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MIMO for Broadcast - results from a high-power UK trial

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ABSTRACT

Results are presented from a 250W ERP trial of a dual polarisation MIMO/DVB-T system carried out at the Guildford Transmitter site in the UK. Survey work using custom MIMO receiving hardware has allowed a coverage comparison with standard DVB-T and the development of a simple model of the 2-by-2 propagation channel for both fixed and portable reception.

Practical details of the survey work and analysis of the results are presented. It has been found that the dual polarisation MIMO system coverage compares very well with that obtained from standard DVB-T, yet offers up to twice the payload bit-rate in the same 8MHz channel. A system offering such an increase in capacity is particularly valuable at a time when efficient use of spectrum is an important consideration, and the opportunities to acquire new spectrum for additional services post digital switchover may be limited.

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INTRODUCTION

The results of recent experiments with a low-power dual-polarised MIMO broadcast system were encouraging [1], and suggested that a more realistic trial employing higher radiated power from an existing transmitter site was worthwhile. Hence a group was formed to install and evaluate an experimental 2 x 250W ERP DVB-T/MIMO system at Guildford transmitter site. This paper outlines the experimental equipment and describes the geographical coverage achieved by the MIMO system in comparison to a conventional DVB-T signal radiated from the same antennas.

This is followed by a description of the form a MIMO channel model could take for terrestrial broadcasting to fixed, portable and mobile terminals, thereby providing an experimental basis for future system simulation work.

Also included is an illustrative spectrum planning study to show how a future MIMO/DVB 32K mode (g.i. = 1/8) could potentially be used, regulatory constraints permitting, to provide a UK-wide SFN of 44Mb/s in just 8MHz of spectrum.

EXPERIMENTAL TRANSMITTER AND RECEIVER

The experimental transmitter was located at an existing broadcast station near the town of Guildford, approximately 32 km South West of London. The site is located overlooking the town, at a height of 188m above ordnance datum. The effective radiated power of the experimental service is a little above that of the existing digital TV services (200W or 100W), which serves the town itself and the surrounding area to a distance of around 19km. The station broadcasts numerous analogue and digital TV and radio services, leaving only a few locations on the structure where new antennas could be accommodated. Fortunately it was possible to identify two suitable locations. The first of these was near the top of the structure immediately below the existing UHF antenna cylinder, at a height of approximately 45m. Two antenna arrays, one vertically polarised, the other horizontally, were mounted on the corner of the structure. Each array consists of a pair of log-periodic antennas spaced a short distance apart horizontally. This arrangement provides a horizontal -3dB beam-width of around 40^o. Both arrays are oriented on the same bearing to provide equivalent coverage areas, as far as can be readily achieved given the inevitable slight difference in radiation pattern between the polarisations. The array is fed by a ½" foam-filled feeder, giving an overall antenna system gain of around 3dB. Details of the MIMO modulator can be found in [1].

Figure 1 shows the architecture of the receiver as outlined in [1]. Significant recent changes to the functionality of the receiver include a real time output of all the scattered pilots for both receiver paths and some useful receiver status data. This is embedded in a 32Mbit/s ASI stream. The embedded receiver status information is detailed synchronisation information (clock, start pulse position and frequency), lock status of each part of the receiver, AGC information and channel state information. This real time data access allows dynamic channel profiles to be captured rapidly at a large number of receiving locations.

PC based logging software captures the transport stream using a Dektec ASI-to-USB interface box. For each measurement location this also records a GPS location, an accurate power measurement of the received signal from each antenna, pre and post-Viterbi error rate measurements and whether the pictures were visible at each location. The control software lets the operator view various points in the receiver in real time such as the channel frequency response or the equalised constellation.

