# GSLC ARCHITECTURE FOR SEQUENCE DETECTORS USING SPATIAL DIVERSITY

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**ABSTRACT**

The role of advanced front-ends including spatial diversity, has been considered as an independent part of peak-distortion equalizers, Wiener and Viterbi equalizers. This involves that the optimum processing to remove point or distributed sources, together with inner and outer intersymbol interference is analyzed independently at the beamformer and at the equalizer stages. Recently, based on extensions of the works performed with forward equalizers and optimal combining in communications systems with spatial diversity, several solutions to the joint design of sequence detectors and spatial combiners have been reported. All these solutions have in common the principle that the optimum design holds the constraint of matching the spatial response of the combiner to the DIR (Desired Impulse Response) of the sequence detector. This work enhances the matched DIR concept with the Generalized Sidelobe Canceller architecture; proving that, for stationary Intersymbol Interference (ISI) for the desired user, the GLSC represents a suitable spatial processing. The GSLC allows continuous updating of the combiner either in order to reject late arrivals and co-channel interferers, without requiring the presence of training sequence or to maximize the effective SNR.

## 1.INTRODUCTION

The basic receiver front-end using spatial diversity and a sequence detector (Viterbi Equalizer VE) is shown in Figure 1. Note that the existence of the VE is not a question since its effectiveness in the receiver performance is well supported [1],[2]. Also, the VE is a common processing in any mobile communications system, like in the GSM [3]; in consequence, the beamforming will be introduced taking into account this fact, with lesser modifications to the baseline detector which includes the VE.

In general, the length of the DIR of the VE is bounded to a maximum in order to do not increase the complexity and delay of detection process, assuming that this is set to $P_2$ samples. The DIR will be denoted by vector $\underline{h}_o$ , of $P_2$ components. The spatial diversity is formed by $N_s$ sensors with weights $b(0),..,b(N_s)$. The so-called matched DIR design minimizes the MSE ( $= E(| \; (n)|^2)$ ) between the combiner output and the VE output to a given training sequence $I_n$.

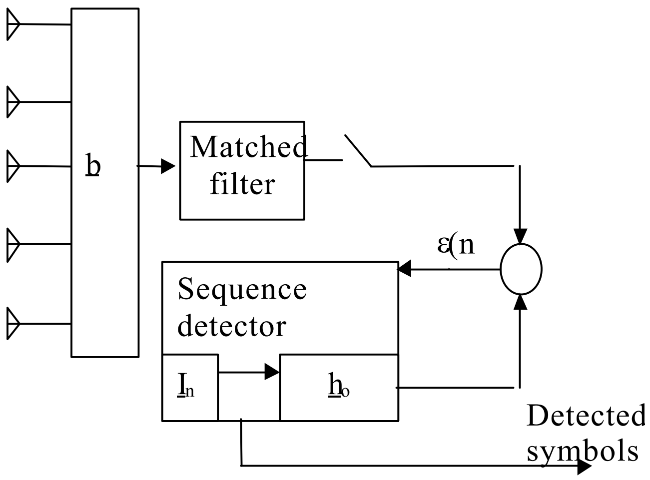


Figure 1. Spatial diversity processing with sequence detector.

Given $\underline{h}_o$, the procedures to design the combiner are identical to those used for the design of forward equalizers. An example can be found in [5],together with its evaluation over different channels in [6]; further references on the different objectives in selecting the target DIR( the $\underline{h}_o$ vector), can be found in [7] for direct truncation of ho, [8] for global transmitted and received optimization, [9] for energy constrained optimization and [10] for maximum effective SNR. Nevertheless, a compound paper on the methods for forward equalizer design is provided by reference [10].

In general, the procedure for jointly design the combiner and the DIR starts from a training reference. Given a reference sequence $\underline{I}_n$ of $P_2$ symbols, the MSE objective will be (1), where [.] stands for the square norm of a vector.

$$\xi ?= E\{ [\, \underline{b}^H.\underline{X}_n - \underline{h}_o^H.\underline{I}_n ] \} \qquad (1)$$

and its minimization, constrained for maximum SNR at the combiner output provides the following result:

$$\underline{\underline{R}}.\underline{b} = \ _{min}.\underline{\underline{H}}_o.\underline{\underline{H}}_o^H.\underline{b} \qquad (2.a)$$

$$\underline{h}_o = \underline{\underline{H}}_o^H.\underline{b} \qquad (2.b)$$

$$= \ _{min} - 1 \qquad (2.c)$$

where matrix $\underline{\underline{R}}$ is estimated from the received snapshots and the channel matrix $\underline{\underline{H}}_o$ is estimated as the cross correlation of the snapshots with the vectors of the training sequence.

Constraint (2.b) provides the name of matched DIR since the response of the VE is matched to the response of the beamformer, plus the communications channel, to the transmitted sequence. It can be viewed in [12] that the joint design of a wideband beamformer plus the DIR, allows the design of the narrowband beamformer and the matched filter by means a rank-one approximation of the wideband beamforming matrix. This work traduces the above design to a GSLC architecture which proves to be effective in the performance/complexity trade-off to implement additional features and refinements to the traditional MDIR design [12].

