Patching a DVD firmware to make it region-free.

by xvi.

Important notice

Use this document at your own risk.

Patching firmwares is a non-trivial operation that may cause permanent damage to your or somebody else's drive.

Version History

2.5	18-NOV-2023	Minor modifications.
2.4	05-JUN-2022	Minor modifications.
2.3	10-DEC-2021	Minor modifications.
2.2	22-OCT-2013	Corrected some typos.
2.1	27-JUL-2012	Corrected some typos.
2.0	11-FEB-2009	Corrected some typos and minor modifications.
1.9	10-FEB-2008	Minor modifications.
1.8	26-NOV-2007	Corrected some typos and added a few words.
1.7	18-DEC-2005	Corrected some typos and removed any email references.
1.6	15-DEC-2003	Added about the Read Disc Key command.
1.5	25-FEB-2003	Changed email references.
1.4	18-DEC-2002	Corrected some typos and minor modifications.
1.3	22-JUL-2002	Added some general interest information, corrected some typos.
1.2	08-NOV-2001	Added some general interest information.
1.1	30-SEP-2001	Corrected some typos and small enhancements. (private release)
1.0	08-JUL-2001	First release.

Goal

This document tries to explain the specifics about patching a DVD firmware to make it region-free. It will (try to) give you (or point you to) required information.

Non-goal

This document isn't a tutorial about patching. If you want to learn about patching, you're on the wrong way. Find appropriate material elsewhere, then come back.

A few words

It's been a while now since I totally retired from the DVD patching community. I can't be contacted at all, don't waste your time trying. In case you wonder, I had no trouble whatsoever for everything I did for the DVD community. Life goes on, that's all.

Prerequisites

You will need to be experimented in some assembly language patching. Of course, DVD drives generally don't use the same processor as the one you're accustomed to patch, so you will need to learn another processor. If you know an assembly language, you'll have little to learn to understand another processor's instruction set and architecture. Registers are found in every processor, and instructions have the same basic features: you can add and subtract two values, you can compute the logical AND or OR of two values, call a subroutine and return from that subroutine to the caller, etc. To patch a DVD firmware, you don't need to know everything about the target processor, but at least you will need its architecture and instruction set description.

You must understand hexadecimal notation as most numbers in this document are listed in hex form.

You must have some hex editor to view, search and edit the binary file.

Some knowledge about SCSI or ATAPI commands won't hurt.

How to use this document

This document is quite dense. Some important technical informations are given without further explanation. *I suggest that you first use this document with a firmware that already has been patched, understanding the patch that was done, until you feel more familiar with such firmwares.* Get both the original and patched files, disassemble them, compare them, analyze the original, and check that you understand the patch. If needed, repeat the same job on another region-freed firmware, until you feel ready to go on your own.

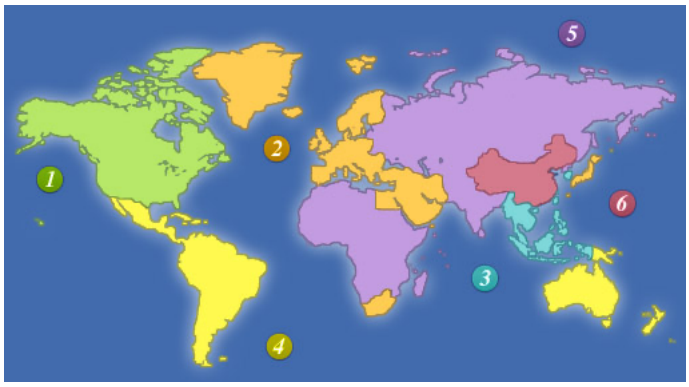
Some may want to skip this step and immediately analyze and patch a firmware.

About Region locking

What is that region stuff? Why would anyone bother patching a DVD firmware? Patching a drive's firmware sounds harder than patching some Windows/Linux/Mac program, so why would anyone do it the hard way?

