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A Field Measurement Campaign for a DVB-T/H System with Transmit Delay Diversity

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Research Article

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Abstract: In order to quantify the practical benefits of applying transmit delay diversity to DVB-T/H systems, this article describes a field measurement effort conducted by the IST PLUTO project. In order to evaluate transmit diversity gain projections derived from theoretical modeling and laboratory data, a comprehensive field testing was conducted in Uxbridge, UK. The 730 MHz frequency range was used for DVB-T/H broadcasts. Transmit delay variety is shown to significantly increase reception quality in hard-to-reach places without affecting the standard or making receivers more complicated.

Keywords: Field trials, transmit delay diversity, DVB-T/H.

INTRODUCTION

While next-generation digital TV service providers who target mobile and fixed reception are discovering that coverage inside and in non-Line of Sight (LOS) regions is a critical necessity and a difficulty, current broadcast TV networks are built to allow reception via rooftop antennas. Such networks must be developed with the least amount of environmental damage and at the lowest possible cost. In Non Line of Sight (NLOS) SISO reception scenarios, multipath may cause significant fading. When forecasting service availability, a radio network design must consider this. Broadcast reception in multipath scenarios has traditionally been achieved by increasing the number of transmitters and/or the radiated power.

The performance and capacity of wireless systems have long been suggested to be enhanced by transmit diversity methods using multiple antennas (MISO). The same data is concurrently sent from two or more spatially distant antennas using transmit Delay Diversity (DD), although there is a delay of many OFDM symbol intervals T. Diversity improves receiving quality by lowering the likelihood of deep fades being seen at the receiver. As long as the receiver can take advantage of the detected signals' uncor-related fading, a diversity gain will always be seen in NLOS scenarios. This reduces the number of transmitter sites and radiated power needed to provide effective coverage. In order to confirm earlier theoretical and laboratory observations, the findings of a comprehensive transmit diversity DVB-T/H field testing conducted in Uxbridge, UK, over the winter of 2007/2008 are described in this work [1, 2]. DVB-T broadcasts with a mean power of 18.4dBW were carried out at 730 MHz. Other OFDM broadcast technologies (such as DVB-SH, DAB, DMB,

Mediaflo, etc.). As part of the PLUTO project's research operations, Brunel University and Broadreach Systems performed this measuring campaign [3].

The structure of the paper is as follows: The experimental network configuration for the measurement campaign is described in Section 2, and the measurement methods and parameters utilized to analyze the diversity gain performance are presented in Section 3. The measurement findings are presented in Section 4, and the article is concluded in Section 5.

1. EXPERIMENTAL NETWORK SETUP

The transmitter was situated 1.2 kilometers south of Uxbridge at Brunel University on the west side of London. The measuring area is typical of a suburban region and is rather flat. Two 100W power amplifiers were employed in the field testing to provide an array of directional antennas.

The tests compared the quality of reception in the measurement area when half of the total power was transmitted from each of the two separate antennas (Multiple Input Single Output (MISO)) and when the entire power was transmitted from a single antenna (Single Input Single Output (SISO)). With a central frequency of 730 MHz and a bandwidth of 8 MHz, the single transmitter on channel 53 had an effective isotropic radiated power (EIRP) of 18.4 dBW. Each antenna in the MISO scenario transmitted half of the SISO scenario's EIRP, or 15.4dBW.

The transmissions complied with the DVB-T standard's RF signal spectrum [3]. To make sure the signal quality was acceptable, it was examined at several points across the transmission chain. The spectrum shoulders' relative values completely conform to the DVB-T standard's RF signal spectrum mask. When the two amplifiers were running in SISO configuration (e.g., at maximum power), no significant non-linear effects were introduced. Power levels were meticulously monitored and the power transfer mechanism was calibrated.

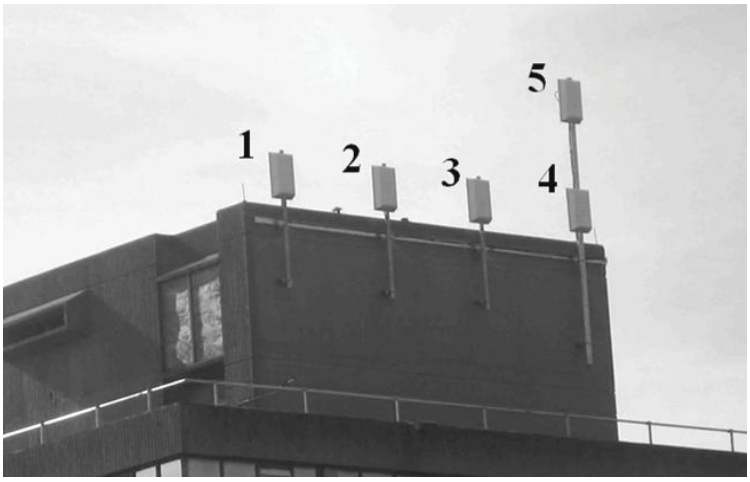


Fig. (1a). Transmit Diversity Antenna Array at Brunel University.

