Final Report

On the technical performance of TV receivers in Australia

Report prepared by Free TV Australia Ltd for the Australian Communications and Media Authority

December 2023

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1.1 Project overview

In April 2023, Free TV Australia contracted with the Australian Communications and Media Authority (ACMA) to conduct laboratory testing of the performance of a representative sample of Australian TV receivers in a range of alternative reception scenarios. The scenarios explored receiver RF performance, including in conjunction with single frequency networks (SFNs), and performance with digital multiplexes shared by two or more TV networks.

As far as practical, the aim was to emulate real broadcast operation. The use of 'realistic' transport stream content is critical when modelling how receivers would perform in conjunction with shared multiplexes, so care was taken that the relevant transport streams were representative of typical Australian broadcast programming and typical program content across multiplexes. In selecting programming, account was taken of the various types of content normally provided by broadcasters, such as sports, and the likely mix of content that would be found during prime time. Whether the transport stream content was realistic was not material to all the tests, e.g., receiver performance in conjunction with SFNs. In these cases, it was more efficient to use simplified transport streams.

In selecting a sample of TV receivers for evaluation, the intention was to provide a reasonable representation of TV receivers currently available on the Australian market and currently owned and used by households. Free TV and its sub-contractors sought to ensure this also included a representative sample of chipsets used in TV receivers. When they were available, older TV receivers still in use by Australian households were included in the sample.

The studies tested and compared both sequestered and holistic statistical multiplexing performance for various video coding scenarios. The studies were performed with both DVB-T and DVB-T2 transmissions.

Full details of the ACMA's receiver performance testing requirements are included at Attachment A.

The following reception issues were examined.

1.1.1 Receiver RF performance, including in conjunction with Single Frequency Networks (SFNs)

TV receiver RF performance was tested in conjunction with several single frequency network (SFN) reception environments. This included the use of DVB-T and possible 'wider area' SFN operations enabled by DVB-T2.

1.1.2 Receiver performance in conjunction with multiplexes shared by two or more TV networks

TV receiver performance was tested assuming that broadcasters might share multiplexes under the following scenarios:

a) 3 broadcasters share the entire capacity of one multiplex on equal basis (33.3%, 33.3%, 33.3%)

b) 2 broadcasters share one multiplex on a (66.6%, 33.3%) basis.

c) 2 broadcasters share the entire capacity of one multiplex on equal basis (50%, 50%)

d) 1 broadcaster using the entire capacity of one multiplex (current arrangement) – test control.

e) 5 broadcasters share the entire capacity of one multiplex on equal basis (20%, 20%, 20%, 20%, 20%)

f) 5 broadcasters each operate with 50% of the capacity available in 3 multiplexes, with the remaining 50% multiplex divided equally between the 5 broadcasters (10%, 10%, 10%, 10%, 10%).

g) 2 broadcasters operate with 60% of the capacity of 2 separate multiplexes. One broadcaster operates with 30% of the capacity in each of those 2 multiplexes. Another 2 broadcasters share a third multiplex 50%, 50%) with the remaining 10% each allocated to the first 2 multiplexes.

The studies tested and compared both sequestered and holistic statistical multiplexing performance for various video coding scenarios:

a) mix of MPEG-2 and MPEG-4 with Standard Definition (SD) and High Definition (HD) (similar to existing arrangements),

b) all MPEG-4 with SD and HD

c) all MPEG-4 with HD only.

d) mix of MPEG4 and HEVC with SD and HD (and HD+ or Ultra High Definition (UHD)) content. These scenarios used DVB-T2 only.

1.1.3 Shared multiplex acceptable picture quality

In generating transport streams for these tests, the intention was to maximise the number of programs that could be accommodated within a multiplex, at an acceptable picture quality, for each testing scenario. The notion of 'acceptable' picture quality introduced an unavoidable subjective element to the assessment. For the purpose of this work, acceptable picture quality was determined by reference to the quality of current broadcast TV services, using full-reference quality metrics. In other words, the picture quality typically found on similar grades of content on free-to-air TV in Australia today was used as the benchmark.

1.1.4 Key observations of the project

- The receiver testing shed new light on the 'fortuitous' capabilities of a large sample of Australian TV receivers.
- The RF (including SFN) testing results showed that all models tested from 2017 onwards supported both DVB-T2 and HEVC. Of the two sets tested that were older, the 2014 model supported DVB-T2 but not HEVC and the 2015 model supported neither standard.
- Testing with a selection of different formats at the shared multiplex stage provided a more varied and qualified representation of the capabilities of the HEVC-compatible TVs. 31 of the 33 sets (93.9%) decoded 1080i HEVC content; 30 of the 33 sets (90.9%) decoded 1080p HEVC content; 19 of the 33 (57.6%) supported HEVC in all picture formats tested (that is, 1080i, 1080p and UHD). 11 of 33 (33%) did not support AC4 audio. Downscaling was not a feature of any of the HEVC-capable receivers, that is, they were not able to display UHD content unless fitted with a UHD LCD panel which was present in 19

of the 33 (57.6%) sets tested. Table 9, at 3.2.1, lays out the full technical capabilities of all 33 models tested.

- The performance of receivers using the existing DVB-T mode showed that they were within the existing planning parameters and, in some cases, well within the existing planning parameters.
- The performance of receivers when demodulating DVB-T2 Mode B showed that they were within the reference levels.
- Should DVB-T2 Mode D be further considered for potential future implementation in Australia, further detailed testing is recommended to better quantify the co-channel performance of receivers operating in this mode for the reference levels used in this testing.
- Overall, performance of all TV receivers in the sample was the same whether operating with shared or with single broadcaster multiplexes.
- All shared multiplexes worked with all receivers tested with no adverse findings in relation to service discoverability, service identification, or EPG or LCN navigation between services within and between multiplexes.
- The testing shed new light on the issue of cross-carriage of Event Information Table (EIT) and Service Description Table (SDT) data by broadcasters using more than one multiplex to broadcast their service. In general, TV receivers worked well either with or without cross-carriage. The additional data requirements of cross-carriage also proved to be smaller than forecast.
- Receivers varied in their responses when multiplexes were turned off, e.g. some 'remembered' EIT information from multiplexes they had been exposed to previously even after a power cycle. This situation is very rare in real life and a full reset of affected receivers resolved the issue.
- The results of the PQ analysis supported the close correlation between the amount of bandwidth available and the average picture quality of services carried.
- The differences in picture quality were irrelevant to receiver performance.
- The testing showed that, as predicted, holistic statistical multiplexes generally provided improved picture quality on average compared to equivalent sequestered statistical multiplexes, but this was not the result everywhere and in all cases.

1.2 Consortium overview

To address the ACMA's requirements, Free TV secured the collaboration of several other parties and coordinated the overall delivery of the work. Other participants included TV playout provider NPC Media, transmission service providers BAI Communications and TX Australia, the Seven, Nine and Ten television networks, Regional Broadcasting Australia (RBA) Holdings, the ABC, Freeview, and experienced broadcast industry consultants. The number of sub-contractors reflected the diverse requirements of the work, as follows:

1.2.1 Creation and design of Multiple Program Transport Streams

NPC Media (NPC), a subsidiary of the Seven and Nine commercial television networks, delivers complex services for both broadcast and online TV, including media management, playout, and delivery to multiple platforms, in multiple formats. NPC Media possessed, or was able to secure, the equipment, knowledge and skills needed to design and create all transport streams necessary for the receiver testing. The involvement of the Seven, Nine and Ten networks, also ABC, ensured that NPC would have access to samples of a wide range of network TV programming as required to create the transport streams.

1.2.2 Transmission simulation

BAI Communications (BAI) operates 750 broadcasting sites in metropolitan, regional, and remote Australia for or on behalf of a number of commercial and national TV networks. TX Australia Pty Limited (TXA) is a joint venture company owned equally by the Seven and Nine television networks. Like BAI, TXA owns, operates, manages, engineers, maintains, and markets transmission and retransmission facilities in Australia, and provides television transmission for broadcasters. BAI and TXA possessed, or were able to secure, the equipment, knowledge and skills needed to simulate transmissions to fully test TV receivers in a lab environment.

1.2.3 Receiver testing facility design and set-up

Freeview provides free digital television services in Australia, bringing together content from the ABC, SBS, Seven, Nine, Ten and Southern Cross networks, which together control the organisation. Freeview's roles include the certification of Freeview-compliant set-top boxes and smart TVs. It operates a receiver testing centre in Sydney and holds a range of current and older receiver models. Its management team possessed some of the equipment and skills required to create and operate the test environment, and obtained assistance from BAI, TXA and other participants.

1.2.4 Receiver testing and reporting

BAI, TXA, NPC, Freeview and participating TV networks contributed appropriately skilled staff as required. Free TV was also assisted in its oversight role by a project board of key specialists drawn from participating organisations. BroadSpectrum Consultants Pty Ltd assisted with the picture quality analysis (PQA) and other aspects of the work.

2. Methodology

2.1 Introduction

The TV receiver tests were performed using Freeview's testing laboratory as well as its extensive collection of TV receivers. It was estimated that around four out of five TV receivers sold in Australia are Freeview-accredited makes and models. Most of the 33 TV sets chosen as part of the sample were drawn from devices submitted to Freeview for accreditation. A small number of additional sets were purchased.

The laboratory was configured in different ways for the SFN testing and the testing of shared multiplexes. For the SFN testing, four SFN transmitters and the associated combining and transport stream playout equipment were configured to simulate multiple different SFN reception environments. The tests were conducted by human observers watching the TV sets in the sample and recording the subjective failure point of the services. For the testing of shared multiplex scenarios, the same transport stream playout equipment was used with internal DVB-T and DVB-T2 RF modulators. For these tests, human observers checked the TV sets in the sample for service discoverability and navigation, also logical channel number behaviour and the operation of the electronic program guides.

For all tests, the ACMA requested that the content should be generated to maximise the number of services that can be accommodated, at an acceptable picture quality, within a multiplex for the particular testing scenario. Acceptable picture quality was determined by using full-reference picture quality metrics.

28 scenarios were chosen for testing in this project. The primary aim was to evaluate how current TV receivers would perform in a range of possible scenarios, including:

* use of more advanced technical standards than employed today;

* expanded use of single frequency networks (SFNs); and

* a range of different ways more than one TV network could share a single multiplex.

Three of the scenarios were aimed at testing SFN performance, while the remaining 25 tested multiplex sharing scenarios in various configurations.

2.2 Receiver sample – justification of sample selection

The first step in the Receiver Performance Testing project was identifying a representative sample of TV receivers in the Australian market. The functionality of Australian TV receivers results from individual manufacturer, retailer, and viewer decisions, providing TV broadcasters with only limited insight into the capabilities of the receivers they transmit to. Freeview runs Australia's only technical accreditation facility for television receivers. Though an estimated four in five TVs sold are makes and models that have been submitted for Freeview accreditation, Freeview's testing process is focused solely on Hybrid Broadcast Broadband TV (HbbTV) functionality and does not capture information about the other technical capabilities of accredited receivers. Non-mandatory standards developed by Standards Australia provide guidance to manufacturers and importers as to the technical capabilities and minimum performance requirements of TV sets offered for sale in Australia. Currently published receiver standard AS4933 does not include requirements for receivers to support DVB-T2, newer encoding technologies or shared multiplex operation. While this has not prevented the inclusion of these features or capabilities in television receivers sold in Australia, the absence of a published Australian standard for DVB-T2 capable TV receivers means manufacturers do not have a standard to measure their receivers' performance against. This limits their willingness to promote some capabilities, such as DVB-T2 demodulation and HEVC decoding, for fear of consumer litigation should a receiver not perform under a future Australian standard when eventually published. The competitive nature of the market also creates a reluctance from some manufacturers to disclose detailed information about their available models. These circumstances made it challenging to select a representative sample of receivers based on technical specifications, with much that was unknown about the actual technical capabilities of Australian TV receivers.

Free TV consulted with experts from Freeview and the Consumer Electronics Suppliers Association (CESA) when selecting a representative sample of television receivers for the project. CESA represents several major receiver manufacturers and retailers. To make the final selection as objective as possible, several datasets and data sources were considered:

- Manufacturer organisation national sales volume data, covering the last two years.
- Retailer organisation national sales volume data, covering the last two years.
- Freeview user--agent data.
- Advice, based on knowledge and experience of receiver industry experts.

Manufacturers advise approximately 2 million new receivers are currently sold into Australia each year. In 2022 there were at least 15 manufacturers supplying the Australian market, distributing over 500 models (and their variants).

Sales volume data was an important input to determining a representative sample. Both manufacturer and retailer sales volume datasets were carefully assessed. The top-selling 200 models from 2020-2022 were used as a first cut to objectively weight the ratio of makes and models most likely to be found in use across the Australian market. From this, a short-list of 60 receivers was made. 20 were selected from the top 50 selling models, 10 from the 51-100th selling models, 10 from the 101-150th selling models, 10 the 151-200th selling models, then a final 10 from a selection of smaller suppliers including special builds for specific retailers. The selection of 60 models was then filtered for any duplications, based on factors such as equivalent models of differing screen size and other technical similarities not affecting functionality. The outcome of this filtering process revealed a much smaller number of receivers could represent functionality and performance of those within the 200 top selling models for 2020-2022.

To achieve as much diversity as possible while minimising duplication, technical information about receiver internal hardware (chipsets), operating platforms and feature sets (price) was considered. Specific chipset deployment information is difficult to obtain, however Free TV understands there are a relatively small number of chipsets in use across all major receiver manufacturers. Industry advice is that greater than 85% of the 200 top selling receivers utilise chipsets from only 4 chipset manufacturers. Based on the very limited information available, Free TV tried to ensure as many variants as possible were represented in the final selection of receivers.

The contract required a reasonable representation of the TV receivers currently available on the Australian market, but also of TV receivers currently owned and used by households. The majority of households will be using televisions purchased before 2020 and these may have different technical characteristics from sets currently sold. Free TV and its sub-contractors lacked accurate data on the ages, makes and models of TVs in use in 2023. According to recently published survey data from the ACMA, TV ownership remains almost universal – as at June 2022, 62% of Australian adults had access only to a smart TV, a further 11% had both a smart and a 'standard' TV, and 24% had only a standard TV, totalling 97%[1] of all adults. 2021 census data indicates there are nearly 11 million private residences in Australia. Current sales volumes of 2 million units per year suggest a new television is acquired per household, on average, every five to six years. Many viewers retain TVs for much longer than this average, either as primary sets or as second, third or fourth TVs. As most TVs sold over the past six years have smart features, the ACMA's estimate of 24% of adults with only a 'standard' TV as late as June 2022 suggests a substantial proportion of viewers are using TV sets that are more than 6 years old.

Including older TV receivers in the sample posed a series of practical problems, including:

- lack of information about their share of the market at the time of sale;
- lack of information about their level of utilisation, including their share of the primary set population, today; and
- difficulties with obtaining access to sets for testing.

For receivers beyond a certain age, many of the tests conducted in the present study are of limited or no relevance. MPEG-4 functionality only began to appear in Australian TV receivers from 2008 and did not became universal for several years - Freeview estimates that all TV sets on the market supported MPEG-4 by 2012. Prior to the current study, study participants lacked any data on the percentage of sets purchased before 2017 that would potentially support DVB-T2/MPEG-4, or DVB-T2/HEVC. The DVB-T2 standard was first published in 2008, and HEVC was first published in 2013. It is reasonable to assume there was a lag before these features began fortuitously appearing in sets sold in Australia (for comparison, the MPEG-4 standard was first published in 1999, nine years before it began fortuitously appearing in Australian TVs). The mux-sharing tests undertaken in the present study are of no relevance to any surviving TVs that are DVB-T/MPEG-2 only, and of only limited relevance to any sets that do not support DVB-T2.

