An uplinking technique for Eureka-147 satellite DAB

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The Eureka-147 terrestrial DAB system has been shown to be also suitable for satellite broadcasting at an international level. However, a method is needed to uplink the programme datastreams from, perhaps, several widely differing locations – to form a single DAB multiplex at the satellite for transmission to the consumer.

This article describes the possibility of using a conventional geostationary satellite, in conjunction with the TDM technique, to achieve multi-uplink access to the satellite.

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1. Introduction

While Eureka-147 DAB is becoming the world-wide standard for terrestrial digital radio broadcasting, in recent years it has also been shown to be suitable for satellite delivery, via tests on the Optus B3, Solidaridad 2 and EMS geostationary satellites.

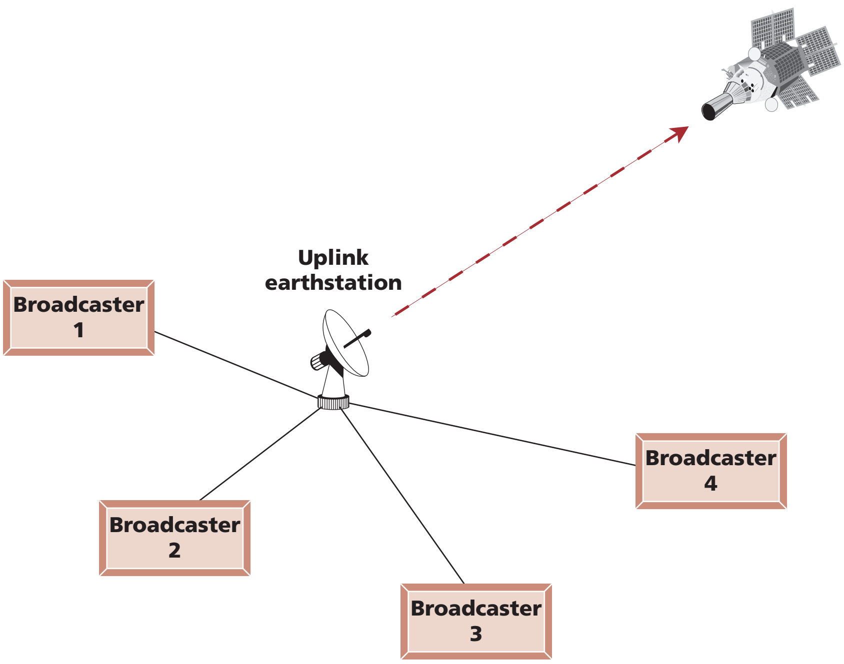


Figure 1
Conventional multiplexing of EU-147 S-DAB.

The Eureka-147 system is based on a programme multiplex which carries a combination of many separate services, each at a variety of bit-rates. However, given the international flavour of satellite broadcasting, it is likely that these services would originate from widely separated locations and this creates the problem of how the various data streams can be brought together into a single DAB multiplex or "ensemble" for transmission to the consumer.

2. Multiplexing options

The simplest multiplexing option would be to use a single central “hub” earthstation, fed by long-distance telecommunications links from the broadcasters’ studio centres, as shown in *Fig. 1*. However, with reliability issues, ongoing costs and the political situation outside the broadcaster’s control, this may not be popular. Therefore, each broadcaster may prefer to uplink the audio and data channels from an earthstation located at their own premises, and under their own direct control.

One possibility for local uplinking would be to use an on-board processing (OBP) satellite and, while this is a possibility for the Eureka-147 system, issues of cost, reliability and flexibility are seen by some as major drawbacks. A far more attractive option is the possibility of using a conventional satellite with its “transparent transponder” architecture, in conjunction with the TDM technique. This is the method described here.

3. Time-division multiplexing

With the TDM approach, each local earthstation (see *Fig. 2*) is allocated its own time-slot (T1, T2, T3 etc.) within the DAB transmission frame, during which it contributes a complete audio sub-channel via a burst of a few COFDM symbols. Using accurate synchronization techniques, the various transmissions from the many earthstations simply slot together at the satellite’s input antenna to create a composite signal which conforms exactly to the Eureka-147 standard.