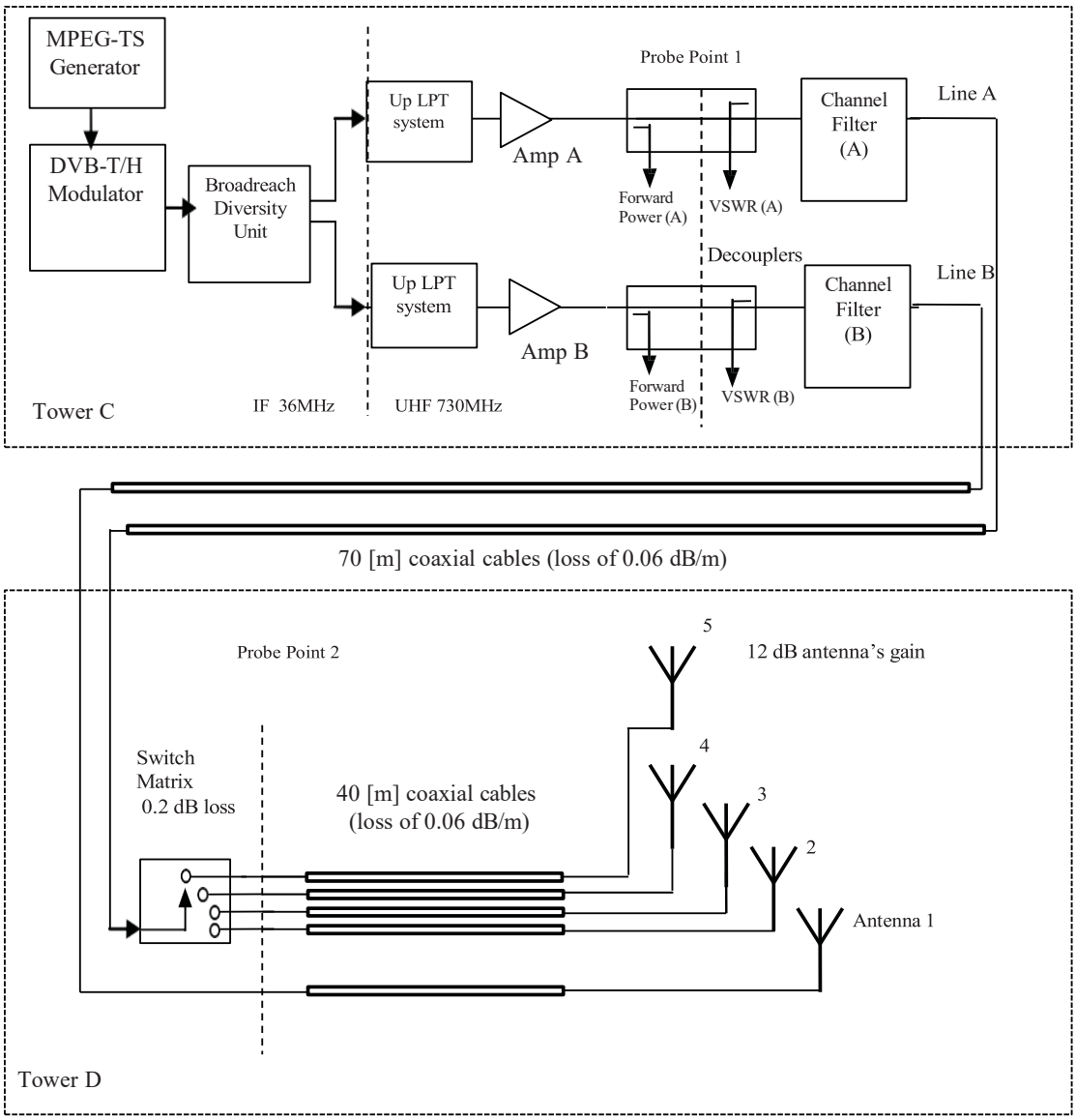


Fig. (1b). Transmit Diversity RF System.

adjusted and monitored during the measurements using a power measurement device with calibration traceable to national standards.

A directive linear antenna array was installed at the top of one of the university buildings (Tower D) pointing toward the east. The antennas are horizontally polarized panels with a gain of 12dB, a half-power beam-width of 53° degrees in the horizontal plane and 24° degree in the vertical plane. A maximum number of two antennas (out of five) were active at any time. The horizontal spatial separations between act-ive antennas could be selected from 7, 14 or 20 wavelengths. A vertical separation of 5 wavelengths can be optionally selected as shown in Fig. (**1**). The total feeder loss was 6.8 dB and the switch matrix connecting the amplifier with one of the diversity antennas had a loss of 0.2 dB. In Table **1** the main technical characteristics of the transmission are summarised.