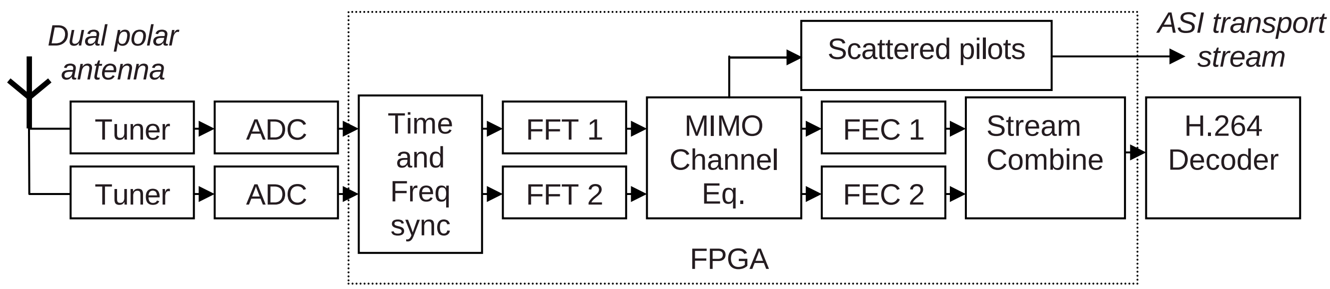

Figure 1 - Receiver architecture

A prototype dual-polarised 11.5dBi Yagi antenna was used for fixed reception trials, whereas a dual-polarised 0dBi omni was used for portable measurements.

MIMO COVERAGE COMPARISON

A major goal of this trial has been the assessment of the difference in service area coverage between DVB-T and the experimental MIMO system under investigation. Fixed location reception measurements with a receive antenna height of 10m above ground level were taken using a survey van. UHF channel 53(-) was used, coverage being primarily interference limited.

All measurements at a given location were taken within a few minutes of each other, with the receiving antenna locked in the same physical position. This maintained the same RF channel, as near as possible, allowing for a fair comparison between the transmission modes. Mobile phone remote control of the transmitter allowed quick mode changes. The measurement campaign had two elements.

a) Measurement of DVB-T (Horizontal polarisation), DVB-T (Vertical polarisation) and dual polar MIMO transmissions at a location.
b) Measurement of only the MIMO transmission at a location.

A total of 175 locations were surveyed. Of these, a set of geographically evenly distributed 87 locations were subjected to type (a) measurements and the remainder, primarily within the predicted service area were subjected to type (b) measurements.

Figure 2 shows coverage in terms of whether pictures were receivable. Figure 3 indicates excess noise at each location. Excess noise arises in matrix inversion if the channel matrix is not orthogonal. It gives an indication of how difficult a channel will be to invert and decode. Predicted coverage for horizontal DVB-T is shown shaded in green. Note that a known problem with the prediction tool causes an incorrect indication of coverage behind the antenna. This area (marked with a dashed line) is therefore not treated as part of the service area.