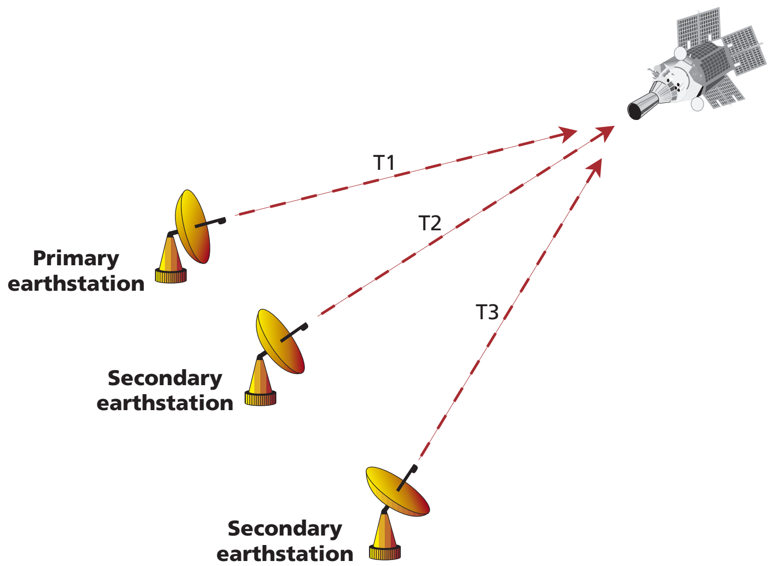


Figure 2
Multiple local earthstations in a TDM network.

This process has similarities to conventional TDMA operation but, whereas the data bursts in TDMA systems are generally unrelated and intended for different receivers, the TDM uplinking system aims to combine the data bursts into a single composite signal at the satellite which is then rebroadcast and made available to all receivers.

With no requirement for telecommunications links or a dedicated OBP satellite, and freedom to uplink from any location visible from the satellite, this TDM system would be most attractive. Although applicable to both GEO and HEO satellites, this article focuses on the GEO application.

4. DAB and the COFDM system

The Eureka-147 DAB system was designed to operate in one of four transmission modes, according to the frequency band used for transmission.

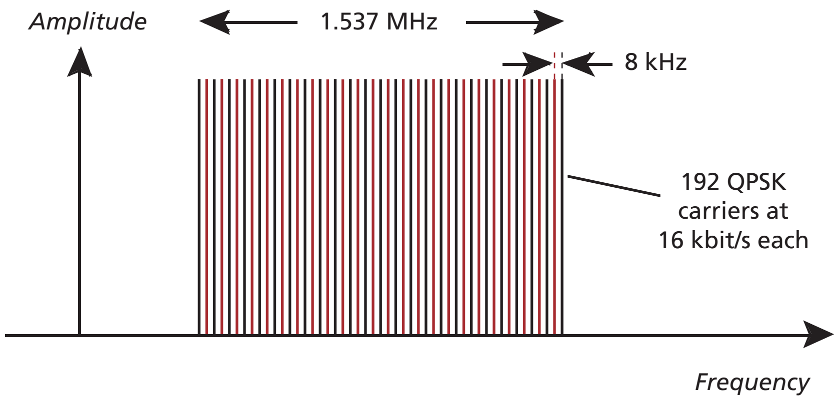


Figure 3
The Eureka-147 signal in the frequency domain (Mode III).

Each mode uses a different number of QPSK carriers, but an overall bandwidth of around 1.5 MHz. Following WARC-92, satellite digital audio broadcasting (generically) has been assigned spectrum in L-band from 1452 MHz to 1492 MHz. This article concentrates on Mode III which is suitable for use at up to 3 GHz. Mode III specifies 192 carriers, with each carrier modulated at 16 kbit/sec, and an inter-carrier spacing of 8 kHz, (as shown in *Fig. 3*). The symbol duration is 156 µs (including a 31 µs guard interval) with a transmission frame of 24 ms duration.

