DIGITAL TELEVISION BROADCASTING VIA UHF SATELLITE

Mark Walker BEng, MSc, CEng, MIEE.
Electronics Hardware Engineer, Processor Group, Astrium-Space, [1]. (mark.walker@astrium.eads.net)
Communications EngD student at UCL, 31-03-2005 to 30-03-2009

ABSTRACT: The UK currently has both analogue and digital terrestrial UHF television (TV) broadcasting. The proposed (terrestrial) digital switchover (DSO), due to complete by 2012, will release UHF-bandwidth, providing a 'digital dividend.' However, UHF digital TV broadcast by satellite requires only a fraction of the investment currently needed to upgrade the terrestrial network. It provides full national coverage, compatible with existing terrestrial receivers. It is based on commercially available technology, with a proven track record in flight. It can be operational by 2011, providing a full national digital TV service from switch-on. It is also environmentally friendly offering a substantially reduced carbon footprint and releasing more spectrum, thus enlarging the digital dividend. This paper investigates the options for including UHF digital television broadcasting via satellite as part of the UK's DSO programme and also considers other potential applications of this novel approach.

1. INTRODUCTION

Historically, the UK has led the world in digital television; five years after launch over 50% of all UK homes were accessing digital television (TV) services [2]. This is a faster rate of adoption than colour TV, compact disk players or even mobile phones. By June 2005, nearly 62% of UK households (≈ 15 million) had digital TV [2]. The UK also spends more on its TV market than any other country, at approximately 1% of GDP [3]. Today the UK has full national broadcasting of analogue TV, plus digital TV broadcasting from 80 of the most powerful 1,154 UHF transmitters. The proposed digital switch over (DSO) is planned to be complete by 2012. The aim is to reach 98.5% of the population, the same as judged to receive terrestrial analogue today. It is also estimated that 10% of households will need to replace their analogue aerial.

2. DIGITAL TV BROADCASTING VIA KU BAND SATELLITE

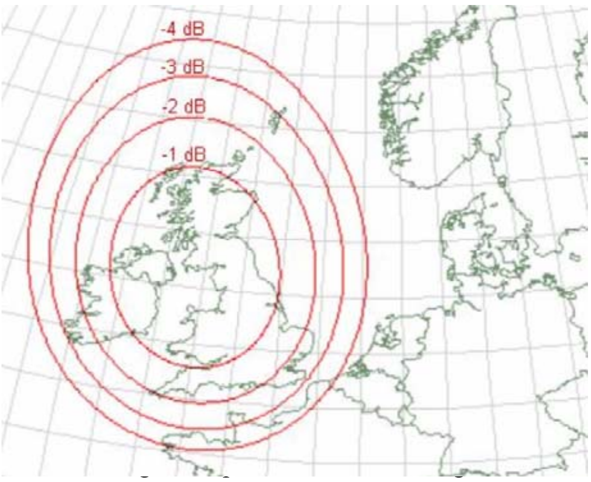
This platform enjoys low operating costs. Transmissions at Ku-band are not bandwidth limited, enabling high quality reception and easy migration to high-definition TV. Subscription and free-to-air content are both currently available, as is low cost free-to-air receiving equipment. However, these Ku-band transmissions are not compatible with terrestrial set-top-boxes. Receiving aerials are subject to some planning restrictions and require precision alignment. They also suffer from signal path blockage, particularly in urban environments.

3. DIGITAL TV BROADCASTING VIA UHF SATELLITE

A broadcast satellite based on current commercial high power platforms, employing key enabling technologies can provide a national UHF digital TV service that may be received by existing off the shelf TV aerials, that are compatible with existing free view set-top boxes, which can be received anywhere in the UK. This system requires a fraction of the economic and environmental cost of the terrestrial DSO. Existing UHF TV aerials may simply be re-pointed south and elevated; precision alignment is not required, making this a DIY installation.

3.1 COVERAGE

The UHF satellite would illuminate the British Isles with a single spot beam, powered by solar energy. It would provide similar power to the set top box as the current terrestrial service. It would illuminate valleys, thus eliminating the need for the 1,154 terrestrial transmission stations and offer a consistent service over the whole British Isles. However, the single beam would not allow for regional programming. A multi-spot system would require frequency reuse, reducing the digital dividend and necessitating an infeasibly large antenna, of 50 to 100 meters in diameter. The scheme will also require cooperation from Ireland and mainland Europe.



3.2 KEY ENABLING TECHNOLOGIES

Standard satellite, ground segment and launch technology is assumed, except:

High linearity solid state power amplifiers (SSPAs), based on the L-band designs flown on Inmarsat 4 in 2005 [4, 5], are required to deliver sufficient carrier power from the available solar power. They are suitable for COFDM on a 16 QAM carrier and will use the available power of ≈ 2.5 kW, the limit of contemporary satellite platforms, to provide the 1.8 kW nominal RF output power (i.e. for nine multiplexes at 200 Watts each).

