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**Key words:** LSI Logic, L64782

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# Diversity Reception of Digital Terrestrial Television (DVB-T)

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## ABSTRACT

Using the European standard for digital terrestrial television, DVB-T, it is possible to achieve more robust reception by using more than one receiving antenna and combining the signals from the separate antennas in the digital processing as part of the normal COFDM demodulation process. The improved reception that this technique offers can be used to increase transmission reliability to both portable television sets and to mobile television receivers, such as those found in cars. The necessary circuitry to implement diversity reception is now implemented in the latest consumer DVB-T integrated circuits. This paper begins with a technical description of diversity reception and then outlines a set of mobile measurements that were made in a car in London and a set of measurements that were made to illustrate how diversity reception can be used to improve reception to portable television receivers using DVB-T.

## DIVERSITY RECEPTION

When two (or more) antennas are placed sufficiently apart in a demanding reception environment, such as in a moving vehicle or with indoor portable reception, it can be expected that there will be little correlation between the two signal paths. This can be exploited to make a receiver that is more reliable than a receiver connected to either of the two antennas individually. In a typical COFDM-based receiver, there are several places where the signals from two antennas could be combined.

The first is that the signals could be combined at the antenna outputs (this would typically provide a form of beam steering rather than true diversity).

The second is that the signals could be combined at the output of the channel correction process. If the combination process is done appropriately then this is equivalent to maximum ratio combining.

The third is that the signals could be combined at the input to the Viterbi decoder. If the combination of signals is done appropriately at this point, then this is also equivalent to maximum ratio combining.

The fourth is that the signals can be combined at the output of the Reed-Solomon decoder by selecting, on a packet-by-packet basis, whichever packet is error free (if any) at that moment. This technique is often referred to as "packet switched diversity".

This paper concentrates on the third technique where the signals are combined at the input to the Viterbi decoder. It is assumed that the processing is such that the combining process is equivalent to maximum ratio combining. This is the diversity combining technique that is incorporated into COFDM demodulator integrated circuits (IC), such as the LSI Logic L64782. The usual arrangement for connecting COFDM demodulator ICs is shown in figure 1.

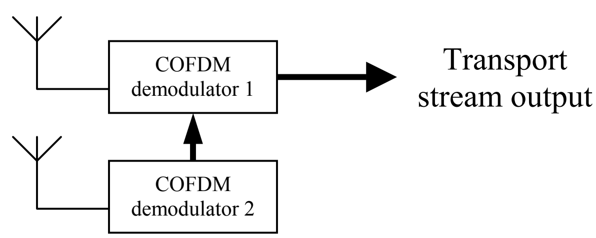


**Figure 1: Connection of two demodulators for diversity**

Because the signals take different paths between the transmitter and the receivers they will arrive at different times. Inside the COFDM demodulator, it is necessary to align the two signals by delaying the earlier signal until the later signal arrives. In aligning the signals, there are various things to consider, such as the possibility that the relative timing of the signals might change or that one or both of the signals may disappear (and perhaps reappear sometime later) or that one or both receivers may lose synchronisation.

The soft decisions that form the input to the Viterbi decoder are made by **combining** the soft decisions from each receiver. It is important to realise that at no time is there a selection of the signals between the two receivers.

The next section will show the results of a series of mobile tests that were carried out in London.

## MOBILE RECEPTION

In these tests an estate car was equipped with a diversity receiver and two horizontally polarized crossed dipole antennas were mounted on the roof of the vehicle. The receiver was set up to receive signals from the Crystal Palace transmitter in south London in an 8 MHz wide UHF channel. Channel 28 with a centre frequency of 529.833 MHz was used. The signals were transmitted in the 2K FFT mode, with a guard interval fraction of 1/32, a 16-QAM constellation and an FEC code rate of ¾. The useful bit rate in this mode is 18.096 Mbit/sec. This gives 2.262 Mbyte/sec and 12032 Reed-Solomon packets/sec. Figure 2 shows the set-up in the vehicle.

**Figure 2: Photo of the equipment used in the mobile tests**

In general the reception using the diversity receiver was very good. However, in order to provide a useful test we selected an area with difficult reception. Figure 3 shows the route recorded by the GPS receiver.

