

Investigating the cross-compatibility of IR-controlled active shutter glasses

Andrew J. Woods* and Jesse Helliwell

Centre for Marine Science & Technology, Curtin University, GPO Box U1987, Perth 6845 Australia

ABSTRACT

Active Shutter Glasses (also known as Liquid Crystal Shutter (LCS) 3D glasses or just Shutter Glasses) are a commonly used selection device used to view stereoscopic 3D content on time-sequential stereoscopic displays. Regrettably most of the IR (infrared) controlled active shutter glasses released to date by various manufacturers have used a variety of different IR communication protocols which means that active shutter glasses from one manufacturer are generally not cross-compatible with another manufacturer's emitter. The reason for the lack of cross-compatibility between different makes of active shutter glasses mostly relates to differences between the actual IR communication protocol used for each brand of glasses. We have characterized eleven different 3D sync IR communications protocols in order to understand the possibility of cross-compatibility between different brands of glasses. This paper contains a summary of the eleven different 3D sync IR protocols as used by a selection of emitters and glasses. The paper provides a discussion of the similarities and differences between the different protocols, the limitations for creating a common 3D sync protocol, and the possibility of driving multiple brands of glasses at the same time.

Keywords: stereoscopic, 3D, active shutter glasses, 3D sync, infrared, protocols, universal.

1. INTRODUCTION

Active Shutter Glasses (also known as Liquid Crystal Shutter (LCS) 3D glasses or just Shutter Glasses) are a commonly used selection device used to view stereoscopic 3D content on time-sequential stereoscopic displays. Time-sequential (or time-multiplexed) stereoscopic 3D displays operate by displaying discrete left and right images in alternating sequence often at image rates of 100, 120 or 144 images per second. The active shutter glasses alternately blank the left and right eyes in sequence with the sequence of images shown on the display such that the left eye only sees the left perspective images and the right eye only sees the right perspective images, ideally without crosstalk. The active shutter glasses usually contain two liquid crystal cells, each acting as a shutter – one in front of each eye.

In order for the active shutter glasses to switch in synchrony with the sequence of left and right images presented on the time-sequential stereoscopic display, some form of timing signal must be sent from the display to the glasses. Most wireless active shutter glasses use an infrared (IR) communication protocol similar to that used for IR remote controls used for TVs and other consumer electronics. In some cases an RF (radio-frequency) communication protocol (such as Bluetooth or ZigBee) are used. The DLP Link™ protocol uses pulses of visible light in its protocol.

Active shutter glasses have been used as a viewing device for time-sequential stereoscopic displays as far back as 1922 for the Teleview¹ system. The first wireless active shutter glasses to be commercially available were the StereoGraphics CrystalEyes which were released in the mid-1980s, used liquid crystal shutters, were battery powered, and used an IR communication protocol for synchronization. Many other brands and designs of IR controlled wireless active shutter glasses have been sold over the years² and in early 2010 the largest consumer release of active shutter glasses occurred with the consumer launch of 3D HDTVs by several consumer electronics manufacturers (including Samsung, Panasonic, Sony, LG, Sharp, and others³).

Regrettably most of the IR controlled active shutter glasses sold to date by various manufacturers have used a variety of different IR communication protocols which means that active shutter glasses from one manufacturer are generally not cross-compatible with another manufacturer's emitter. For example, a pair of 2010 Panasonic active shutter glasses cannot be used directly with a 2010 Samsung 3D HDTV, and vice versa.

* A.Woods@curtin.edu.au; phone +61 8 9266 7920; www.AndrewWoods3D.com

The technical reason for the lack of cross-compatibility between different brands of active shutter glasses mostly relates to differences between the IR communication protocol used for each brand of glasses (other reasons for incompatibility which are discussed in Section 4.1). In this study we have characterized eleven different 3D sync IR communications protocols in order to understand the possibility for implementing cross-compatibility between different brands of 3D glasses and 3D displays.

2. EXPERIMENTAL METHOD

The protocols were measured by connecting the IR protocol emitter (either a stand-alone emitter or an emitter integrated into a 3D display/projector) to a 3D video or 3D sync source. In the case where the IR emitter was integrated into the 3D display/projector, the 3D display/projector was switched into a 3D mode. A high-speed IR photo-sensor (Osram Opto-Semiconductors SFH213 Silicon PIN Photodiode – wavelength range 400-1100nm, 5ns response time) was aimed at the IR emitter and analyzed using a digital storage oscilloscope (TiePie Engineering Handyscope HS3 – 50MHz bandwidth). The timing of the IR pulses was measured relative to the 3D sync signal, the light field emitted by the display, and/or the timing of the shuttering of the eyewear.

