Introduction to DAB Digital Radio

Digital audio broadcasting (DAB) is a free-to-receive terrestrial radio transmission system, like AM and FM, and uses a separate region of the radio spectrum. This article begins with a brief explanation of how DAB is transmitted, followed by an introduction to DAB in England, Scotland, Wales and Northern Ireland. Sound quality and reception quality are then discussed, followed by an overview of DAB in other countries and a discussion of other digital radio standards.

DAB Transmission

DAB digital radio uses a transmission system known as coded orthogonal frequency division multiplex (COFDM). This divides the signals amongst several hundred low bit rate carriers. Because the bit rates are low, the signal can be subject to large multipath dispersion without any adverse effect on reception. In fact, multipath reinforces and improves reception. For DAB, the bit rates on the individual carriers are low enough for different transmitters carrying the same programmes to broadcast on the same frequency, provided they are correctly synchronised. This enables much more efficient use of the radio spectrum.

Each DAB transmission, known as a multiplex, is spread over about 1.5 MHz, with 4 phase (2 bit) symbols. This gives a data rate of about 2.4 Mbit/s, about half of which is used for error correction (though this may be varied). Each multiplex carries between 6 and 15 radio stations, depending on the bit rate (and hence sound quality) allocated to each station. The data for all the stations is distributed amongst all of the carriers. This is to ensure that interference to a few carriers does not cause more disruption to a particular station's bit stream than the error correction software can handle. Time interleaving is also used to protect against short duration interference spikes.

DAB broadcasts in VHF band III between 174 and 240 MHz. This spectrum is shared with other users, including TV in some countries. Band III is divided into eight 7 MHz channels, numbered 5 to 12, each of which may be used for a TV multiplex, plus the 10 MHz wide channel 13. Note that channels 1-4 are in band I, which is no longer used for broadcasting. Each 7 MHz channel is subdivided into four smaller channels, designated A, B, C and D, and channel 13 is subdivided into six channels, A-F. Thus, each DAB channel is designated by a number and a letter. For example, the BBC national multiplex uses channel 12B. DAB can also operate in the L band between 1452 and 1492 MHz. However, no country is operating permanent services in this band and most radios only receive VHF band III.

Digital Radio in the UK is changing transmission format from the original DAB standard to the newer DAB+ standard. Multiplexes can broadcast a mixture of original DAB and DAB+ stations. Therefore, the format transition is happening station by station with very little publicity, If your DAB radio is not compatible with the new DAB+ format, radio stations will either go silent or disappear completely when they switch to DAB+. Most car radios and most new portable radios are DAB+-compatible, whereas most radios bought before 2013 are not compatible. If you have a Pure radio has a USB socket, it may be possible to upgrade its software to receive DAB+. Otherwise, you will have to replace your radio. Many retailers and manufacturers do not indicate whether or not their radios are compatible with DAB+. Therefore, it is recommended that you buy a radio which is clearly marked as compatible with DAB+ or has the green tick mark.

DAB in England, Scotland, Wales and Northern Ireland

In September 1995, The BBC launched the world's first digital radio service on DAB in the London area, carrying its five national networks with outdoor coverage extended to 60% of the population by mid 1998 as receivers started to become available. A national commercial network, Digital One, launched with five stations in November 1999 as receivers started to become available, albeit relatively expensive. Further stations launched on Digital One in 2000, together with the first local multiplexes. In 2002, the BBC launched five digital-only national radio stations and the first sub-£100 radios became available. By 2007, local radio multiplexes covering 40 different areas were on air, each typically carrying 8 to 11 stations. Additional regional multiplexes served Central Scotland, the North East, North West, Yorkshire, the West Midlands, the Severn Estuary region and London (2), while coverage of the BBC and Digital One multiplexes had reached about 80%. Channels 11B to 12D were used.

An additional four channels (10B to 11A) were allocated to DAB in 2006 and licences were awarded in 2007-8 for 12 new local radio multiplexes for previously unserved areas and a third national multiplex. However, the economic recession reduced advertising income, resulting in a halt in commercial DAB development. Digital One was reduced to four stations in 2008 and none of the new multiplexes launched, though services on the local and regional multiplexes continued. Digital One gradually filled up again by 2011, initially attracting minority broadcasters.

