SIRDUKE

Saphir Innovatively Rescues
VRT Disks Using Knowledge and Equipment

Project report

by Adrien Bailly – Gecko

In collaboration with:
Jean-Hugues Chenot – INA
Klaas Janssens – VRT
Brecht Declercq – meemoo
Lobke Vanden Eynden – meemoo

Table of contents

I. Introduction

This report provides an overview of the SIRDUKE project, which was carried out between May and October 2021 by the four project partners: Gecko, INA, VRT and meemoo. In this project 51 out of 52 lacquer disc sides severely damaged by delamination - the contents of which had hitherto been regarded as irretrievably lost - were digitised via optical readout.

This report first presents the project, focusing on the partners, the idea for the project and the scope and timing. After that, the lacquer discs as a sound carrier type are discussed. The fourth chapter focuses on the optical playback technology and it shows why it is particularly suited for the discs involved in this project. Chapter five extensively tells about the process steps, The final chapter six can be considered as a conclusion. It gives a statistical analysis of the project results, it shows the difficulties encountered and it compares the productivity of the optical digitisation of lacquer discs to traditional playback methods. It also provides a few suggestions for improvement of the hardware and software used.

The project name SIRDUKE stands for 'Saphir Innovatively Rescues VRT Disks Using Knowledge and Equipment'. The name refers to the song 'Sir Duke' by American soul artist Stevie Wonder featuring the lines:

"Just because a record has a groove,
don't make it in the groove."

II. Project presentation

2.1. Project partners

2.1.1. VRT

The VRT is the public broadcaster of the Flemish Community in Belgium and presents high-quality and distinctive content in the areas of information, culture, education, entertainment and sports. The VRT archive represents an almost entirely digitised collection from 1931 till now. In 1931 the broadcaster (National Institute for Radio - NIR) started broadcasting radio programs, 1953 was the start of television broadcasting. From those early years, the VRT owns a large collection of lacquer discs that have largely been digitised in collaboration with their partner meemoo.

A part of the collection of lacquer discs could not be digitised because of heavy damage. That is why VRT was very interested in participating in the R&D project SIRDUKE. Unique recordings could still be saved. VRT is currently working on the digital restoration of the lacquer disc sides. Parts of a recording may be missing because one side of the record was in too bad condition to be able to be digitised. This unique test project could provide a solution for these problems.

2.1.2. Meemoo

Meemoo - until February 2020 known as VIAA - is the Flemish Institute for Archives. Since 2012 it initiates, coordinates and funds the digitisation of the Flemish audiovisual heritage preserved by content partners in cultural, media and government sectors. It also organises the influx of the partners' existing digital collections into a large scale, sustainable archive system, so they can manage it and ensure it's available to be used again. Furthermore meemoo provides access to the content stored in its archives via several access platforms. Lastly meemoo actively gathers and shares knowledge about the various aspects involved – for example through our projects, training and advisory reports.

2.1.3. INA

Institut National de l'Audiovisuel (INA) is a French public institution founded in 1975 in charge of collecting, preserving, promoting and transmitting the national broadcast audiovisual heritage.

INA holds 22.5 million hours of TV and radio contents, including 2.230.000 hours from public broadcasters, available for licensing (2020). Amongst the 276.000 lacquer disc radio recordings from 1930 to 1958 in INA vaults, some 20.000 cannot be played conventionally using a turntable and stylus.

The INA-Saphir process was developed within INA's Research Department, patented in 2004 and still improving. It allows for the recovery of those endangered soundtracks. INA-Saphir was made available for the recovery of the disc records selected for the SIRDUKE project.

2.1.4. Gecko

Gecko, a company based in Montreuil, France, offers digitisation and restoration services for all audio carriers, analog and digital. Gecko has worked since 2005 on a large number of projects:

- archives of French and European institutions (INA, BNF, VRT, RTS, Unesco)
- private label and record companies collections (Universal, peer Music, ...)
- unique projects such as the digitisation and digital restoration of all the instantaneous disc recordings of the Nuremberg Trial (International Court of Justice, Mémorial de la Shoah).

Gecko has been a recognised expert for years in the digitisation of lacquer discs. With the know-how and the experience, acquired in particular on the collections of the INA and the RTS, Gecko always succeeded in playing back almost all the discs of these periods, whatever their state of conservation.

Gecko uses the following methods when preparing discs and then editing files:

- in-depth cleaning and manual physical reconstitution of the lacquer

layer,
- choice in various stylus and manual groove tracking during playback, high-end equipment (turntable/preamp/converter chain),
- detailed work when editing audio files.

Gecko has always managed to extract the vast majority of the content of the discs entrusted to them, with a sound quality allowing the exploitation of these archives. For the few disc sides that cannot be played in the traditional way or for which even a single stylus playback will permanently deteriorate the disc, Gecko has always been passionate about the development of Saphir at INA and is very proud today to be able to process these extreme cases.

2.2. Genesis of the project

As part of its long-term mission to safeguard the Flemish audiovisual heritage through digitisation, meemoo started in 2017 – then still under the name VIAA – a large-scale digitisation project for lacquer and shellac records, called 'Golf 5'.

Since the vast majority of the records to be digitised were in the VRT collections, given the expertise and equipment available at the VRT and given the risks associated with the transport of these delicate sound carriers, it was decided to carry out the project at the VRT and to involve VRT employees in the implementation. In view of the timing of the project and the required throughput volumes, the available equipment and expertise was supplemented with equipment and expertise from an external partner, appointed through a European tender procedure coordinated by meemoo. In the summer of 2017, this contract was awarded to the French Gecko SAS.

In the Golf 5 project, more than 47.800 disc sides were digitised from June 2017 to December 2020. About 12.500 of these came from lacquer discs, the rest were shellac based. The great majority of these lacquer disc sides, more than 11.100, belonged to the collection of the Flemish public broadcaster VRT. During this operation it turned out that a (fortunately) small number of lacquer discs could no longer be digitised because the lacquer layer had separated too much from the core of the disc, a phenomenon known as delamination.

In the spring of 2020, towards the end of the 'Golf 5' project, Gecko contacted meemoo to propose to digitise VRT lacquer discs in too poor condition via optical readout, using the Saphir technology from INA. This meant the start of a partnership of four parties (Gecko, INA, meemoo and VRT) to try to save these records, whose contents had been thought irretrievably lost.

The project details were further elaborated at the end of 2020 and the beginning of 2021, the contract between the four parties was signed in May 2021 and the discs were transported from VRT's premises in Brussels, Belgium to Gecko's facilities in Montreuil, France on 12 May 2021.

2.3. Scope and timing of the project

The scope of the SIRDUKE project was predefined as the optical digitisation, via the Saphir technology, of several dozen of disc sides that were too damaged to be digitised via the traditional readout method with a stylus. A conscious decision was made not to determine a definitive number of disc sides to be digitised in advance, because there was still a lot of uncertainty about what a realistic digitisation rate would be. A total of 35 heavily damaged discs were delivered. Not every disc had two badly damaged sides. In the end, as planned, a digitisation attempt was made for 52 disc sides, equal to the total number of sides for which a stylus based digitisation was not considered a real option.

However, the objective of the project went further than the actual digitisation and the recovery of historical sound material thought lost. Through this project, the project partners also wished to contribute to and to learn more about the possibilities of optical digitisation in a broader sense. For Gecko it was important to learn how high the productivity of optical digitisation could be. VRT wanted to find out whether it would be a realistic option to have even more disc sides digitised. INA wanted to learn about the daily use of the Saphir technology in the context of a commercial provider of digitisation services. Finally, meemoo wanted to contribute to the development of an innovative technology for the rescue of audiovisual heritage.

Although the project was not strictly time-limited, it was envisioned that the actual digitisation should be completed before the end of 2021.

III. Lacquer discs

The carriers concerned by the SIRDUKE project are called 'instantaneous disc' or 'lacquer discs'.

When we think of an analog audio disc, we most often think of shellac 78 rounds per minute (RPM) records or their descendants, 45 or 33 RPM vinyl records, which are copies pressed from a matrix in very large numbers for distribution to the public. Micro-groove stereophonic vinyl discs use both horizontal and vertical engraving to reproduce both channels, the groove spacing at each turn is about 0.1 mm, the groove width is 0.50 mm.

Fig. 1 – 2 – 3: three examples of disc sides digitised in the SIRDUKE project.

Instantaneous discs on the other hand are unique copies and were used as a carrier for recording, editing and broadcasting. They consist of a core, most often in aluminium, zinc, steel, glass or cardboard, covered with a lacquer which was engraved by a cutting chisel during recording.

These discs can be cut (engraved) from the centre to the rim (edge), or in the other direction. They are recorded mainly at 78 RPM, but sometimes also at 120, 90 or 33 RPM.

The groove spacing at each turn is approximately 0.3 mm and the groove width is around 0.140 - 0.180mm, medium groove sometimes as low as 0.080mm. These discs are monophonic. There was initially a vertical cut (the waveform is engraved in the depth of the lacquer) as for some Pathé Sapphire or Edison Hill-And-Dale discs, but subsequently most of these discs were cut with horizontal (or radial) engraving. Disks were the main recording carriers in the first half of the 20th century, after the gradual disappearance of wax cylinders and before the arrival of magnetic tape in the early 1950s.

As with most audio disc technologies an equalisation curve was applied during the recording (and thus the reverse curve has to be applied during replay). This was done in order to prevent the groove from overlapping itself during engraving and to avoid having to space the grooves too much, which would reduce the capacity of the disc and thus the maximum duration of the sound that could be recorded on it. This equalisation curve also greatly improves the signal to noise ratio (SNR) in the trebles, as the noise floor could be particularly annoying in the high frequencies.

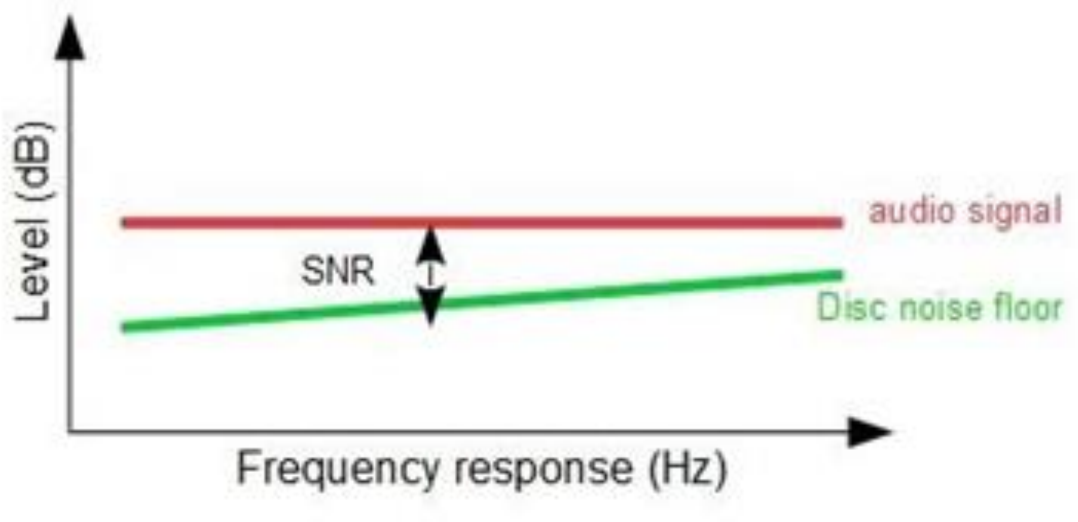


Fig. 4: schematic representation of what the signal would look like during playback if no curve were applied.

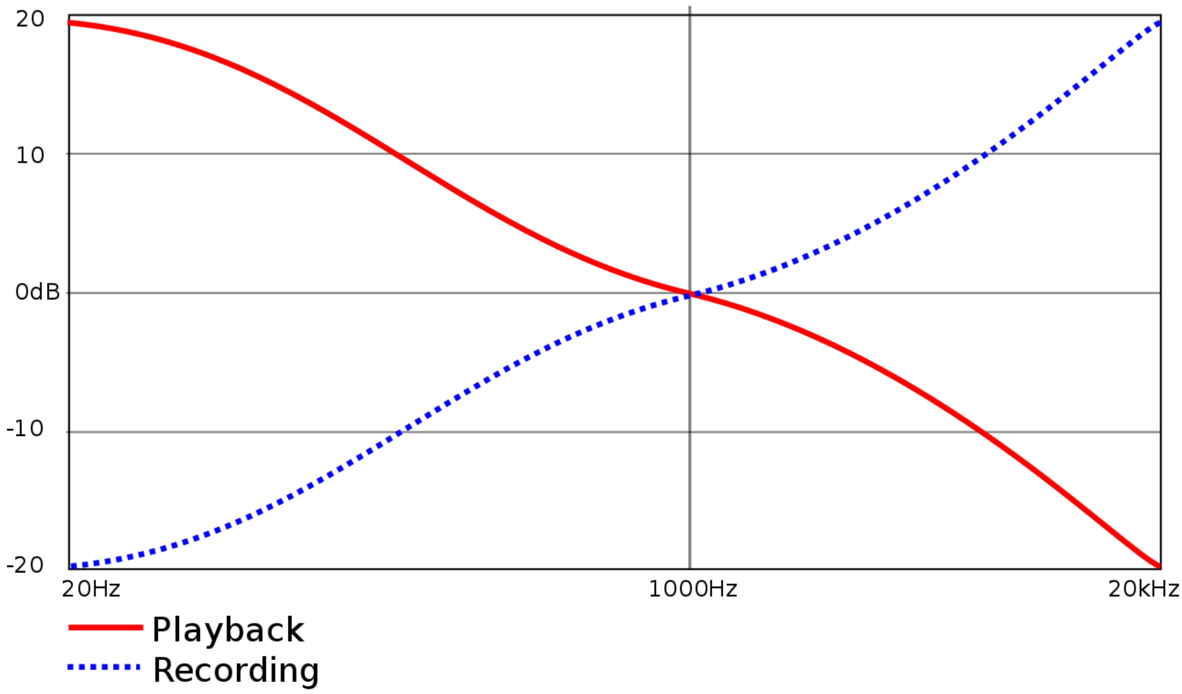


Fig. 5: Typical curve (here: RIAA curve) used on the signal before recording the disc and the inverted curve used during playback.

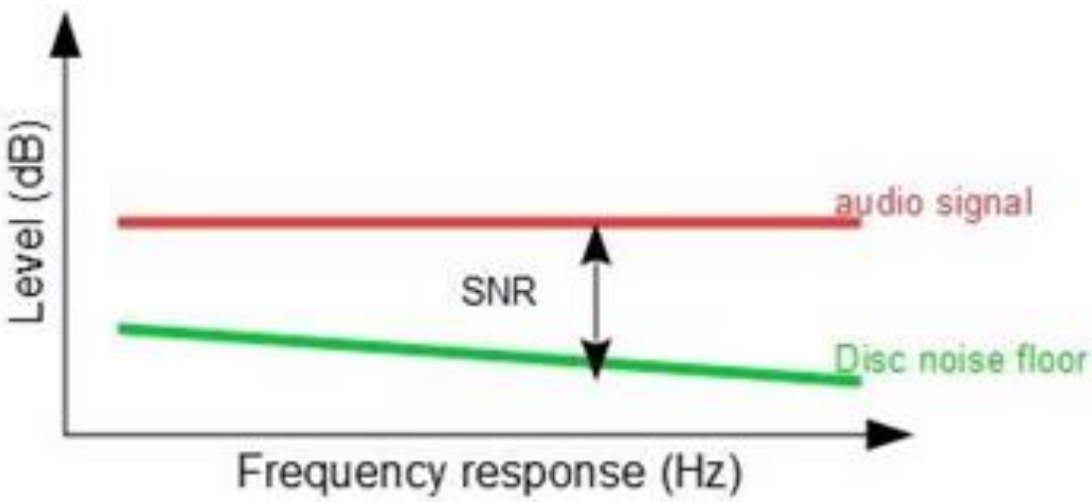


Fig. 6: schematic representation of the resulting signal if a curve is used.