Eleven pairs of active shutter glasses were tested in this study and ten of them are shown in Figure 1. Some of the stand-alone emitters tested in this study are shown in Figure 2.



Figure 1: Ten of the eleven active shutter glasses tested in this study: (a) StereoGraphics CrystaleEyes CE-1, (b) ELSA/H3D, (c) NuVision 60GX, (d) NVIDIA 3D Vision, (e) Panasonic TY-EW3D10U, (f) Samsung 2007, (g) Samsung (2010) SSG-2100AB, (h) Sony TDG-BR100, (i) Viewsonic PGD-150 DLP Link, and (j) Xpand X103 Universal. Sharp AN3DG10 not shown.



Figure 2: Some of the stand-alone IR 3D emitters tested: (a) Samsung 2007, (b) NuVision, (c) NVIDIA 3D VISION, (d) CrystalEyes 1, and (e) H3D/ELSA.

In order to verify the accuracy of the protocol measurements, a custom-built universal IR emitter was constructed⁴ and used to send a regenerated version of the various IR protocols to the various active shutter glasses. We were able to reliably drive all of the tested active shutter glasses using the appropriate measured IR protocol. There was only one exception to this testing, which was that we were unable to reliably drive the Xpand X103 universal glasses in the Samsung (2010) protocol mode using our regenerated Samsung 2010 protocol. This might indicate a slight timing error

in our measurement of the Samsung 2010 protocol, however we were able to use this protocol timing to drive an actual pair of the Samsung 2010 active shutter glasses.

3. 3D SYNC PROTOCOLS

The timing diagrams for the eleven protocols measured in this study are detailed below in Figures 3 to 13.

It is important to note that:

- not all of the diagrams are drawn to scale.
- the timings are as measured from commercially released hardware and were not provided or endorsed by the manufacturers.
- there might be timing errors in the measurements and descriptions.
- the Samsung and DLP Link protocols have a subtly different mode of operation which are detailed below.
- all measurements are in units of microseconds (μs).
- the timing of the opening and closing of the left and right shutters is not indicated in these diagrams and do not necessarily coincide exactly with the timing of the tokens. Most notably the Sharp protocol has a 1ms offset between the token and the shutter switching. (In the scope of this paper, a token is defined as a single pulse or group of pulses which define an action for the glasses to perform, e.g. ‘open the left eye’, or ‘close the left eye’ – in the timing diagrams below there is one token per row).
- In a 120fps (frame per second) 3D system, these protocols would repeat every 16.7ms (or every 20ms for a 100fps 3D system) (except Samsung 2010).

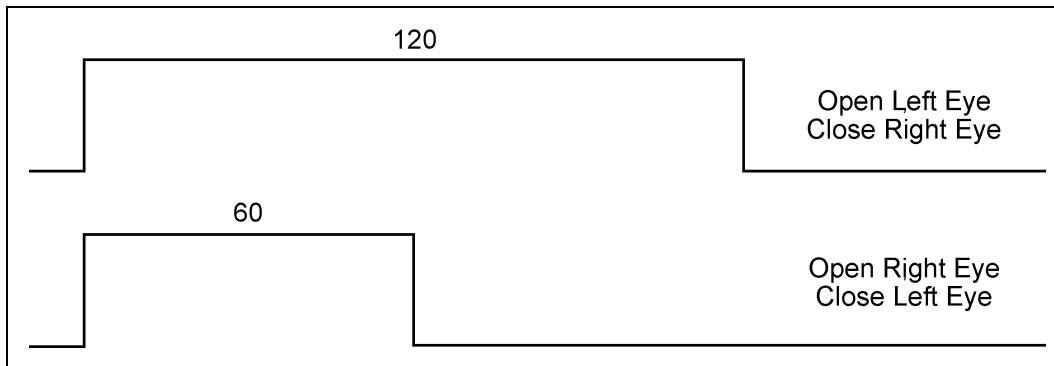


Figure 3: The 3D sync IR protocol for the StereoGraphics Crystaleyes 1 stand-alone emitter and glasses. (Units: μs)