4.1. The DAB transmission frame

Looking at the Eureka-147 Mode III signal in the time domain, it is made up of a series of transmission frames, as shown in *Fig. 4*. Each frame consists of 154 symbols identified as:

- the null symbol used for coarse synchronization;
- the phase reference symbol for fine synchronization and tuning;
- the 8 fast information channel (FIC) symbols which carry (amongst other things) the multiplex configuration information (MCI);
- the 144 symbols of payload data which form the main service channel (MSC).

The MSC carries the audio data and is divided into sub-channels, with each sub-channel carrying 24 ms of audio for a particular service. Note that the position of each sub-channel within the transmission frame is fixed from frame to frame, which simplifies the implementation of the TDM process.

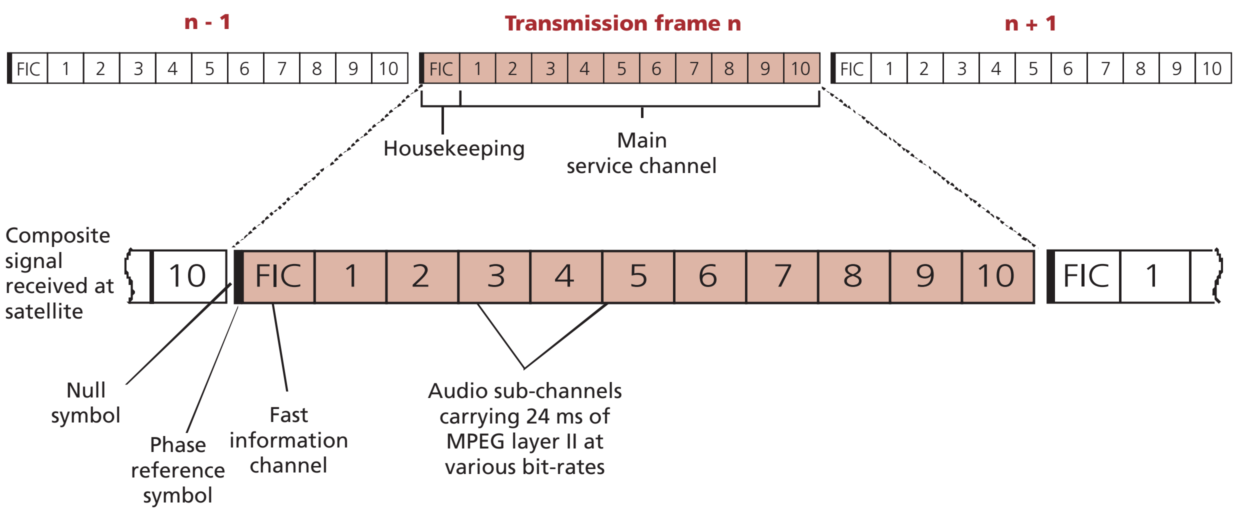


Figure 4
Multiple local earthstations in a TDM network.

The TDM system works by partitioning the transmission frame into several contribution slots, each allocated to a different earthstation (if necessary). The first contribution of the frame will carry the phase reference symbol, the FIC, and presumably (though not necessarily) at least one sub-channel. This originates from the earthstation designated as the primary earthstation. The other sub-channels, which make up the MSC and the bulk of the multiplex, originate from secondary earthstations, which only transmit their own contribution(s).

Due to the multi-carrier nature of DAB, one symbol in one particular transmission frame carries 384 bits. Therefore, a particular symbol – which is allocated to a sub-channel on a continuous frame-by-frame basis – occupies 16 kbit/s. So, for example, an audio channel coded at 128 kbit/s and rate 0.5 FEC would occupy 16 symbols per frame, which is approximately 11% of the multiplex capacity. *Fig. 5* shows how several contributing earthstations could create such a composite multiplex in this way.