Unlike the modern, standardised curves used for vinyl discs (RIAA curve), the curves used on instantaneous discs are different depending on the era, country and brand of recording equipment.

The most commonly used solution, especially at Gecko, is to play these discs with a stylus, without any curve on the preamp and then to find the best equalisation by listening during a digital restoration step, based on the documentations mentioning the curves used at the time.

IV. Why use optical playback?

4.1. The disadvantages of traditional stylus based playback

Traditional playback, whether from the mechanical era with a needle, or electric with a stylus and a preamp, involves the rapid movement of the stylus, guided into vibration by the groove. This method definitely remains relevant in most cases, but this method causes, by its principle, the following problems:

- The resulting sound quality is dependent on the different elements of the digitisation audio chain and it is not necessarily as neutral and faithful to the signal as desired.
- The repeated contact between the groove and the stylus leads to wear of the groove walls, mostly because of the fragility of the lacquer.
- On some discs of which the lacquer tends to lift or peel off, a single playback with a stylus can permanently destroy the lacquer.
- Sometimes, a piece of lacquer is missing, causing the disc to be unplayable for at least as many turns as covered by the missing piece.
- On warped discs of which the lacquer is lifted, the stylus will jump and bounce at each rotation of the disc, requiring a manual follow-up of the cartridge holder if the phenomenon is slight, or making the disc impossible to play back if the phenomenon is more pronounced.
- The great diversity in the shape of the groove (width, depth, shape of the cutting chisel) requires choosing from many types of styli.
- The objective sound quality (SNR, distortion, bandwidth) is very dependent on the cleanliness of the disc. A dusty groove, for example, will seriously degrade the signal. If the cleaning and pre-playback methods have been proven successful, this is a time consuming step and some lacquer discs cannot be cleaned as this will deteriorate the lacquer.
- Last but not least: many instantaneous discs, depending on the brands and the storage conditions, are victims over the years of cracks caused by lacquer retractation. These cracks, perpendicular or parallel to the groove, vary in width and number depending on the discs and make it very difficult to playback with a stylus. In the best cases, the disc can be played partially, by ensuring a manual 'follow-up' which consists in guiding the stylus during the rotation, then in

editing on an digital audio workstation (DAW) each small piece of groove that could be played. This method allows some discs to be saved at least partially and maintains correct audio quality, but it takes a long time and tends to weaken an already damaged lacquer. For the most deteriorated discs, it is simply impossible to playback with a stylus as the cracks cause the stylus to jump at random from one turn to another, several times per second.

Another term to describe optical playing would be ‘contactless playback’, it is then easily understood that one could overcome the above problems with such a method.

4.2. Conservation status of the discs involved in the SIRDUKE project

The 52 disc sides selected by the VRT contain a very heterogenous sample of Belgian public radio broadcasting between 1942 and 1948. The discs suffer from several of the phenomena described above and complicating the digitisation greatly: delamination, cracks, groove wear etc., but mainly missing parts of lacquer. All discs were rejected for digitisation in the ‘Golf 5’ project. The recordings include music, spoken word and parts of radio programmes, in German, English, Flemish and some French.

A spreadsheet table of all disc sides – an export of the registration database including title, date of recording and some additional data - was provided to Gecko by VRT.

As the SIRDUKE project is an experimental project, it was uncertain that all the disc sides entrusted to Gecko could be processed in time. The spreadsheet table therefore featured an indication of 21 ‘priority’ sides, as indicated by the VRT.

An XML file containing metadata was been provided for each disc side by meemoo. During the digitisation, these XML files have been enriched at Gecko with new data documenting the Saphir digitisation process.

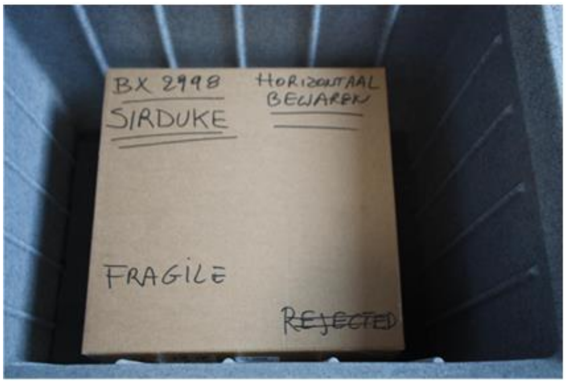


Fig. 7 - 8: the discs as delivered at Gecko, packed in a cardboard box in an insulated container provided by Gecko to avoid further damage through the impact of physical, humidity and temperature shocks.

The discs were delivered by meemoo to Gecko's premises on May 12, 2021. As the discs were sometimes very damaged, they remained wrapped and protected. They were kept in an insulated box to limit the effects of physical, temperature and humidity shocks. They remained stored horizontally throughout the whole duration of the project as the slightest manual manipulation could lead, for some discs, to detachment and loss of already peeled off lacquer pieces.

Fig. 9 - 10: A typical case of a disc delivered for digitisation in the SIRDUKE project: the lacquer layer still sticks well onto the glass core, but the disc is broken. The note 'kapot glas' means 'broken glass' in Dutch.

Fig. 11 – 12: This glass core disc looks like it is in good state, but the lacquer lifts on the edge of the side.

Fig. 13 - 14: Disks with retracted lacquer, moderate on the left and extreme retractation on the right.

Fig. 15: discoloured disc side suffering from delamination

Fig. 16: a disc suffering from delamination, covered with exuded palmitic acid. This side cannot be cleaned because of the risk of further delamination.

Fig. 17: a moderate case of delamination: a disc side with a missing part in the lacquer

Fig. 18: an extreme case of a disc side with missing parts in the lacquer. This is the only side which couldn't be processed by Saphir.

Fig. 19: disc side with discoloured and crackled lacquer. Some very small pieces of lacquer are peeling off, making stylus playback impossible.

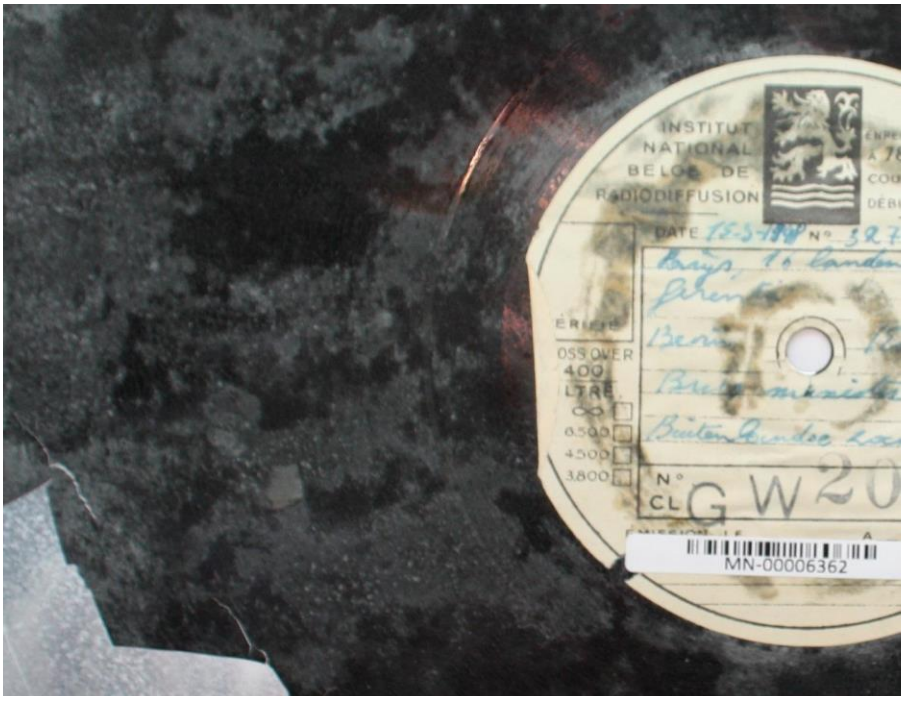


Fig. 20: disc side with palmitic acid spots. Cleaning of this disc side can only be done with a brush.

