DVD+RW Recorder

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1. ABSTRACT

DVD+RW optical disc recorder is a consumer device combining features of a DVD player and a Video Cassette Recorder (VCR). Philips Consumer Electronics is currently developing the first generation of such appliance. Although this device is a first-of-a-kind, both DVD and VCR are already being produced by Philips. To facilitate reuse and shorten the development lead-time, it has been decided to reuse the software stacks from both DVD and VCR as much as possible.

However, both stacks were developed with the assumption that they are sole agents in a “box”, i.e. they have full control of the user interface including displays (TV screen menus, front panel display) and input devices (remote control unit, front panel keys). Still, the two subsystems need to be combined into one system without causing a substantial redesign of them.

So, here’s the design challenge:
What kind of mechanism can you think up so that the subsystems still think they are in control whereas they actually are cooperating?

Examples of constraints to this design problem are:

The subsystems operate independent from each other and even run on separate processors. Both can initiate user interaction and respond to user inputs, even the same ones. E.g. a digit key 3 on the remote control is interpreted by the DVD subsystem as “play track 3 of the DVD disc” while the VCR can interpret this as “switch to channel 3 on the TV”.

Another example conflict occurs when the user is operating a DVD screen menu like setting the preferred subtitle language and suddenly decides to program a recording timer. The latter is a VCR functionality, so the VCR subsystem needs to get into control of the TV screen.

2. DESCRIPTION OF A DOMAIN/ANALYSIS

When comparing the system with currently available Consumer Electronics products, one could see the system as an ordinary VCR with a DVD+RW drive instead of a tape. In this system the tape is replaced by an optical disc.
In all these products one common part is distinguished, called the media-independent part. It is able to control each kind of storage medium regardless of the type. In fact, it could deal with tapes, optical drives or even a hard-disk. Building a

new product with another type of storage medium, shouldn't have an impact on the media-independent part.

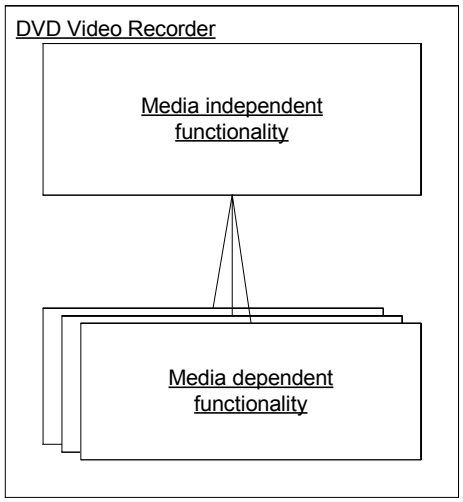


Figure 1 DVD Video Recorder platform concept

This model is used as the starting point to decompose the system into subsystems. How this is done will be explained in the next section.

2.1. SUBSYSTEM APPROACH

A very important requirement for the development of the system is a fast time-to-market. One way to accomplish this is to apply an approach where reuse of available components can be maximised. This in order to limit the total needed development effort. Another important issue is the encouraging of concurrent development. The latter requires that parts of the system can be developed totally independent on the rest of the system. The rest of this section will explain why subsystems are introduced in the architecture and how they address reuse and concurrent development.

The goal of the subsystem approach is to partition the system in subsystems in such a way that independent blocks appear with well-defined responsibilities. These blocks take care of their individual responsibility with as less as possible interaction between each other. To accomplish this, each block contains its own User State Machine (USM) and its own resources (HW and drivers).
Instead of developing these subsystems again, reuse can be done from currently available systems. In fact, the needed subsystems behave much like these currently available systems. They too have one USM and have complete control upon their input and assume that all needed resources are always available.

The currently available DVD and VCR systems together cover the main functionality of our system. The subsystem that covers all DVD functionality is called Playback Subsystem (PBS). The subsystem that covers all VCR related functionality is called Recording Control Subsystem (RCS). See Figure 2. Unlike PBS, RCS is media-independent as all tape related functions are removed and covered by PBS.

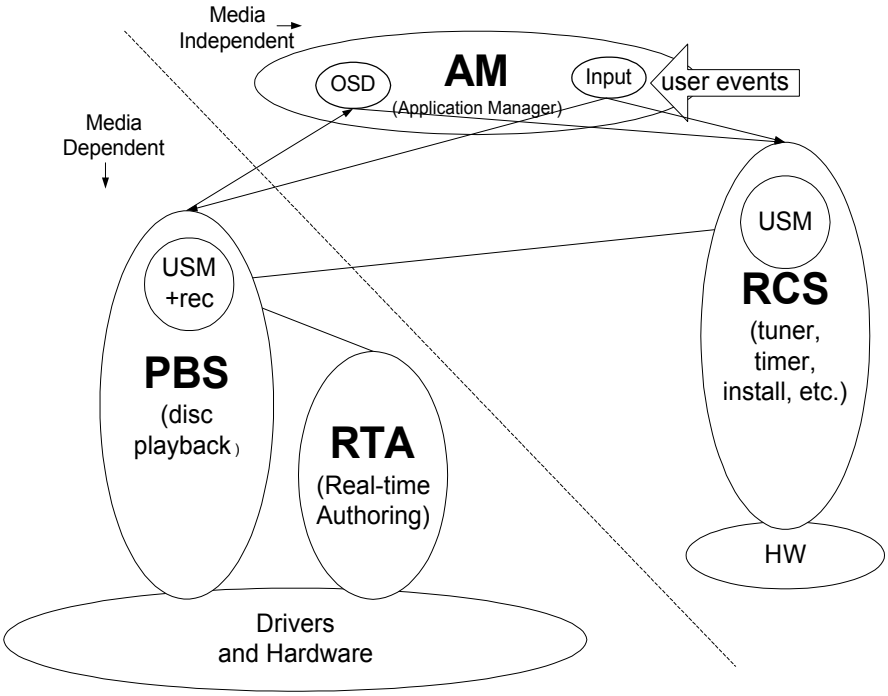


Figure 2 Conceptual view on subsystems

All functionality related to DVD-authoring is done in the Real-time authoring (RTA) subsystem.
Although RTA is controlled by PBS, they are separated from each other. This because of the complexity and the very nature of RTA: Real-time recording is a different kind of functionality then playback of a disc. However, PBS can easily be extended to cover the RTA states. So, RTA has no USM and is considered to be a slave subsystem of PBS.

Ideally, subsystems are independent and do not share resources. In practice however, a lot of resources are shared: drivers and hardware. Every hardware function that is shared amongst subsystems is considered to be a resource. How the system deals with resources in general is described further in section 2.3.