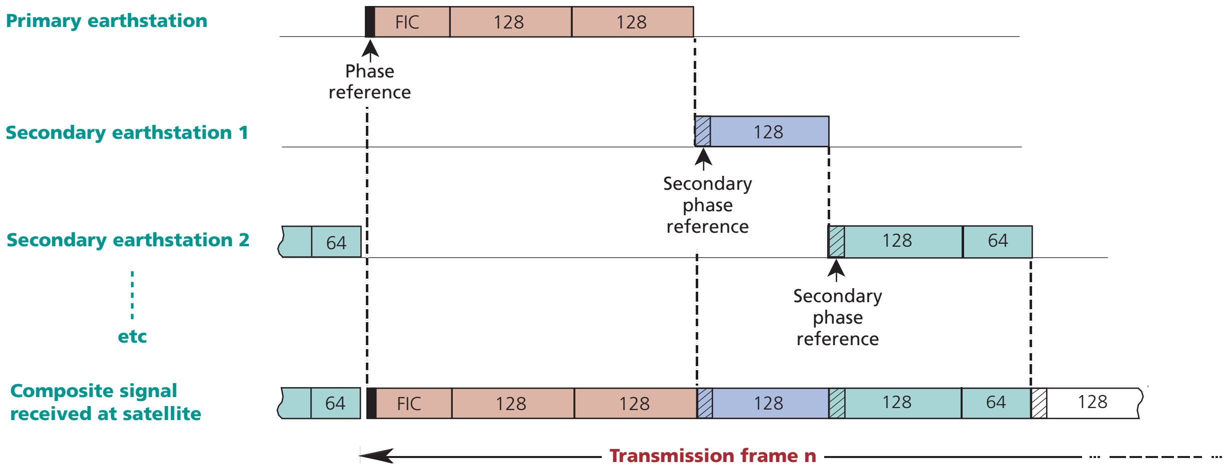


Figure 5
Multiple contributions combined via TDM. The example shows 128 and 64 kbit/s audio contributions.

Eureka-147 uses *differential* QPSK modulation, and at the hand-over point between contributions there will be a phase discontinuity. This prevents the first symbol of every secondary contribution from being decoded correctly. This first symbol effectively re-establishes the new phase reference, allowing the second and subsequent symbols of that contribution to be decoded as normal.

This secondary phase reference symbol cannot, therefore, be used to carry any user data, and this leads to a reduction in the available user capacity. However, with 144 payload symbols per frame, this is not a great problem as each lost symbol amounts to just under 0.7%.

4.2. Hardware

In order to prove the concept of TDM uplinking, two complete transmission chains were constructed at BBC R&D Department. Each chain consisted of audio coders, a sub-multiplexer, a COFDM generator, a proprietary switching unit and a GPS receiver, as shown in *Fig. 6*.

In each transmission chain, the sub-multiplexer is synchronized directly to both the 1 Hz reference signal and also the time code from the GPS receiver. The output of the sub-multiplexer is then sent to the COFDM generator where it first passes through a FIFO buffer. This FIFO delay

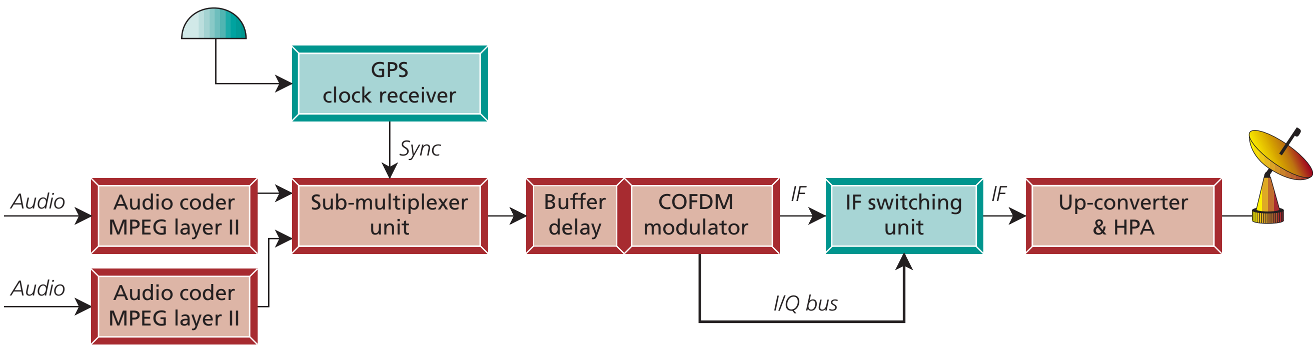


Figure 6
Block diagram of the TDM uplinking system.

is set to compensate for the differences in the path lengths between an individual earthstation and the satellite.

