Retournement Temporel en ULB: Étude Comparative par Mesures pour des Configurations SISO, SIMO, MISO et MIMO
UWB Time Reversal: Experimental and Comparative Study for SISO, SIMO, MISO and MIMO Configurations

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Résumé

Des mesures de retournement temporel (RT) sont effectuées en ultra-large bande (ULB) dans une chambre réverbérante (CR) pour différentes configurations de systèmes multi-antennaires : SISO, SIMO (1 X 2), MISO (2 X 1) et MIMO (2 X 2). Une étude comparative est réalisée entre ces quatre configurations. La mesure du canal est effectuée en mettant en œuvre un générateur de formes d'ondes arbitraires (AWG) à l'émission et un oscilloscope numérique rapide (DSO) à la réception. Dans tous les cas, les signaux reçus sont renversés dans le temps puis re-transmis par l'antenne d'émission. Les performances du RT sont analysées et comparées pour toutes ces configurations, en considérant les caractéristiques suivantes : la puissance crête reçue, le gain de focalisation, le rapport signal à lobes secondaires et l'étalement de délai RMS. Cette étude montre que, pour la même puissance transmise, la configuration MIMO apporte une amélioration significative des performances par rapport aux autres configurations.

Mots clés: Retournement temporel (RT), ultra-wideband (UWB), focalisation spatiale, focalisation temporelle, multiple input multiple output (MIMO)

Abstract

Time reversal (TR) measurements are conducted for ultra-wideband (UWB) signals in a reverberation chamber (RC) for different multi-antenna configurations: SISO, SIMO (1 X 2), MISO (2 X 1) and MIMO (2 X 2). A comparison is made among the four configurations. Channel measurement is done using an Arbitrary Waveform Generator (AWG) at the transmitter and a high speed digital storage oscilloscope (DSO) at the receiver. For all these configurations, the received signals are time reversed and re-transmitted from the transmitting antenna. TR performance is analyzed and compared for all the configurations by considering different TR characteristics i.e. received peak power, focusing gain, signal to side lobe ratio (SSR) and RMS delay spread. It is shown that MIMO-TR outperforms all other configurations for a fixed transmitted energy.

Key Words: Time reversal (TR), ultra-wideband (UWB), spatial focusing, temporal focusing, multiple input multiple output (MIMO)

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Introduction

Ultra-wideband (UWB) communication has drawn considerable attention recently. Due to its large bandwidth, UWB system can resolve individual multi-path components. However, large number of resolvable paths and low power limitations necessitate a complex receiver system. Different type of receiver systems such as Rake, transmit-reference or the decision feedback autocorrelation receivers can be implied [1]-[3] to detect such a signal. Each technique has different difficulties and drawbacks.

Time reversal (TR) shifts the design complexity from the receiver to the transmitter. Classically, TR has been applied in acoustics and under water communication applications [4], [5], but recently, UWB TR communication has been studied in a number of articles [6]-[17]. The received signal in a TR system is considerably focused in spatial and temporal domains. Thus, the received power is concentrated within few taps and can be detected by using a simple energy threshold detector [6].

In [14], the authors have presented the first time domain measurements for an indoor environment. In [17], time domain SIMO measurements were presented. This paper presents time domain MISO-TR and MIMO-TR measurements in a reverberation chamber (RC). The RC is electrically large, high quality factor cavity that obtains statistically uniform fields by either mechanical stirring or frequency stirring [18]. RC is a highly controllable test environment and can be considered as a reference environment. It is a good environment to show the effectiveness of the TR. Therefore a comparison is made between single input single output (SISO), single input multiple output (SIMO (1 X 2)), multiple input single output (MISO (1 X 2)) and multiple input multiple output (MIMO (2 X 2)) configurations in a RC.

The rest of the paper is organized as follows. A brief introduction of TR is presented in section 1. The diversity and multiplexing gains are discussed in section 2. Experimental measurement setup and results are presented and analyzed in section 3 and section 4 respectively. Finally, section 5 concludes this paper.

1. Time Reversal

Time reversal (TR) transmission scheme uses a time reversed channel impulse response (CIR) as a transmitter pre-filter. The signal then propagates in an invariant channel following the same paths and results in coherently adding all the received signals in the delay and spatial domains. With this technique, strong temporal compression and high spatial focusing can be achieved [14]. The temporal compression reduces the root mean square (RMS) delay spread and inter-symbol interference (ISI) while multi-user interference is reduced due to spatial focusing. The received signal at the intended receiver *(j)* can be mathematically represented as:

$$y_j(t) = s(t) \star h'_j(-t) \star h_j(t) \approx s(t) \star R^{auto}_{h_j h_j}(t) \qquad (1)$$

where $h'_j(t)$ is the estimated (measured) CIR from the transmitting point to an intended receiver (*j*), *s(t)* is the transmitted signal, $\star$ denotes convolution product and $R^{auto}_{h_j h_j}(t)$ is the autocorrelation of the CIR, $h_j(t)$. The received signal at any non intended receiver (k) is:

$$y_k(t) = s(t) \star h'_j(-t) \star h_k(t) \approx s(t) \star R^{cross}_{h_j h_k}(t) \qquad (2)$$

where $h_k(t)$ is the CIR from the transmitting point to an unintended receiver (k) and $R^{cross}_{h_j h_k}(t)$ is the cross-correlation of the CIRs $h_k(t)$ and $h_j(t)$. If the channels are not correlated, then the signal transmitted for one receiver will act as a noise for a receiver at any other location. Therefore, a secure communication is achieved with a low probability of interception.

