THE BROADCAST BRIDGE

Connecting IT to Broadcast

Hybrid IP and SDI Test and Measurement

Essential Guide

EG

ESSENTIAL GUIDES

Introduction from Leader

The broadcast industry has always been at the forefront of technological innovation. What initially appears daunting and impossible to implement very quickly becomes the de-facto standard whilst retaining and even improving upon the high QoS that ensures the services provided by broadcasts remain appealing and engaging to consumers.

Broadcasters and production companies are continually competing against each other to stay one step ahead with the services they can offer, while remaining price competitive. This competition has been compounded by the 'service-provider' model many broadcasters implement. Service level agreements for performance failures demonstrate how risk-adverse broadcasters are. The service-provider model generates strong competition, with broadcasters prepared to shop around to find the most cost-effective solutions for their services. This has opened the door for COTS-based IP solutions.

The COTS-based solutions broadcasters and service providers are deploying are not your bargain-basement, entry-level variety but enterprise-level solutions that carry an enterprise price premium which can make the solution equal or even exceed serial digital equivalent costs. The major benefit of COTS-based solutions to broadcasters and service providers is a promise of more predictable expansion costs. With serial digital infrastructure you either designed your infrastructure for the worst-case scenario and paid for a system that is under-used or you prepared yourself for potentially high future expansion costs. COTS-based IP infrastructure gives broadcasters and service-providers predictable upgrade costs, meaning their systems can be used to the maximum and cost-effectively expanded when required.

This 'Essential Guide to Hybrid IP and SDI Test and Measurement' outlines the challenges broadcasters and service-providers face. It also explains the test and measurement techniques and products that are allowing COTS adopters to deliver the QoS for which the professional broadcast industry is renowned.

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Kevin Salvidge, European Regional Development Manager, Leader Europe Limited, has over 20 years of broadcast industry experience. He joined Marconi Instruments in 1982 as an apprentice and later field service engineer. In 1994 he progressed to Sony Transcom as a field service representative before moving into sales roles with Sony, Grass Valley, Thomson Multimedia and Omneon.

Hybrid IP and SDI Test and Measurement

By Tony Orme, Editor at The Broadcast Bridge

One of the principal roles of a broadcast engineer in the analog days of the past was calibration and monitoring. Cable losses, component drift, and temperature all conspired against systems resulting in changing colors, brightness and contrast levels, and even picture shift due to timing anomalies. But as our digital transition continues, especially with SDI and IP hybrid systems, we're discovering monitoring is playing an increasingly important role in broadcast television.

Even as we move to ever more complex digital systems, one fact hasn't changed, that is the way the human visual system (HVS) interprets the light around us to form images in our mind. Reflective surfaces provide color, brightness, and perceived dimension. Our light transducers, otherwise known as eyes, use a complex combination of rods and cones to turn the light entering through the lens into electrical impulses to be processed by the brain, with the iris acting as a gatekeeper to moderate the amount of light to keep within the tolerable limits of the rods and cones.

Fundamentally, television is an illusion, there are no moving images, just a series of still frames played quickly enough to remove flicker and give the perception of motion. And there are no continuous spectra of color, just three primary pigments taking advantage of metamerism to give the illusion of different colors.

Limited Dynamic Range

The fundamental role of the television camera is to provide a system that approximates the HVS to give the illusion of motion and color. However, cameras do not benefit from the complexities of the human mind and the sensitivity of the human eye and have significantly less color and dynamic range representation than the HVS. For example, the human eye can achieve 24 stops of dynamic range, a broadcast camera can achieve 14 stops, an HDR with 1,000 NITs mastered content can achieve 10 stops, and an SDR monitor can only achieve 6 stops.

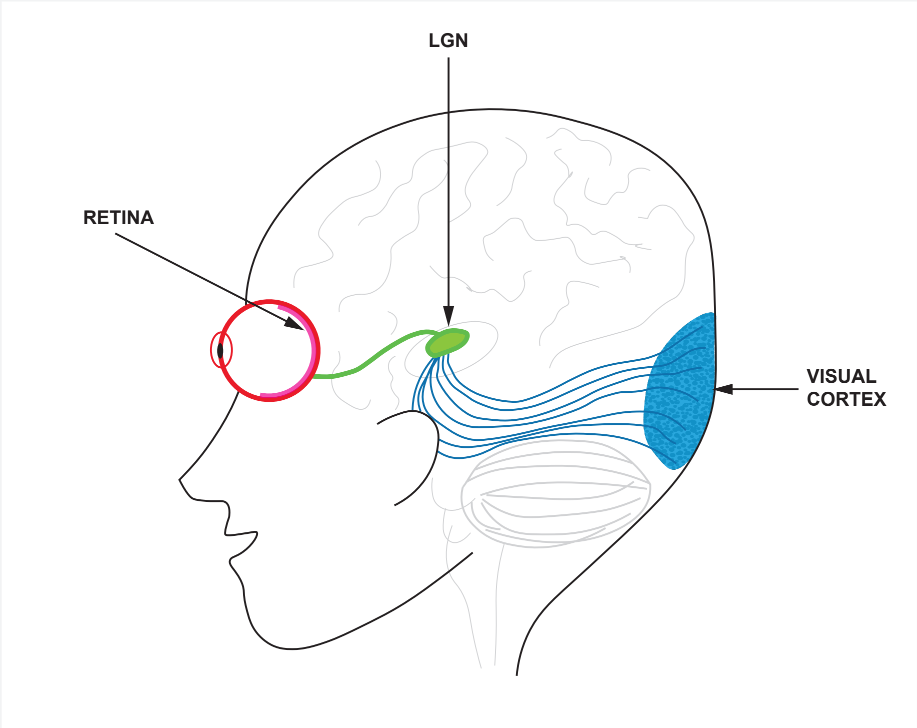

Figure 1 – The human visual system consists of four stages, optical processing (eye lens), retinal processing (back of the eyes), LGN (lateral geniculate nucleus) processing serves as a bridge between the eyes and the visual cortex, and cortical processing (visual cortex).