In the prototype implementation of the TDM uplinking system, each COFDM generator produces a continuous DAB signal throughout the duration of the transmission frame, and its RF output is then switched on / off in order to select only the symbols required for the local contribution. The resulting bursts of contribution data (occurring every 24 ms) are then passed to the uplink equipment for transmission in the conventional way.

If all the earthstations are synchronized, if the multiplexers are configured correctly and if the appropriate delay is set in the COFDM generator, then the uplinked contributions will arrive at the satellite's input antenna in the correct order and at the exact time required to construct the standard Eureka-147 multiplex, on-air.

4.3. Impairments to the composite multiplex

Although the composite signal broadcast from the satellite will be the combination of data bursts from several different earthstations, it must not exhibit any artefacts of its TDM origination. The three fundamental factors which affect the quality of the composite signal are (i) the synchronization of the data bursts arriving at the satellite, (ii) the accuracy of the uplink frequency and (iii) the power level.

Each of the impairments has the potential to degrade the transmitted signal, and in combination the effect will be additive. A series of tests using the two complete transmission chains to represent a primary and a secondary earthstation was performed in the BBC R&D laboratory at Kingswood Warren. This enabled the effect of each parameter to be assessed in isolation and under controlled conditions.

4.4. Transmission synchronization

The contribution data bursts must be accurately synchronized so as not to create any overlaps or gaps in the signal at the hand-over points. The curve for synchronization error vs. BER (*Fig. 7*) shows a negligible degradation for timing errors between approx. ± 15 µs, which is to be expected for a guard interval of 31 µs. Outside this region the BER increases steeply, until approximately ± 20 µs when impairments to the decoded audio will be heard.

While the synchronization accuracy required for a satellite-only delivery system would therefore be just a few microseconds, the use of co-channel terrestrial gap-filler transmitters would require that the COFDM guard interval should not be eroded. Therefore in a real system it would be wise to aim for a figure of around 1 µs. Using a specialized GPS timing receiver, we can expect to achieve an accuracy of better than 300 ns for most of the time.

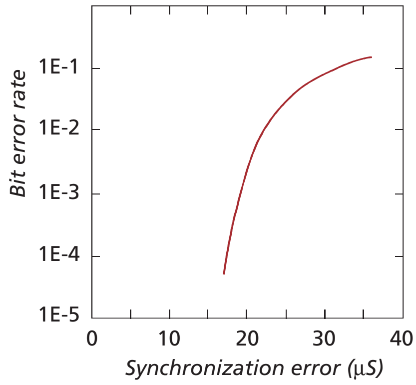


Figure 7
Synchronization vs. BER of the secondary contribution.

4.5. Slant path length compensation

Each of the contributing earthstations could be located at almost any point on the Earth's surface and, therefore, the slant-path length between each earthstation and the satellite will be different. A compensating delay is therefore required to equalize the propagation delays and to ensure accurate synchronization of the data bursts arriving at the satellite. The maximum possible difference in the slant-path delay between any two earthstations within the uplink beam of a geostationary satellite is 18 ms. Fortunately, this fixed difference can easily be compensated for, by using the buffer delay built into the existing COFDM generators (which was originally designed for SFN synchronization in the case of a terrestrial DAB network).

4.6. Satellite station-keeping errors

Apart from the fixed path-length difference for each earthstation, there is also an additional element due to the effect of orbital drift. Depending on the location and separation of the contributing earthstations, the orbital drift may cause significant *differential* delays, requiring a small but continuous adjustment to the fixed delay value.

4.7. Frequency matching of earthstations

In a single uplink (non-TDM) application using a "hub" earthstation, the up-conversion oscillators need not be particularly stable as the receiver's AFC is capable of compensating for some error. However, in the TDM uplinking system, because the receiver's AFC and phase reference circuitry operate only on the phase reference symbol at the very start of the DAB frame, the receiver will effectively only "tune in" to the contribution from the primary earthstation. Any secondary contribution may create a step change in the frequency at the handover point, and any frequency difference here will degrade the signal. Up-converter frequency stability is therefore a key issue.