A **24 meter unfurlable antenna** reflector, similar to the nine meter diameter model developed for and flown on the Inmarsat 4 satellites (shown in Fig. 2) is required to give a sufficiently small beam spot. A 22 meter L-band reflector will be flown on MSV in 2009 (satellite contract awarded January 2006 [6]). UHF operation requires antenna diameter to be scaled up but needs a less demanding dimensional accuracy.

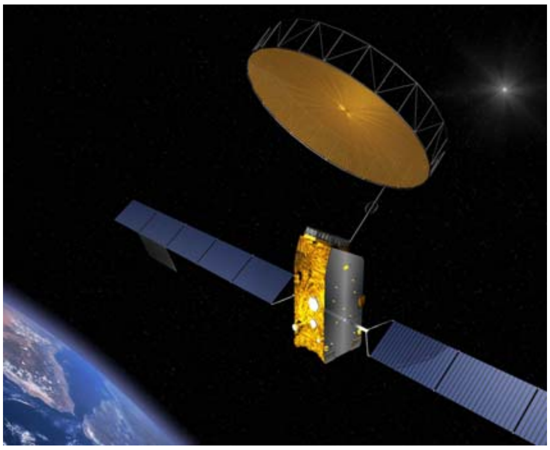


Fig. 2: Inmarsat 4 unfurlable antenna

Satellite lifetime is limited to approximately 15 years by the quantity of fuel carried onboard, which is used to maintain the craft's orbital altitude and position. Lifetime could be extended to around 20 years, by allowing the satellite to drift in elevation, because the user's aerial has a 30˚ beam width.

Ion propulsion would further extend satellite life to about 25 years. Novel orbit injection techniques, such as the super synchronous method, may extend fuel reserves even further, by reducing the amount of fuel used to initially achieve the target orbit.

3.3 ENVIRONMENTAL IMPACT

The DTI's original cost benefit analysis (CBA) [7] for digital TV switchover (DSO) did not consider the environmental trade-off. The analysis presented below is not a full Carbon audit because it ignores the manufacturing, installation and maintenance of the terrestrial Digital TV network, the manufacturing of the satellites and launch vehicles and the satellite ground station(s). It concentrates instead on the terrestrial network electricity consumption and the Ariane 5 rocket's CO_2 emissions during launch.

The current terrestrial mix of national analogue and selective digital TV broadcasting is inefficient. There are 48 transmitters with an effective isotropic radiated power in excess of 50 kW broadcasting for the BBC, ITV and channel four. They have a total output of 14,925 kW. A further 14 transmit channel five, with an additional 3,946 kW EIRP. Assuming the smaller infill transmitters collectively output 250 kW, then the total terrestrial output is 18.5 MW. Assuming a transmitter efficiency of 30%, the total broadcasting power consumption is 61.6 MW, or 539 GWh per annum (P.A.). The reduction in transmitter power consumption due to DSO is estimated by the Government [8] to be 186 GWh, which gives a DSO transmitter power consumption of 353 GWh P.A. This is about 0.1% of the total British electricity consumption [9]. Assuming that this power is generated by coal fired power stations,[1] with one kilogram of CO_2 released per kWh generated, then the terrestrial transmitter power consumption is responsible for 353 thousand tonnes of CO_2 P.A. Assuming a commercial rate of two pence per unit, this costs £7.06 M per annum, or £106 M over a 15-year satellite lifetime.

A satellite's electrical power is obtained from solar cells so is free from greenhouse gas emissions. However, it takes about 841 MW of energy for an Ariane 5 rocket to place two satellites into geosynchronous orbit, which is about the same amount of energy required to fly a Boeing 747 from London to New York. During the launch, Ariane burns 615 tonnes of propellant but produces only 123 tonnes of CO_2 [10], equivalent to 0.03% of the CO_2 resulting from the UK's annual digital terrestrial transmitter power consumption. The 747 flight will burn about 75 tonnes of aviation fuel but generate 170 tonnes of CO_2 [11]. Ariane's Hydrogen and Oxygen core stage propellants yield only steam as a by-product. They are produced by electrically reforming bio-ethanol, using sugarcane and hydro-electricity local to the Korou launch site. The solid rocket boosters (SRBs) use a fossil carbon derived binder, constituting less than 10% of their fuel. They also produce Aluminium Oxide and Hydrogen Chloride (the white smoke), which are quickly 'rained out' of the lower atmosphere, into the ocean.

[1] Because coal fired stations emit the most CO_2 per kWh and should therefore be the first to cease production.

4. Option 1: Provide the UK's Digital TV Service via UHF Satellite

The digital switchover programme plan [12] claims that completing the UK terrestrial DSO will result in quantifiable benefits in the region of £1.1 to £2.2 billion in NPV terms. The CBA [6] estimates the differences between continuing with dual analogue and digital terrestrial TV transmission and the terrestrial DSO. It excludes sunk costs. Sensitivity analysis estimates a loss of £250 to £300 million in NPV for every year of delay and is most sensitive to the value of released spectrum. The CBA model discounts figures back to 2004 using the treasury rate of 3.3%. The year of switch over is the key variable, ranging from 2010 to 2015 and the model ends in 2026, when the multiplex licences reach the end of their second period of 12 years.