4.3. Saphir

Saphir is a hardware and software technology that allows analog audio discs to be played optically, without contact with the disc's groove. It has been in development at INA since 2002. After numerous prototypes and improvements the system is now functional, small in size, with simplified components and it can now enter a phase of production and daily use. The operating principle of Saphir, which will be detailed in the next chapters, is based on three main steps:

- A **scanning phase**, during which the disc spins slowly on a platter (about 30 minutes per side). A color-coded light beam is projected on the groove while a camera captures the variations in colour due to the reflection on the wall of the groove, taking pictures of this reflection.
- A **decoding phase**, during which the Saphir playback software generates an audio signal, in small pieces, from the pictures. The many parameters to be adjusted during this step allow the software to correctly follow the groove and to decode the colours and the angle of the groove in order to obtain the best possible signal/noise ratio combined with the lowest distortion.
- A **repair phase**, which consists of placing these pieces of audio signal in the right order and reconstituting the complete path of the groove on the entire disc side. The general principle is that the operator manages the software and provides his indications on the way to go, while the software solves the details of the reconstruction.

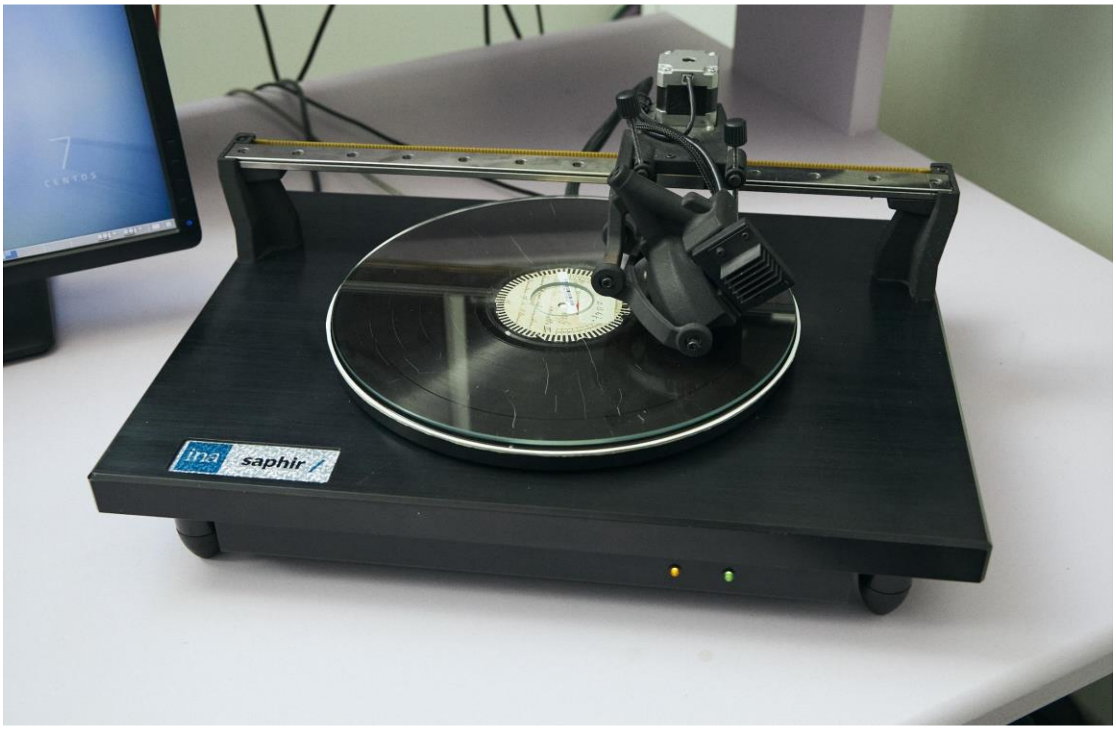


Fig. 21: the Saphir D scanner

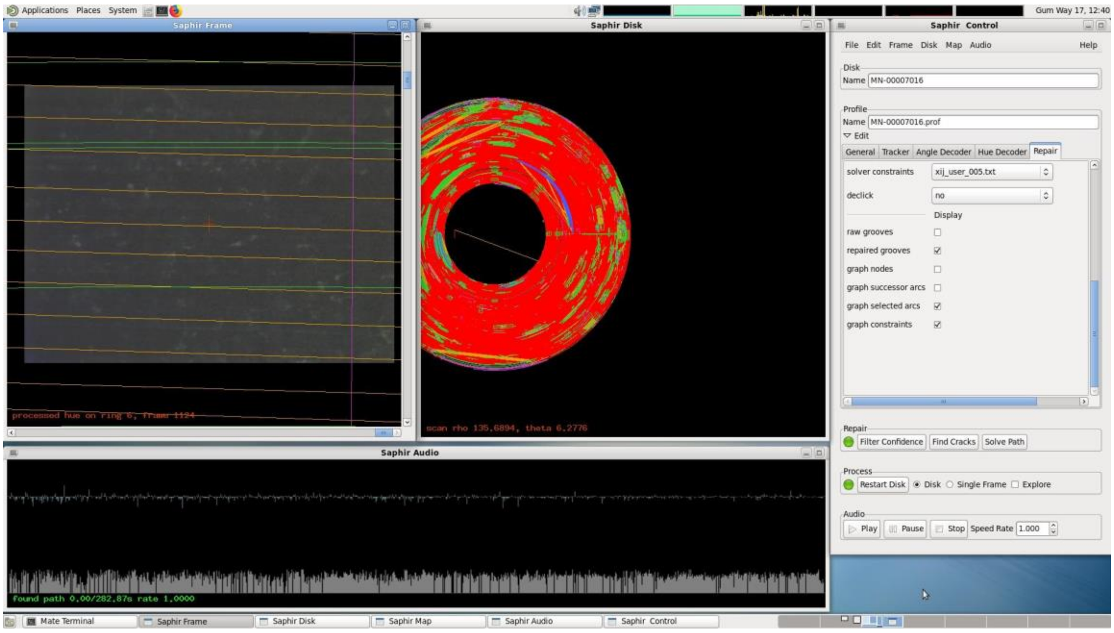


Fig. 22: screenshot of the Saphir decoding application.