In effect, the camera and broadcast chain in general, acts as an approximation to the HVS. And as we compromise, the models which we base television on must have better tolerances otherwise small errors magnify quickly and become detectable by our eyes. Furthermore, as the eye has a greater accuracy it can see even the smallest of errors. An example of this is banding in low light gradients with limited bit depth.

Another example is the magnified effect of shadows in a sports stadium. Vision engineers constantly fight to maintain a viewable image as the cameras pan across the stadium moving in and out of the shadows and bright sunlight, both sometimes appearing in the same image. The dynamic range in a stadium could easily exceed 6 stops, this is generally fine for HDR but not so for SDR. If the engineer racks for HDR to achieve the greatest dynamic range, then the SDR signal will be blown out in the highlights or crushed in the shadows. If the engineer racks for SDR then they run the risk of not achieving the dynamic range offered by HDR.

The BBC have carried out extensive testing on simultaneous SDR/HDR productions and have summaried their experience on their web-site. Read it here.

To save bandwidth and ease distribution in SDI infrastructures, the fundamental red, green, and blue signals are compressed to Y, Cb, and Cr. The color difference signals, derived through a matrix system, take advantage of the limited color requirements of the HVS. In each eye, we have approximately 6 – 7 million cones to interpret color and 120 million rods sensitive to the brightness, or luminance.

Although the YCbCr system reduces bandwidth, the process of conversion can have the unintended consequence of generating out of gamut signals that can cause image distortion, signal crosstalk, and modulation issues.

Even in baseband video infrastructures such as SDI, the signal monitoring relating to the HVS still plays an incredibly important role as poor signal levels can result in unacceptable pictures. In the early days of broadcast this would result in a telephone call to the duty office. But in the highly competitive world of pay-per-view, the viewer has many options and will simply switch to another service provider if the broadcast is not of an acceptable quality.

Art Or Engineering?

But as we move to HDR, the role of the traditional vision engineer is becoming increasingly blurred. To get the most out of HDR cameras, creative directors are becoming more involved in the technical aspects of vision control. The creative look is more important than ever, and engineers are finding they need to consider the aesthetic aspects of an image as well as the technical ones. To achieve this, they are digging deep into the camera shading, matrix, and gamma functions to deliver the look needed.

Although producers and program makers will tend to want to move to the new and interesting HDR technology, SDR is still the prevalent format for broadcast television. Many distribution networks transmit in 8-bit video and to really do HDR justice we need to broadcast in 10-bit.

Unless a production company is going to provide two sets of workflows, the general rule of thumb is to rack camera's for SDR and down-convert the HDR-4K video to SDR-HD to provide the correct feed for the majority of viewers.

Modern graphics generators can suffer similar gamut and level issues. Possibly more so if the image has been generated by a PC running non-broadcast software.

Image processing software can easily create out of gamut signals and in the wrong hands, can cause all kinds of video distortion problems. Menu presets allow creation of non-broadcast color space and image sizes not meant for television. Consequently, image processing may be applied which further reduces the quality and potentially increases the risk of distortion and out of specification signals.

Maintain Signal Levels Throughout Workflow

All these workflows must still be taken into consideration whether working with SDI, IP, or a combination of the two. The signal must be within specification from the beginning and any processing should maintain and respect the relevant specifications and signal levels.

One of the important aspects of SDI is that the technology is nearly thirty years old and has had much time to mature. Over the years, manufacturers have made SDI incredibly reliable and ironed out most of the bugs. Monitoring equipment has matured, and the underlying infrastructures are understood by a wide population.

Although many broadcasters are transitioning to IP, the majority are going to do so in a piecemeal manner. The complexity and ubiquity of their existing SDI infrastructures makes the possibility of completely redesigning and building a new IP infrastructure too risky. This brings new and interesting challenges as broadcasters are now faced with a combination of SDI and IP infrastructures working closely together and therefore requiring hybrid equipment to retain QoS.

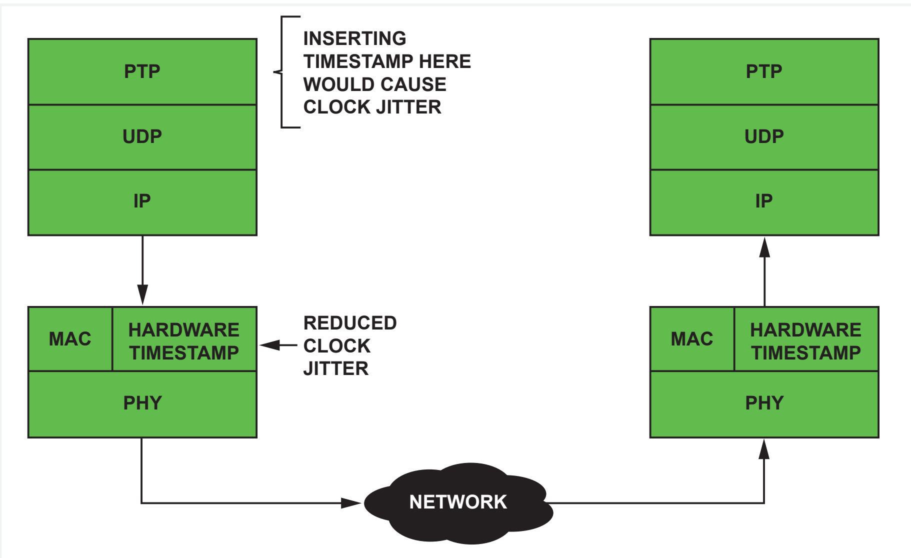

Figure 2 - Care must be taken when making PTP IP timing measurements as results can be easily skewed if hardware timestamps are not used.