To make more money out of it, major companies decided that a DVD bought somewhere in the world should not be watched somewhere else. For example, a Japanese user shouldn't be able to watch a movie bought in the U.S.A., or a Peruvian customer shouldn't watch a movie bought in Spain. This has nothing to do with languages or incompatible TV standards like NTSC or PAL. Users still always need to understand one of the audio tracks of the movie, and need to have a compatible topset DVD player/TV (or a computer) to enjoy the movie. This has nothing to do with anti-piracy either, the intent is to forbid the movie playback of some genuine, original, legally bought movies.

The region locking mechanism was specifically designed to achieve this goal, the world was divided in 6 regions :



The region locking mechanism is the following: each DVD player or drive can only play movies from one and only one region. That is, a region 1 player can only play region 1 movies, etc. Topset players are sold preconfigured for the region they are sold in, and generally their region can't be changed. Computer DVD drives can be changed 5 times, then they are locked in the last region they were set to. To be sure every manufacturer enforces these limitations, these were tied in the CSS licence agreement that every vendor has to sign to be allowed to sell CSS-compliant drives (and every DVD drive has to be CSS compliant). Without agreeing this licence, no one can sell DVD players or drives. When agreeing this licence, you must comply with the region locking mechanism.

First point is: Region locking isn't a law, neither national nor international. It's just a licence agreement that ties the drive's manufacturer to the CSS licensing association. You, as a customer, aren't tied to it in any way to this agreement. The region lock isn't an anti-piracy technology, just a market fragmentation tool. Although tied to the CSS licence, region-locking isn't technically related to CSS decryption. Region freeing doesn't involve "cracking" the CSS or circumventing any anti piracy protection. The only link with the CSS encryption is that, when the movie region doesn't match the drive's region, the drive won't return the CSS Title Key which is needed to play the movie. Other very effective means to deny movie playback could have been chosen, but they weren't.

Second point is: This is why no manufacturer will send you a region-free (a.k.a. RPC-1) firmware. They *agreed* not to do it. So don't waste your time asking them.

Third point is: As the region locking is implemented in the DVD drive, the drive's firmware must be patched. It may be technically possible to bypass this protection by some host computer program, but this is much more difficult and complex. As the required CSS Title Key is unknown, you will need to "crack" it; and an adequate movie player software must be used to support this feature. The easiest way to achieve region freeing is to patch the drive's firmware, and let the computer software untouched.

A word about SCSI and ATAPI

DVD drives exist different flavors, SCSI, ATAPI, USB or IEEE1394 (a.k.a. FireWire), and maybe others. This will make no or little difference for patching them, as all use the same command packets to communicate with the host. For what matters to DVD firmware, you may think of ATAPI, USB and IEEE1394 as "SCSI commands over some sort of bus".

All SCSI commands work the same way: the host sends a command packet that is a few bytes long, possibly followed by some bytes of parameters, and gets the answer bytes (if any). Most command packets are 6, 10 or 12 bytes long, and the first of these bytes contains the code of the operation that the drive is asked to perform.

Some DVD specific commands

ATAPI/SCSI commands description can be found by searching on the world wide web.

DVD specific commands are known as MMC, so a good start is to look for "scsi mmc pdf".

You probably should fetch and read the latest MMC commands description, at least the "Report Key" and "Send Key" commands (opcodes A3 and A4) as these are the two commands that include the region-locking mechanism (and we will patch them). Here is a short reminder of both command packets:

Byte \ Bit	7	6	5	4	3	2	1	0
0	Operation code (**A3**)							
1	Reserved			Reserved				
2	Reserved							
3	Reserved							
4	Reserved							
5	Reserved							
6	Reserved							
7	Reserved							
8	Parameter List Length							
9								
10	AGID			**Key Format**				
11	Control							

Send Key command packet

Byte \ Bit	7	6	5	4	3	2	1	0
0	Operation code (**A4**)							
1	Reserved			Reserved				
2	Reserved or Logical Block Address							
3								
4								
5								
6	Reserved							
7	Key Class							
8	Allocation Length							
9								
10	AGID			**Key Format**				
11	Control							

Report Key command packet

The "Key Format" parameter for the "Send Key" command (A3) can take the documented values 01, 03, 06, 3F and sometimes undocumented values, such as 02 that is frequently used for the vendor reset command. The command packet is followed by a few bytes of parameters.