The transport stream comprised Pseudo Random Binary Sequence (PRBS) packets for field measurements. The sys-tem is also capable of delivering multimedia content, encoded into MPEG-2 Transport Streams (TS) packets and transmitting it over the network for demonstration purposes. A standard DVB-T Modulator was used to feed IF signals directly into the Broadreach Diversity Unit (custom made), introducing a 1.1 μs relative delay between the two signals at the output. **Table 1. DVB-T System Parameters**

Configuration Name	**SISO**	**MISO**
Transmit Frequency	730 MHz	

Bandwidth	8 MHz	
Code Rate	3/4	
Signal Constellation	QPSK	
DVB-T Mode	2K	
Hierarchy (α)	Non hierarchical	
Guard Interval	1/32	
Bitrate (Mbit/s)	9.05	
Total Feeder Losses	6.8 dB	
Antenna Gain	12 dBi Horizontally Polarised	
EIRP (dBW)	18.4	15.4 (Ant. 1) +15.4 (Ant. 4)
Antenna separation (λ)	-	20
Diversity Delay (μs)	-	1.1

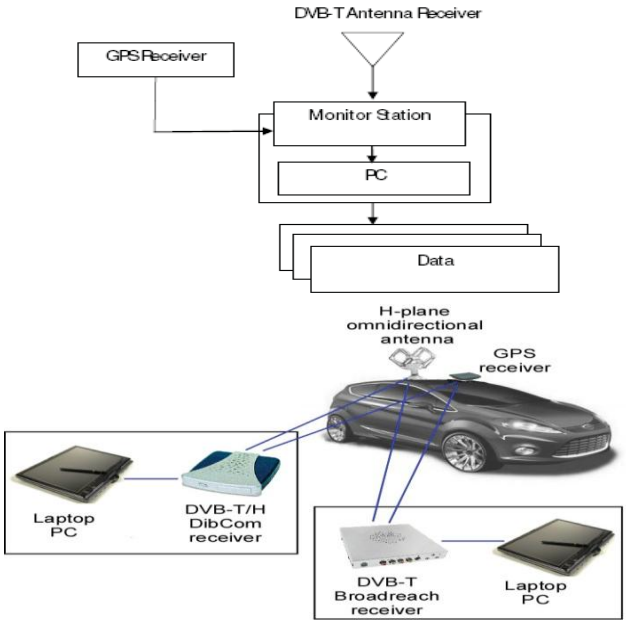


Fig. (2). The car experimental set-up.

The mobile reception was measured using a car equipped with a DVB measurement system provided by Broadreach Systems. Fig. (**2**) illustrates the integrated system used to record seconds in which uncorrectable Reed-Solomon blocks are observed, from which the Errored Seconds Ratio (ESR) is calculated. ESR is the ratio of errored to non-errored seconds. The Signal to Noise Ratio (SNR) and the received signal strength indication (RSSI) are also measured together with location coordinates acquired using a global position system (GPS) receiver. The signal was received using an omnidirectional horizontally polarized antenna, installed on the rooftop of the test vehicle. This system was used to measure the ESR, SNR and RSSI. Every measurement was recorded and tagged with the corresponding location coordinates.

2. MEASUREMENT METHODOLOGY

2.1. Measurement Area Classification and Route

The area in which the measurements were conducted was classified into six different environments (zones) (Fig. **3** and Table **2**). The experiment receiving conditions can be associated to a class C reception [4].

Table 2. Description of Zones

Scenario	Zone	Description
Car, 20 km/h	A	"University Campus" includes high buildings, offices, and residential halls. The typical heights of these buildings are 30 m and the area includes several trees. Several locations are in LOS with the transmitter antenna array.
Car, 20 km/h	B	"Sub-urban" can be described as a low-density suburban area, with a significant presence of trees and vegetation. Residential streets within this zone are typically 10 meters wide.
Car, 20 km/h	C	"Playground fields" include typically football or tennis playgrounds, without a significant presence of buildings or trees.
Car, 20 km/h	D	"Trees areas" is of the same type as the playground fields' zone, but with a significant presence of trees.
Car, 48.2 km/h	E	"Wide roads" are 19.7 meters wide roads, 2 lanes each way, holding moderate traffic and surrounded by 2 floor residential houses. The speeds on these roads varied significantly with many accelerations and decelerations due to the variable traffic level.
Car, 48.2 km/h	F	"Medium roads" are 11.5 meters wide roads with 1 lane each way. They hold light traffic, but the speeds varied significantly.



Fig. (3). Measurement route and zones.

The selected route covered mainly sub-urban zones and included wide and medium roads in all directions reaching marginal areas of the service coverage. The route was in the main direction of the transmit power, it is approximately 13.2 km long and was selected mainly to measure the diversity gain. The maximum range covered by the route was 1.72 km. It should be mentioned that the measurements were repeated many times to confirm repeatability. In total more than 447 km of mobile measurements were recorded. Fig. (**3**) shows the selected route. Typical speeds were in the range of 0 to 48.2 km/h, with an average of 30 km/h. The time required to drive along the route was approximately 30 minutes. The measurements taken when the receiver was stationary were removed from the data presented here to eliminate the effects of ran dom stops due to traffic lights on the total reception statistics.

