Portable Digital Links for Mobile Applications

By Ian Trow

With the establishment of the MPEG-2 video compression standard and widespread deployment of digital terrestrial networks, the door is open to manufacturers to develop portable digital video links using the best aspects of both these technologies. The objective is to produce reliable video feeds for a wide range of mobile applications; until now, these video links have been mainly satisfied by analog technology. The move to digital has been demonstrated successfully, but often incurs the drawbacks of large end-to-end delays, high bandwidth, or bulky equipment overhead. This paper discusses how digital video links for mobile applications can be achieved by combining MPEG-2 video compression, terrestrial modulation, RF up-conversion, and low-power radio amps in a small, DC-powered unit. It will describe the technology and algorithms used, comparing them with other approaches, and the experience gained from deploying equipment in the field.

Analog microwave links are in widespread use, but limitations in terms of coverage, reliability, bandwidth, and transmission power mean that digital technology is being adopted quickly as a replacement for many applications. Digital techniques have been refined for terrestrial broadcast and provide solutions to many of the limitations of analog in existing applications:

- A reliable transmission link is established that will behave in a predictable manner in a wide range of target applications.
- Minimal bandwidth is used to allow economic deployment within existing radio channel allocations while retaining optimum picture quality for a given bit rate.
- Low end-to-end delay performance allows the digital link to be used in conjunction with wired cameras eliminating the problem of latency.
- Small packaging allows the unit to be used alongside existing ENG cameras in space and weight-critical areas such as helicopters.

Analog Microwave: Applications and Limitations

Until comparatively recently the use of wireless video links relied upon high-power FM signals occupying large bandwidths. A wide range of applications has developed for these links typified by content exchange in a contribution network or camera feeds in sports or news coverage. The use of analog microwave has been extensive, but the technology requires careful application, as there are a number of pitfalls that either restrict its usage or result in unreliable links.

Analog FM transmissions (depending on bandwidth and deviation) require an SNR of 10 dB for operation above threshold and significantly more to avoid noisy pictures. They also occupy around three times the bandwidth of a digital transmission. This results in a like-for-like power advantage of at least 20 dB for a digital system over analog, even under line-of-sight channel reception conditions. The 20-dB difference equates to 1 W used for analog systems to achieve the same performance offered by a digital system using a power level of 10 mW. Low-power amplifiers are significantly easier to package and operate and so make widespread usage more attractive for systems based on digital modulation techniques. Power is not the only issue, but its use coupled with the large FM bandwidths needed to make analog systems function are significant drawbacks, especially when efficient spectrum usage at low power levels are increasingly being demanded by consumers and regulators. Within the existing television infrastructure analog microwave is used to carry data between studios, playout centers, and regional transmitters, and adherence to line-of-sight transmission between the sender and receiver is key to its success.

Wireless cameras have made use of FM channels to relay sports or news events from locations where a wired camera could not be placed. Alternatively, they exploit the freedom given by not having the associated signal and power leads to gain more creative shots and so enhance the user's involvement with the coverage. However, analog microwave used in this way can suffer from degradation due to multipath interference. The effects of multipath on FM video are qualitatively slightly different from the familiar ghosting that occurs on AM broadcast transmission. However, under conditions of strong multipath they can be at least as objectionable. The causes of multipath are numerous and any object breaking line-of-sight transmission can potentially cause signal disruption. The lack of error correction techniques for analog microwave means that picture breakup, chroma flutter, and audio artifacts result when an analog microwave system is struggling to provide a stable transmission.

Attempts to overcome these difficulties include seeking a high vantage point for a transmit and receive antenna, employing elaborate tracking mechanisms between the antennas, and using high RF powers in an effort to guarantee reception. As is all too evident in many mobile video links, these measures do not hide the inherent limitation of analog microwave, and broadcasters are left with pictures that fail regularly in an unpredictable way.

Acronyms

COFDM	Coded Orthogonal Frequency Division Multiplexing
DV	Digital Video
DVB	Digital Video Broadcasting
DVB-T	Terrestrial Digital Video Broadcasting
GOP	Group of Pictures
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key

The Move to Digital: Key Technologies

Recently, more efficient use of radio spectrum and developments in video compression has enabled mobile links to be catered for using digital techniques. The MPEG-2 standard achieves high compression ratios, retains good picture quality, and allows digital transmission algorithms to be applied. Small, lightweight, low-powered devices targeted at new and existing applications are now possible.