In general, user input and output can be considered as shared resources between the subsystems. In order to avoid I/O sharing conflicts some simple operating system I/O services are added.
To avoid the complexity of a windowing system simple services are provided instead. This results in the following constraint that only one subsystem can have output on the screen at the time.
With regard to user input special precautions have to be taken in order to avoid race conditions whenever events are pushed into the system. So, processing of user events has to be managed by a centralised input controller. This input controller will dispatch the incoming events to the correct subsystems depending on the current system-state.
The Application Manager subsystem (AM) is introduced to provide the operating system I/O service to these main subsystems.

The systems we used to build before (like DVD and VCR) had one monolithic large USM. This concept was easy because there is one module that has overall control. In this way sharing conflicts of resources can be resolved at a high level. As a consequence of applying the subsystem approach, our system on the other hand has to deal with several distributed USMs. They are inherited by merging the DVD and VCR systems. As multiple subsystems can be involved when processing a user event, state transitions in the USMs of the various subsystems should be synchronised.

2.2. SUBSYSTEMS

The following subsystems are defined:

1. **Application Manager (AM)**
   AM provides some operating system like services to allow co-operation between subsystems: e.g. input event dispatching (from remote control, local keyboard, P50 link), user feedback (on-screen display / local display).

2. **Playback Subsystem (PBS)**
   PBS contains all media specific applications: Playback of all supported disc types and master of RTA. The latter means that it contains the control applications related to DVD recordable discs (e.g. editing). PBS provides services for on-screen display.

Responsibilities:

- Playback of all required disc types.
- Disc loader and recognition
- Present Table of Contents (In case of a DVD+RW disc, this is partly covered by the DVD-Video format)
- User interface for editing application (title operations)
- Manages the 'video background switch': selects running video or still background picture.
- 'No disc' application
- Handle title/disc manipulation screens and edit screen (erase title, delete chapter marker)
- Main (system) menu.
- On-screen display (OSD) control

3. **Recording Control Subsystem (RCS)**
   RCS represents the media independent part of the system. Included are timer programming, tuner, A/V-selection and standby.

Responsibilities

- Provide control functions for the following recording functions:
  - Immediate recording (start record from current selected input)
  - One-Touch Recording (OTR) (to limit the length of the recording)
  - Direct record (from standby – record the same channel as currently on the TV set)
  - Record prepared recording (start recording after an external trigger)
  - Timer programming (Add, edit and clear a timer)
- Trigger PBS to start or pause/continue recording.
- Provide user interface and control functions for the following Installation functions:
  - Auto-install + sorting of TV Channels

    - Manual Install
- Tuner control
- A/V-routing (i.e. providing RTA with a proper A/V signal and sending the A/V signal produced by PBS/RTA to rear connectors)
- Settings (E.g. Recording settings, etc.)
- Low level P50 I/O processing and output generation (on high level P50 events can be treated equally to user events).
- Standby Control

4. **Real Time Authoring Subsystem (RTA)**
   The subsystem RTA records audio/video data to a DVD+RW disc in the DVD format. The External A/V-stream is not only encoded to MPEG and recorded to disc, but also decoded and routed back to the RCS subsystem.

Because PBS and RCS run on different processors, the only communication between them and AM is through asynchronous events (with optional data)

2.3. RESOURCES

As a result of assigning responsibilities and consequently corresponding tasks to subsystems, some common functionalities can not be allocated to just one subsystem. This is reflected by the common Drivers and Hardware block in Figure 2. Instead, some of these key-components are used by multiple subsystems. In that case they are considered as resources.

The following important shared resources are identified:
- Decoder: A/V data is put on the disc on a compressed form called MPEG. Decoder is a device used to decode compresses MPEG stream. This device is used by PBS during playback and displaying the Table of Contents (TOC) and by RTA during recording.
- Basic Engine: a DVD+RW drive allowing pro reading and writing of DVD discs. Shared between PBS (playback, TOC) and RTA (recording).
- On-Screen Display (OSD): Pixel-based display overlaid on top of the A/V output of the recorder. Can only be visible with a TV set connected to the recorder A/V output. This is the main means for the user interface display of the recorder.
- Local Display (LD): a small display device using light-emitting diodes (LEDs), put on the front of the recorder, providing the uses with compact information about the disc content and the recorder state.
- User Input: There ate three types of it: (1) using the remote control (RC), which is the most common and most sophisticated; (2) local keyboard – a few buttons put on the front of the recorder, realising the most important functions (e.g. On/Standby); (3) P50 which is remote control relayed through a TV set.

3. DESCRIPTION OF THE MECHANISM THAT IS WANTED

To simplify the problem, we will consider here only the problem of sharing three types of resources:
- On Screen display
- Local Display

- Local Keyboard/Remote Control (User Input)

Also, we will not consider further RTA in this picture.

A mechanism is needed that will allow the two major subsystems, RCS and PBS, to co-operate together such that both can keep their user state machines and user interfaces unchanged. This mechanism is to be implemented by AM, which is the "glue" between the subsystems and the outer world. It is allowed to change the communication interfaces of those subsystems, what is also the minimum change that is needed, since originally both subsystems communicated with the environment themselves, but now it must be done through AM.

Specifically, we require the following changes in the existing subsystems:

3.1. RCS

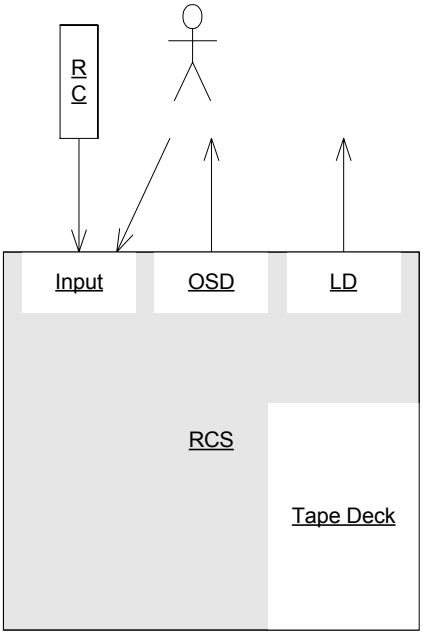


Figure 3. Original RCS communicates directly with the user through its own RC Controller, Local Keyboard, On-Screen Display, and Local Display.