Being new to television signal distribution, IP provides interesting challenges for broadcasters, especially those working in live, uncompressed video. With ST-2110, the timing information has been removed from the underlying hardware layer making the distribution asynchronous.

With current broadcast formats, video must be frame synchronous at the camera's sensor and at the viewers television screen. The intermediate IP distribution network is asynchronous but the variance in packet jitter directly affects latency leading to potentially longer video and audio delays than we have come to expect from SDI infrastructures.

With SDI systems, even low-level hardware measurements for timing jitter, eye height measurement and esoteric measurements such as pathological test signals are mainstream. Jitter occurs when a signal varies in time or amplitude outside of the ideal waveform shape. Graticules on the measuring devices make clear when a signal is in or out of tolerance.

IP timing is quite different. In IP we don't directly measure the physical layer jitter but instead packet timing. Abstracting away the video and audio essence from the hardware infrastructure and the fact that we must synchronize the packets at the playout device, demands a timing system of some sort. Precision Time Protocol (PTP) SMPTE 2059-2 provides this method of timing with its sub-microsecond accuracy.

Demarcation Is Blurred

In traditional SDI infrastructures, if the picture was breaking up then we could easily diagnose a faulty cable, connector, or in the extreme, the sync-pulse-generator (SPG). However, if the SPG had failed then many clues would manifest themselves as other monitors would show picture break up from other sources. There are clear single points of demarcation and failure.

With IP, the source of the breakup may not be immediately clear. It's entirely possible that an unstable video feed would show correct timing, no packet loss, and good data integrity. So, there would be no immediately obvious source of failure. In this scenario, IP packets with large timing variance could cause video breakup as the packets would fall outside of the receiver buffer window. The packets were not lost or even out of sequence, just late.

Furthermore, if the IP stream was feeding an ST-2110-to-SDI converter, it's entirely possible that the picture would break up when viewed on the SDI monitor but not when viewed on the IP monitor. By chance, the buffer in the IP monitor might be just slightly larger than that in the ST2110-SDI converter and appear to be stable. The implication is the SDI feed is at fault when really, it's the IP stream.

It's not unknown for the optics on the fiber interface at the connection to an Ethernet switch to be contaminated with dirt causing intermittent packet loss. This might be so small that it's not seen on an IP monitor but could be seen on an SDI monitor. Or vice-versa.

Source Of An Issue Is Not Always Obvious

The point here is problems that may seem to be unrelated are indeed related. This calls for a monitoring system that is highly correlated. It's important to be able to measure and monitor signals and streams simultaneously on the same device.

When we transitioned from analogue PAL and NTSC to SDI, the difference between SDI and analog signals was limited to timing. Peak white was an absolute voltage in analogue and a well-defined number in digital. Although SDI was component, the color difference signals were closely referenced to the modulated color difference signals in the analog. The major challenge was making sure the correct number of SDI clock cycles occurred to maintain strict horizontal and vertical frame timing. This was usually addressed with the SPG. As SDI developed, clock phase, frequency, and jitter could be accurately measured to help maintain integrity between analogue and SDI systems.

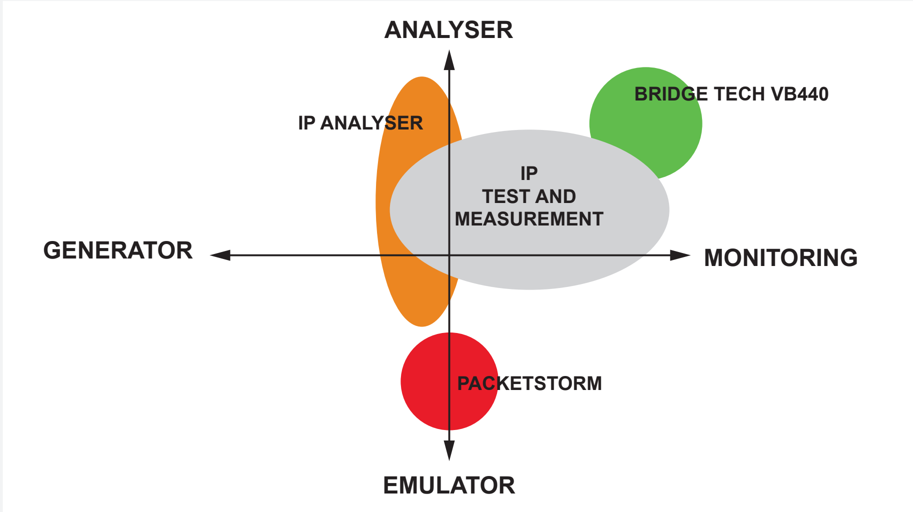

Figure 3 - IP Test and Measurement Monitoring Systems.

Although uncompressed video such as that provided by ST2110 does map to the active video parts of SDI, two major changes have occurred; the PTP and SPG may or may not be the same device, and signal distribution in IP is asynchronous and multiplexed. Furthermore, the PTP distribution relies on phase locked loops to provide synchronization and correctly specified PTP-aware Ethernet switches. Now we have an asynchronous PTP system that has its own variable jitter influenced by Ethernet switches, transmission lines, and terminal equipment, as well as a synchronous SDI system. In the ideal world both would be GPS locked but this is not necessarily the case, especially with SDI.

A major benefit of IP is expected to be that we can process signals in software, as such buffers are expected to be used to iron out Ethernet switch congestion, asynchronous influences from operating systems and delay provided by redundant networks. This is an area that is still developing, processing real-time, uncompressed video flows all in software is still not easy and that widespread.