The "Key Format" parameter for the "Report Key" command (A4) can take the documented values 00, 01, 02, 04, 05, 08, 3F, on CPRM compliant devices, the documented value 11 and sometimes undocumented values. The drive returns some information bytes to the host when it receives this command.

Of particular interest are the Send Key command with Key Format set to 06, and the Report Key command with Key Format set to 04 or 08. These will be henceforth referred as the A3/06, A4/04 and A4/08 commands.

The A4/08 command is used to query the drive's region and counters, the A3/06 command is used to change the drive's region. The A4/04 command returns the Title Key, which is needed to decrypt a CSS-encrypted movie.

Here is how the drive's reply to the A4/08 command is formatted:

Byte \ Bit	7	6	5	4	3	2	1	0
0	00							
1	06							
2	00							
3	00							
4	State		Resets left			Changes left		
5	Region Mask							
6	01							
7	00							

Report Key Format 08 reply

The 'Changes left' field contains the number (from 0 to 5) of region changes that still can be done. The 'Resets left' field contains the number (from 0 to 4) of vendor resets that still can be done.

The 'State' field that will depend on the 'Changes left' field. If the 'Changes left' is 0, the 'State' will be binary 11. If the 'Changes left' is 1, the 'State' will be 10, if the 'Changes left' is 2, 3 or 4, 'State' will be 01, and when 'Changes left' is 5, 'State' is 00. The official name of these 4 states are 'None', 'Set', 'Last Chance', 'Permanent'.

The above are the most important commands pertaining to the DVD drive region lock. Now come a few, less important, but that you should be aware nonetheless:

Another useful command is the READ DVD STRUCTURE, with the DISC KEY format selector. It allows the host to read the Disc Key sector. This sector is outside of the range of the data sectors, so it can't be read by normal read operations, and contains encrypted keys that are part of the CSS decryption process:

Byte \ Bit	7	6	5	4	3	2	1	0
0	Operation code (**AD**)							
1	Reserved			Reserved				
2	Address							
3								
4								
5								
6	Layer Number							
7	**Format (02)**							
8	Allocation Length							
9								
10	AGID		Reserved					
11	Control							

Read DVD Structure command packet

While this command is normally unaffected by the region control lock, I have found firmwares (e.g. Matsushita UJ-815 drives) that will perform a region compatibility check before returning the Disc Keys sector.

Also, the various Read command (operation codes 28, A8 and sometimes 08, 88) can perform a region compatibility check before performing their function (Matsushita firmwares, again...).

The Region Mask format

The Region Mask is a format used to represent a region. It is made of a single byte, whose bit 0 corresponds to region 1, bit 1 to region 2, up to bit 7 that maps to region 8. Each bit can take two values: true and false. 'True' is represented by a 0 bit, while 'false' is represented by a 1 bit. Pay attention that this is *opposite* to common habits.

The A3/06 and A4/04 commands use the region mask format to represent the drive's region. The region mask is built by setting to 'true' the region you want to select, so that region 1 is represented by the FE value, region 2 by the FD value, etc.

Here are the most common values of a Region Mask:

No Region
FF

Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
FE	FD	FB	F7	EF	DF	BF	7F

Note the 'No Region' corresponding to value FF. When returned by the drive as its current region, it means that no region has been set yet. The factory defaults are: No Region set, 5 changes left, 4 vendor resets left. A vendor reset will reset the region change counter to 5, the region mask to FF, and will decrement the vendor resets count. A region change will change the region mask and decrement the changes left counter. The drive will reject region change requests if the changes left counter is 0.

As a DVD drive can only be set to one region simultaneously, A3/06 commands with region mask with multiple regions selected (such as 00) will be rejected.

The region mask is also used by movies to specify in which region they may be played. If a region's bit is true (i.e. 0), it may be played by a drive set to that region. This region authorization mask is stored in the sector header of the infamous CSS disc key sector, buried deep in the DVD's internal structure. A copy of this region mask is accessible at hex offset 23 of the VIDEO_TS.IFO and VIDEO_TS.BUP files located in the VIDEO_TS folder (or directory) of a movie.