The MPEG-2 compression standard was initially applied to program distribution. However, it has since gained widespread acceptance in the professional arena for contribution applications. The standard allows the user to select 4:2:2 or 4:2:0 chroma sampling, field and frame-based picture and DCT processing, GOP length, and the type of prediction used on individual pictures making up a GOP. Additionally the size of buffer used to absorb bit rate peaks during I frames can be adjusted in order to trade off reduced end-to-end delay performance against picture quality. This reduction in buffer size does have an impact on picture quality, as the purpose of the buffer is to regulate fluctuations across different picture types.

The level of buffer size is picture related and for simple scenes the buffer variation is high; for more complicated scenes, such as those including fast motion, there is less variation, requiring less buffer. When the buffer size is reduced to achieve a low end-to-end delay performance, the rate at which the buffer is filled during I frames must be regulated. Adjusting the level of quantization applied after the DC is the method by which the flow is controlled.

The MPEG-2 compression standard lends itself to many wireless video applications, from broadcast video, where optimum end-to-end delay may be of most importance, to surveillance, where multiple channels offering “face recognition” picture resolution at a low bit rate may be the main requirement. The ability of the MPEG-2 compression standard to be applied across a wide range of bit rates makes it ideal for terrestrial use, where the most attractive modulation setups offer limited bit rate to achieve a highly reliable link. The requirement of high-quality, low bit rate video compression has limited many commonly used broadcast video standards to mobile applications. An example is DV and equipment based on restricted subsets of the MPEG-2 specification (i.e., I-frame only encoding), due to the fact that they require more bit rate than the method of transmission allows.

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Digital transmission was initially applied to satellite applications. The single carrier modulation used here works well for line-of-sight communication, but is not well suited for use in channels affected by multipath propagation or, even worse, the time varying multipath that occurs when mobile links are used. To overcome these limitations, DVB defined the DVB-T terrestrial-broadcasting standard, which uses a modulation technique known as COFDM. COFDM is a means of transmitting a high data rate by modulating carriers in parallel, each at a comparatively low data rate. In the case of DVB-T, either about 2000 or about 8000 carriers is used. The carriers are modulated by symbols consisting of “square pulses,” resulting in a $(\sin x/x)^2$ power spectrum for each individual carrier. The carrier frequencies are chosen so that they are mutually orthogonal over the symbol period (i.e., an integer number of cycles of the carrier fit into the symbol period). The spectra of the modulated carriers overlap, resulting in a near rectangular composite spectrum with a spectral efficiency that is somewhat better than can be achieved with an equivalent single carrier system. Each carrier can be modulated by QPSK, 16 QAM, or 64 QAM, allowing the user to trade spectral efficiency for signal-noise performance.

DVB-T defines the addition of a guard interval to improve multipath performance. The guard interval consists of a cyclic repetition of part of each OFDM symbol added to the beginning of each symbol. DVB-T uses the same powerful concatenated error correction scheme (inner k=7 convolution code with an outer 204,188 shortened RS code) as other standards in the DVB family. However, additional interleaving is used so that the decoder can exploit frequency diversity. The code can be punctured allowing code rates from 1/2 to 7/8.

Finally, the DVB-T signal contains a number of types of training signal that allow the receiver to estimate and correct the channel even in mobile reception environments. These features of DVB-T give very good signal protection against the effects of multipath interference. Coding and interleaving give excellent protection against frequency selective fading, and the guard interval protects completely against inter-symbol interference for echoes of duration less than the guard interval.

The wide range of parameters available to an operator of a DVB-T system can be somewhat confusing. For this reason equipment designed for use with portable digital links restricts the choices to just a few combinations. Generally, the 2000 carrier DVB-T variant is most appropriate for mobile links, since it can deal with dynamic multipath better than the 8000 carrier system and, often, the shortest available guard interval (7 microseconds for an 8-MHZ channel) is sufficient. For robust operation, the QPSK or 16 QAM modulation together with a low code rate (1/2 or 2/3) is usually appropriate. This allows data rates from about 5 to 15 Mbits/sec in an 8-MHz channel.