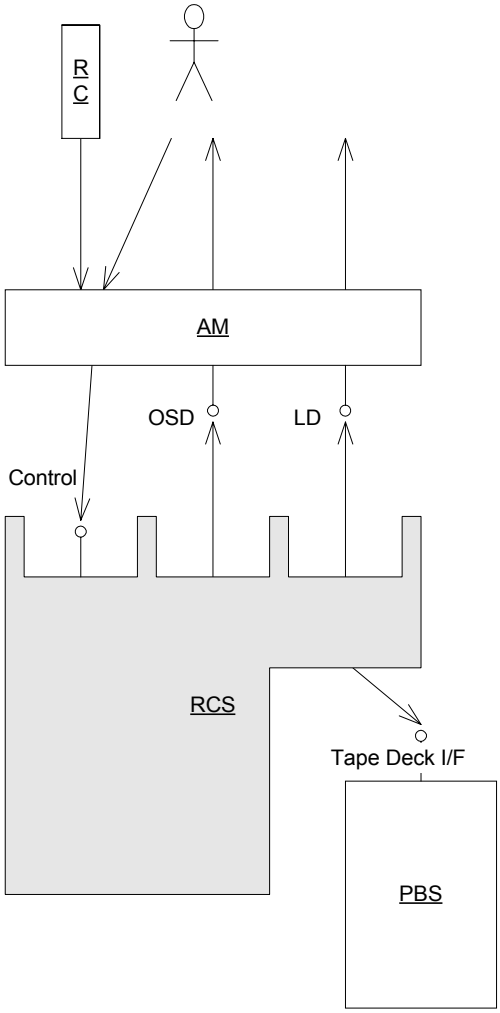


Figure 4. RCS adapted for DVD+RW has removed input code, OSD, LD. AM provides now that functionality exporting the same interfaces. The input interface may change if the proposed mechanism needs more control of AM over RCS or vice versa. Also the tape deck part is removed and replaced by PBS functionality. In our exercise, we will not take this last fact into consideration.

3.2. PBS

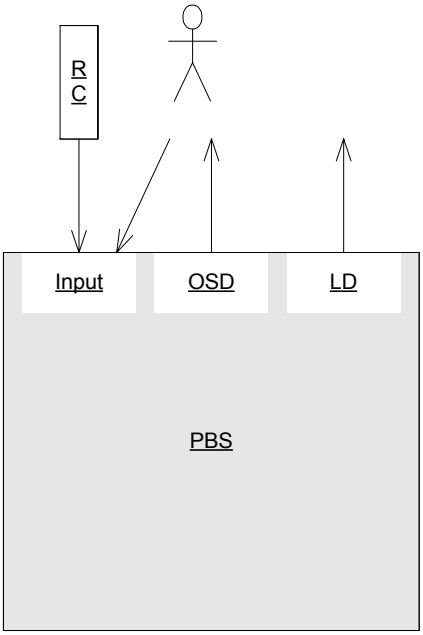


Figure 5. Also original PBS has its own input and output code.

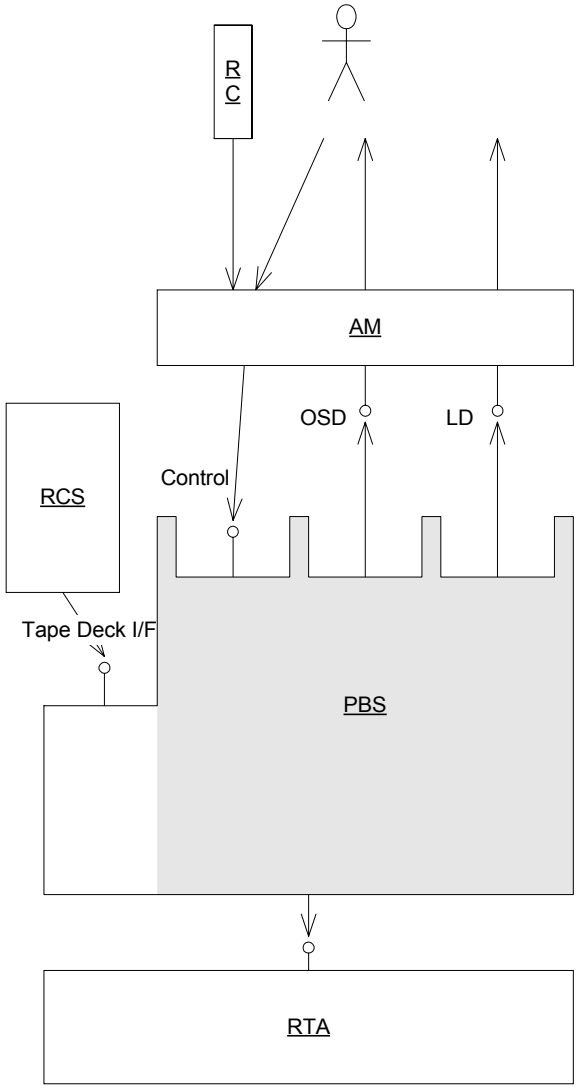
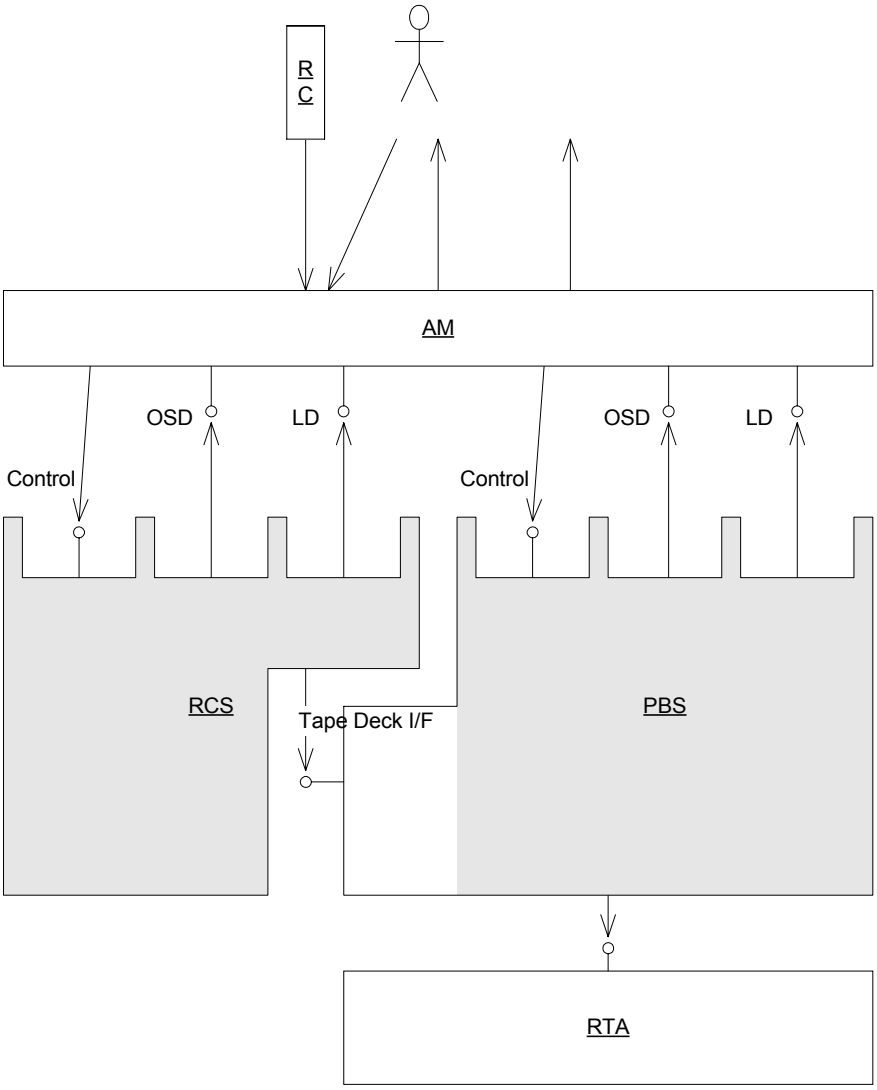


Figure 6. As in case of RCS, this code is removed and the functionality is provided by AM. Additionally, PBS has to provide the deck control interface to RCS and control RTA. The latter is not part of our design problem discussed here.