Some of the TR characteristics are defined in the following: TR received peak power is defined as the power of the received peak for a TR system for a fixed transmitted energy. Signal to side lobe ratio (SSR) is defined as ratio of the power of the first to second strongest peak in a TR received signal:

$$SSR = 20\, log_{10}\left(\frac{y_j(t_{peak})}{y_j(t'_{peak})}\right) \tag{3}$$

where t_{peak} is the time for strongest peak and t'_{peak} is the time for the second strongest peak. SSR is an important parameter and is a measure of the quality of the received signal.

Focusing gain (FG) of a TR system is defined as the ratio of the strongest tap power of the received signal in TR scheme to the strongest tap power of the pulsed system:

$$FG = 20\, log_{10}\left(\frac{max|y_j(t)|}{max|h'_j(t)|}\right) \tag{4}$$

It is also an important TR property as higher FG can translate into higher communication range for a communication system as compared to a pulsed UWB communication system. The average received power with the TR scheme increases as compared to the pulsed system for a fixed transmitted energy.

Another important TR characteristic is the instantaneous RMS delay spread (σ_τ). It can be calculated by the first and the second moment of the measured TR response or the CIR:

$$\sigma_\tau = \sqrt{\frac{\sum_{l=1}^{N} PDP(l)\tau_l^2}{\sum_{l=1}^{N} PDP(l)} - \left(\frac{\sum_{l=1}^{N} PDP(l)\tau_l}{\sum_{l=1}^{N} PDP(l)}\right)^2} \tag{5}$$

where $PDP(l) = |y_j(l)|^2$ or $|h'_j(l)|^2$, y_j is the measured TR response, h'_j is the measured CIR, τ_l is the excess time delay and N is the total number of taps in the PDP. RMS delay spread is considered as a metric for temporal compression in TR systems. The comparison of all these TR characteristics is made for different multi antenna configurations in a RC.

2. Gains for SISO and MIMO Configurations

There are two types of gains associated with the configurations having more than one antenna either at the transmitting end or at the receiving end or both. One gain is the diversity gain achieved through the antenna diversity. The upper bound for the diversity gain is the product, M_TM_R, where M_T is the number of transmitting antennas and M_R is the number of receiving antennas. The upper bound for the multiplexing gain is $min\ (M_T, M_R)$.

In a TR system, same bounds for the multiplexing gain and diversity gain apply. In this paper we compare different TR properties for different cases of MIMO configurations and not the throughput or bit error rate performance of the system. Thus, diversity gain is taken into account and we combine the received signal in the case of SIMO and MIMO configurations where as transmitted signal is combined for MISO configuration.

3. Experimental Setup

Experiments are performed in RC and typical indoor environments. RC is a metallic chamber of dimensions 8.7 m X 3.7 m X 2.9 m present inside IETR laboratory. Measurement setup is illustrated in Fig. 1. A set of four conical mono-pole antennas (CMA) are used as the transmitter and receiver for different configurations. Fig. 2 shows two CMAs placed inside the RC. The height of the transmitter and the receiver is 1 m from the ground. The distance between the transmitter and receiver is 6 m. The channel sounding pulse with a rise time of $230\, ps$ (see Fig. 3) and the time reversed CIR are generated through the arbitrary waveform generator (AWG 7052) having a maximum sampling rate of 5 GS/s. The received signal is measured by a digital storage oscilloscope (Tektronix DSO 6124C) with a bandwidth of 12 GHz and a maximum sampling rate of 40 GS/s. DSO captures the CIR of the channel as well as the TR response. DSO is operated in average mode so that 8 samples are taken and averaged together.