Differences between a region-free and a region-locked drive

A ***region-free drive*** always will report the Title Key to the host, and, as it has no region, it doesn't know about the A3/06 or A4/08 command and cannot report neither change its region. When a A3/06 or A4/08 command is issued to a region-free drive, it will report an "INVALID FIELD IN CDB" error meaning that the issued Key Format parameter was unrecognized. Some region-free drives may report other errors, such as "MEDIUM NOT PRESENT" when no movie is inserted. Anyway, region-free drives won't report nor change their region settings.

A ***region-locked drive*** will be set to one and only one region, and will remember this region even after being powered down. It will honor the A4/08 command by returning its current region and counters, it will also honor the A3/06 command by changing its region (if the region change counter hasn't been decremented down to 0). The A4/04 command has a slightly modified behavior, as it won't report the Title Key if the movie isn't authorized for playback in the drive's region. If the movie is authorized for the drive's region, the A4/04 command is honored normally. If the movie isn't marked as playable in a drive's region, the player software will miss the Title Key, so won't be able to decrypt nor play it.

Your computer will detect that your drive is region free by sending it the A4/08 command. If the drive replies with the region settings, the drive is region-locked. If the drive aborts the command with error, the drive is region-free. All utilities that check your drive's RPC status work this way.

How do region-locked drives remember their region and counters?

Of course, they all use some kind of non volatile memory, but what value do different drives store in that memory?

Different drives may store their regions by different means. Some store the region mask, other store the region by its number (1, 2, 3, etc), and other means can possibly exist.

Counters can also be remembered by multiple ways. They can be stored as a countdown, representing the number of operations left, decremented at each region change or vendor reset. They also can count from 0 upward, representing the number of times the region was changed. It may also be that they aren't remembered at all, but computed back from a 'region change log' flash memory area where successive region change are recorded. The counter can be infered from the number of region changes that are logged in this area.

These different ways of storing the region and counters yield different algorithms to manipulate them, so you will have to analyze the code that handles these values to find out the way they are stored.

How does a region-locked drive determine if it can "play" a movie?

In fact, a drive doesn't disallow reading any DVD, it only refuses to return the CSS Title Key of unauthorized region's movies, so the host is unable to decrypt the movie. *Well*, some DVD drive go a bit beyond this and prohibit more operations, like reading the Disc Key sector, or even reading the encrypted sectors. To check if it can return the Title Key of a movie, the drive's firmware will check the movie's region mask bit corresponding to its own region. Depending on how the drive remem-

bers its own region, different algorithms can be used.

If the drive remembers its region mask, it can simply compute the binary OR of its region mask and the movie's one, if the result is FF, the movie is not authorized, if the result is not FF, the movie is authorized. This operation is easy to identify in an assembly listing as it is built of an OR instruction, followed by a COMPARE, and then a EQUAL/NOT EQUAL CONDITIONAL BRANCH.

If the drive remember its region by its number, it can compute its region mask and then check region compatibility as described just above, or it can test the specific bit of the movie's region mask. The later is less obvious in a firmware listing, but is still easily identifiable.

Note: Region 7 and 8 may or may not be recognized by the drive, as they are special cases among regions: region 7 is currently not defined, and region 8 is a region for international venues such as airplanes, rarely used.

The patching process will now be described. Remember, this is a basic example, and some firmwares will require additional steps.

Patching, step 1

First of all, get a firmware to patch. A common source of firmware is a firmware file extracted from a firmware update kit published by the drive's manufacturer. If the firmware comes in .HEX or .MOT format, it must be translated into binary form. Doing this is beyond the scope of this document, and utilities are available all over the net. Beware that .HEX files can hold more than 64 KB of data, and some conversion utilities aren't able to handle these large files.

Patching, step 2

You must now disassemble the firmware file. This implies that you must know which processor the drive uses. If you don't known, here is a list of the most common processors I found in DVD drives: Hitachi H8S, Intel 8051, Zilog Z80, Matsushita 102000, Mitsubishi 7902, Hitachi SuperH. Try to disassemble the file according to each of this processors, and find out which one is used by looking at the assembly listing, one and only one should make sense.

Raw disassembly listing are enough, you don't need an intelligent disassembler that will identify data and code sections, a brute force disassembly of all bytes of the firmware is fine enough for patching a firmware.

