The changing world of TV displays

— CRTs challenged by flat-panel displays

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The CRT has dominated the display industry for 100 years. Its reign is coming to an end, not tomorrow, but in the not-too-distant future. This article provides an overview of the progress being made by flat-panel displays in chipping away at the TV market. Plasma display technology has been developing fast but, watch out – here comes the LCD juggernaut, sweeping all before it …

There are other technologies to watch as well, and there could still be more surprises round the corner. Beware; there's some hype about, but there's also some well-founded market research to guide the way.

For some years now it has been said that the increasing sales and reduced cost of large flat-panel displays will, very soon, have an impact on the way the viewers look at the pictures we broadcast. This revolution has in fact been rather slow in coming. Plasma Display Panels (PDPs) of 42- and 50-inch diagonal have been available for some years now, and their costs have fallen dramatically – but their market penetration is not enough to have yet made any serious impact on broadcasters.

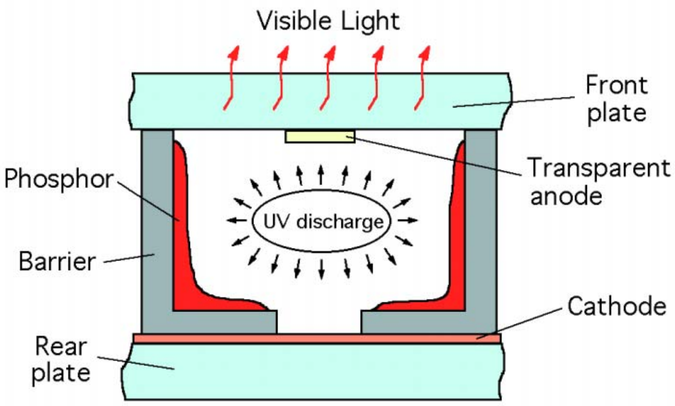
In the last year, however, it has become apparent that this slow evolution is about to be transformed by the arrival of a serious competitor, the Liquid Crystal Display (LCD). The received wisdom had been that we were years away from being able to make LCDs large enough to challenge plasmas, but great strides have recently been made which suddenly change the rules. LCDs now pose a serious challenge to PDPs, not least because it is hard to make the feature size of PDPs small enough to make a high resolution panel, which is not an issue for LCD.

Back projection, especially the use of Digital Micro-mirror Devices (DMDs), is another type of display expected to make big inroads into the traditional TV market. Before discussing these newer challengers in some detail and having a quick look at the new display interfaces as well, it is worthwhile reviewing the current state of PDPs.

Plasma displays – still a growing market

The advantage of the PDP was to have been ease and cheapness of manufacture, as compared to LCD, since it could take advantage of printing, rather than photo-lithography, in its production processes. It has not turned out this simple though, and the benefits of scale are now being felt in new LCD plants which could turn the panel-cost balance on its head.

The PDP manufacturers have invested a lot of money in their factories, and not surprisingly are still confident, in public at least, that there is a good market for their products. Due to high panel costs, these displays initially



The heart of a plasma display is the discharge cell. Sandwiched between two sheets of glass, constrained by barriers, the cell has an anode and cathode. A plasma discharge in the low-pressure helium/xenon gas mixture in the cell generates ultra-violet radiation, converted to red, green or blue visible light by a conventional phosphor. The PDP is therefore self-emissive, but the form of construction leads to a relatively heavy and fragile panel.

found a niche as public data displays in airports and railway stations *(see the photo below)*, but have been found to suffer from a lack of brightness when viewed in natural light. Often, when displaying basically static or repetitive information, they exhibit image-sticking and phosphor burn-in.

A major problem for PDPs has been motion portrayal, with colour fringing becoming visible due to the pulse-width-modulated greyscale. There has also been concern over life-time, a problem exacerbated by the need to make them brighter. Improved contrast can also only be achieved at the cost of reducing brightness.

The historic advantage of PDPs over LCDs was the ease of making a large panel. Higher resolution was harder, and this is reflected in the preponderance of 480-line panels of around 40 - 42 inch diagonal and now 768-line panels, usually around 50 inches in size.

Only now are full HD-resolution PDPs being demonstrated in prototype form, and only at sizes over 70 inches. The real advantage of being able to process these super-large panels is actually that the same production facility can make three 42″ panels simultaneously from a single sheet of glass, thus cutting the costs.