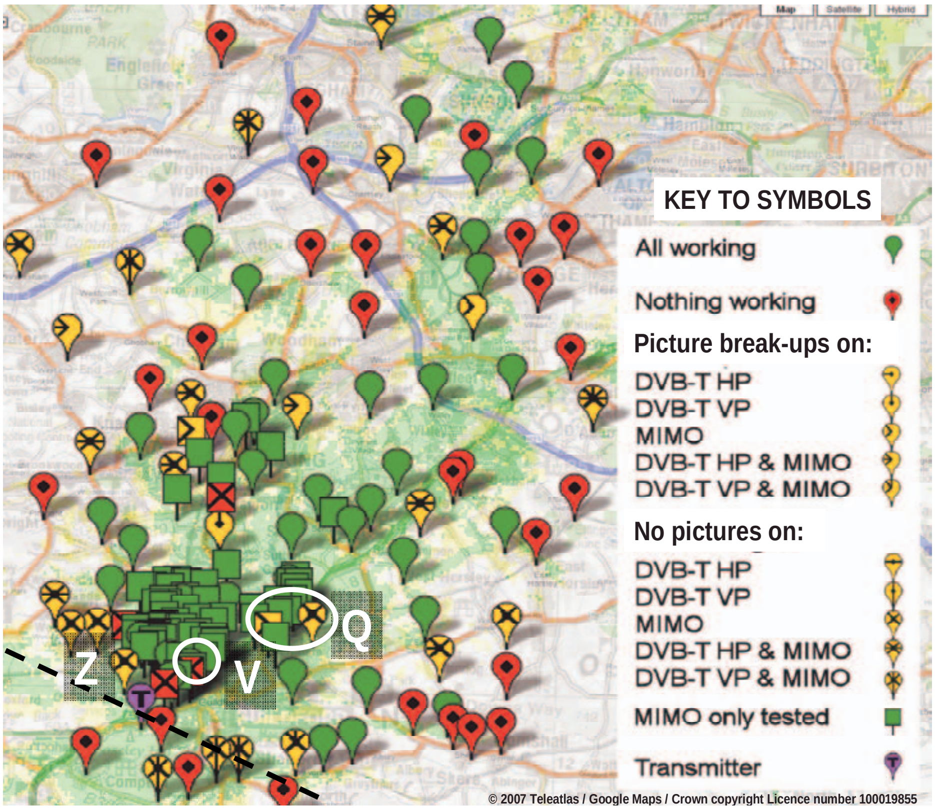

Figure 2 - Predicted and measured service area

It can be seen that the majority of the service area is covered by all 3 modes of operation. This shows that coverage of the MIMO system is comparable to that of DVB-T. At some extremities of the predicted service area, one of the DVB services was not receivable and as would be expected, neither was the MIMO transmission. Of greater interest are a number of locations,

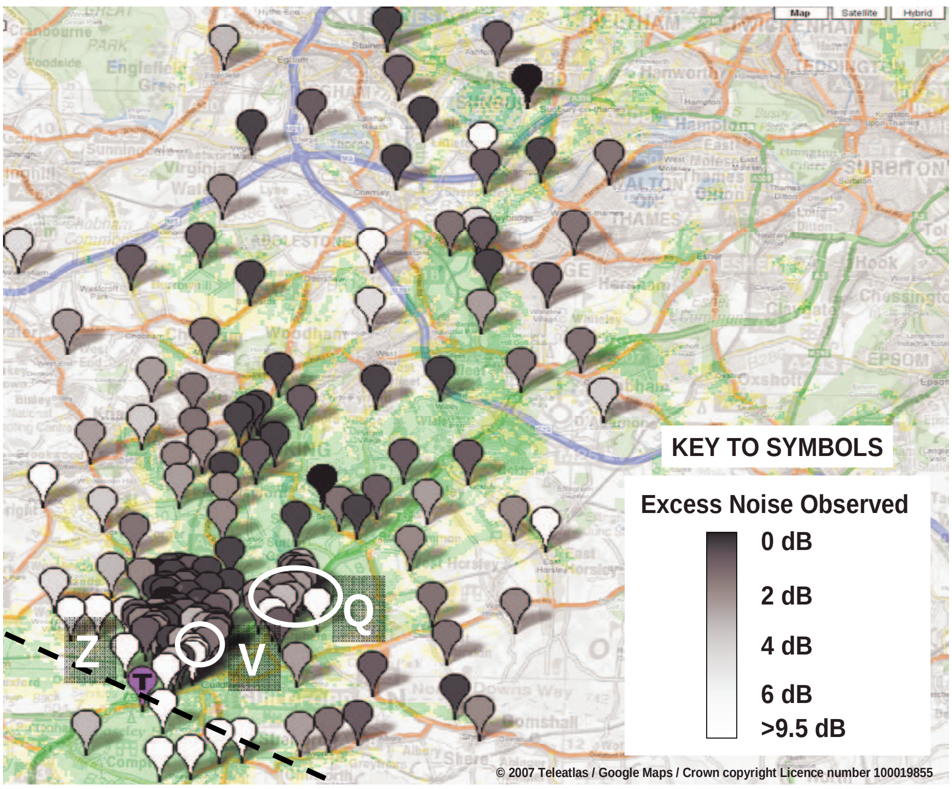

Figure 3 - Excess noise at each location

again mainly at the periphery of the service area, where both DVB-T modes were receivable but MIMO was not. One such cluster of locations is labelled **Z**. These 3 locations have highly non-orthogonal channel matrices. The received horizontal and vertical power levels are very different and the cross polarisation energy is high. This is in part due to being at the edge of the transmit antenna radiation patterns, which are not perfectly matched between polarisations.