For completeness, here is the whole puzzle:



3.3. ADDITIONAL REQUIREMENTS

The mechanism must cause no more changes than shown above.

The mechanism should be defined as a simple set of rules that the subsystems must follow, and at the same time, that are clear enough to lead directly to the design of AM and the new control interfaces of subsystems. The structure of new control interfaces should be similar to the original input events.

The mechanism should be extensible to N-subsystems, (future-proof, when we decide to integrate additional existing appliance, e.g. Super Audio CD. In such case, of course, the use cases and scenarios would change, but the mechanism should be sufficient).

The mechanism should be flexible enough to accommodate changes in scenarios (because of changes in requirements or because of late bugs in scenarios).

4. DETAILED REQUIREMENTS

4.1. INPUT

Some key presses have a different meaning when depressed for a longer time. The mechanism should allow for distinguishing short and long key presses. Note that the system has to react on key down event, not key up.

User events from the remote control, local keyboard, P50, although all received by AM by different means, are semantically the same and may be regarded as indistinguishable from each other. Below is the list of those events. Note however that P50 protocol requires that a command received has to be acknowledged (accepted or aborted). This means that all user events forwarded to subsystems must be acknowledged to AM.

User events:

clear	Depending on context: eg. In timer overview list: delete timer; in edit text field (as when changing disc name): delete character.
digit (numeric keys [0..9])	In TOC: play title number [pressed number]; in tuner view: switch to channel [pressed number], in other contexts: literal (eg. type start time when programming a timer).
dim	Dim local display (RCS)
TV/DVD	Switch between TV and DVD screen (Signal on P50 – RCS)
disc_menu (root menu)	Jump to TOC (PBS)
edit	During playback: enter edit menu (PBS), during recording: set bookmark (PBS)
enter/OK	Context specific: accept; in TOC: play selected title
ff, fr (=speed)	Fast forward, fast reverse (playback). In TOC, navigation within the title. (PBS)
manual gain, rec volume+/-	Volume control (RCS)
open_close,	This is a toggle, before the tray may be opened, all system activities (playback, tuner, recording, menus) must be stopped
P+/-, alt	Change channel; not allowed during recording (unless recording is paused)
pause,	Pause playback or recording. When already playback is paused: skip one frame forward.
play	In TOC: play selected title. In DVD play: jump to resume position (where playback was last stopped).
power_off	As in open tray case: all activities must be ended before power down.
power_on	Wake up the system and bring it to TOC
prev, next	In play: jump to next/previous chapter; in TOC: jump to next/previous title.
rec	Start recording; during recording, set end time, if pressed within 5s from start
repeat, repeat A-B, shuffle, intro-scan	Playback features (PBS)
select	In menus, selects items from lists
slow (+jog-shuttle)	Playback features (PBS)
standby	Switch off the set; wake up on timers
step_fwd, step_rev	Playback features
stop	Stop playback or stop recording (but not timer recording)

sys_menu	System menu invocation: main menu controlling a.o. system default settings, recording mode, preferences, but also a number of DVD playback and navigation features: played title, chapter, language, camera angle, subtitles etc.
timer,	Open a timer menu (add new timer, list timers, delete timer)
title/chapter	Short cut to title/chapter navigation entries in system menu
Tuner	Toggle between TOC display and tuner or external input preview (i.e. what will be recorded when “record” is pressed)
up, left, down right	General navigation keys for menus and TOC
Zoom, angle, subtitle, audio	DVD playback features

4.2. OUTPUT

Subsystems are used to full screen output. This must remain so or AM provides a special mechanism, invisible to subsystems, if it wants to show output of both subsystems at the same time.

Output of both subsystems is a collection of icons and/or menus. PBS generates its OSD output in a form of semi-transparent pixmaps. RCS generates text output.
Both subsystems put their OSD on three types of background:

- Still picture
- TV tuner input signal
- DVD disc that is played back

Switching between all three types of backgrounds is under PBS authority. Therefore, RCS has a problem: originally it was in charge of background for its OSD, now it has to tell PBS in a way to create appropriate background. Of course, this must happen only then the RCS output is shown to the user, so it must be part of the AM mechanism as well.