2.2. Measurement Metrics

A complete set of radio channel and signal data were gathered every second. The parameters of interest include the Errored Seconds Ratio (ESR), the RSSI, the SNR and the Channel Impulse Response (CIR).

For DVB-T, $ESR_{\%}$ denotes the percentage of the time when seconds are marked as erroneous. An erroneous second consists of a second containing at least one faulty MPEG TS packet. The degradation point is set to the 5% value [5] and it is denoted as $ESR_{5\%}$ (Errored Seconds Ratio at 5%) and denotes a maximum of one erroneous second in 20 seconds as the maximum ESR for acceptable reception. Errored seconds are a good metric as they are observable in the received picture and therefore reflect the impact of signal quality on the user's experience.

3. MEASUREMENTS RESULTS

3.1. DVB-T Tests

The time required for driving along the route was approximately 30 minutes. The diversity gain was estimated by comparing SISO and MISO driving tests performed sequentially to ensure analogous traffic conditions for the two measurements. Weather conditions were sunny or partly cloudy and background traffic was generally light/medium. The tests results presented here were obtained employing the broadcast conditions described in Table **1**.

Channel Impulse Response Estimation

Channel features were derived from measurements and a channel model was used to characterize the propagation scenario. The resulting models represent an outdoor mobile channel for SISO and MISO DVB-T/H networks. It was shown in [2] that the transmit DD gain is related to the propagation channel and to its parameters, particularly to the root mean square (rms) delay spread. The Broadreach receiver was used which was capable of capturing Channel Impulse Responses (CIRs) consisting of 77 sample taps, equally spaced by 74ns. The CIRs were measured every 1 second and stored in a text log file.

After studying the measurement data, it was concluded that 30 dB is an appropriate value for the dynamic range of the impulse responses. This means that signals, which are 30 dB below the strongest power level, were considered to be noise. This threshold is also consistent with other published works [6]. Path loss and shadowing effects were removed by

$$ESR_{\%} = \frac{\text{Total Number of Erroneous Seconds}}{\text{Total Number of Measured Seconds}} \times 100\% \quad (1)$$

normalizing the peak power of each impulse response to 0 dB. For each IR, the first tap with maximum power (0 dB) was chosen as reference starting point and the last tap with approximately -30 dB threshold was chosen as last value.

For DVB-H, incorrect tables can (sometimes) be corrected by the Multi-Protocol Encapsulation Forward Error Correction (MPE-FEC) code. The Dibcom DVB-H receiver was supplied with a tool, which logs parameters such as Carrier to Noise Ratio (CNR), Frame Error Rate (FER), and Multi-Protocol Encapsulation FER (MFER). MFER is the ratio of the number of residual erroneous frames (i.e., not recoverable) and the number of received frames. FER is the ratio of the number of erroneous frames before MPE-FEC correction and the number of received frames.

$FER_{\%}$ is defined as the ratio between the number of the erroneous frames and the total number of frames. A frame is marked erroneous if any TS packet within the frame is erroneous. The degradation point is set to 5% value and it is denoted as $FER_{5\%}$. Finally the CIRs were averaged yielding an average power delay profile (PDP). A typical number of 1000 CIRs were averaged. Fig. (**4**) show the PDP over the measurement route for SISO and MISO configuration. The second cluster of echoes generated by the second diversity antenna starts at about 1.1μs. It should be noted that the average peak power of the second cluster is very similar to the peak power of the first cluster (0.2 dB below the first cluster peak), providing a qualitative confirmation of the equal average power radiated from the two transmit antennas.

Three parameters were also analysed from the acquired data: the total excess delay, the rms delay spread and the number of taps as summarized in Table **3**. Comparisons of the SISO channel model with previous published works [6] shows good agreement. It can be seen that the measured rms delay spread (0.24 μs) falls between the rms delay spread of

$$FER_{\%} = \frac{\text{Number of Erroneous MPE Frames}}{\text{Total Number of Frames}} \times 100\% \quad (2)$$

COST 207 [8] rural area RA (0.1 μs) and typical urban TU6 (1 μs) channels.

$MFER_{\%}$ is the ratio between the number of erroneous frames after the MPE-FEC correction and the total number of frames. The degradation point is set to 5 % value and it is denoted as $MFER_{5\%}$.