As we have seen, in an IP infrastructure, especially as we transition from SDI, a fault that appears to be timing related may not be, and a fault that appears to be level related may not be. To be able to diagnose a fault with any level of confidence, an engineer will want to see the SDI signal at precisely the same time as the IP signal it is being compared to.

A vision engineer may see a picture breaking up on their camera's IP HDR output but not on the SDR output. The logical assumption is the HDR IP feed is at fault. But if the engineer looks at an SDI waveform monitor, they may see the picture is perfectly intact and the eye-height and clock frequency are correct. Furthermore, they may look at their IP analysis tool and see that the IP feed is also correct, the PTP jitter may be low and the packet integrity correct. But the multiviewer feed is still breaking up.

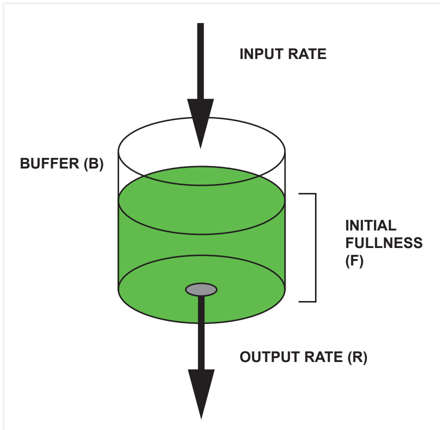

Figure 4 - this diagram shows conceptually why we need buffers, in the short term the input rate and output rate may differ, but over a long period of time they must be the same or underflow and overflow will occur. That is, Long Term Input Rate = Long Term Output Rate. If the buffer B is too big then significant latency will occur, if it is too small, then it could empty in the short term. Determining what is meant by short and long term is a skill broadcast engineers will learn as we continue our IP journey.

In this scenario, it might be that the relative timing between the SDI and IP timing planes has drifted apart slightly, just on the edge where it's only noticeable on some terminal equipment. It's almost impossible to make any sense of this system as our source of truth, the monitoring equipment, is giving us contradictory information as the two are not synchronized and cannot be adequately compared to each other.

And more importantly, we must understand what exactly is being measured in the IP world. Are you measuring packet jitter on the wire or after the operating system has copied it to memory? In broadcasting, especially in SDI, we would have said "on the wire", but we cannot make this assumption in IP as it depends how the vendor has designed their equipment.

Hardware Timestamps

When an Ethernet frame enters a Network Interface Card (NIC) it is usually copied directly to a kernel buffer, and then the operating system will copy it to user memory. In this process, any meaningful timing information is destroyed. To give the most accurate timing information, the Ethernet packet must be hardware-timestamped at the point where it is received off the wire and before it's copied to its receiver buffer. And this timestamp must stay with the IP packet for later processing.

Hardware measurement prior to any buffering must be adopted to gain any meaningful measurements for the PTP frequency and jitter accuracy. Again, if this measurement takes place in the processor's user space the measurements will have a large amount of error due to the unpredictable influence of the operating system.

The only way to make any meaningful comparisons between SDI and IP signals in a broadcast facility transitioning to IP is to use SDI and IP monitoring and analysis equipment that resides within the same unit. That way, direct comparisons between SDI and asynchronous IP streams can be easily made. Also, any IP measurements must be made in hardware to maintain the levels of accuracy we need. It might be that we need to compare SDI and IP signals at various parts of the infrastructure and compare them directly. The only way to truly achieve this is to measure and reference in the same unit.

There is an argument to suggest that we could measure with independent SDI and IP units and synchronize them together, but this just adds another variable into the system and adds uncertainty to our analysis.

As broadcasters transition from SDI to IP, a whole plethora of opportunities awaits including moving to HDR. But in doing so, hybrid monitoring becomes even more important than ever as more detailed comparisons must be made between intricate parts of the two networks. This will help diagnose and quickly rectify faults and maintain the highest standards possible.

The Sponsors Perspective

Essential Guide to Hybrid Test and Measurement

Familiarity breeds contempt and to a certain extent that is what has happened among broadcasters when it comes to serial digital interface (SDI) technology. Since SDI was first standardised by the SMPTE in 1989, broadcasters have forgotten the trials and tribulations they went through to get those initial systems working. Over the past 30 years, products have been developed that have resulted in an almost plug-and-play approach to building SDI-based broadcast infrastructure.

Since the introduction of commercial-off-the-shelf (COTS) hardware, broadcasters have faced a new series of challenges that, like SDI when first launched, will revolutionize the broadcast industry and allow it to remain economically viable.

Like SDI, IP comes with a suite of SMPTE standards. Organizations like the Alliance for IP Media Solutions (AIMS) have been at the forefront of establishing product interoperability. The challenge now is that we have new manufacturers involved who are not familiar with professional broadcasters' rigorous demands.

Established broadcast systems integrators and solution architects are fully conversant with SDI-based equipment and its deployment capabilities. However, the core of future systems will no longer be a bespoke SDI router but a COTS network switch. If a facility is going to be deployed over a WAN, its IP video signals will undoubtedly encounter other devices from manufacturers outside the traditional broadcast sphere.

Compare SDI and IP infrastructure test and measurement requirements

	SDI	IP
Connectivity	Physical Layer Coding Baseband Video	7 Layer OSI model
Essence	Single essence per BNC - 1X 1080p60 unidirectional	Multiple essence per Fibre - 100GbE > 75x1080p60 bidirectional
Measurement	Direct Measurement	Indirect Measurement
Transportation	Synchronous Transport	Asynchronous Transport
Cause of Error - Occurrence	Cable loss Connector contact failure Impedance mismatch Jitter Signal rise and fall time	Packet loss due to network overload - Excess network traffic - Bandwidth restrictions due to compensation technologies like FEC, ARQ and hitless protection (1+1) Error frame discard
Measurement Methods	Monitoring CRC and TRS errors	Monitoring FCS and CRC errors

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Although this guide outlines the next generation of test and measurement tools that broadcasters will be deploying to ensure that the already excellent QoS they deliver using SDI infrastructure is maintained and improved upon using IP, one should not forget that the traditional waveform and vector scope display will still remain relevant for monitoring the color signal forms for the vision engineer, vision supervisor and broadcast engineer's, irrespective of the infrastructure.