Mobile wireless applications are often powered from

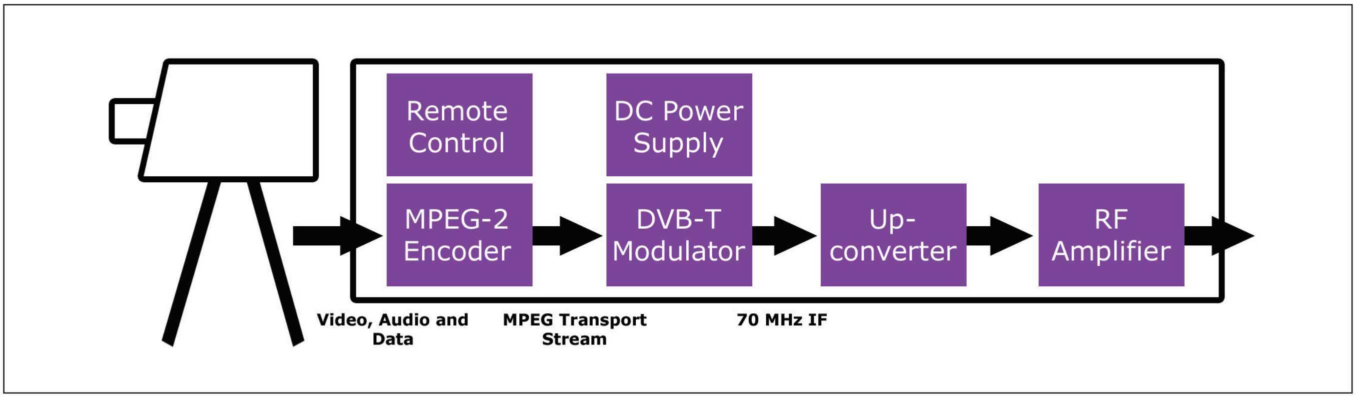

Figure 1. Digital link system transmitter.

batteries. Electronics hardware has reduced power consumption levels considerably, and the power capability of modern Lithium Ion batteries has increased. The result is coverage periods from a mobile link of over an hour are now possible with a single battery.

The Digital Link System

Figure 1 shows the elements that make up a digital link system at the transmitter.

MPEG-2 encoders can offer a wide range of bit rates covering 1.5 to 50 Mbits/sec in either 4:2:0 or 4:2:2 profile. However, the DVB-T modulator can only carry a payload between 5 to 32 Mbits/sec, which is further restricted when the characteristics of the modulation mode are matched to those of a mobile application. Realistically, only QPSK and 16 QAM are suitable for mobile applications; the most rugged mode of DVB-T operation is offered with QPSK modes. Applications where extra bit rate can be provided, due to an easier transmission environment, can be catered for by 16 QAM. To get the best out of a system operating in the most rugged mode requires careful setting of the video encoder. The following parameters can be adjusted in order to optimize picture performance, MPEG-2 profile, GOP length, and horizontal picture resolution.

Table 2—Typical Horizontal Resolution/Video Bit Rate

Horizontal Resolution Setting, Pixels	Video Bit Rate
720	>= 6 Mbit/s
704, 640	
544	>= 4 Mbit/s
528	
480	>= 2.5 Mbit/s
384,368	
352	< 2.5 Mbit/s
320	

The decision whether to use Main Level (4:2:0) or 4:2:2 profile is determined by the allowable bit rate dictated by the particular modulator mode being used. As a rule, the crossover between Main Level (4:2:0) and 4:22 is between 5 to 6 Mbits/sec; therefore, for the most rugged modes, optimum picture quality is offered using Main Level (4:2:0) profile (Table 1). The numbers included in Table 1 show the range of bit rates that are supported by QPSK and 16 QAM modulation modes. If a multichannel service is to be carried using QPSK, the use of Main Level (4:2:0) profile might need to be supported by dropping the horizontal resolution of the input picture to achieve optimum

Table 1—Modulation Mode/Transport Bit Rate (DVB-T, 2000 Carriers)

Modulation Mode	Guard Interval	FEC	Transport Bit Rate*	Description
QPSK	1/4	1/2	4.976 Mbit/s	Rugged setting
QPSK	1/8	2/3	7.372 Mbit/s	Typical mobile setting
16 QAM	1/8	2/3	14.745 Mbit/s	Typical studio setting
16 QAM	1/32	7/8	21.112 Mbit/s	Highest bit rate setting

*Transport bit rate in 188-Byte mode

Table 3—Typical Applications for GOP Structure

Selected GOP	Typical Application
IBBP or IBP	Program distribution
IP	Low delay mode (no B frames)
IBBI or IBIB	Editable formats
I	Frame accurate editing (i.e., DV)

picture quality. Table 2 shows settings for horizontal resolution and the corresponding video bit rate ranges where these should be used.

The selected GOP also has a large impact on picture quality. Long GOPs are suitable for applications where bit rate is limited and the material will not be edited or switched with wired cameras. For this reason, long GOPs are used predominantly for distribution. MPEG allows considerable scope for the adjustment of the GOP (Table 3).