Patching, step 3

Now that you disassembled the firmware, you'll need to find what and where to patch. First, you need to identify where the drive's region is stored. The easiest way to achieve this goal is to find the A4/08 handler that returns the drive's region mask to the host.

Common firmware are 64 KB, 128 KB or even larger, so finding the right code area in several tens of thousand assembly lines may seem like a hard job. Hopefully, there is a particular operation that has always been a faithful helper: the format parameter of the A3 and A4 operations must be extracted from the byte it shares with the AGID parameter. This is commonly done by ANDing the byte with 3F. A regexp (a.k.a. "regular expression") search for "AND.*3F" (or a similar syntax adapted to the target processor) will yield a few code area candidates (of course, you need a text editor that supports regular expression searches). Among these candidates, you can find out the two that corresponds to the A3 and A4 commands by examining the code that follows. The different format options will either be checked one by one, comparing them with the different values that it can take, or by indexing into a table. Both methods are quite easily identified, and by checking the different values that are checked, you will quickly find the two command handlers. Note that the table dispatching or successive compares are frequently preceded by other parameter's validity check. The AGID for example, as it hasn't to be valid with the particular formats that we are looking for; so the A4 handler might be identified by an immediate compare of the ANDed value with 08.

Now that you found the A4 handler, follow the code for the 08 Key Format. You'll end up at the A4/08 handler and you will find the code that returns the region. Note how the region is stored (by its mask or number, etc) and where it is stored, e.g. its address.

This step is the most important step in patching a firmware because this is where you pry into the firmware. From this initial code area analysis, most things can be inferred.

Patching, step 4

Now let's look for all references to the drive's region (or region mask) in the firmware. We must try to identify all of these, at least know what they do with the drive's region. Possible uses are (all are not present in every firmware):

- Initialization. At startup, the drive read the non volatile memory to restore the last region that was remembered. Some firmware read the region from NVRAM or Flash memory every time it is needed, so this code may be called from several locations.
- Defaulting to no region set. The first time it is powered on (during the manufacturing process), the drive's non-volatile memory is uninitialized, so the firmware enforces the following settings: "no region selected", "5 changes left", "4 vendor resets left".
- Storing the region. When the region is changed, it must be remembered and written to non volatile memory.
- Exact compares. These comparisons are followed by conditional branches whose condition is either "EQUAL" or "NOT EQUAL". Such a comparison is needed as part of the A3/06 handler, when the host has requested the last region change, that is, there is exactly one change left (or four changes done). In this case, to prevent user from trivial errors, it is mandatory to have a movie inserted in the drive that is authorized for the target region, and for that region only.
- Inexact compares. These are region compatibility checks. Some are part of the A3/06 handler as a drive will only change its region if a movie that is authorized for that region is inserted. Some are part or the region locking scheme, e.g. in the A4/04 handler that checks if returning the Title Key is allowed. You should carefully check all of the above compares, as some may be part of commands that usually need no patching. The "Read DVD Structure/ Disc Key" (AD/02) or the various "Read" (28, A8) commands are more and more frequently running region compatibility tests. For short, every region compatibility checks is a suspect. Check it, check it again and again. If in doubt, don't hesitate: patch it.

Patching, step 5

Enough rambling, it's now time to patch!

First, modify the A3 handler so that it doesn't recognize the 06 Key Format code. You have to patch a conditional branch and/or the table that is looked up.

Then, do the same for the A4 handler so that it wont recognize the 08 Key Format code.

Now, patch all the region compatibility checks so that they ever match.

You might also want to modify the firmware name, if so, beware that the it may appear also byte swapped on ATAPI devices, as an ATAPI drive has two ways of being "inquired": the ATAPI inquiry command packet, and the old style IDE identification. The IDE identification string may be stored byte swapped, so that the firmware named "ABCD" may also appear as "BADC" or "A...CBD" somewhere else in the firmware file. Renaming patched firmwares is a matter of personal choice. Some patchers do, some patchers don't. What's important is that the patched firmware is region-free, not its name.

Some tricks I didn't tell you yet...