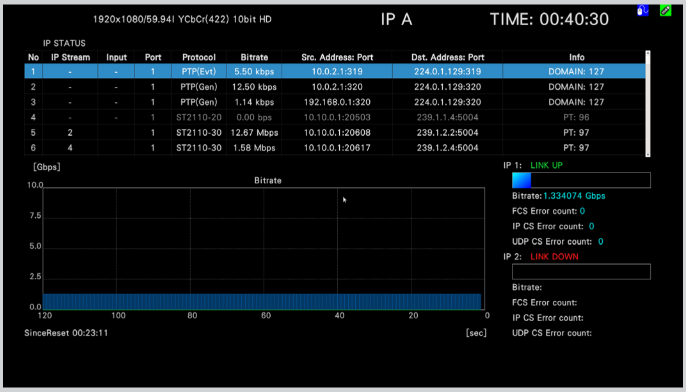
IP infrastructure brings new challenges and new test and measurement requirements. Broadcast quality video-over-IP is a constant bit rate (CBR) stream that cannot easily tolerate loss. Loss of data means loss of video and to compensate for these technologies like forward error correction (FEC), retransmission (Automatic Repeat Query ARQ) and hitless protection (1+1) have been introduced.

While FEC, retransmission and hitless protection help against glitches, faults and failures, they don't help if your network is continuously overloaded. To overcome this, IP networks need to be designed either with over-provisioning capacity or by using per-node bandwidth reservation technologies.

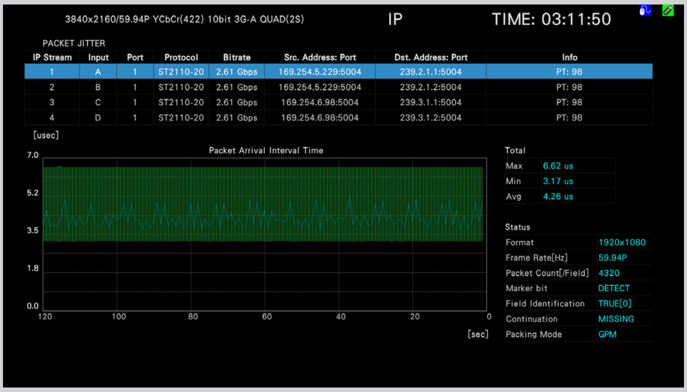
So, clearly the test and measurement techniques used in the SDI world will be replaced by a new series of tools that broadcasters will become familiar with over the coming years.

Those tools will include:

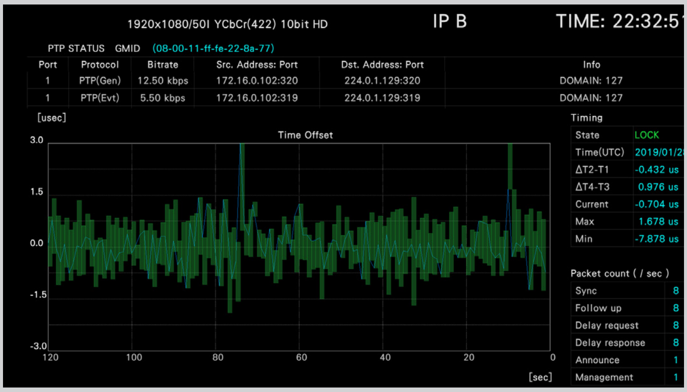
IP Status – Identifying IP sources

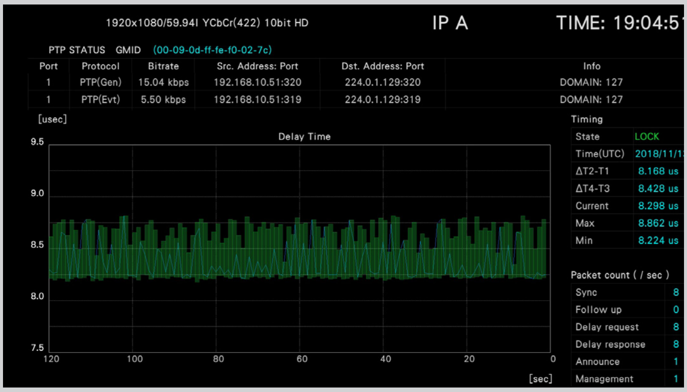


Inter-packet arrival time measurement – Displaying the Packet Jitter



PTP Reference measurement – Offset and Delay





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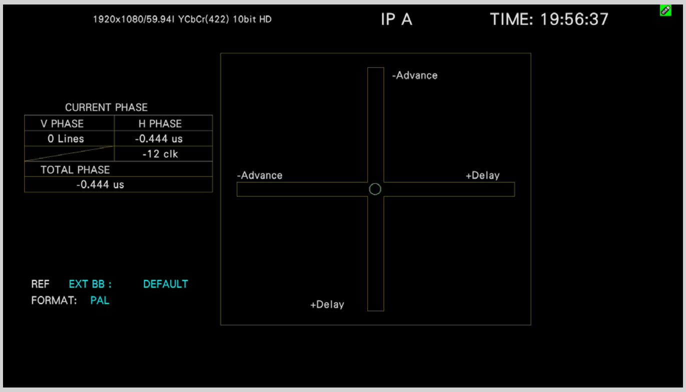
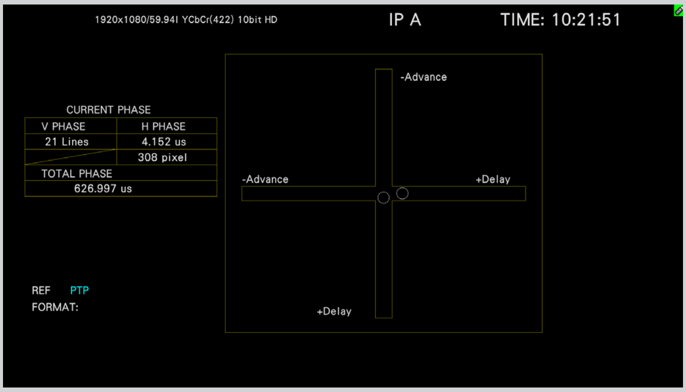
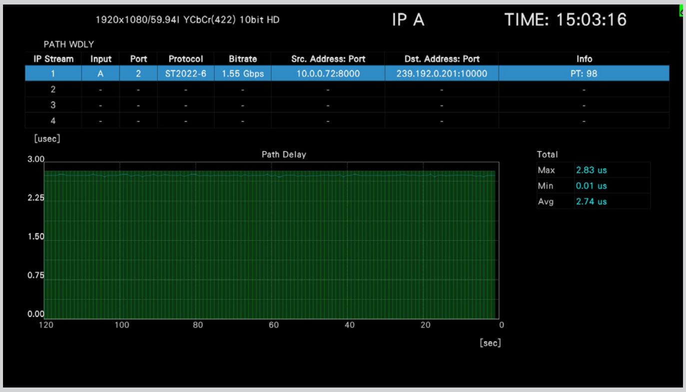
Reference Timing – SDI EXT BB and PTP

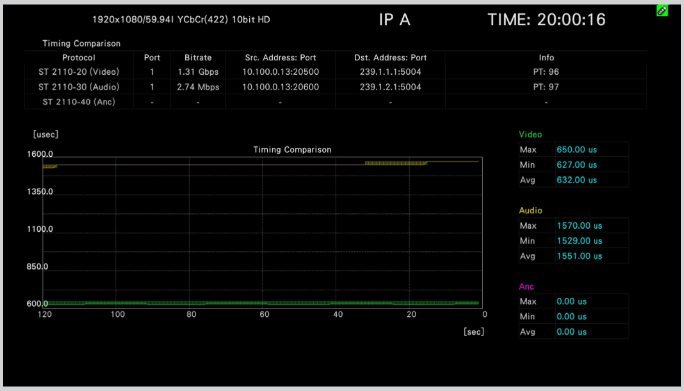




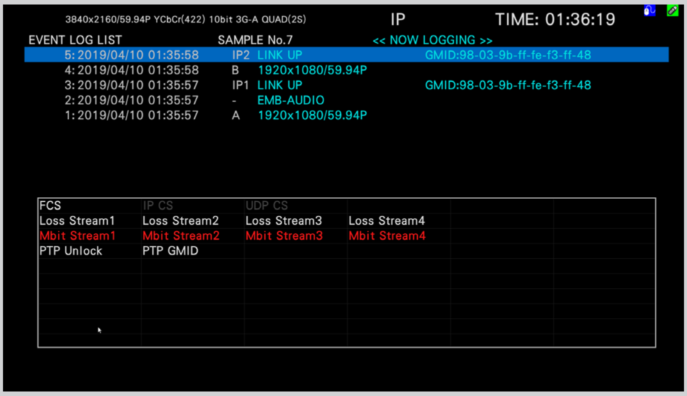
Path Differential – Graphical display of the path delay between the input ports.



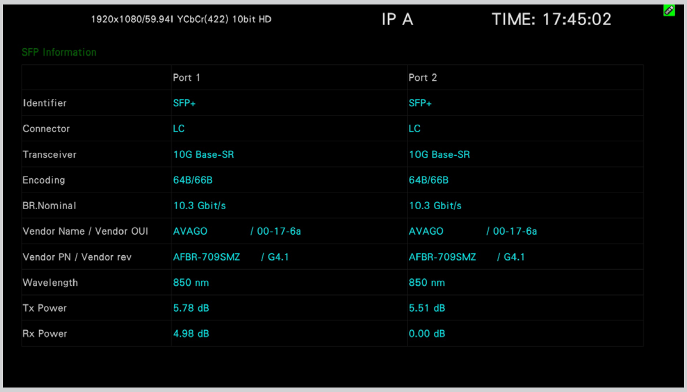
Timing Comparison – SMPTE ST.2110 -20/-30 &-40 timings of the RTP relative to PTP