Selected GOP structure is also an important factor in an encoder to control end-to-end delay. The inclusion of B frames has a direct impact on the delay introduced by the encoder. Removal of B frames can also reduce the decoder delay, if the pipeline processing needed for B frames can be removed when it is not required. This can be flagged to the receiver via a low delay flag in the transport stream.

The size of the buffers used at the back end of the encoder and the front end of the decoder can be adjusted to improve overall end-to-end delay. This is known as the video buffer verifier (VBV) delay and is reduced when end-to-end delay must be minimized. Use of field pictures is now widely implemented in MPEG encoders, and usage is assumed for good low-delay performance, especially for portraying of fast motion.

In addition to careful control of the MPEG encoding process, ensuring that the signal source is noise free and the camera work is as steady as the application allows has a great impact on picture quality. Both noise and camera shake are difficult to encode and waste bits. The scope for applying preprocessing is limited for mobile applications. The usual approach is to use a clean feed, preferably SDI, but, more realistically, a good composite feed from a high-end camera or VTR.

The use of digital modulation techniques has a benefit of requiring less radio power when compared to analog techniques but places stricter criteria on amplifier linearity. Nonlinearity causes intermodulation products that fall both in OFDM signal bandwidth and outside it; in-band products cause the BER to rise. The distortion power due to these products must be kept sufficiently low to avoid degradation to system performance. As a rule of thumb, the distortion signal/interference power density should be 10 to 15 dB below the signal/noise failure point of the coding and modulation scheme in use. Therefore QPSK is the easiest to satisfy and 64 QAM, the most difficult. In practice, out-of-band interference due to intermodulation is likely to be the limiting factor, since it affects adjacent channel, often allocated to other radio users.

One disadvantage of OFDM is that the signal amplitude distribution is approximately Gaussian, signifying a moderate probability of high peaks in the signal power. The greatest problem with nonlinearity is in the final power output stages of the transmitter. The high peak mean ratio of the OFDM signal means that the power amplifier must be run at several fewer decibels (typically 6 to 8) from its saturated power rating. The definition of power rating of an amplifier varies from manufacturer to manufacturer, as do the characteristics of the

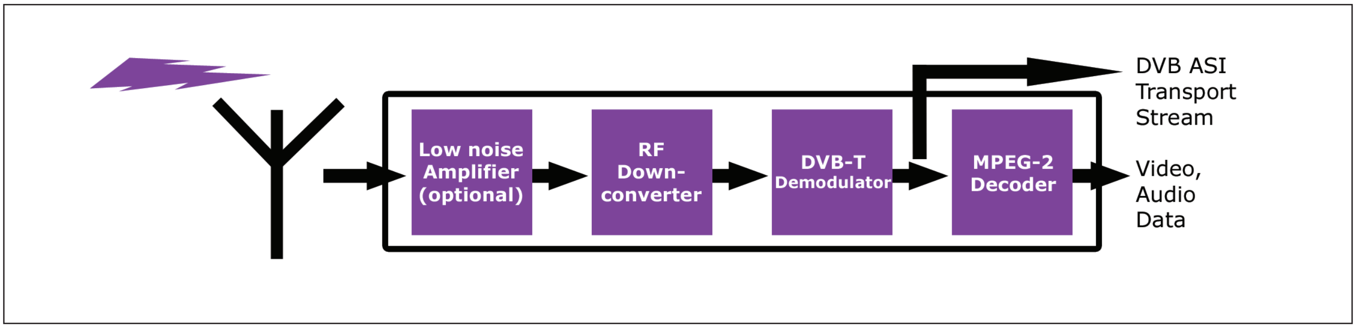

Figure 2. Digital link system receiver.

amplifiers; therefore, the actual power that can be achieved must be determined by experiment.

Performance constraints to achieving a digital link and a wide variety of regulatory issues must be addressed before the equipment can be licensed. Easily identifiable standards for video formats, such as PAL and NTSC, do not exist for the radio frequencies and power levels used for mobile applications, due to different radio channel usage and frequency reallocation to make the most of a scarce resource. The drawback for suppliers is that units require evidenced configuration if the licensing of the equipment is to be performed by the manufacturer. Often, it is the responsibility of the user to gain regulatory approval. This complication makes commissioning a system difficult and has limited the application of this technology to date.

Figure 2 shows the elements of a digital link system at the receiver.

