells $1/\varepsilon^2$ times improvement can be achieved by the above method.

The mechanism of the improvement is depicted in the following figure.



If ε<<1, then the combined SIR and SNR of the output signal is improved quite significantly.

Generation of desired signal replica

In digital communications the desired signal replica is regenerated by demodulation of the signal. In this case ε is approximately equal to the bit error rate (BER), which is usually very small. Thus a very great improvement can be achieved by the proposed method. The method is generally called "decision feedback equalizer" and has been widely used.

5. Hard Limiting

In general communications including analog modulations the demodulation of the desired signal in interference environment is not easy. A useful method in such situations is hard limiting if the initial condition is met that the power of the desired signal is sufficiently greater than that of the interferences signals.

Let us now analyze how hard limiting works on a desired signal and an interference signal. Let

$Z = A \cdot \cos(\omega c.t) + a. \cos(\omega 1.t + \phi)$

The first and second terms are respectively the desired and the interference signals. They are different in frequency and phase.

By setting

$\Theta = (\omega 1 - \omega c).t + \phi$

we can rewrite

$Z = (A + a.\cos(\Theta)). \cos(\omega c.t)$
$\quad - a.\sin(\Theta). \sin(\omega c.t)$

If A > a, the in-phase component a.cos (Θ) is cancelled in the hard limiter which gives the output;

$Zh\ (=)\ A.\cos(\omega c.t) - a.\sin(\Theta). \sin(\omega c.t)$
$\quad (=) A.\cos(\omega c.t - \Phi)$

where

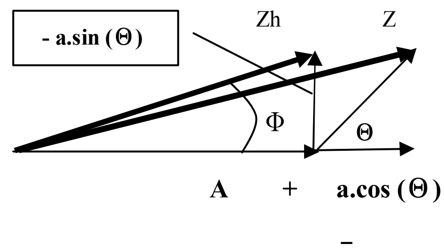
$\Phi = \arctan(a/A.\sin(\Theta))$

and (=) means nearly equal.

The mechanism of the hard limiting is depicted in the following phasor diagram.

The hard limiter output is

$Zh\ (=)\ Z - a.\cos(\Theta). \cos(\omega c.t)$
$\quad = A. \cos(\omega c.t) + a/2. \cos((2\omega c - \omega 1).t - \phi)$
$\qquad - a/2. \cos(\omega 1).t + \phi)$



Phasor diagram of Hard Limiting

We observe the following points about Zh(t);

(1) The amplitude of the interference signal is halved.

(2) A mirror image of the interference signal against the desired signal appears with the same amplitude as the interference signal.

(3) The desired signal, the interference signal and the mirror image of the interference signal are mutually uncorrelated or orthogonal in the signal space.

(4) The amplitudes of the interference and the generated mirror image signals are halved to reduce the power to 1/4 of the original value. Hence the SIR of the output of the hard limiter is improved by 3dB in total and 6dB against the interference signal itself.

This is an instance of *small signal suppression effect* in non-linear devices[2].

Desired signal reduction

We subtract Zh with adaptive weight V from Z to get Z'.

$Z' = Z - V.Zh$

The Z' is controlled to be orthogonal to Zh;

$(Z', Zh) = 0$

From the equation we get

$V = (1 + \delta^2/4) / (1 + \delta^2/2)$

where $\delta = a/A$

If $\delta \ll 1$, then

$Z' \propto \delta^2/2 \cdot A \cos(\omega c.t)$
$\quad + a. \cos(\omega 1).t + \phi)$
$\quad - a. \cos((2\omega c - \omega 1).t - \phi)$

Thus the desired signal is reduced by the factor $(a/A)^2/2$ which will improve the performance of the correlation measurements between Z' and the auxiliary paths signals {Yi i=1,2,,,n}.

6. Circuits and Performances

We have at the receiver, the main path signal X and the auxiliary signals {Yi; I = 1,2,,,,n}. We try to cancel the interferences signals in X by subtracting Yi multiplied with adaptive weight Wi to the the output Z;

$$Z = X - [i=1,n]\, \Sigma\, Wi \cdot Yi$$

From Z we regenerate the desired signal Sd' and subtract the element from Z by LMSE method to get Z'.

