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Digital Radio Mondiale (DRM): multi-transmitter networks and diversity reception

O.P. Haffenden, A.J. Murphy *and* J.E. Elliott

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Propagation in the short-wave bands is subject to deep and unpredictable fading, so that, in the margins of the coverage area, a frequency that is generally useable is likely to fail from time to time.

A promising way to overcome this problem is to transmit the same signal on more than one frequency simultaneously, in the hope that fading will occur at different times on the two frequencies. Such transmissions can be exploited by a number of possible receiver techniques.

This paper presents tests performed using a synchronised two-frequency network operated by VT Merlin Communications, together with a diversity receiver developed by BBC R&D.

Single-frequency networks are also possible, and might offer some of the same advantages but with better spectral efficiency and a simpler receiver. Such a network is currently being set up, and first results are expected in time for the presentation at IBC.

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DIGITAL RADIO MONDIALE (DRM): MULTI-TRANSMITTER NETWORKS AND DIVERSITY RECEPTION

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ABSTRACT

Digital Radio Mondiale (DRM), the new international standard for digital broadcasting below 30MHz, was launched in June 2003 and a large number of transmissions are now on the air.

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INTRODUCTION

Digital Radio Mondiale (DRM) was officially launched at the World Radiocommunication Conference (WRC03) in June 2003 in Geneva. DRM is a new system for digital broadcasting on the short-, medium- and long-wave bands currently used for AM (1). It aims to provide the large coverage areas associated with transmissions in these bands, while giving improved (FM-like) audio quality and extra features made possible by the digital delivery mechanism.

Coinciding with the launch, several broadcasters began transmitting regular services in DRM, replacing test transmissions which had already been on the air for over two years. These include transmissions by the BBC World Service, and the opportunity was taken to make measurements of the quality of reception of these services whilst en-route to Geneva and in the European Broadcasting Union (EBU) building where demonstrations were being given as part of the launch.

MULTI-FREQUENCY TRANSMISSION AND DIVERSITY RECEPTION

Since short-wave transmissions travel long distances by sky-wave propagation, the received signal is affected by continual changes in the ionosphere. These changes occur rapidly and can cause fading that is impossible to predict except on a long-term statistical basis. DRM's use of Orthogonal Frequency Division Multiplexing (OFDM) combined with forward-error-correction coding (FEC) allows it to deal with a certain amount of frequency-selective fading, whilst the use of time interleaving of up to two seconds can provide some resistance against short-term fades of the entire signal.

However, longer-lasting fades are also possible, and these cannot be dealt with by the interleaving.

Many short-wave AM broadcasters attempt to overcome this by targeting the same area with more than one frequency at the same time, from either the same or different transmitting sites. Their hope is that if one particular frequency cannot be received in a given location, one of the others might be more reliable. To benefit, however, the listener has to be aware of the alternative frequencies, and have the inclination to try them.

In digital broadcasting, the alternative frequencies can be signalled directly to the receiver. There are several possible ways in which the receiver could make use of such parallel transmissions.

Firstly, it could compare them to see which is the best, switching between them as necessary, without the listener needing to know this was happening. DRM has been designed with this possibility in mind. It provides a mechanism for signalling which alternative frequencies are available at any given time, using a modulation scheme that is more robust than that used for the audio signal itself. It also includes a regular section during which only repetitive information is transmitted, which will in principle allow a receiver to switch seamlessly to an alternative frequency without loss of audio (see 1, annex G3).

A more sophisticated receiver could exploit the transmissions in a second way, if it were equipped with two radio-frequency front-ends. Instead of simply switching between alternative frequencies, it could *combine* the information from both; in other words, it could perform diversity reception.

Although a frequency-switching receiver may be less expensive to produce because it would need only one front-end, the algorithms required would be more complicated, requiring substantial research and development effort. The issues include determining whether the alternative frequency really carries the same signal as the current frequency, and if so whether it is better or worse than the current one; rapidly achieving time- and frequency-synchronisation and equalisation on the new channel; and doing this with the minimum of degradation to reception on the current frequency.

Diversity Reception in the BBC Receiver

BBC R&D have developed a professional monitoring receiver, which is capable of performing several types of diversity reception. This can be used to give some indication of the potential benefits of a frequency-switching receiver, and hence whether development of such a receiver is worthwhile.

The architecture of the diversity receiver is shown in Figure 1.

The signal from the antenna is first digitised at a high sampling rate. Each of the two alternative frequencies is then separately selected and mixed down to complex baseband ("I/Q") using a digital down-converter IC. The two baseband signals are then demodulated completely separately, in a digital signal processing IC, up to the point at which equalised Quadrature Amplitude Modulation (QAM) constellations are recovered.

There may be a relative delay between the two demodulated signals, due to differences in buffering and synchronisation. A compensating delay is added, so that constellation points corresponding to the same OFDM carrier and symbol are aligned.

The aligned, received constellation points are then combined. A number of different combination methods are provided in the receiver. The best performance is given by Maximum-Ratio Combining (MRC), in which a weighted mean of the two points is calculated, with the weight for each being proportional to the receiver's estimate of their (power) signal-to-noise ratio (SNR). The signal-to-noise ratio of the combined constellation point is also estimated, and this information is passed to the FEC decoder. The FEC decoding and subsequent audio decoding are the same as for a single-channel receiver.

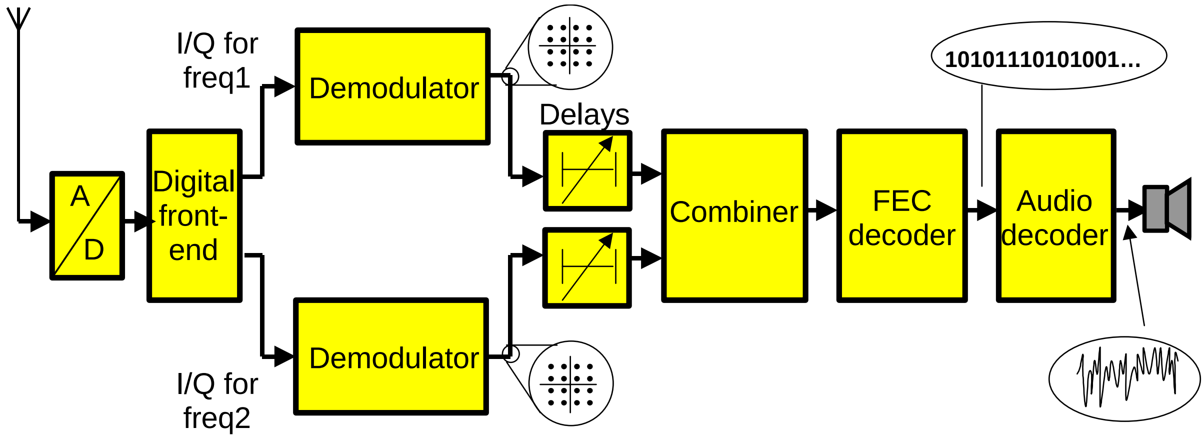


Figure 1 – Architecture of BBC diversity receiver

The other combining methods include cell switching, in which the constellation point with the better estimated SNR is used and the other one discarded, and frame switching, in which the entire frame is taken from one frequency or the other according to the overall SNR. This latter method is intended to approximate more closely the behaviour of a switching receiver, albeit without the problems of synchronisation mentioned in the previous section.

EXPERIMENTAL SETUP

Synchronised Multi-Frequency Transmissions

In order to test the performance benefit of multiple-frequency transmissions, it was necessary to put together a multiple-frequency network. For a frequency-switching receiver to be able to work, the transmissions need to be synchronised sufficiently well that the switching windows overlap in the two transmissions. In practice, it is likely that more accuracy is needed than this, to allow the synchronisation and comparison algorithms to gather enough information about the alternative frequency.

A diversity receiver receives both frequencies all the time, so the synchronisation accuracy need only be better than the maximum compensating delay that the receiver can provide.

The most stringent timing requirement is for a single-frequency network (SFN), in which the time delay between the signals needs to be a fraction of the OFDM guard interval.

A synchronised network was put together using BBC-designed modulators; these have sufficient accuracy for an SFN, so are easily capable of MFN operation. It was operated by VT Merlin Communications from the Rampisham transmitting station in the UK, using frequencies of 7320 kHz and 9410 kHz. The network is described in a separate paper (2).

Receiving Setup

Receiving equipment was installed in a survey van, as shown in Figure 2. An active antenna was mounted on the van roof, and fed via a passive splitter arrangement to three BBC receivers.

The receivers output detailed reception information through their Ethernet interfaces, using the DRM Receiver Status and Control Information protocol (RSCI), currently being standardised through the European Telecommunications Standards Institute (ETSI) (3). The receivers were configured to send this RSCI data to a Macintosh "Powerbook" computer over a small local network.

This setup has been used for a range of investigations, but was designed principally for comparative measurements of the benefits of diversity reception in an MFN. In this case, one receiver is tuned to the first frequency, another is tuned to the second frequency, and a third, set to diversity mode, receives both frequencies at once. The reliability of reception on the three receivers can then be logged and compared.

Significant effort was required to reduce the level of RF interference from the van itself into the receiving antenna. Originally, the equipment had been powered by an inverter, but this was found to produce an unacceptable increase in the noise floor. Consequently, measures were taken to eliminate it entirely: the active antenna was powered from two lead-acid batteries, the Powerbook was run on its own batteries, and a passive splitting arrangement was used in the antenna feed instead of the distribution amplifier envisaged in the original plan. The receivers themselves and the Ethernet switch were powered from the van's technical battery.

