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# The BBC Digital Radio Camera Project

Research & Development
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BBC Research & Development
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## Abstract

Cable-free television cameras have been used for years in sports, news and outside broadcasts. Unfortunately, with analogue transmission the pictures often break up. Now the team at BBC R&D has developed new digital technology to deliver a reliable, lightweight radio camera. Producers and directors are now making programmes that would not have been attempted with the previous generation of equipment.

Our key input to this work was to recognise that technology being engineered for digital television broadcasting was ideal for incorporation in the transmitters for the radio camera. This gave us the heart of the system, capable of miniaturisation and with low power demands. We then worked with programme makers and equipment manufacturers to ensure that the technology was engineered to provide a solution that met everyone's requirements.

The proof of the technology is the popularity with which the early prototypes have been received. The project is continuing to develop and refine the digital radio camera concept together with other organisations, such as spectrum standardisation bodies. The project vision is that one day radio cameras could become as widely used as radio microphones are today.

This paper was presented to the Royal Television Society as a submission for the RTS 2001 Technical Innovation Awards.

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**Key words:** digital radio camera, COFDM, DVB-T, DVCPRO

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Research & Development

# The BBC Digital Radio Camera Project

BBC

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*Cable-free television cameras have been used for years in sports, news and outside broadcasts. Unfortunately, with analogue transmission the pictures often break up. Now the team at BBC R&D has developed new digital technology to deliver a reliable, lightweight radio camera. Producers and directors are now making programmes that would not have been attempted with the previous generation of equipment.*

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## OVERVIEW OF THE DIGITAL RADIO CAMERA PROJECT

This section gives an overview of the project, and the following sections review the project's activities in more detail.

The project has its roots in the BBC's research on digital television, where considerable expertise was built up on the use of the Digital Video Broadcasting Terrestrial (DVB-T) transmission standard. Coded Orthogonal Frequency Division Multiplexing (COFDM) modulation was chosen for DVB-T due to its ability to work in television reception areas where there is a large amount of ghosting (multipath), which is also a major problem for radio cameras.

The use of COFDM actually turns multipath into a benefit in most situations because the COFDM demodulator can use all the reflected energy as well as the energy in the direct path. Provided enough reflected energy is available a digital radio camera can work even if the direct propagation path is blocked by an obstruction. In contrast, analogue radio cameras require a line-of-sight path to the receiving antenna. In addition, this antenna must have a narrow acceptance angle, such as a dish antenna, to try to avoid picking up reflections, and so this antenna has to be pointed by an operator to follow the radio camera. BBC R&D worked on various ways to improve analogue radio cameras, culminating in a system using sectored-antenna switching, but digital systems have since proven to be more rugged, even using a fixed wide-angle receive antenna.

Various experiments were carried out at BBC R&D in the latter half of the 1990's to test specific technical aspects of digital modulation, in the microwave bands used by radio cameras, to check that there were no fundamental technical reasons why a digital radio camera could not be made to work.

The project formally started in Summer 1998 by reviewing the operational requirements for the BBC's existing use of radio cameras. By May 1999, we had built an experimental test bed that we used for a detailed investigation into the suitability of the use of DVB-T in the frequency bands allocated to radio cameras. The next stage was to design compact electronic circuits for the transmitter and make prototypes leading, by April 2000, to the world's first hand-held digital radio camera suitable for programme use.

The project constructed three prototypes using MPEG video encoding, which were loaned to BBC programme-makers and were used on a number of sports, news and events programmes broadcast from October 2000 to the present. Key members of various BBC operational departments have taken particular interest in the project and have become important members of the team.

Feedback from operational trials has recently resulted in the development, by Summer 2001, of a new prototype based on DVCPRO video encoding that has a much lower latency (delay) in the signal path (down from 18 frames to 2.5 frames), and so making it much easier to use operationally. Work is continuing in order to turn this prototype into a fully functional operational radio camera.