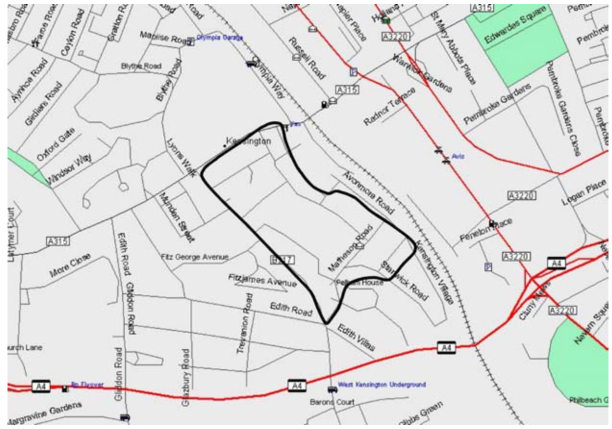


**Figure 3: Route of mobile test recorded by the GPS receiver**

The route was driven many times to test different modes, antennas and the benefit provided by the diversity receiver. The route typically took about five minutes to drive round. The receiver was set up to record the number of uncorrectable Reed-Solomon packets in each second. Table 1 shows the percentage of Reed-Solomon packets that have uncorrectable errors in each second over the whole route.

| Mode | Percentage of seconds with errors |
|---|---|
| No Diversity | 45% |
| Diversity | 20% |

**Table 1: Percentage of seconds containing errors over the route**

When using a receiver with diversity reception there is a significant reduction in the number of seconds that have uncorrectable errors.

Figures 4 and 5 show the number of uncorrectable Reed-Solomon packets per second throughout the test route. For example, using the non-diversity receiver, at 97 seconds into the route, there were about 12000 uncorrectable Reed-Solomon packets in one second. This corresponds to almost a complete loss of data for that second (because there are 12032 Reed-Solomon packets in total in one second).

You can clearly see from these two figures that using a receiver with diversity reception significantly improves the ability of the receiver to successfully decode the signal over the test route.

In general, the subjective "entertainment quality" was much better when using the diversity receiver than when using the standard receiver. For example, it was generally possible to follow the transmitted program.