The predictions from market research group DisplaySearch [1] are that PDPs might take 3.3% of the TV market in 2007. This is based on expected manufacturing capacity, and it seems likely that prices will continue to fall, as they must if this volume of panels are to be sold. Prices have halved in the last year, and a typical 50″ 768-line PDP TV is now $7000.

1. DisplaySearch: www.displaysearch.com and at DisplayForum 2003, Den Haag, October 2003

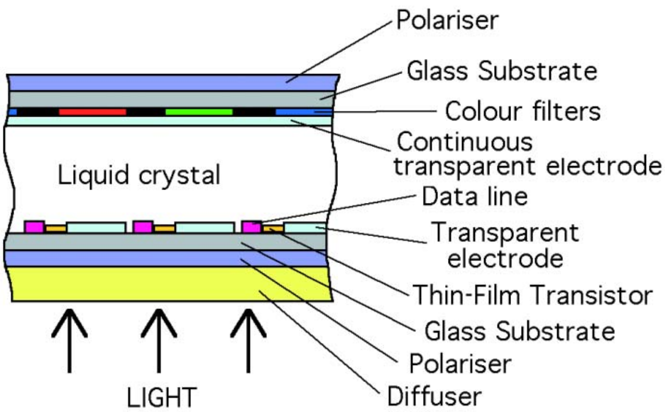
PDPs used as data displays in a major UK railway station. This photo indicates the brightness/contrast problem, which has had to be cured by placing ever larger canopies above the displays to block light coming in from the glass roof above, during daylight hours.

LCD – the juggernaut that's just round the corner

The LCD panel, starting from a natural niche market in the laptop computer, has branched out into desktop PC monitors, and has achieved phenomenal sales growth rates, such that 50% of that market is now for LCDs. The volumes are enormous, as is the investment in new fabrication facilities (fabs). In the two-year period starting Q2 2003, DisplaySearch has identified 47 new LCD fabs starting production, under construction, or planned around the world (mostly in Korea, Taiwan, Japan and China). Of these, 34 are suitable for making direct-view TVs. This level of investment dwarfs that in PDP manufacturing plants, and the manufacturers have targeted the domestic TV as the one remaining market for their continued expansion.

As one commentator put it, LCD may not be the ideal technology for TV, but the same was true for the VHS recorder. Indeed, many of the LCD TVs seen in shops today are far from ideal in terms of picture quality. Until very recently, LCD was not seen as a serious contender for the large-screen TV market. This was not just due to the problems of making the larger sizes, but also related to motion blur caused by slow response speeds, poor colorimetry and viewing angle, as well as high costs. So what has happened to turn this on its head?

The TFT-LCD basically consists of a layer of liquid crystal sandwiched between polarising sheets. When a voltage is applied across the electrodes, the polarisation of light passing through the panel is altered, and hence the transmission of the cell can be varied. A colour display is achieved by adding filters, so that a triplet of cells is used for each pixel of red, green and blue. It is, in direct view designs, a transmissive technology, requiring a back-light.



Colorimetry improvements have proved relatively simple to implement. AU Optronics [2] (formerly ACER), who manufacture both PDPs and LCDs, now consider their 46″ LCD to give better colour performance than their own 50″ PDP, and Nikkei Microdevices [3] in Japan now rate LCD picture quality as surpassing plasma quality for the first time. Motion blur is greatly improved by a variety of proprietary techniques which aim to speed the transitions between grey levels by modifying drive voltages during the transition. LCDs with 170° angles of view are becoming increasingly common, and cheaper backlights – now a significant part of the cost of a large display – are under development.

The key to the remaining questions of cost and panel size lies in the new fabs under construction. Samsung [4] made 0.4 million LCD panels of 28″ and larger last year, and expects this to grow to 2 million units this year. They plan to bring their next generation of fab on stream next year, which will make up six of their 46″ panels at a time.

The largest LCDs from LG Philips [5] are now 52″, and they predict that the average size of an LCD TV will increase from 18.5″ now to 28.8″ by 2007. This is roughly in line with other industry predictions, and many foresee the average flat-panel TV size rising to 30″ by then.