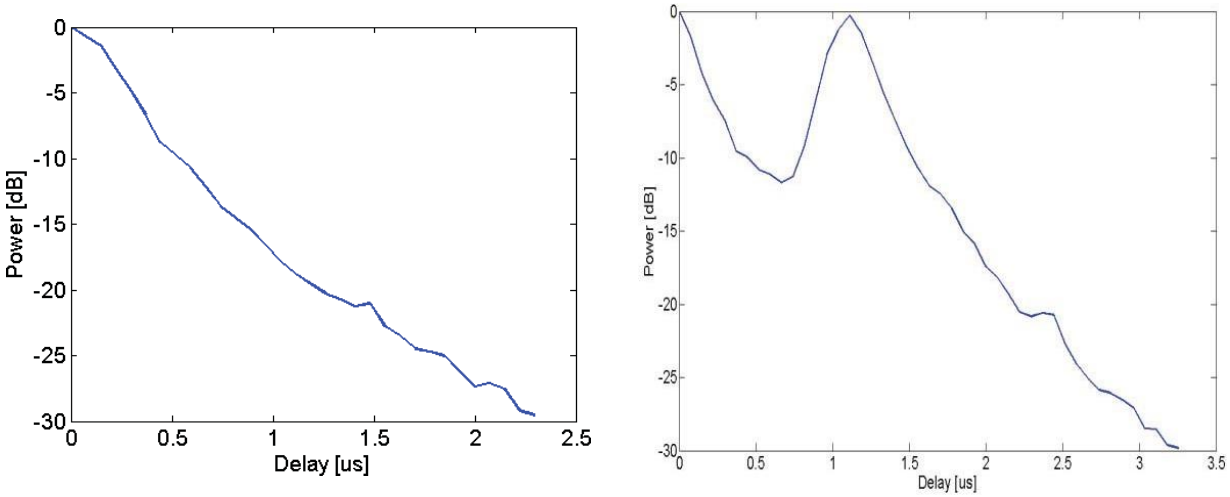
Table 3. Channel Parameters

$$MFER_{\%} = \frac{\text{Number of Erroneous Frames}}{\text{Total Number of Frames}} \times 100\%$$

	SISO	MISO
Number of CIRs used in the estimation	998	1018
Rms Delay Spread (us)	0.24	0.59
Excess Delay (us)	2.07	3.03
Number of taps	32	45

(3)

(a) SISO



(b) MISO

Fig. (4). Average Power Delay Profile derived from Measurements.

Performance of Transmit Delay Diversity

Fig. (**5**) shows the $ESR_{\%}$ for the entire route for SISO and MISO configuration. The measurements were taken during different days. In each case, multiple measurements were conducted during the same day. The MISO performances were compared with the SISO performances for antenna 1. The measurement procedure for diversity gain estimation is summarised as follows:

1. The $ESR_{\%}$ for SISO transmission was measured.
2. The $ESR_{\%}$ for MISO transmission was measured. The EIRP is the same as the SISO case.
3. The EIRP for MISO was reduced in steps of 1 dB until the observed $ESR_{\%}$ was equivalent to the SISO $ESR_{\%}$ case.
4. The Δ_{ERP} is the reduction of MISO EIRP required to achieve MISO $ESR_{\%}$ equivalent to the SISO $ESR_{\%}$

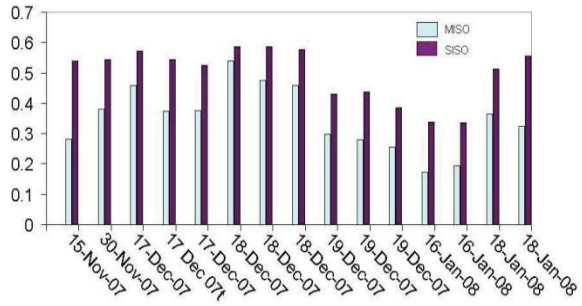


Fig. (5). $ESR_{\%}$ of all experiments.

Fig. (**6**) shows the SISO and MISO $ESR_{\%}$ against the RSSI values. For each RSSI point, at least 100 seconds are considered to calculate the $ESR_{\%}$. The curves show a diver-

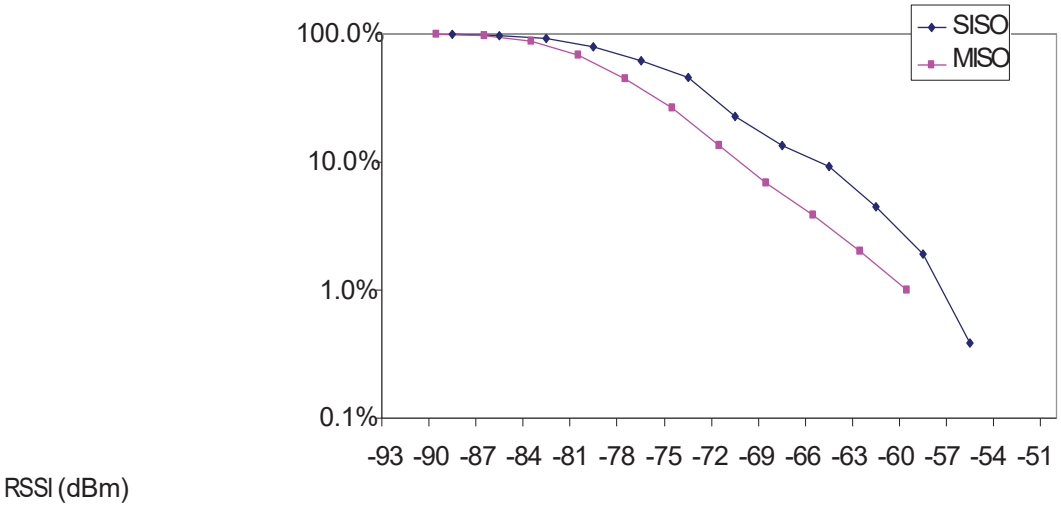


Fig. (6). SISO and MISO $ESR_{\%}$ *versus* RSSI.