In 2012, a decision was taken to abandon the regional multiplexes and invest in the local and national multiplexes. The local multiplexes licensed in 2007-8 launched between 2012 and 2015, with most of the regional multiplexes closing in 2013 (Central Scotland and London continue, while Yorkshire closed in 2015). Some stations broadcasting on the regional multiplexes moved to local multiplexes or Digital One while others closed. In 2015, the third national multiplex was re-awarded to the Sound Digital consortium, which launched in February 2016 and a plan to increase coverage of the local multiplexes to 90% (indoors) was completed in early 2018. Over this time, coverage of the BBC multiplex has also grown, reaching 97.4% indoor population coverage. Digital One also expanded coverage to 91% (indoor). Additional local multiplexes for the Channel Islands and Cumbria launched in 2021. By 2017, DAB radios were available from £18 and fitted to about 80% of new cars. DAB's share of all radio listening peaked at 41% in 2021 and has subsequently declined slightly.

Most people in the England, Scotland, Wales and Northern Ireland can receive about 60 stations, about three times as many as on AM and FM combined (excluding out of area stations). All FM and AM national stations and most city, county and regional FM and AM stations are also available on DAB. The main areas where local and regional stations are not available on DAB are parts of West Norfolk, Powys, Scottish Borders, Dumfries and Galloway, North West Scotland, and the Isle of Man. Many commercial stations have much wider coverage on DAB than on FM/AM, while about half the stations available on DAB are exclusive to digital radio. Thus, programme choice is a key advantage of DAB in comparison with FM and AM.

The next stage of DAB development in the England, Scotland, Wales and Northern Ireland is the introduction of a tier of small-scale (SS) multiplexes, typically broadcasting over a 10 km radius. These enable smaller-scale stations to broadcast on DAB for the first time. Trial broadcasts ran in ten areas from 2015 until the launch of the permanent SSDAB service in that area. The licensing of the permanent multiplexes began in 2020 with the first launches in 2022. About 50 multiplexes were on air at the start of 2024 with major cities and large towns amongst those served first. Ofcom has allocated the additional channels 7D, 8A, 8B, 9A, 9B and 9C for use by small-scale DAB. The remainder of band III in the UK is used by various communication services, including radio microphones and private mobile radio.

By 2015, most countries had abandoned the original DAB standard in favour of DAB+. However, England, Scotland, Wales and Northern Ireland had stuck with the old DAB standard because there are millions of old DAB radios in use that can't receive DAB+ stations. From 2016, DAB+ has been used for some new stations. It is now widely used by smaller broadcasters, particularly on the small-scale multiplexes. During 2019, the process of switching the main commercial stations to DAB+ began. This is being done on a station-by-station basis to make room for new launches in the DAB+ format, so the transition is likely to take several years. As of January 2024, more than three quarters of the stations on the two national commercial multiplexes were using DAB+. However, most of the county level multiplexes use only the original DAB standard. The BBC is currently sticking with the old DAB standard for the moment (except for local radio on new multiplexes), but will likely switch to DAB+ once the commercial sector has done so.

DAB Sound Quality

The marketing people will tell you that DAB gives you 'digital quality' sound. This may be true, but it is also meaningless as digital quality ranges from mobile phone quality up to CD quality. Although DAB is capable of near CD quality sound, there is a trade-off between the number of stations and the sound quality. Broadcasters in England, Scotland, Wales and Northern Ireland have prioritised station choice.

In the British Isles, most DAB stations sound similar to FM on a mono radio. However, in stereo, FM can sometimes sound better, provided the reception is good (i.e. no background noise or multipath interference). Furthermore, a lot of stations broadcasting in the original DAB format, including some music stations, broadcast in mono. Stereo broadcasting in the original DAB format is reserved for the most popular stations, generally those that are also available on FM. Note that Radio 4 sometimes broadcasts in mono when 5 Live Sports Extra is on air. The vast majority of DAB+ stations broadcast in stereo.

A CD codes audio at a rate of about 1.2 Mbit/s. Using the same coding standard on DAB would only allow one station per multiplex - not very practical. Therefore audio compression is used to reduce the data rate of each station. Audio compression techniques all make use of psycho-acoustic coding. This takes advantage of the fact that when a sound on one frequency is heard, the ear is rendered much less sensitive to quieter sounds on nearby frequencies. A psycho-acoustic coder performs a Fourier analysis of the sound to be coded and calculates a noise floor. Sound below the noise floor cannot be perceived by the listener, so can be discarded. Only the sound above the noise floor need be calculated and this requires much fewer bits than coding the whole sound, as is done on CDs.

The original audio coding standard used for DAB is MPEG (Motion Picture Expert Group) 2 Layer 2, abbreviated to MP2. This samples at 48k samples per second (twice the maximum audio frequency). Each block of 384 samples is broken into 32 equal frequency bands of 12 samples each and a separate noise floor and scale factor is set for each band. Noise floor and scale factor information is shared between sets of three blocks to save bits. Stereo stations mostly use a technique known as joint stereo whereby lower bit rate stereo separation data is added to a mono signal rather than coding the left and right channels in full.

A feature of these audio coding techniques is that some types of programming are easier to code than others, so, on a music station, the quality will vary from track to track. Relatively sparse music, such as R&B, soft rock and country tends to code well, whereas busy music, such as loud rock and over-produced pop can present more of a problem.

DAB was designed in the early 1990s and MP2 is now a rather dated coding standard, requiring 192 kbit/s to transmit a high quality joint stereo signal. Its successor, MPEG 2 layer 3, or MP3, only requires 128 kbit/s because it uses narrower frequency bands at for the lower frequency components of the signal, enabling the noise floor to be set much more efficiently. Newer techniques, such as AAC and HE-AAC v2 (used by DAB+), are even more efficient.

As well as the bit rate and coding algorithm, sound quality is affected by dynamic range compression and transcoding. Dynamic range compression (DRC) increases the amplitude of weaker frequency components of a sound signal. This makes the overall sound seem louder, making a station 'stand out' on the dial and helping to mask background interference on AM and FM. In recent years it has become fashionable, especially amongst commercial broadcasters, to use extreme amounts of DRC. This makes music sound distorted, particularly percussion, on all transmission platforms. On DAB, it creates an additional problem: the DRC brings more frequency components above the noise floor of the psycho-acoustic coder. This means that more bits are required (particularly at the higher frequencies) to encode the sound to a certain standard. Conversely, if the bit rate is fixed, high levels of DRC cause the perceived sound quality to drop. Turning down the dynamic range compression would be a very simple way of improving the sound quality on many stations.

Transcoding is where broadcasters code and decode the programme material several times through the transmission chain, often starting with a compressed playout system in the studio. A psycho-acoustic coder has trouble telling the difference between weak frequency components and the noise floor left by an earlier lossy audio coding process, leading to poorer sound quality than if it had coded the original sound, even if the previous coding stage was at a higher quality. A good analogy is photocopying - a copy of a copy always looks poorer than a copy of the original. In a well-engineered DAB system, such as the BBC's, audiocoding is performed once, at the studio, and all further distribution between studio and transmitters is in coded form.

Although DAB was designed to transmit stereo stations at 192 kbit/s or higher, the vast majority of stereo stations in the England, Scotland, Wales and Northern Ireland transmit at 112 or 128 kbit/s, significantly limiting the sound quality. Only Radio 3 transmits at 192 kbit/s. Mono stations typically use 64 or 80 kbit/s. DAB Ensembles Worldwide (http://www.wohnort.org/DAB/) lists the bit rates for each station. Note that all bit rates listed here include error correction information and other data associated with the audio program, such as the accompanying text. When such low bit rates were first introduced for DAB in the early 2000s, there noticeable distortion to the sound. Since then, a new MP2 coder, about 10-15% more efficient than its predecessor, has been gradually introduced. The BBC national stations adopted it in 2006. There have also been other improvements in the audio processing chain, such as reducing transcoding and limiting the audio bandwidth. Today, audio distortion is not a major problem on DAB. However, DAB can sound flat compared to FM on stereo equipment.

The newer DAB+ standard uses the AAC family of audio coders. AAC is more than twice as efficient as MP2. HE-AAC additionally uses a technique called spectral band replication (SBR). SBR fully codes the lower frequency half of the audio spectrum and then generates the upper half by replicating the octave below and rescaling. HE-AAC v2 additionally uses a technique called parametric stereo to code stereo audio using only slightly more information than its mono counterpart, enabling bit rates as low as 32 kbit/s to be used for stereo audio (albeit with limited sound quality). The switch to DAB+ gives broadcasters a choice between minimising the transmission cost per programme and improving the audio quality. Broadcasters are generally going for the former, but music stations are at least switching from mono to stereo and there are small improvements in audio quality in some cases.

Table 1 below summarises the subjective audio quality at bit rates commonly used in the UK. A “generally acceptable” quality sounds acceptable to most people on a portable radio (where the speaker quality is a limiting factor) or in a car (where there is background noise), but the limitations are noticeable on hi-fi speakers and headphones. Whether this sounds better or worse than FM is a matter of personal opinion. A “slightly degraded” quality may have audible distortion, reduced bass and/or reduced treble, depending on how the broadcaster processes the audio; it generally sounds inferior to FM, but is good enough for speech-based programming. The major UK

broadcasters generally use “generally acceptable” and “slightly degraded” bit rates, but small independents use a wider range. Radio 3 is the only major station to broadcast in higher quality stereo using the original DAB standard.

Quality	Original DAB standard		DAB+	
	Stereo	Mono	Stereo	Mono
Higher	160, 192 kbit/s	96 kbit/s	48, 56, 64 kbit/s	40, 48 kbit/s
Generally acceptable	128 kbit/s	80 kbit/s	40 kbit/s	32 kbit/s
Slightly degraded	112 kbit/s	64 kbit/s	32 kbit/s	24 kbit/s
Poor	96 kbit/s	48, 56 kbit/s	24 kbit/s	16 kbit/s

Table 1: Correspondence between bit rates and audio quality

DAB Reception

The DAB system was designed to improve upon FM reception, particularly in cars. However, it is difficult to directly compare DAB coverage with that of FM because the reception characteristics are quite different. DAB+ either gives perfect sound or doesn't work at all, while classic DAB will exhibit 'bubbling mud' interference for signal to noise levels up to 3 dB (a factor of two) above the level at which both DAB+ and DAB fail. By contrast, FM reception fades gradually. A weak FM signal manifests as background hiss, particularly in stereo mode. Switching to mono reduces the hiss. Car radios automatically switch to mono as the signal strength degrades and also filter out the higher frequency parts of the audio to reduce hiss. Thus, hissy mono reception is possible at a signal to noise level 20 dB (a factor of 100) lower than that required for perfect stereo reception.

Where a DAB and FM signal are transmitted from the same transmitter with equivalent coverage areas, DAB will give solid reception where FM is a little hissy in stereo. Further out, FM will still give a listenable mono signal where DAB does not work at all. Because DAB broadcasts at about twice the frequency of FM, it does not diffract as well around local obstacles, such as hills and tall buildings. Thus, DAB is more susceptible to local holes in reception. In many areas, this problem is addressed by using more than one transmitter to serve a given area. Thus, most major towns and cities are served by two or more overlapping DAB transmitters.

In practice, DAB and FM transmitter coverage areas are not equivalent. FM national radio coverage is provided mainly by high power (>10 kW) and low power (≤100W) transmitters, whereas most DAB transmitters are medium power (100W-10kW). DAB does not use high power transmitters because transmitters more than about 70 km away cannot be time synchronized and tropospheric ducting under certain weather conditions causes signals to travel much further than usual (this also affects FM and TV). One 100 kW transmitter will cause as much interference to distant reception as one hundred 10 kW transmitters (because unsynchronized transmitters are equally likely to combine destructively as constructively). Consequently, many areas that receive a good reception from a high-power FM transmitter will receive poor DAB reception. However, for areas served by a low-power FM transmitter, the corresponding DAB transmitter is higher powered, compensating for the greater diffraction losses and sometimes providing better reception than FM.

FM is susceptible to multipath interference, which manifests as sound distortion, particularly in stereo and at higher audio frequencies, and can affect strong signals. Multipath interference occurs when signals of similar strength reach the receiver via different paths from the transmitter. This is caused by reflections off tall buildings and hills and is a particular problem where the line of sight signal is weak. Multipath interference is most likely to occur in valleys and in cities with tall buildings. RDS car radios may not re-tune where multipath is encountered as the signal strength may remain high, even though the sound is poor. DAB is designed to be unaffected by multipath; signals reaching the receiver by different paths reinforce each other instead of interfering. Thus, DAB usually provides better reception than FM in areas affected by multipath interference.

