Digital Video Recording System

Mark Lewis
Andrew Levine
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Project description

The goal of this project is to apply systems engineering principles to develop the scenarios and use cases, requirements and specifications, system level design, and verification and validation of a digital video recording (DVR) system. Lastly, a subset of a system test plan will be presented.

A DVR system is a common hardware set and service provided by cable TV companies (i.e. Comcast, Cox, Time Warner), or 3rd party services such as TiVo, who typically charge a monthly fee for the service portion. The service (and corresponding hardware) allows users to record TV, set a recording, search a schedule for programs to record, set a schedule to record programs, watch recorded programs, watch and record live TV, and configure the DVR system. Once the system is configured and set up, the system will run automatically according to user settings. Goals of this project include fully identifying the system requirements, use cases, system specifications, and validating and verifying the system design.

For the purposes of this project, several common DVR characteristics will be ignored. These functions and characteristics include full menu functionality, ability to record multiple channels simultaneously, links to personal computers to transfer media, video, pictures, audio, links to web applications and podcast subscriptions, interactive games, DVD burner, and HD compatibility.

Stakeholder and Scenario Identification

One of the first steps towards requirements capture and development is the identification of stakeholders and the analysis of their high-level concerns and needs of the system. For a basic DVR system, we identified the following stakeholders:

Stakeholder Name	Description
Customer	The end user of the system who has purchased the DVR system and will be the one who most interacts with the system.
Retailer	The store or company who is responsible for selling system units to customers.
Data Service Provider	The entity that provides and maintains a data service needed by the DVR system.
System Developer	The group that designed, tested, and produced the DVR system, both hardware and software.
System Maintenance Personnel	The group that is responsible for handling failed units and providing repair services.
Content Provider	A group (typically a television programming provider) whose product access is controlled via the DVR usage.

As this table is examined, it is clear that some stakeholders could be combined into one in certain situations. For instance, one company could design, sell, and repair DVR units, as well as provide the data service, effectively combining four stakeholders into one.

The primary focus for this section (and most subsequent ones) is on the requirements of the end user of the system. Our original intent had been to conduct a survey of known DVR users to determine their concerns and needs of these systems. However, time limits and a concern over producing a survey that didn't lead the respondent to certain answers ended this endeavor. In lieu of the surveys, both team members provided inputs from the end user standpoint as both of us use and own DVR systems.

Each stakeholder in this system is involved in a group of scenarios that can help determine the high-level requirements of the system. The table below shows some scenarios for the system and the associated stakeholders linked to the scenario:

Scenario Number	Scenario Description	Stakeholders Affected
1	Customer purchases DVR system	Customer, Retailer
2	Customer configures DVR system	Customer, Data Service Provider
3	Customer schedules recording	Customer, Data Service Provider, Content Provider
4	Customer watches recording	Customer
5	Customer uses DVR to watch "live" TV	Customer, Data Service Provider, Content Provider
6	Customer experiences system failure	Customer, Retailer, System Maintenance Personnel

Use Case Modeling

From the scenarios described in the previous section, use case analysis was performed in order to reach high-level requirements for the system.

The first step in use case modeling is to identify actors who interact with the system (either provide input or receive output from the system). For a typical DVR system, three actors were identified. The first is the customer who purchased the system and interacts with it to record and watch television. The second is the DVR data service that is required to update schedule information on the system. The third is the television provider (typically a cable or satellite TV company) used by the customer and whose signal is connected to the DVR unit.

Below is the use case diagram for the DVR system:

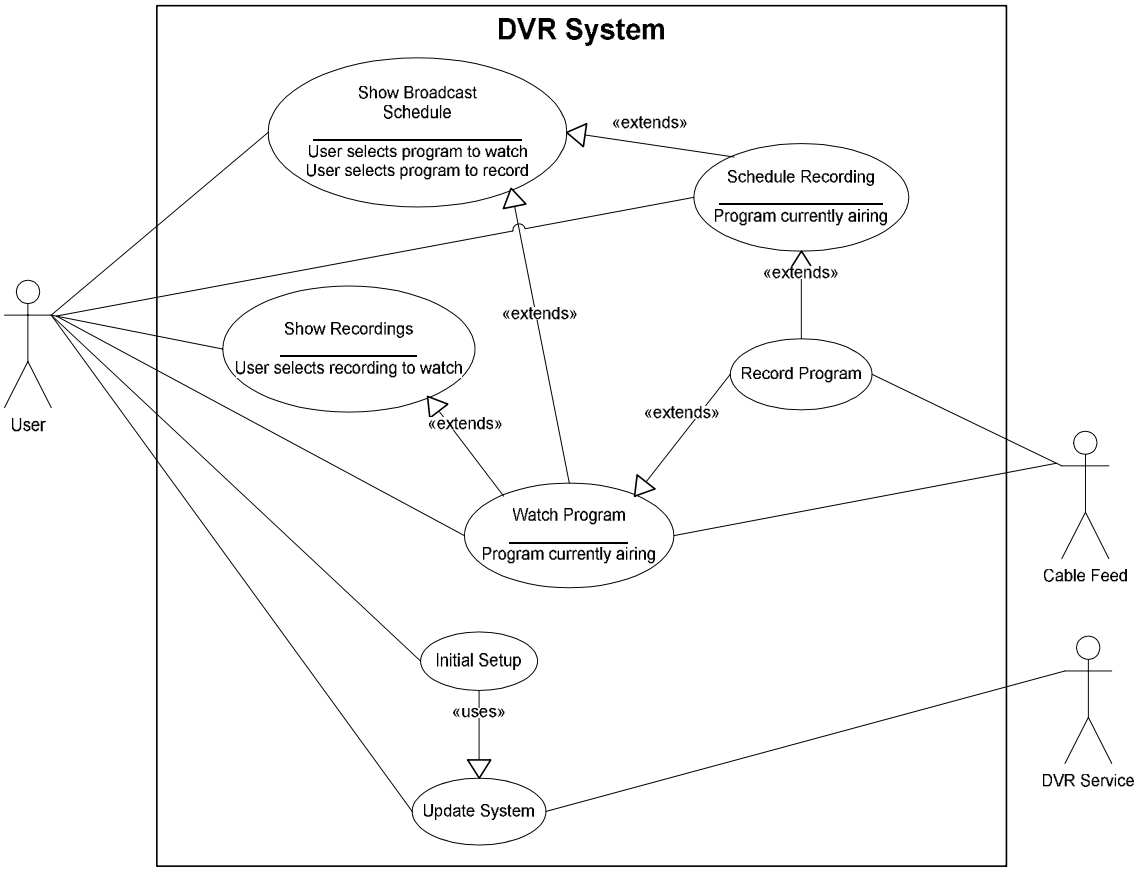


Figure 1. Use Case Diagram.