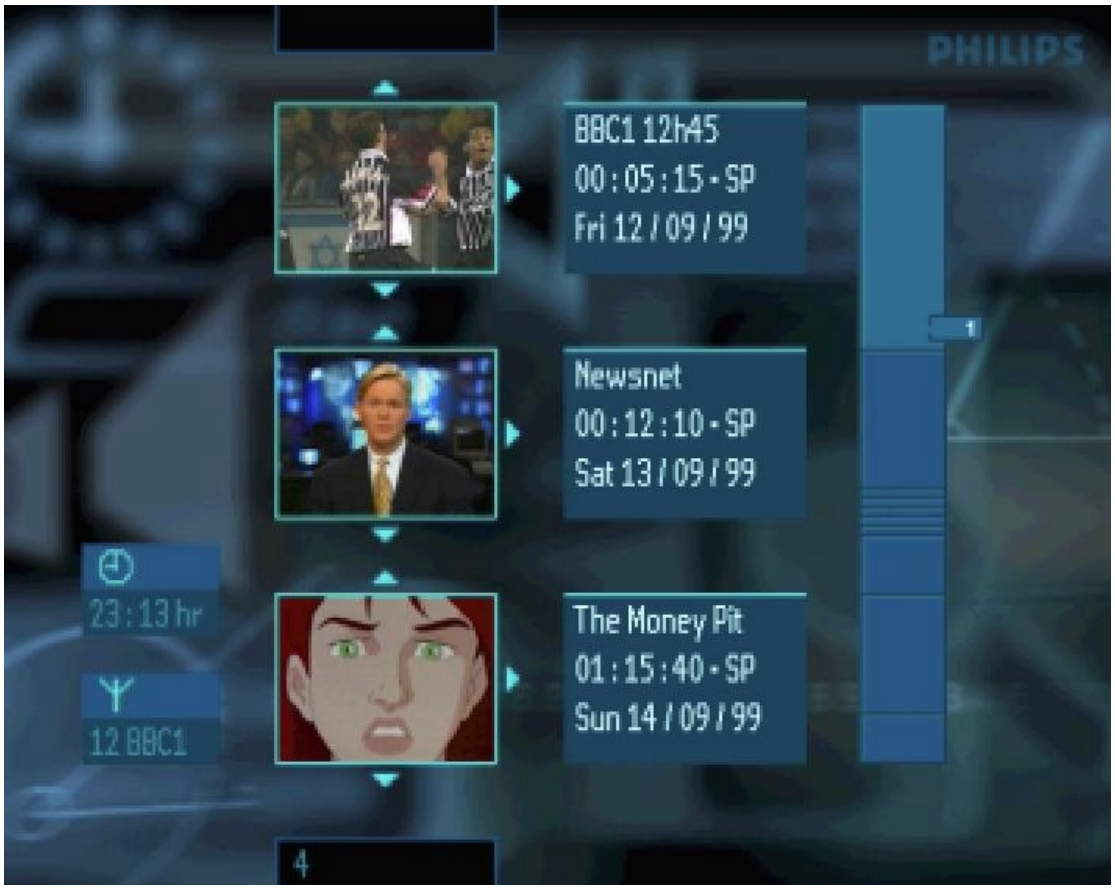
4.3. ABBREVIATIONS

A/V	audio and video
AM	Application Manager – a special component on the DVD recorder software that allows for co-operation of the existing legacy systems, PBS and RCS.
CD	Compact Disc – read-only optical medium for audio and general data, invented by Philips and Sony; capacity 650 MB.
DULDROS	digit, up, left, down, right, OK, select – set of common navigation keys of audio/video devices.
DVD	Digital Versatile Disc – read-only optical medium for video and general data, established by the DVD Forum; capacity 4.7 GB (single layer, single side).
DVD+RW	DVD +ReWritable – DVD-compatible medium co-invented by Philips, allowing of recording and erasing data on a disc that is readable by DVD devices.
HW	hardware
I/O	input and output
LD	local display

LED	light-emitting diodes – elements used in flat display panels
MPEG	Moving Pictures Expert Group – organisation that defined a compression format suitable for video and audio streams; also a name of this compression format.
OSD	On-Screen Display – a technique of presenting transparent or semi-transparent user interface on top of a screen which main purpose is display of other information. E.g. the main purpose of TV screen is to show the channel video, but TV can put its menus on top of it for temporarily interfacing with the user.
OTR	One-Touch Recording – a technique to program the end of recording at the moment the recording is started. Normally, starting of the recording requests for the “first touch” – pressing the “record” button. Stoipping the recording requests the “second touch” – pressing “stop” button. When OTR is used, the user can program the duration of the recording (in units of 30 min) by pressing “record” several times when starting recording. E.g. pressing “record” three times would result in recording of one hour (first press starts recording, two next count for 30 min each).
P50	(commercial name: EasyLink, CinemaLink) – a protocol on a wire that allows control of the appliance through another device. A practical example is a case then the user points the remote control of the recorder in the direction of the TV set (instead the recorder), and TV forwards it to the recorder on the P50 wire.
PBS	Playback Subsystem – one of the three main subsystems of the DVD+RW recorder; originates for the DVD player software
RC	Remote Control – a small wireless control device using infra-red light to pass user commands (mostly button presses) to a controlled device.
RCS	Recording Subsystem – one of the three main subsystems of the DVD+RW recorder; originates for the VHS video cassette recorder software
RTA	Real-Time Authoring – one of the three main subsystems of the DVD+RW recorder; does “on-the-fly” conversion of the input audio and video to a DVD disc image.
TOC	Table of Contents – an interactive menu present on a DVD+RW disc, representing all recordings available on the disc.
TV	television
UI	user interface
UOP	user operation prohibited – information from a DVD disc about certain user operations that are temporarily not allowed by the author of the disc; this information changes dynamically during playback of the disc.
USM	user state machine
VCR	video cassette recorder

4.4. SCREEN SHOT

TOC screen as example (to get a better feeling of the UI).



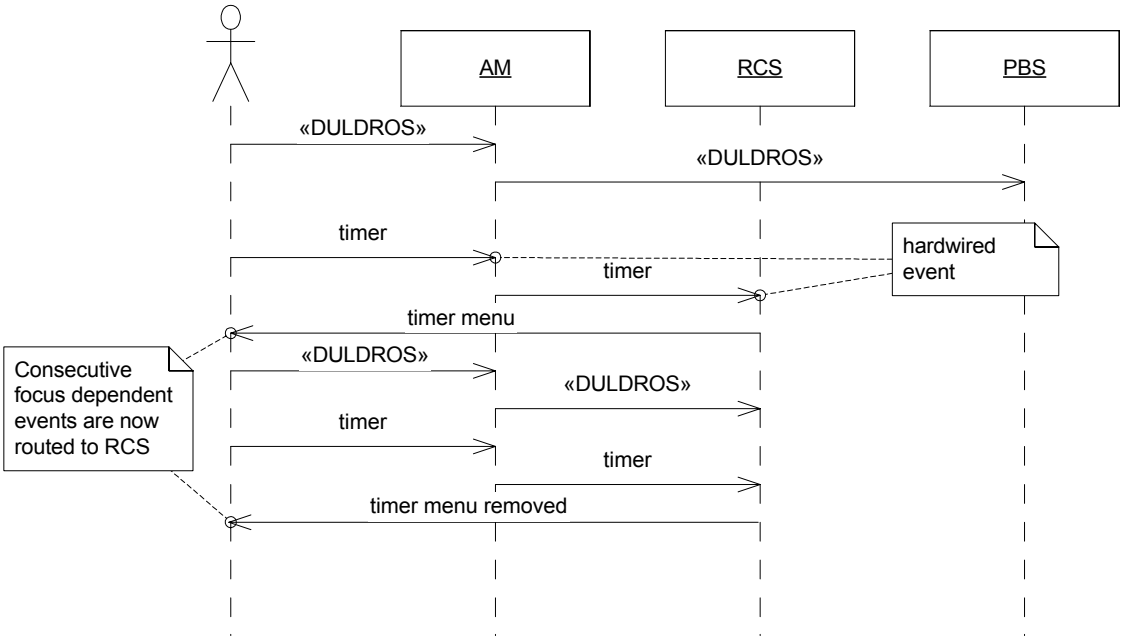
5. USE CASES

The scenarios below are intended to explain requirements. It does not mean that the actual interaction between the subsystem must be identical to the interaction shown in the use cases. The actual interaction will be dependent on the AM mechanism chosen. However, in all cases the overall system behaviour toward the user must mimic the example scenarios below.