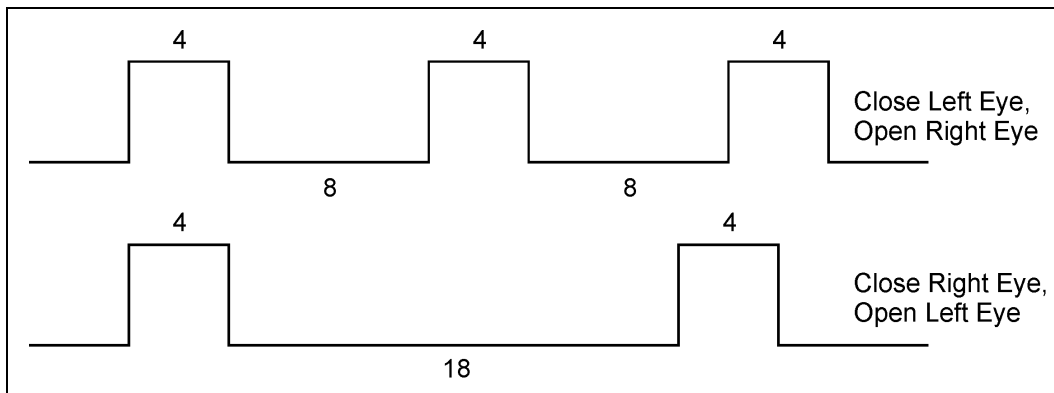


Figure 4: The 3D sync IR protocol for the NuVision stand-alone emitter and 60GX glasses. (Units: μs)

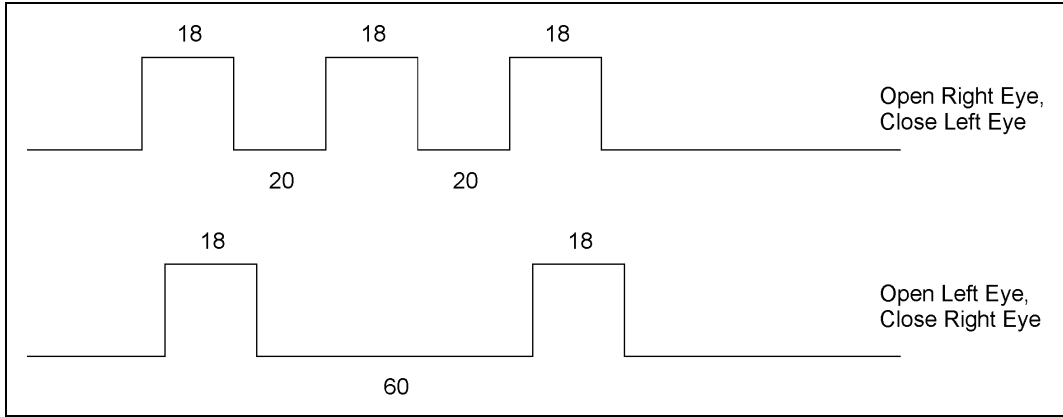


Figure 5: The 3D sync IR protocol for the Xpand stand-alone emitter and glasses. (Units: μs)

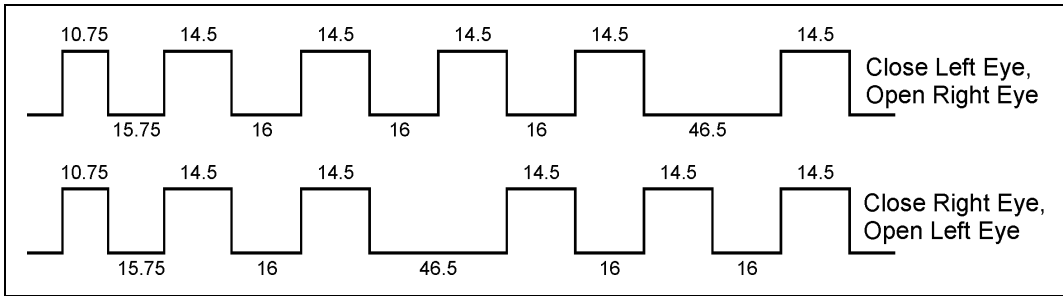


Figure 6: The 3D sync IR protocol for the ELSA/H3D stand-alone emitter and glasses. (Units: μs)

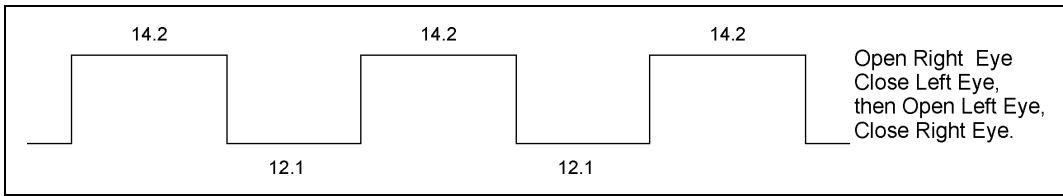


Figure 7: The 3D sync IR protocol for the Samsung 2007 stand-alone emitter and glasses. (Units: μs)
 NB: This is a one token protocol. The single token is output once every right+left frame pair period (at the beginning of the right frame period). The glasses must assume a duty cycle of approximately 50% and calculate the intermediate timing internally.