High-Level Requirements

Based on the scenarios and use cases, the initial high-level requirements are as follows:

Requirement Number	Requirement Description
1	System must provide video I/O of formats and using connectors that are compatible with consumer video standards.
2	System must have a remote control.
3	System must have menu-based software interface that can be navigated by the user.
4	System must have displayable and searchable schedules of all programs.
5	System must provide user standard video player functions.
6	System must provide user ability to specify programs to record.
7	System must have digital storage media for recording programs for future retrieval.
8	System must be able to access a recording as it is being written to the storage media.
9	System must have a data link to connect to a data service.
10	System must provide user the ability to get and set system configuration parameters.

11	System must be built from Commercial Off-The-Shelf (COTS) components.
12	System must be capable of digitizing, recording, and displaying a standard video signal input.

Use Case Analysis

Use Case #1 – Show Broadcast Schedule

1. Description: The user wants to view the program broadcast schedule.
2. Pre-Condition: The user has set up the DVR system and a connection to the cable feed has been established.
3. Actors: User
4. Flow of Events:
   a) User chooses to display broadcast schedule through interface.
   b) DVR shows schedule by set organization method on TV screen.
   c) User can navigate schedule using interface and select a specific program to watch or record.
   d) Schedule display terminates upon user request or timeout.
5. Post-Condition: Recording scheduled if requested, program displayed if requested; otherwise previous display restored.

Use Case #2 – Show Recordings

1. Description: The user views a list of previously recorded programs.
2. Pre-Condition: Programs have been recorded and are saved on the system's hard drive.
3. Actors: User
4. Flow of Events:
   a) User selects menu option to view list of previously recorded programs.
   b) User can select a recording to view or delete.
5. Post-Condition: If program selected to view, program begins and is displayed; otherwise previous display is restored.

Use Case #3 – Watch Program

1. Description: The user watches either a recorded program or a live program.
2. Pre-Condition: The user has turned on the power to the cable box and the television, the cable feed is connected and active, and the program has been previously recorded (if watching recording).
3. Actors: User, Cable Feed
4. Flow of Events:
   a) User selects program from list of recordings or current schedule of programs.
   b) The program selected is shown on the TV screen.
5. Post-Condition: User can manipulate video using standard video player functions. Upon program termination, user will be asked to delete if previously recorded or automatically taken to next program on channel if live TV.

Use Case #4 – Schedule Recording

1. Description: The user schedules a future program to record automatically.
2. Pre-Condition: The user has configured the system and is viewing the broadcast schedule.
3. Actors: User
4. Flow of Events:
    a) The user searches for the desired program by channel, time, or genre.
    b) The user locates the desired program and selects.
    c) The user selects to record program once, to record the entire series (first run only), or to record the program each time it is shown. Depending on the choice, the correct option is chosen.
    d) The user confirms the selection.
    e) System adds program to recording schedule.
5. Post-Condition: The selected program will automatically be recorded.

Use Case #5 – Record Program

1. Description: The system records the current program coming through the cable feed to the storage media.
2. Pre-Condition: None required, but user could have previously scheduled a recording.
3. Actors: User, Cable Feed
4. Flow of Events:
    a) The DVR service is ready and has space on the hard drive to record the program, as scheduled.
    b) The program is recorded to the storage media.
    c) If a previously scheduled recording, the program file is stored long-term on the media.
5. Post-Condition: The user can watch the video as it is recorded. If the recording was scheduled, the resulting file is available for future viewing.

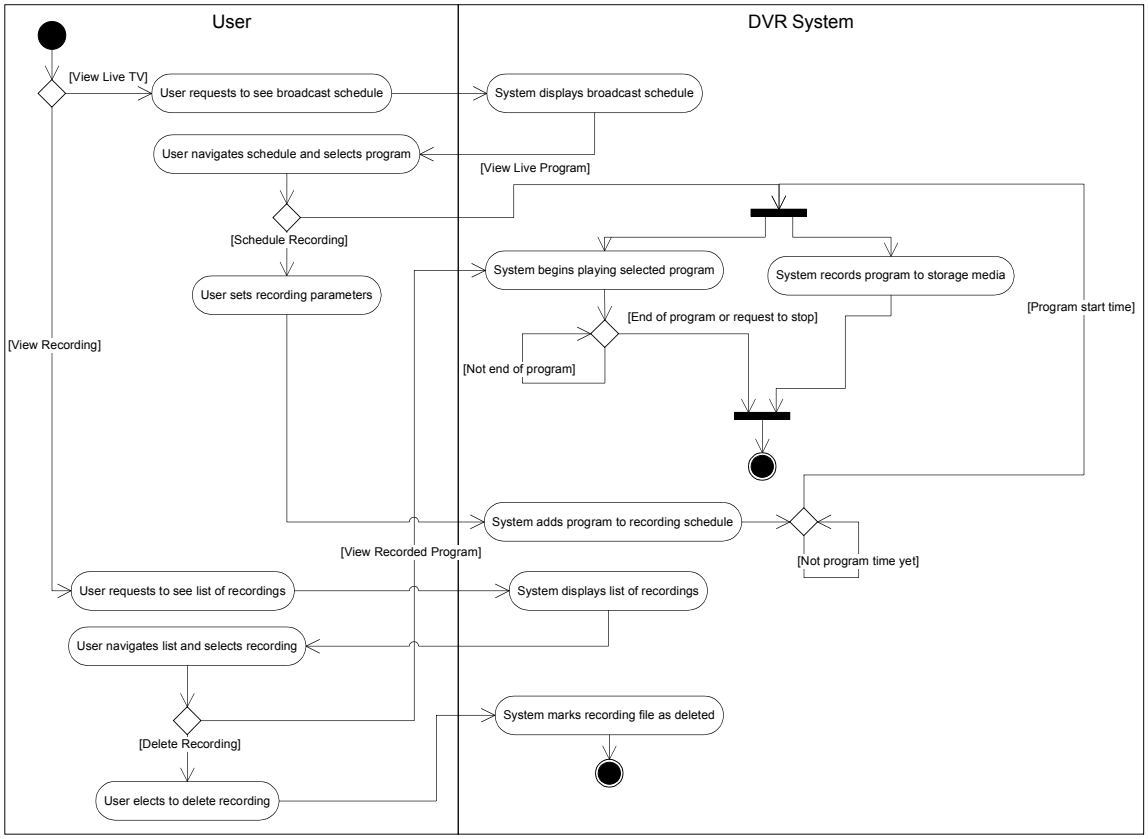


Figure 2. Activity Diagram for Use Cases #1 through #5.