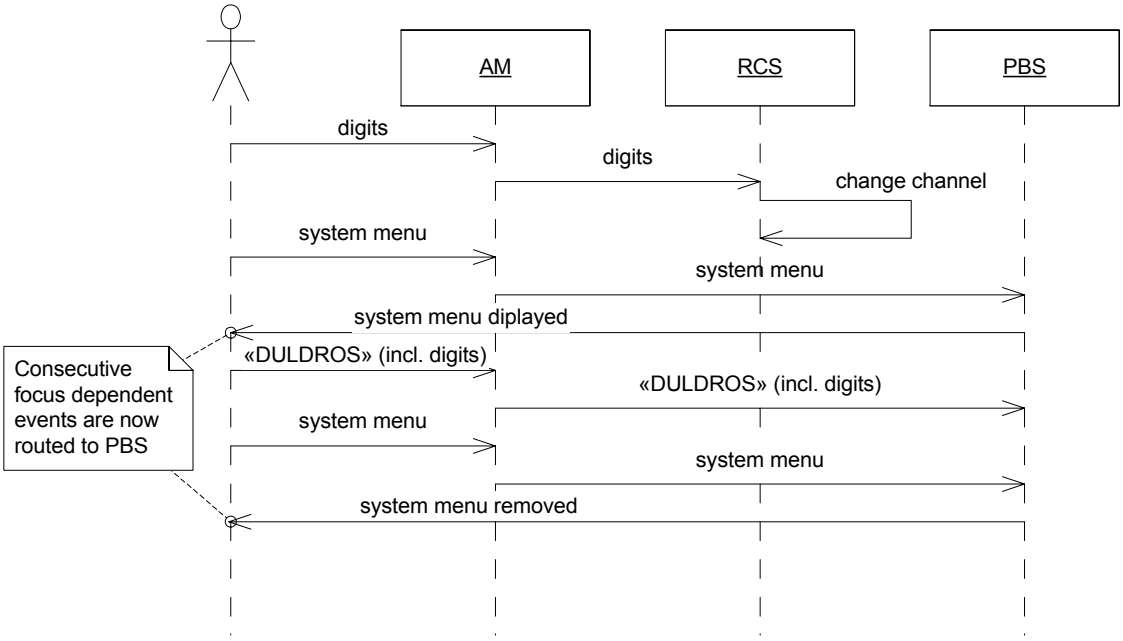
5.1. SUBSYSTEM FOCUS DEPENDENT EVENTS

The target subsystem of some events is constant. For instance, the TV/DVD key is always processed by RCS. We call them “hardwired” events since they are always routed to one and the same subsystem. Some other user events are routed to the currently communication with the user. Example case:

Precondition: system in TOC
Digit, up, left, down, right, OK, select (“DULDROS”) is routed to PBS.
User presses “timer” → routed to RCS.
RCS presents a timer menu.
Digit, up, left, down, right, OK, select (“DULROS”) is routed to RCS.
User presses “timer” again → RCS exits the timer menu.
Digit, up, left, down, right, OK, select (“DULROS”) is routed to PBS.



In the example above, it is RCS which causes some events to be re-routed to itself. But the same can happen with PBS:

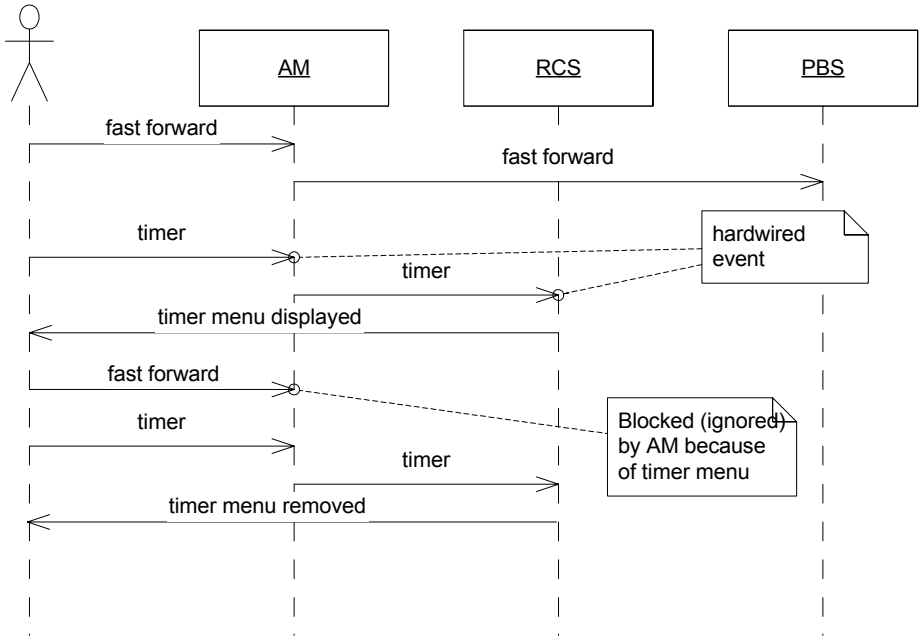


5.2. BLOCKED EVENTS

In some cases, some hardwired events may be blocked by actions of the other subsystem. Here is an example:

Precondition: System is playing a disc.
Play trick mode keys (slow motion, pause, fast forward, next chapter, etc.) are routed to PBS.
User presses “timer” → routed to RCS.

RCS presents a timer menu (semi-transparent, on top of running video).
User presses “fast forward” but this event is blocked by AM.
User presses “timer” again → RCS exits the timer menu.
User presses “fast forward” → routed to PBS.