MIMO reception failed at only 7 out of 108 locations within the predicted service area where DVB-T was receivable. Three of these had difficult channels to decode, due to path obstructions. The remaining locations are in 3 clusters of high excess noise areas, labelled **Z**, **V** and **Q** on figures 1 and 2, believed to be due to local terrain. One of the areas is elevated and although receiving good signal strength is subject to high levels of co-channel interference from nearby PAL transmissions, compounding decoding difficulty introduced by the poor channel orthogonality. It can be seen from figure 2 that in the majority of the predicted service area, excess noise is low, the mean excess noise being 3dB, with a standard deviation of 1.4dB. Use of a maximum likelihood decoder, in place of zero-forcing matrix inversion, should significantly improve the ability to receive the most difficult channels encountered.

CHANNEL MODEL

General approach

The aim is to provide a model of paths shown as h_{11}, h_{12}, h_{21} and h_{22} in the figure below, where Tx1 and Tx2 represent twin antennas at a terrestrial transmitter site and Rx1 and Rx2 the two elements of a MIMO receive antenna whether fixed or mobile.

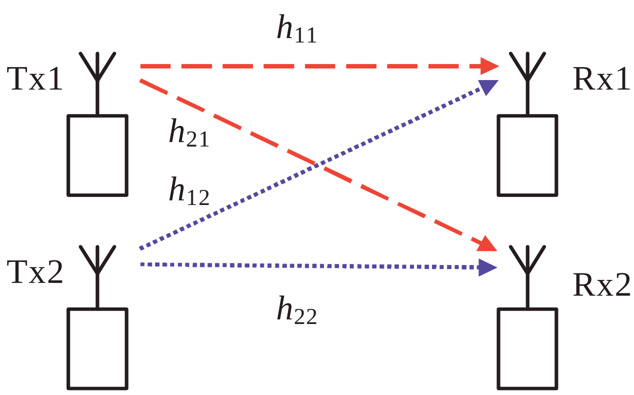

Figure 4 - 2-by-2 MIMO system

Since the 7.6MHz-wide MIMO/DVB-T signal is itself being used to sound the channel, there is a corresponding time resolution of about 132ns in the derived model. This, together with the observed time span of the typical channel impulse response, prompted creation of an 18-tap FIR channel model. The first four taps are spaced at one-quarter of the interval of the next 14. This was to capture more detail in the low excess delay region whilst keeping the total number of taps required to cover the observed delay spread reasonably low. The tap spacings are 263ns and 1.053µs respectively for the two regions, numbers that result from the existence of 142 DVB-T pilots in a symbol. In the normalised form of the model, first 'fine' tap is the sum of a line-of-sight term and a Rayleigh distributed term. It hence has a Ricean distribution. The remaining 17 taps are drawn from a Rayleigh distribution. The overall PDP is scaled so that the total of all taps is unity for h_{11}, and h_{22}.

Mathematically we can express the proposed channel model as

$$\mathbf{vec}(\mathbf{H}^T(t)) = \mathbf{L}\delta(t) + \sum_{j=1}^{18} \mathbf{R}_j^{1/2}\mathbf{x}_j\delta(t-\tau_j) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Here $\mathbf{vec}(\mathbf{H}^T) = \begin{pmatrix} h_{11} \\ h_{12} \\ h_{21} \\ h_{22} \end{pmatrix}$, $\mathbf{L} = \begin{pmatrix} \sqrt{\frac{K_{11}}{1+K_{11}}} \exp j\theta_{11} \\ \sqrt{\frac{K_{12}}{1+K_{12}}} w_{12} \exp j\theta_{12} \\ \sqrt{\frac{K_{21}}{1+K_{21}}} w_{21} \exp j\theta_{21} \\ \sqrt{\frac{K_{22}}{1+K_{22}}} \exp j\theta_{11} \end{pmatrix}$ ......(2)

where t is the time index and τ_j the time position of the jth tap (zero for j=1). K_{ij} are the Ricean K-factors for each term and θ_{ij} are uniformly distributed random phases. This form of **L** ensures the total impulse response power in h_{11}, h_{22} is unity and the w_{12}, w_{21} terms[1] adjust the LOS level appropriately for h_{12}, h_{22}. $\mathbf{R}_j$ is the 4-by-4 covariance matrix of the vectorised elements of the channel matrix at the j^{th} tap[2]. $\mathbf{x_j}$ is a (distinct) random vector for each j with i.i.d. complex Gaussian components of unit variance. The required square root of $\mathbf{R}_j$ satisfies $\mathbf{R} = \mathbf{R}^{1/2}\mathbf{R}^{*/2}$ and can be obtained by taking the Cholesky decomposition of $\mathbf{R}_j$ and then taking the Hermitian transpose.

Parameter extraction

For each reception scenario (e.g. fixed, portable or mobile), the model must be customised by a suitable Ricean K-factor, PDP and correlation matrix **R**. This work is ongoing at the time of writing, and early indications are that for fixed reception the K-factor is relatively high (greater than 10) and **R** has only quite small off-diagonal terms, indicating low correlation of the fading terms of the channel matrix. Shown here, however, is a typical result for the average PDP of a number of portable channels, which has somewhat lower K-factor and higher levels of cross-polar coupling.

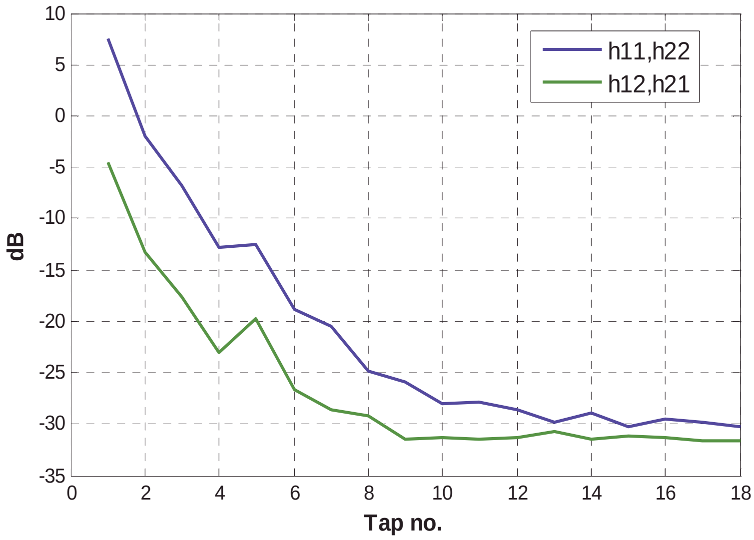

Figure 5 - Typical Portable Power Delay Profile

Figure 5 shows the profile of the principal components (h_{11} and h_{22}) and of the cross terms (h_{12} and h_{21}). The line-of-sight path (tap 1) shows a cross-polar discrimination of about 11dB.

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1 $w_{12} = w_{21}$ in this model

2 Excluding line-of-sight terms; i.e. the Rayleigh fading part of tap one and the whole of all other taps

ILLUSTRATIVE STUDY: 32K MIMO SFN

The potential coverage of a dual polarisation MIMO network has been investigated by carrying out coverage predictions for an example national transmitter network in the UK.

We assume that UHF channel 31 will be used to implement a MIMO system as a single frequency network (SFN). In the UK this channel will be released as part of the transition from analogue to digital television. The system characteristics are based on the DVB-T2 standard under development which is likely to include a 32K carrier option with sufficient guard interval for a national SFN.

The planning assumptions used in the coverage analysis are shown in table 1, alongside the characteristics for the 64QAM DVB-T variant which will be used in the UK following the analogue to digital transition. We assume that all viewers will install new roof-top antennas to enable reception of both MIMO polarisations. This will include an active antenna system to allow the existing feeder cable to be used and will compensate for both the reduced gain of the dual-polar antenna and the higher C/N requirement relative to a non-MIMO system. Replacing existing receive antennas has significant cost implications but in many cases this would still be necessary for non-MIMO applications due to reasons of antenna alignment or channel grouping.

	MIMO	**DVB-T** **UK Variant I**
Modulation/FEC	64 QAM 2/3	64 QAM 2/3
Carriers	32K	2K
Guard interval	1/8 (448 µs)	1/32 (7 µs)
Data rate	44.24 Mbit/s	24.1 Mbit/s
C/N in Ricean channel	18.6 dB	17.1 dB
Practical C/N	24.3 dB	22.8 dB
Receiver antenna gain	9 dBd	10 dBd
Feeder loss	0.5 dB	3 dB
Minimum field strength	46.8 dBµV/m	46.8 dBµV/m

Table 1 - Reception technical assumptions

The coverage predictions have been based on a network of 113 existing broadcast sites including the main TV sites and major relays. Population coverage estimates are shown in table 2 for different percentage coverage thresholds at the edge of service. Results for two scenarios are included. Scenario A assumes no use of channel 31 in other countries so there are no outgoing interference restrictions or incoming interference. The maximum effective radiated power (ERP) at each site has been based on the power in the GE-06 plan. For most of the sites we have assumed that the GE-06 ERP can be transmitted on both polarisations but on the highest power sites the power has been split with half on each polarisation because we believe implementation of the full power will be very difficult due to lack of antenna space on the transmitter towers.

In Scenario B the aim is to be compatible with the planned use of channel 31 in neighbouring countries. Power reductions and simple antenna patterns have been applied to keep the interference to neighbouring countries within the levels produced by the channel 31 transmitters in the agreed plan. In most cases the UK plan entries are single polarisation but we have assumed that use of the other polarisation would be possible if the power is reduced to keep interference to planned levels. Incoming interference from assignments on channel 31 in neighbouring countries has been included as they appear in the plan.

Interference from the non-UK transmitters is single polarisation which means that the predicted coverage of our two MIMO polarisations is different. The MIMO system requires both polarisations to be received. The horizontal polarisation coverage is the most important in determining the overall coverage because the main interferers are horizontal.

		Population		
Scenario	**Coverage**	**Acceptable** **70% locations** **99% time**	**Good** **90% locations** **99% time**	**Good** **95% locations** **99% time**
A	Both Polarisations*	98.5%	97.6%	96.9%
B	Horizontal Polarisation	96.6%	93.8%	92.0%
B	Vertical Polarisation	97.1%	94.9%	93.5%
B	Both Polarisations*	96.6%	93.8%	92.0%

*required for MIMO reception

Table 2 -Population coverage results, percentage of UK population

The predicted coverage for Scenario B is shown on the map in figure 6. The covered areas are shaded grey. The results show that a network providing a high level of coverage over most of the UK could be designed provided that international coordination of interference limits can be reached within the framework of the RRC-06 agreement. . Interference from other countries is a problem for some areas because the MIMO system cannot rely on the polarisation discrimination of the receive antenna. The outgoing interference restrictions and incoming interference levels will be different for each channel and the channel studied here (channel 31) may not be typical.

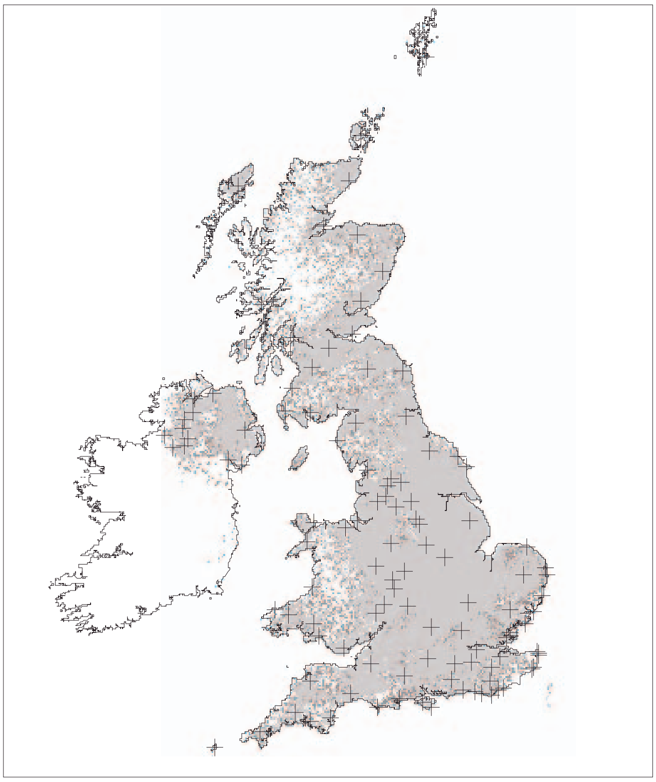

Figure 6 - Coverage prediction map for MIMO network, Scenario B

It is important to note that this is only a high level planning exercise based on simple assumptions about spectrum usage in neighbouring countries and how a UK SFN might be coordinated with it.

A real network would require more detailed planning and antenna design and may be subject to different power restrictions and incoming interference.

POTENTIAL DIFFICULTIES AND SOLUTIONS

For a viewer to receive the signal, a new dual-polar antenna and set-top box would be needed. However, if the benefits of new services are significant, this may be acceptable to the consumer. The need for a dual down-lead can be avoided by using a phantom powered pre-amplifier, frequency block converter and diplexer integrated into the antenna. This converts one of the received polarisation's UHF signals to another band (e.g. 1-1.5GHz) before combining with the other polarisation's unshifted UHF signal and transmitting both down the existing co-axial feeder cable to the viewer's set top box. Preliminary calculations have shown that such circuitry will require a high dynamic range, but should be achievable with commercial grade components.

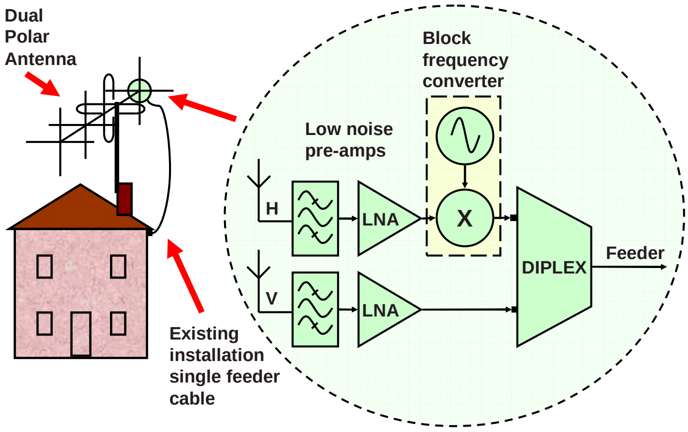

Figure 7 - Block frequency conversion allows reuse of existing single feeder cable

If permanent broadcast services were to be launched using the MIMO techniques evaluated in this paper the challenges for the broadcast site owner are similar to those encountered for the trial. Most structures are heavily utilised by numerous broadcast and ancillary services, and are highly valuable to numerous parties. Finding suitable aperture to launch new services is always a challenge. Improved antenna gain, and hence reduced transmitter capital and running costs, can usually only be achieved with increasing aperture thereby providing the operator with a design trade-off. As indicated earlier achieving equivalent radiation patterns, and hence equivalent coverage areas, for either the two polarisations or the two diversely spaced arrays, would present a further design issue. The arrays used for the trial were relatively directional, low-gain designs. Achieving equivalence of radiation pattern for horizontal and vertical versions is therefore relatively simple. Achieving such equivalence in an omni-directional high-gain system may be more difficult.

CONCLUSIONS

A high-power MIMO/DVB-T transmitter has been installed at Guildford transmitting station and the resultant coverage surveyed. Results are very encouraging and show that the system works very well in practise, providing virtually the same coverage as a conventional DVB-T transmitter at the same site. In addition, an illustrative study of a 32K SFN shows how a UK-wide 44Mb/s multiplex could in principle be established. Such a system would make highly efficient use of limited spectrum resources.

REFERENCES

1. J.D.Mitchell, P.N.Moss and M.J.Thorp 2006 "A Dual Polarisation MIMO TV Broadcast System" Proceedings of the 2006 International Broadcasting Convention pp. 303-310.

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