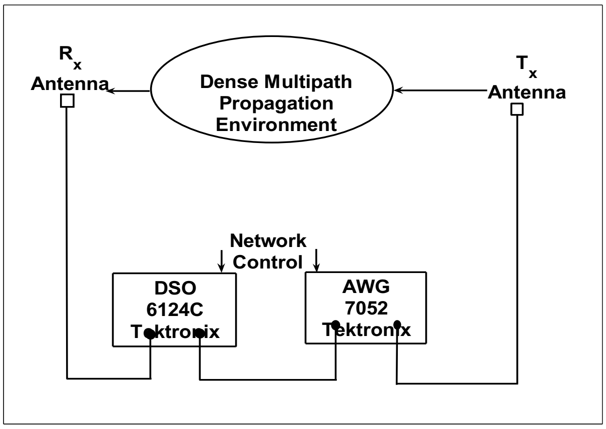

Fig. 1: Measurement setup

Fig. 2 Two conical monopole antennas placed inside a reverberation chamber

4. Experimental Results

Fig. 4 shows power delay profile (PDP) of the received TR signal in RC for SISO, SIMO, MISO and MIMO configurations for a fixed transmitted power. It is evident that MIMO, MISO and SIMO TR have a better TR peak performance compared to SISO-TR. The comparison for all TR characteristics for these configurations is summarized in Table 1. TR peak performance normalized to the SISO-TR system improves with SIMO, MISO and MIMO configurations compared to the SISO-TR. MIMO-TR outperforms SISO, SIMO and MISO TR for the same transmitted power. For instance, TR peak power with MIMO-TR is 6.08 dB more than SISO-TR, 3.39 dB more than MISO-TR and 2.43 dB more than SIMO-TR. It should be noted that it is the peak power and not the average power which increases by 6.08 dB.

The configurations having multiple antennas at the transmitter (MISO and MIMO), have slightly better FG than the configurations having one antenna at the transmitter (SISO and SIMO). The SSR remains almost constant for all configurations. The RMS delay spread also remains constant for all configurations. As SSR and RMS delay spread affect the ISI, therefore, all the configurations have a similar signal to interference (SIR) performance. However, the bit rate of the system can be increased taking advantage from the multiplexing gain of multi-antennas configurations.

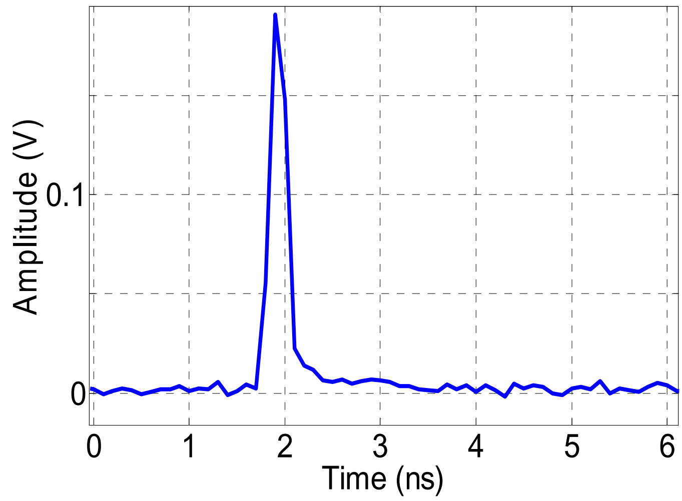

Fig. 3 Channel sounding pulse

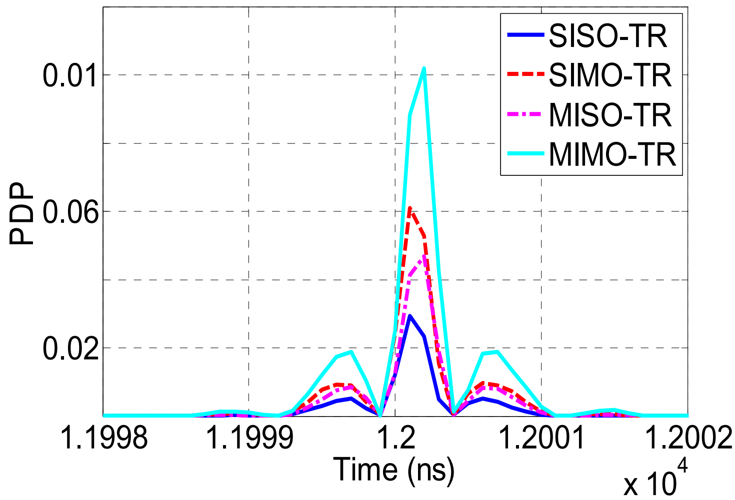

Fig. 4: PDP of the received TR signal with SISO, SIMO and MIMO configuration

TR Property	SISO−TR	SIMO−TR	MISO−TR	MIMO−TR
Focusing Gain (dB)	31.96	32.74	34.44	34.21
SSR (dB)	7.44	7.74	7.49	7.34
Normalized TR peak (dB)	0	3.65	2.69	6.08
$\sigma_\tau^{TR}(ns)$	0.31	0.33	0.31	0.33
$\sigma_\tau^{CIR}(\mu s)$	5.74	5.73	5.74	5.73

Table 1: Time Reversal characteristics in the reverberating chamber

5. Conclusion

In this paper, a comparison of time domain measurements is presented for SISO, SIMO, MISO and MIMO configurations in a reverberating chamber (RC). It is shown that MIMO-TR outperforms MISO, SIMO and SISO TR for same value of transmitted energy. For instance the received peak power for MIMO-TR is 6.08 dB better than SISO-TR. It is observed that configurations having multiple antennas at the transmitter (MISO and MIMO), have a better FG than the configurations having one antenna at the transmitter (SISO and SIMO). All three configurations have similar RMS delay spread and SSR which suggests the SIR performance for all the configurations is similar.

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