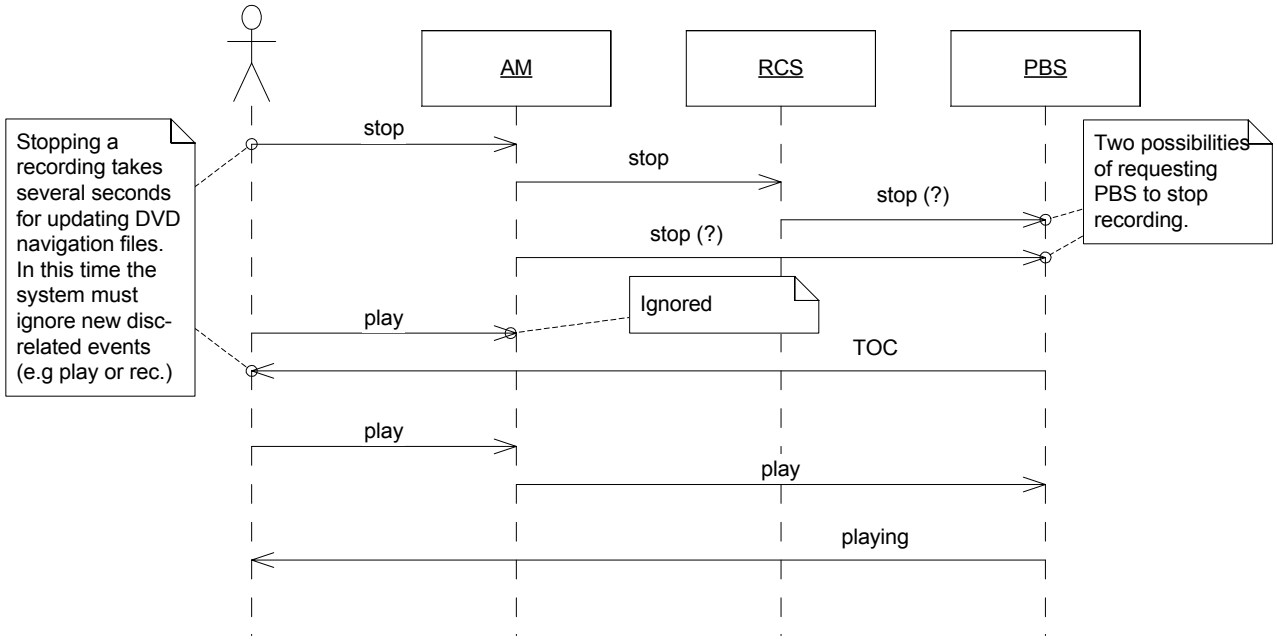


The basic principle behind this behaviour (and also for focus dependent events) is the golden UI rule “what you see is what you control.”

5.3. STATE CHANGE EVENTS

Some events cause important state change in both subsystems. Therefore they have to be forwarded to them all:

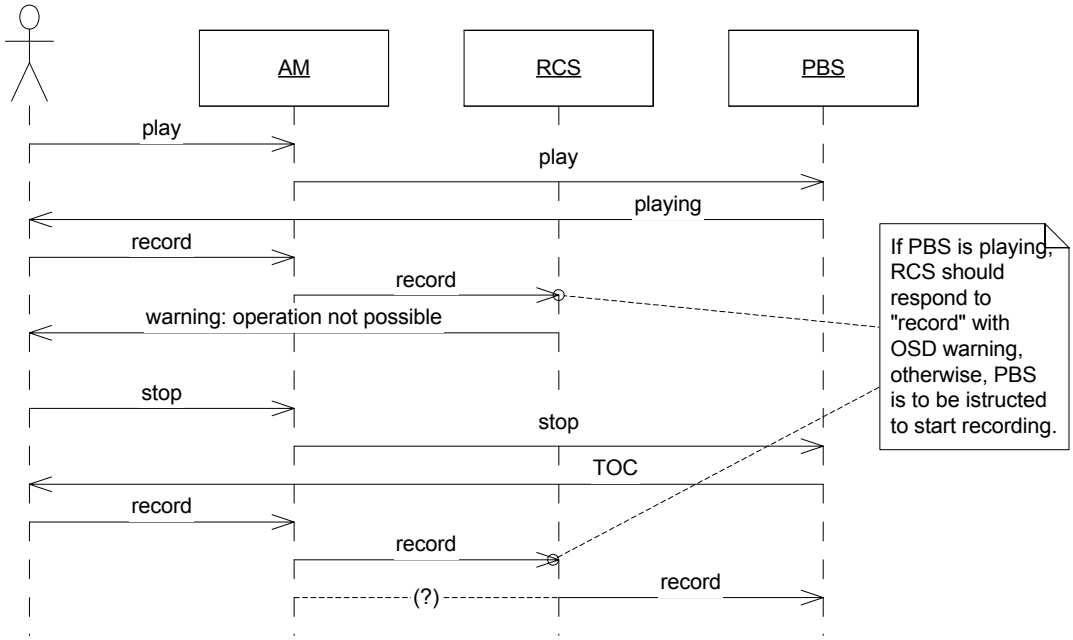
Precondition: system is recording.



Since RCS can control PBS as tape deck, it can send stop request directly to PBS (depending on the mechanism chosen).

As shown above, some state changes are mutually exclusive, e.g. playback and recording. In some cases, behaviour of one subsystem is influenced by the state of another subsystem.

Consider the following scenario:
Precondition: TOC displayed.

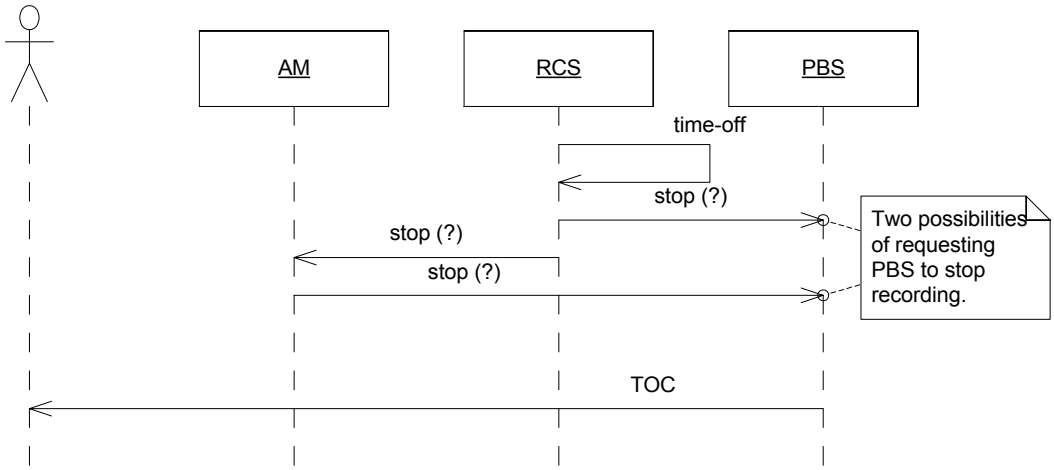


Note: whether PBS gets the record request from AM or directly from PBS depends on the mechanism to be designed.

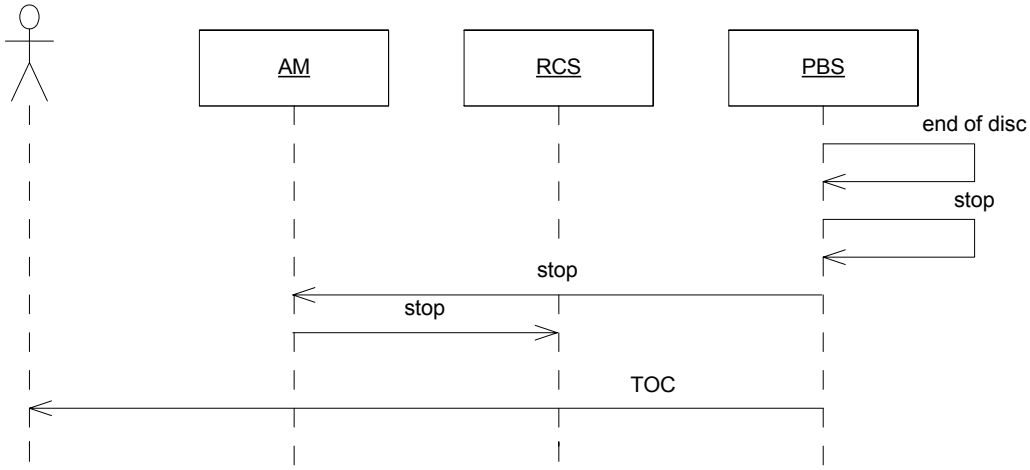
5.4. SPONTANEOUS STATE CHANGES

Also subsystems themselves can generate events that have impact on the peer subsystem. In the example above, the recording was stopped by a user action. But in case of a timer-initiated recording, or user-initiated recording with programmed fixed duration (so called One-Touch-Recording, OTR), it is RCS who knows when to stop:

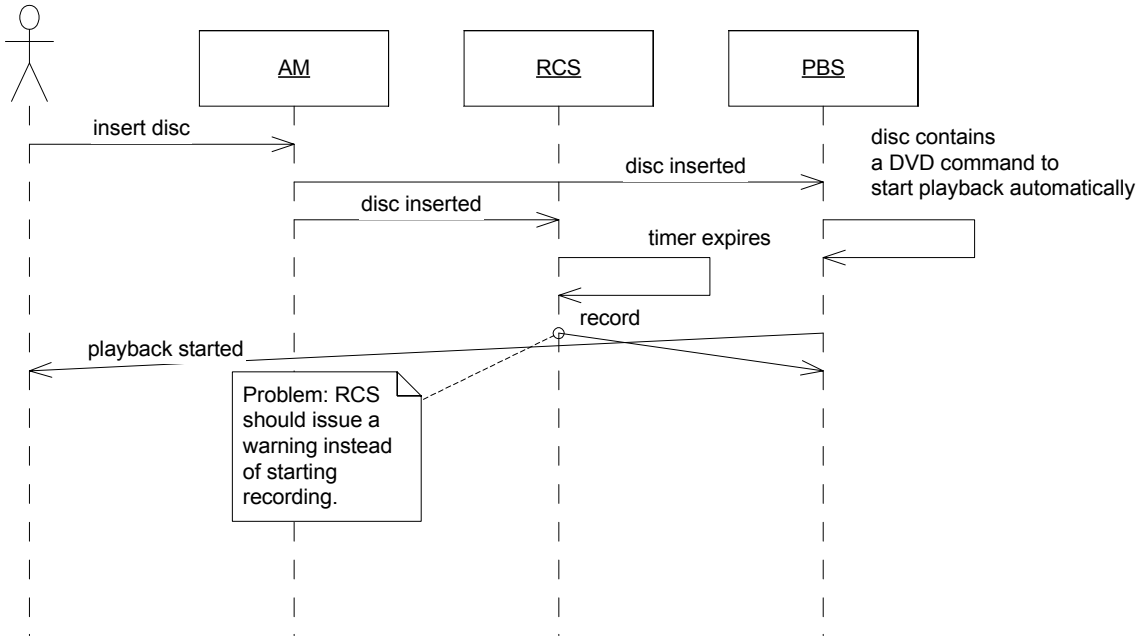
Precondition: timer or OTR recording taking place.



Also PBS may trigger stop recording:



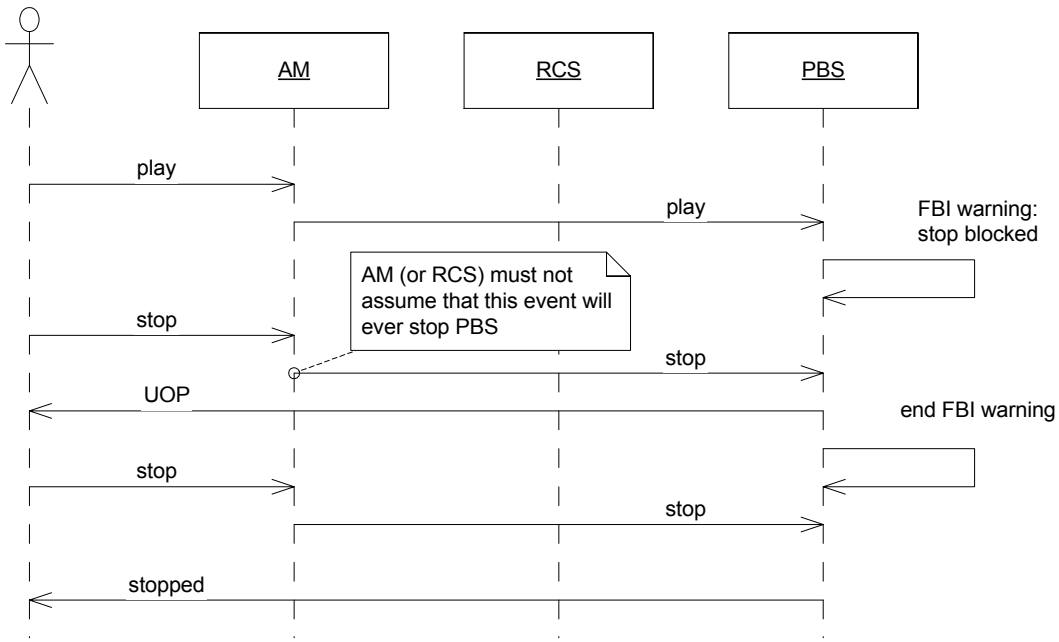
Beware of race conditions! Since both subsystems can trigger state changes, the following situation has to be avoided:



5.5. USER OPERATION PROHIBITED (UOP)

This is a specific DVD problem. We have already seen that some events are blocked by actions of one of the subsystems. However, the DVD standard allows the disc navigation structures to block specific actions on some occasions. A typical example is when the FBI Warning is played, the “stop” or “skip” operations are prohibited. Because of its volatile character, such events cannot be blocked by AM but have to be tried first in PBS.

Example:



5.6. DISTRIBUTED MENUS

The system has three different menus, which are all mutually exclusive (i.e. the system can only execute one of them at a time:

- System menu – main system features and navigation
- Timer menu – fully controlled by RCS
- Edit menu – fully controlled by PBS and available only during playback

There is also a fourth type of menu, but we exclude it from the discussion here since it is generated by the disc content rather than the system itself.

The system menu is a distributed menu because of the reuse of the existing subsystems. The main menu list is created by PBS, but some of the items lead not to PBS submenus but to RCS menus. When entering such submenu, PBS menu is removed and the RCS menu takes place. Upon leaving the RCS menu, PBS menu is restored.

Another interesting problem is the background for the menus. In the most cases, menus are put on top of the current screen, so no change in the background is necessary. Sometimes, however, a moving background is not appropriate and a menu is put on top of a still picture. Further, some RCS menus require TV tuner input to be visible (e.g. when fine-tuning channel frequencies).

Example: