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RESEARCH ARTICLE

TIRE PRESSURE MONITORING SYSTEM INTERFERENCE SUPPRESSION USING BEAM FORMER TECHNIQUES

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Abstract: This paper presents the interference suppression based on different beam form techniques. The Tire Pressure Monitoring System (TPMS) is a system for measuring the temperature and pressure of each tire of vehicles. In the past minimum-variance distortion less-response (MVDR) technique is used to removing the external interference and receiving the accurate data, but it is high computational complexity and high power consumption. In this work, we suggested a recursive least square algorithm (RLS) based on angle of arrival for suppress the interference, low computation complexity and low power consumption of a battery. The simulation results show the performance of different beam form techniques.

Index term-— Sensor Communication, Tire Pressure Monitoring System (TPMS), Minimum-Variance Distortion less-Response (MVDR), RLS, Interference Suppression, Beam former, Generalized Side lobe Canceller (GSC)

I. INTRODUCTION

If air pressure of a tire is too high or low comparing with a reference pressure, it is likely to cause the serious accident. The Tire Pressure Monitoring System (TPMS) is a system for measuring the temperature and pressure of each tire by means of the installed sensor to transmit the measured data to the CPU in the vehicle in order to prevent the accident [1]. The TPMS transmits and receives data through wireless communication between the transmitting antenna on the tire and the receiving antenna in the center of the vehicle, the transmission module installed on the tire needs a battery for supplying power, and it is thus currently required to develop compact battery technology and the technology for prolonging the life span of the TPMS through a low-power consuming device [2].

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Since September, 2007, it is compulsory to install the TPMS on vehicles produced in the U.S.A and imported from other countries by the Act on compulsory TPMS installation in the U.S.A [3]. The EU is promoting an act for compulsory installation of the TPMS on vehicles from 2012 to 2014. The Korean government is also promoting enforcement of compulsory installation of the TPMS on vehicles since 2013, and introduction and development of vehicle safety devices in addition to the TPMS is underway in Korea. The TPMS uses communication frequency of 433.92 MHz in the U.S.A and Europe, 433.92 MHz and 447 MHz in Korea [4]. The interference signal with the high-power from external devices should interfere with exact transmission and reception of the TPMS data. For suppressing such interference, we suggests AOA vector-based (minimum-variance distortion less-response) MVDR beam former with excellent performance. While the precedent switch beam forming technology [5] cannot create null in the AOA direction of interference to result in low performance of interference suppression, the MVDR beam forming technology creates null in the relevant AOA to implement highly effective performance of interference suppression. However, the MVDR uses the autocorrelation matrix to result in very high complexity.

In this paper is organized as follows. MVDR based beam former in section II. Detail explains the GSC beam former in section III. RLS beam former in section IV. The simulation results are presented in Section V. Concluding remarks are made in Section VI.

II. MVDR BASED BEAMFORMER

It is used for suppressing the interference and receiving the data accurately. The block diagram of MVDR based beam former as shown in figure 1

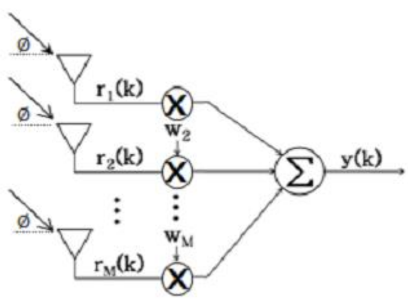

Figure 1. MVDR beam former for TPMS

Firstly, installing TPMS in a vehicle and then calculate the angle of arrival (AOA) of the TPMS signal. The weight vector of MVDR technique based on AOA is given by

$$a^H w=1$$

where w is the weight vector of TPMS signal

a is the auto correlation matrix of the received signal. So, it is high computation complexity because of calculation of an autocorrelation matrix. H is the complex conjugate transpose. The weight vector is given by

$$\mathbf{w}_\ell = \left[\mathbf{a}_\ell^H \mathbf{R}_r^{-1} \mathbf{a}_\ell\right]^{-1} \mathbf{R}_r^{-1} \mathbf{a}_\ell .$$

The weight vector generates a beam factor of one for the *l* th tire and creates nulls to the unwanted interference signals, at the same time. The final output of MVDR of AOA signal is given by

$$Y=WX$$

Where x is the desire MVDR signal. The main drawback of MVDR technique is high power consumption and high computation complexity.

III. GSC BEAMFORMER

It has better performance compare to MVDR beam former. GSC beam former has low computational complexity comparing to MVDR because it not require auto-correlation matrix calculation. The GSC technique suppressing the interference and receiving the data accurately. The block diagram of GSC based beam former as shown in figure 2

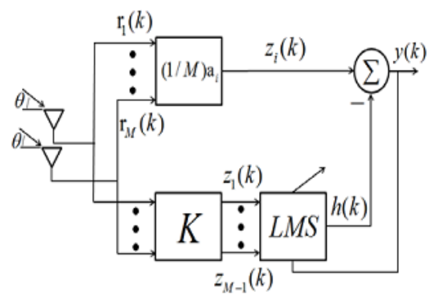

Figure 2. GSC based beam former for TPMS

The GSC weight vector is same as adaptive algorithm like the least mean square (LMS) algorithm. The weight vector of GSC signal is given by

$$W(n+1) = W(n) + \mu X(n)[d^*(n) - X^H(n)W(n)]$$

Where W is the weight vector GSC signal. 0 µ < is a step-size parameter, x is an input signal vector, and H complex conjugate operator.

The weight vector of GSC based on the LMS algorithm is calculated with

$$\mathbf{w}_{gsc}(k) = \frac{1}{M}\mathbf{a}_\ell - K\mathbf{w}(k).$$

The GSC weight vector given in (12) generates the beam factor sized one for the *l* th tire and nulls the interference signal, thus it improves signal-to-interference ratio (SIR).

The output of GSC beam former is given by

$$Y=WX$$

The estimation error signal of GSC signal is given by

$$Error = d(n)-X(n)W(x)$$

The main drawback of GSC beam former is high power consumption in a batter of each tire of vehicle.

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IV. RLS BEAM FORMER FOR TPMS

It has better performance compare to GSC beam former. RLS beam former has low computational complexity and low power consumption comparing to GSC. The RLS algorithm does not require any auto correlation matrix computations as the inverse correlation matrix is computed directly. In RLS beam former requires reference signal and correlation matrix information.

The block diagram of RLS technique is shown in figure 3.

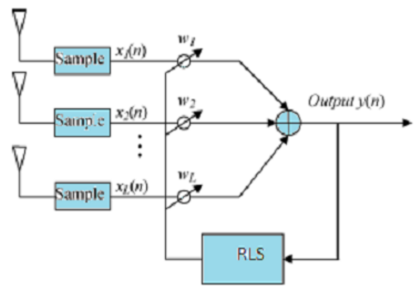

Figure 3 RLS adaptive beam forming network

The array output of RLS is given by

$$y(n) = w^H x(n)$$

The weight vector W is a complex vectors, that is W=[w1,w2,…..wk]. Typically, the adaptive beam former weights are computed in order to optimize the performance in terms of a certain criterion. X(n) is the baseband received signal at the Nth antenna is sum of phase shifted and attenuated versions of the original signal Si is given by

$$x_N(t) = \sum_{i=1}^{N} a_N(\theta_i) S_i(t) e^{-j2\pi f_c \tau_N \theta_i}$$

Where Si(t) is desire and interference signal. Final we write base band received signal with noise is given by

$$x(t) = A(\theta) S(t) + n(t)$$

Here A(Ø) is the array propagation vector of desired signal and n(t) is additive Gaussian noise.

We write the x(t) by separating the desired signal from the interfering signals.

$$x(t) = S(t) a(\theta_0) + \sum_{i=1}^{N_c} U_i(t) a(\theta_i) + n(t)$$

Where s(t)a(Ø) is the desire signal of RLS beam former and U(t)a(Ø) is the interference signal.

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The weight vector of RLS beam former of TPMS is given by

$$w(n) = w(n-1) - \hat{R}(n)x(n)\varepsilon^*(w(n-1))$$

Where inverse matrix R(n) is given by

$$\hat{R}^{-1}(n) = \frac{1}{\delta_0}\left[\hat{R}^{-1}(n-1) - \frac{\hat{R}^{-1}(n-1)x(n)x^H(n)\hat{R}^{-1}(n-1)}{\delta_0 + x^H(n)\hat{R}^{-1}(n-1)x(n)}\right]$$

Where δo denoting a real scalar less than but close to 1. The δo is used for exponential weight of past data and is referred to as the forgetting factor as the update equation tends to de-emphasize the old samples.

V. EXPERIMENTAL RESULTS

In this section shows the performance of different beam former techniques. Fig. 4. Shows the beam patterns of the MVDR beam former with six receiving antennas. In Fig. 4. the MVDR forms two beams to 60° (right front) and 300° (left rear) direction, and it created nulls for three directions of 87°, 165°, and 268°, at the same time.