We then determine the weight Wi (I = 1,2,,,,n) by the orthogonalization condition;

$$(Z', Yi) = 0$$

$$(I = 1,2,,,,n)$$

Time sections control

We conduct the above processing in successive time sections {Ts.n ; n= 0,1,2,3,,,,,,}. The time length of each section Ts needs to be selected to achieve sufficiently accurate time averaging in each section. We denote the variables in the n-th time section by added [n] as follows;

$$. (Z', Yi)[n] = [t= n.Ts, (n+1).Ts] \int Z'(t) \cdot Yi^*(t)dt$$

Adaptive control of weights Wi

We control the adaptive weights Wi by the following difference equation;

$$Wi[n] = Wi[n-1] + g.. (Z', Yi)[n-1]/(Yi,Yi)$$

$$Z[n] = X - [i=1,n]\, \Sigma\, Wi[n] \cdot Yi$$

where g is the loop gain of the interferences signal cancellation loop..

The steady state Wi[n] = Wi[n-1], is achieved when the orthogonality is completed; $(Z', Yi)[n] = 0$

Desired signal elimination

Let the regenerated desired signal in time section n by Sd'(t)[n], then the desired signal is eliminated from the output signal Z[n] by the formula;

$$Z'(t)[n] = Z(t)[n] - V[n-1].\ Sd'(t)[n]$$

$$V(n) = V(n-1) + g' \cdot (Z', Sd')[n-1]/ (Sd',Sd')$$

where g' is the loop gain of the Desired signal elimination loop. The steady state Vi[n] = Vi[n-1], is achieved when the orthogonality is completed; $(Z',Sd')[n] = 0$

Loop stability

The stability of the interferences cancellation loops now needs to be examined. As the desired signal elimination is not relevant in this theme we will exclude it in the following analysis.

What to be checked are ;

$$Wi[n] - Wi[n-1] = g.(Z, Yi)[n-1] /(Yi,Yi) \quad (i = 1,2,,,n)$$

$$Z[n] = X[n] - [i=1,n]\, \Sigma\, Wi[n].Yi[n]$$

The above two equations are joined to give;

$$Wi[n] - Wi[n-1]$$

$$= g.\{ (X, Yi)[n-1] - [j=1,n]\, \Sigma\, Wj[n-1].(Yj,Yi)/(Yi,Yi) \}$$

$$= g.\{ \alpha i - [j=1,n]\, \Sigma\, Wj[n-1].\ \beta ji / \beta ii \}$$

where

$$\alpha i = (X, Yi)[n-1] = (X, Yi)$$

$$\beta ji = (Yj,Yi)[n] = (Yj,Yi)$$

$$(i,j = 1,2,,,,n)$$

Note α i, β ji are stationary in time hence constant.

In Z-transformation

$$(1- z\hat{}-1).Wi(z) = g.\ \alpha i / (1-z\hat{}-1)$$

$$- [j=1,n]\, \Sigma\, Wj(z).z\hat{}-1.\ \beta ji / \beta ii$$

$$(i= 1,2,,,n)$$

where

$$W(z) = [n=0,\infty]\, \Sigma\, W[n].z\hat{}-n$$

The above equation is modified;

$$[j=1,n]\, \Sigma\, \{ (1-z\hat{}-1)\, \delta ji + g.\ \beta ji/ \beta ii.\ z\hat{}-1\}.Wj(z)$$

$$= g.\ \alpha i / (1-z\hat{}-1)$$

In vector and matrix format;

$$<Wj(z)].[(1-z\hat{}-1)\, \delta ji + g.\ \beta ji / \beta ii.\ z\hat{}-1]$$

$$= g./ (1-z\hat{}-1)< \alpha i]$$

Where δ ji is Dirac delta function and <xj] is row vector and [xji] is matrix with xji as (j,i) element..

Case of a single auxiliary path

The above equation reduces to

$$[1- (1- g.)\, z\hat{}-1].W(z) = g.\ \alpha / (1-z\hat{}-1)$$

Or

$$W(z) = g.\ \alpha .z\hat{}2 / \{(z-1) \cdot (z- (1- g))\}$$

The n-th output is obtained by the inverse z-transform;

$$W[n] = 1/ (2 \pi i).[\ |z| =1] \int W(z).z\hat{}(n-1)\, dz$$

$$= \alpha / \beta .\{ 1 - (1- g)\hat{}\, (n+1) \}$$

The stability condition is

$$|1- g| < 1$$

Or

$$0 < g < 2$$

The correlation error ;

$(Z[n], Y) = (X,Y).(1\text{-}g)^n$

exponentially converges to zero.

Case of two auxiliary paths

$[(1-z^{-1})\, \delta_{ij} + g.\, \beta_{ij} / \beta_{ii}.\, z^{-1}][W_j(z)\rangle$

$= g./ (1-z^{-1})[\alpha_i\rangle$

Or

$$\begin{bmatrix} 1-(1-g).z^{-1} & g.\beta_{12}/\beta_{11}.z^{-1} \\ g.\beta_{21}/\beta_{22}.z^{-1} & 1-(1-g).z^{-1} \end{bmatrix} \begin{bmatrix} W1 \\ W2 \end{bmatrix}$$

$$= g / (1-z^{-1}) \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix}$$

where the dashed boxes denote matrix or vectors.