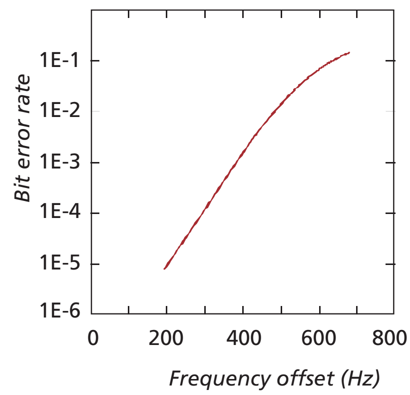


Figure 8
Frequency-matching vs. BER of the secondary contribution.

Tests in the laboratory using the experimental dual-transmission-chain equipment showed that a negligible degradation to the signal occurs for a frequency error of less than 200 Hz, (using the Mode III inter-carrier spacing of 8 kHz) as can be seen from *Fig. 8*. Because the absolute frequency tolerance does not vary with transmission frequency, this translates into an error of around 1 part in 10^8 at Ku band (14 GHz).

4.8. Power-level matching

Laboratory tests, which looked into the requirement for power-level matching, showed that an imbalance between the output powers of the primary and secondary earthstations was not in itself a problem: the system was able to withstand considerable variation in envelope amplitude through the transmission frame.

However, as this is a downlink power-limited system, the satellite must always operate at its optimum power output throughout the transmission frame, simply to maximize the received signal level. Because TDM uplinking uses a transparent transponder approach, it is not possible to compensate for incorrect uplink power levels at the satellite. Therefore the EIRP of each earthstation would need to be balanced to within a fraction of a dB at the satellite's input antenna to maximize the link budget.

4.9. Fault tolerance

As with any time-division-multiplexed system, a lack of data at the appropriate time, or a major overlap between two contributors, will lead to some disruption of the service. However, it was found that the Eureka-147 TDM system is surprisingly tolerant of fault conditions.

During periods of gross disruption to the frame structure, such as during complete loss of a secondary uplink contribution, some receivers at least are still able to maintain uninterrupted operation, provided that the primary earthstation continues to transmit the phase reference symbol and the FIC satisfactorily. Any failure of a secondary earthstation only affects those customers listening to the contributions from that particular earthstation. Listeners to other services on the same multiplex should be unaffected.

Abbreviations

AFC	Automatic frequency control
BER	Bit error rate
COFDM	Coded orthogonal frequency division multiplex
DAB	Digital Audio Broadcasting
DASA	Daimler-Benz Aerospace
EIRP	Effective isotropic radiated power
ESA	European Space Agency
ETSI	European Telecommunication Standards Institute
FEC	Forward error correction
FIC	Fast information channel (DAB)
FIFO	Fast in, fast out
GEO	Geostationary orbit
GPS	Global positioning system
HEO	Highly-inclined elliptical orbit
ITU	International Telecommunication Union
MCI	Multiplex configuration information (DAB)
MSC	Main service channel (DAB)
OBP	On-board processing
QPSK	Quadrature (quaternary) phase-shift keying
SFN	Single-frequency network
TDM	Time-division multiplex(ing)
TDMA	Time-division multiple access
WARC	(ITU) World Administrative Radio Conference

5. TDM uplinking verification tests

While the laboratory tests showed that the TDM uplinking appeared to work, in order to prove the concept conclusively it was necessary to realize the system over an actual satellite link, using multiple earthstations.

For the tests, the EBU made available part of their permanent capacity on transponder 25 on Eutelsat II-F4. This transponder can carry a variety of services, including two 2 Mbit/s QPSK *Euroradio* channels, which are normally used for high-quality contribution circuits over Europe. With a similar bandwidth to the 1.5 MHz-wide Eureka-147 COFDM signal, the *Euroradio* channel was well suited to carry the TDM tests.