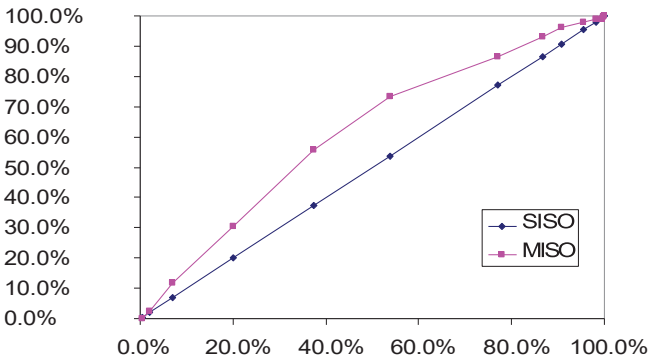


Fig. (7). MISO *versus* SISO coverage.



gain at $ESR_{5\%}$ of about 4 dB. Diversity gain estimated from laboratory measurements conducted in [2] was com-pared to the value obtained from field trials. The average maximum Doppler shift of driving tests was 20 Hz while the minimum and the maximum

Doppler shifts were 4.4 Hz and 32.3Hz, respectively. It can be seen that the estimated diversity gain is within the expected range of 2 to 5 dB for TU6 thus validating the measured 4 dB of diversity gain at 20 Hz for $ESR_{5\%}$.

The $ESR_{\%}$ shown values shown in Fig. (**6**) can be also considered as coverage percentages. A similar approach can also be found in [7]. For each value of SISO coverage a corresponding value of MISO coverage can be mapped for the same RSSI. Fig. (**7**) shows that MISO coverage of 95% and 70% ("good" and "acceptable" reception [4] are equi-valent to SISO coverage of 88% and 50% respectively.

Fig. (**8a**) shows the typical RSSI distribution along the measurement route for the SISO setup. Fig. (**8b** and **8c**) show the errored and error free seconds along the route for SISO and MISO reception, respectively. The circles of Fig.(**8c**) highlight the zones where the ESR reduction is more evident. These zones correspond approximately to RSSI values between -63.5 and -78.5 dBm.



Fig. (8a). RSSI profile for SISO configuration. (RSSI 15 dB steps).



Fig. (8b). Errored and error free seconds for SISO reception.



Fig. (8c). Errored and errors free seconds for MISO.

Measurements have also been conducted to explore how transmit Diversity might be used to enhance system through-put capability. SISO and MISO ESR$_{\%}$ was compared at 3 different code rates of 1 / 2, 2 / 3, and 3 / 4. The tests were repeated over 4 different days. Fig. (**9**) shows that MISO ESR$_{\%}$ with a code rate of 3/4 always outperform SISO ESR$_{\%}$ with a code rate of 2/3. Since code rates of 2/3 and 3/4 cor-respond to bit rates of 8.04 and 9.05 Mbps, the measure-ments suggest that a minimum improvement of 1 Mbps data rate can be achieved.

Effect of Antenna Separation

The spatial separation of transmit antennas is required to achieve a sufficient de-correlation of the fading between channels. Modelling predicts that a minimum separation of approximately 10 times wavelength of the carrier frequency is required for a typical urban transmitter [9]. In [2], it was shown that diversity gain is fully effective over uncorrelated channels. However, in reality, the respective signal paths between spatially separated antennas and the mobile receiver are likely to be correlated to a certain degree because of insufficient antenna separation at the transmitter and the lack of sufficient multipath in the channel. In LOS or near LOS conditions, the respective signal paths between spatially separated antennas and the mobile receiver are likely to be correlated to a certain degree because of insufficient multipath in the channel. This results in a diversity loss and methods of overcoming this effect include amplitude profiling where the power transmitted from each antenna is deliberately unbalanced and spectrum shaping where an amplitude profile that varies across the signal spectrum is applied to achieve a 6dB difference in power level between the two antennas across subcarriers. Under this perspective it is also worthwhile to investigate the relation between the antenna horizontal and vertical spatial separation and the MISO performances.

The ESR$_{\%}$ has been measured along the standard test track and effect on MISO gain measured as a function of antenna distance. The test was repeated on consecutive days.

Fig. (**10**) shows the test performed on two different days. The results were near identical and it was decided not to conduct further tests. The results suggest that the optimal antenna separation corresponds to the MISO setup with antennas 1 and 4 (horizontal separation of 20λ). A smaller horizontal separation would increase the channel correlation and thus degrade the performances. However, a larger antenna separation would not necessary improve the performances [9] suggests that a decorrelated channel should be already achieved with 20λ antenna separation.

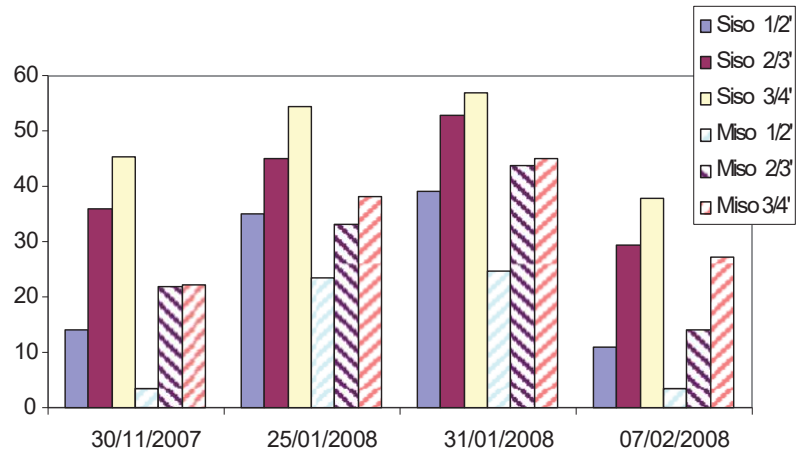


Fig. (9). SISO and MISO ESR for different code rates (QPSK with 1/32 guard interval).

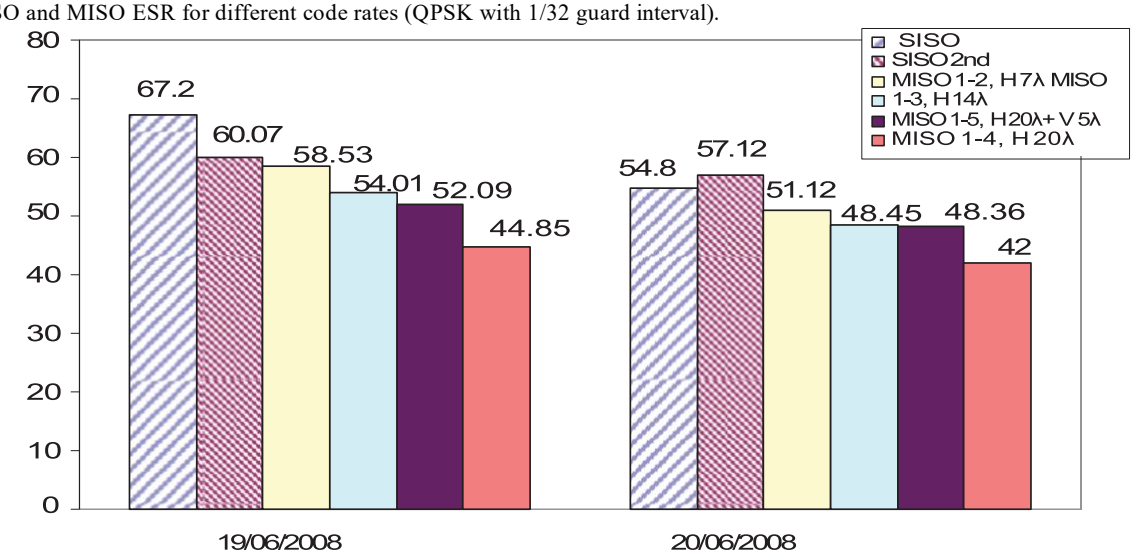


Fig. (10). ESR% for different antenna separations.

receiver thus reducing the transmit diversity gain. With 20Z horizontal separation a good diversity gain is observed since reception from these antennas exhibits a lower K factor (i.e. the receiver is in a NLOS situation during most of the drive).

3.2. DVB-H Tests

The transmitter set-up is the same as the above DVB-T test, except that a DVB-H transport stream (TS) with video content is transmitted instead of PRBS. The transmission parameters are summarized in Table **4**.

Table 4. Transmission Parameters for the DVB-H Tests

Constellation	**4 QPSK**
Sub-Carriers	2K, 8K
Guard Interval	1/32

Bandwidth	8 MHz
MPE-FEC Rate	7/8
Frame rows	256
Code Rate	3/4
Transmit Antenna Separation	20Z

The Dibcom DVB-H receiver implements proprietary channel estimation algorithms especially designed for high-speed mobility. This optimization has been shown to improve the SISO performance while leaving the MISO performance unchanged resulting in a smaller diversity gain after Reed Solomon decoding compared to the standard DVB-T receiver. The MPE-FEC extension is required to combat deep and long shadowing encountered in some mobile channels. The transmit delay diversity gain is more obvious when the MPE-FEC is not taken into account, since this already partly exploits time diversity by introducing a virtual time-interleaving. The implementation of MPE-FEC is not compulsory for a DVB-H receiver, since an MPE-FEC incapable (but MPE capable) receiver will be able to receive the data stream in a fully backwards-compatible way. The actual performance figures with $FER_{5\ \%}$ are very similar to what would be achieved using $ESR_{5\%}$ criterion to the transport stream directly. MPE-FEC requires a parity overhead from 12.5% to 50% of the total bit rate and it is worthwhile to investigate in which situations transmit delay diversity can help improving the capacity.