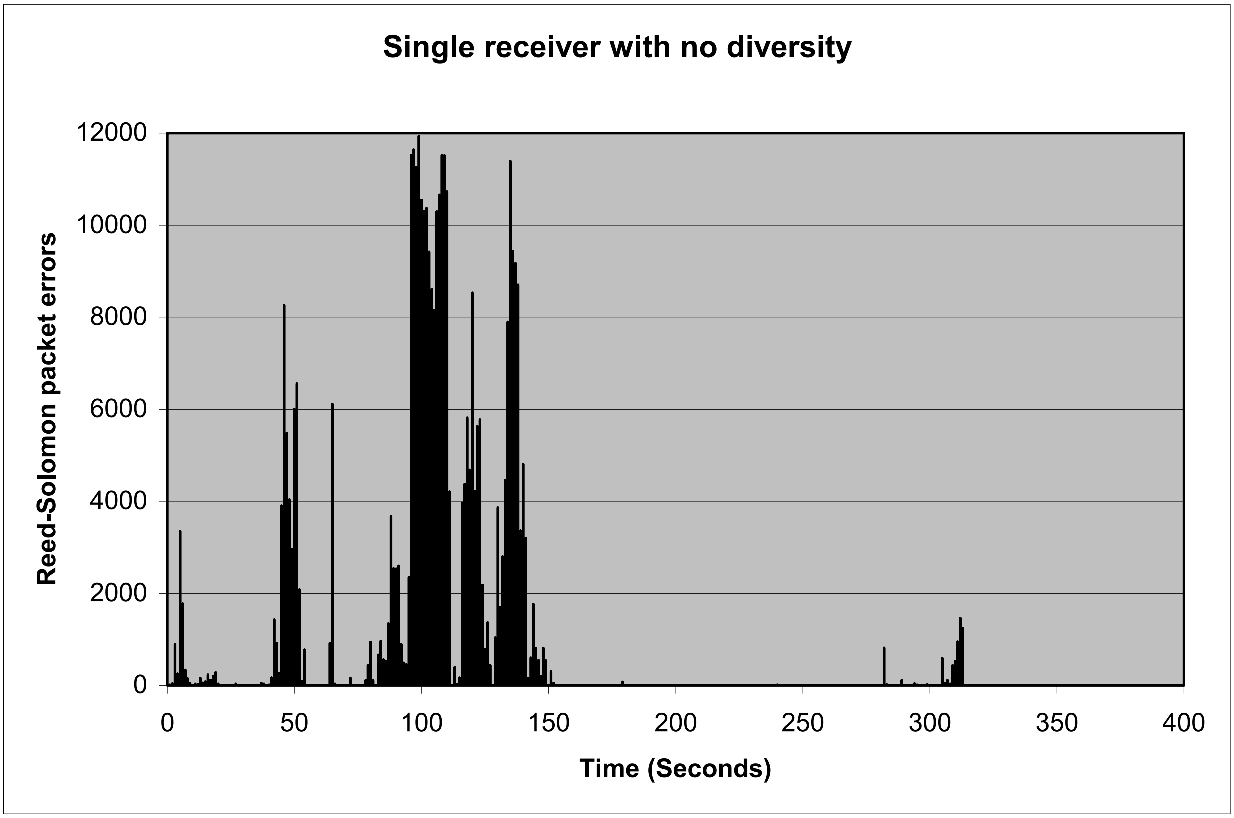


**Figure 4: Number of packet errors per second without using diversity**

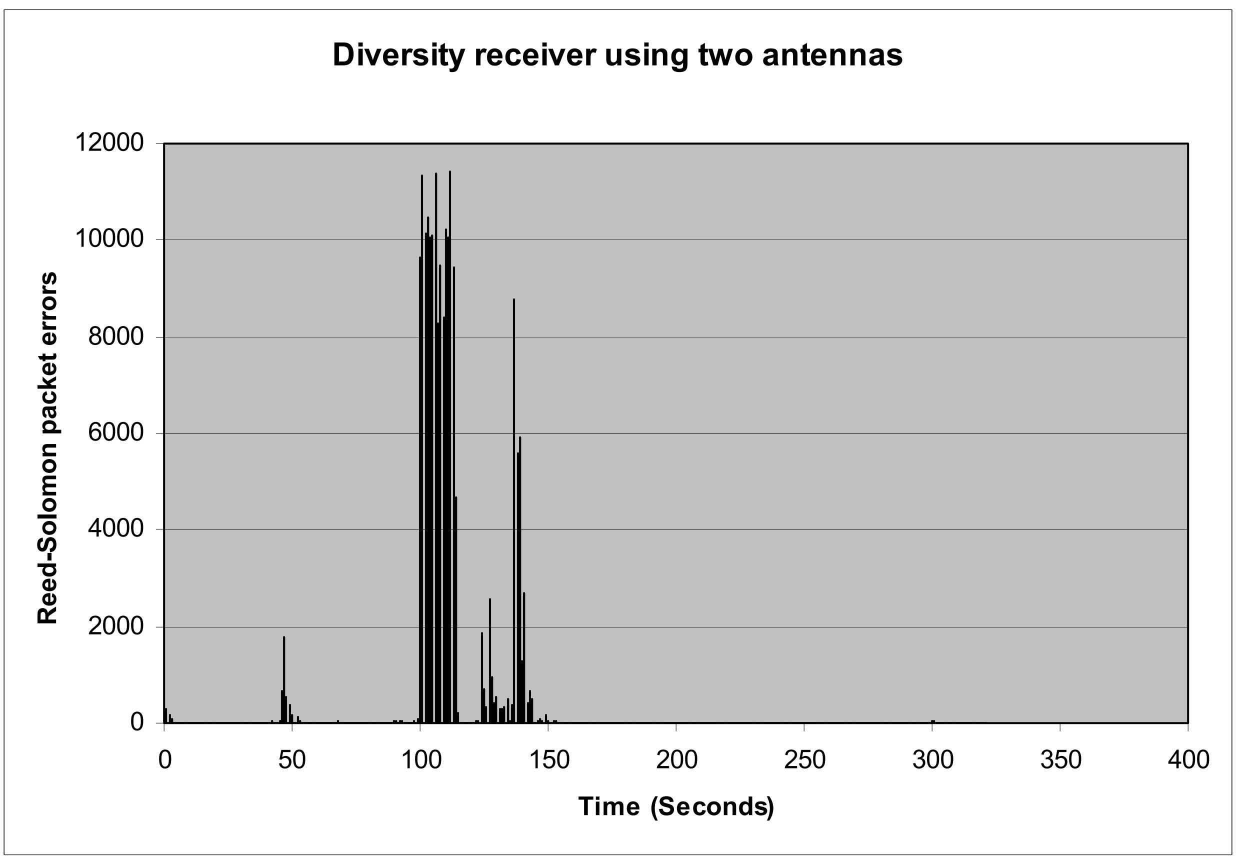


**Figure 5: Number of packet errors per second using a diversity receiver with two antennas**

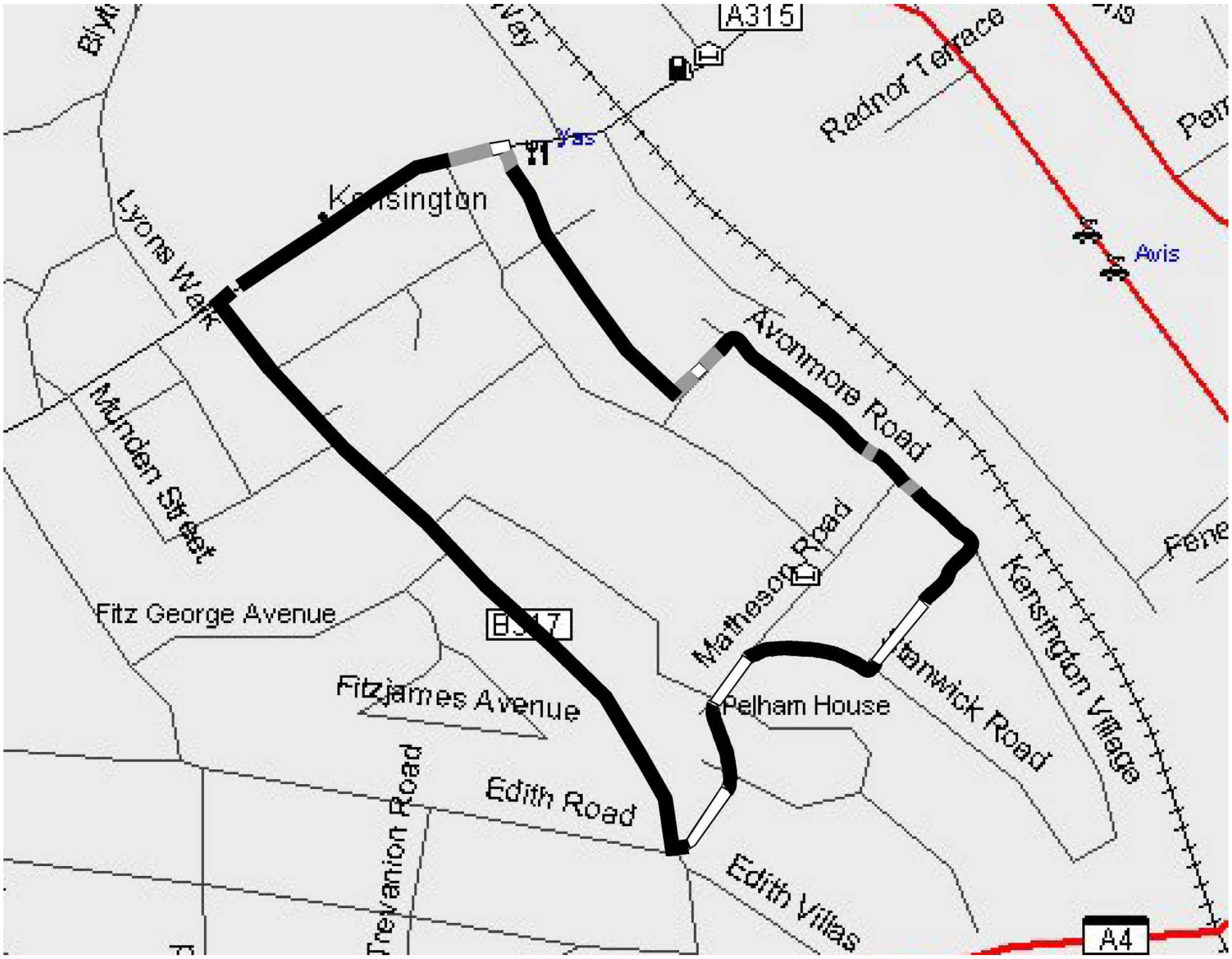


**Figure 6: Map of the route driven showing the improvement offered by the diversity receiver**

Figure 6 shows how reception on the route was improved when diversity was used. The route is coded to indicate the different types of reception. A black line on the route indicates that there were no uncorrectable errors during that part of the route. A white line indicates that neither the standard receiver nor the diversity receiver was able to successfully decode the signal at that point. A grey line indicates that the diversity receiver was able to decode the signal whereas the standard receiver was not. There were no cases where the standard receiver was able to decode the signal and the diversity receiver was not.

As you can see from figure 6, there is a significant advantage offered by the diversity receiver over the standard receiver. When using the diversity receiver there were very few places where there were uncorrectable errors.

MPEG-2 video decoding is very sensitive to uncorrectable errors and usually one uncorrectable Reed-Solomon packet is sufficient to cause a disturbance to the video or the audio.