Antenna selection at both the transmitter and receiver is determined by the tolerance of the application and the coverage required. At the transmitter, options are usually limited to small antenna to allow the unit to be mobile. For wireless cameras, two linear polarized 6-dBi antennas are stitched into the rucksack used to house the transmitter (Fig. 3). One is mounted on the front and the other on the back to give adequate omnidirectional coverage. For van and helicopter applications a 6-dBi omnidirectional antenna can be used, although for any airborne application the choice of antenna is heavily governed by air-worthiness standards.

At the receiver either an omnidirectional or directional antenna can be used. With a wireless camera, the range of coverage is limited and removing the need for a stick man to point the transmitting antenna in the right direction is often key. If the transmit site, i.e., a pit lane, is within a limited area, it might be suitable to use a linear antenna with limited beam width and high gain; alternatively, a lower gain omnidirectional antenna may be used to give the cameraman freedom to roam. When greater coverage range is required, directional or steered antenna have been used to transmit packages mounted in a plane where distance coverage is needed in a pre-defined direction.

Acquiring in the digital domain, as opposed to the analog, is a big advantage for system design, because program content can be carried as a compressed bit stream after reception. For example, in multihop DVB-T networks on a golf course, one radio channel is used for coverage of a specific hole, then this content together with feeds from other holes is relayed back to a central receive site on another radio frequency. All the content can then be transmitted to a satellite modulator for return to a studio. This scenario has many applications in sports coverage, and with the increasing availability of IP links preserving a compressed signal, allows for multiple transmission stages to be tolerated with minimal degradation of the original content.

Figure 3. Voyager Lite in a backpack.

New Applications

Analog radio cameras to cover games, such as football matches, are in limited use, since only high profile events can afford the necessary budget. Motor racing has been using analog technology for some time, and the move to digital should improve picture stability and increase the range of coverage. These improvements will then allow events such as rallying, where the transmission environment is considerably more difficult than a racetrack. Currently both are being catered for using either a limited number of analog microwave links and/or VTRs mounted within the cars. In both instances, the number of possible links increases due to more efficient use of the spectrum. The need for tape runners decreases and the likelihood of covering an incident, such as a crash is greater, and no VTR is involved in the process.

Many OB or studio cameras require triax cables to link the camera to a scanner or vision mixer. Digital links have been emerging and could yield significant savings for broadcasters if the analog systems can be replicated in a wireless environment. Security and surveillance, where the freedom to roam and still provide coverage, or the wireless link makes moving to a digital infrastructure cost effective.

Future Developments of Digital Technology

Technology based on digital program distribution has given a boost to the successful use of digital links in professional and business applications. There are, however, further developments required before widespread adoption can take place. End-to-end delay of a digital link is a problem: no more than a video frame is acceptable when switching between a wired and wireless camera, if the results are to be acceptable to a producer. To realize this requires frame-based encoders, an example being I-frame MPEG encoders, operating at a high bit rate to maintain contribution quality.

Although DVB-T is an excellent transmission standard, it is somewhat compromised as the result of being many different targets. Since the design of DVB-T, there have been some advances in the theory of modulation and coding. The amount of signal processing circuitry that can be put on a single chip has increased significantly, which means that non-DVB-T systems can be designed for even better performance in the difficult channels associated with mobile links.

On a more practical level, the receivers being used are often derived from consumer DVB-T receivers and are usually optimized for high data rate operation using 64 QAM, not portable/mobile operation.

Implementing a bidirectional digital link system that allows video, communications, and control data to and from the receiver will prompt the further replacement of triax systems by digital links. This requires further work to implement a spectrum-efficient two-way link. Overcoming significant control and interfacing problems are also key to tackling this application area.

Conclusion

Digital links can cater for many applications previously the preserve of analog technology. Lower radio and equipment power, efficient spectrum usage, and greater signal coverage are all attributes that have helped this technology gain a foothold. Digital links offer the user the benefits of improved performance, simpler system infrastructure, and lower operating costs.

Digital links provide a significant new technology to be exploited by manufacturers and users. What will determine how this market grows is further enhancing the use of digital modulation techniques to gain more useful bit rate; improvements in compression schemes to make low-delay coders acceptable for mixed wired and wireless environments; and signaling to users when a link is marginal so picture loss live on-air can be avoided. Many of the issues driving radio spectrum reallocation have not been fully resolved, creating uncertainty in the market.

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Since 1996, Trow has worked at TANDBERG Television (formally NDS) and is responsible for the development of mobile contribution products, primarily targeted at the professional broadcast market, but being developed increasingly for non-broadcast applications. These products allow the delivery of MPEG-2 compressed material over satellite (DSNG) and terrestrial (DENG) links.