The digital radio camera is coming at time when there is increasing pressure on the available microwave spectrum from mobile telecommunications services and wireless local area networks (W-LANs). The project team now includes spectrum planning specialists, who are participating with the various bodies, CEPT, ITU and JFMG Ltd, to ensure spectrum for digital radio cameras.

Throughout the project, the BBC R&D team has maintained regular contact with BBC operational departments and with the broadcast industry. We brought in available technologies from outside and we licensed technologies developed within the project to encourage the creation of a competitive market.

Although the technology developed so far can be used as the basis for commercial products, the project is continuing its work to both refine the system and to explore other applications of the technology, such as mobile and transportable microwave links.

## DETAILED REVIEW OF THE PROJECT'S ACTIVITIES

### EARLY EXPERIMENTS

These experiments brought together experience from BBC R&D's work on analogue radio cameras, Digital Terrestrial Television and participation in various European Union collaborative projects.

The first laboratory bench experiments – to test the researchers' ideas on the use of the DVB-T standard COFDM modulation – had to rely on large rack-mounted electronics for the transmitter. The problem was how to compress the electronics so that it could be attached to the back of a hand-held camera? Of the three main parts of the transmitter (video coder, COFDM modulator and microwave transmitter), both the video coder and the COFDM modulator were much too big. An initial redesign of the COFDM modulator reduced its size from a unit as big as a domestic television to just five 4U circuit cards.

The new COFDM modulator was combined with a commercial rack-mountable MPEG video coder and built into a lightweight camera dolly. This test bed was shown at the BBC R&D Open Days in May 1999. The experiments with the test bed demonstrated very good multipath immunity in any of the strongly-error protection coded modes of DVB-T. We decided to use the 16-QAM (Quadrature Amplitude Modulated) ½-rate, 1/32 guard interval mode as giving the best trade off between ruggedness and coded picture quality.

The ability of COFDM to make constructive use of the reflected signal meant that only a simple fixed wide-angle or even omnidirectional receive antenna was needed, instead of a narrow-angle manually steered dish.

A bonus from using DVB-T modulation was that a standard DVB-T receiver could be used, just with the addition of a microwave downconverter at the receiving antenna. This has enabled the project to concentrate its limited resources on the transmitter.

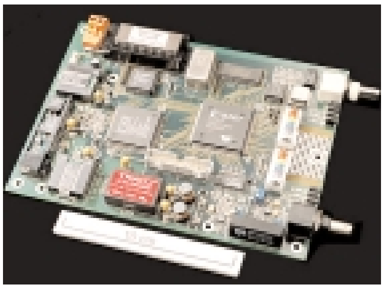
The confidence gained from using the dolly test bed set the project to the task of making the transmitter electronics small enough for hand-held operation.

**Dolly-mounted digital radio camera.**

## WORLD'S FIRST DIGITAL RADIO CAMERA

The main tasks in making a hand-held digital radio camera was to miniaturise the video coder, COFDM modulator and microwave transmitter. Resources and skills available to the project meant that the last two tasks could be tackled, but not the video coder miniaturisation.

### COFDM modulator



**Single card COFDM modulator.**

A single-card COFDM modulator was designed using a field-programmable gate array (FPGA) for most of the processing. One function, the Fast Fourier Transform needed to generate the COFDM carriers, was too complex to be done in the FPGA and so this was carried out in another chip, jointly developed between BBC R&D and LSI Logic for set-top box DVB-T reception. BBC R&D's engineers' forward thinking was specifically responsible for allowing this functionality to be available from the chip (as mentioned in the RTS Judge's Award submission from the BBC DTT Technical Team last year).

The single-card COFDM modulator can be used as the building block for many types of digital wireless link and so has been licensed to industry.

### Video coder

The development of a compact video coder is a difficult task to tackle from scratch, but the camera industry has been working on such coders to use, for example, with tape recorders. Sony Corporation provided the project with three compact MPEG encoders for use by the project. These coders fitted onto the back of SX camcorders, but performed their coding independently of the SX coding used by the tape mechanism.

For use with the prototype, the coders were set up to provide MPEG video and audio in a 12 Mbit/s transport stream, as determined from the dolly tests. The latency in the signal path for this coder was about 18 frames (0.75s), which is relatively long – we wondered if this delay would be acceptable operationally?

### Backpack transmitter

**Backpack digital transmitter.**

The COFDM modulator was put into a backpack along with a relatively bulky microwave transmitter in December 1999. This enabled engineering trials to be carried out on location. The backpack also contained an analogue transmitter connected to the same transmit antenna as the digital transmitter to allow a direct A-B comparison by picking up both signals on the same receive antenna and splitting the feed to both analogue and digital receivers.

The project carried out engineering trials in the *Top Of The Pops* studio at BBC Elstree, which used stainless steel sets and stages. The studio was, therefore, a very difficult radio environment with much multipath. The analogue system did not work very well, as expected, but the digital system was faultless, even in non-line-of-sight conditions, due to the ability of COFDM to make constructive use of signal reflections. The video tape included in this submission shows an excerpt from these tests.

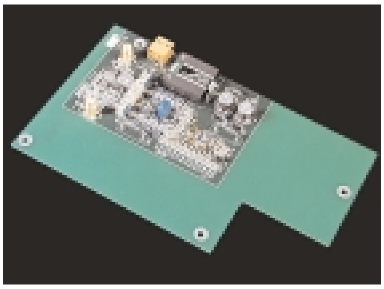
The backpack transmitter has been, and remains, a very useful test bed, since it is easier to use than the dolly system, but has more room than the later cameraback systems for adding prototype circuits for testing.

#### Microwave transmitter

The project developed a microwave transmitter where the usual upconversion via a 70 MHz intermediate frequency was replaced with direct conversion of the digital in-phase and quadrature (I/Q) outputs of the COFDM modulator to the 2.5 GHz operating frequency band. We used compact integrated circuits from the mobile communications industry. This approach provided a highly frequency agile transmitter without the need for bulky filters. We had to pay careful attention to the detailed design to minimise distortion over the operating band.

The project developed a compact 2.5 GHz-band frequency-synthesised oscillator to drive the I/Q upconverter circuit. This oscillator needed to have a very low degree of phase noise to avoid adding distortion to the COFDM signal.

Both the I/Q upconverter and the synthesiser are being licensed to industry.



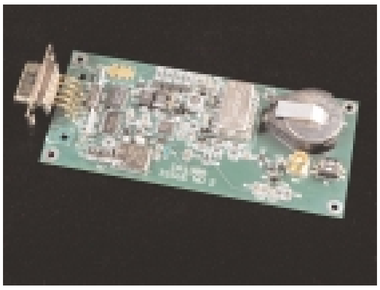
**I/Q upconverter.**

#### Hand-held digital radio camera

The various elements described above were put together into a compact transmitter attached to the back of a camcorder [1]. This resulted in the first practical digital radio camera that could be used in programme-making. We first demonstrated this MPEG digital radio camera at the NAB Exhibition in Las Vegas in April 2000.

Various engineering trials were carried out with the MPEG prototype during Summer 2000. These trials verified the good results obtained with the backpack, even the non-line-of-sight operation, where there was the opportunity for the signal to bounce around obstructions using nearby structures. As might be expected, this effect worked best indoors where the ceiling could contribute to the ability of COFDM to make use of reflections.

Three MPEG digital radio cameras were built and made available for assessment by programme-makers.



**Frequency synthesiser.**

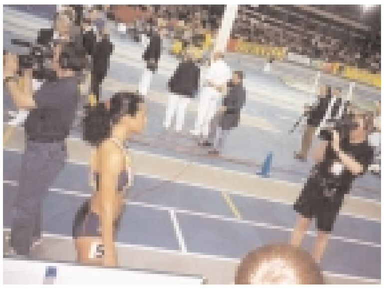
## PROGRAMME TRIALS

The three MPEG digital radio camera prototypes were made available from October 2000 to programme-makers for operational trials and potential use in broadcast programmes, if they were confident [1].