## MOBILE TEST CONCLUSIONS

A route in London was driven several times to investigate the advantage offered by a DVB-T diversity receiver over a standard DVB-T receiver. The route was chosen to be difficult for a standard receiver to receive error free signals. The results of the mobile tests show that, over the selected test route, the number of seconds with uncorrectable errors can be reduced by a factor of between two and three. This means that using a diversity receiver it would be possible to have twice as many seconds free from video and audio artefacts. With the diversity receiver, it was generally possible to follow the content of the transmitted programme.

A broadcaster wishing to operate a mobile service for transmission to moving vehicles would be advised to consider a more robust transmission mode, such as 16-QAM rate ½ or QPSK rate ½. However reception was shown to be acceptable even when using the less robust mode of 16-QAM rate ¾. This mode was used as it is one of the modes currently transmitted in London.

## PORTABLE RECEPTION

Indoor reception on a portable antenna is often difficult because of relatively low signals and non-flat channel response. Severe multipath will cause the overall signal power to vary significantly over very short distances and the received signals will have amplitude variations that change with frequency over the channel. The rapidly changing signal levels mean that the exact position of the receiving antenna will be important. The variations in amplitude across the channel will decrease the signal-to-noise ratio in the receiver. The effect is an Effective Noise Degradation (END) and it will require a stronger signal at the receiver to overcome noise in the receiver[1].

Before a diversity receiver was available for use we had wanted to assess the benefits of antenna diversity inside buildings. Antenna diversity was expected to show improvements to both of the multipath effects. Using two antennas will increase signal voltages presented to the receiver; this advantage was expected to be similar to the power sum addition of the two input signals. Also, the detrimental effects of END on the "combined" signals were expected to be lower than those of the individual signals.

Measurements of received signal levels were carried out in 10 buildings to quantify the advantages of antenna diversity. For these test measurements, two omni-directional antennas were mounted on a mobile test-jig and measurements were recorded in a matrix of positions over rectangular floor areas of about 1 $m^2$. The test-jig was moved in 100 mm steps in the x and y planes within the floor space. This enabled 64-channel sets of measurements to be recorded for each of the two antennas. Figure 7 shows a matrix of measurements.