Use Case #6 – Initial Setup

1. Description: The DVR system is set up for use by the user.
2. Pre-Condition: The user has purchased a DVR unit and service.
3. Actors: User
4. Flow of Events
    a) The user hooks up the correct cables to the TV.
    b) The user hooks up the correct cables from the cable service.
    c) The user selects the cable service provider.
    d) The user selects the frequency that the system updates with the service.
5. Post-Condition: The system is set up and ready to use.

Use Case #7 – Update System

1. Description: The DVR system is updated from the cable service.
2. Pre-Condition: The DVR service is set up for use by the user and a data connection has been established.
3. Actors: User, DVR Service
4. Flow of Events
    1 Update request initiated (manually or automatically)
    2 DVR service sends schedule data
    3 DVR software application parses data into broadcast schedule and applies subscription and recording settings to create recording schedule
5. Post-Condition: The system is configured and both schedules are populated

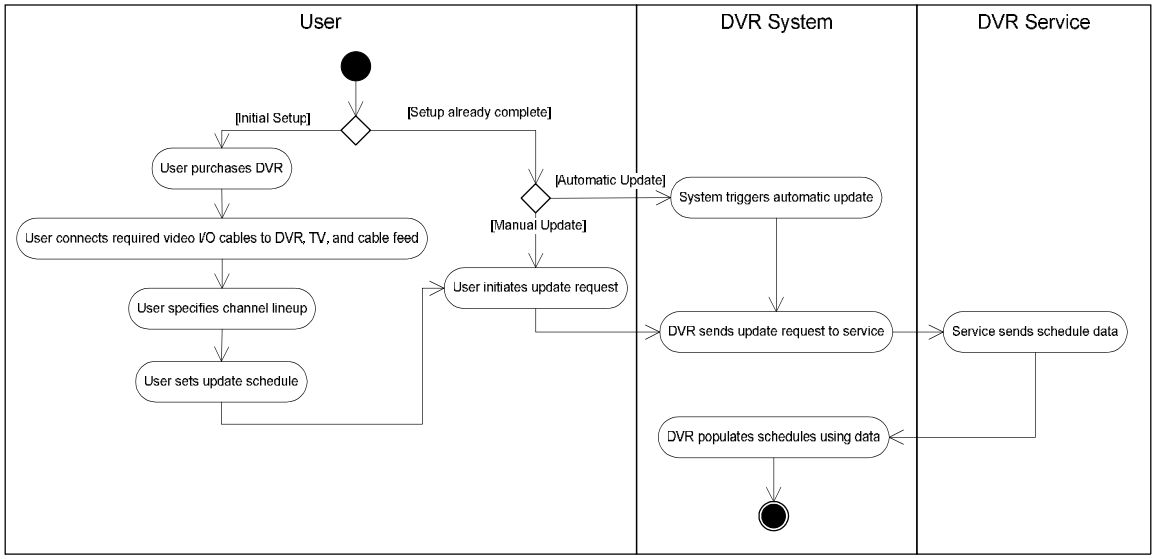


Figure 3. Activity Diagram for Use Cases #6 & #7.

Requirements Synthesis and Traceability

Based on the expanded use case analysis, we were able to develop further refined requirements from our initial list of eleven high-level requirements. The matrix below shows these low-level requirements, as well as the scenarios and use cases to which they trace back:

Use Case	Scenario	Low-Level Req. No.	Description
Initial Set Up	1,2	1.1	System must accept standard cable video feed input using coax cable and coax cable connector.
		1.2	System must accept standard audio feed input using coax cable and coax cable connector.
		1.3	System must provide standard cable video feed output using coax cable and coax cable connector, S-video cable and S-video cable connector, and RCA cable and RCA cable connector.
		1.4	System must provide standard audio feed output RCA cable and RCA cable connector, and optical cable and optical cable connector.
Initial Set Up	1,2	2.1	System must accept all control inputs from a remote control.
		2.2	Remote control must an effective range of 30 feet.
		2.3	System must be compatible with standard and COTS remote control inputs.
All	2,6	3.1	System must not have access to change or reprogram the menu-based software.

		3.2	User must have access to the menu via the remote control.
Show Broadcast Schedule	3	4.1	Schedules must be loaded in less than 0.5 seconds.
Watch Program	4,5	5.1	System must allow user to pause, or hold, video playback.
		5.2	System must provide user with 3 rewind speeds defined as 2X playback, 3X playback, and 5X playback.
		5.3	System must provide user with 3 fast forward speeds defined as 2X playback, 3X playback, and 5X playback.
Show Broadcast Schedule	3	6.1	System must allow the user to search for programs, using the remote control, by program title, channel, genre, or time.
Schedule Recording, Record Program	3,6	7.1	System must inform user when the hard drive is 95% full.
		7.2	System shall not record additional video if the hard drive is 100% full or if the entire program will not fit with the space available.
		7.3	System hard drive must be able to access recorded programs within 0.5 seconds of user request.
		7.4	System hard drive must have a capacity to record at least 50 hours of programming.
Record Program	4,5	8.1	System must continue recording program even if previously recorded program is still recording.
Initial Set Up, Update System	1,2	9.1	System must provide a standard phone (modem) connection and Ethernet (RJ45) connection.
		9.2	System must connect at the standard baud rate for phone connection and standard data rate for RJ45 connection.
Update System	2	10.1	System must communicate with specified cable/DVR service provider based on user input and identification.
Initial Set Up, Update System	1,2	11.1	System must use standard, industry accepted, interfaces and connectors for hard drive, processor, memory, and any other components.
		11.2	System must use standard, industry accepted hard drives.
Record Program	3,5	12.1	System must be able to convert a standard video signal into a corresponding digital representation.
		12.2	System must be able to stream digitized video to a storage device in line with digitization.
Watch Program	3,4,5	12.3	System must be able to regenerate digitized video using a commercial video standard parallel to digitization and storage in “real time”.