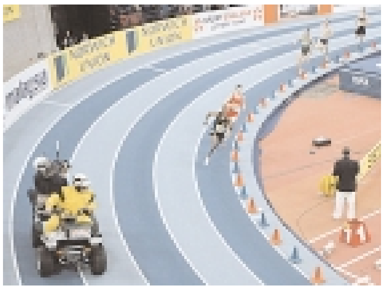
BBC Location Facilities, who make outside broadcast programmes, have been using the digital radio camera at a range of events, mainly sports. BBC News Resources have used the camera for a mixture of news reports at short-notice or planned events. The following summarises some interesting aspects of the trials:

- Athletics at the National Indoor Arena, Birmingham. Here the digital radio camera would work ruggedly in areas completely out-of-bounds to analogue radio cameras, such as the curved end of the stadium furthest from the receive antenna.
- Three cameras working into one fixed receive antenna. All three prototypes were often used together at several events ranging from athletics to the TV Bafta Awards.

**World's first digital radio camera.**



**Digital radio camera used for athletics coverage.**



**Buggy-mounted digital radio camera.**

**Live strolling news report.**

- Buggy camera. The camera was used from a small buggy at several athletics events to hold on to dramatic close-ups of runners round the track.
- Motorbike camera via a helicopter mid-point. The digital radio camera was used from a motorbike at the Great North Run in Newcastle, where the transmitted output power was boosted using an extra power amplifier mounted in the motorcycle pannier.
- Live strolling news report. During Budget Day 2001 (planned event). News reporter Robert Hall was able to perform a live interview into BBC News 24 while walking along a mall in the Milton Keynes shopping centre. Rugged reception was obtained with a fixed receive antenna despite occasional non-line-of-sight conditions.
- Live report from a news scrum around a politician on walkabout. The digital radio camera was used to follow Baroness Thatcher when she visited a supermarket during the 2001 General Election campaign. BBC News 24 was the only broadcaster able to cover this event live and get close-up pictures of Lady Thatcher, which was immediately followed by an on-the-spot piece to camera by the reporter.

Programme-makers quickly gained confidence with using the digital radio camera, such that it was often featured highly in the programmes broadcast. However, it had to be used carefully to avoid the 18-frame latency in the signal path becoming apparent, since it was not possible to delay the other cameras and microphones at the event to match. These trials showed that reducing delay in the signal path was the main operational requirement for any new digital radio camera.

In addition to its latency, the first prototype digital radio camera was not very rugged mechanically and it was awkward to use due to having two bulky boxes (video coder and digital transmitter) attached to an already large camcorder. Many programme-makers prefer to use cameras that have a docking interface onto which various optional attachments can be added, e.g. a tape recorder or a triaxial cable adapter, according to requirements. For analogue radio camera operations, it is common practice to use a docking microwave transmitter as the attachment, which makes a mechanically rugged arrangement that is easy for camera operators to use and provides a greater freedom in the choice of camera. Therefore it was requested that the next prototype digital radio camera follow the same pattern.

## NEW LOW-DELAY DIGITAL RADIO CAMERA

The operational requirement to reduce latency in the digital radio camera from the 18 frames of the first prototype requires a new video coder design. It was clear to the R&D engineers that it would take about two years to develop a low delay MPEG coder that was small enough to fit into a dockable back, and so an alternative was sought.

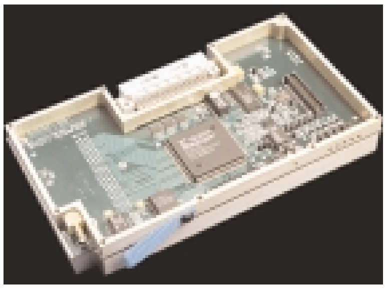
Panasonic make a compact DVCPRO codec module with a latency of 2.5 frames. A design based on this codec module could be produced relatively quickly. The main disadvantage was that the gross bit rate was around 28 Mbits/s (including audio) and there was no rugged DVB-T mode available with sufficient capacity. It was decided to use two DVB-T signals in parallel and so a circuit had to be designed to split the DVCPRO data between them. This was feasible because the two COFDM modulators and microwave upconverters could be made very small. Also the 16 MHz of spectrum now required will still fit comfortably within a 20 MHz channel in the microwave bands as set for analogue radio cameras.

The split DVCPRO data has to be fitted into a 64-QAM mode of DVB-T, if ½-rate coding was still needed. Previous work on digital television transmission indicated that it was better to use this mode than the alternative 16-QAM mode because there was a greater benefit to be gained from the more powerful error protection compared to the loss of ruggedness from he higher level modulation. The experimental backpack transmitter mentioned in a previous section was originally designed to include a dual-channel transmitter, because the split-channel idea had been already considered for transporting a high bit rate MPEG signal to get higher picture quality, perhaps for HDTV. Results from those backpack tests showed that dual-channel operation of the rugged 64-QAM mode would give performance close to the 16-QAM mode in multipath limited conditions.

Gigawave, a microwave company familiar with making analogue radio cameras, was contracted to manufacture a rugged dockable digital transmitter that would be operationally more acceptable to programme-makers.

Pictures through the first prototype were first demonstrated at the BBC R&D Open Days in May 2001. Since then work has continued to add audio and remote control of camera settings (e.g. iris and gain). An engineering trial at the Royal Albert Hall showed that the new digital radio camera is potentially almost as rugged at the original digital radio camera (as forecast by the backpack tests). However, these first tests highlighted some problems with recombining the data at the receiver which required a redesign of the data combiner circuit. These problems have now been solved and the prototype is now ready to be used on a suitable programme-making trial.

A batch of six of the new low-delay digital radio camera is being manufactured and they are due to be available in November 2001 for long term loan to programme-makers for broadcast trials.

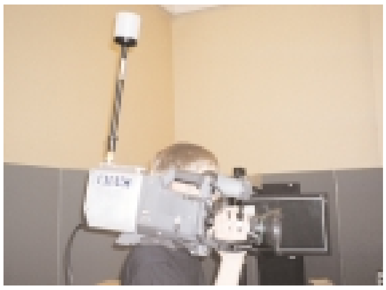


**DVCPRO codec data splitter.**

## SPECTRUM ISSUES

Radio cameras and microwave links used by broadcasters have specific frequency bands allocated through international and national standardisation. The migration from analogue operation to digital requires modifications to the band plans and so the digital radio camera project is contributing to the standardisation process at various levels.

The characteristics of the digital signal influence the parameters required of the individual frequency channels allocated for each camera's operation. Traditionally this is approached by defining the spectrum mask for the transmitter. However, the project has submitted a proposal to European Telecommunications Standards Institute Task Group 17, Working Party 4, Digital Video Links (ETSI TG17 WP4) for a more flexible approach based on specifying the maximum allowable power in various regions in and around the allocated channel [2]. This approach offers more flexibility to introduce new digital modulation schemes once the limits of DVB-T in the microwave bands have been reached. This is an example of the project keeping an eye to the future.



**DVCPRO digital radio camera.**

Digital radio cameras are likely to be used more widely than analogue systems, as programme-makers gain confidence in their rugged performance, so it is important to ensure that there is sufficient spectrum available to meet the increased demand. This is difficult because there are also demands for more spectrum for use by other wireless devices. The 2.5 GHz band, for example, often favoured for radio cameras, has been earmarked for the extension of the new 3G mobile communication system. Project members are actively participating directly in various working groups of the European Posts and Telecommunications Committee (CEPT) and the International

Telecommunications Union (ITU), plus working together with the Broadcasters' Joint Frequency Management Group Ltd (BJFMG Ltd), to make the case for spectrum for digital radio cameras and related temporary digital video links needed by broadcasters.