Demand for LCD panels is currently outstripping supply by 1.7%, resulting in the manufacturers being able to sell panels with defects which would normally cause them to be dumped. Samsung does not see prices falling significantly until the second half of 2004, due to these supply shortages. However, with so many new fabs coming on stream, the balance is then expected to tip the other way, with over-capacity leading to massive price reductions, and further increases in sales volumes. By the end of 2007, there is predicted to be a 17.5%

2. AU Optronics: **www.auo.com**
3. Nikkei Publishing: **www.nikkeibp.com/html/pub/engineering.html**
4. Samsung: **www.samsung.com/Products/Semiconductor/TFTLCD/index.htm**
5. LG Philips: **www.lgphilips-lcd.com**

surplus of manufacturing capacity, which should see prices fall further than the manufacturers are expecting. To the manufacturers, the larger panel sizes are attractive – since they make good use of the new larger fab lines, eating up the over-supply – but also because of the higher profit margins available on the larger products.

Consider next the capital cost of the new plants. Taking the current generation (4th gen.) fab as a reference, the depreciation charge per unit volume of production for a 5th gen. (brand new) plant is about half of that, whereas the plants coming on stream in 2005 will generate only 34% of the depreciation charge of the current plant. At this point, the costs of the materials used in the panels start to become much more significant than they have been before. Of course, older plants continue in production – with their initial investment now written down – and are still able to service the market for smaller screen sizes, allowing the new plants to concentrate on the larger panels.

LCD TV products

Samsung's existingt widescreen TV models are 15.3″, 17″, 22″, 26″, 32″ and 40″, and they are currently receiving 20% more orders than they can supply. This year they expect to add 42″, 46″ and 54″, and have established a service and repair centre in the UK to address the UK market. Their 30″ and 40″ models are currently 1366 x 768 pixels, but they see the 40″ model moving to 1080 lines "later".

Similarly, Philips has 17″, 20″, 23″ and 30″ widescreen TVs available, Panasonic offers 11″, 15″, 22″, 32″ and 40″ widescreen models, and Sony has 23″ and 30″ LCD televisions.

Sharp has a large new panel-manufacturing facility coming on stream at present, and has been giving its LCD TV models a very high level of publicity, with new technology promising considerable quality improvements to sit along side the larger sizes of TVs becoming available and the higher production volumes. In its Aquos range, Sharp currently offers 22″, 30″ and 37″ widescreen, along with smaller sizes in 4 x 3 format.

AU Optronics sees the LCD TV market shifting from 23″ to 26″ in the short term, and on to 40″ for the main family TV before very long.

Current prices are typically under $1000 for a 20″, $3,000 for a 32″ and $4,000 for a 37″ LCD TV. DisplaySearch sees a 37″ 768-line LCD TV, in 2007, falling in price to under $1200 (with the cost of the panel itself

The Sharp stand at IFA in Berlin, 2003, demonstrating a very significant commitment to the marketing of LCD TVs.

LCD panels in a sitting-room environment at IFA, 2003.

falling to under $600). Design elements, brand recognition, fashion, and acceptability in the domestic environment will be of increasing importance.

Where does this leave the PDP?

Most commentators see the LCD as the dominant new force, but with PDPs and projection technologies retaining a significant market share as well. There is no doubt that in the next few years, the CRT will remain dominant, especially at sizes up to 36″, with LCDs making inroads into this market at all sizes from 6″ to 42″. PDPs will find a niche in the 50 - 70″ range, and rear-projectors will dominate at sizes from 60″ to 90″. DisplaySearch predictions for 2007 shows LCD taking nearly 20% of the TV market, with PDPs and projection technologies each accounting for 3 - 4%.

One area where LCDs score significantly over PDPs is in the drive circuits: PDPs still suffer from the requirement to manipulate drive voltages in the region of 50 volts. This imposes a significant cost and integration penalty compared to LCD technology.

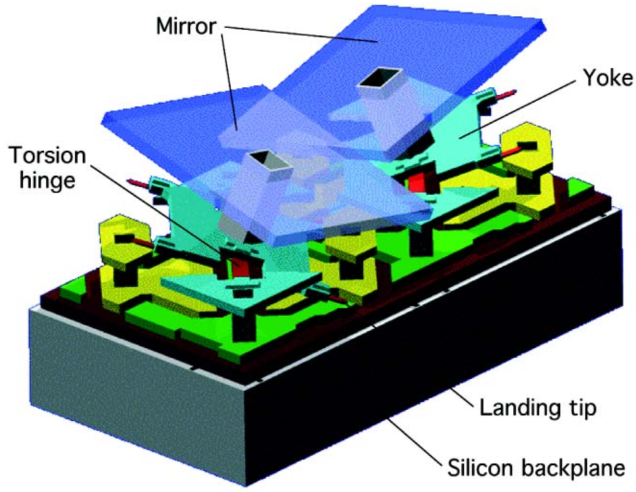
Hitachi, still firmly in the PDP camp, makes the reasonable suggestion that the combined production of LCDs, PDPs and OLEDs (Organic Light-Emitting Diodes) may not meet the foreseeable demand for flat-panel displays.