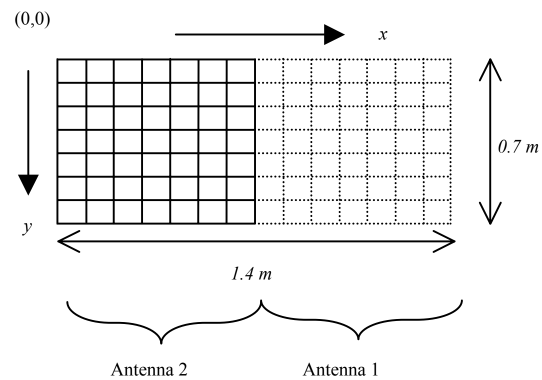

**Figure 7: A matrix of measurements using two antennas**

A measurement in the full 8 MHz channel bandwidth and 25 measurements in bandwidths of 300 kHz were recorded across the channel for each multiplex and with each antenna at each position[2].

The power sum addition of two similar signals would result in an increase of 3 dB relative to their mean value. The power sum of dissimilar signals will be greater than 3 dB because, as the difference between a pair of signals increases so the power sum addition increases relative to their mean value. As the two antennas in these tests were moved in different areas, the signal levels received on each antenna were different. The power sum addition of the 8 MHz measurements from the two antennas showed an average increase in level of 3.7 dB, this indicates an average difference of about 5 dB between signal levels from the two antennas.

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[1] Earlier work by RHM Poole at BBC Research and Development has shown that amplitude variations cause an increase in the effective noise in the receiver. When a signal is subjected to a short delay echo then the amplitude of the resultant signal varies with frequency; the amplitudes of some frequencies within the DVB-T ensemble will be enhanced and at other frequencies the amplitudes will decrease. As thermal noise is always present in the COFDM receiver, the effect of the echo is to increase the signal-to-noise ratio during the maxima, but to decrease it during the minima. The bit error ratio (BER) at the output of the demodulator varies accordingly. It might be thought that the BER would average out across the bandwidth of the signal to the value it would have in the absence of an echo. This is not the case because the BER increase at the amplitude minima is greater than the decrease at the maxima. If the required carrier-to-noise ratio of a receiver increases by 1 dB because of the amplitude response then this can be considered to be an Effective Noise Degradation (END) of 1 dB.
The END may be estimated using the formula:

END = 0.21 x amplitude response ripple, dB pk-pk.

[2] For the remainder of this document, the term signal level refers to the signal voltage measured at the output of an antenna.

As each measurement location is subjected to different path losses and multipath reflections, the resulting amplitude response, and hence END, will be unique to that location and (channel) frequency. For these measurements a response ripple was taken to be the difference between the highest and the lowest of the measurements recorded in the 300 kHz bandwidth.

The mean value of all of the ENDs for all channels at all locations, while considering a single antenna, was found to be 2.3 dB. For each multiplex, each pair of 300 kHz bandwidth measurements (recorded at the same frequency in the channel from each of the two antennas) was power-summed and the ENDs for the resulting signal was calculated. The mean END of the power-summed responses was found to be 1.1 dB. So for these measurements the average reduction in END by the use of antenna diversity is 1.2 dB.

For these measurements the mean benefit of using antenna diversity for reception of a single channel was calculated as the sum of the power gain and the reduction in END, i.e. 4.9 dB.

Figures 8 and 9 show the variation of signal level throughout the matrix as measured in a 300 kHz bandwidth on the two antennas individually. Figure 10 shows the power sum of the signals and it clearly shows an increase in the minimum signal level.