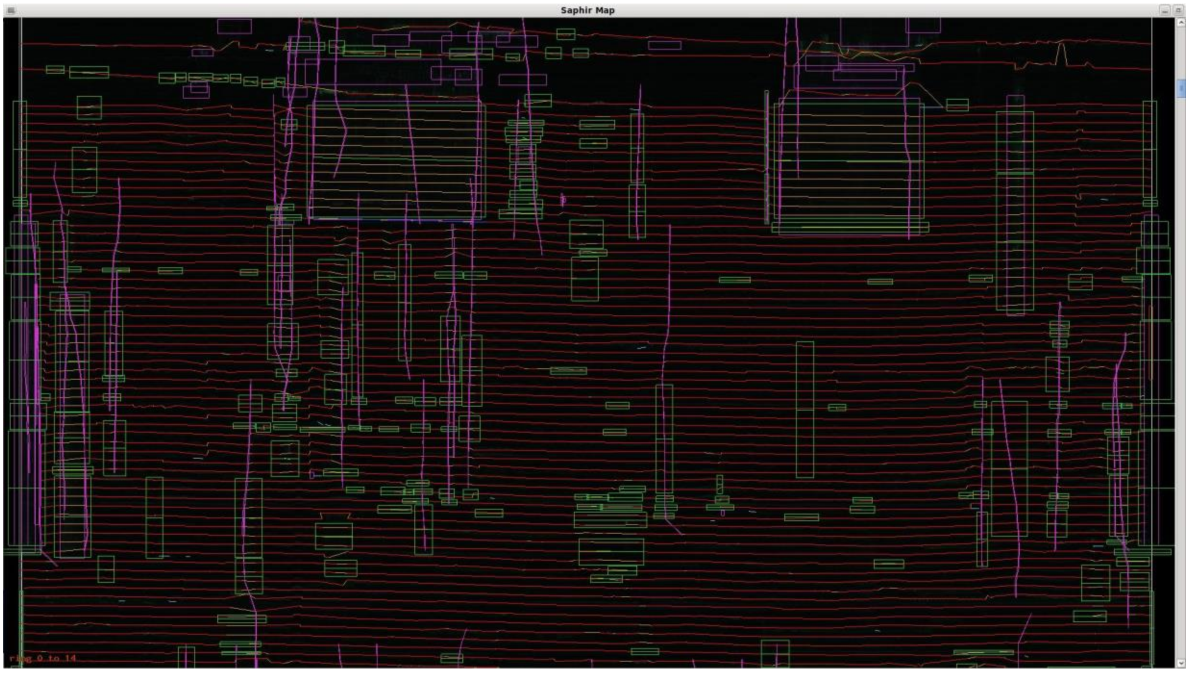


Fig. 23: screenshot of the Map window of the Saphir decoding application.

V. The course of the project

5.1. Saphir training

Until this project, only INA's team - Jean Hugues Chenot and Jean-Etienne Noiré - had been using Saphir. This means that the SIRDUKE project has been the first time that Saphir has been tested in real market conditions beyond pure experimentation, with a relatively large number of discs coming from a third party.

As the production was to be executed in Montreuil by a technician from Gecko, a training period was allocated at the start of the project. Adrien Bailly, sound engineer at Gecko, specialist in the digitisation of discs and other carriers and on digital restoration, had already worked on collections of instantaneous discs, but only during digitisation with traditional stylus playback.

This training phase was a very important phase for Gecko, as it was necessary to switch from a traditional way of working to a new approach to digitisation, to optical techniques and to a complex machine of which the interface and operation differed greatly from the tools in use at Gecko. Likewise, it was an opportunity for INA to get feedback on the progress of the development of Saphir and of its use by an external technician, used to working on disc digitisation in the traditional way.

The Saphir training therefore became a dialogue between the engineer and the sound technician, starting with undamaged shellac discs for the handling of the Saphir system, then quickly moving on to the discs of the SIRDUKE project, gradually discovering all the specific cases of treatment.

The training lasted about 25 hours. Later on Jean-Hugues Chenot also returned to Gecko a few times in the following days, to answer questions. At the end of the project, as Adrien Bailly experienced difficulties in completing all the decoding work of the SIRDUKE discs in time, Jean-Hugues Chenot offered to work at Gecko on the remaining discs to complete the full collection.

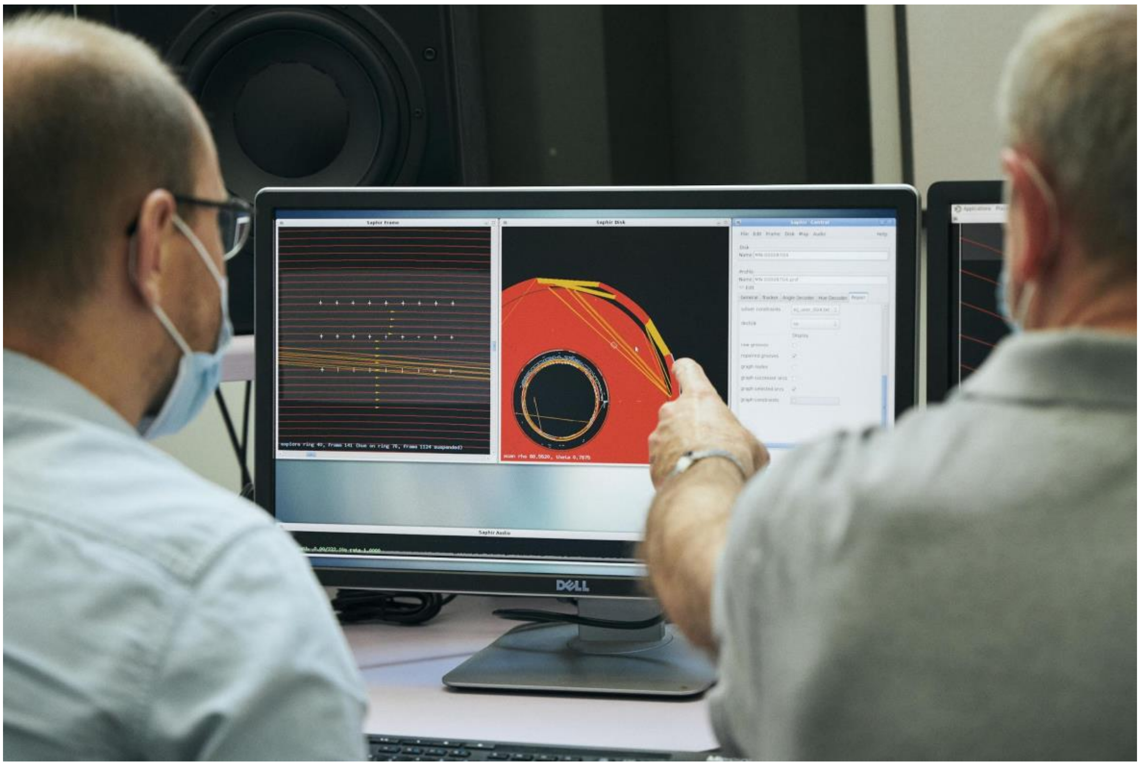


Fig. 24 – 25: Adrien Bailly from Gecko (left) and Jean-Hugues Chenot from INA (right) during the Saphir training period in the Gecko studio.

Fig. 26: INA provided Gecko with one of the four existing exemplars of the Saphir scanner in its compact version, as well as a Linux PC (Centos7) installed by Jean-Hugues Chenot with Saphir applications. Here, Jean-Hugues Chenot at the start of the project adjusts the brightness parameters of the Saphir scanner, after the first trials on the SIRDUKE discs carried out during the training.

5.2. Scanning phase

The principle of the Saphir scanner is based on the fact that the walls of the grooves of a grooved disc laterally behave like a mirror. The process uses a projection of a large light beam (140 ° × 15 °) onto a small area of the disc surface (2.6 × 2 mm). The walls of the groove reflect the rays (whose colour depends on the angle of projection) according to the law of light reflection (the angles of reflection and incidence are equal). Consequently, from a distant point of view (the camera) the walls of the groove appear coloured in the image. The colour received is a function of the orientation of the groove of the wall and therefore varies depending on the modulation of the audio. The advantage of this principle is that simple colour and optical cameras can be used, helping to make the scanner affordable, while remaining efficient at high audio frequencies (up to 20kHz).