The FM system was designed in the 1950s for reception on a directional roof aerial in mono. Stereo and portable reception were later developments. Although new transmitters have been added and the older transmitters converted from horizontal to mixed polarisation to improve in-car and portable reception, the signal is still weak in many places. The official mono coverage of the BBC’s national FM networks is about 99% of the population, but good stereo coverage only reaches about 95% of the population. In some places, a roof aerial is needed for good FM stereo

reception. Stereo reception in cars and indoors is poorer. Conversely, because FM reception fades gradually, mono reception with some background noise is available to nearly all of the population.

DAB coverage is not yet complete. Indoor coverage of BBC national radio on DAB is 97.4% of the population. This is sufficient to provide good indoor and mobile coverage to more people than FM. However, FM provides lower quality but useable reception to nearly all of those who cannot receive DAB. Areas where BBC national radio reception is generally better on DAB than FM include Berkshire, East Hampshire and NW Sussex, Wiltshire, Bedfordshire, SW Shropshire and Nottingham.

Classic FM coverage is lower on both FM and DAB compared to BBC national radio, about 91% in both cases. Thus, there are many places where DAB reception is better than FM and many other places where only FM reception is possible. Local DAB coverage generally matches that of the oldest local commercial station in each area. Consequently most local commercial stations will have either better reception on DAB or no reception at all. BBC local and regional radio reception will continue to be more extensive on FM. However, there will be some areas where DAB reception is better.

In the long term, DAB has the major advantage that transmitters carrying the same programmes can use the same frequency. This means that reception problems can always be solved by building extra transmitters, whereas on FM, there may not be enough frequencies available to do this. The ongoing move to DAB+ marginally increases coverage by providing good reception when classic DAB is subject to 'bubbling mud' interference. As DAB+ is more spectrally efficient, there's also an opportunity for some stations to improve reception by using higher protection levels, though this is rarely done in practice.

DAB in Other Countries

Denmark, Norway and Sweden launched public DAB services in 1995 at about the same time as the BBC (Norway was first). By 2000, DAB had also been launched in Austria, Belgium, Finland, Germany, the Netherlands, Portugal, Spain and Switzerland, with test transmissions running in France and Italy. However, listener uptake was very slow. Portugal, Finland and Austria discontinued DAB in 2001, 2005 and 2008, respectively; France and Italy did not progress to a permanent service; and some other countries scaled back their networks. By 2005, only the England, Scotland, Wales, Northern Ireland and Denmark had significant DAB listenership, driven by a wide range of programming not available on FM. In most other countries, DAB was limited to a single multiplex largely duplicating FM programming. Ireland launched a permanent DAB service in 2008, but this never served the whole country and was discontinued in 2021. Beyond Europe, Canada, Singapore, Taiwan experimented with DAB but did not adopt it. In 2006 South Korea, started broadcasting using the related Digital Multimedia Broadcasting (DMB) standard. However, this mainly carries mobile TV; there is only one radio station on the network.

Following television digital switchover in 2010-12, more band III spectrum became available for DAB in Europe (previously, only channel 12 was available in most countries). Furthermore, the advent of DAB+ has boosted capacity further and reduced the transmission costs per programme. Many countries have therefore re-launched their DAB services with additional multiplexes and use of the DAB+ standard. France and Italy have finally launched DAB+ and many Eastern European countries have adopted it. In most countries, DAB/DAB+ both broadcasts digital only stations and duplicates stations broadcast on FM (and AM where it is still used). Outside Europe, DAB+ has successfully launched in the main cities of Australia and there is limited deployment of DAB/DAB+ in China, Indonesia, New Zealand, South Africa.

See DAB Ensembles Worldwide (http://www.wohnort.org/DAB/) for details of DAB/DAB+ across the world.

Other Digital Radio Standards

In most European countries, radio is also available on all TV platforms: terrestrial, satellite and cable. The choice of stations is typically lower than on DAB. Sound quality varies with the BBC using higher bit rates than DAB on the TV platforms, except for Radio 3 and local radio. Commercial broadcasters often use a higher bit rate on satellite and cable than on DAB, but a lower bit rate than on DAB is often used on terrestrial TV. Unlike DAB, digital TV does not generally offer mobile reception.

In 1996, the original Virgin Radio (now Absolute) became the first European station to broadcast via the internet. Today almost all radio stations are available via the internet using modern audio coding. The internet provides by far the greatest choice with thousands of stations available from around the world. Audio quality varies; the BBC provides substantially better quality than on DAB, but many commercial stations do not. Mobile reception is expensive and coverage is not available everywhere.