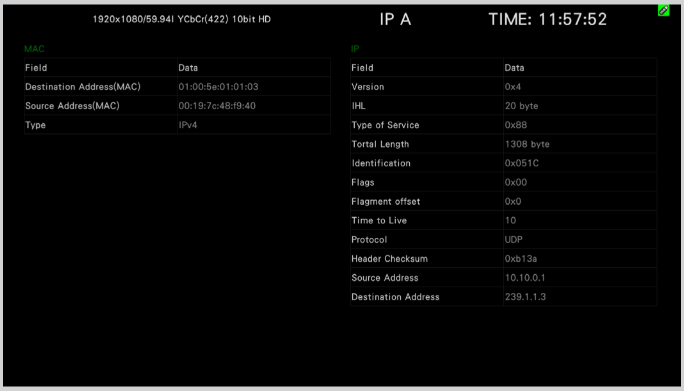
IP Event Log Display

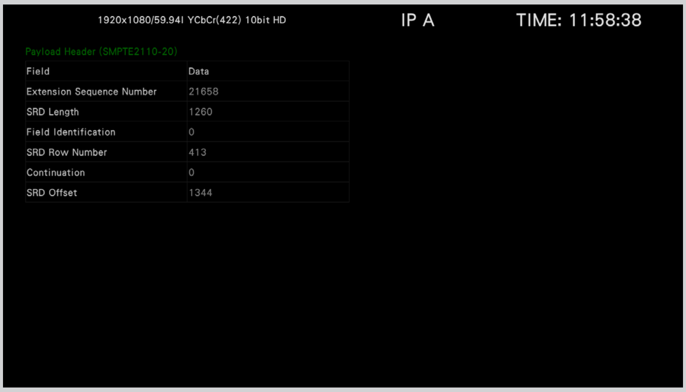


SFP Module Display



Payload Header Information – including MAC/IP/UDP and Payload information





All of these new tools will replace the physical layer measurement tools, such as eye pattern, jitter and status errors, whilst the traditional waveform and vector scope display will remain relevant for monitoring the color signal forms for the vision engineer, vision supervisor and broadcast engineer, irrespective of the infrastructure.

The early adopters of IP infrastructure were restricted by their choice of broadcast products. Most early implementations therefore comprised a combination of SDI and IP products, requiring a hybrid test and measurement strategy.

Unfortunately, the first generation of IP test and measurement products did not contain hybrid SDI and IP capabilities so legacy SDI test and measurement products were deployed to complement the IP-only test and measurement products.

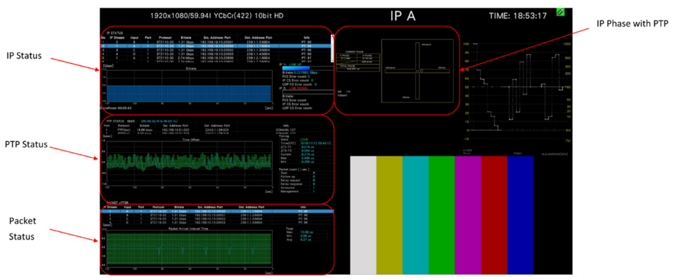
Second-generation hybrid test and measurement products have started to appear on the market over the last two years, but their functionality is restricted either to SDI or IP operation. Switching between these can result in a device having to reboot and reset itself, interrupting the measurement process.

Leader's new ZEN series now offers broadcasters 'True Hybrid' IP and SDI operation by allowing SDI and IP sources to be displayed simultaneously, with the traditional waveform monitor and vector scope displays. The ZEN series also features Leader's real-time false color picture display tools such as CINEZONE, allowing both production staff as well as technicians to monitor signals irrespective of the infrastructure.

The Leader ZEN series features two products – the LV5600 waveform monitor and the LV7600 rasterizer – than can support 'True Hybrid' IP and SDI operation.

Both the LV5600 and LV7600 can support 4x 3G HD/SD-SDI inputs, with re-clocked loop-through outputs, as well as either 10GbE or 25GbE SMPTE ST.2022-6 and 7 and SMPTE ST.2110 interfaces. To support 'True Hybrid' IP and SDI operation both hardware interfaces need to be installed.

They also have the capabilities to allow operators to configure the display to satisfy personal measurement preferences.



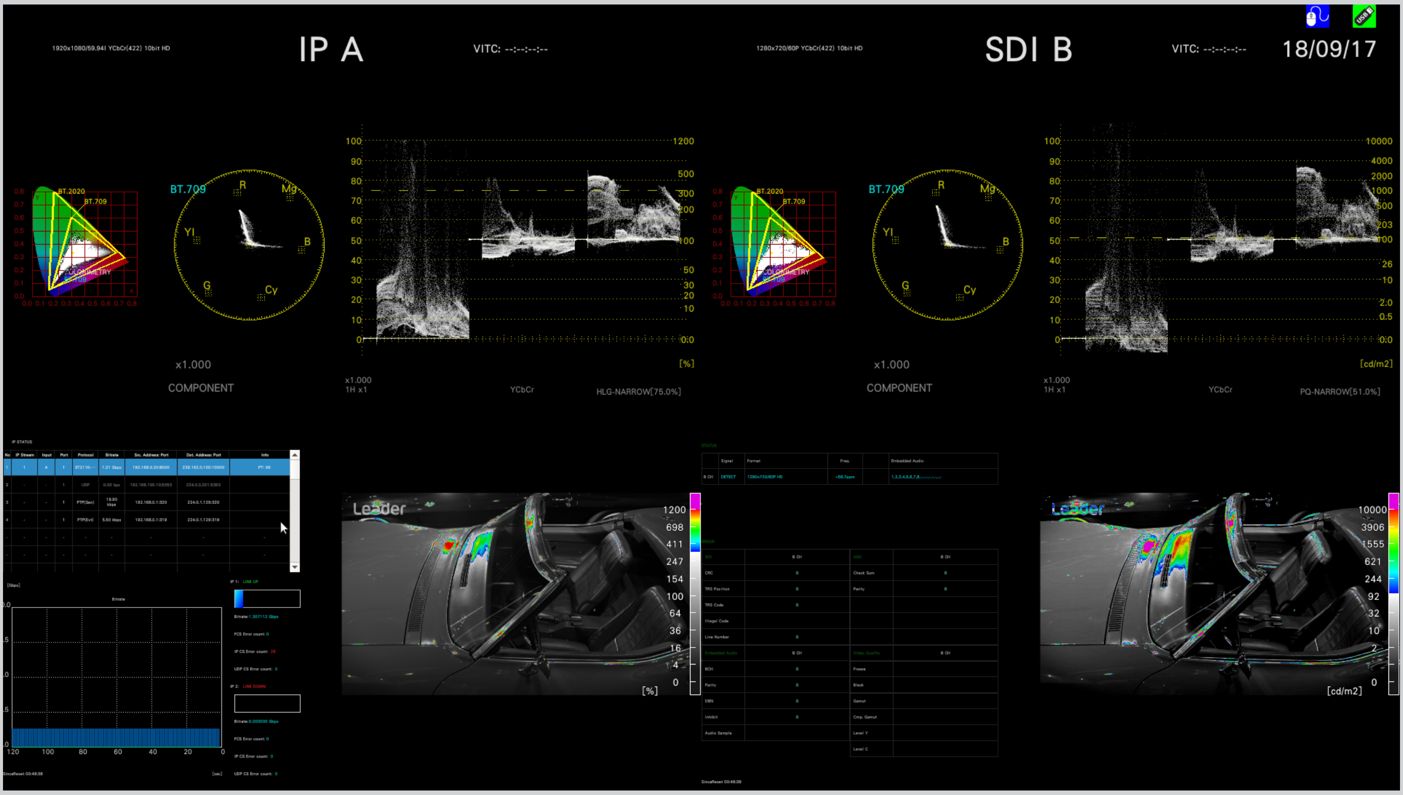
*Software License – LV5600 / LV7600SER26 required