## THE BROADCAST INDUSTRY

The digital radio camera project is giving the BBC a lead in the use of digital radio cameras. In the long term, the project needs to work with the broadcast industry so that they can provide systems in a competitive marketplace to increase the quality and reduce the cost of the equipment. Also systems should have a broad degree of compatibility to enable broadcasters to mix and match so that they can build up systems appropriate to their needs.

Throughout the life of the digital radio camera project, contacts with industry have been maintained resulting in the use of video coders from Sony and Panasonic in prototypes and in contracting Gigawave to the housing and circuit cards for the new prototype.

Technology developed in the project is in the process of being licensed to industry. The COFDM modulator was the first circuit to be licensed in Spring 2000, with 11 organisations around the world taking up licences. Licences for the I/Q upconverter and frequency synthesiser are soon to be made available.

## COMMENTS FROM USERS FROM THE TRIALS

### Remote Cameras in News

*News used the Digital Radio Camera throughout the General Election and it provided us with the ability to obtain footage that would not have otherwise been possible. Speed of deployment is an important benefit, with other systems time is lost running and mapping cables and safety issues related to cables across roads are also eliminated with the Digital Radio Camera. The system allows us to take the camera off the shelf and go, and the digital signal goes all the way through without going through analogue coding. The Digital Radio Camera also gives us reliability of signal, essential for live news events.*

*Examples of footage during the General Election include:-*

- *Margaret Thatcher in Winchester during the campaign, allowing the crew to go further into the Supermarket where she was meeting with local people.*
- *Charles Kennedy in Southwark Market, this allowed us to extend the coverage, giving the ability to follow him further through the crowd.*

*The kit has also been used at the High Court and the Old Bailey. The performance is simply stunning. It enabled a link across the Strand with buses passing close by with no disturbance, the performance with double-decker buses passing close by was particularly impressive.*

*We hope to use the camera at the Conferences this year because normal analogue radio cameras do not perform well inside buildings suffering from multi-path problems. This system will enable us to get top-shots during the conferences without the complex cabling that would otherwise be required.*

*The 18 frame delay on the current version does means the camera can only be used in isolation, it cannot be cut with other cameras, or used during two ways (particularly not over!).*

**Digital Radio Cameras for BBC Sport and BBC Events**

*BBC Resources have provided digital radio cameras for several live programmes this year including UK Athletics for BBC Sport. They have been used as a substitute for conventional analogue radio cameras and have shown some important advantages. It is usually possible to cover the required area from a fixed unmanned receive point which makes providing two or three cameras in the same arena much more simple. The complete absence of the common analogue radio impairments of multipath and patterning is also a huge advantage. Although the operating range is still limited the 'solid' feel of the picture is a great boon for production teams who want to see pictures all the time. We have had good results in the NIA Birmingham, Kelvin Halls Glasgow and a number of other indoor and arena type locations where multipath would have been a problem with analogue systems.*

*Three digital cameras were used at the BAFTA awards ceremony in the Grosvenor House Hotel which produced excellent results in this difficult environment.*

*The latency of the system is still a problem but the system has nevertheless shown itself to be a very useful production tool.*

## CONCLUSIONS

The BBC digital radio camera project has taken an idea from concept to reality. However, it has not stopped at the proof-of-principle stage in the R&D laboratory, but the project has widened its scope to include extensive trials with programme-makers thus bringing R&D closer to tackling practical operational problems. The R&D project is continuing to work with industry and standards bodies to transfer technology from the laboratory to operational systems. Through these processes the project aims to speed the way to its vision that one day all cameras could be radio cameras.

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## ACKNOWLEDGEMENTS

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