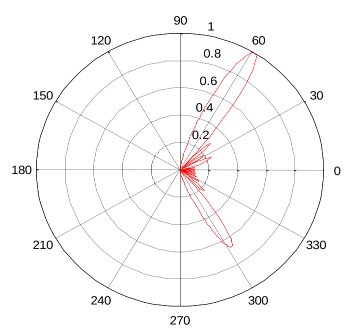

Figure 4. for right tire TPMS signals with 60° and 300° incidence angles using MVDR beam former

We can find two beams for 120° (right front) and 240° (right real) directions and three nulls for 87°, 165°, and 268° in Fig. 5

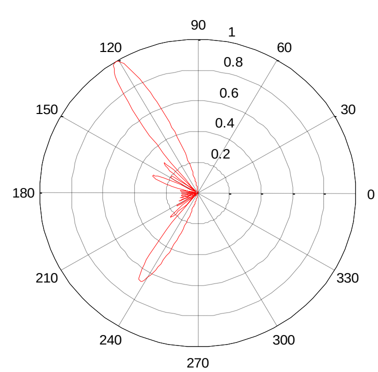

Figure 5. for left tire TPMS signals with 240° and 120° incidence angles using MVDR beam former

In Fig. 6. the GSC forms two beams to 60° (right front) and 300° (left rear) direction, and it created nulls for three directions of 87°, 165°, and 268°, at the same time.

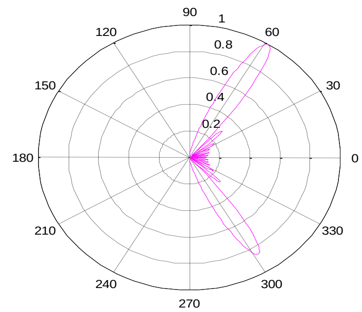

Figure 6. for right tire TPMS signals with 60° and 300° incidence angles using GSC beam former

We can find two beams for 120° (right front) and 240° (right real) directions and three nulls for 87°, 165°, and 268° in Fig. 7

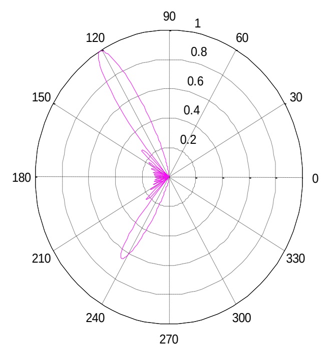

Figure 7. for left tire TPMS signals with 120° and 240° incidence angles using GSC beam former

We can find two beams for 120° (right front) and 240° (right real) directions and three nulls for 87°, 165°, and 268° in Fig. 8

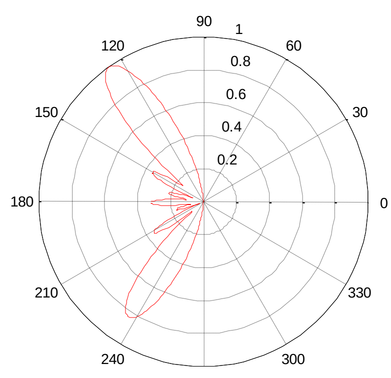

Figure 8. for left tire TPMS signals with 120° and 240° incidence angles using RLS beam former

In Fig. 9. the RLS forms two beams to 60° (right front) and 300° (left rear) direction, and it created nulls for three directions of 87°, 165°, and 268°, at the same time.

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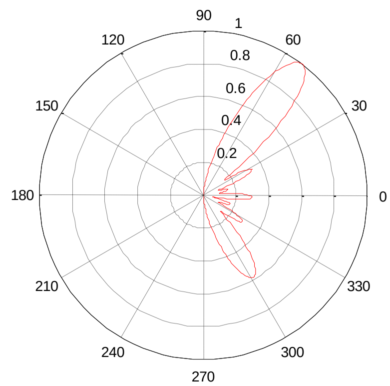

Figure 9. for right tire TPMS signals with 58° and 300° incidence angles using RLS beam former

VI. CONCLUSION

In this paper, we suggested an RLS beam former for TPMS, which has excellent performance of interference suppression. Although the MVDR beam former has excellent performance of the interference suppression, it has very high computational complexity due to the calculation of an auto-correlation matrix. In order to overcome this drawback, we also proposed a RLS beamformer for the TPMS, which has similar performance of interference suppression to that of the MVDR and does not require calculating the auto-correlation matrix to result in the relatively low computational complexity. Performances of interference suppression for the proposed receiver are verified through the computer simulation example.

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