Leader ZEN series LV5600 waveform monitor and LV7600 rasterizer.

IP Test and Measurement Display

The advantage of the Leader ZEN series ‘True Hybrid’ IP and SDI operation is that, as well as featuring a comprehensive set of IP measurement tools, the operator can simultaneously view both IP and SDI sources with the traditional ‘Picture’, ‘Waveform’ and ‘Vector scope’ displays, irrespective of the broadcast infrastructure.

This is ideal for monitoring video signals as they pass through the numerous IP ➞ SDI ➞ IP gateway products now being deployed.



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‘True Hybrid’ IP And SDI Test And Measurement

There is a short video guide to the LV5600 and LV7600 here.

Very few static broadcaster facilities will be afforded the luxury of deploying a complete IP base infrastructure. Not all of the traditional broadcast products will be available today in IP so most broadcasters’ initial IP systems will be small proof-of-concept deployments that will initially mirror traditional SDI infrastructure. Once the concept is proven, most broadcasters will then use the IP system as a backup to the main SDI system. This is the point where ‘True Hybrid’ test and measurement is required. Production and technical staff need to have the confidence that the redundant IP system is ready to seamlessly replace the main SDI system if a major incident arises. Once a satisfactory level of confidence in the IP system has been achieved, the IP system becomes the primary and the SDI system becomes the backup. Deployment of a redundant IP system is then initiated so the SDI system can eventually be decommissioned.

On the other hand, the Outside Broadcast sector which has been able to deploy almost complete IP-based infrastructure and there have been numerous case-studies published about the benefits of OB trucks with IP cores.

OB trucks typically contain a larger percentage of IP to SDI products so there will still be numerous IP ➞ SDI ➞ IP gateway products which require ‘True Hybrid’ IP and SDI monitoring however, it’s not uncommon for them to also retain legacy video standards like analogue composite video. “The Engineer in charge (EIC) needs to instantaneously be able to view all video signals in a truck. With the introduction of IP, that means there can be three types of video signal, IP, SDI and analogue composite video. The installation on the Game Creek Video – Bravo truck gives the EIC a Swiss army knife of measurement tools, that allows them to monitor and compare different video sources simultaneously”, commented Ian Bowker – Icon Broadcast.

Courtesy Game Creek Video – Bravo truck installation of Leader LV5600 and LV5770A. Integration by Icon Broadcast

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With IP OB trucks proving that SDI infrastructure can be replaced by IP, the broadcast industry is now starting to explore REMote Integration (REMI) for sports production with a centrally based static production hub using robust and affordable IP connectivity from the stadium/arena. Most static production hubs are currently SDI based so 'True Hybrid' IP and SDI products like the Leader ZEN series are proving invaluable as the incoming IP sources are converted to SDI.

These static production hubs will eventually migrate from SDI infrastructure to IP. By initially deploying the Leader ZEN series waveform monitor or rasterizer, facilities do not need to worry about having to replace their test and measurement products before the end of their capital expenditure life. Staff will already be familiar with the SDI operation of the leader ZEN series, which is replicated when used in IP infrastructures, reducing the need for additional training.

The Leader ZEN series also supports remote control operation via PCoIP KVM extenders, thus allowing facilities to centralize their test and measurement equipment in data centers equipment rooms and further maximize the products usage.

Both the LV5600 and LV7600 also support AMWA NMOS IS-04. The IS-04 API's expose Nodes, Devices, Sources, Flows, Senders and Receivers. Each resource is identified by a UUID (Universally Unique Identifier), which provides a reliable reference point to build on top of, meaning that even the complex deployments can easily map control systems onto he IS-04 data model. Once you have used an NMOS based system, you will not want to return to manually typing in 'Host Tables'.

Summary

As well as offering significant operational savings, COTS-based solutions are providing broadcasters and service providers with predictable expansion costs so it is only natural that broadcast equipment manufacturers should ensure that their products fulfill this criterion as well.

Leader's strategy is to provide customers with tried and tested products from a broadcast equipment manufacturer that they can trust, whilst at the same time allowing them to migrate from SDI to IP. The time this migration takes will vary from broadcaster to broadcaster. Removing the need to replace SDI equipment before the end of its capital expenditure cycle offers broadcasters and service-providers a significant saving.

Leader's ZEN series 'True Hybrid' IP and SDI test and measurement products address these concerns by providing a product that will assist broadcasters and production companies as they make their first tentative steps into the world of IP right through to the day when the final SDI product is decommissioned. This comes with the reassurance that operational and production staff will not require significant re-training during the SDI to IP migration.

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