## 2.THE GSLC WITH SEQUENCE DETECTORS

The design procedure, outlined in the previous section and summarized in (2), entails the maximization of the SNR at the input of the sequence detector, defined as (3), for vectors $\underline{b}$ and $\underline{h}_o$.

$$SNR = \frac{\underline{b}.\underline{\underline{H}}_o.\underline{\underline{H}}_o^H.\underline{b}}{\underline{b}^H.\underline{\underline{R}}_o.\underline{b}} \qquad (3)$$

where $\underline{\underline{R}}_o$ is defined as (4), and the denominator of (3) coincides with the MSE $\xi$ between the outputs of the beamformer and the DIR.

$$\underline{\underline{R}}_o = \underline{\underline{R}} - \underline{\underline{H}}_o.\underline{\underline{H}}_o^H \qquad (4)$$

It is evident that (3) cannot be considered as a valid SNR since it assumes the use of the ISI, with length less or equal than the DIR length, as desired signal. A proper definition of the effective SNR ($SNR_e$) should take into account the Bit Error Rate (VER) of the detector. A suitable approximation for this VER is (5),

$$BER \propto \sum_i d_i.P_r(\underline{\ }_i).Q\left( \sqrt{\left| \underline{h}_o^H . \underline{\ }_i \right|^2 \Big/ } \right) \qquad (5)$$

where $\underline{\zeta}_i$ is a valid error sequence, Q(.) is the error function, $d_i$ is the Hamming distance of the sequences producing the error sequence and Pr(.) is the probability of the corresponding error sequence.

The direct minimization of (5) is faced in [11]. This direct minimization is done by means of introducing, at every iteration, a perturbation in the quiescent DIR in the direction of the error sequence that minimizes $/\underline{h}_o.\underline{\zeta}_i/^2$, update the beamformer with the matched DIR constraint, update the MSE. The iterations continue until a minimum of the BER is found. In order to reduce the complexity, the error function is approximated as it is indicated in (6).

$$Q(x) \Rightarrow e^{-\frac{x^2}{2}} \qquad (6)$$

Whenever (3) is not the design objective, any alternative procedure has to preserve the matched DIR constraint. In other words, the spatial response have to be always matched to the time response. Since the resulting procedure entails the minimization with constrains it resorts to the GSLC principle and architecture. Next section describes the GSLC architecture for a front-end receiver with sequence detection.

## 3. QUIESCENT AND ADAPTED RESPONSES

The quiescent response is derived from equations (2) which provides the optimum beamformer and DIR. When this quiescent refers to the scenario without partial time jamming or interference, the quiescent design reduces to (7).

$$\underline{\underline{H}}_o^H.\underline{b} = \underline{h}_o \qquad (7.a)$$

$$_{min}.\underline{\underline{H}}_o.\underline{\underline{H}}_o^H.\underline{b} = \underline{b} \qquad (7.b)$$

It is important to remark that, either from (7) or (2), the beamformer and the DIR verify the solution of the GSLC formulated as (8) and consuming only one degree of freedom.

$$\underline{\underline{H}}_o^H.\underline{b} = \underline{h}_o \ ; \ \underline{b}^H.\underline{\underline{R}}_o.\underline{b}\Big|_{min} \qquad (8)$$

To gain insight in the GSLC architecture, note that Figure 1 is just the upper branch of the GSLC. The lower branch is formed by a M-1 by M blocking matrix, where M is the number of antennas forming the aperture. The M columns of this matrix are the eigenvectors of the quiescent design equation, without the eigenvector associated with the minimum eigenvalue. Figure 2 depicts the GSLC, where $\underline{b}_a$ is the unconstrained beamformer and $\underline{\underline{B}}$ is the blocking matrix.

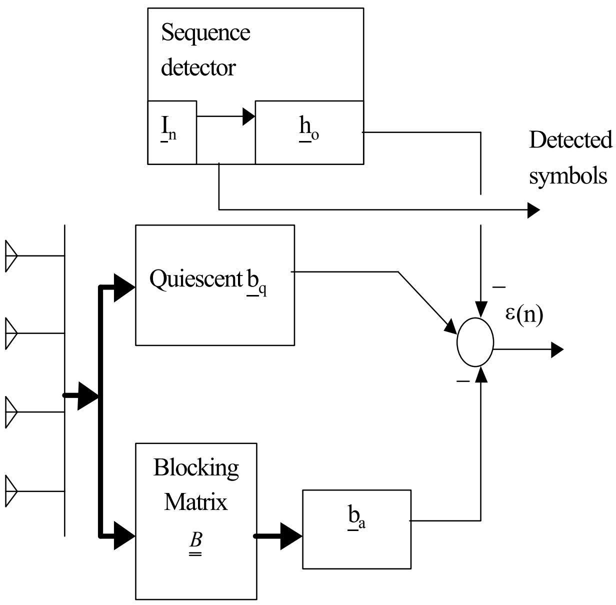


Figure 2. The GSLC architecture with sequence detector

This GSLC covers two signal scenarios of interest in radio communications. Note that partial time jamming produces severe degradation whenever the jammer hits the time interval where the training sequence is not present. Under this circumstance, the lower branch reacts in order to cancel the impact of jammer in the likelihood of the sequence detector.