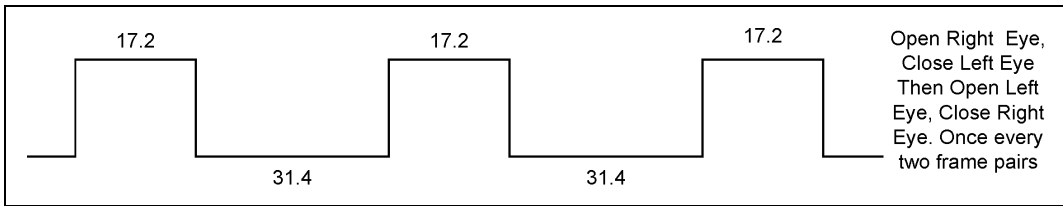


Figure 8: The 3D sync IR protocol for the Samsung 2010 integrated TV emitter and glasses. (Units: μs)
 NB: This is also a one token protocol. The single token is output once every two right+left frame pair periods. The glasses must assume a duty cycle of approximately 50% and calculate the intermediate timing internally.

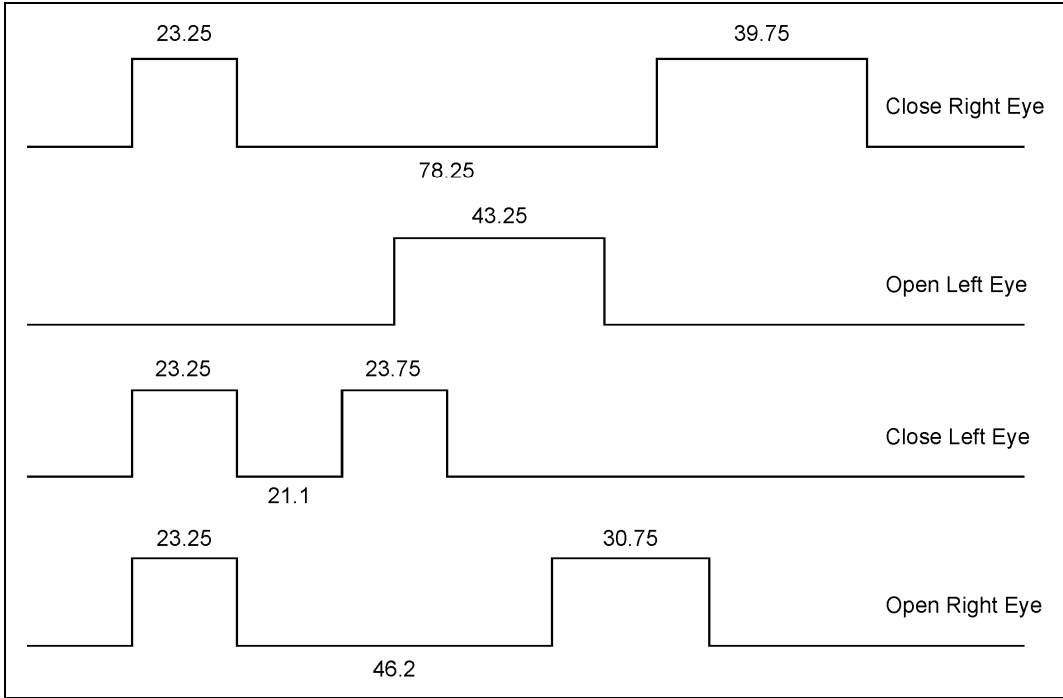


Figure 9: The 3D sync IR protocol for the NVIDIA 3D VISION stand-alone emitter and glasses. (Units: μs)
 NB: This is a four token protocol and hence allows the display to specify the duty cycle for the glasses to operate.

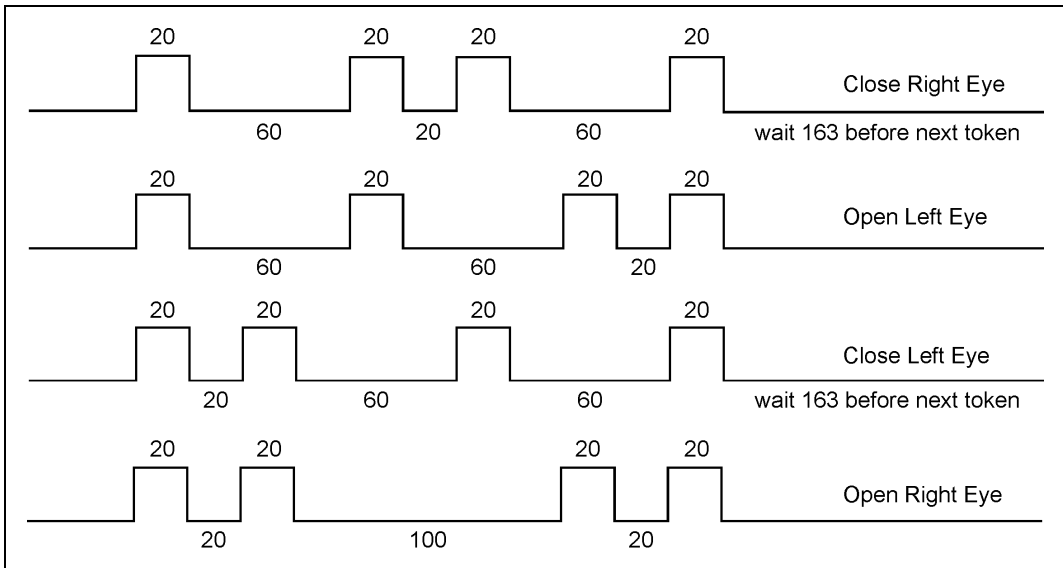


Figure 10: The 3D sync IR protocol for the Panasonic integrated TV emitter and glasses. (Units: μs)
 NB: This is also a four token protocol and allows the display to specify the duty cycle for the glasses to operate.

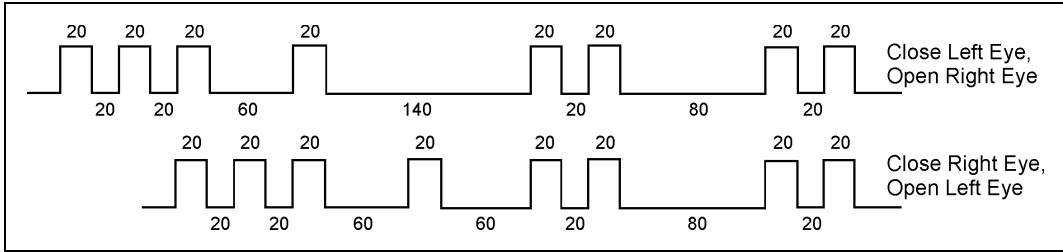


Figure 11: The 3D sync IR protocol for the Sharp integrated emitter and glasses. (Units: μs)

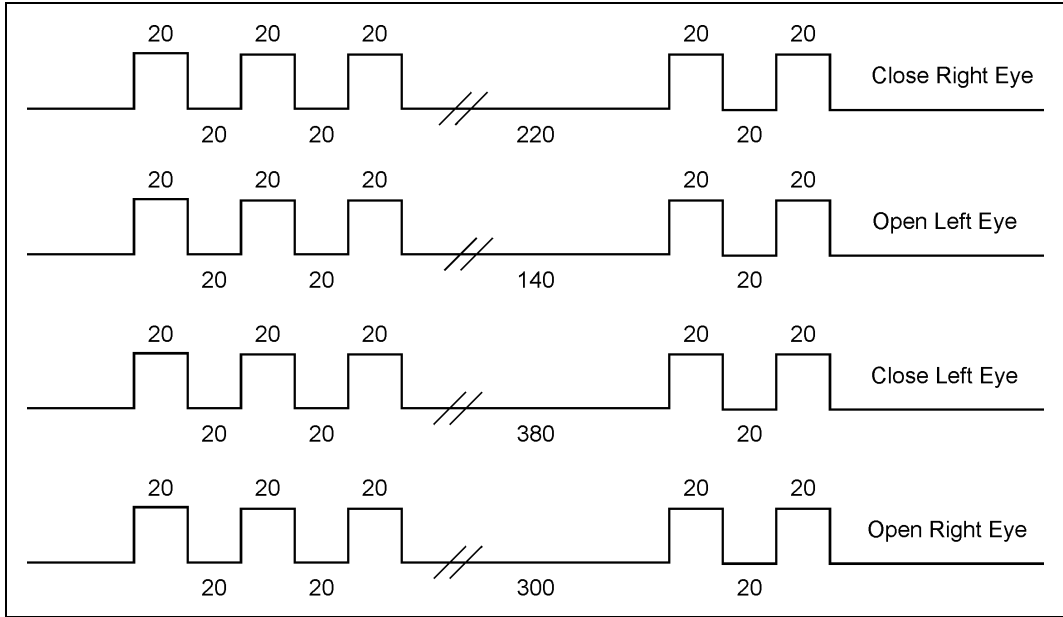


Figure 12: The 3D sync IR protocol for the Sony stand-alone TV emitter and glasses. (Units: μs)
 NB: This is also a four token protocol and allows the display to specify the duty cycle for the glasses to operate.

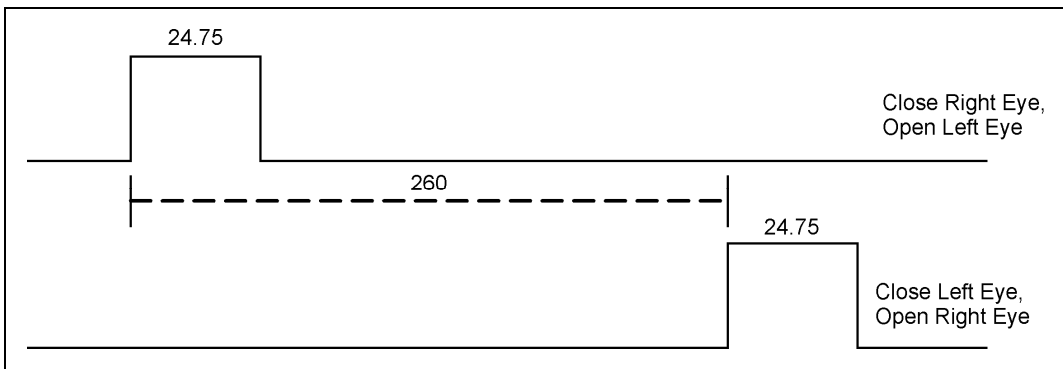


Figure 13: The 3D sync protocol for DLP Link™ projectors and glasses. (Units: μs)
 NB: The left eye token and the right eye token do not differ in width, but in relative timing. The right eye token is delayed relative to the sync reference by $260\mu\text{s}$ as compared to the timing of the left eye pulse. Another way of interpreting this is to say that the timing between pulses for the right perspective image period is $520\mu\text{s}$ ($2 \times 260\mu\text{s}$) less than the timing between pulses for the left perspective image period. Aspects of this protocol appear to be the subject of a US Patent Application⁵.

4. DISCUSSION

4.1 Reasons for Incompatibility

As can be seen in Figures 3-13, there are vast differences between the various 3D sync IR protocols. Even though most current 3D systems use an IR protocol to synchronize the glasses, the differences between the various individual IR protocols severely limits incompatibility between the different brands of glasses. Traditionally most IR controlled shutter glasses have been configured to receive only the IR protocol they are designed for and hence will not receive, or may be confused by, a different 3D sync IR protocol. Needless to say, the incompatibility was there by design. The 3D sync IR protocols are further contrasted in Section 4.2.

In addition to the IR controlled shutter glasses, there are some shutter glasses which use a communication protocol other than IR – specifically: the DLP Link protocol is transmitted in visible light, the Samsung 2011 glasses use the Bluetooth RF (radio frequency) protocol, Bit Cauldron BC5000 glasses use the ZigBee RF protocol, and Volfoni ActiveEyesPro glasses use an unspecified RF protocol (in addition to IR). The use of different electro-magnetic wavelengths to transmit the protocol (i.e. visible light vs. IR vs. ZigBee vs. Bluetooth) will obviously restrict interoperability.

There are also some duty cycle differences between the driving of the shutters for different 3D systems – some use a 50% duty cycle (i.e. the left shutter is open for 50% of the time, and the right shutter is open the other 50% of the time), whereas some glasses use a narrow duty cycle – e.g. 20% (i.e. the left shutter is open for 20% of the cycle, followed by a 30% period when both shutters are closed, followed by the right shutter open for 20% of the cycle, followed by another 30% period when both shutters are closed). Some stereoscopic displays, such as some 3D LCDs, require the use of a reduced duty-cycle switching of the glasses because a full left image (or a full right image) is only visible across the whole display for a short time period⁶. Without this reduced duty cycle operation, severe crosstalk would be evident in the 3D image. In other 3D displays, such as 3D plasma, a slightly reduced duty cycle of the glasses can help reduce crosstalk⁷. A pair of shutter glasses which only supports a 50% duty cycle will therefore not be able to be used on a display which requires reduced duty cycle operation of the glasses.

Finally, some shutter glasses (such as the Sony TDG-BR100) do not use a front polarizer on the shutters – this is a design feature which reduces peripheral ambient flicker while still allowing the 3D LCD TV image to be shuttered to the correct eye because the light emitted by the display is strongly linearly polarized. Glasses without the front polarizer would not be able to be used with Plasma 3D displays or time-sequential 3D projectors, although this limitation can be overcome by the fitting of an appropriate linear polarizer in front of each shutter in the glasses by the user.

4.2 Comparison of IR 3D Protocols

In order to better understand the reasons for incompatibility between the various IR protocols, let's look at the differences and similarities between the protocols shown in Figures 3-13 in more detail. One of the main differences between the various IR protocols is the number of individual tokens per cycle. As mentioned earlier, in the scope of this paper, a token is defined as a single pulse or group of pulses which define an action for the glasses to perform, e.g. 'open the left eye', or 'close the left eye'. Most of the protocols surveyed use a two token protocol, one token to signify switching from left to right, and another token to signify switching from right to left. The three protocols we surveyed which use a four token protocol allow the left and right shutters to be commanded individually (i.e. (1) left shutter open, (2) left shutter closed, (3) right shutter open, (4) right shutter closed). At the opposite end of this spectrum are the two Samsung IR protocols which only use a single token. In this case the token is simply a timing flag sent every one or two cycles to indicate the correct phase and frequency the shutter glasses should operate at and it is up to the glasses to calculate the correct time to switch the left and right shutters using a pre-determined formula. The number of tokens used by each of the sampled 3D sync protocols is summarized in Table 1.

Table 1: The number of tokens used by the various 3D sync protocols (ranked in order of increasing number of tokens).

Glasses	Tokens
Samsung 2007	1
Samsung 2010	1
NuVision	2
Xpand	2
CrystalEyes 1	2
Elsa/H3D	2

Glasses	Tokens
Sharp	2
DLP Link	2
Panasonic	4
NVIDIA	4
Sony	4

It is worth noting that the 4 token protocols are capable of being used to implement custom duty cycle operation of the glasses which is necessary to optimize 3D performance with some displays. As mentioned in section 4.1, some stereoscopic displays require the use of a reduced duty-cycle switching of the glasses for correct operation. The use of a 4 token protocol would therefore seem to offer the most flexibility.

There is a lot of variation in the relative complexity of the various tokens – some use a simple single pulse for each token whereas others use a combination of pulses and some use more pulses than others. The glasses that use a more complex token are less likely to be mis-triggered by spurious IR signals and be able to easily reject other IR signals, however a more complex token also has more chance of being interfered because it has a longer period. Table 2 provides a summary of the number of pulses per token for each of the tested protocols and Table 3 provides a summary of the duration of each token in the eleven protocols.

Table 2: Summary of the number of pulses per token for each protocol (ranked in order of number of pulses per token)

Glasses	Pulses per Token
CrystalEyes 1	1, 1
DLP Link	1, 1
NVIDIA	2, 1, 2, 2
NuVision	3, 2
Xpand	3, 2
Samsung 2007	3

Glasses	Pulses per Token
Samsung 2010	3
Panasonic	4, 4, 4, 4
Sony	5, 5, 5, 5
ELSA/H3D	6, 6
Sharp	8, 8

Table 3: Summary of the duration of each token in the eleven protocols (ranked in order of increasing average duration)

Glasses	Token durations (µs)
DLP Link	24.75, 24.75
NuVision	28, 26
Samsung 2007	66.8
NVIDIA	141.25, 43.25, 68.1, 100.2
Crystaleyes 1	120, 60
Xpand	94, 96

Glasses	Token durations (µs)
Samsung 2010	114.4
ELSA/H3D	195.5, 195.5
Panasonic	220, 220, 220, 220
Sony	380, 300, 540, 460
Sharp	520, 440

Something that is not revealed by the timing diagrams of this paper is the tolerance for signal timing variation of the various glasses. Timing variation can be influenced by manufacturing variation and temperature variation and timing

tolerance should be included in the glasses to allow for this variation. A considerable amount of additional testing would be needed to establish timing tolerance of the glasses and then it would only be valid for a particular set of glasses. Obviously input from the manufacturers would be necessary to establish this tolerance correctly. One example of a large timing tolerance is that the NuVision 60GX glasses can successfully sync to the Xpand protocol, but the Xpand X103 glasses will not accept the NuVision protocol. Tight timing tolerance would mean that a particular pair of glasses would be less likely to be triggered or mis-triggered by the protocol meant for another pair of glasses.