System Structure and Behavior

The class diagram below shows the basic hardware structure of the system with a focus on the high-level components, such as video I/O ports, other I/O connectivity, storage devices, and processor. Minor interface objects and circuitry have been omitted.

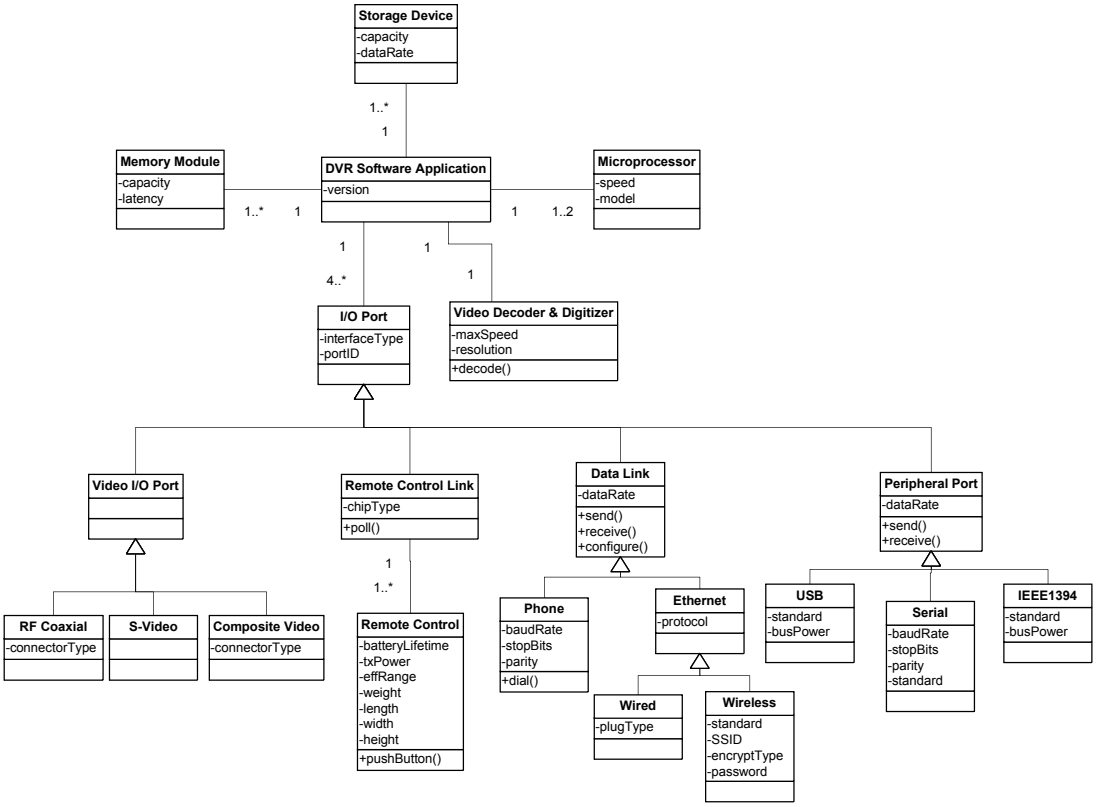


Figure 4. System Hardware Class Diagram.

The next class diagram shows part of the software architecture, specifically the relationship between the two schedules (broadcast and recording) and the items that comprise them (channels, programs, subscriptions, and recordings).

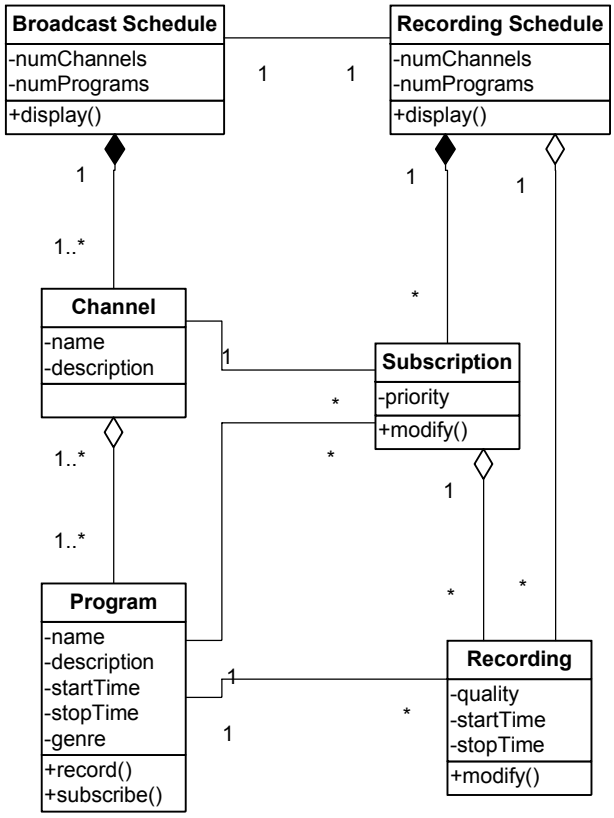


Figure 5. System Software Class Diagram.

The sequence diagrams below show some of the system behavior using these defined structure objects:

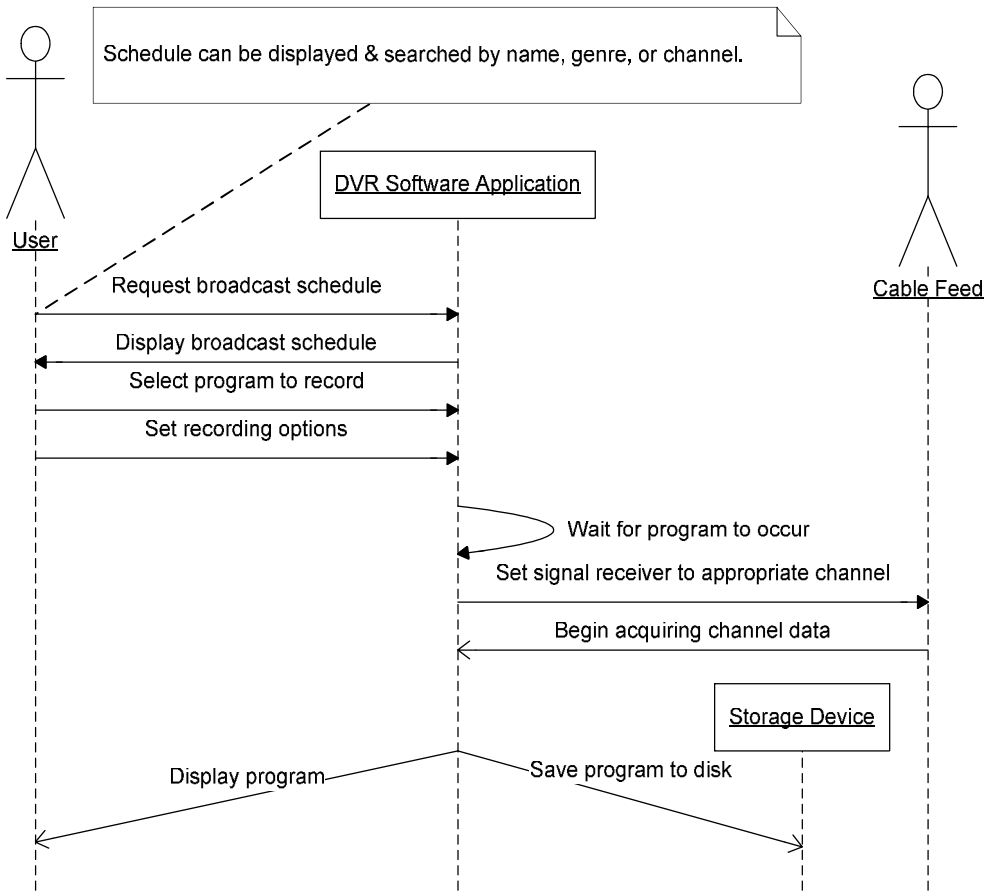


Figure 6. Sequence Diagram for Use Cases #4 and #5.

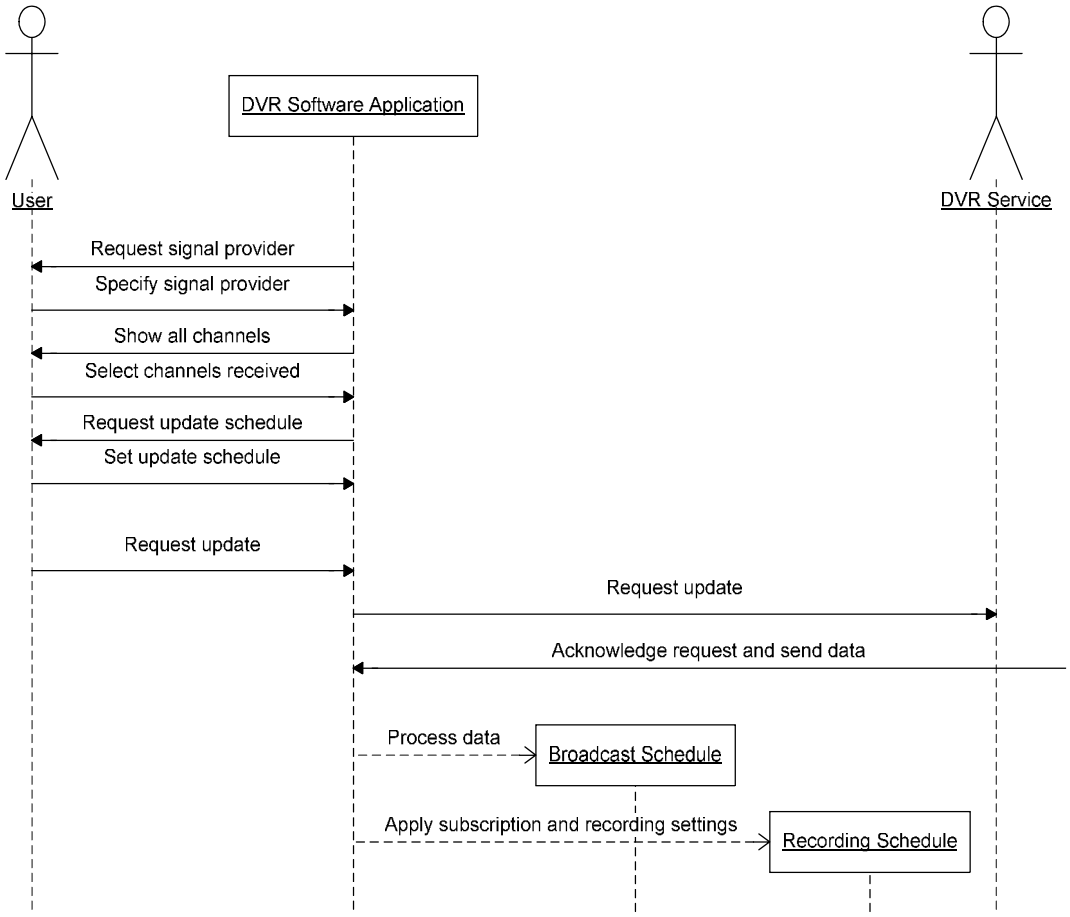


Figure 7. Sequence Diagram for Use Cases #6 and #7.

Resource Allocation Table

The following table shows the relationship between the low-level requirements and the system structure objects defined in the preceding class diagrams:

Req. No.	Structure	Behavior
1.1	Video I/O Port, RF Coaxial	Signal degradation must be less than 3 dB.
1.2	Video I/O Port, RF Coaxial	Signal degradation must be less than 3 dB.
1.3	Video I/O Port, RF Coaxial, S-Video, Composite Video	Signal strength must be at levels compatible with consumer video electronics.
1.4	Video I/O Port, Composite Video	Signal strength must be at levels compatible with consumer audio electronics.
2.1	DVR Software Application, Remote Control Link	Remote control implementation will use industry standard protocols and chipsets.
2.2	Remote Control, Remote Control Link	Remote control will have transmit power and Remote control link will have sensitivity that