Also for those scenarios where the DIR remains the same for several reference or training slots, the update of the GSLC (i.e. the unconstrained beamformer) involves much lower complexity than the full remake of (2). In fact, leaving the quiescent to combat the ISI, as in (7), any co-channel interference or jammer is nulled out by the lower branch.

The architecture is useful in the constrained minimization of the BER, since the channel matrix remains the same, it is no longer necessary to update at each iteration the blocking matrix. This fact alleviates greatly the computational burden of the iterative maximization procedure.

In addition to the features mentioned, the GSLC includes the possibility of controlled quiescent and directional constraints as it does the traditional architecture without sequence detector. Next section reports simulation on the performance of the architecture for the cases of partial time jamming and effective SNR maximization.

**4. SIMULATIONS**

The scenario to evaluate the GSLC performance is the following: The desired is located at 0º (broadside), with received SNR equal to –7 dB.; it is BPSK modulated with BS0 code for training sequence. Four multipath with delays 1,2,3 and 4 symbol intervals respectively; the levels of each path is equal to 1 (severe ISI) and DOAs equal to 7,-10,-40 and –30º respectively. An interference 10 dB. above the desired , BPSK modulated framing BS4 code, impinges the aperture from 20º. The aperture is an ULA array of 5 antennas. The sequence detector has length equal 4, i.e. there is a late arrival at –30º. The framing is 26 symbols of training, followed by 256 information symbols.

architecture reacts in the same manner it does the traditional GSLC.

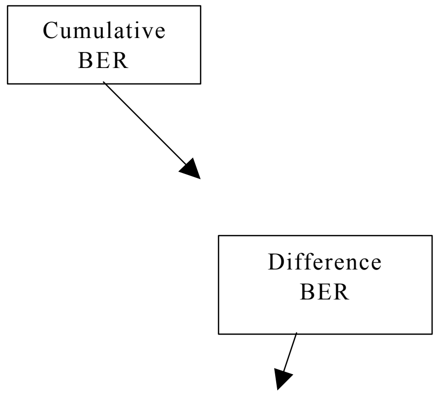


Figure 3. Difference between traditional and perturbed

MDIR, together with cumulative Bit Error Rate difference

Figure 3 represents the difference between the BER of the standard MDIR design minimizing the sequence detector input SNR and the VER of the MDIR minimizing the VER directly. Also the cumulative difference is shown in the plot. The number of frames is 1000. The cumulative plot shows evidence of the improvement derived from the perturbed method.

Figure 4, shows the quiescent, lower branch and adapted response when a partial time jammer show up from 40º broadside in a frame of 256 symbols. Note that the architecture reacts in the same manner it does the traditional GSLC.

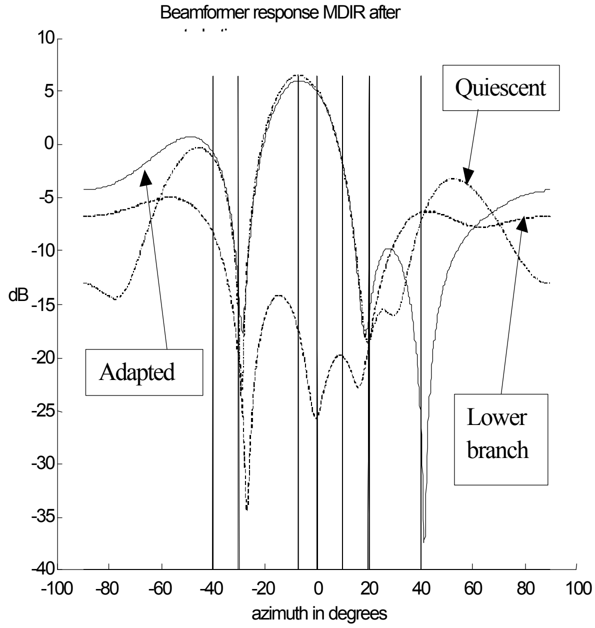


Figure 4. Quiescent, Lower branch and Adapted responses. Desired 0º, Multipath 7,-10-40 and –30º, Jammer 20º and partial time jammer at 40º.

## 5. CONCLUSIONS

Starting from the MDIR design this work proved the interest of a GSLC architecture in order to add extensions and further refinements over the baseline MDIR. The interest of the GSLC for those scenarios, with stationary ISI among several training slots, that may present partial time jamming has been shown. Since the quiescent is the global MDIR processor, the number of degrees of freedom is not affected by ISI with order below the DIR response of the sequence detector. Also the GSLC implementation helps in perturbation methods to achieve actual BER minimization. This is done by a perturbation to the MDIR response until the effective signal to noise ratio is maximized. The matched DIR response is preserved along perturbations, in consequence the optimality of the sequence detector remains.

In summary, the GSLC concept, in terms of spatial quiescent response, has been extended to the case of spatial-time quiescent with unconstrained minimization in the lower branch.

## 6. REFERENCES


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