5.1. Frequency matching in practice

The frequency-critical components in the uplink transmission chain are the COFDM generator and the Ku-band upconverter. Unfortunately, standard commercial upconverters typically have a claimed free-running (i.e. internally-referenced) stability of around 700 Hz error, at Ku band (rather than the 200 Hz accuracy required for TDM operation). Thus, in order to provide sufficient frequency matching, it was necessary to lock the upconverters to an *external* 10 MHz reference input, derived from a GPS receiver. This enabled an accuracy of around ± 3 Hz at Ku band (i.e. 2 parts in 10^{10}) to be achieved.

5.2. Synchronization verification

One of the key issues in TDM uplinking is synchronization and, in order to prove this aspect of the system, it was necessary to select earthstations which were separated by a relatively large distance. Initial test transmissions used earthstations at BBC premises in Glasgow (Scotland) and at Wood Norton near Birmingham (England); these tests showed that the synchronization could be maintained to within the target figure of 1 µs.

The second over-air test was aimed at establishing full TDM operation, and used two BBC mobile earthstations, UKI-35 and UKI-90, both located at the BBC R&D Department at Kingswood Warren near London.

In order to optimize the frequency accuracy and stability of the uplinks, every oscillator in each transmission chain was externally locked to a 10 MHz GPS reference as described above. However, it should be pointed out that *each earthstation had its own GPS receiver and there was no cross-linking of any kind.*

The Kingswood Warren test was entirely successful, with TDM uplinking being established from switch-on. No further frequency or timing adjustments were required. The result of these tests therefore proved that TDM uplinking to a transparent transponder is indeed feasible and causes negligible additional degradation to the COFDM signal.

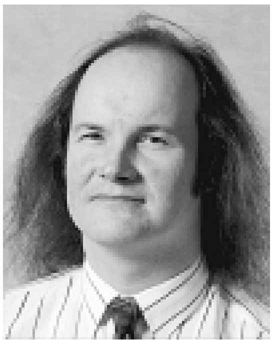
6. Further developments

The experimental system described in this article has proved the TDM uplinking concept. However, it does not incorporate any of the feedback systems which would be required in an operational installation. In particular, compensation for changes in the synchronization due to orbital drift, and for apparent changes in the earthstation's output power due to rain attenuation, would be required.

If the TDM multiplexing technique were to be applied to a satellite in a highly-inclined elliptical orbit (HEO) – e.g. the proposed MediaStar system – the satellite's changing position and velocity would require a sophisticated control system to accommodate the more complex synchronization and uplink frequency changes, but the principle of TDM uplinking remains equally applicable.

7. Conclusions

It has been shown through tests in the laboratory and over an actual satellite that TDM uplinking works. It is now possible to uplink audio contributions from a network of local earthstations to a transparent transponder satellite in order to create a standard Eureka-147 DAB multiplex.



Richard Evans *graduated from the University College of North Wales with a BSc in Electronic Engineering in 1988. In 1989, he joined the Transmission Systems Group at BBC Research Department where he was involved with the development of a variety of high-integrity microwave links for outside broadcast use, including an advanced mobile wireless camera system.*

In 1995 Mr Evans joined the department's DAB project, and was part of the team which carried out the early Eu-147 tests via the Solidaridad II satellite in Mexico.

The TDM uplinking technique allows broadcasters to operate their own local earthstation facility, and not have to rely on a central "hub" earthstation, which would possibly be located in another country and be operated by a third party. The TDM approach eliminates the costs and potential unreliability of an international communications link, which may not even be available in some parts of the world. In addition, the use of a "general purpose" *transparent transponder* satellite, means that the disadvantages of a dedicated on-board multiplexer / on board processing (OBP) satellite are completely avoided.

It was found that the key requirements are the synchronization and accurate frequency matching of the uplink transmission at each local earthstation. Both of these criteria can be readily achieved using reference signals derived from commercial GPS receivers, at relatively low cost. If these criteria are met, then the process of uplink multiplexing does not impair the quality of the DAB signal received on the ground.

The over-air satellite tests were carried out using Eutelsat II-F4, which is a *geostationary* satellite. However, TDM uplinking could be readily extended to a satellite in a highly-elliptic orbit (HEO), such as the MediaStar system proposed jointly by DASA and ESA.

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