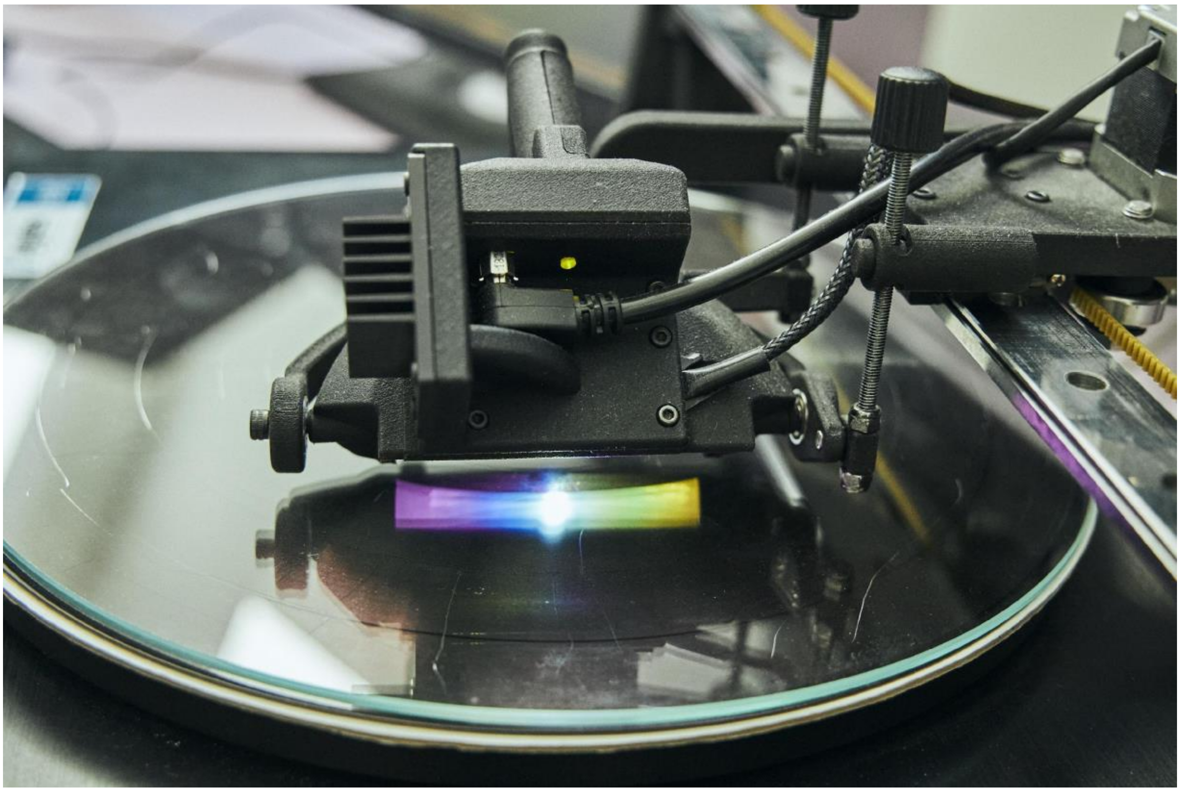


Fig. 27: the Saphir D scanner in operation.

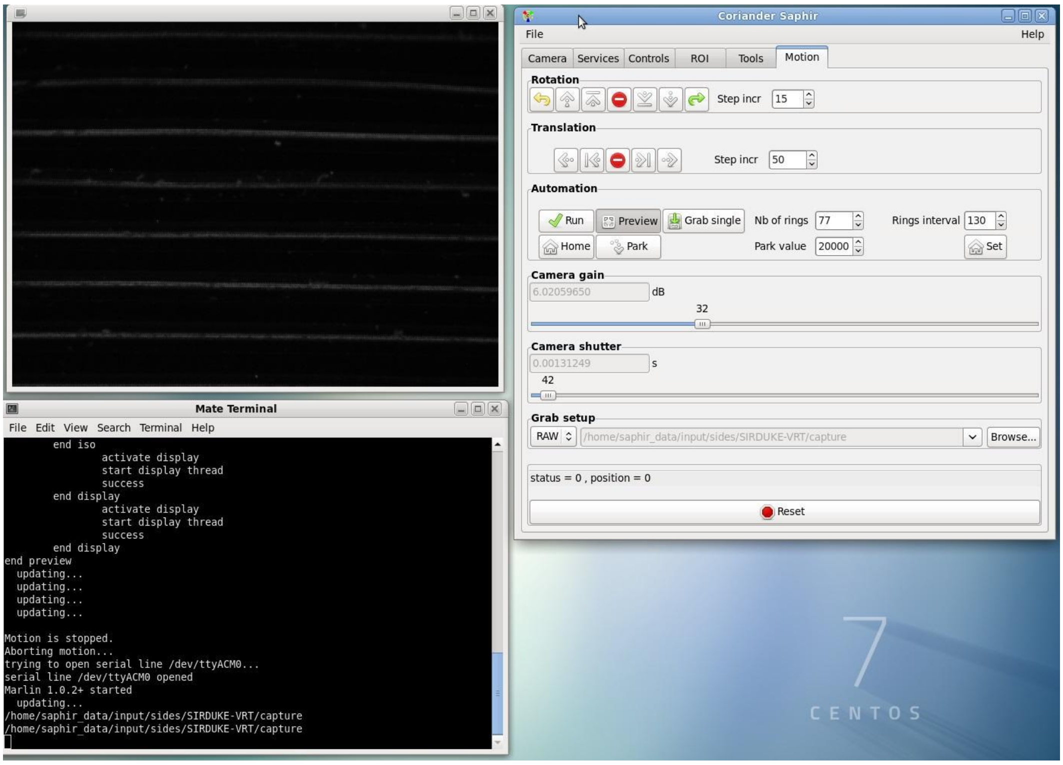


Fig. 28: global scan interface of Saphir's software 'Coriander'.

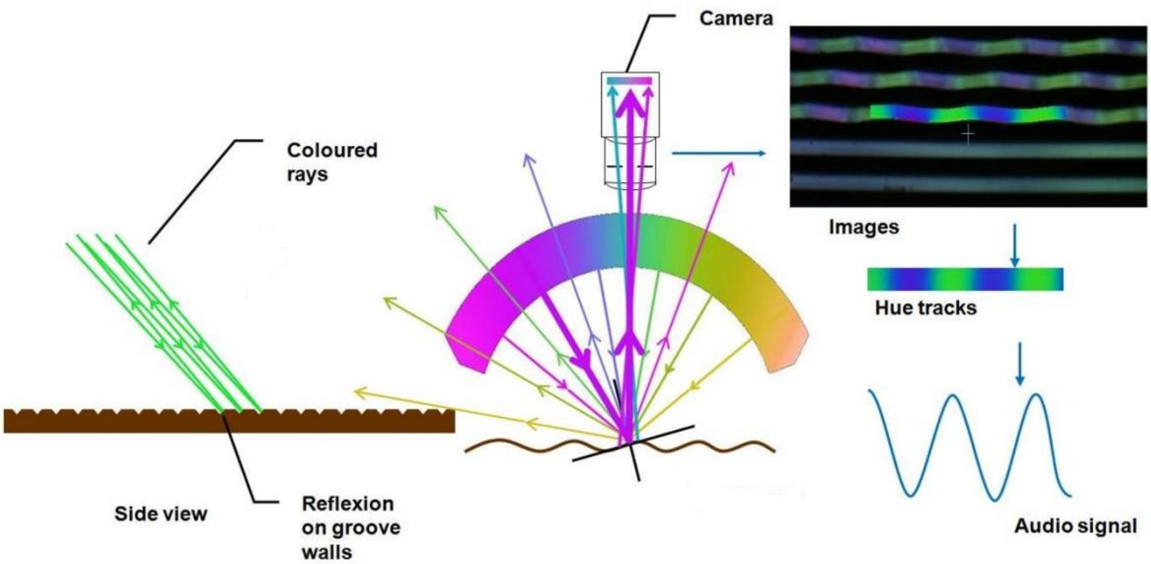


Fig. 29: the principle of reading the groove wall's angle through structured colour illumination.