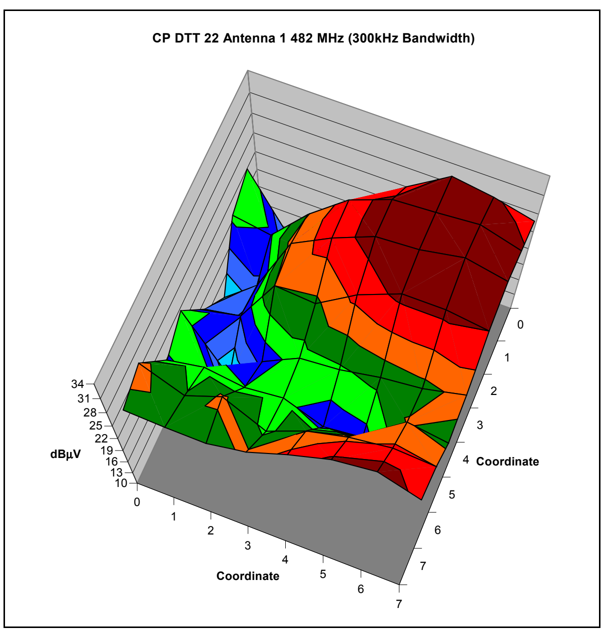


**Figure 8: Signal level measured on antenna 1 in a bandwidth of 300 kHz**

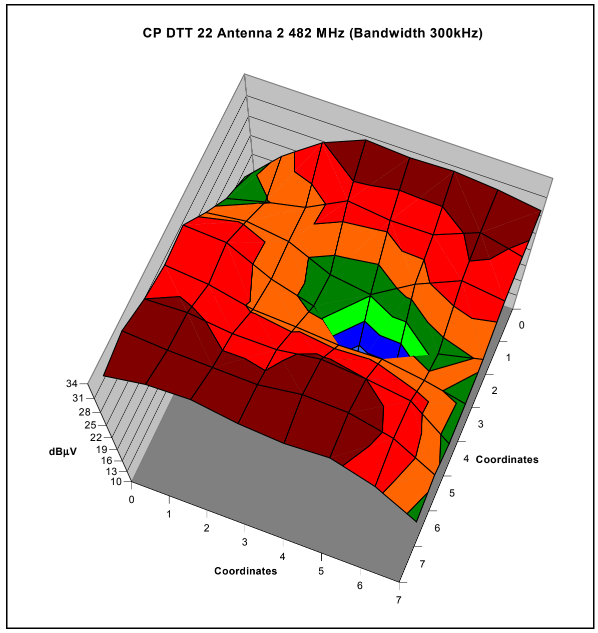


**Figure 9: Signal level measured on antenna 2 in a bandwidth of 300 kHz**

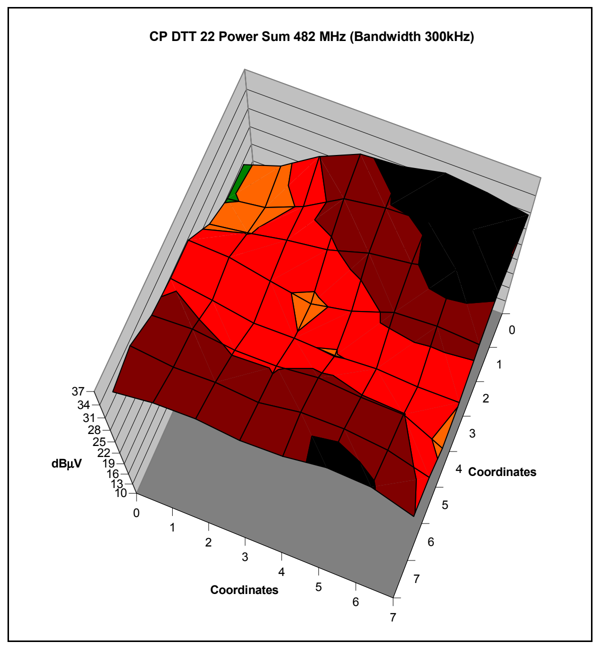


**Figure 10: Power sum of the signal levels measured on the two antennas**

A diversity receiver recently became available for testing. This receiver could be configured to indicate the Uncorrectable bit Errors (UCEs) for either of the two input chains and for the combined chain. A brief series of tests was conducted to validate the theoretical results shown above.

Two further test areas were chosen in other buildings and the original test method was repeated. The areas were further assessed by feeding the signals to the diversity receiver via a pair of variable attenuators. The reception margin was found for each individual chain simply by increasing and noting the attenuation at the onset of UCEs. The margin for the diversity mode of the receiver was found by increasing both attenuators equally until the onset of UCEs. The benefit of diversity was then taken to be the difference between the mean attenuation for the two individual input chains and that for the receiver in diversity mode. Figure 11 shows a typical measurement set-up for this second series of tests.