The stability condition is the characteristic roots of the equation

$$\begin{vmatrix} 1-(1-g).z^{-1} & g.\beta_{12}/\ \beta_{11}.z^{-1} \\ g.\beta_{21}/\ \beta_{22}.z^{-1}] & 1-(1-g).z^{-1} \end{vmatrix} = 0$$

where | matrix | stands for the determinant of the matrix.

It can be calculated to give the characteristic roots r1, r2;

$r1 = 1 - g + g.\ |\ \beta_{12}\ | / \sqrt{(\beta_{11}.\beta_{22})}$

$r2 = 1 - g - g.\ |\ \beta_{12}\ | / \sqrt{(\beta_{11}.\beta_{22})}$

From the condition that the absolute values of r1 and r2 be smaller than 1, we get the stability condition

$0 < g < 2 / (1 + |\ (Y1,Y2)|\ / (\ \|Y1\|\ .\ \|Y2\|\ )$

Note $|\ (Y1,Y2)\ |\ /\ (\ \|Y1\|\ .\ \|Y2\|\ )$ is the likelihood between Y1 and Y2, which equals to 1 if Y1 and Y2 are identical and zero if they are uncorrelated. The stability condition for the case of two auxiliary paths signals is the same as for the case of a single auxiliary path signal if the two auxiliary paths signals are mutually orthogonal, because then the two cancellation loops will function independently.

In general the cancellation loops with n auxiliary paths (n >2) signals cases will function stably if the loop gain g is properly selected.

Orthogonalization of auxiliary path signals

From the auxiliary paths signals {Yi ; I = 1,2,,,,n} we can measure the mutual correlations (Yi, Yj) to get the matrix [(Yi, Yj)] which is Hermite ((Yi, Yj) = (Yj,Yi)*, * means complex conjugate) hence possesses real igen-values and mutually orthogonal eigen-vectors. Those eigen-vectors can be used to orthogohalize the auxiliary paths signals to get {Y'i; i = 1.2....n} which are mutually orthogonal.

(Yi', Yj') = 0 (if i =/= j)

Then the cancellation loops can be formed with {Y'i} to guarantee the stability condition of the loops.

7. Applications

The interferences cancellation technologies have been applied to wide ranges of applications.

<> Channel equalizers for digital signal transmission

The inter-symbol interferences occur by channels fading or equipments faults such as channel filters mismatches or errors in symbol timing recovery circuits. The main path is the symbols at data decision timing and the auxiliary paths signals are at symbol timings in the past and future around the decision timing. The decision-feedback equalizer is an exact implementation of the interferences cancellation as described in this paper.

<> Echo cancellation

The echoes occur by the reflection of the voice signal at the far end of the receiver. An exact replica of the interference is readily available at the sender as delayed version of the transmit signal hence can be fully cancelled by a simple interference cancellation.

<> Dual polarization radio wave system

Dual polarizations of radio waves can readily double the channel capacity with the same frequency bandwidth.

Let the receive signal be

$Y1 = L11.S1 \quad + L12\ .S2$

$Y2 = L21.S1 \quad + L22.\ S2$

Here both S1 and S2 are desired signals and interferences signals.

In order to cancel mutual interferences we conduct

$Z1 = Y1 - W1.Y2$

$= (L11\text{-}\ W1.L21).S1 + (L12\text{-}\ W1.L22).S2$

Z2 = Y2 – W2.Y1

= (L21 –W2.L11).S1 + (L22 - W2.L12).S2

The exact solutions are

W1 = L12 / L22

W2 = L21 / L11

which perfectly regenerate the original signals.

In order to get those transmission links parameters pilot signals are inserted with the signal transmitter or beacons from the satellites are utilized [3].

In this paper we will study the methods that can work without pilot signals.

From Z1, Z2 we regenerate replicas of S1, S2 denoted as S1' and S2'.

Demodulator methods

In digital communications good replicas of the desired signals can be regenerated at the receiver.

S1' = √(1- ε ^2).S1 + S1"

S2' = √(1- ε ^2).S2 + S2"

The S1" and S2" are errors generated in the desired signal regeneration processes. The norm of S1" is

‖ S1" ‖ ˆ2 = ε ^2

so

‖ S1' ‖ ˆ2 = ‖ S1 ‖ ˆ2 = 1

‖ S2' ‖ ˆ2 = ‖ S2 ‖ ˆ2 = 1

In digital communications the error rate ε ^2 is roughly the symbol error rate at the demodulator.