In practice, the lacquer disc is placed under a glass disk to protect and keep the disc flat. The Saphir Coriander software is launched by terminal command prompt and allows to control the scanner.

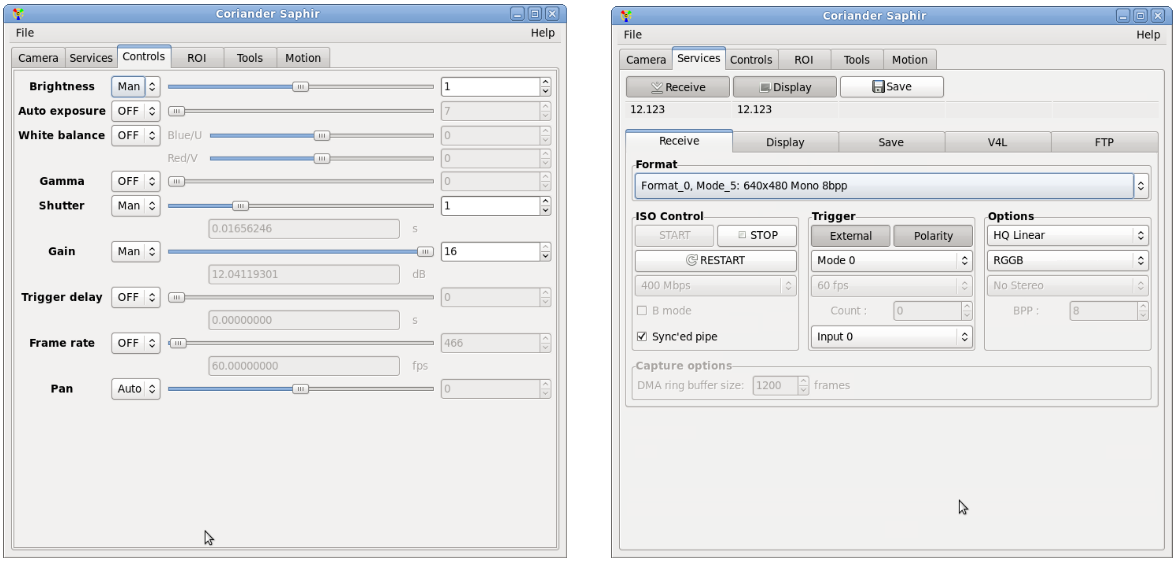


Fig. 30: two of the tabs of the Coriander interface, which allow access to the camera adjustment parameters.

The main window is used to control the camera movements and the rotation of the scanner platter. The disc is centred by rotating the platter continuously and by following the behaviour of the grooves on the display. The adjustment is done manually.

Then the operator manually moves the camera on its rail to find an area of the disc that seems relevant and adjusts the height of the camera and its angle to the disc. The goal is to visualise a groove as clear as possible and in the most colourful way. The window also allows adjusting the gain of the camera and its shutter.

Once all the parameters have been verified, the operator initiates the scanning process, which lasts between 20 and 40 minutes per disc side. The platter performs one rotation in 30 seconds, the fixed camera acquires one ring per rotation.

Fig. 31: motion settings tab of Saphir's Coriander software.

After each turn, the platter stops and the camera moves slightly from the inside to the outside. The grooves on the periphery of the picture will also be captured on the next rotation. This means that there is an overlap of part of the picture at each turn. A turn is called a 'ring' in Saphir. The operator foresees the number of rings necessary according to the grooved surface of the disc (for example, if the disc is grooved on a radius of 89 mm, it will be necessary to set up 70 rings).

The software captures 1125 images per ring, in 640 x 480 RAW. Each picture covers 2.6 x 2 mm^2 of disc area. The amount of data for one side can quickly become rather large (22 GB per side). The camera is oriented so as to capture the light reflection on the outer wall of the groove. The outer wall of the groove is in the vast majority of cases the least damaged. It is possible to place the camera on the other side to capture the inner wall of the groove, but the resulting audio signal is usually worse because of the amplified parallax and the fact that the inner wall is often more damaged.

Adjusting the focus and angle of the camera is decisive on the signal quality obtained during the following steps. Angle is adjusted through back screw. Focus is adjusted by changing the height of the camera head (front screw). The reflection on the groove wall should be as bright and as wide as possible, and focused near the picture centre.

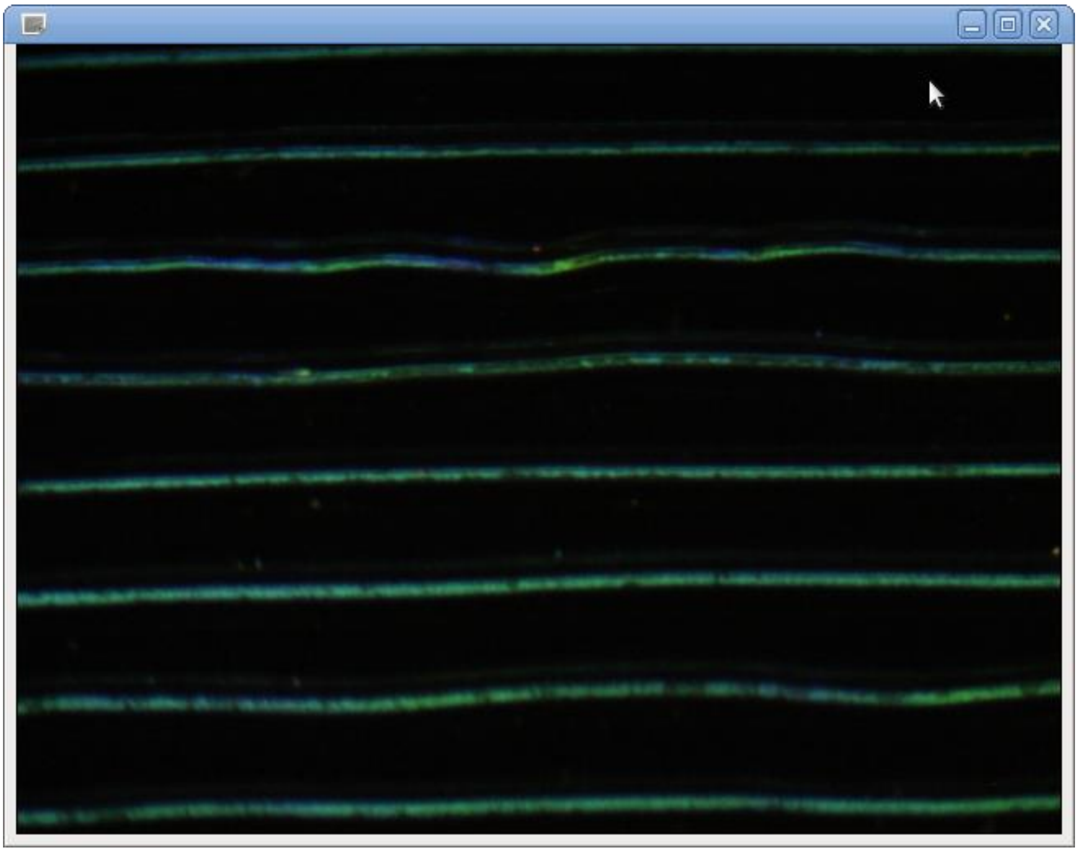


Fig. 32: example of a picture of a ring. A well-focused groove on which the audio signal and its coloured variations is visible.