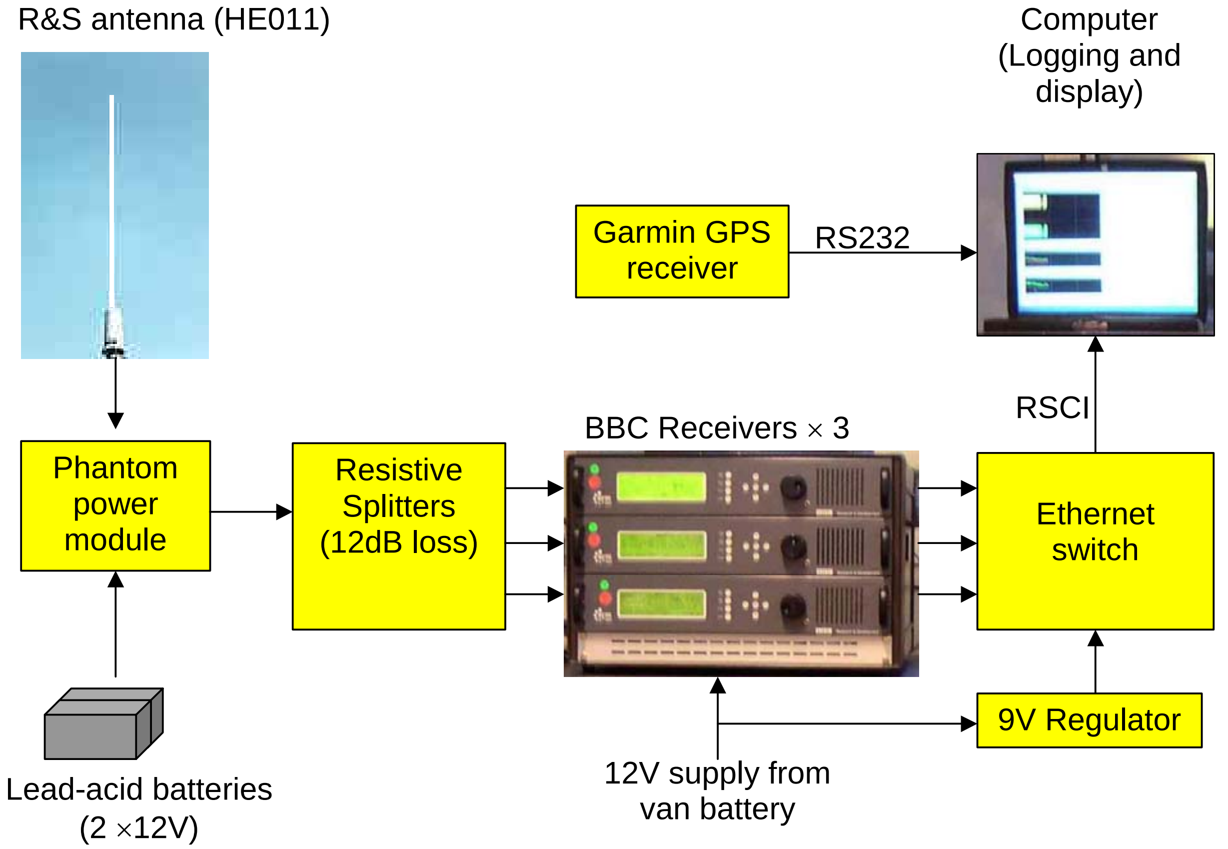


Figure 2 – Receiving set-up in the survey van

Logging and Presentation Software

A custom-written application was run on the Powerbook, to provide an informative real-time display of the changing channel conditions and comparative performance. The information was also stored to disc, allowing detailed analysis to be performed later.

Amongst the information displayed and logged are the signal strength, the Modulation Error Ratio (MER) and the audio reception status. The signal strength is measured at the antenna input of the receiver; a separate calibration exercise was undertaken to obtain an estimate of the antenna factor, allowing these values to be converted to approximate field strengths.

The MER is the receiver's estimate of the overall signal-to-noise ratio (SNR), derived from the received constellation points. The audio reception status indicates the presence of bit-errors in each 40ms received audio frame; these can be detected because the audio frames contain checksums.

RESULTS

Examples of Diversity Reception

A typical screenshot from the logging and presentation program is shown in Figure 3. This example demonstrates several of the key phenomena that were observed during the tests – the white numerals have been added to indicate points of particular interest.

Figure 3 – Screenshot from the diversity monitoring application

The various graphs show the evolution of the reception over a three-minute period of time. The coloured bars show audio dropouts for the three receivers. The top (yellow) bar corresponds to the diversity receiver, while the bottom two (red and green) bars are for the two receivers each tuned to a single frequency (A or B respectively). Where the colour is present, the audio was error-free; the black sections indicate audio errors. The white line superimposed on the bottom bars indicates the proportions in which the diversity receiver is combining the two frequencies. At the top of the bar for receiver A, it is using only frequency A; at the bottom of receiver B's bar, only frequency B is used.

The other graphs show the signal strength and the MER for each frequency; the same colour is used for each frequency as for the corresponding audio status bar in the top graph. In both graphs the vertical divisions correspond to 10 dB.

In this example, neither frequency on its own is particularly reliable, with frequent dropouts occurring on both. The dropouts generally coincide with periods of low signal strength – flat fading – and a corresponding drop in the MER can be seen.

The fading on one frequency is not noticeably related to that on the other, and so many of the dropouts on one frequency occur when the other frequency is being decoded correctly (e.g. at point 1). At these times, the diversity proportion graph indicates that the diversity receiver favours the better of the two frequencies, so is also able to give uninterrupted audio.

At other times, the two frequencies fade together such that both single-channel receivers stop decoding. Nevertheless, in many of these cases the diversity receiver was able to carry on working (e.g. at point 2). This is possible because the noise on the two frequencies will in general be uncorrelated, so an improvement in SNR of up to 3 dB can be achieved when the two signals are combined.

Finally, there are a few occasions where the simultaneous fading on the two frequencies is too much even for the diversity receiver to tolerate, and it too suffers audio dropouts (e.g. at point 3). However, it is clear from the graph that the overall reliability has been improved substantially by the use of diversity reception.

Analysis

The results were analysed by dividing the reception into fixed, ten-second time periods. For each period, the overall proportion of correctly decoded audio frames over the period was calculated, for each receiver. Periods were classified as good or bad according to whether 90% of audio frames were correct.

Each period could then be assigned to an overall category according to the combination of the classifications for the three receivers. The following categories were used:

- Frequency 1 works, as does the diversity receiver, but frequency 2 does not
- Frequency 2 works, as does the diversity receiver, but frequency 1 does not
- Both frequencies work, as does the diversity receiver
- Neither frequency works individually, but the diversity receiver does work (i.e. there is diversity benefit over and above simply choosing the best frequency)
- None of the receivers work.
- The other three cases: one or other frequency worked individually, yet the diversity receiver failed. This should not happen and is classified as a ‘diversity problem’.

Analysis Results – EBU building

Many impressive screenshots demonstrating the benefits of diversity reception were obtained during the outbound trip to Geneva. The route taken went from Calais to Paris and then followed a fairly direct line through France to Geneva. Reception at the beginning of the journey was very poor, because the receiver was in the “skip-zone” of the transmitter. On the approach to Geneva, the signals became gradually stronger, and it was in this area of marginal coverage that the benefits of diversity were most noticeable, since neither frequency was entirely reliable on its own.

Unfortunately, problems were encountered with the logging computer, which for various reasons meant that no logging data was recorded for this part of the trip. On the return leg, a more easterly route was taken. Good reception was obtained almost all of the time on a single frequency, except when passing through tunnels. Consequently there was no scope for improvement from diversity reception.

During the WRC, the same equipment was set up in a room in the EBU building where demonstrations were being given. This allowed more comprehensive logging results to be obtained, over several days, and these were analysed as described.

The results of this analysis are presented in Figure 4. The pie chart shows the proportion of the total reception time-periods falling into each category.

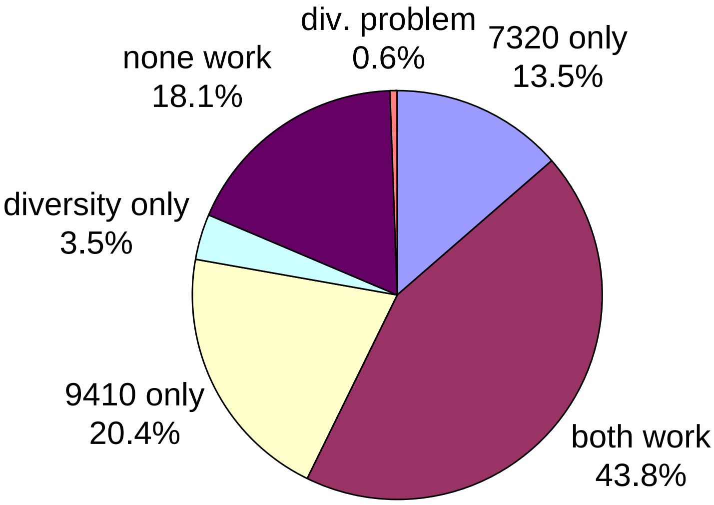


Figure 4 – Reception proportions in the EBU building

A diversity problem was evident for 0.6% of the time. This should be investigated, but the proportion is small enough to be ignored in the following discussions.