Having regard to the above sources of uncertainty, also the pointlessness of testing the very oldest receivers, Free TV initially proposed to include models going back to 2017 in its selection of receivers. As it could not access sales volume information older than 2020, to compile a sample of older receivers it interrogated Freeview 'user-- agent data', which reports the volume of various makes and models of receivers actively accessing the Freeview programme guide information. Receiver manufacturers advise that approximately

[1] 'How we watch and listen to content,' February 2023, Australian Communications and Media Authority, accessed on 8 June 2023 at https://www.acma.gov.au/sites/default/files/2023-03/HOWWEW~1.PDF

80% of televisions sold into Australia are Freeview accredited. With Freeview accredited TVs representing such a large proportion of the market, Free TV used the volume of various makes and models inferred from user--agent data as a proxy for sales volumes, to inform its selection of older models to be included in the sample.

Combining the final selection of 2020-2022 models and including models dating back to 2017 resulted in a list of thirty models that was included as part of Free TV's March 2023 Approach to Market (ATM) submission. Subsequently, some of the models proposed became difficult to obtain for testing purposes as they had sold out. These were replaced with equivalent models. Free TV was also able to take account of additional information from some manufacturers regarding chipsets, etc. It added [another] current model to the list. Finally, Free TV also considered the strong evidence that many viewers continue to rely on sets purchased long before 2017. While consortium members were confident that any pre-2008 TV would support only DVB-T and MPEG-2, making their inclusion in the sample pointless, Free TV had no information about when TVs sold in Australia began fortuitously including DVB-T2/MPEG-4 functionality or DVB-T2/HEVC functionality. After discussions with the ACMA about the evidentiary problems involved, a small number of older TVs dating back to around 2014 were added to the sample. Examples, from 2014 and 2015, were chosen of two popular TV brands that happened to be available.

Table 1 below is the list of 33 receivers tested, along with the additional hardware information obtained after the March lodgement of the ATM.

Table 1 Final of 33 TV receivers tested

FreeTV RX #	Freeview Label #	Brand	Year	Model	Chipset Manufacturer	Chipset Model	T2 Ready	Notes
1			2022				Y	
2			2021				Y	
3			2020				Y	
4			2019				Y	
5			2018				?	
6			2017				?	
7			2022				Y	
8			2021				Y	
9			2020				?	
10			2019				Y	
11			2018				Y	
12			2022				Y	
13			2021				Y	
14			2020				Y	
15			2017				Y	
16			2022				?	
17			2022				?	
18			2020				?	
19			2018				?	
20			2022				?	
21			2023				Y	
22			2021				Y	
23			2018				Y	
24			2018				?	
25			2020				Y	
26			2022				?	
27			2022				?	
28			2022				Y	
29			2022				Y	
30			2022				?	
31			2022				?	
32			2015				?	
33			2014				Y	

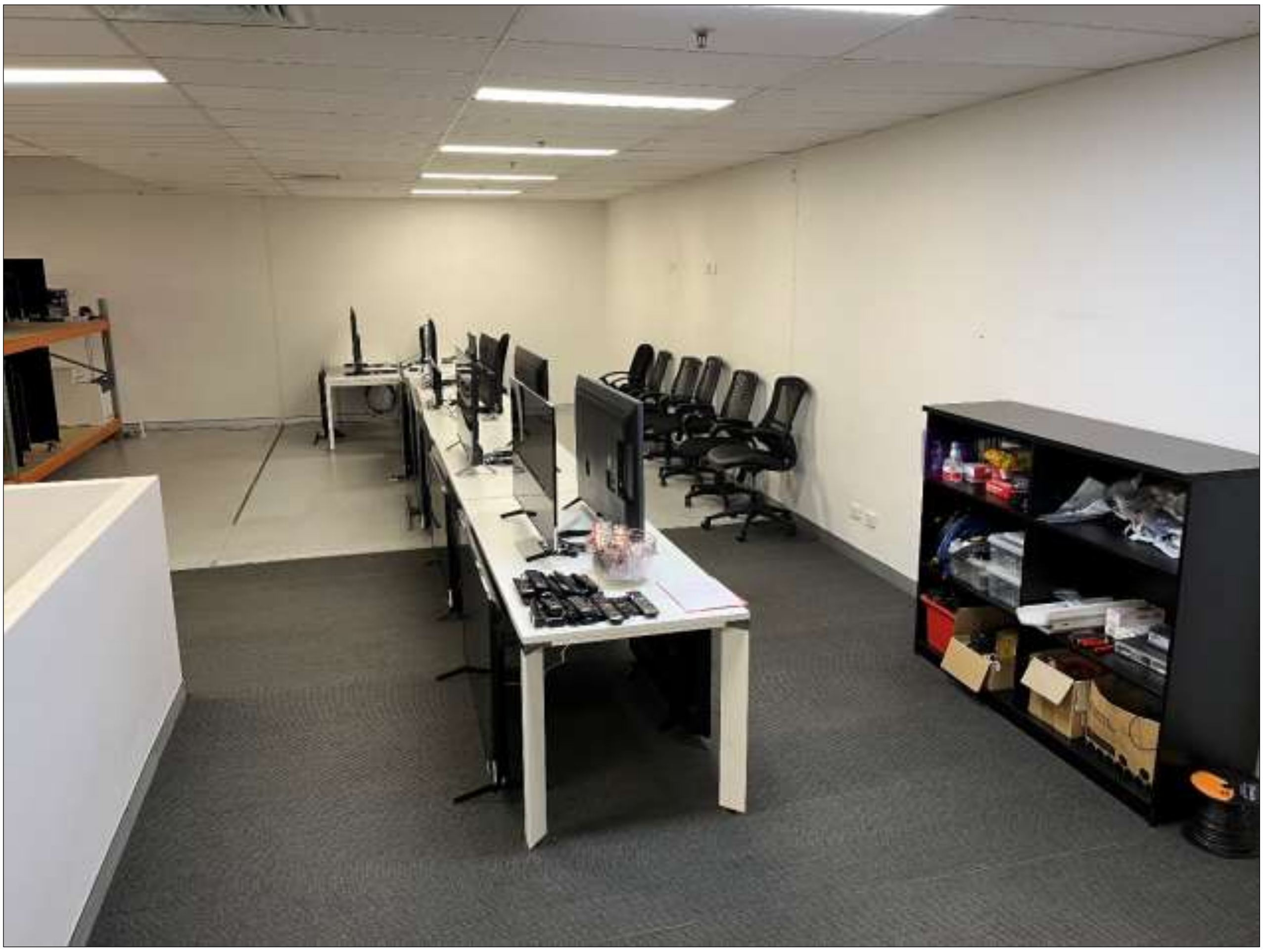
This selection of 33 receivers is believed to represent an informed balance of TV receivers available for sale and in current use, based on known sales volumes by make/model, internal hardware variations, software platforms, typical lifespan, and consideration of access to samples for testing. While the selected sample cannot claim to be truly representative of all televisions still in service, Free TV believes it to be as close as practically possible to a representative sample of primary receivers being used by the Australian television audience.

2.3 Freeview test centre

To emulate real-world broadcast transmissions in a laboratory setting, the project used Freeview's television receiver testing facility in Bourke Road, Alexandria. Before the project commenced, some minor capability enhancements were introduced to expand the facility's capabilities for the project. These included expansion and equalization of the RF distribution system, upgrading of the transport stream playout server RF modulator cards to facilitate DVB-T2 testing and the purchase of a small number of receivers required for the sample that were not already held in Freeview's catalogue of receivers.

The facility was configured to test up to 20 receivers simultaneously, with the combined RF signal equally distributed to all receivers at a standardized level of -60dBm across Australian VHF and UHF channel allocations.

Photograph 1 Freeview test facility



2.4 The 'acceptable picture quality' test

A key challenge when estimating the carrying capacity of a shared multiplex scenario is the flexibility digital TV transmission offers to vary the data rate required for each service. In the real world, the number of services able to be carried in any given scenario will vary depending on subjective and business decisions made by each broadcaster. In undertaking these studies, a methodology was adopted that would ensure objective rather than subjective measurement of picture quality and replicability of results.

For the purposes of the shared multiplex tests, as far as possible, the quality chosen by TV networks today when putting to air the same or similar content on equivalent services was used as the benchmark of acceptable picture quality. For services where this comparator was available, the version in the shared multiplex transport streams was compared with the average quality of this and similar content of TV networks going to air today[2]. For the live sport components, a somewhat different approach was needed, as real-time sampling from a TV broadcast was not practicable in the time and with the resources available. For these excerpts, a loop of HD sport was recorded and replayed as the program content on the primary HD service of all sharing scenarios.

Some of the shared multiplex scenarios were required to include HEVC content. As Australian free-to-air TV multiplexes do not carry services at 1080p High Definition or at Ultra High-Definition (UHD) – the video profiles that HEVC was designed to support - the picture quality broadcast by Australian TV networks was not available to use as a benchmark. While some Australian on-line streaming platforms offer Ultra-High-Definition content, delivery mechanisms are quite different, and Free TV and its sub-contractors did not have access to technical information sufficient to permit a direct comparison of their picture quality with free to air services. Section 2.3 of attachment D details the final approach taken to Ultra High-Definition picture quality assessment and benchmarking.

There are industry-accepted metrics for picture quality, supported by IT tools that permit a frame-by-frame rating of the picture quality of a service. This enabled objective scoring of the picture quality of all the services on the shared multiplexes that were tested. Objective scores of picture quality are based on both spatial and temporal comparisons between source and encoded, or compressed, material. Using the same tools to objectively assess the quality of existing broadcast services, an appropriate benchmark was produced for comparison of picture quality of similar content when compressed to fit into various shared multiplexes scenarios. This also helped validate a requirement of the project, which was that content should be generated to maximise the number of services that can be accommodated, at an acceptable picture quality, within a multiplex for the particular testing scenario.

The full-reference quality metrics measured, and how they were used, are discussed at 2.10.

[2] For example, to set the 'benchmark' for all services transmitted at HD quality, Free TV used an average of scores for all HD-quality streams currently provided by metropolitan commercial TV services - it was not practicable in the time available to include national TV services in setting the benchmark.

2.5 SFN transport streams - justification of content being representative

2.5.1 Type of content

Unlike the situation with the transport streams used to test shared multiplex scenarios, from an RF performance (including SFN) perspective the number and type of programs in the transport stream is irrelevant to how TV receivers perform. The transport stream needs to use a transmission standard and compression codec the receiver can support.

Receiver RF performance in conjunction with an SFN was tested by detecting the subjective failure point of the service. As detailed in the methodology section of Attachment B, this was determined using the relevant ITU recommendations for DVB-T and DVB-T2. The test of TV receiver RF performance in conjunction with SFNs is whether a given receiver can demodulate the RF signal to reconstitute an error-free transport stream. The subjective failure point is the point at which the pictures start to pixelate. Demodulation errors will manifest in any service in the transport stream, meaning if the receiver is unable to display one service, it will be unable to display all services. As the choice of services for the transport streams is otherwise not material, the content of an existing DVB-T commercial broadcaster transport stream was used as a starting-point, with the bitrate increased to match the expanded channel capacity in the case of the DVB-T2 configurations.

2.5.2 Receiver capabilities

The tests also provided an opportunity to test the capability of TV receivers to handle different video compression codecs. As the testing of receiver RF performance preceded the shared multiplex testing, the opportunity was taken to include a service encoded using HEVC in the DVB-T2 transport streams used to test receiver RF performance. One of the MPEG-4 services in the transport streams was encoded with the HEVC codec, using the same interlaced video content. This provided early confirmation of the actual capability of TV receivers in the sample to decode HEVC, speeding up the assessment of TV receiver performance with shared multiplexes.

In preparing the transport streams for DVB-T2 RF and SFN testing, the MPEG-2 services were also converted to MPEG-4. The reasoning for excluding MPEG-2 content from all DVB-T2 transport streams is canvassed in the justification for multiplex sharing transport streams, below. The presence or absence of MPEG-2 services has no effect on the SFN test results.

2.6 Shared multiplex transport streams - justification of content being representative

Shared multiplex transport streams needed to be as realistic as possible. Free TV took as its starting point the type and technical quality of TV services broadcast today, noting that different genres of program may pose different challenges for encoders and the quality of TV programs broadcast today will vary within the one multiplex. Developing ‘realistic’ shared multiplex transport streams also posed some issues and choices not faced by networks today. For example, broadcasters do not share multiplexes, or broadcast Ultra High-Definition services, or High-Definition services using 1080p scanning. How these issues were dealt with, so as to develop transport streams that were never-the-less as realistic as possible, is set out below. In effect, the project required Free TV to work with participating TV networks to consider how they would actually use a shared multiplex under the various scenarios, taking today’s program genres and broadcast picture quality as their starting-point.

2.6.1 Type of program content

As the type of content needed to be typical of free-to-air commercial or national television broadcasts, the transport streams primarily used actual network programming, supplied by participating TV networks.

Where a particular type of content imposes unique demands on transport stream design, this type of content needed to be included. This means the multiplexes needed to contain live sport content. Sport is dynamic in nature and often requires very high bitrates to encode highly detailed images effectively with large amounts of movement between successive frames without loss of fidelity so viewers can still follow the action. Scenarios where two or more networks simultaneously broadcast live sports pose a particular challenge for shared multiplex operation. In designing the transport streams, it was assumed all sharing networks had simultaneously scheduled live sporting events on one of their premium (HD) services.

Free TV canvassed with participating TV networks whether other variables were important, such as whether content should be prime time or of particular genres. Apart from sport, these variables were not considered to place unique demands on multiplex design. For this reason, excerpts were used from a selection of typical commercial television programs broadcast today at the relevant picture resolutions. Within the test transport streams created for the project, the premium HD service for each broadcaster carried a loop of pre-recorded sport content, while the other services within each multiplex utilized whatever content was running through the playout facility at that time at the appropriate video resolution. This is an important point to understand when objective picture quality assessments are discussed in section 2.4 of attachment D.

2.6.2 Technical parameters of the program content

In addition to program type, TV broadcasters typically transmit multiple services of varying video resolutions and compression settings. Programming in a typical transport stream might include:

- Both High Definition and Standard Definition content.
- Content that is offered as a premium, average, or low picture quality service. Premium services are typically High Definition and might be appropriate for programs shown on the network’s primary channel. Average picture quality might be appropriate to some, though not all, genres of programming on a multi-channel and be broadcast in SD or HD resolution. A datacasting channel might be transmitted in SD resolution with relatively high compression settings, resulting in a lower perceived picture quality.

Different broadcasters offer different permutations and combinations of these service picture qualities, and the commercial and national broadcasters also differ in their approaches. For example, national broadcasters offer radio as well as TV services in their multiplexes. Rather than selecting two, or three, real-life TV networks for the shared multiplex transport streams, for ease of comparison Free TV proposed sharing scenarios where all broadcasters would offer a standardised package of services representing an average of services broadcast today. Use of a standardised network offering provided a more equitable basis for modelling shared multiplex capacity and behaviour and simplified the testing process. Free TV consulted with all participating TV networks in modelling a typical transport stream that makes maximum use of the data capacity available. For the purposes of the shared multiplex tests, its starting point was that each network offering would nominally consist of six services using the following technical parameters:

- Two High-Definition services at premium technical quality [1920 x 1080i resolution], described from here throughout this report as High Definition or HD services; and
- Two Standard Definition services at mid-technical quality [720 x 576i resolution], described from here throughout this report as multi-channel or MC grade services; and
- Two standard definition services at low, or datacasting, technical quality [720 x 576i resolution but with a lower bitrate than the mid-quality services], described from here throughout this report as Datacast or DC grade services;
- (Where required) One Ultra High-Definition service at premium technical quality [3840 x 2160p resolution to be substituted as appropriate], described from here throughout this report as UHD grade services.

In choosing examples of each type of service, there is an issue that regional affiliates of the three commercial networks do not necessarily broadcast the same services, at the same picture quality, as the originating metropolitan commercial TV licensees. TV broadcasters that re-transmit the Viewer Access Satellite Television (VAST) service also offer a somewhat different range of commercial services than other terrestrial broadcasters. 7HD, 9HD and 10HD are current examples of premium technical quality, high-definition commercial TV services that are available in all markets. In major metropolitan markets, 7MATE, 9GEM and 10BOLD are all also broadcast in high definition, but this is not be the case in all markets. All HD content used in the tests was drawn from metro area services, and the average picture quality used for the 'acceptable picture quality' test was similarly based on the metropolitan versions of current TV services.

In selecting current examples of the other two technical quality grades, Free TV also chose to focus on metropolitan commercial TV markets. Examples of MC services include 7TWO, 9GO and 10PEACH. Seven's Racing.com, Nine's Extra and 10's TVSN are examples of DC grade services.

As far as possible, similar content was used for each of the transport streams. For practical reasons, some content – notably, the programming on some multi-channels – could only be sampled in real time. As the transport streams were built consecutively, similar content from the same service was used where it was not possible to use identical content. Overcoming this practical difficulty was not feasible in the time and for the budget allocated for this work. As the type of program content on the multi-channels tends to be fairly consistent and to have similar bitrate demands over time, Free TV does not believe it adversely affects the validity of the results.

Finally, in designing the no-sharing DVB-T2 transport stream, used as a control, the study participants faced the question of what broadcasters might do with considerably more data capacity than they have today (or would have under any of the sharing scenarios). If that scenario ever arose, it is unlikely that TV broadcasters would feel constrained to the 2 + 2 + 2 formula adopted for the present studies, with either or both better picture quality or more services the probable result. Introduction of UHD is a potential future competitive requirement for Australian free to air broadcasters, and inclusion of this content was a requirement of the shared multiplex tests being performed. Inclusion of a UHD grade service in the no-sharing DVB-T2 transport stream was not only a plausible use of the extra data capacity, but it also provided an opportunity to test whether UHD could be carried on a no-sharing multiplex, at an acceptable picture quality, without sacrificing the number and quality of other services offered.

The no-sharing DVB-T2 transport stream used identical content to DVB-T multiplexes currently broadcast, with MPEG-2 SD simulcasts removed and one additional UHD service added using HEVC encoding. Using the latest, most efficient HEVC and AC4 codecs, carrying UHD progressively scanned content at acceptable quality requires approximately three times the bitrate of equivalent HD interlace scanned content using MPEG-4 encoding. Statistical multiplex gain can be helpful, but an average of approximately 15Mbit/s was utilised in DVB-T2 trials carried out some years ago. This was found to be insufficient for some content, resulting in noticeable artifacts. Given ongoing improvements in codec efficiency, an initial question was whether these findings were still valid. Carriage of a UHD grade service at acceptable quality was found possible, although the content was interlaced scanned, so required different bandwidth to equivalent progressively scanned content. Detailed results of this test are available in Attachment D.

2.6.3 Treatment of simulcasting

Another question that arises, when basing 'realistic' shared multiplexes on current Australian TV network practice, is whether to reproduce the current universal practice of simulcasting one or more services using both MPEG-2 and MPEG-4 compression codecs.

All digital TV transmissions in Australia originally used MPEG-2. As the uptake of MPEG-4 ready TV receivers increased, individual TV networks began inserting MPEG-4 content and, more recently, progressively closing the MPEG-2 version of services. However, all networks continue to simulcast their primary channels in MPEG-2 and MPEG-4. In most cases, the HD version of the primary channel is encoded using MPEG-4, while the MPEG-2 version is broadcast at SD quality. TV broadcasters have no current plans to cease MPEG-2 simulcasting of primary channels. A minority of viewers continue to use MPEG-2 only TV receivers as primary TVs, or as second, third or fourth sets, or use personal video recorders (PVRs) that are MPEG-2 only.

While it is unknown whether or when MPEG-2 simulcasting of primary channels will end, there are sound reasons to exclude simulcasting from the transport streams for shared multiplex testing. In the case of DVB-T2 transport streams, all DVB-T2-ready receivers in the market will also be MPEG-4 ready. In the case of DVB-T transport streams, it is considered highly unlikely broadcasters would move to mux sharing without the added efficiency benefits of full conversion to MPEG-4, as any multiplex sharing scenario that involved one or more MPEG-2 services in DVB-T transport streams would require deep cuts to the present number and picture quality of TV services available on affected TV networks. While care has been taken not to anticipate future policy outcomes in the conduct of these tests, Free TV notes that the Government's 2020 *Media Reform Green Paper* proposed a move to multiplex sharing based on full conversion to MPEG-4.

For these reasons it was concluded that 'realistic' transport streams for any plausible shared multiplex scenario would not include MPEG-2 simulcasting.

2.6.4 Service Information

Service information refers to the instructions to the TV receiver about the various components within the transport stream. For example, it tells the receiver how to assemble and display the correct service when the viewer keys in the corresponding logical channel number or clicks on the link in the electronic program guide. The overall amount of service information required varies depending on the number of services carried, including discrete service components such as Audio Description.

Service information is an umbrella term. At a high level, two of its components are:

1. The logical channel numbers of services; and
2. The Event Information Tables (EIT). This includes 'now' and 'next' information and the 7-day Electronic Program Guide (EPG).

While there are many other components to service information, these two are critical to the shared multiplex component of the TV receiver performance tests, which examined the capacity of TV receivers to navigate successfully between TV channels based on logical channel numbers and the EPG.

The current service information requirements of TV networks cannot simply be taken and applied to a shared multiplex scenario. A TV multiplex in Australia today carries the service information for one TV network only, meaning all services from that TV network are immediately discoverable and fully described including relevant EIT information. When a broadcaster's services are split across more than one multiplex, the issue arises whether EIT information for the entire suite of the broadcaster's services needs to be reproduced on each multiplex used, and if so, what the impact would be in terms of additional data requirements.

To help answer this question, cross-carriage of EIT was included in some scenarios but excluded in others, and the effects on both TV receiver performance and data capacity requirements were observed. The testing showed that all TV receivers in the sample could successfully construct an EPG from the relevant data available regardless of whether or not EIT data was cross-carried. The only difference observed was that if EIT data is cross carried, the EPG will display program information for services carried in the other multiplex (or multiplexes), whether the other multiplex is present or not, or tuned to or not.

The testing also showed the impact of EIT cross-carriage on data requirements, while real, was smaller than predicted. Provided that minimum EIT data refresh rates, as specified by DVB, are respected, modern headend configuration settings allow the additional volume of EIT data to either utilise extra instantaneous bandwidth or be delivered more slowly using constrained bandwidth settings. For the purposes of the current tests, the 'constrained bandwidth' option was selected, and a target of 500 kb/s chosen for all EIT carriage. In real life the actual data rate chosen would be at the discretion of the broadcaster.

In summary, additional SI is a necessary component of mux sharing, however, cross-carriage of EIT may not be essential for the TV's operation. All sets tested were able to constitute a full EPG with or without cross-carriage. Without cross-carriage, however, viewing scenarios could arise where the set would be unable to populate the EPG for any of a 'split mux' broadcaster's services which were on a multiplex the set did not regularly tune to.

Finally, in the context of this project, the shared multiplex transport streams that were created did not utilize DVB Bouquet Association Tables (BAT). A part of the DVB suite of capabilities, a BAT instructs TV receivers to link all services provided by a single broadcaster irrespective of whether delivered by satellite, cable or terrestrially. A BAT can be useful when different services provided by a single broadcaster are delivered via two or more DVB multiplexes. As this capability was not required under the initial model adopted in Australia for TV digitization, the Australian TV receiver standard has never mandated support for BAT in Australian receivers. For this reason, Free TV assumed there was no point in including them in the current tests. Multiplexes were designed to model a hypothetical situation where broadcasters would each contribute a standardized suite of 6 services to a centralized aggregation provider. The aggregation provider would then combine discrete services in agreed configurations into shared Multi-Program Transport Streams (MPTS) complete with Service Information (SI) tables ready for transmission.

As no BAT was included in the test transport streams, the overall structure was not very different to transport streams generated for live on-air services by broadcasters today.

2.6.5 Choice of audio codecs and Audio Description

Just as with video compression codecs, audio compression codecs evolve over time and there is an issue that older TV sets may not support the newer (and more efficient) codecs. For this reason, TV broadcasters in Australia may transmit more than one audio service per video service.

The oldest or 'legacy' audio codec in use is MPEG-1 Audio Layer 2. As this is typically associated with MPEG-2 video compression, it was not included in any of the shared multiplexes.

The Dolby AC3 audio codec, commonly known as Dolby Digital, has always been part of the Australian TV industry's digital broadcasting platform. It was chosen for its ability to carry discrete surround sound. All television sets in the Australian market should be able to decode AC3.

The MPEG AAC family of audio codecs is typically associated with MPEG-4 video compression. Australian broadcasters are using AAC-LC (low complexity) or HE-AAC (high efficiency) for some services.

In the future, with more modern video codecs such as HEVC, Australian broadcasters are planning to introduce the Dolby AC-4 audio codec with their premium services.

For the test transport streams, AC3 was used as the audio codec for the premium quality HD grade services. For MC grade services and DC grade services, AAC-LC was used. For services that Include Audio Description, HE-AAC was also used as the audio codec. For UHD grade services, which use the HEVC codec, the AC-4 audio codec was used.

The current implementation of Audio Description (AD) in Australia varies between broadcasters, so whether or not to provide for AD required consideration in designing 'realistic' transport streams. The ABC and SBS currently provide AD. While commercial TV broadcasters do not, Government has commenced discussion about when and how a range of other Australian broadcasters, including commercial TV broadcasters, might begin providing AD. Without seeking to anticipate either future government policy or commercial industry practice, Free TV considered it prudent to assume all broadcasters would be required to carry some AD content. The ABC and SBS currently provide AD for four of their services each, so it was assumed other broadcasters would have a similar obligation. Further support for the working assumption of four services with AD is that:

- commercial broadcasters currently already provide another accessibility tool, closed captioning, for the first four of their services only; and
- the fifth and sixth services will be of DC grade only.

2.6.6 Summary of shared multiplex transport stream components

As described in 2.6.2, three service categories were created with the aim of each broadcaster being able to provide two services of each category. The categories are:

- HD – a high-definition service for the broadcaster's premium content services,
- MC – a multichannel service for broadcaster's additional services, and
- DC – a datacast service for broadcaster's lower grade services.

Tables 2 and 3 below provide the technical details of the Service Profiles and the Channel Names and content generally used on those services for the shared multiplex test transport streams. It would have been preferable to have the same content on each service for comparative measurement, but this was not possible due to limitations of the test system and equipment availability. Content for services 1000, 2000 and 3000 used a pre-recorded loop of sport content so these are the most appropriate services to examine for comparisons of PQ results.

Table 2 Service profiles (bitrates in Mbit/sec)

Profile Name	Video Resolution	Audio 1 Codec	Audio 2 Codec	Summary	Stat-Mux Priority %	Min Bitrate	Max Bitrate	Audio 1 Bitrate	Audio 2 Bitrate	Caption Bitrate
UHD	2160p50	AC-4	HE-AAC	HEVC/ UHD/AC4	80	6	22	0.160	0.064	0.075
HD	1080p50	AC-4	HE-AAC	HEVC/ HD/AC4	80	4	15	0.160	0.064	0.075
HD1	1080i50	AC-3	HE-AAC	MP4/HD/AC3	80	2.5	10	0.384	0.064	0.075
HD2	1080i50	AC-3	HE-AAC	MP4/HD/AC3	80	2.5	10	0.384	0.064	0.075
MC1	576i50	AAC-LC	HE-AAC	MP4/SD/AAC	75	1.5	8	0.128	0.064	0.075
MC2	576i50	AAC-LC	HE-AAC	MP4/SD/AAC	75	1.5	8	0.128	0.064	0.075
DC1	576i50	AAC-LC	-	MP4/SD/AAC	40	0.8	3	0.128	0	0.075
DC2	576i50	AAC-LC	-	MP4/SD/AAC	40	0.8	3	0.128	0	0.075

Table 3 Service ID's and typical content source

Profile Name	Service Name	Service ID	Broadcaster A	Service Name	Service ID	Broadcaster B	Service Name	Service ID	Broadcaster C
UHD	UA		UHD Reel	UB		UHD Reel Time offset1	UC		UHD Reel Time offset2
HD	A1		V8 Supercars or AFL	B1		NRL or Bathurst 6 hour cars	C1		Soccer
HD1	A1	1000	V8 Supercars, AFL or 7HD Sydney	B1	2000	NRL, Bathurst 6 hour cars or 9HD Sydney	C1	3000	Soccer or 10HD Cairns
HD2	A4	1003	7mateHD Sydney	B6	2005	9Gem HD Sydney	C4	3003	10 Bold
MC1	A3	1002	7two Sydney	B4	2003	9Go! Sydney	C3	3002	10 Peach
MC2	A5	1004	7flix Sydney	B7	2006	9Rush Sydney	C5	3004	10 Shake
DC1	A6	1005	7bravo Sydney	B5	2004	9Life Sydney	C6	3005	Sky News Regional
DC2	A7	1006	RACING.COM	B8	2007	Extra	C7	3006	SBN

Note: Yellow highlighting indicates services which did not have a reference recording made for the PQ analysis due to system limitations. Accordingly, these services have been noted in the transport stream analysis as being present, but do not appear in any of the PQ analysis results.

2.7 Multiplex design

2.7.1 Introduction

A major component of the Receiver Performance Testing project was to investigate the ability of TV receivers to operate with various shared multiplex configurations. Consultation between the ACMA and the consortium resulted in a selection of 25 shared multiplex configurations. These are some possible sharing scenarios if shared multiplexes were to be implemented by Australian broadcasters in the future. In addition to the three RF Modulation/Bitrate scenarios tested for SFN performance, these shared multiplexes were defined as scenarios 4 through to 28.

As described in section 2.6.2, multiplexes were designed based on a standardized contribution model where broadcasters would hypothetically contribute a standardized collection of 6 services each to a centralized aggregation provider. Using this model, new transport streams were built to test several possible sharing scenarios.

- Three broadcasters sharing a mux 1/3, 1/3, 1/3 (sharing scenario **S1**).
- Two broadcasters sharing a mux 2/3, 1/3 (sharing scenario **S2**); and
- Two broadcasters sharing a mux 1/2, 1/2 (sharing scenario **S3**).

S1	S2	S3
33.3%	*66.6%*	*50%*
33.3%		*50%*
33.3%	*33.3%*	

Eventual combinations of these scenarios to share five broadcasters across three shared multiplexes might be **S1** x2 + **S3** x1, or **S2** x2 + **S3** x1.

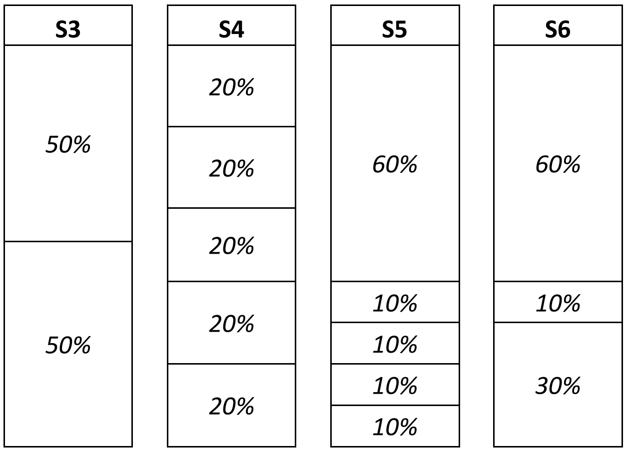
Mux #1	Mux #2	Mux #3
Broadcaster-1 33.3%	*Broadcaster-1 33.3%*	*Broadcaster-4 50%*
Broadcaster-2 33.3%	*Broadcaster-2 33.3%*	*Broadcaster-5 50%*
Broadcaster-3 33.3%	*Broadcaster-3 33.3%*	

OR

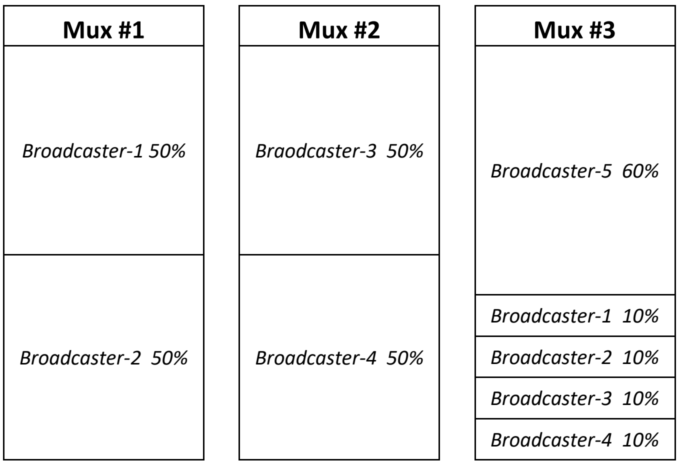
Mux #1	Mux #2	Mux #3
Broadcaster-1 66.6%	*Broadcaster-2 33.3%*	*Broadcaster-4 50%*
Broadcaster-2 33.3%	*Broadcaster-3 66.6%*	*Broadcaster-5 50%*

Part way through testing, the ACMA requested an extension to the scope of the project to include additional scenarios. These additional scenarios were:

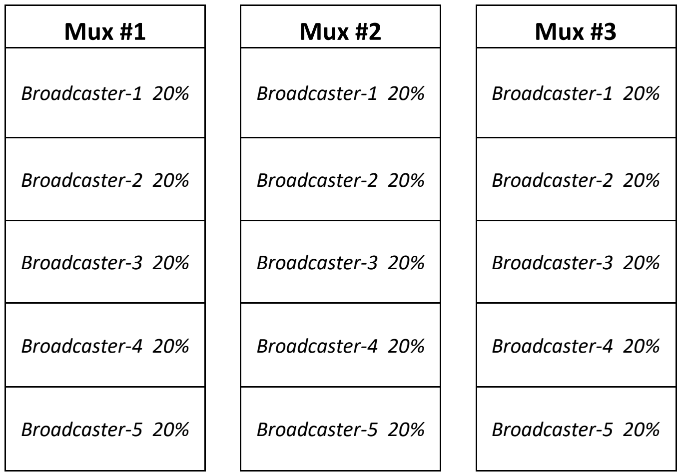
- Five broadcasters sharing a single multiplex - 20%, 20%, 20%, 20%, 20% - sharing scenario **S4**.
- Two multiplexes carrying four broadcasters split evenly 50% each, (already tested as scenario **S3**). Then 60% of a third mux carrying the fifth broadcaster along with the remaining 10% of the other four broadcasters - 60%, 10%, 10%, 10%, 10% - sharing scenario **S5**.
- One multiplex carrying two broadcasters split evenly 50% each, (already tested as scenario **S3**). Then two multiplexes, each carrying one broadcaster using 60%, one broadcaster using 30% and one broadcaster using 10% - sharing scenario **S6**.



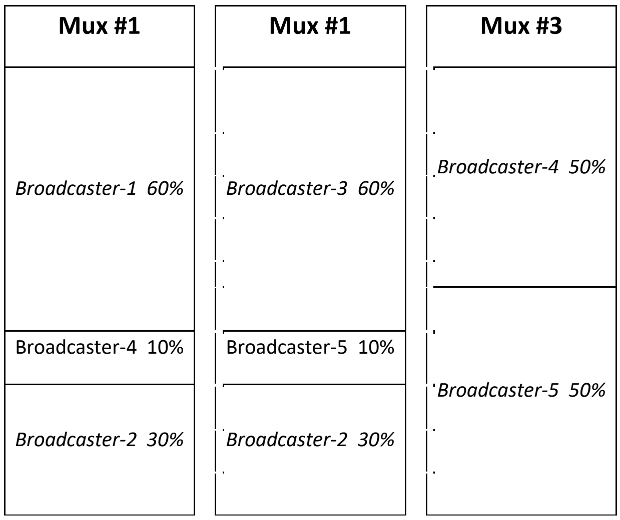
Eventual combinations of these scenarios to carry five broadcasters with equal shares of the capacity of three shared multiplexes might be **S3** x2 + **S5** x1, or **S4** x3



OR



OR



To fully test receiver navigation where broadcasters' services were split across more than one multiplex, several tests required a pair of transport streams. Services belonging to two or three broadcasters were divided into pairs of transport streams as efficiently as possible based on the codec, video resolution and allocated bitrate combinations, respecting the broad sharing scenario designs (50/50% or 60/30/10% for example). For additional comparison, and to test the assertions made in section 2.6.4 about cross-carriage of EIT and SDT information, some pairs of transport streams were deliberately built containing EIT 'other' and SDT 'other', while other pairs of transport streams did not cross-carry this information. Not all conceivable combinations of paired transport streams were tested. However, we believe the combinations tested were sufficient to validate receiver behavior where a broadcaster's services were split across more than one multiplex.

2.7.2 Final transport streams

Transport Stream files created for the project are to be provided to the ACMA on a portable Hard Disk Drive (HDD) at the completion of the project.

The tested sharing scenario configurations along with resulting statistical multiplex gain, presence of EIT and SDT 'other' and file names of the transport stream files used during the project are detailed in table 4 below:

Table 4 Final test transport stream configurations

No	Sharing Scenario		RF Modulation / Bitrate	Codec/s Scenario	Video Resolution/s	Stat-mux design	Stream ID for Receiver Testing	Stream Description	EIT & SDT 'other' Present	Transport Stream Filename for PQ Analysis
1	SFN testing	No sharing	DVB-T @23Mbit/s	MPEG2/ MPEG4	HD/SD	Holistic	01SFT1MMH-1 (not used for RX testing)	Current on air example as benchmark. 7 services for Broadcaster A (3xHD, 3xMC, 1xDC). All 7 services in one stat-mux	No	SevenSyd_Onair_TS1_20230628_200000
							(not used for RX testing)			SevenSyd_Onair_TS1_20230616_153000 ACMA_TS1_20230516_080000
							01SFT1MMH-2	Current on air example as benchmark. 8 services for Broadcaster B (2XHD, 5xMC, 1xDC). All 8 services in one stat-mux	No	NineSyd_Onair_TS2_20230628_200000
							(not used for RX testing)			NineSyd_Onair_TS2_20230616_153000 ACMA_TS2_20230516_080000
							01SFT1MMH-3 (not used for RX testing)	Current on air example as benchmark. 7 services for Broadcaster C (2xHD, 4xMC, 1xDC). All 7 services in one stat-mux	No	TEN_20230627_1900
2			DVB-T2 @32Mbit/s Mode (B)	MPEG4/ HEVC	HD/SD	Holistic	02SFB2MHH-1	7 services for Broadcaster A (3xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	No	ACMA_TS1_20230517_152000
							02SFB2MHH-2	8 services for Broadcaster B (2xHD, 5xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 8 services in one stat-mux	No	ACMA_TS2_20230517_152000
							02SFB2MHH-3 (not used for RX testing)	7 services for Broadcaster C (2xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	No	ACMA_TS3_20230517_152000

3			DVB-T2 @36Mbit/s Mode (D)	MPEG4/ HEVC	HD/SD	Holistic	03SFD2MHH-1	7 services for Broadcaster A (3xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	No	ACMA_TS1_20230517_150000
							03SFD2MHH-2	8 services for Broadcaster B (2xHD, 5xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 8 services in one stat-mux	No	ACMA_TS2_20230517_150000
							03SFD2MHH-3 (not used for RX testing)	7 services for Broadcaster C (2xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	No	ACMA_TS3_20230517_150000
4	Sharing scenario (S0)	No sharing	DVB-T @23Mbit/s	MPEG2/ MPEG4	HD/SD	Holistic	04S0T1MMH-1	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	No	ACMA_TS1_20230517_163000
							04S0T1MMH-2 (not used for RX testing)	6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	No	ACMA_TS2_20230517_163000
							04S0T1MMH-3 (not used for RX testing)	6 services for Broadcaster C (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	No	ACMA_TS3_20230517_163000
5			DVB-T2 @36Mbit/s	MPEG4/ HEVC	UHD/HD/SD	Holistic	05S0D2MHH-1 (not used for RX testing)	7 Services for Broadcaster B (1xUHD, 2xHD, 2xMC, 2xDC). 1xUHD and 1xHD service use HEVC, all other services MPEG-4. All 7 services in one stat-mux	No	ACMA_TS2_20230522_134000
							05S0D2MHH-2	7 Services for Broadcaster B (1xUHD, 2xHD, 2xMC, 2xDC). 1xUHD and 1xHD service use HEVC, all other services MPEG-4. All 7 services in one stat-mux	No	ACMA_TS2_20230530_164000
6 - 1	Sharing scenario (S1)	Three broadcasters sharing each	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	06S1T1MMS-1	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~ 7Mbps for each Broadcaster.	No	ACMA_TS1_20230613_110000

6 - 2		mux 1/3, 1/3, 1/3					06S1T1MMS-2	3 services for Broadcaster A (1x HD, 1x MC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~7Mbps for each Broadcaster.	No	ACMA_TS3_20230613_110000
7 - 1			DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	07S1T1E1H-1	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	No	ACMA_TS1_20230613_113000
7 - 2							07S1T1E1H-2 (not used for RX testing)	3 services for Broadcaster A (1x HD, 1x MC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	No	ACMA_TS3_20230613_113000
8 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	08S1D2E1S-1	3 services for Broadcaster A (1x HD, 2x MC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~11.5Mbps for each Broadcaster.	No	ACMA_TS1_20230613_115000
8 - 2							08S1D2E1S-2	3 services for Broadcaster A (1xHD, 1xMC, 1xDC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~11.5Mbps for each Broadcaster.	No	ACMA_TS3_20230613_115000
9 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	09S1D2E1H-1	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	No	ACMA_TS1_20230613_121000
9 - 2							09S1D2E1H-2	3 services for Broadcaster A (1xHD, 1xMC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	No	ACMA_TS3_20230613_121000
10 - 1			DVB-T2 @36Mbit/s	MPEG4	HD only	Holistic	10S1D2E2H-1	2 services for Broadcaster A (2xHD). Same 2 for Broadcaster B and Broadcaster C. All 6 services in one stat-mux	No	ACMA_TS1_20230609_155000
10 - 2				SD	SD only	Holistic	10S1D2E2H-2	Remaining 12 SD services in second mux	No	NA
11			DVB-T2 @36Mbit/s	HEVC/ MPEG4	UHD/HD	Holistic	11S1D2E3H	1 service for Broadcaster A (1xUHD). Same for Broadcaster B and Broadcaster C. All 3 services in one stat-mux	No	ACMA_TS1_20230621_160000
12 - 1	Sharing scenario (S2)	Two broadcasters sharing 2/3, 1/3	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	12S2T1E1S-1	6 services for Broadcaster A (2xHD, 4xMC) stat-muxed @ ~14Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1xDC) stat-muxed @ ~7Mbps	Yes	ACMA_TS1_20230609_145000
12 - 2						Sequestered	12S2T1E1S-2	6 services for Broadcaster C (2xHD, 2xMC, 2xDC) stat-muxed @ ~14Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1xDC) stat-muxed @ ~7Mbps	Yes	ACMA_TS3_20230609_145000

13 - 1			DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	13S2T1E1H-1	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux	Yes	ACMA_TS1_20230609_151000
13 - 2						Holistic	13S2T1E1H-2	6 services for Broadcaster C (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux.	Yes	ACMA_TS3_20230609_151000
14 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	14S2D2E1S-1	6 services for Broadcaster A (2xHD, 2xMC, 2x DC) stat-muxed @ ~24Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1x DC) stat-muxed @ ~12Mbps	No	ACMA_TS1_20230609_153000
14 - 2						Sequestered	14S2D2E1S-2	6 services for Broadcaster C (2xHD, 2xSD, 2xDC) stat-muxed@ ~24Mbps. 3 services for Broadcaster B (1xHD, 1xSD, 1xDC) stat-muxed @ ~12Mbps	No	ACMA_TS3_20230609_153000
15 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	15S2D2E1H-1	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux	Yes	ACMA_TS1_20230609_142000
15 - 2						Holistic	15S2D2E1H-2	6 services for Broadcaster C (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux.	Yes	ACMA_TS3_20230609_142000
16 - 1			DVB-T2 @36Mbit/s	MPEG4	HD only	Holistic	16S2D2E2H-1	6 services for Broadcaster A (6xHD). 3 services for Broadcaster B (3xHD). All 9 services in one stat-mux	Yes	ACMA_TS1_20230616_113000
16 - 2					SD only	Holistic	16S2D2E2H-2	6 services for Broadcaster C (6xMC). 3 services for Broadcaster B (3xMC). All 9 services in one stat-mux	Yes	ACMA_TS3_20230616_113000
17 - 1			DVB-T2 @36Mbit/s	HEVC/ MPEG4	UHD/HD	Holistic	17S2D2E3H-1	3 services for Broadcaster A (1xUHD, 2xHD). 1 service for Broadcaster B (1xUHD). All 4 services in one stat-mux	Yes	ACMA_TS1_20230718_173000
17 - 2						Holistic	17S2D2E3H-2	3 services for Broadcaster C (1xUHD, 2xHD). 2 services for Broadcaster B (2xHD). All 5 services in one stat-mux	Yes	ACMA_TS3_20230718_173000
18	Sharing scenario (S3)	Two broadcasters sharing 1/2, 1/2	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	18S3T1E1H	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 12 services in one stat-mux	No	ACMA_TS1_20230808_172000

19			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	19S3D2E1S	6 services for Broadcaster A (2xHD, 2xMC, 2xDC) stat-muxed @ ~18Mbps. 6 services for Broadcaster B (2xHD, 2xMC, 2xDC) stat-muxed @ ~18Mbps	No	ACMA_TS1_20230809_100000
20						Holistic	20S3D2E1H	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 12 services in one stat-mux	No	ACMA_TS1_20230809_093000
21			DVB-T2 @36Mbit/s	MPEG4	HD only	Holistic	21S3D2E2H	6 services for Broadcaster A (6xHD). 6 services for Broadcaster B (6xHD). All 12 services in one stat-mux	No	ACMA_TS1_20230809_103000
22			DVB-T2 @36Mbit/s	HEVC/ MPEG4	UHD/HD	Holistic	22S3D2E3H	2 services for Broadcaster A (1xUHD, 1xHD). 2 services for Broadcaster B (1xUHD, 1xHD). All 4 services in one stat-mux	No	ACMA_TS1_20230613_161000
23 - 1	Sharing scenario (S4)	Two muxes 50/50, 1 mux 50/10/10/10/ 10/10	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	23S4T1E1S-1	5 services for Broadcaster A (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps. 5 services for Broadcaster B (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps.	No	ACMA_TS1_20230718_153000
23 - 2							23S4T1E1S-2	5 services for Broadcaster C (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps. 5xDC services (one each for Broadcaster A, B, C, D & E) stat-muxed @ ~11.5Mbps	No	ACMA_TS3_20230718_153000
24 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	24S4D2E1S-1	5 services for Broadcaster A (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps. 5 services for Broadcaster B (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps.	No	ACMA_TS1_20230718_155000
24 - 2							24S4D2E1S-2	5 services for Broadcaster C (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps. 5xDC services (one each for Broadcaster A, B, C, D & E) stat-muxed @ ~18Mbps	No	ACMA_TS3_20230718_155000
25 - 1	Sharing scenario (S5)	Five broadcasters share each mux 1/5, 1/5, 1/5, 1/5, 1/5	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	25S5T1E1H-1	5xHD services (one for each Broadcaster A, B, C, D & E). 5x DC services (one for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	No	ACMA_TS1_20230614_145000
25 - 2							25S5T1E1H-2	10xMC services (two for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	No	ACMA_TS3_20230614_145000
26 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	26S5D2E1H-1	5xHD services (one for each Broadcaster A, B, C, D & E). 5x DC services (one for each	No	ACMA_TS1_20230614_150000

								Broadcaster A, B, C, D & E). All 10 services in one stat-mux		
26 - 2							26S5D2E1H-2	10xMC services (two for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	No	ACMA_TS3_20230614_150000
27 - 1	Sharing scenario (S6)	Two broadcasters share 50/50 of one mux + 10% in a 60/30/10 mux	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	27S6T1E1H-1	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster D (1xDC). All 10 services in one stat-mux.	No	ACMA_TS1_20230615_123000
27 - 2							27S6T1E1H-2	6 services for Broadcaster C (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster E (1xDC). All 10 services in one stat-mux	No	
							27S6T1E1H-2 (not used for RX testing)	5 services for Broadcaster D (2xHD, 2xMC, 1xDC). 5 services for Broadcaster E (2xHD, 2xMC, 1xDC). All 10 services in one stat-mux	No	ACMA_TS3_20230824_123000
28 - 1			DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	28S6D2E1H-1	6 services for Broadcaster A (2xHD, 2x MC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster D (1xDC). All 10 services in one stat-mux.	No	ACMA_TS1_20230615_122000
28 - 2							28S6D2E1H-2	6 services for Broadcaster C (2xHD, 2x MC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster E (1xDC). All 10 services in one stat-mux	No	
							28S6D2E1H-2 (not used for RX testing)	5 services for Broadcaster D (2xHD, 2xMC, 1xDC). 5 services for Broadcaster E (2xHD, 2xMC, 1xDC). All 10 services in one stat-mux	No	ACMA_TS3_20230824_122000

Stream ID Code key: (NN)(SS)(TT)(EE)(X)

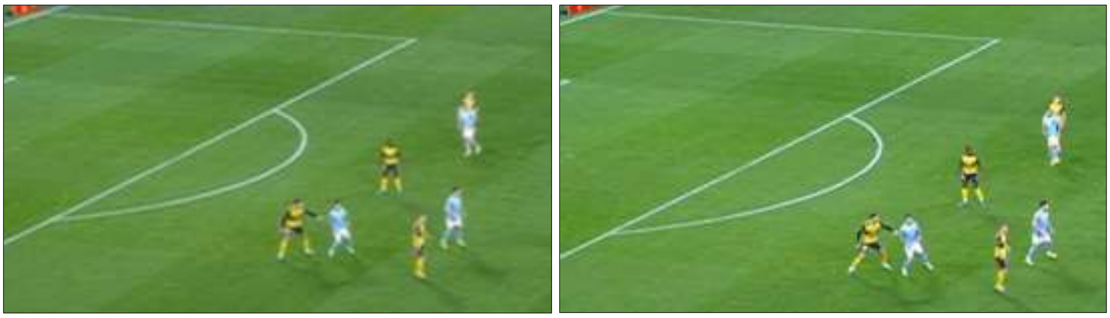
(NN) Stream number	**(SS)** Sharing Scenario			**(TT)** Modulation			**(EE)** Encoding			**(X)** Statmux		
		SF	*SFN Testing*		T1	*DVB-T*		E1	*MPEG4, HD & SD*		S	*Sequestered*
		S0	*No sharing*		B2	*DVB-T2 Mode B*		E2	*MPEG4, HD only*		H	*Holistic*
		S1	*3x equal sharers*		D2	*DVB-T2 Mode D*		E3	*HEVC & MPEG4, UHD & HD*			
		S2	*2x broadcasters 2/3, 1/3*					MM	*MPEG2/MPEG4*			
		S3	*2x broadcasters 1/2, 1/2*					MH	*MPEG4/HEVC*			
		S4	*5x broadcasters 1/2, 5x 10%*									
		S5	*5x equal sharers*									
		S6	*5x broadcasters 50,60/30/10*									

2.7.3 Shared multiplex transport stream modifications during receiver testing

Tight project time constraints often resulted in test transport streams being delivered for receiver testing just in time. Best practice for broadcast transport stream configuration typically involves a number of development iterations and subtle refinement, often taking many weeks. Without time for these minor iterative adjustments, initial configurations were based on experience and inevitably resulted in settings for some services being less than optimized. Picture quality issues were observed during receiver testing using some early transport streams, with picture quality as viewed on several receivers noticeably much poorer than expected. Investigation showed the basic structure and components of each service within the transport stream were correct and as expected, however, settings affecting the statistical multiplex performance required adjustment. Changes were made to the priority settings related to different grade services within some of the statistical multiplex pools and the transport streams re-made. The re-made transport streams contained more appropriate average bitrate allocations for each of the HD, MC and DC grade services, resulting in noticeably improved picture quality. This iterative approach is quite normal to optimize statistically multiplexed transport streams. Since the transport streams were to be objectively assessed for picture quality, optimizing bitrate allocations wherever possible was a requirement of the project. Wherever possible, the re-made transport streams were also used for the receiver testing. However, time constraints meant that some receiver tests used transport streams with the less-than-optimal settings.

An example of the difference between a first-run transport stream and a re-made, better optimized version, is shown in the pictures below taken from the top left corner of the same clip. The first image comes from a first-run multiplex. The second image is from the same multiplex after optimizing settings.

Figure 1 Multiplex setting optimisation



As only the bit-rate constraints and priority of video services within the statistical multiplex pool were modified, Free TV were confident that the receiver performance related to SI being tested would be unaffected.

As evidence this was a reasonable assumption, scenario 15 was tested on the receiver sample twice, using both optimized and pre-optimized transport streams. As expected, use of the re-made transport streams had no effect on receiver performance. Objective picture quality assessments were also carried out on both versions of scenario 15, to quantify the subjective difference to observable picture quality after optimizations were made. The results are discussed in section 3.3.

2.8 Methodology for receiver RF performance (including Single Frequency Network) testing

2.8.1 Introduction

A range of radiofrequency (RF) tests were carried out on the TV receiver selection using the DVB-T mode in most common use by Australian broadcasters, and two modes of DVB-T2.

Testing was carried out at Freeview premises in Sydney using the methodology previously agreed between the consortium and the ACMA.

Across the three DVB-T/T2 modes, tests included demodulation and decoding capabilities, RF threshold measurements, co- and adjacent channel performance, and a range of Single Frequency Network (SFN) performance criteria. SFN tests were carried out with up to four contributing signals at various relative signal level and timing configurations.

2.8.2 TV receiver performance testing methodology summary

Testing of all receivers was conducted using one DVB-T mode and two DVB-T2 modes as set out in Table 5 below.

Table 5 Modulation modes used during SFN testing

Mode	FFT (e)=extended mode	Guard Interval (uS)	Pilot Pattern	Modulation	FEC	Payload (Mbit/s)	C/N Ricean Channel (dB)
DVB-T	8K	1/16 (64)		64 QAM	3/4	23.052768	20
DVB-T2 (mode B)	32K(e)	1/16 (256)	PP4	256 QAM	2/3	32.090273	20
DVB-T2 (mode D)	32K(e)	19/256 (304)	PP4	256 QAM	3/4	35.706789	23

SFN-capable broadcast transmitters were configured to simulate a multi-transmitter SFN. As required, a suitable test transport stream was played out of Freeview's StreamXpress server and fed into all contributing transmitters for each test. Synchronisation timing signals were provided to the transmitters from an on-site GNSS derived source.

For DVB-T, the test transmitters were configured to reflect the mode in Table 5, matching current Australian broadcaster operational parameters. For DVB-T2, the test transmitters were configured to reflect modes B and D in Table 5, and aligned with Table 8.1 from the latest working party draft of AS4599 as circulated to the working group on 9 May 2023.

Performance was recorded using a combination of professional receiver measurements and SFP methods detailed in Recommendation ITU-R BT.1368-13 (DVB-T) and Recommendation ITU-R BT.2033-2 (DVB-T2) respectively and compared in Table 5.1 from Report ITU-R BT.2389-0.

Table 6 Receiver SFN performance tests

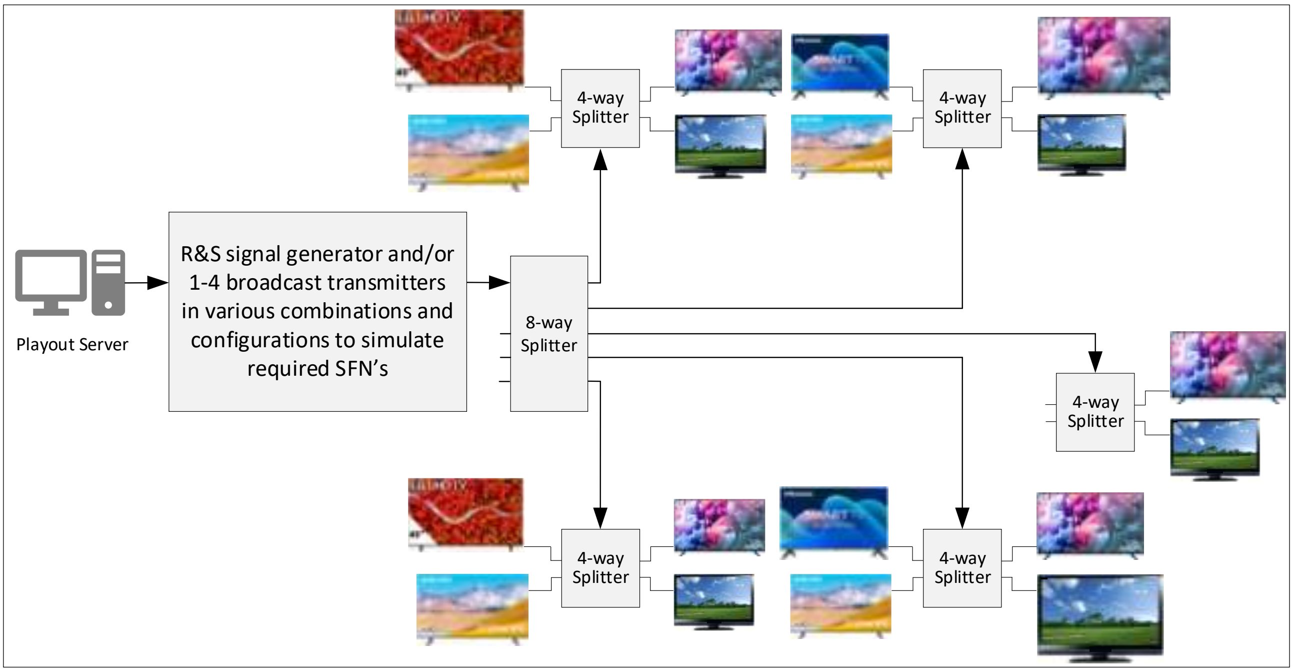
Transmission Modes	Test		Relative Amplitudes	Relative Timing Delays
DVB-T	Threshold test (E_{min})			
	Co-channel Protection Ratio		Unwanted=Wanted -30dB, increased until SFP	
	SFN equal level echo test	2 Tx test	0dB (Equal levels)	Tx 2 varying +/- 1.2x GI
	SFN echo timing v's echo level tolerance test	4 Tx test	Tx 1=-6dB; Tx 2=0dB; Tx 3=-10dB; Tx 4=-30dB, increased in 1dB steps until SFP	Tx 1=0uS; Tx 2=0.25x GI; Tx 3=0.7x GI; Tx 4=-1.2x GI, varied in 0.05x GI steps to +1.2x GI for each Tx 4 power increase step
DVB-T2 mode B, and DVB-T2 mode D	Threshold test (E_{min})			
	Lower adjacent channel Protection Ratio		Unwanted=Wanted 0dB, increased until SFP	
	Co-channel Protection Ratio		Unwanted=Wanted -30dB, increased until SFP	
	Upper adjacent channel Protection Ratio		Unwanted=Wanted 0dB, increased until SFP	
	SFN equal level echo test	2 Tx test	0dB (Equal levels)	Tx 2 varying +/- 1.2x GI
	SFN echo timing test 1	3 Tx test #1	Tx 1=0dB; Tx 2=-1dB; Tx 3=-1dB	Tx 1=0µs; Tx 2=0.5x GI; Tx 3 varying +/- 1.2x GI
	SFN echo timing test 2	3 Tx test #2	Tx 1=0dB; Tx 2=-1dB; Tx 3=-1dB	Tx 1=0µs; Tx 2=0.9x GI; Tx 3 varying +/- 1.2x GI
	SFN echo timing test 3	3 Tx test #3	Tx 1=0dB; Tx 2=-6dB; Tx 3=-6dB	Tx 1=0µs; Tx 2=0.5x GI; Tx 3 varying +/- 1.2x GI
	SFN echo timing test 4	3 Tx test #4	Tx 1=0dB; Tx 2=-6 dB; Tx 3=-6dB	Tx 1=0µs; Tx 2=0.9x GI; Tx 3 varying +/- 1.2x GI
	SFN echo timing v's echo level tolerance	2 Tx test	Tx 1=0dB; Tx 2=-30dB, increased in 1dB steps until SFP	Tx 1=0uS; Tx 2=-1.2x GI, varied in 0.05x GI steps to +1.2x GI for each Tx 2 power increase step
	SFN echo timing v's echo level tolerance test	4 Tx test	Tx 1=-6dB; Tx 2=0dB; Tx 3=-10dB; Tx 4=-30dB, increased in 1dB steps until SFP	Tx 1=0uS; Tx 2=0.25x GI; Tx 3=0.7x GI; Tx 4=-1.2x GI, varied in 0.05x GI steps to +1.2x GI for each Tx 4 power increase step
	SFN receiver re-synchronisation test 1	2 Tx test	Tx 1=0dB; Tx 2=-6dB	Tx 1=0uS; Tx 2=0.5x GI, moved to 0.25x GI during Rx standby mode
	SFN receiver re-synchronisation test 2	2 Tx test	Tx 1=0dB; Tx 2=-6dB	Tx 1=0uS; Tx 2=0.5x GI. RF input disconnect/reconnect

Testing typically involved two or three RF transmission system experts from BAI operating the broadcast equipment, four staff from a labour hire company observing the selection of TV receivers, and a staff member from Freeview assisting with general facility operation and receiver operational issues.

Over a period of 6 working days, all tests were performed on all 33 TV receivers. The receivers were tested in two batches, one of 15 receivers and the other of 18 receivers.

BAI personnel methodically adjusted and called out various transmission settings in accordance with the test being carried out. They also monitored professional test equipment attached to the system and recorded results where appropriate. The observers were required to record the last transmission settings called out when any of between 3 and 5 TV receivers assigned to them breached the subjective failure point (SFP) threshold.

Figure 2 Overview of SFN receiver testing system



Full details of the receiver RF and SFN performance testing conducted by BAI, including the methodology and a minor required modification, are set out in the separate report prepared by BAI, 'Final Receiver RF (including Single Frequency Networks) Performance Testing DVB-T and DVB-T2 Receivers', included as Attachment B to this report.

2.9 Methodology for shared multiplex testing - receiver performance

2.9.1 Introduction

Shared multiplex test transport streams were created to be carried by transmitters in either DVB-T or DVB-T2 mode. DVB-T mode was configured to carry a transport stream of 23.052768 Mbit/s (equivalent to broadcast services operating in most areas of Australia). DVB-T2 mode was configured to carry a transport stream of 35.706789 Mbit/s (labelled Mode-D in RF and SFN testing section earlier in the project).

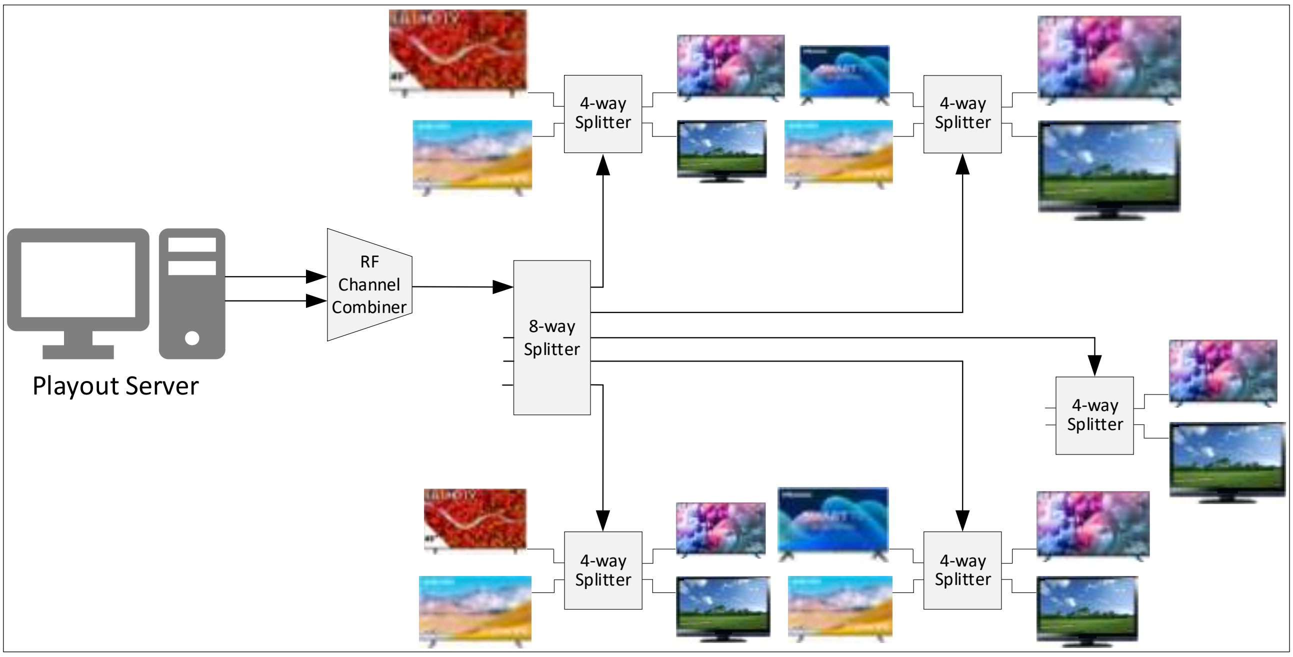
Table 7 Modulation modes used during shared multiplex testing

Mode	FFT (e)=extended mode	Guard Interval (uS)	Pilot Pattern	Modulation	FEC	Payload (Mbit/s)	C/N Ricean Channel (dB)
DVB-T	8K	1/16 (64)		64 QAM	3/4	23.052768	20
DVB-T2	32K(e)	19/256 (304)	PP4	256 QAM	3/4	35.706789	23

2.9.2 TV receiver performance testing methodology

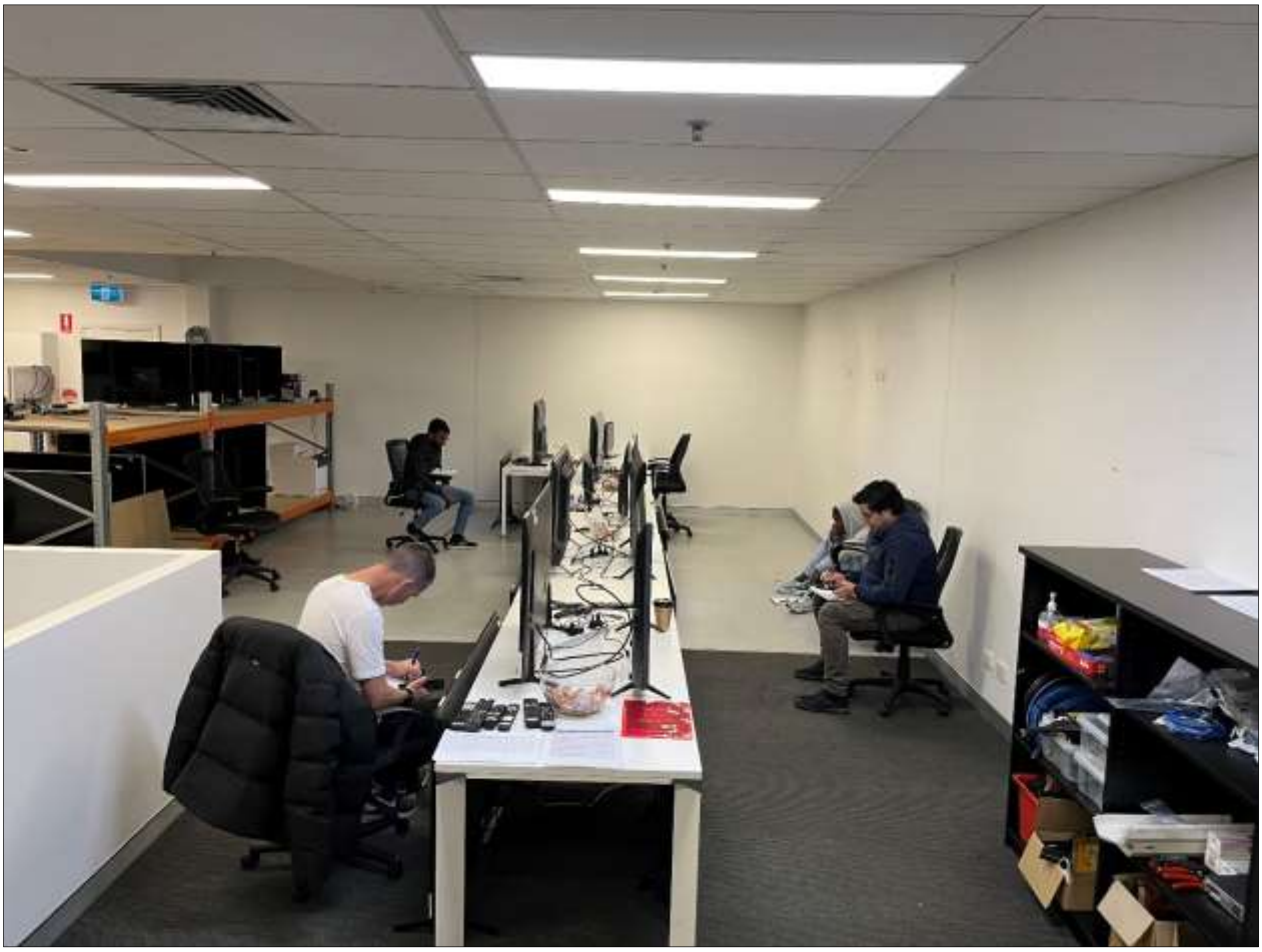
The Freeview test facility was configured to play multiple pre-recorded transport streams concurrently from a server running multiple instances of DekTec StreamXpress software and containing DekTec DTA-2111 PCI RF modulator cards. The RF outputs of the modulator cards were combined, and the combined output then fed into the test facility's RF distribution system.

Figure 3 Playout and RF distribution system



TV receiver testing was mainly carried out by the four personnel hired externally for the project. Testers were supervised at all times by two experts drawn from Free TV, participating broadcasters and/or Freeview based on an agreed roster. Supervisors managed transport stream playout, general management of the testing process and technical support operating the receivers where necessary. Supervisors occasionally participated in the testing process for validation of procedures and confirmation of results as required, along with some additional participation to meet time constraints – although this was limited to rare occasions towards the end of the testing period. Testing was carried out over 15 working days, between 30 May and 20 June 2023.

Photograph 2 Testing underway



TV receivers were tested in two batches. Between 3 and 6 transport streams were tested sequentially on each batch of receivers with each tester allocated 4-5 receivers. The TVs were then swapped, and testing repeated on the same transport streams followed by the next round of transport streams and the process repeated. TV receivers were randomized between testers at each batch change-over. Transport streams were tested in random order, primarily based on availability but also to provide some variability in program content, particularly audio content, and minimize repetition for the testers.

Several functionality tests were performed to assess each receiver's performance in the following areas:

1. Service discoverability following a factory default reset of the receiver and subsequent automatic channel rescan.
2. Ability to navigate successfully between services within the selected shared multiplex and across to a second multiplex.
3. Correct service identification following channel changes, correct codec selection and service decoding.
4. Ability to correctly read and navigate Electronic Programme Guide (EPG) information for services within the shared multiplex and a second shared multiplex.
5. Correct display of now/next and 7-day EPG program information.
6. Correct service navigation using Logical Channel Numbers (LCN's).
7. Response time when changing between services (channel changes), both within the shared multiplex and across to a second shared multiplex.
8. Ensuring quasi-error free (QEF) picture decoding of services within the shared multiplex and noting any objectionable degradation of the picture.
9. Ensuring quasi-error free (QEF) audio decoding of services within the shared multiplex and noting any objectionable degradation of the audio.
10. Recording any unexpected anomalies in operating the TV receiver or affecting the picture and sound reproduction.

The detailed procedures set out under 'Methodology,' in Section 6 of Attachment C, were used to test all 33 TV receivers when fed with each, or the appropriate combination, of the 25 shared multiplex transport streams.

Testers did not directly assess receiver performance. They simply recorded receiver behavior using test checklists. TV industry experts made the performance assessments afterwards, using the checklists recording test results and supervisor notes taken on receiver behavior during the testing. The testers were not aware of the specific functionality being assessed. TV receivers were identified by a catalogue number only (although branding on the TVs and associated remote controls did provide some unavoidable identification). A cross reference to specific makes and models, chipset (where available) and other identifiable information is included in Table 1 in section 2.2.

Test checklists evolved during the testing period in the interests of speed and efficiency, with some fields becoming pre-filled with options to circle or cross off, rather than requiring everything to be handwritten, however there was no substantive change to the content being captured. The standard checklist template at Table 8 below sets out the 23 steps testers performed on each set for each scenario. Observable picture breakup and audio loss during step-14 was based on a 30-second observation of each service within the transport stream. This was the same as the Subjective Failure Point (SFP) procedure practiced by the testers during SFN testing.

Table 8 Standard checklist template showing relationship to Annex 2 testing requirements

	TV Catalogue Number:	**Transport Stream Number/s: #xx xxxxxxxx-1 & 2**	**Annex 2 Test Requirements**
1	Connect the TV receiver to power and antenna cable		**Set-up**
2	Power on the TV receiver and navigate to the set-up menu		
3	Navigate to the settings menu and perform a factory default reset to remove all settings and stored channel lists. Some TVs may do this by performing a channel re-scan only.		
4	Perform a channel re-scan to discover available services		**Test #1**
5	Check the resulting channel list and record the channel numbers and names that appear in the list. Note if any are doubled up. Are there any numbered between 350 and 400?		
6	Select the first channel and watch that service for 10 seconds or so. It could be 110, 210, 310, 410 or 510 - write down the number		**Tests #2, 3 & 4**
7	Select the EPG or guide button and check the services that appear and note if any are missing, named incorrectly or doubled up compared to the channel list you noted at step 5		**Test #5**
8	Go back to the TV channel list and select the last channel in the list		
9	Select the EPG or guide button and check the services against the checklist and note if any are missing, named incorrectly or doubled up compared to the list you noted at step 5		
10	Navigate between each of the channels using the EPG and ensure the correct service is displayed when you select each service.		**Tests #2, 3 & 4**
11	Navigate between each of the channels using channel numbers and ensure the correct service is displayed when you select each service		**Test #6**
12	When navigating between channels, ensure each produces correct picture and sound, information displays the correct service name and note if it carries a second sound language or audio description. Note down any that do not display a picture or make sound at all or only partially (only sound for example), or any that do not carry a second language or audio description		**Tests #3, 6, & 7**
13	Estimate the time the receiver takes to display a locked picture after selecting a different channel number. Is any lag noticeable or objectionable or does the response time seem normal.		**Test #7**
14	Select the first channel in the list that gives picture and sound and view for 30 seconds. If no picture or sound disturbance is noticed, move to the next test. If any picture or sound disturbance is noticed, record this.		**Tests #8 & 9**

15	Power down the TV - remove the power cord for ~30 seconds		Tests #4 & 5
16	Stop one of the streams from playing		
17	Power up the TV		
18	Tune to a channel that displays a picture - some channels will appear in the list, but the TV will not be able to display a picture because we have stopped one of the streams		
19	Select the EPG or guide button. Note which channels appearing in the list but which have no EPG programme content displayed		
20	Restart the previously stopped stream		
21	Select one of the channels that previously couldn't be displayed		
22	Select the EPG or guide button. Confirm that channels which previously had no EPG programme content are now populated		
23	Make a note of any unusual or unexpected behaviour of the TV receiver while carrying out these tests.		**Test #10**

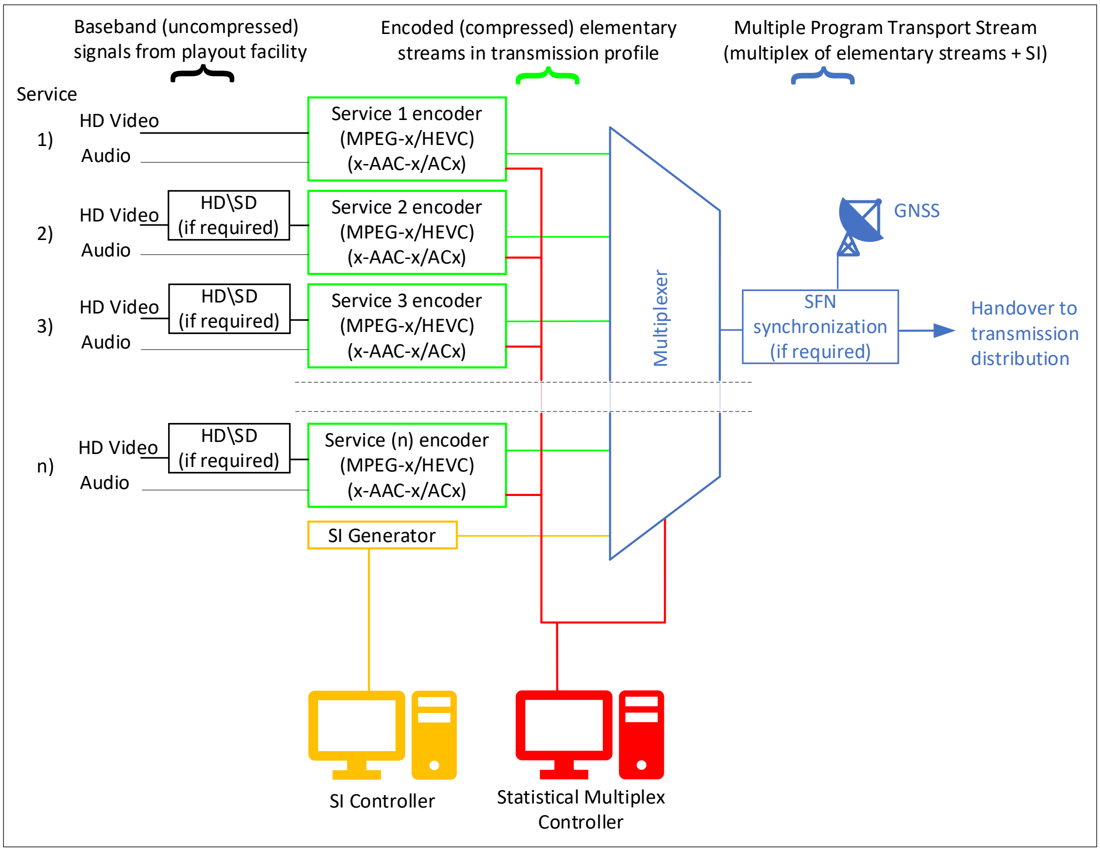
Tester:	

2.10 Methodology for shared multiplex testing - picture quality analysis

In addition to testing a sample of TV receivers in connection with SFN and shared multiplex operation, the ACMA requested that content should be generated to maximise the number of services that could be accommodated, at an acceptable picture quality, within a multiplex for each testing scenario. It also invited observations about the overall capacity, i.e., if there are any potential loss(es) in terms of how much content can be accommodated and its quality. It asked for the results to be compared with the existing arrangements. If losses were identified, it sought information about whether they were in terms of the number of services that can be accommodated, the picture quality (i.e., the available bit rate of individual services is reduced), or both.

The number and quality of services carried in a multiple program transport stream (MPTS) is a function of the headend system used to produce the multiplex. A headend is a collection of appliances and/or software that encodes (compresses) baseband video and audio content of broadcast services leaving a playout facility in real-time to a lower bitrate, suitable for transmission. It then combines multiple services into a single multiplex while injecting necessary service information and SFN synchronisation data. Bitrates can be dynamically assigned between various video services in the multiplex to maximise picture quality. This dynamic assignment of bitrate is known as statistical multiplexing and is carried out in real-time during the encoding process via high-speed negotiation, based on demand and pre-determined constraints, between the multiplexer and encoders within the headend.

Figure 4 Typical simplified headend



For the reasons outlined at 2.4, there is no easy way to express the different carrying-capacity of multiplexes, or multiplex shares, under different scenarios, in terms of the relative number of services that can be carried. Instead, in consultation with ACMA staff, consortium members developed alternative approaches to the comparison of scenarios that used the quality of current on-air TV services as the benchmark for acceptable picture quality (except in cases where there was no current on-air equivalent service), and which used full reference picture quality metrics, rather than human observation, to determine picture quality scores.

Two types of comparison were performed:

- To compare the capacity available to broadcasters under the various scenarios, full-reference quality metrics were used to assess the average picture quality of services under each sharing scenario. The scores achieved under various scenarios could then be compared with the average picture quality of equivalent on-air services, wherever known. They could also be compared with other sharing scenarios.
- To estimate the 'gain' from statistical multiplexing under each sharing scenario, each multiplex was compared with a hypothetical multiplex where there was no statistical multiplexing, but where each service was allocated a 'constant bitrate'. This required consortium members to determine what a 'realistic' constant bitrate for each service would be. Making the constant bitrate as realistic as possible ensured that estimates of the benefits of statistical multiplexing were based on realistic, rather than fanciful, assumptions about what might have occurred in a world where statistical multiplexing was not used. A single, consistent approach to constant bit-rate values is also important if the work is to be replicated in future.

The approaches to these two types of comparison are canvassed in detail in Attachment D.

3. Test results summary

3.1 TV receiver RF performance in conjunction with Single Frequency Networks

3.1.1 TV receiver test results summary

(Taken from section 9: Conclusion, of attachment B.)

The set of receivers tested had greater functionality than expected, with 31 of the 33 receivers being capable of demodulating DVB-T2 and decoding HEVC (interlace) video content. The only two exceptions were the two oldest sets tested. The 2015 set was unable to decode DVB-T2 at all. The 2014 set was DVB-T2 capable but unable to decode HEVC. (Subsequent testing of HEVC capability in various picture formats, during the shared multiplex performance phase of the study, disclosed a more nuanced picture of HEVC capability in the sample: the full results are summarised in Table 9, in 3.2.1, below.)

All receivers (where capable of decoding the modulation) recovered from the receiver synchronisation tests for all modes when the relative SFN configuration was changed during both loss of signal and power-on from standby mode.

The test results showed that receiver performance for signal threshold was better than the reference for 90^{th} percentile of the receivers.

Co- and adjacent channel protection ratio receiver performance for DVB-T and DVB-T2 Mode B exceeded the reference for 90^{th} percentile of receivers.

Adjacent channel protection ratio receiver performance for DVB-T2 Mode D exceeded the reference for the 90th percentile of receivers. The co-channel protection ratio receiver performance for DVB-T2 Mode D exceeded the reference for the 50^{th} percentile of receivers, however, was 2.1 dB worse for the 90^{th} percentile of receivers.

SFN performance tests showed that the receivers performed better than the Guard Interval alone would indicate for the 90^{th} percentile of receivers.

The performance of receivers using the existing DVB-T mode showed that they were within the existing planning parameters and, in some cases, well within the existing planning parameters.

The performance of receivers when demodulating DVB-T2 Mode B showed that they were within the reference levels.

Should there be a decision to use DVB-T2 Mode D, further detailed testing is recommended to better quantify the co-channel performance of receivers operating in this mode for the reference levels used in this testing.

Full results of receiver RF performance in conjunction with SFN's are contained in BAI's report, included as Attachment B to this report.

3.2 TV receiver performance with shared multiplexes

3.2.1 TV receiver test results summary

All shared multiplexes worked with all receivers tested with no adverse findings in relation to service discoverability, service identification, or EPG or LCN navigation between services within and between multiplexes. Service LCNs, service names and Program now/next information as well as 7-day EPG information was displayed correctly on all receivers. Receivers also correctly interpreted cross-carried EIT information across multiplexes when present, with no missing or doubled-up information shown in the EPG's. All receivers compiled an accurate EPG for all services when first scanned.

For a broadcaster split across two multiplexes, cross-carriage of EIT proved beneficial to maintain accurate EPG information about the broadcaster's services in the 'other' multiplex. Some receivers retained a populated EPG for services in a multiplex after that multiplex had been removed from the receiver's input, even following a several-minutes long power cycle. Some receivers in the sample exhibited this data retention more than others.

No pattern of lag was reported by testers in relation to channel change speed. Variations became evident between different receivers, but this was attributed to different operating systems and software etc. rather than being a function of shared multiplex operation.

From time to time, some receivers exhibited odd behaviours. These unexpected behaviours were almost universally resolved by resetting the receivers back to their factory default settings and rescanning. Occasionally, power cycling was also required and in a small number of cases both were required several times. As these behaviours were more often experienced towards the end of testing days, and the receivers were intentionally powered down overnight, this would suggest some receivers needed very long power down periods to fully clear any spurious information causing the unexpected behaviour.

Testing revealed several unexpected results, including a more complex and nuanced representation of receiver capabilities than disclosed at the RF and SFN testing stage. Overall, more receivers than expected were DVB-T2 and DVB-T2/HEVC capable, with only the very oldest sets in the sample lacking these capabilities. However, subtleties such as an ability to decode HEVC encoded progressive and/or interlaced scanned video content emerged as differentiating factors in some receivers. Similarly, audio codec capabilities such as AC4 could not necessarily be correlated to video codec capabilities. In the absence of a published Australian Standard for DVB-T2 receivers, any fortuitous DVB-T2 or HEVC functionality can be considered a bonus, so it is notable how capable the receivers were particularly given the age range of units in the sample. Downscaling was not a feature available in any of the receivers tested. As such, if receivers were HEVC capable, UHD content was not displayed unless the receivers were fitted with a UHD LCD panel.

A summarized table (9) of results is below. As previously mentioned in this report, the sets numbered 24 and 33 (which performed worst in the comparison) are also the oldest, dating from 2015 and 2014 respectively.

Table 9 Demodulation and decoding capabilities of the receiver sample

No	DVB-T	DVB-T2				
	MPEG4	MPEG4	HEVC			AC4 Audio
	HD (i)	HD (i)	HD (i)	HD (p)	UHD (p)	
1	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✗	✗
5	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✗	✗
7	✓	✓	✓	✓	✓	✓
8	✓	✓	✓	✓	✓	✓
9	✓	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓	✓
11	✓	✓	✓	✓	✓	✗
12	✓	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✗	✗
14	✓	✓	✓	✓	✗	✗
15	✓	✓	✓	✓	✓	✓
16	✓	✓	✓	✓	✗	✗
17	✓	✓	✓	✓	✓	✓
18	✓	✓	✓	✓	✓	✓
19	✓	✓	✓	✓	✗	✗
20	✓	✓	✓	✓	✗	✓
21	✓	✓	✓	✓	✓	✓
22	✓	✓	✓	✓	✓	✓
23	✓	✓	✓	✓	✓	✓
24	✓	✗	✗	✗	✗	✗
25	✓	✓	✓	✓	✓	✓
26	✓	✓	✓	✓	✓	✗
27	✓	✓	✓	✓	✗	✓
28	✓	✓	✓	✓	✗	✗
29	✓	✓	✓	✓	✓	✓
30	✓	✓	✓	✓	✗	✗
31	✓	✓	✓	✓	✗	✓
32	✓	✓	✓	✗	✗	✓
33	✓	✓	✗	✗	✗	✓

Some breakup was noted on UHD content during testing. On investigation this was found to be a problem with the source video material prior to encoding. Where possible, this content was replaced and remade transport streams used for PQ assessments.

For the reasons discussed at 2.6.5, above, audio description (AD) was included in a selection of UHD, HD and MC services using the HE-AAC codec. While AD functionality testing was outside of the scope of the project, some functionality issues were captured on several receiver checklists. Investigations disclosed the issue was one of transport stream design rather than receiver functionality, and the affected receivers had behaved appropriately[3]. In a real-life situation, this issue would be corrected through more thorough transport steam design and fine-tuning than was possible during the current study.

Receivers were reset to their Factory Default mode before testing each new scenario. Factory reset functionality was often difficult to locate in the menu structure. Differing terminology was used, such as 'factory reset', 'reset', 'set-up' and 'shipping', to describe the basic function of returning the receiver to factory settings. Some models included an easier to find 'restart' function, which did not clear any settings, but rather served as a pseudo power cycle. Testers became familiar with these subtleties, although it is worthy of mention as standard advice to viewers experiencing receiver behaviour problems is to perform a reset to factory settings and rescan. The terminology and menu navigation to achieve this reset is often not intuitive.

While subjective picture quality assessments are prone to many variables, it is worth including some generalised comments made during the testing.

The untrained, externally hired, testers made comment about poor picture quality while testing some scenarios. Pixilation and general loss of detail were commented on when viewing sport content in highly constrained scenarios, such as scenarios 18 and 23.

Technical broadcast experts are skilled in recognising video encoding artifacts, regardless of the television receiver display and other environmental variables. While on site supervising, the technical experts generally observed that where a broadcaster was allocated an aggregate of approximately 20Mbit/s or more in the shared multiplex, picture quality of services was satisfactory and comparable with live on-air services. Lower aggregate bitrate allocations resulted in noticeable picture degradation. This is not surprising, as on-air broadcasts typically carry 6, 7, or 8 services in a 23 Mbit/s multiplex. It stands to reason that the standardised 6-service/3-tier quality suite of services used for testing would require in the order of 20 Mbit/s of capacity or more to replicate similar picture quality. While these observations were subjective, they are based on decades of collective experience and support the objective picture quality assessments reported in section 3.3 and attachment D to this report.

Detailed results of TV receiver testing using shared multiplexes are included at Attachment C to this report.

[3] Investigation of the relevant transport streams found the SI descriptor signalled AD as 'present' and a 'receiver-mix' as opposed to 'broadcast-mix'.

3.3 Shared multiplex picture quality and statistical multiplex gain assessment

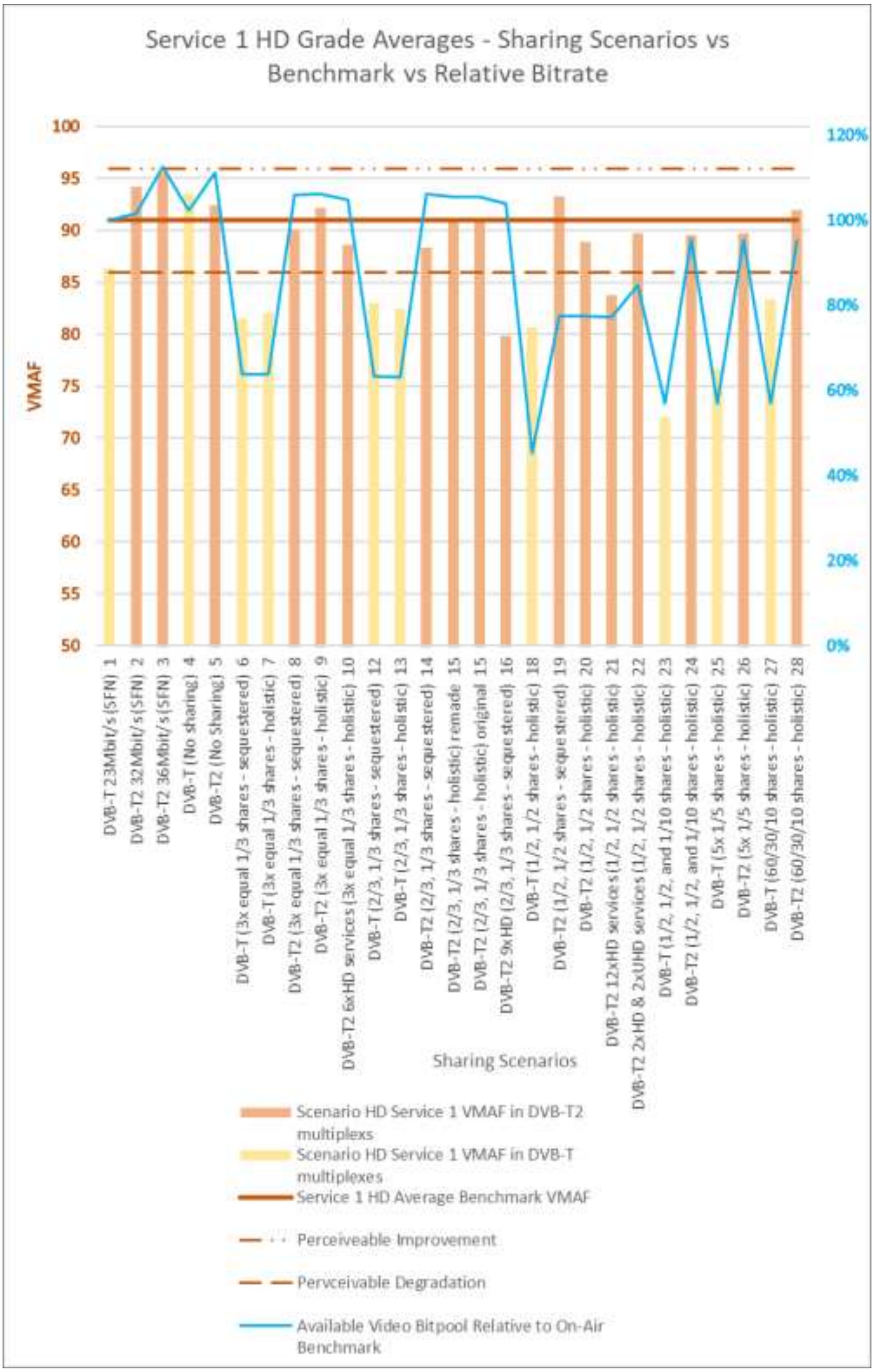
3.3.1 Summary of picture quality results

The scenarios tested as part of the study varied in terms of the data capacity available to each broadcaster. To measure the picture quality achieved under each scenario, the consortium adopted an objective (and replicable) approach using full reference picture quality metrics. With a few exceptions as required, the same (fixed) number and grade of services was carried under each scenario, being 2 x HD services at premium quality, 2 x SD services at mid-technical quality, and 2 x SD channels at low or 'datacasting' quality for each broadcaster. The average picture qualities obtained under each scenario were measured, allowing objective comparison of the different average scores both with other scenarios, and with a benchmark of 'acceptable' picture quality based on the quality of those grades of content shown on TV today.

The graph below in figure 5, which focuses only on the primary HD service carried, shows the correlation between the amount of bandwidth available and the average picture quality of services carried. The comparisons used VMAF, which compares the quality of each frame before and after encoding in the broadcaster's head end. The result is a score out of 100 for fidelity, with a 6-point change being the threshold at which a human observer will notice a difference in subjective picture quality. The 'average VMAF scores' used in this report are the averages of all scores in each sample tested.

The graph shows the average picture quality achieved under each scenario (the vertical brown and yellow bars showing 'VMAF' scores) and the amount of available bandwidth under each scenario (the blue line), as a percentage of the amount available to a broadcaster today. The solid brown horizontal line represents the average quality of comparable existing TV services, which was used as a benchmark.

Figure 5 Comparison of average VMAF scores for primary HD grade services



Detailed results of shared multiplex picture quality analysis and information about interpreting VMAF scores are included at Attachment D to this report.

3.3.2 Summary of statistical multiplex gain results

The scenarios tested as part of the study also varied in terms of the choice of approach to statistical multiplexing – whether 'sequestered' or 'holistic'. In a sequestered multiplex, the transport stream is divided into segments of fixed capacity and the statistical multiplexing is separately applied to the video services within each of the segments. For instance, if two broadcasters share one multiplex (1/2, 1/2), then one segment with one half of the capacity is allocated to each broadcaster and the statistical multiplexing is then applied within each segment separately. Holistic multiplexing is without any segmentation, i.e., all the video services within the transport stream are statistically multiplexed in a holistic manner.

Comparison of the statistical multiplex gain between sequestered versus holistic multiplexing scenarios, that were otherwise identical, clearly confirmed the expected greater efficiency of holistic statistical multiplexing, as shown in the following graph.

Figure 6 Relative statistical multiplex gain - sequestered v's holistic

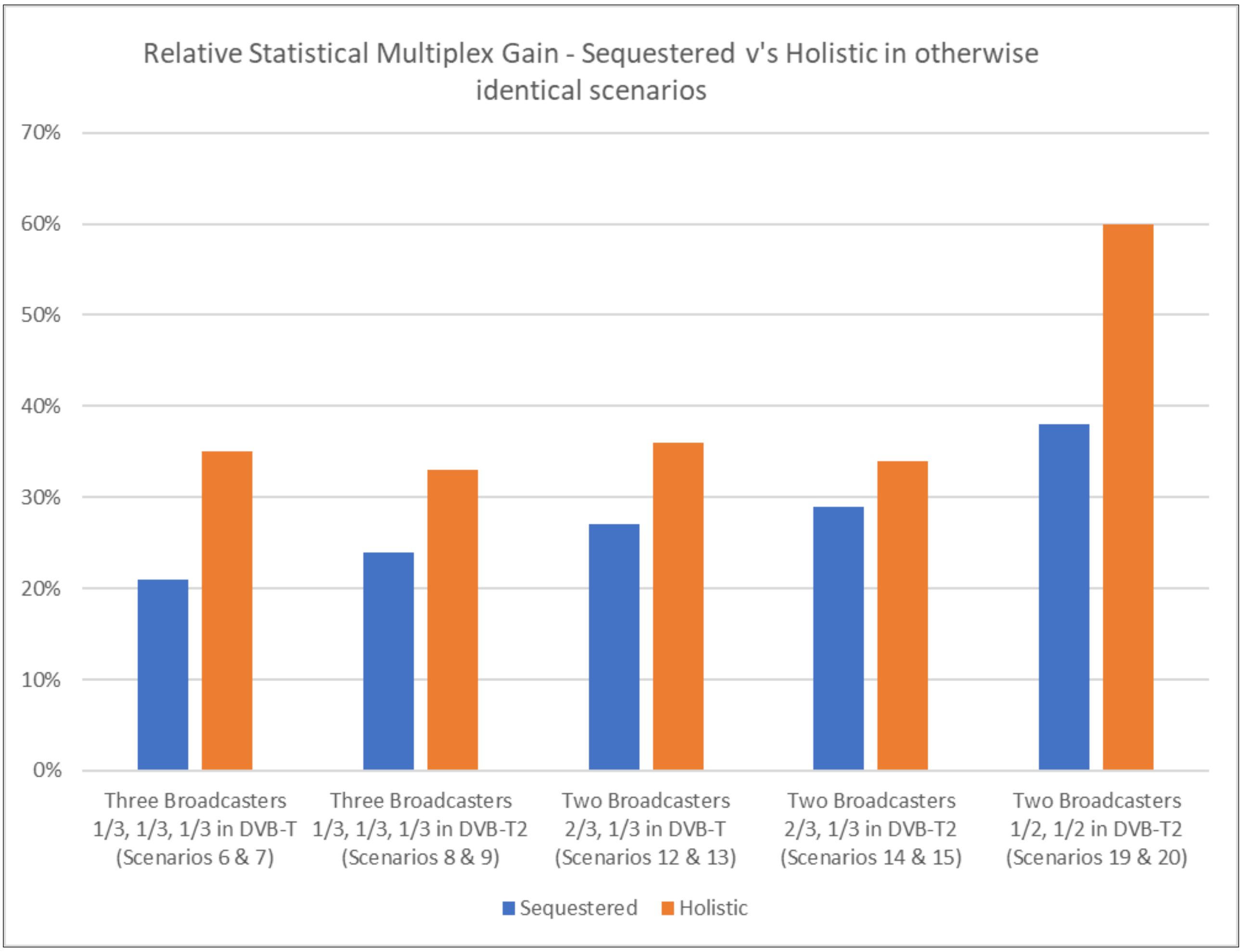


Table 10 below details the calculated statistical multiplex gain for each transport stream under each scenario tested. Further results for statistical multiplex gain under the sharing scenarios are included at Attachment D to this report.

Table 10 Statistical multiplex gain results

No	Sharing scenario		Modulation / Bitrate	Codec/s	Video resolution	stat-mux	Description	Stream	Average Gain per stream	Average Gain per scenario
1	SFN Testing	No sharing	DVB-T @23Mbit/s	MPEG2 /MPEG4	HD/SD	Holistic	Current on air example as benchmark. 7 services for Broadcaster A (3xHD, 3xMC, 1xDC). All 7 services in one stat-mux	Stream 1 - 1	50%	42%
							Current on air example as benchmark. 8 services for Broadcaster B (2XHD, 5xMC, 1xDC). All 8 services in one stat-mux	Stream 1 - 2	43%	
							Current on air example as benchmark. 7 services for Broadcaster C (2xHD, 4xMC, 1xDC). All 7 services in one stat-mux	Stream 1 - 3	33%	
2			DVB-T2 @32Mbit/s	MPEG4 /HEVC	HD/SD	Holistic	7 services for Broadcaster A (3xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	Stream 2 - 1	46%	47%
							8 services for Broadcaster B (2xHD, 5xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 8 services in one stat-mux	Stream 2 - 2	42%	
							7 services for Broadcaster C (2xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	Stream 2 - 3	52%	
3			DVB-T2 @36Mbit/s	MPEG4 /HEVC	HD/SD	Holistic	7 services for Broadcaster A (3xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux	Stream 3 - 1	34%	27%
							8 services for Broadcaster B (2xHD, 5xMC, 1xDC). Current on air example with 1xHD (interlaced) service changed to HEVC, all other services use MPEG-4. All 8 services in one stat-mux	Stream 3 - 2	20%	
							7 services for Broadcaster C (2xHD, 4xMC, 1xDC). Current on air example with 1xHD (interlaced)	Stream 3 - 3	27%	

						service changed to HEVC, all other services use MPEG-4. All 7 services in one stat-mux			
4	No sharing	DVB-T @23Mbit/s	MPEG2 /MPEG4	HD/SD	Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	Stream 4 - 1	41%	37%
						6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	Stream 4 - 2	39%	
						6 services for Broadcaster C (2xHD, 2xMC, 2xDC). All 6 services in one stat-mux. Similar to Scenario #1, with MC/MPEG-2 simulcast of main HD service	Stream 4 - 3	32%	
5		DVB-T2 @36Mbit/s	MPEG4 /HEVC	UHD/HD/SD	Holistic	7 Services for Broadcaster B (1xUHD, 2xHD, 2xMC, 2xDC). 1xUHD and 1xHD service use HEVC, all other services MPEG-4. All 7 services in one stat-mux	Stream 5 - 1	28%	30%
						7 Services for Broadcaster B (1xUHD, 2xHD, 2xMC, 2xDC). 1xUHD and 1xHD service use HEVC, all other services MPEG-4. All 7 services in one stat-mux	Stream 5 - 2	31%	
6	Three broadcasters sharing each mux 1/3, 1/3, 1/3	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~ 7Mbps for each Broadcaster.	Stream 6 - 1	20%	21%
						3 services for Broadcaster A (1x HD, 1x MC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~7Mbps for each Broadcaster.	Stream 6 - 2	23%	
7					Holistic	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux.	Stream 7 - 1	31%	35%
						3 services for Broadcaster A (1x HD, 1x MC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	Stream 7 - 2	40%	
8		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	3 services for Broadcaster A (1x HD, 2x MC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~11.5Mbps for each Broadcaster.	Stream 8 - 1	23%	24%
						3 services for Broadcaster A (1xHD, 1xMC, 1xDC). Same 3 for Broadcaster B and Broadcaster C. Sequestered @ ~11.5Mbps for each Broadcaster.	Stream 8 - 2	24%	
9					Holistic	3 services for Broadcaster A (1xHD, 2xMC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	Stream 9 - 1	32%	33%
						3 services for Broadcaster A (1xHD, 1xMC, 1x DC). Same 3 for Broadcaster B and Broadcaster C. All 9 services in one stat-mux	Stream 9 - 2	35%	

10			MPEG4	HD	Holistic	2 services for Broadcaster A (2xHD). Same 2 for Broadcaster B and Broadcaster C. All 6 services in one stat-mux	Stream 10 - 1	44%	46%
				SD	Holistic	Remaining 12 SD services in second mux	Stream 10 - 2	49%	
11			HEVC	UHD	Holistic	1 service for Broadcaster A (1xUHD). Same for Broadcaster B and Broadcaster C. All 3 services in one stat-mux	Stream 11 - 1	48%	48%
12	Two broadcasters sharing 2/3, 1/3	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	6 services for Broadcaster A (2xHD, 4xMC) stat-muxed @ ~14Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1xDC) stat-muxed @ ~7Mbps	Stream 12 - 1	25%	27%
						6 services for Broadcaster C (2xHD, 2xMC, 2xDC) stat-muxed @ ~14Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1xDC) stat-muxed @ ~7Mbps	Stream 12 - 2	28%	
13					Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux	Stream 13 - 1	33%	36%
						6 services for Broadcaster C (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux.	Stream 13 -2	38%	
14		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	6 services for Broadcaster A (2xHD, 2xMC, 2x DC) stat-muxed @ ~24Mbps. 3 services for Broadcaster B (1xHD, 1xMC, 1x DC) stat-muxed @ ~12Mbps	Stream 14 - 1	28%	29%
						6 services for Broadcaster C (2xHD, 2xSD, 2xDC) stat-muxed @ ~24Mbps. 3 services for Broadcaster B (1xHD, 1xSD, 1xDC) stat-muxed @ ~12Mbps	Stream 14 - 2	31%	
15					Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux	Stream 15 - 1	32%	34%
						6 services for Broadcaster C (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). All 9 services in one stat-mux	Stream 15 - 2	35%	
16			MPEG4	HD	Holistic	6 services for Broadcaster A (6xHD). 3 services for Broadcaster B (3xHD). All 9 services in one stat-mux	Stream 16 - 1	22%	34%
				SD	Holistic	6 services for Broadcaster C (6xMC). 3 services for Broadcaster B (3xMC). All 9 services in one stat-mux	Stream 16 - 2	47%	
17			MPEG4 /HEVC	UHD/HD	Holistic	3 services for Broadcaster A (1xUHD, 2xHD). 1 service for Broadcaster B (1xUHD). All 4 services in one stat-mux	Stream 17 - 1	2%	13%

						3 services for Broadcaster C (1xUHD, 2xHD). 2 services for Broadcaster B (2xHD). All 5 services in one stat-mux	Stream 17 - 2	23%	
18	Two broadcasters sharing 1/2, 1/2	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 12 services in one stat-mux	Stream 18 - 1	44%	44%
19		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	6 services for Broadcaster A (2xHD, 2xMC, 2xDC) stat-muxed @ ~18Mbps. 6 services for Broadcaster B (2xHD, 2xMC, 2xDC) stat-muxed @ ~18Mbps	Stream 19 - 1	38%	38%
20					Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 6 services for Broadcaster B (2xHD, 2xMC, 2xDC). All 12 services in one stat-mux	Stream 20 - 1	60%	60%
21			MPEG4	HD	Holistic	6 services for Broadcaster A (6xHD). 6 services for Broadcaster B (6xHD). All 12 services in one stat-mux	Stream 21 - 1	46%	46%
22			MPEG4 /HEVC	UHD/HD	Holistic	2 services for Broadcaster A (1xUHD, 1xHD). 2 services for Broadcaster B (1xUHD, 1xHD). All 4 services in one stat-mux	Stream 22 - 1	39%	39%
23	Two muxes 50/50, 1 mux 50/10/10/10/10/10	DVB-T @23Mbit/s	MPEG4	HD/SD	Sequestered	5 services for Broadcaster A (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps. 5 services for Broadcaster B (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps.	Stream 23 - 1	7%	21%
						5 services for Broadcaster C (2xHD, 2xMC, 1xDC) stat-muxed @ ~11.5Mbps. 5xDC services (one each for Broadcaster A, B, C, D & E) stat-muxed @ ~11.5Mbps	Stream 23 - 2	36%	
24		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Sequestered	5 services for Broadcaster A (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps. 5 services for Broadcaster B (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps.	Stream 24 - 1	42%	48%
						5 services for Broadcaster C (2xHD, 2xMC, 1xDC) stat-muxed @ ~18Mbps. 5xDC services (one each for Broadcaster A, B, C, D & E) stat-muxed @ ~18Mbps	Stream 24 - 2	54%	
25	Five broadcasters share each mux 1/5, 1/5, 1/5, 1/5, 1/5	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	5xHD services (one for each Broadcaster A, B, C, D & E). 5x DC services (one for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	Stream 25 - 1	24%	37%
						10xMC services (two for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	Stream 25 - 2	49%	
26		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	5xHD services (one for each Broadcaster A, B, C, D & E). 5x DC services (one for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	Stream 26 - 1	38%	41%

						10xMC services (two for each Broadcaster A, B, C, D & E). All 10 services in one stat-mux	Stream 26 - 2	44%	
27	Two broadcasters share 50/50 of one mux + 10% in a 60/30/10 mux	DVB-T @23Mbit/s	MPEG4	HD/SD	Holistic	6 services for Broadcaster A (2xHD, 2xMC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster D (1xDC). All 10 services in one stat-mux.	Stream 27 - 1	16%	15%
						5 services for Broadcaster D (2xHD, 2xMC, 1xDC). 5 services for Broadcaster E (2xHD, 2xMC, 1xDC). All 10 services in one stat-mux	Stream 27 - 2	13%	
28		DVB-T2 @36Mbit/s	MPEG4	HD/SD	Holistic	6 services for Broadcaster A (2xHD, 2x MC, 2xDC). 3 services for Broadcaster B (1xHD, 1xMC, 1xDC). 1 service for Broadcaster D (1xDC). All 10 services in one stat-mux.	Stream 28 - 1	12%	30%
						5 services for Broadcaster D (2xHD, 2xMC, 1xDC). 5 services for Broadcaster E (2xHD, 2xMC, 1xDC). All 10 services in one stat-mux	Stream 28 - 2	48%	