DRM (Digital Radio Mondiale) is a digital radio system designed to operate on the same spectrum as AM and FM radio. DRM30 operates in the long, medium and short wavebands currently used for AM broadcasting. Like DAB, DRM uses COFDM modulation, splitting the signal between a series of low bit-rate carriers. This enables signals transmitted over different paths to be combined without interference. Unlike AM, DRM is not subject to fading and distortion as a reflection by the ionosphere. Thus, using DRM enables clear reception on short wave for the first time and allows clear medium and long range reception on medium wave at night. In addition, networks of DRM transmitters carrying the same programme can share a single frequency without interference. DRM and AM can operate side by side on the same wavebands. As DRM can operate with a lower signal to noise level, it can use frequencies not suitable for AM broadcasting in a given area.

Using a standard 9 or 10 kHz width channel in the AM bands, DRM30 can deliver audio at around 20-30 kbit/s, depending on the level of protection used. Using the HE-AAC audio coding standard, this enables mono audio with at a quality slightly poorer than FM, but dramatically better than the sound quality offered by AM in Europe. If two channels are used, doubling the bit rate, DRM30 can deliver reasonable quality stereo. A channel may also be shared between AM and DRM, though this reduces the DRM bit rate and the AM audio bandwidth, though most AM receivers use a lower bandwidth than transmitted in order to limit adjacent channel interference.

Currently, All India Radio is the only major broadcaster that is using DRM30 for domestic broadcasting. Several European countries experimented with DRM during the 2000s. However, DRM receivers are not widely available and Europe is focusing on DAB/DAB+ for domestic digital broadcasting. Many international broadcasters have deployed DRM30 on short wave. However, international broadcasting to developed countries has already moved to the internet, while for developing countries short wave AM has the advantage of lower receiver and battery costs.

DRM+ has been developed for use in VHF broadcast bands I and II (the FM radio band) with 96-kHz-wide channels and a capacity of up to 185 kbit/s. As it uses narrower channels than FM and requires less power to attain a given coverage level, it can share band II with FM, making use of frequencies where new FM transmitters cannot be accommodated, much in the same way that digital terrestrial TV in the British Isles used to share broadcast bands IV and V with analogue TV. Currently, no country has any firm plans to implement DRM+. However, it would provide an opportunity for the smaller FM (and AM) stations, whose coverage areas do not match a DAB multiplex, to broadcast digitally.

The future of DRM will depend on receiver availability. DRM+ can be added to a DAB+/FM radio at very little cost as the audio decoders and band II tuner are already there, while the DRM protocols may be used without paying royalties. However, DRM30 will cost a lot more as, at minimum, a medium wave tuner and antenna must be added. Furthermore, medium wave antennas are bulky (thus, no smartphones incorporate AM radios). Thus, DRM+ has greater potential.

In the United States, Canada and Mexico, a proprietary system known as HD Radio (HD stands for high density) has been adopted for terrestrial digital broadcasting on medium wave and VHF band II. It makes use of spectrum at the edges of the channels already allocated to AM and FM broadcasters and is designed to be used alongside the analogue signals. The medium wave version typically just simulcasts the corresponding AM programmes, whereas the VHF version has capacity for up to three programmes, one of which must be a simulcast of the corresponding FM station. More than 2000 US radio stations currently transmit HD radio. Many new cars are equipped with HD radio but only a few portable radios are available.

The United States and Canada also use a subscription-based digital radio system, known as Sirius XM. This provides national coverage to car and portable receivers via satellite, supplemented by terrestrial transmitters in major cities. In 2013, over 100 advert-channels were available for $15 per month and there were 25 million subscribers. In France, a similar service known as Onde Numérique was licensed at the end of 2012. It was supported by the major public and commercial broadcasters, but failed to launch.

Finally, Japan has adopted a standard known as ISDB-Tsb for digital radio. This is related to the ISDB-T television standard and is similar to DAB in operation. However, it has yet to progress beyond test transmissions.

Further Information

W. Hoeg and T. Lauterbach, (eds.), *Digital Audio Broadcasting: Principles and Applications of DAB, DAB+ and DMB*, 3rd ed., Chichester, England: Wiley, 2009.