For 18% of the time, none of the receivers were able to decode audio. 44% of the time, both frequencies worked on their own, and the diversity receiver also worked, as expected.

The periods when only one frequency worked came to 13.5% for 7320kHz and 20.4% for 9410kHz; at these times the diversity receiver was able to make use of the working frequency and give audio. During these periods, a receiver with a single front-end but able to switch between the two frequencies would also have been able to give audio output, at least in principle. This assumes that such a receiver would always make the correct decision; moreover, it would have to decide *in advance* which frequency to use. Any real switching receiver would inevitably make the wrong decision some of the time, and so perform less well than this.

For 3.5% of the time, diversity reception worked even though neither frequency worked on its own: the phenomenon explained in an earlier section. This is a fundamental benefit of diversity reception over switching, since even an ideal switching receiver could never work in this case.

Combining the appropriate segments, we see that the receiver tuned to 7320kHz worked in total for 57.3% of the time while that tuned to 9410kHz gave 64.2% reception. An ideal switching receiver would have given 77.7% reception whilst full diversity gave 81.2%. Most of the benefit of having two frequencies could be obtained with a switching receiver, with full diversity only giving a marginal extra improvement. This is encouraging, since a diversity receiver requires two entire front-ends and demodulation chains. It is therefore likely to be more costly than a switching design, at least in current technology.

If the audio frame errors on the two frequencies had been entirely statistically independent, we would expect that the proportion of bad time-periods for the ideal switching receiver would be the product of the proportions for each frequency alone. This would lead to about 85% of periods being good, compared to the 78% observed. This suggests that the errors are not completely independent, but there is nonetheless a high degree of decorrelation.

The overall reliability obtained was relatively low, even with the benefit of diversity. The observations made in the van suggested that the receiving location was in the fringes of the coverage area for the particular transmitting arrays and frequencies used. This was made worse by the antenna installation used in the EBU building, where the feed from a single passive antenna was shared between a large number of receivers using passive splitters. It was also suspected that the level of man-made interference was unusually high.

On the other hand, this made it possible to obtain a statistically significant measure of the benefits of diversity reception in a relatively short time. Given that the fading on the two frequencies appears to be essentially uncorrelated, the same technique applied to two frequencies each giving 98% reliability could improve the reliability to almost 100%. However, a much longer period of logging would be necessary to investigate this.

CONCLUSIONS

Diversity reception has been shown to give a significant improvement in reliability compared to single-frequency reception. It has also been seen that most of the benefit of frequency diversity would also be achieved by an ideal switching receiver with a single front-end. How close a real switching receiver would come to this performance is a matter for substantial further study, since there are a number of problems to be addressed in designing such a receiver.

Another important question is what benefit would be obtained by a large-scale SFN. In this case, two signals are received on the same frequency, but they have both arrived by totally different paths, involving different parts of the ionosphere. Again, we might expect the fading and errors to be relatively independent on these two paths, so that the probability of both fading out together is much less than for each on its own.

Whereas an MFN should always improve reliability, there is a potential performance penalty in the case of an SFN, because the presence of delayed versions of the same signal introduces frequency-selective fading. This makes the channel more difficult, increasing the overall SNR required. The question is whether the reduced incidence of a complete fade-out improves performance by more than the degradation caused by the artificial multi-path.

Experiments are underway to investigate this in conjunction with VT Merlin and Radio Netherlands Worldwide; results will be given in the oral presentation at IBC.

REFERENCES

1. Digital Radio Mondiale (DRM); System Specification, ETSI ES 201 980, April 2004

2. Murphy, A.J. et al., Digital Radio Mondiale (DRM): Transmission Infrastructure and Synchronised Networks. Proceedings of the International Broadcasting Convention, September 2004

3. Digital Radio Mondiale (DRM); Receiver Status and Control Interface (RSCI) ETSI TS 1XX XXX (currently being drafted)

ACKNOWLEDGEMENTS

The authors would like to thank VT Merlin Communications for providing the transmissions, the European Broadcasting Union for providing the room in which the reception tests took place, and Radio Netherlands Worldwide for providing the antenna used at the EBU.

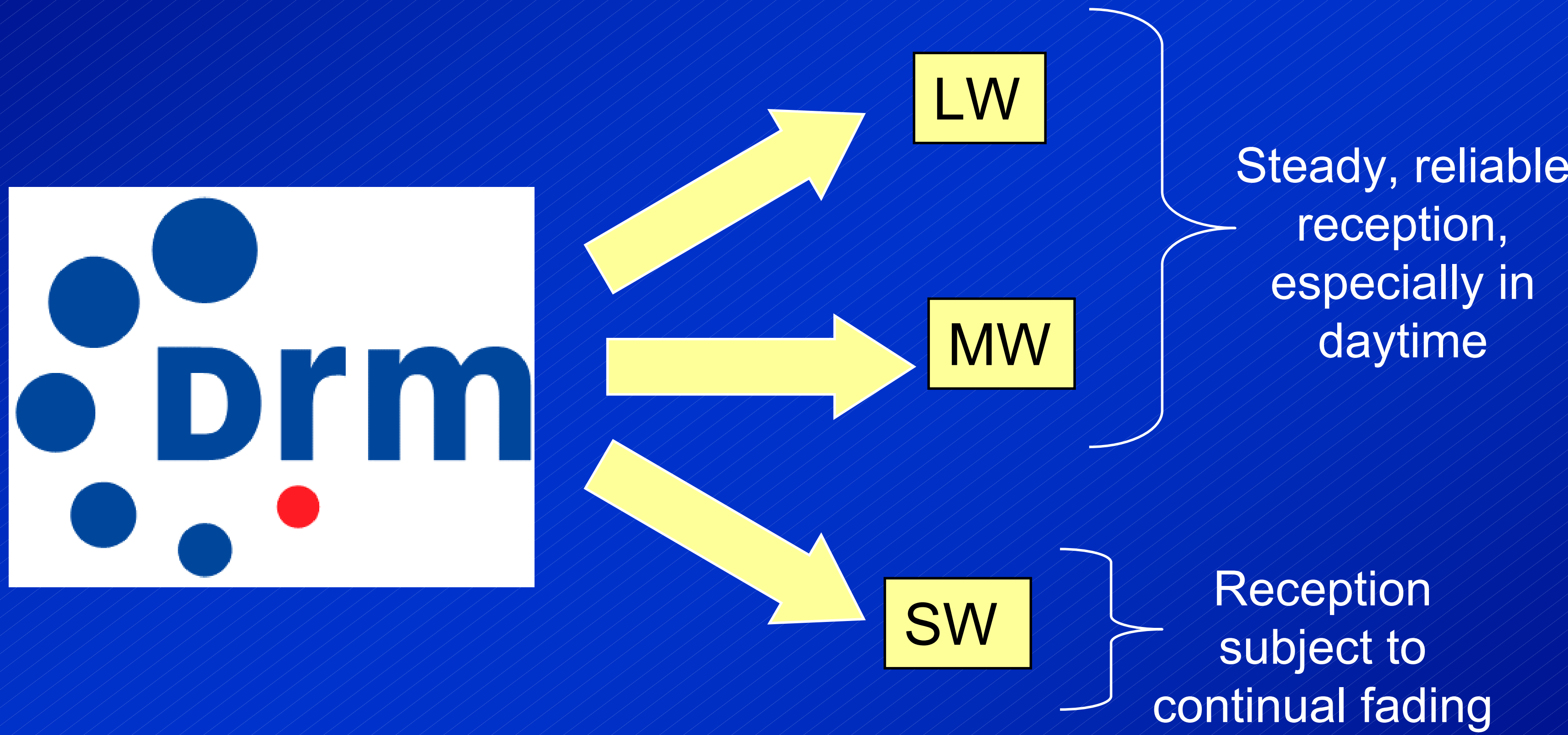
Digital Radio Mondiale (DRM): Multi-Transmitter Networks and Diversity Reception

O.P.Haffenden

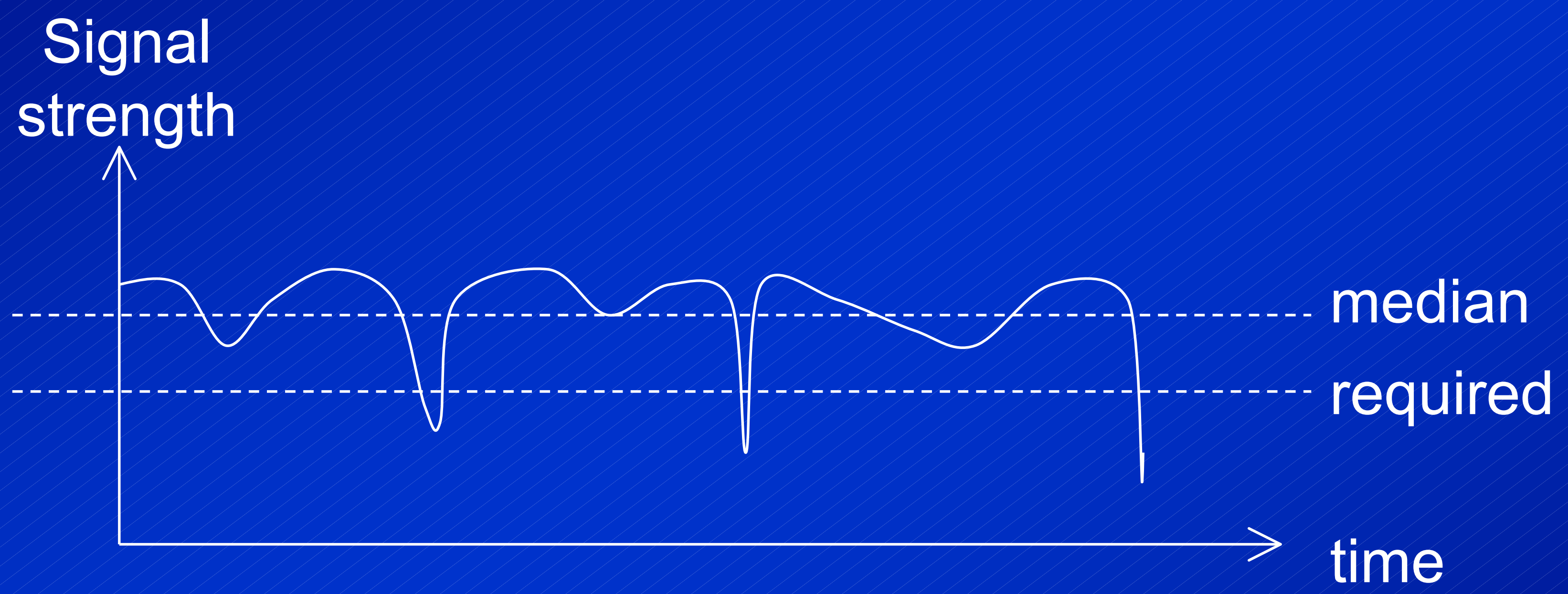
9th September 2004

… or … Taming the Ionosphere

DRM: A digital system for all three bands below 30MHz

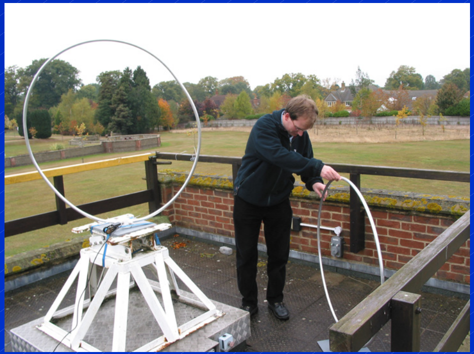


Fading in SW channels

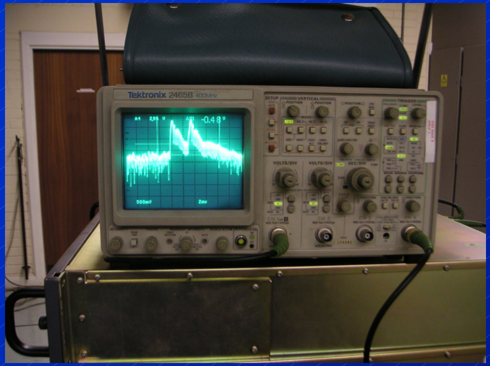


Achieving reliable reception with minimal power

1. Multiple-Frequency Networks