Additionally, some of the glasses will only operate at a certain frame-per-second (fps) range – usually 100-120 fps. This aspect was not tested exhaustively with all the glasses, but it was found that the Panasonic glasses would not operate at some fps rates outside the usual 100-120fps range.

4.3 Cross-Compatibility

The large variation between different protocols described here reveals the main reason for incompatibility between different sets of IR shutter glasses and different 3D displays. There is no doubt the various manufacturers have intentionally used different protocols and this may be for several reasons: to avoid intellectual property problems, to try to ensure consumers only purchase a certain brand of shutter glasses, or to improve quality control.

The current incompatibility between different brands of shutter glasses and displays is a significant problem for consumers and reduces their motivation to purchase multiple pairs of shutter glasses (because they will only work with one brand of display). The improvement or implementation of cross-compatibility of different shutter glasses would be highly desirable for consumers.

Four options for implementing cross-compatibility between shutter glasses and displays are worth considering: (a) configuring displays to output multiple protocols (to drive multiple brands of shutter glasses), (b) a single standardized protocol to be used across multiple vendors, (c) a universal 3D emitter, and (d) the implementation of universal shutter glasses which can be driven by different protocols.

Regarding the output of multiple protocols, we conducted some experiments in this regard and found that some protocols will co-exist while others will not co-exist, meaning whether a single emitter can output two sets of protocols simultaneously and thereby drive two different brands of shutter glasses to view the same 3D display at the same time. The ability for two protocols to co-exist will be determined by the similarity of the two protocols, and the timing tolerance of the glasses. For example, our tests found that the Xpand and Samsung 2010 protocols would not co-exist which will probably be because both protocols use a three-pulse sequence with similar pulse widths – if the glasses are unable to distinguish between the two protocols, they may be confused by the mixture of protocols. This provides another reason to establish the protocol timing tolerance of different glasses, which will determine whether one glasses protocol might drive or mis-trigger another set of glasses, and in turn determine whether a TV can successfully output multiple protocols to drive multiple brands of glasses at the same time. On the other hand, our testing found that the ELSA/H3D and Xpand protocols will co-exist. We were able to successfully allow an audience wearing a combination of ELSA/H3D glasses and Xpand/NuVision glasses to view the same 3D projection display using an emitter which output both ELSA/H3D and Xpand protocols simultaneously. Our testing has also found that the Xpand and Panasonic protocols won't co-exist. The inability for several different protocols to co-exist severely limits the applicability of this option and therefore rules it out as a viable solution for cross-compatibility between shutter glasses.

Regarding a single standardized protocol, in early 2011 the CEA launched an initiative to define a common standardized protocol which would hopefully be adopted by all manufacturers⁸. Also in early 2011, Panasonic and partners announced “The Full HD 3D Glasses Initiative” to license a single common protocol across manufacturers⁹. The difficulty with defining a single standardized protocol is that it ignores all of the displays and glasses which have already been released into the market using other protocols, which hampers its success.

Another option to aid cross-compatibility would be to use a universal 3D emitter - an intermediate device which converts from one 3D sync protocol to another. Examples of such devices are the BitCauldron BC100 and BC010 combination which convert IR 3D sync to Zigbee 3D sync, and the Volfoni ActiveHubPro universal 3D emitter which converts DLP Link 3D sync and IR 3D sync to RF 3D sync.

Regarding the implementation of universal shutter glasses, this would seem the most viable option for implementing cross-compatibility because it has the potential to support a wide range of 3D displays already installed in consumers homes. This would be aided by the industry standardization on a small subset of protocols because it attempts to resolve future cross-compatibility between glasses and displays. One important factor with universal shutter glasses is that they

must correctly implement each of the protocols that they reportedly support. One example of incorrect support is that at least two models of universal shutter that we have tested have not correctly implemented the Sharp 3D sync IR protocol with what should be a 1ms delay between the token and the shutter switching.

In later announcements, the Full HD 3D Glasses Initiative indicated that other protocols have been included in the licensing program which also suggests the use of universal shutter glasses. It will be interesting to see whether the manufacturers support these standardization initiatives and answer consumers' calls for cross-compatibility between shutter glasses.

5. CONCLUSION

The analysis of the various 3D sync IR protocols has certainly been an interesting revelation into what is normally an invisible process. The results have revealed a considerable amount of variation between different 3D sync IR protocols and also some overlap. The paper has outlined options and limitations for cross-compatibility between different brands of 3D displays and 3D shutter glasses.

Please note that the protocol measurements outlined in the document have been provided for research and discussion purposes only. The protocol measurements may be subject to error and should not be used as an actual technical definition of each of the protocols.

6. ACKNOWLEDGEMENTS

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