The above patching process is idealized. The real thing can be a bit harder (or easier):

- Another adequate way to patch a firmware to ensure the region compatibility checks will ever match is to patch the code that reads the movie's region mask from the medium and stores it to some memory, storing a 'all regions allowed' mask (i.e. 00).
- Anti-patching techniques: I have found firmwares (Matsushita DVD-RAM drives) that call a subroutine *outside* the firmware area to check the region compatibility (as it's outside of the flashed firmware area, it's unpatchable). I found other firmwares that contain an hidden checksum (Toshiba 1502/2502) and make the drive eject the medium when the checksum mismatches. Both are pathetic attempts to hinder patching. I understand that vendors are tied to RPC-2 by the CSS license agreement, but I can't imagine why they would want to sell less drives by preventing them to be region-freed.
- And then, some firmwares are crypted or signed. Resolving this issue is beyond the scope of this document. *Good luck*.
- Checksums: Most drives will check uploaded firmware before flashing it. The firmware file can contain headers and/or checksums. You will have to find the checksum algorithm in the firmware itself, then make a little program to recompute a patched firmware file's checksum. This kind of checksums are not part of any anti-patching conspiracy, but acts as a safety mechanism to avoid flashing a drive with a corrupt firmware that could damage the drive. Some firmware flash utilities are even kind enough to tell you the correct checksum, so you sometimes don't

even have to bother about knowing how to compute them!

- Some firmware are already RPC-1 able. In such firmwares, a check is made to determine if the drive is RPC-1 or RPC-2. Look for such tests in the A4/08 handler code area. If you find such a test, it can either check if a jumper is set or removed, it can check a hard-coded flag somewhere in the firmware, or a flag set by an undocumented command, etc.
- When you found the A4/08 handler, do you remember you found that ANDing with 3F? The source byte was taken from the eleventh byte of the command buffer. Substract 0A from its address to compute the address of the byte that holds the operation code. Search references to that byte to find the command dispatcher, then look for undocumented opcodes or functions (mostly in the C0-FF range, but also in vendor specific MODE PAGES or DIAGNOSTICS PAGES). Some may be *very* interesting to analyze, such as commands that dump the drive's memory (about every drive), reset the change and vendor reset counters (Hitachi GD-7000 and 7500), or even switch the drive to RPC-1 temporary (LG drives) or permanently (Hitachi GD-3000 and GD-5000).
- Removing the A3/06 command from the firmware is maybe superfluous, as the drive will be identified as RPC-1 if the A4/08 command has been removed. I've seen patched firmware where this command was still present, and they worked fine. However, as the A3/06 command is part of the RPC-1/RPC-2 differences, I suggest you remove it nonetheless. It wont take much time, and it's safer.
- Some firmwares check if a region is set before checking for region compatibility (and if none is set, the command aborts with error), so either patch that code too, or ensure a region has been set to the drive before updating it with the patched firmware. In either case, it is a good idea to ensure a region has been set to the drive before applying a patched firmware. This is why I frequently set this as a prerequisite before flashing a drive.
- You may be tempted to patch a firmware by simply removing the change counter decrement of the A3/06 command (a.k.a. the *infinite lives* patch, in reference to games patched so that your lives aren't decremented anymore). I warn you against this, as most non volatile memory used in DVD drives have a limited number of write cycle lifetime (sometimes as low as 100). Such a patch will lead a drive to write and write again this memory, and this will sooner or later cause a NVRAM or Flash Memory breakdown. Other drives store the region change by filling up a reserved memory range. In this case, when the range is exhausted, the drive will either corrupt contiguous memory or fail to change its region. In either case, it will take some time before such a firmware fails, so publishing such a patched firmware is like spreading landmines. So, once again: *don't patch a firmware this way*.
- *Gotta patch'ém all*. A whole product line frequently shares firmware development resources (team, program sources, etc), so firmwares from a drive to the next are very similar. If you patched one, the next one should be pretty easy. Most users do not have the necessary skills to patch, so if you succeed in patching your drive's firmware, please consider patching more drives of the same product line. It shouldn't take you much time, and it will help thousands of people all around the world.

Final words

I would like to thank all the people that helped me in many ways to build my tools and firmware patches. They are too numerous to list here. You know who you are. I had a lot of fun doing all this job!