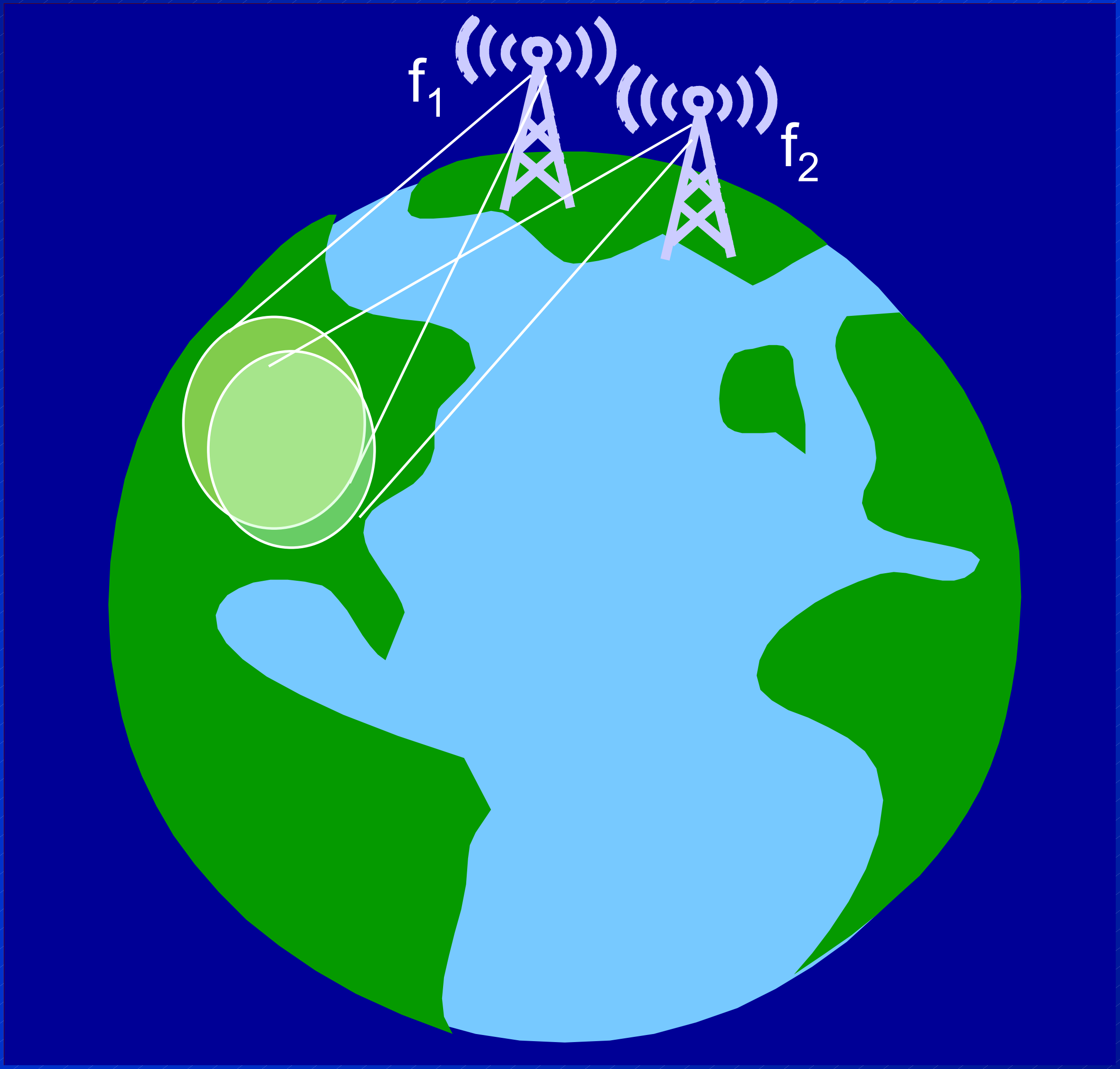


2. Polarisation diversity

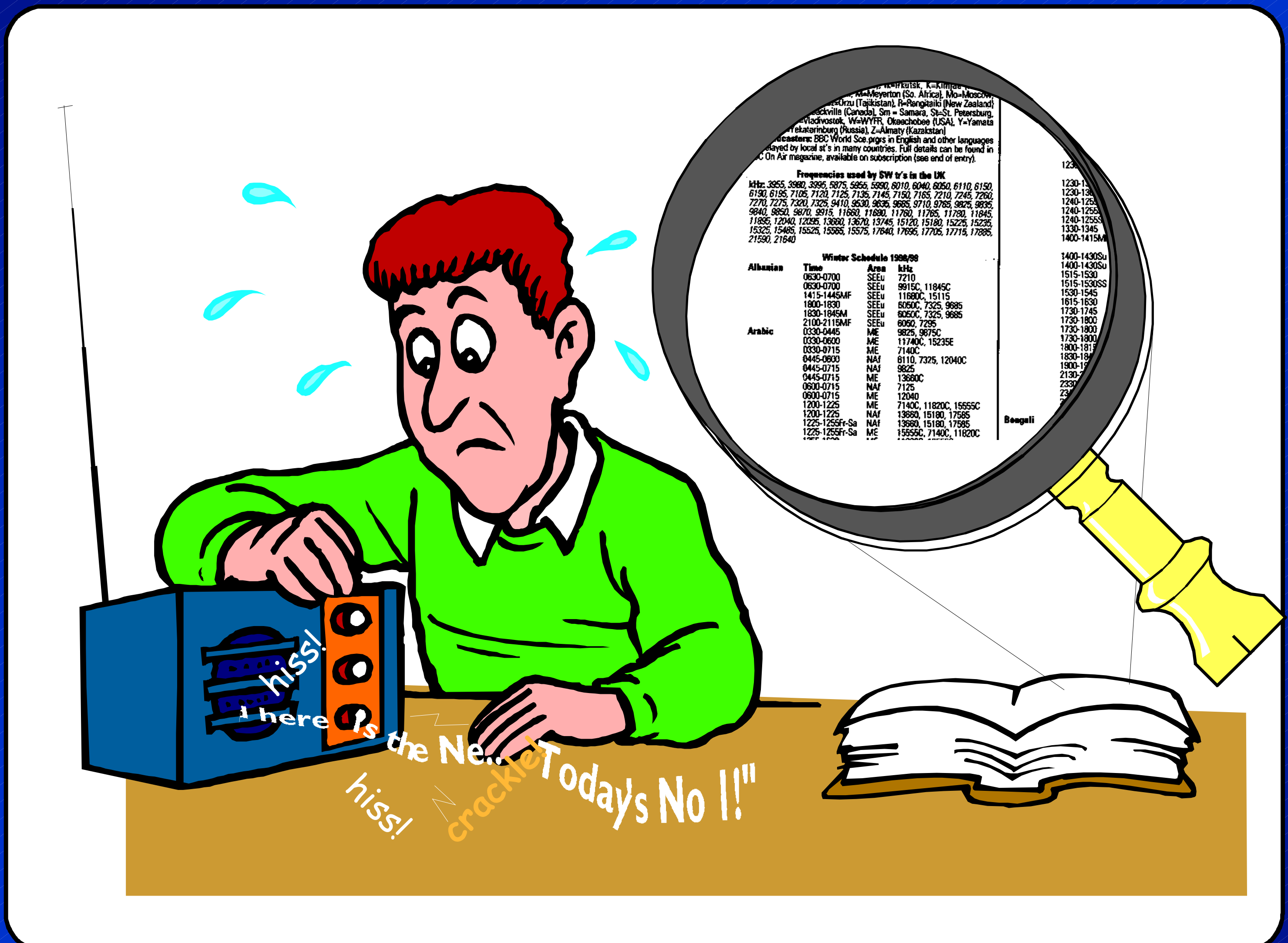


3. Single-Frequency Networks

Multiple-frequency networks



In AM, the listener has to find the alternative frequency…



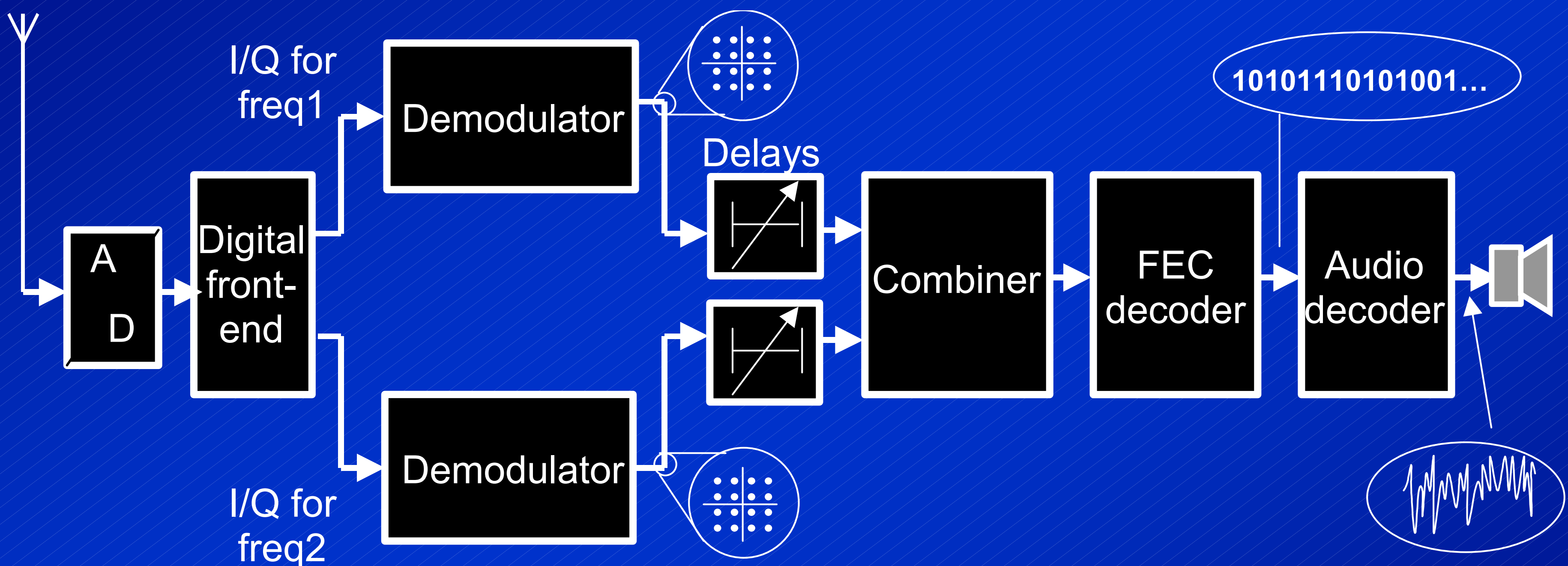
DRM can signal the frequencies directly to the radio…

Switches automatically:
Automatic Frequency Switching (AFS)

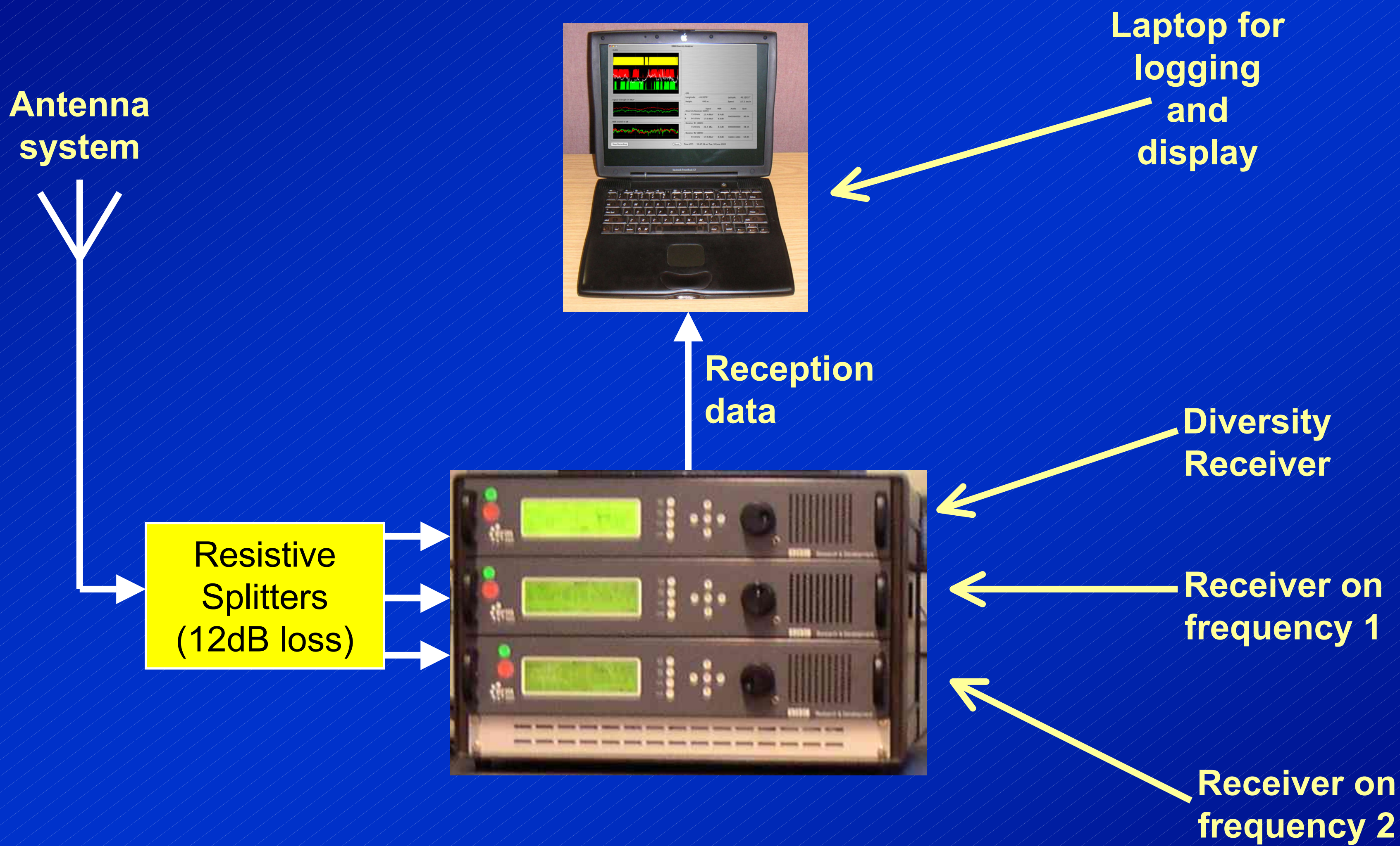
OR

Uses both at once:
Diversity reception

Architecture of BBC R&D diversity receiver



Diversity reception test setup

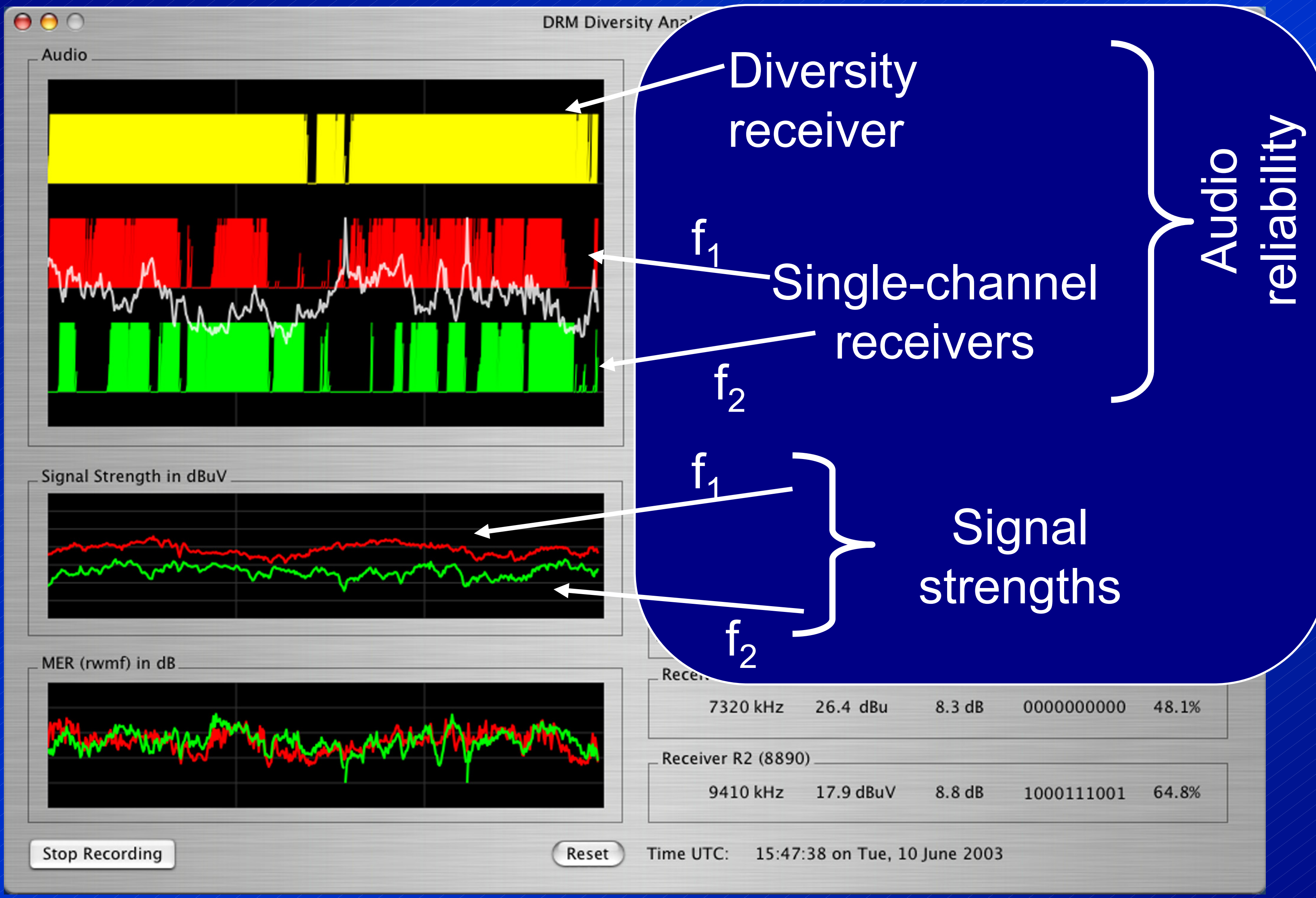


Experimental MFN transmissions

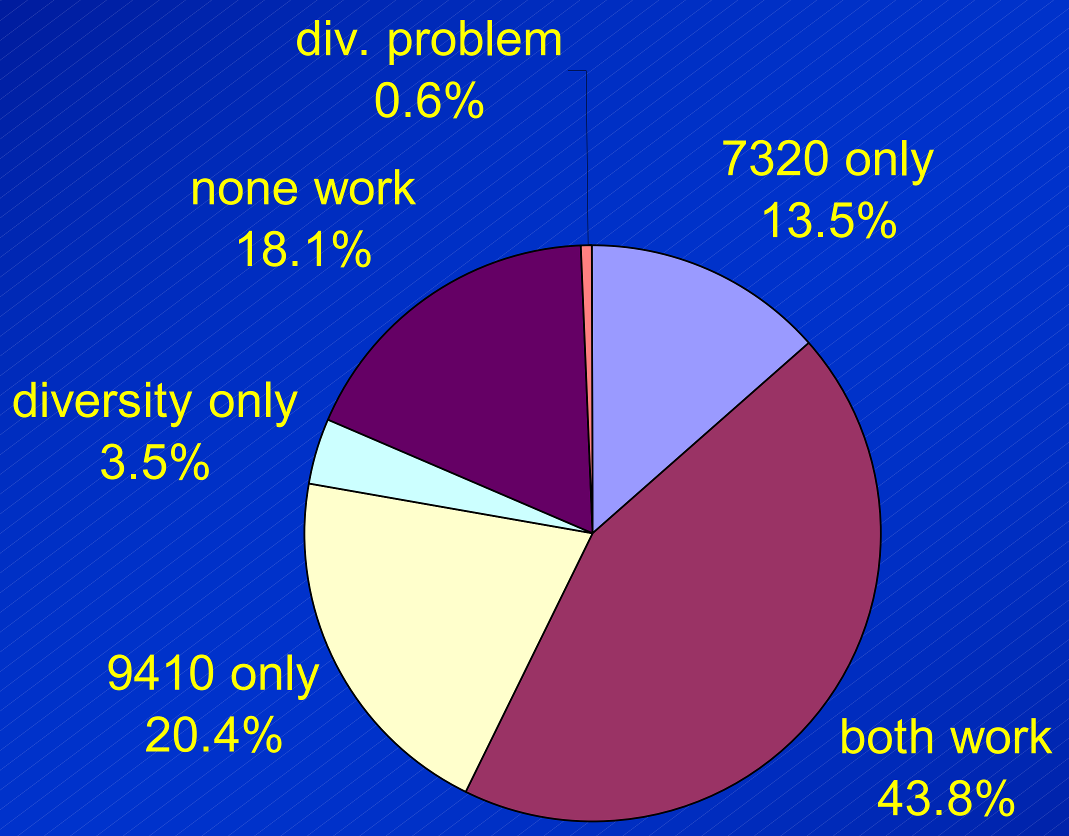
- **Identical transmissions on 7320kHz and 9410kHz, in June 2003**
- **Transmitted by VT Merlin Communications from Rampisham, UK**

- **Transmissions synchronised using MDI and GPS – see our paper in this session**

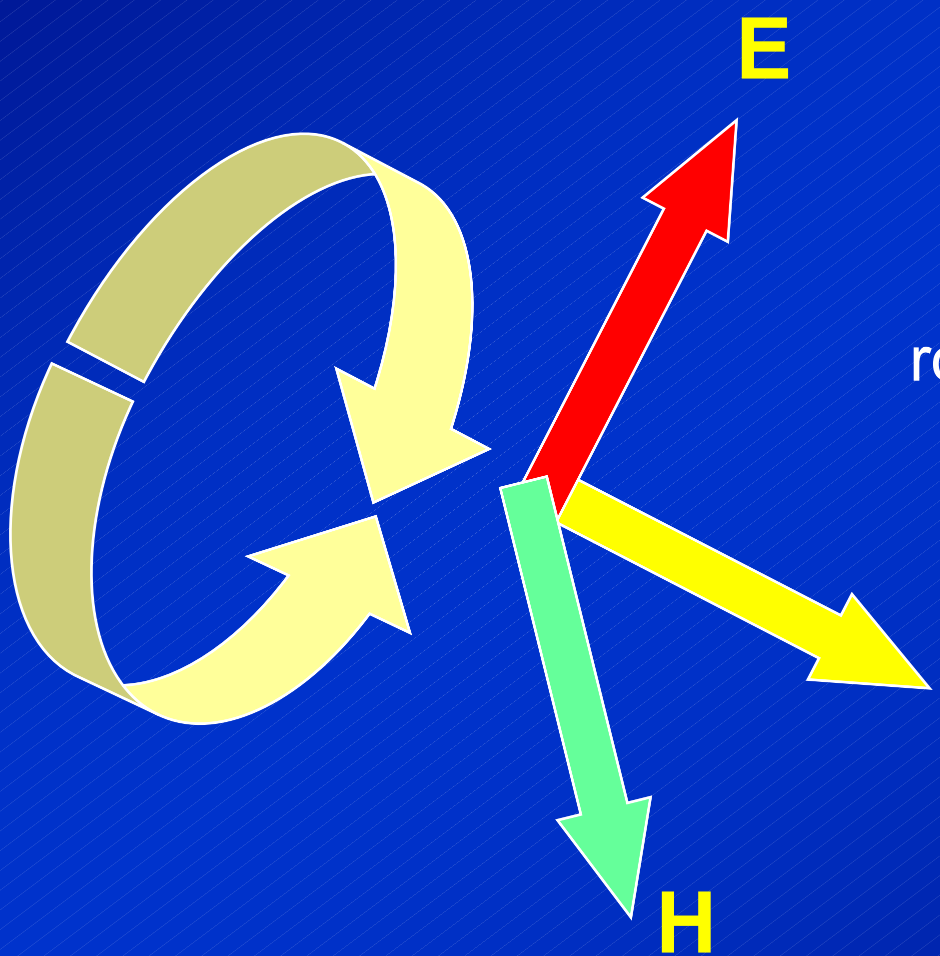
Example of diversity reception results



Diversity reception: summary of results

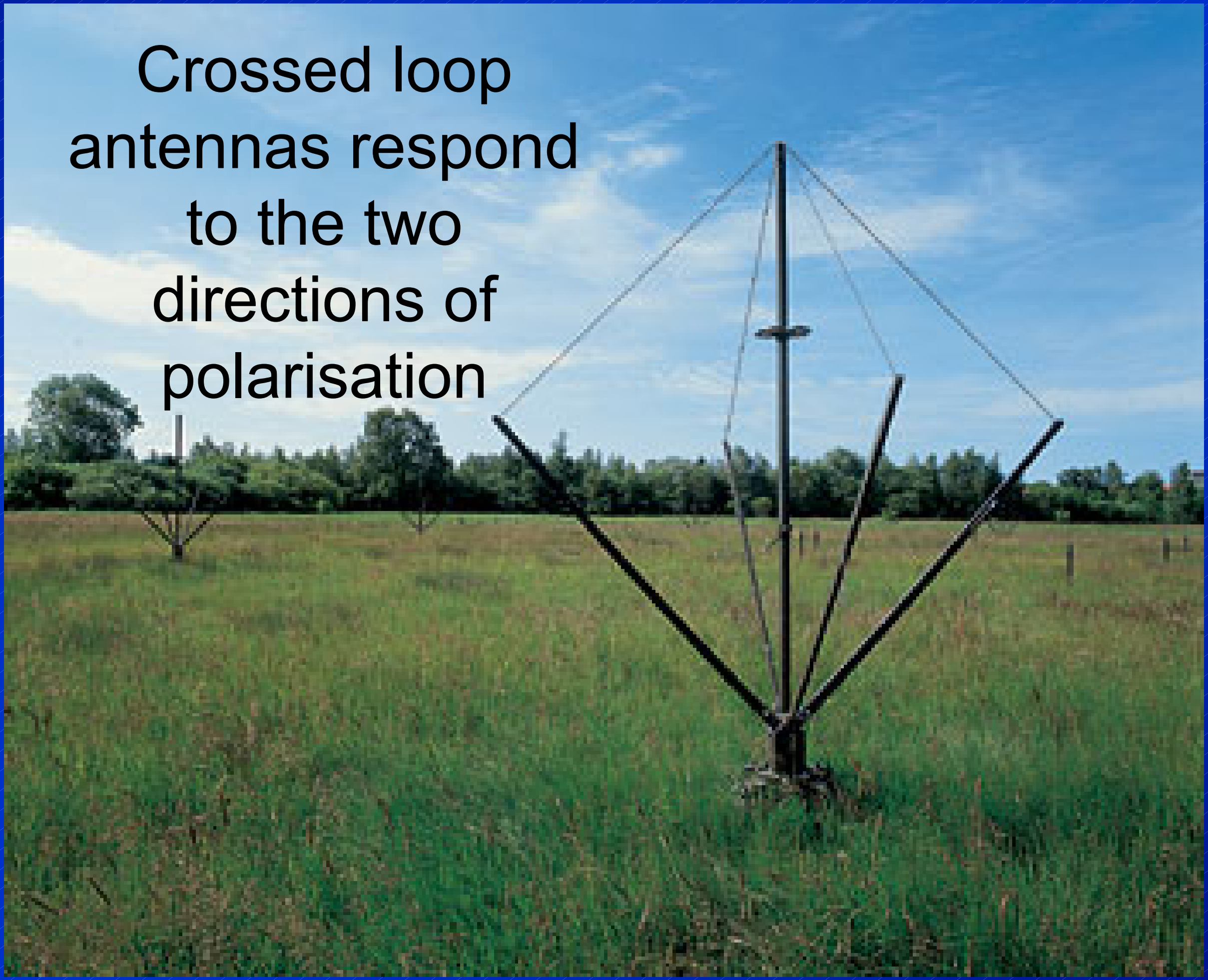


Polarisation diversity

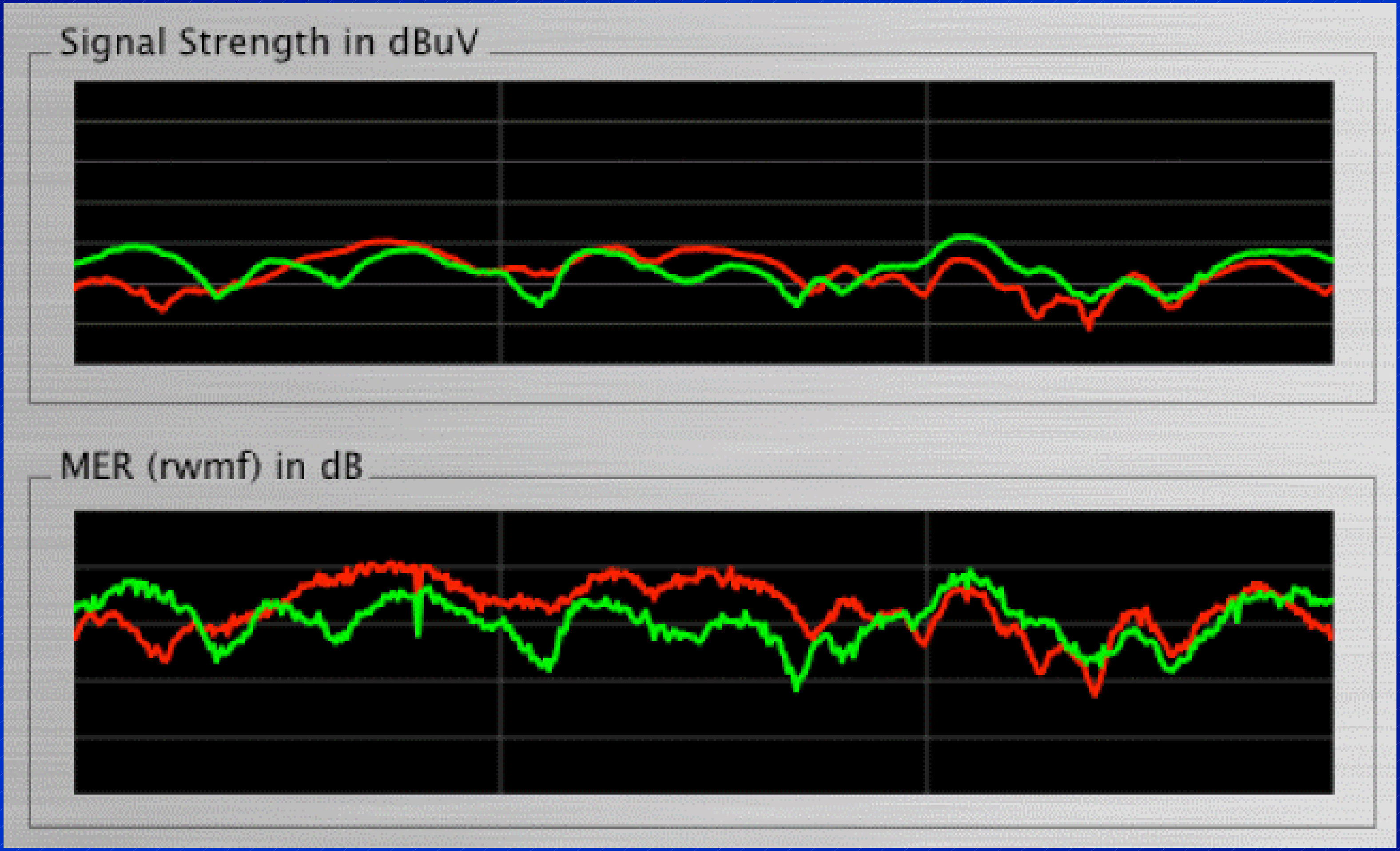


Direction of polarisation rotates randomly with time

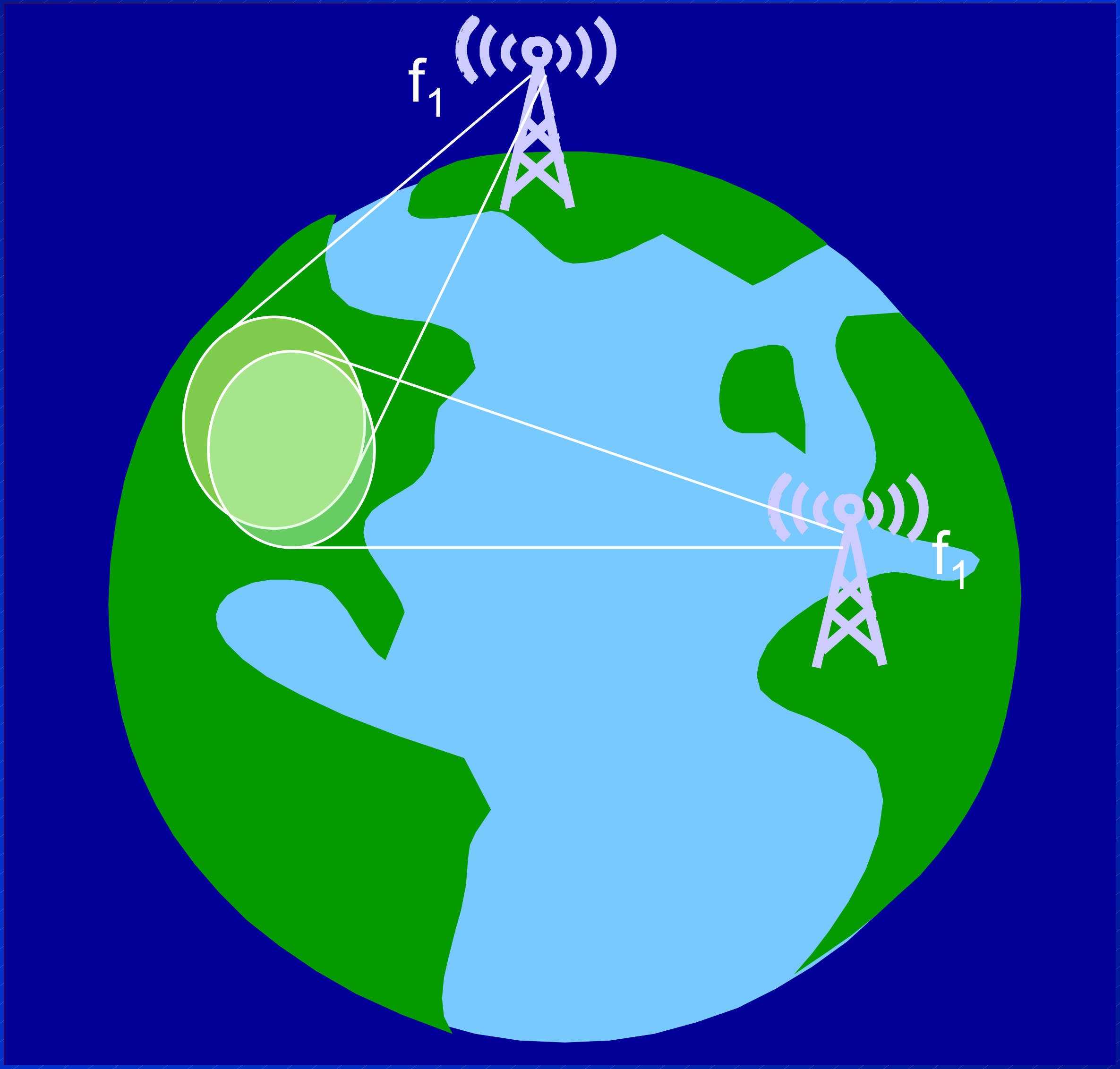
Polarisation diversity



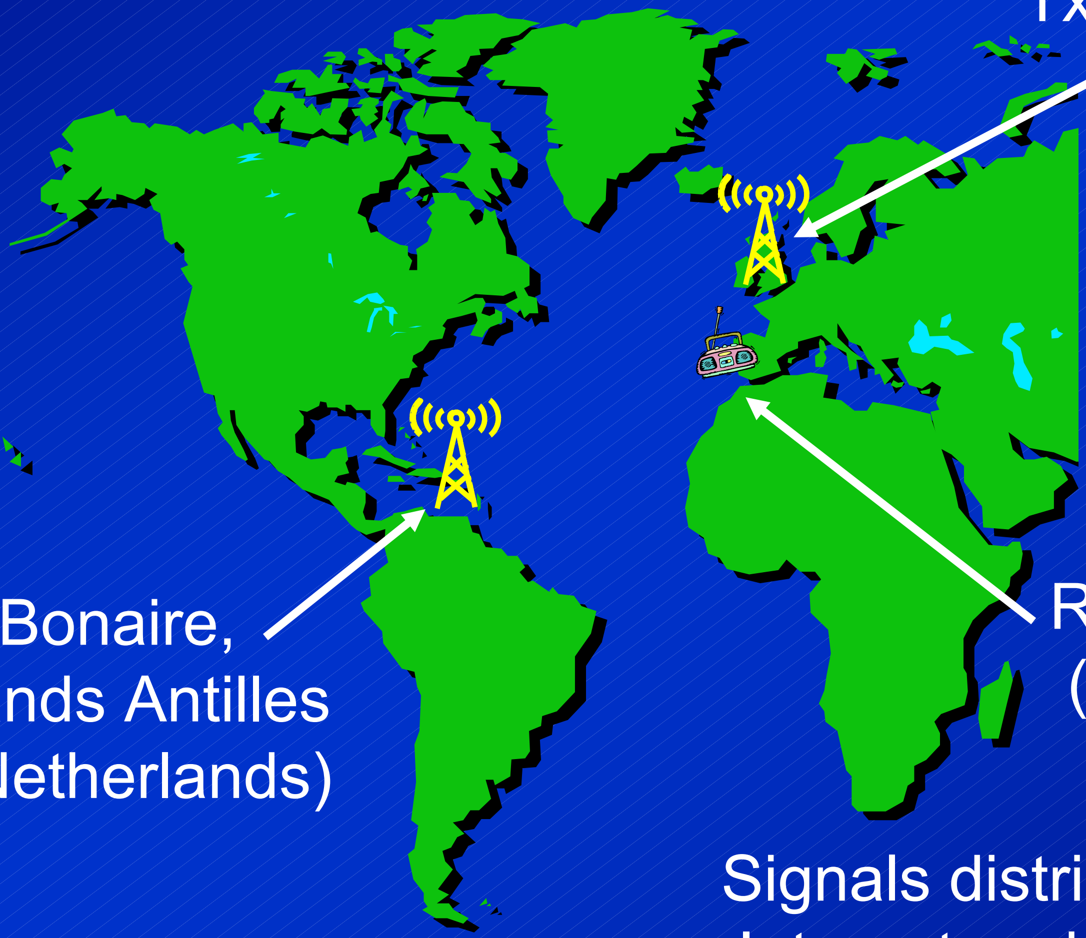
Fading on the two loops



Single-frequency networks (SFN)

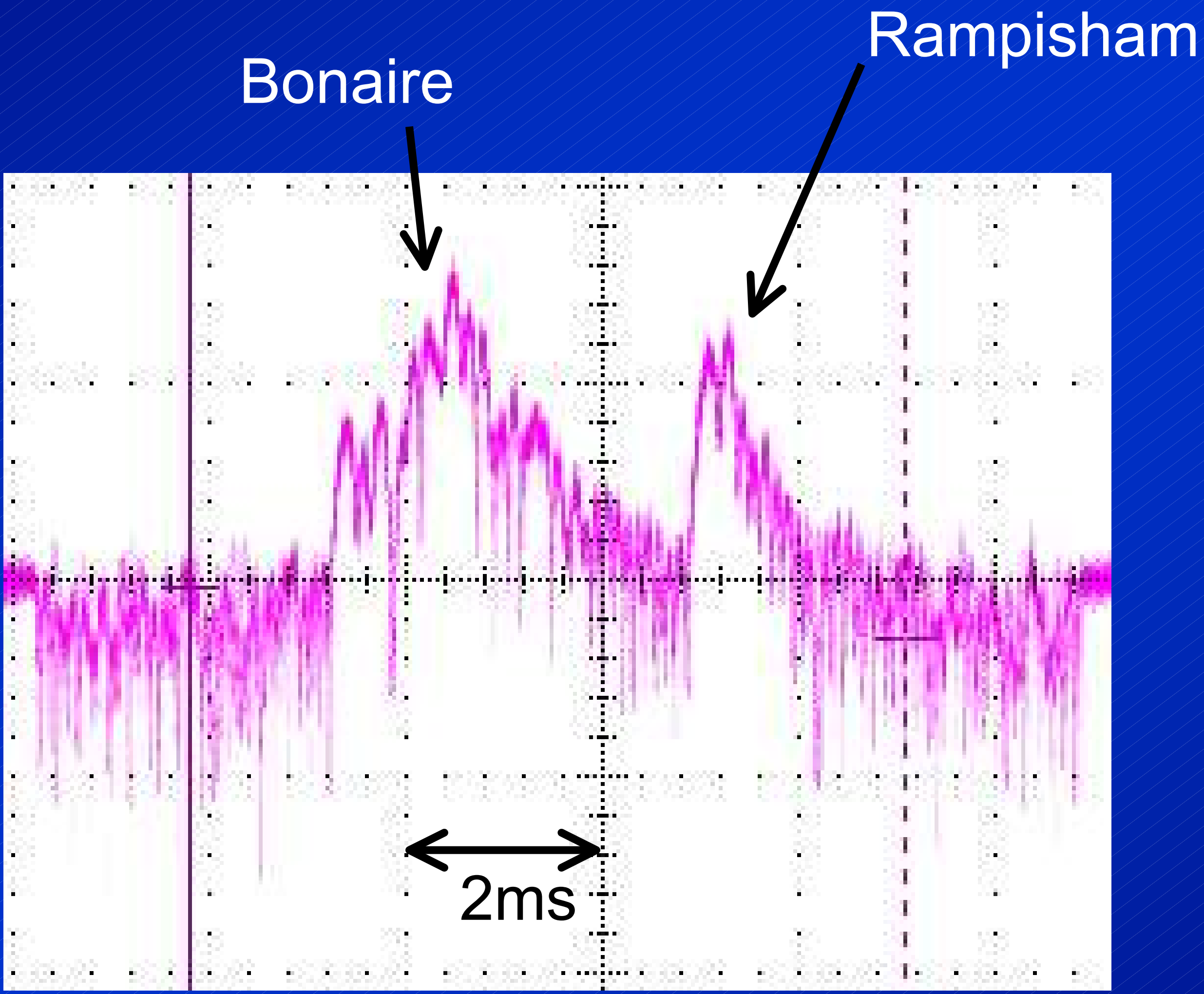


SFN trial, July 2004



Signals distributed by Internet and satellite

SFN trial: received impulse response



Comparison of methods

	Frequency Diversity	Polarisation Diversity	Single-frequency network
Spectral efficiency	Two channels needed	Single channel	Single channel
Transmitter requirements	Needs two transmitters	Single transmitter	Needs two transmitters
Receiver complexity	2 front-ends + more complex receiver	2 antennas + 2 front-ends + more complex receiver	Ordinary receiver
Benefit	Most likely to give benefit	Good for some freqs and times	Not guaranteed – could make it worse

Conclusions

- Three methods described:
  - Frequency diversity / Multiple frequency networks
  - Antenna diversity
  - Single Frequency Networks
- Can get reliability without large power increase
- DRM specification supports all three methods
- Can use in combination
- Thanks to:
  - VT Merlin Communications
  - Radio Netherlands Worldwide
- See DRM on stand 8.484