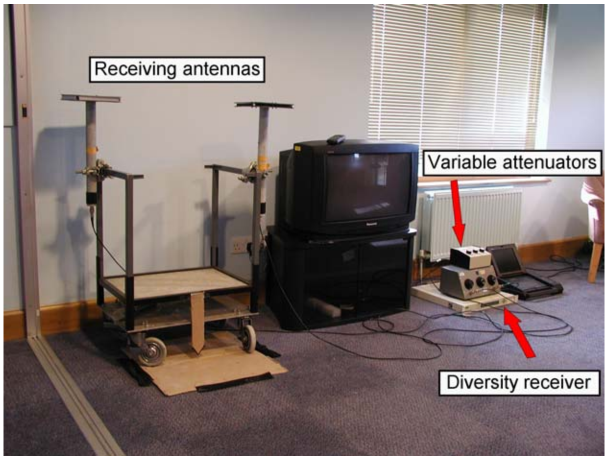


**Figure 11: A typical measurement set-up.**

Table 2 shows the results of the analysis for the two buildings.

| Measurement | Building 1 | Building 2 |
|---|---|---|
| Mean signal gain | 3.9 dB | 3.3 dB |
| END improvement | 0.9 dB | 1.8 dB |
| Benefit shown from the signal measurements | 4.8 dB | 5.2 dB |
| Improvement in margin using a diversity receiver | 4.8 dB | 4.3 dB |

**Table 2: Diversity reception improvements using signal measurements and a diversity receiver.**

The values obtained by the two methods are similar for one building and to within 1 dB for the other building. Although it is recognised that the size of this sample is limited, the results give confidence in the earlier results. On the basis of an effective advantage of 5 dB by the use of antenna diversity, plots of coverage from a DVB-T transmitting station were calculated to show indoor coverage both with and without the use of antenna diversity.

Fenham is a low powered DVB-T relay station designed to enhance coverage in Newcastle-upon-Tyne in north east England. It has a directional radiation pattern and a maximum ERP of about 20 W. Figure 12 shows the expected service areas for portable indoor coverage from Fenham, with and without the use of antenna diversity. Field strength predictions for the production of this figure were carried out at a resolution of ½ km.

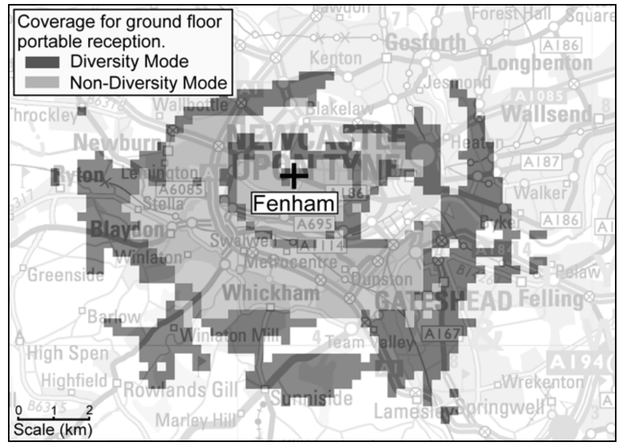


**Figure 12: The improvement to indoor coverage by the use of antenna diversity**

## PORTABLE TEST CONCLUSIONS

A diversity receiver gives improvements to reception by two different mechanisms. Firstly the receiver enjoys higher signal levels because of the additive effects of the two inputs and secondly the detrimental effects of amplitude response ripples are decreased. Measurements in the indoor portable environment have shown that antenna diversity offers a mean improvement of about 5 dB over reception using a single antenna.

## FINAL CONCLUSIONS

The latest generation of DVB-T integrated circuits, such as the LSI Logic L64782, include the ability to combine the signals received from more than one antenna. This means that a receiver offering diversity reception can now be built at consumer prices.

The two sets of tests reported in this paper show the advantages of diversity reception in different circumstances. The mobile tests showed that using a diversity receiver improves the periods that can be received with uncorrectable errors by a factor of between two and three.

The tests in the indoor portable environment show that using a diversity receiver offers a mean improvement of about 5 dB over reception using a single antenna.

From the results of these tests, it is clear that there is a worthwhile improvement available to viewers who wish to receive digital terrestrial television in a difficult reception environment such as a moving vehicle or an indoor reception environment using a portable television receiver.