Note S1", S2" are uncorrelated with any other signals as they are randomly generated.

By LMSE we achieve

(Z1, S2') = (Z2, Si') = 0

Then we get

W1 = (Y1, S2') / (Y2, S2') = L12 / L22

W2 = (Y2, S1') / (Y1, S1') = L21 / L11

which are the exact solutions.

Thus we can expect to realize accurate dual polarization signal transmission radio systems.

Hard limiter methods

For the input

Z1 ∝ S1+ a.S2 (|a| < 1)

the output of the hard limiter is

Z1h ∝ S1' = S1+ δ . a.S2+ δ . a.S1" (| δ |<1)

S1" is the mirror image of S2 against S1. Note S1" is orthogonal to both S1 and S2.

Likewise for Z2;

Z2 ∝ S2+ a.S1 (|a| < 1)

the output of the hard limiter is

Z2h ∝ S2' = S2 + δ . a.S1 + δ . a.S2" (| δ |<1)

By LMSE function Z1 is made orthogonal to S2' and Z2 to S1'. By hard limiter functions S2' is produced from Z2 and S1' from Z1 with improved SIR.

Thus we have the following cycles.

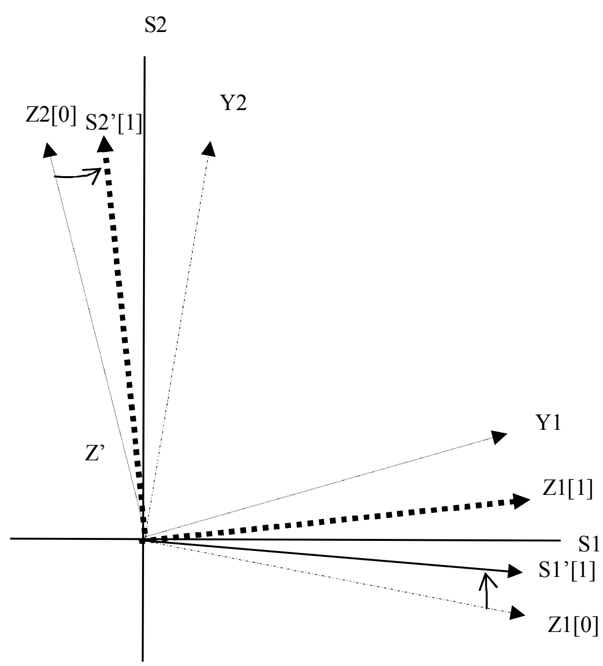
Z1 -- improvement → S1'

S1' -orthogonal → Z2

Z2 -- improvement → S2'

S2' -orthogonal → Z1

The above process is depicted in the following figure.



In the initial phase Z1[0], Z2[0] are respectively made orthogonal to Y2 and Y1. Then the hard limiters produce S1' [1] and S2' [1] respectively from Z1[0] and Z2[0]. The loops then function to make Z1[1] and Z2[1] respectively orthogonal to S2' [1] and S1' [1]. The above procedure continues endlessly. In each step generation of S1’[n], S2’[n] respectively from Z1[n-1], Z2[n-1] the SIR are improved, S1’ and S2’ approach to S1 and S2 coordinates. Thus the above improvement process repeats itself until it comes to the limits caused by thermal noise.

<> Multiple Input Multiple Output (MIMO)

The above dual polarization mode communication system can be readily generalized to MIMO systems with larger numbers of the signals and receivers.

The conventional MIMO system was based on the orthogonalization of the receive signals by eigen-vectors methods making use of the Hermitian nature of the correlation matrix of the receive signals [4]. The orthogonalization alone is insufficient for MIMO function because the originality of those signals are not regenerated or enhanced.

In the herein proposed system the SIR improvement is achieved by the use of *small signals suppression effect* of non-linear operations such as demodulation or hard-limiting.

<> Others

The methods described in this paper can be applied to a wide range of applications.

> Satellite systems

adjacent satellites, inter-beams or interferences with terrestrial communications networks.

> Cellular systems

- Inter-cells interferences at the mobile
- inter-sectors interferences at a base station

> Noise cancellers

8. Conclusion

The signal space analysis proposed in the previous paper [1] was applied to general cases including external interferences and thermal noises.

The function of interferences cancellation system was analyzed on a concrete model to establish the stability conditions of the loops..

The function of hard limiter as a device for generation of the desired signal replica was analyzed.

The function of the dual polarization communication system is analyzed for two different methods to generate the desired signal replica; demodulation and hard limiting.

The methods are applicable to general MIMO (Multi-Input-Multi-Output) system with more than 2 signals.

The methods proposed in the paper are fundamental and applicable to wide ranges of applications.

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