The DVB-H receiver can monitor one MPE stream at time, by logging the CNR, and the DVB-H parameters every second. An external 12 dB attenuator has been added at the receiver for both SISO and MISO experiments. This attenuator is needed to significantly increase the number of frame errors after the MPE-FEC without reducing the EIRP at the transmitter. Results are summarized in Fig. (**11**). The experiment was repeated on four different days. The improvement in the FER figure was on average 8.03% for the MFER was on average 5.12%. It can be concluded from these results that generally the diversity gain observed before MPE-FEC is higher than after MPE-FEC. $MFER_{\%}$ is lower than $FER_{\%}$ because the MPE-FEC decreases the Carrier to Noise Ratio (CNR) demand by 5 dB to 8 dB. To have more data points at different levels of CNR, additional measurements were made with 0 dB and 6 dB attenuators connected to the receiver's antenna input. Each $FER_{\%}$ and $MFER_{\%}$ points are calculated by taking into account at least 100 tables. The obtained diversity gain was approximately 2.5 dB and 1 dB for $FER_{5\%}$ and $MFER_{5\%}$, respectively.

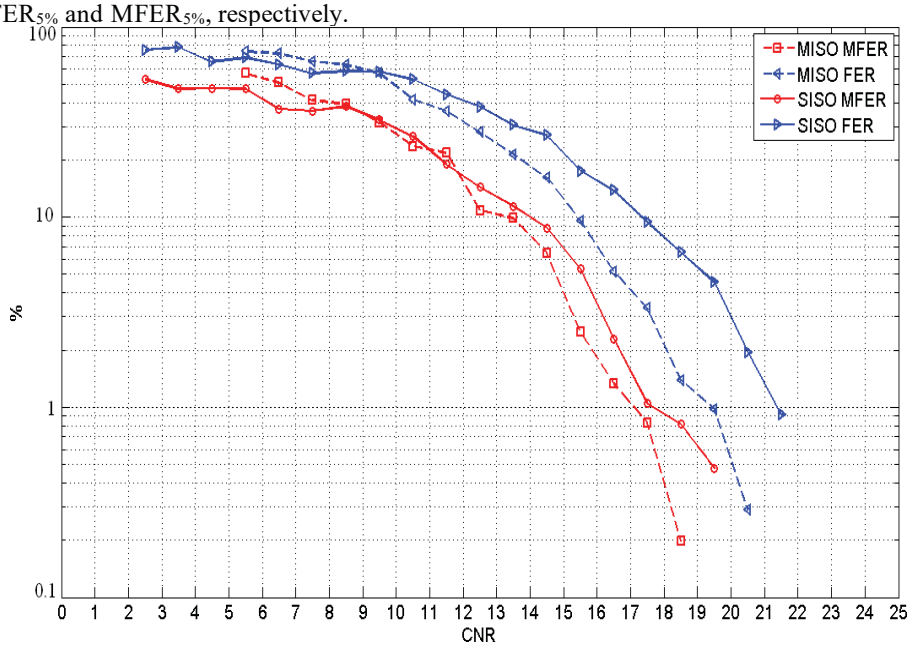


Fig. (12). MFER and FER *versus* CNR in dB for DVB-H MISO and SISO.

4. CONCLUSIONS

Transmit delay diversity is successful when applied to a conventional DVB-T/H system, as shown by the reported field trial findings. Additionally, the performance anticipated earlier via theoretical research and laboratory measurements may be realized in real-world scenarios. Driving in a suburban region dramatically reduces the number of errored seconds recorded and increases the occurrences of satisfactory reception, according to DVB-T measurement data. In general, the reported diversity increase of 4 dB employing the ESR5% agreed with earlier theoretical estimates. For network planning reference coverage of 95% and 70%, respectively, DVB-T coverage increased by around 7% and 20%. Transmit variety has been shown to boost data bitrate by around 1 Mbps. Ultimately, using a 20-degree horizontal spacing between transmit antennas resulted in the best performance increase. As the Ricean K factor number rose, an extra 5 □ of vertical separation decreased the gain.According to Dibcom's DVB-H experimental findings, diversity gains of around 2.5 dB and 1 dB were obtained for FER5% and MFER5%, respectively. Because the chipset implementation is already designed for high mobility reception, the FER5% gain is much lower than the ESR5% recorded with the Broadreach receiver. The MPE-FEC encoding's temporal interleaving effects result in a lower MFER5% gain than FER5%. This work has shown that the transmit diversity approach may be used with DVB-T/H standard systems to enhance reception in hard-to-reach locations without affecting the standard or making receivers more complicated. Rather of reducing overall range, transmit variety improves the quality of reception by spotlighting challenging non-Line of Sight circumstances.