4.1. The Cost to Consumers

This is not considered in detail, as it is approximately equal for both terrestrial and satellite UHF digital TV broadcasting schemes. It includes equipment procurement, additional electricity consumption and the inconvenience caused to those who suffer degraded reception, but offset by the value of improved content. The satellite may have a slight advantage due to 100% UK coverage, versus the 98.5% target for the completed UHF digital terrestrial network.

4.2. A Reduced Infrastructure Cost

Today's terrestrial network transmits digital television from 80 of the 1,154 sites. The cost of conversion is for the remaining 1,074 sites and is estimated at £4.8 billion:

Cost of DTT network up to 2002 [13]	£ 2.0 B
BBC service contract for 1154 transmitters [14]	£ 1.8 B
Cost to upgrade the other 4 multiplexes [15]	£ 1.0 B
	£ 4.8 B

Typical Inmarsat 4 figures [16], may be used to illustrate the cost of a contemporary satellite system:

Satellite (Inmarsat 4, from Astrium)	$ 250 M
Ground segment	$ 50 M
Launch	$ 100 M
Insurance against launch failure (optional)	$ 50 M to 100 M
Total for an operational orbiting satellite	$ 400 M to 500 M

A reliable system would fly two satellites (on different rockets to spread the risk) with a third kept as a ground spare. The total cost would be between £500 M and £800 M, allowing for exchange rate variation and insurance.

4.3. An Increased Digital Dividend

There are 49 eight MHz channels allocated within the UHF-band, 46 of which are currently used for analogue and low power digital TV broadcasting. After DSO, the digital terrestrial network will leave 14 channels fully cleared and 32 partially cleared, carrying digital TV in different regions.

The proposed digital UHF satellite system, carrying the full post-DSO capacity of eight multiplexes requires 11 channels, thus freeing up 35 channels. The improvement is therefore 21 fully cleared channels, which are generally regarded as more valuable than interleaved channels because they enable nation wide services.

The digital dividend consultation paper, published by Ofcom on 19th December 2006 [17], estimates the released spectrum value at between £5 and £10 billion over 20 years in NPV terms. It also discusses possible future spectrum uses and auction designs.

5. Option 2: Augment UK Terrestrial DTV with HDTV via UHF Satellite

Some of the UHF bandwidth released by the DSO could be used for HDTV broadcasting. Satellite transmission does not require frequency reuse, making it about four times as efficient as terrestrial transmission, which does. Assuming an HDTV bit-stream can be compressed to about 12 - 16 Mbit/s and using a modulation scheme with 4 bits per Hz, it should be possible to transmit two HDTV channels per 8 MHz UHF channel.

However, the UHF satellite system would not have regional programming, including advertising. It could also be argued that HDTV is a luxury, given the price of HDTV compatible screens, so the cost of Ku-band receiving equipment and aerial installation is relatively low. Ku-band transmission is not bandwidth limited to the same extent as the UHF band and would not suffer coexistence problems in the same way as UHF satellite systems.

5. Option 3: UHF Satellite TV For Intrinsically Suitable Locations

The simplest scenario is to consider a geographically isolated country, where there are no co-existence issues. One such example is New Zealand. The beam size would need to be larger than for the UK, requiring either a smaller satellite antenna reflector or shaping of the beam by varying antenna feed weights. Since satellite power output is limited, fewer channels would be supported than in the UK scenario.

An alternative is to broadcast to equatorial regions, including upper South America and Central Africa, where a broadcast satellite appears to be approximately overhead. Receive aerial directivity (nulls at 90˚) permit the satellite transmissions to co-exist on the same frequencies as current terrestrial TV. UHF satellite transmission is likely to provide the cheapest means to achieving ubiquitous coverage. These areas will also benefit most from the low cost receiving equipment and simple aerial alignment. Vertical receive aerial alignment is also possible in the UK, using a highly elliptical (Molniya) satellite orbit. This may solve the frequency coexistence problems but could prove to be commercially unattractive, because at least three satellites are required for a 24hr service.

6. Conclusion

Despite a significantly reduced infrastructure cost and environmental impact, combined with an increased digital dividend, the terrestrial DSO programme is probably too far advanced for UHF digital TV via satellite to be a viable proposition. For geosynchronous orbits, co-existence with existing users is problematic in the UK scenario. Such a scheme would also lack regional programming and advertising. HDTV could be provided by UHF satellite, with about four times the spectral efficiency of a terrestrial network. If a Molniya orbit were used, coupled with a vertical receiving aerial alignment, the co-existence issues may be mitigated. Intrinsically suitable locations include isolated countries, such as New Zealand and Equatorial regions, which require a vertical aerial alignment for geosynchronous satellite reception, thus mitigating co-existence issues.

7. Acknowledgements

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