		will guarantee communication within 30 ft range with minimal error rate.
2.3	Remote Control, Remote Control Link	Remote control implementation will use industry standard protocols and chipsets.
3.1, 3.2	DVR Software Application, Remote Control, Remote Control Link	System software will provide accessible menus via remote interface that allow user to view and control system settings.
4.1	DVR Software Application, Remote Control, Remote Control Link, Microprocessor	Software architecture and processor speed must be selected as such to guarantee given response time.
5.1, 5.2, 5.3	DVR Software Application, Remote Control, Remote Control Link	Remote control will be designed to provide buttons for basic player functionality (play, pause, record, rewind, fast forward) and software will have functions to react appropriately to each button.
6.1	DVR Software Application, Broadcast Schedule, Remote Control, Remote Control Link	System software will provide search capabilities of schedule based on name, time, channel, or genre as specified by user via remote.
7.1, 7.2, 7.3, 7.4	DVR Software Application, Storage Device, Recording Schedule, Remote Control, Remote Control Link	System storage drives will be selected to match capacity and data rate requirements; system software will monitor state of drives and alter recording schedule as needed.
8.1	DVR Software Application, Storage Device	System software will be architected so that access to files on storage drives can be achieved from parallel processes of application.
9.1, 9.2	Data Link, Phone, Ethernet	Standard phone & Ethernet components will be used in system to be compatible with existing networks.
10.1	DVR Software Application, Data Link, Remote Control, Remote Control Link	User must be able to specify identification criteria to be checked by system and control access to DVR service.
11.1, 11.2	Memory Module, Storage Device, Microprocessor, I/O Port, Video Decoder & Digitizer	As much as possible, COTS components will be used to minimize cost, improve ease of component repair or replacement, and provide modular design options.
12.1	Video Decoder and Digitizer	Component must have conversion speed capable of maintaining standard video frame rates (typically 30 fps).
12.2	Storage Device	Storage drives must have data read/write rates greater than data footprint of one frame times 30 frames per second.
12.3	Storage Device, Video I/O Port, Video Decoder and Digitizer	System components must perform signal digitization, storage, and regeneration with end-to-end delay of less than 1 millisecond.

System Specifications

Based on the high level requirements identified, quantitative and qualitative specifications have been determined.

1 System must provide video I/O of formats and using connectors that are compatible with consumer video standards.
- 1.1 Standard consumer grade video and audio plugs are provided on the back of the machine including coax cable, RCA (audio and video), S-video, and optical audio.

2 System must have a remote control.
- 2.1 The remote control will have a logical button and control layout.
- 2.2 The remote control will allow the user to access all menus needed and all functions needed to control the DVR scheduling, recording and playback functions.

3 System must have menu-based software interface that can be navigated by the user.
- 3.1 The menus will be accessible by the remote control or the front of the DVR box (limited functionality on the DVR box).
- 3.2 The menus will allow the user to perform all needed DVR functions.
  - 3.2.1 A scheduling menu will be provided.
  - 3.2.2 A playback menu will be provided.
  - 3.2.3 A recorded programs menu will be provided.
  - 3.2.4 A system set-up and update system menu will be provided.

4 System must have displayable and searchable schedules of all programs.
- 4.1 Schedules will be navigated and selected via the remote control.
- 4.2 All schedule selections will allow the user to set recordings via the search schedule menu options.
- 4.3 The menu options will be shown on the screen and programs will be listed.
- 4.4 User will be able to search and display schedules based on program broadcast time, genre, title, and channel.
- 4.5 Schedules will be uploaded to the DVR system from the cable feed service.

5 System must provide user standard video player functions.
- 5.1 Video playback functions will be controlled by the remote control and by buttons on the front of the DVR box.

6 System must provide user ability to specify programs to record.
- 6.1 Program choices will be displayed on the television via a list from the main menu option.
- 6.2 The user will select the programs to record using the remote control.

7 System must have digital storage media for recording programs for future retrieval.

7.1 The digital storage media will be a hard drive with a capacity of at least 50 GB.
7.2 The system will access recorded programs within 0.5 seconds of user request.
7.3 The hard drive will have a standard interface within the DVR box.

8 System must be able to access a recording as it is being written to the storage media.
8.1 The user will have access to currently recorded programs via the remote control.
8.2 The system will continue to record scheduled programs while the user watches another channel or the currently recorded program.

9 System must have a data link to connect to a data service.
9.1 Standard consumer grade phone and Ethernet plugs are provided on the back of the machine.
9.2 The system will automatically detect which type of interface is connected and connect to the cable provider accordingly.
9.3 The system will be able to connect to the cable service at the transfer speeds allowed by the service.

10 System must provide user the ability to get and set system configuration parameters.
10.1 System set up and configuration parameters will be accessible via the remote control and buttons on the front of the DVR box.
10.2 User will have access to global recording options such as time to record, first-run recording, series recording, clock options, and update system frequency options.

11 System must be built from Commercial Off-The-Shelf (COTS) components.
11.1 All internal components will have industry standard interfaces to allow for simplified repairs.
11.2 No new technologies will be developed for the internal components.

12 System must be capable of digitizing, recording, and displaying a standard video signal input.

System Validation and Verification

One of the final steps in the systems engineering process is to look back and perform validation and verification. Validation checks that the design matches the intended purpose of the system and that all stakeholders are satisfied. Verification checks compliance with established requirements developed during the process.

The V-Model of System Development promotes the hierarchy of requirements development. Beginning with the stakeholder requirements, system and then subsystem and component requirements are developed. The same model recommends performing validation and verification using a similar hierarchy.

The table below shows the verification plan for each major and minor design requirement. Following the table is a list of the Verification String Numbers used.

Design Requirement	Verification Method				Level of Application
	Test	Analysis	Demo	Exam	
1.1, 1.2, 1.3, 1.4	VSN-1				Component
2.1, 2.3			VSN-2		Component
2.2	VSN-3				Component
3.1				VSN-4	System
3.2			VSN-2		Component
4.1	VSN-5				Component
5.1			VSN-6		System
5.2, 5.3	VSN-7				Component
6.1			VSN-8		System
7.1	VSN-9				Component
7.2	VSN-9				System
7.3	VSN-10				Component
7.4		VSN-11			Component
8.1			VSN-12		System
9.1				VSN-13	Component
9.2			VSN-14		System
10.1			VSN-15		System
11.1, 11.2				VSN-13	Component
12.1, 12.2, 12.3	VSN-16				System

VSN-1: Video (with corresponding audio) test signal will be generated and sequentially routed to each input connection on the system. Corresponding output will be measured and compared to the original. The test will be considered a success in the generated and reacquired signals match.

VSN-2: Using a sample set of standard remote controls, a tester will demonstrate that the system responds to each input button on the remotes. A visual or audio response is required for each possible input. The demonstration will include navigating a subset of the software system's menus.

VSN-3: A remote will be placed 25 feet from the system. A particular signal will be generated manually from the remote and the response of the system will be monitored. If the system responds correctly, the remote will be placed back one foot and the process repeated to estimate the range of the remote. The test fails is range is less than 30 feet.

VSN-4: Software architecture and deployment practices will be examined to ensure software cannot be modified by the system itself.

VSN-5: A test system will provide external stimulus akin to a remote control request to display the broadcast schedule. The video output of the system will be monitored and the time between input stimulus and change in the video output (to show the schedule) will be measured. Test fails if time is greater than 0.5 s.

VSN-6: A tester will demonstrate standard video control features on a remote and the corresponding functionality executed by the system in response.

VSN-7: A test system will provide signals for increasing and decreasing playback speed of a recording of known length. System will be monitored to determine when recording ends. A timer will determine if playback speed is set to the rates specified by the requirement.

VSN-8: A tester will demonstrate the different search criteria available via the remote and menus to search the schedule. Programs will be selected based on name, channel, genre, and time.

VSN-9: A test application will write random binary data to the system storage device at a set data rate. Capacity will be monitored in parallel, and when 5% available space is reached, an alert is expected to be seen on the video output. If this alert does not occur within 1 s of reaching 95% capacity, the test is a failure. At this point, the test application will attempt to set a recording that would take up 6% of the storage drive. If this request is allowed, or an alert is not generated, the test fails.

VSN-10: A playback requested will be generated by a test system. Video output will be monitored to make sure playback occurs within 0.5 s of request; otherwise the test is a failure.

VSN-11: Analysis will be performed on expected output rate of video decoder and digitizer, expected data footprint per frame, and frame rate used to determine total data footprint per hour of recording. Storage capacity must be at least 50 times 105% of this for analysis to pass.

VSN-12: While the system is recording one program, a tester will demonstrate manipulating the playback of that program as well as displaying an older recording.

VSN-13: All interface ports and hardware will be examined to determine that they are COTS components. Each COTS component should have supplier information (vendor name and part #).

VSN-14: Connections to the DVR service will be demonstrated using both phone and Ethernet connections. Connection settings will be varied to show that common phone & Ethernet parameters are controllable via the system interface.

VSN-15: A tester will demonstrate inputting user identification information into the system and then connecting to the DVR service. A connection denial will be demonstrated for incorrect user information.

VSN-16: An input A/V signal will be generated from a test system. This signal will be digitized by the system's video decoder & digitizer. The test system will reacquire the original signal and the resulting digitized output and compare them. If they differ beyond a tolerance level, the test fails.

The system will also write this digitized data to disk. That will in turn be read by the test system and compared to the original. Again, any significant difference results in a failure.

Lastly, the test system will acquire the regenerated video output of the system and compare it to the original. The phase difference of the signals will be determined to estimate system delay. If this value is greater than 0.1 s, or the output signal differs from the original, the test fails.

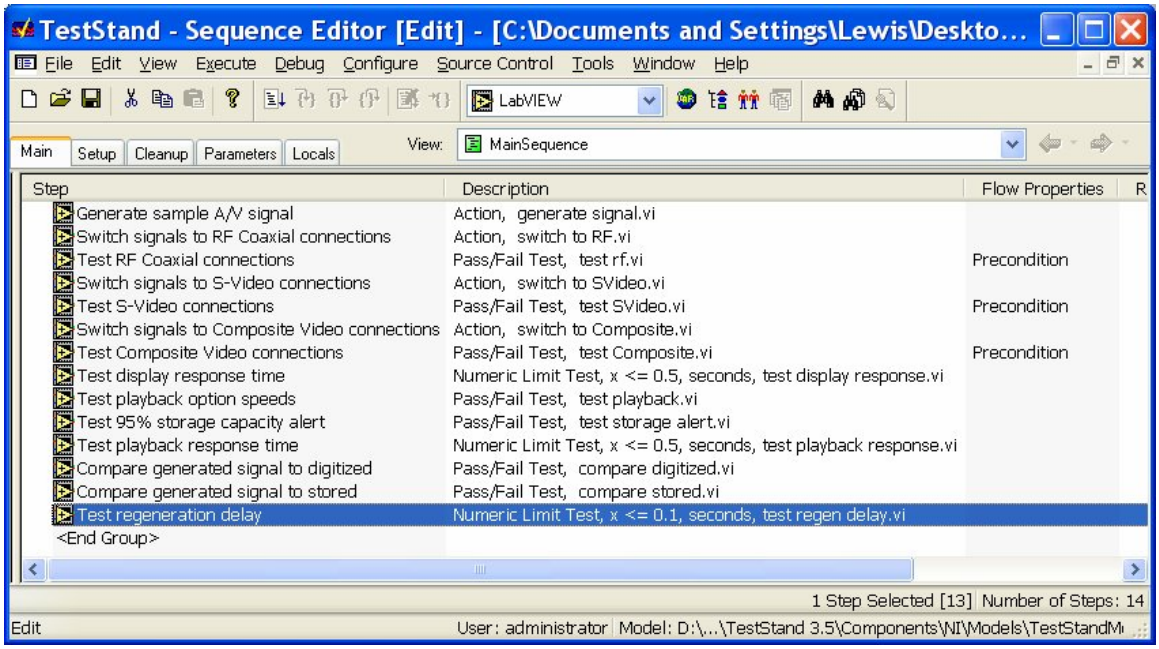
The steps listed above should provide validation of the high-level stakeholder goals as well as the lower level system and component requirements.

System Test Plan

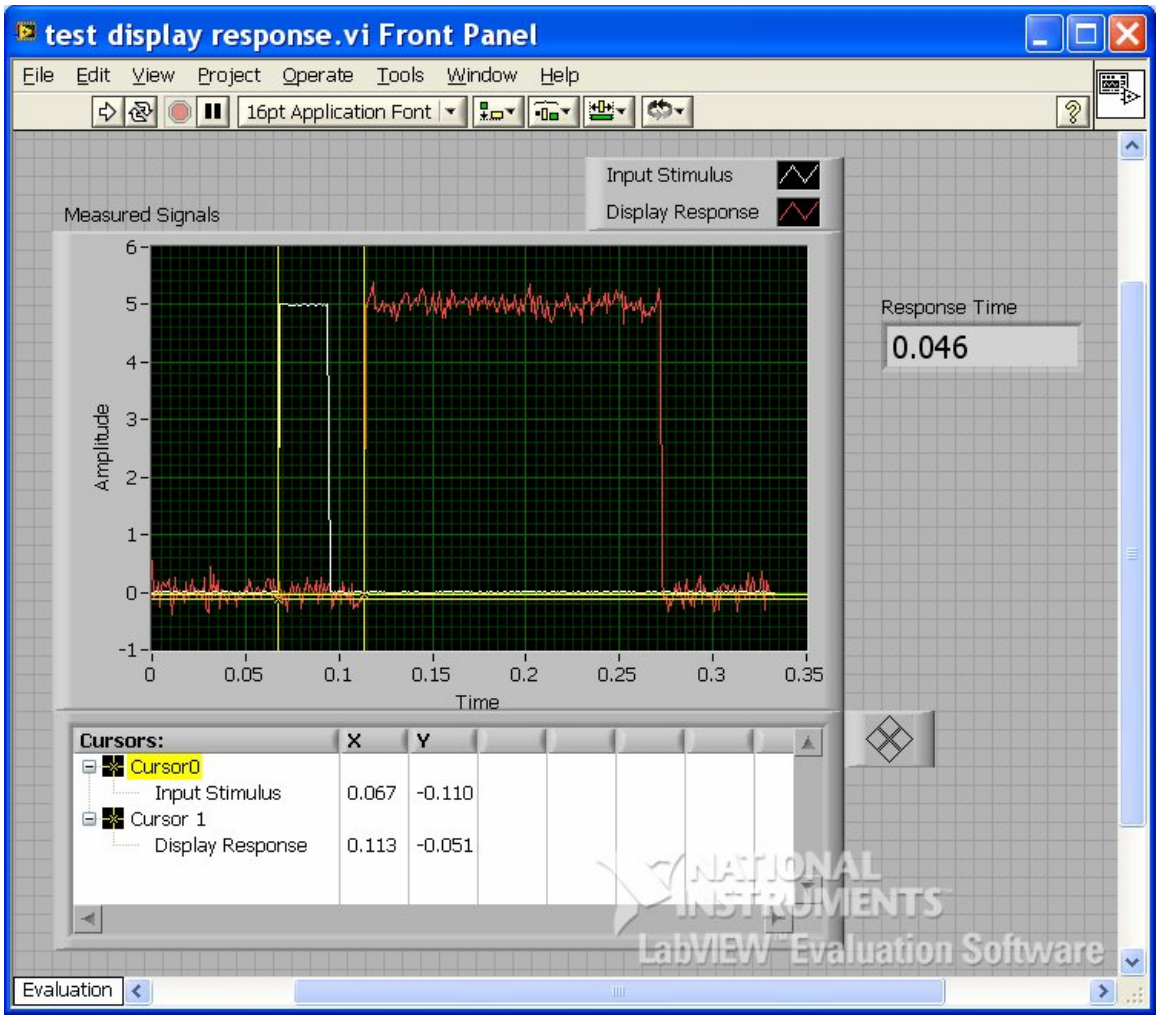
Using the verification traceability matrix in the prior section, a test plan for a DVR system can be put together. Such a test would have specific hardware requirements, such as a high speed arbitrary waveform generator, a high speed digitizer, software capable of encoding & decoding typical A/V signals, and signal switching. The software side would require a development environment to program test steps and a test executive to manage the test plan and generate reports.

For the example plan to be presented, we will ignore the hardware portion and focus on the software. The test executive used will be TestStand. The development environment will be LabVIEW. Both packages are products of National Instruments.

Below is a screenshot of the test sequence for the test steps in the verification traceability matrix:



Below is a sample screenshot for one of the test steps (specifically Test Display Response Time):



(NOTE: due to a last minute computer failure, the development software had to be loaded on a secondary machine for last minute edits and screen captures. Unfortunately this system could only run the software in evaluation mode. Please disregard the evaluation watermark in the previous screenshot.)

Finally, a sample test result report is shown below. The original report was generated as HTML.

UUT Report

- **Station ID:** **DARTH**
- **Serial Number:** **123456**
- **Date:** **Tuesday, December 12, 2006**
- **Time:** **4:50:56 PM**
- **Operator:** **administrator**

- **Execution Time:** **12.8912616 seconds**
- **Number of Results:** **14**
- **UUT Result:** **Failed**
- **Failure Chain:**

Step	Sequence	Sequence File
Test S-Video connections	MainSequence	DVR Test Plan.seq

Begin Sequence: MainSequence
(C:\Documents and Settings\Lewis\Desktop\ENPM 643 Project\DVR Test Plan.seq)

Generate sample A/V signal	
Status:	Done
Module Time:	0.0505265

Switch signals to RF Coaxial connections	
Status:	Done
Module Time:	0.0425434

Test RF Coaxial connections	
Status:	Passed
Module Time:	0.3735321

Switch signals to S-Video connections	
Status:	Done
Module Time:	0.0479745

Test S-Video connections	
Status:	Failed
Module Time:	0.3591683

Switch signals to Composite Video connections	
Status:	Done
Module Time:	0.0506254

Test Composite Video connections

Status:	Passed
Module Time:	0.4270384

Test display response time

Status:	Passed
Measurement:	0.046
Units:	seconds
Limits:	
Low:	0.5
Comparison Type:	LE (<=)
Module Time:	0.2553766

Test playback option speeds

Status:	Passed
Module Time:	2.7257213

Test 95% storage capacity alert

Status:	Passed
Module Time:	4.4399643

Test playback response time

Status:	Passed
Measurement:	0.4259579383826
Units:	seconds
Limits:	
Low:	0.5
Comparison Type:	LE (<=)
Module Time:	0.7439138

Compare generated signal to digitized

Status:	Passed
Module Time:	0.9445768

Compare generated signal to stored

Status:	Passed
Module Time:	1.7545529

Test regeneration delay

Status:	Passed
Measurement:	0.0450021685328

Units:	seconds
Limits:	
Low:	0.1
Comparison Type:	LE (<=)
Module Time:	0.4884325

End Sequence: MainSequence

End UUT Report