Projection technologies

Mention of rear-projection and OLED technology indicates that the CRT/LCD/PDP battle is not the entire story.

Projection, particularly rear-projection, has been of much greater interest to North American consumers than Europeans in the past. It is difficult to predict whether this will change in the future, but the projector market is currently subject to just as radical a change as the direct-view market. Gone, except at the bottom of the range, are the fuzzy pictures from heavy CRT-based back-projectors. DisplaySearch predicts that projectors will take as big a slice of the global TV market as PDPs in 2007.

The heart of the DMD (as seen in this schematic, courtesy of TI) are mirrors just 17 or 13.8 µm across, formed on the surface of a silicon chip. The mirror, supported on a torsion hinge only a few atoms wide, tilts by means of electro-static forces generated by writing to memory elements beneath the landing tip. Thus the light falling on the chip is reflected either out through the projector lens, or into a "black hole" absorber. As with a PDP, the grey-scale is generated by means of pulse-width modulation.



The Digital Micro-mirror Device (DMD) has come a long way since the first demonstrations of Digital Light Processing (DLP) technology by Texas Instruments [6] a decade ago. TI still controls the technology, and its licensees are busily turning out projectors at a variety of resolutions, using a single chip and a colour-wheel in cheaper models, and three-chip solutions for professional applications. Pacific Media Associates [7] sees the DMD taking an increasing share of the consumer projector market, although still behind the traditional poly-silicon LCD.

The best DLP-based projectors, capable of 2k resolution, are just starting to be installed in some cinemas in the US, Taiwan and Thailand. In domestic products, DLP HD2-chip back-projection TVs, of 720-line HDTV resolution, are marketed for around $4,000, with many new products being launched this year from a wide variety of manufacturers.

Technically, DLP has advantages over most other technologies in that it is immune from most of the ageing problems seen on other products. Thanks to the reflective nature of the technology, except for stray light falling down the slight gaps between pixels, the chip is able to handle higher levels of projector brightness that would leave many other technologies struggling to dissipate the heat absorbed. On the other hand, the sequential-colour approach used on the cheaper single-chip projectors can leave a slight feeling of grittiness on some pictures.

An alternative projection method is JVC's DILA (Direct-drive Image Light Amplifier) technology. This technology suffers a cost and complexity penalty from the need always to use three chips, one each for red, green and blue, but it is starting to appear in lower-cost applications, as well as being a contender for the high-end digital cinema market.

Another big player in the future of projection displays is likely to be the reflective LCoS (Liquid Crystal on Silicon) technology. Intel [8] is predicting great things for it and, reading their press statements, it is easy to forget that they are talking about *projection*. They talk of light-weight 50″ displays only 7-inches deep, costing around $1000, and possibly available by summer 2004. Intel would have us believe that they will revolutionize the market, so we are certainly in for an exciting time.

Pacific Media Associates expects 1080-line (or WXGA) chips to take 10% of the consumer projector market by 2007 and 720p chips, 25% of the market – with poly-silicon losing share to DLP, which will reach 36.5% of the consumer market and 44% of the professional market. It would be the sub-$1000 HD projector which might see the market really take off, for gaming and home-cinema applications, but that is a few years off yet. Taiwanese projector manufacturers are shifting production to China to cut costs; they see market growth of 166% in the next three years, but with revenues only growing 106%, indicating the likely level of price reductions.

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6. Texas Instruments DLP: **www.dlp.com**
7. Pacific Media Associates: **www.pacificmediaassociates.com**
8. Intel LCOS Technology: **http://developer.intel.com/design/celect/technology/lcos/**

Other technologies

Organic Light Emitting Diodes (OLEDs), or Light Emitting Polymers (LEPs), are a class of display that has been developing steadily over recent years. In 2003 they hit the headlines, with a million units sold as part of a Philips shaver to give an indication of battery level. A full-colour OLED appears very successful as the display on the back of a recent Kodak camera (Kodak are themselves a major player in this technology). As an emissive display they are much thinner than LCDs with their back-lights, and have found a ready market for secondary displays in mobile phones. It appears only a matter of time before they take a significant portion of the mobile phone main-display market. The technology is also expected to move up to larger display sizes. However, it is expected to be some years before they will have a serious impact on the TV industry, although Cambridge Display Technology [9], a major patent holder in the field, predicts that LEP could be a giant-killer in ten years time. Display lifetime is the main problem which is holding back development, but solutions to this problem appear to be likely soon.

There are other technologies too with the ability to disrupt the expected trends. Screen Technology has an iTrans display [10], made by tiling 16 small LCD panels to make a 68″ display, using light-guiding techniques to avoid the joins being visible. Another company, Seamless Display [11], with research spun out from Oxford University, has a 40″ tiled display on the market. The availability of larger single-panel displays at reasonable prices in the near future may render these developments unnecessary, but Screen Technology is aiming to deliver its first products in the next few months, so tiled displays cannot yet be discounted.

A decade ago, one of the big hopes for a new display technology was the cold cathode, or field emission, display. Work in this area had all but stopped, although carbon nano-tube technology has caused a minor re-invigoration of research effort. One company, PFE (Printable Field Emitters) [12], believes it can produce displays in the 20 - 40 inch range which will undercut PDPs and LCDs by a factor of 2 or 3 in price terms.

Finally, saving what is potentially the most interesting new technology until last, Thick-film Dielectric Electro-Luminescent (TDEL) technology – developed by the iFire [13] subsidiary of Canadian company Westaim, in conjunction with Dai Nippon Printing Co., Ltd. and Sanyo Electric in Japan – has moved on from a 17-inch prototype to a 34-inch full-colour display in only a few months. A consultant's study has suggested that a TDEL display of this larger size would have half the capital and manufacturing costs of a similar LCD or PDP, so I'd certainly rate this as a technology to watch.

Display pre-processing: the big challenge

The pre-processing of video signals for display on these new panels is a big challenge. Traditional TV manufacturers have never needed to de-interlace, since a CRT could display the interlaced signal directly. Similarly, image scaling/resolution changes are accommodated on a CRT by adjusting the scan size. With the new displays, which have fixed rasters addressed sequentially, the TV manufacturers have suddenly found they need to incorporate de-interlacing and scaling technologies. These technologies are well understood in the broadcast environment, but less so by the consumer electronics or IT industries.

There are several chipsets available from a variety of manufacturers, all of whom claim to meet every possible requirement. Almost universally, though, these scaling chips are characterized by poor de-interlacing and too-few taps on their scaling filters. They offer many "features" to mask these shortcomings, or they are used with inadequate additional memory to save a few pennies. For the present, it appears that the best way of mapping a picture to a display is to transmit the signal in a progressive format, pixel mapped to the display. Based on current trends, DisplaySearch only sees 11% of the flat-panel market as 1080-line, and 65% as 768-line. With

9. Cambridge Display Technology: www.cdtltd.co.uk
10. Screen Technology iTrans: www.screentechnology.com/info
11. Seamless Display: www.seamlessdisplay.com
12. Printable Field Emitters: www.pfe-ltd.com
13. Westaim iFire: www.ifire.com

Abbreviations

CRT	Cathode Ray Tube	**LCOS**	Liquid Crystal On Silicon
DILA	(JVC's) Direct-drive Image Light Amplifier	**LEP**	Light Emitting Polymer
DLP	Digital Light Processing	**OLED**	Organic Light-Emitting Device (Diode)
DMD	Digital Micro-mirror Device	**PDP**	Plasma Display Panel
DVI	Digital Visual Interface	**PSF**	Progressive Segmented Frame
HDCP	High-bandwidth Digital Content Protection	**TDEL**	Thick-film Dielectric Electro-Luminescent
HDMI	High-Definition Multimedia Interface	**TFT**	Thin-Film Transistor
HDTV	High-Definition Television	**WXGA**	Wide Extended Graphics Array
LCD	Liquid Crystal Display		

the manufacturers producing so many displays with 1365 x 768 pixels, there is no obvious transmission format to suit. 720p transmission requires a 16/15 scaling ratio to fit a 768-line panel, which is not particularly appealing. However, the LCD panel manufacturers have the ability to respond rapidly to the demands of the market, and could decide to focus on higher resolutions to gain market advantage.

On a digital panel, overscan should probably be considered to be redundant, since the edge of the picture is clearly defined. There might be a case for a few pixels here and there to maintain easy scaling ratios.

Another area where virtually all panels fall down is in the presentation of film-mode material carried on an interlaced format (sometimes known as PSF – Progressive Segmented Frame). Virtually all current display pre-processing fails to take advantage of the chance to treat film-mode material as such, and applies a de-interlacer to the signal, so degrading a signal which, by the progressive nature of flat-panel devices, should actually be much easier to scale and display.

Interfaces to the screen – DVI and HDMI

There are big changes afoot here also. In the analogue world, Europe led the way with the SCART or Peritel connecter. Now, the digital version of this is coming. In the longer term, the HDMI (High-Definition Multimedia Interface) [14] looks set to become the norm, and is currently being considered by the various international standards organizations. HDMI specifies a means of conveying uncompressed digital video and multichannel audio. It can support data rates up to 5 Gbit/s, and video from standard definition, through the enhanced progressive formats to HDTV at 720p, 1080i and even 1080p.

HDMI uses HDCP (High-bandwidth Digital Content Protection) [15] to prevent piracy of the uncompressed digital signal. It is this aspect of the interface which has proved the hardest part to agree. The system encrypts the signal before it leaves the source, and the display then decrypts the signal to allow it to be watched. It should be noted that HDCP is only a link protection system, and does not have a wider role in copy protection. The first products incorporating HDMI interfaces are now becoming available.

The DVI (Digital Visual Interface) [16] is the predecessor of HDMI. It is becoming increasingly popular on computers and display products, and uses very similar technology to HDMI, but lacking the audio capability. There is a measure of electrical compatibility, enabling adaptors between the different connectors, but the connectivity of DVI-capable equipment to HDMI (when HDCP is implemented) is, to say the least, uncertain. Products capable of using HDCP over DVI are also becoming available, and these should be fully compatible with HDMI.

One big advantage of HDMI over DVI will be cable length. Usually limited to about 2m for DVI, 15m (and beyond) should be possible with HDMI.

14. High-Definition Multimedia Interface: **www.hdmi.org**
15. High-bandwidth Digital Content Protection – Digital Content Protection, LLC: **www.digital-cp.com**
16. Digital Visual Interface – Digital Display Working Group: **www.ddwg.org/dvi.html**

Richard Salmon, a Senior R&D Engineer, has worked for the BBC at Kingswood Warren since graduating from the University of Cambridge, UK, in 1987. He has been involved in many different projects over the years, with a particular interest in colorimetry, video compression, watermarking, HDTV and video systems engineering. He also spent six months on attachment to NHK in Japan, working on Plasma Display technology.

Mr Salmon is a member of the EBU project group B/TQE (Television Quality Evolution), the work of which is closely aligned to that of BBC R&D's Image Unit in which he currently works.

Impact on broadcasters

The forecasts are that, by 2007, 20% of TVs sold will be large-screen, with the market growing rapidly. This represents perhaps 3% of households in Europe having 30″ or larger flat-panel TVs, as their principal receiver in 2007 – growing to an installed base of maybe 15% of households by 2010. The majority (probably 75%) of these will be capable of displaying higher resolution than standard definition. Current digital TV bitrates do not generally look good on these large panels, especially compared to DVD, D-VHS and Blu-Ray DVD, so 2008 - 10 is when broadcasters will probably need to be implementing improvements, but we (in research and strategic planning departments) will need to start considering this now, so that we are ready with a range of options when they are needed.

The new EBU technical group B/TQE (Television Quality Evolution) was formed specifically to address these issues. It follows on from an ad-hoc group which had been considering the impact of flat-panel displays on the broadcast environment. B/TQE immediately achieved a high profile during discussions with panel manufacturers at IBC in September 2003. Its remit is broad, covering ways of delivering the very best images via the current transmission standards, and tracking all the significant display, camera, recording and compression technology changes. The group will be considering how to make best use of the islands of HD equipment that are beginning to appear in European broadcast centres, and suggesting ways in which, at the appropriate time, HD broadcast services might be delivered within Europe.