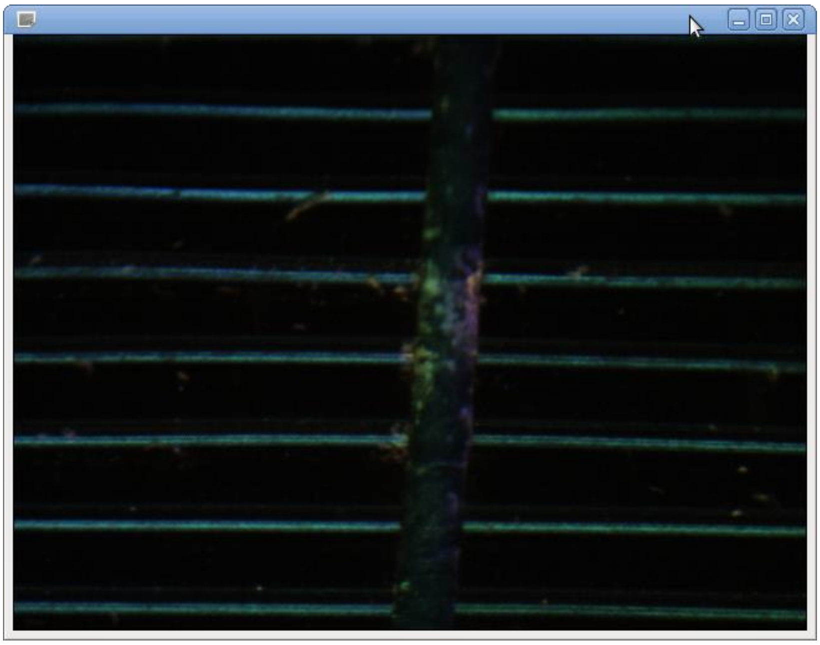


Fig. 33: in this picture the groove is also well defined and a crack in the lacquer is clearly visible.

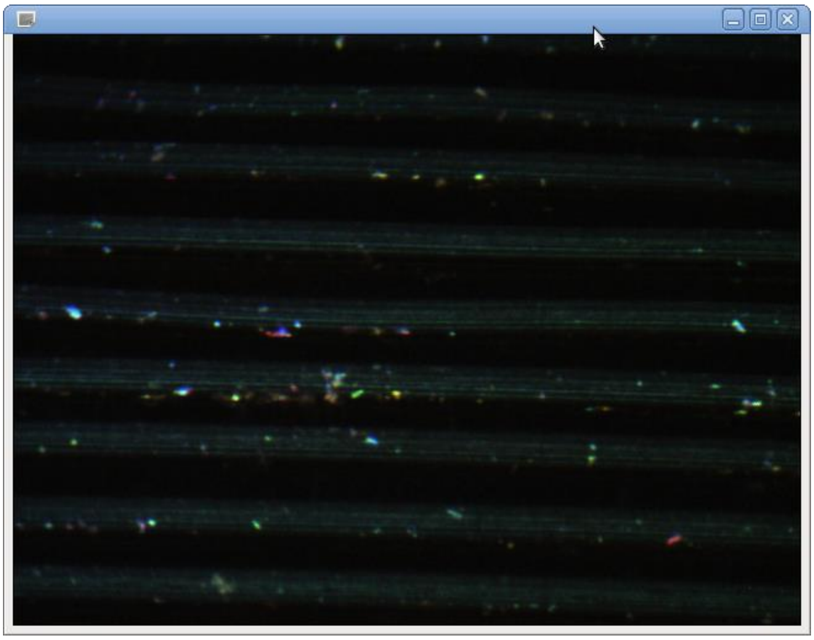


Fig 34: in this picture the signal is very weak, despite the focus made right in the middle of the side of the groove. In addition, we can see a lot of exudates which will cause noise problems during decoding.

Before the scanning step the disc is cleaned if possible and the pieces of lacquer detached but still present in the sleeve are put back as well as possible in their original location. This manipulation is done with gloves, using a small piece of paper to handle the lacquer. The pieces are not glued back, only brought back in their original place.

None of the disc sides in the SIRDUKE project were cleaned with soap and water. The fragility of the lacquer proscribing this type of cleaning. For the less damaged discs, a light cleaning has been done using a dry microfiber cloth. Only for one of the 52 disc sides selected for the SIRDUKE project cleaning was not attempted, because more than 80% of the recorded surface was missing (cf. fig. 18).

5.3. The decoding phase

The disc decoding phase consists of performing the following steps :

- Merge the groove which is overlapping from one ring to another during the scan
- Identify and track the groove on the pictures
- Extract a signal from this groove
- Generate sound fragments from this signal

The decoding phase is carried out with the Saphir Play software, which is launched from a terminal command prompt.

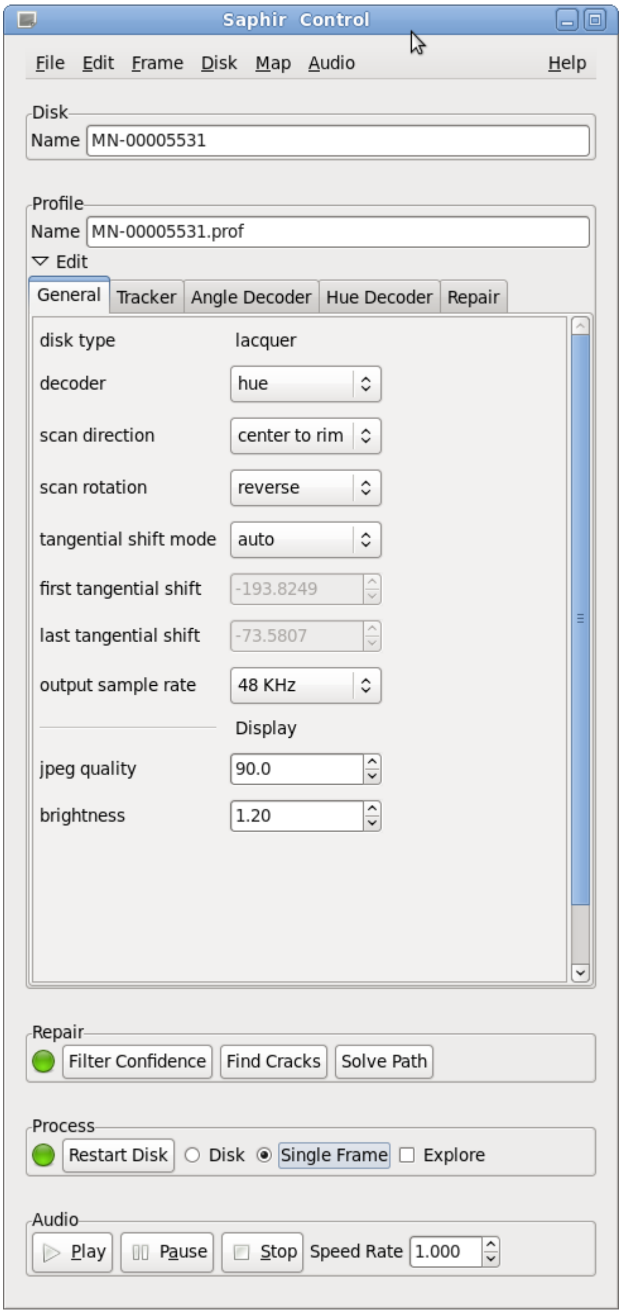


Fig. 35: one of the main decoding windows of Saphir Play.

When the Saphir Play session is launched for a certain disc side, the first measurement, which consists in correcting the tangential shift, is automatic. The second operation must be done by hand, it is the adjustment of the anamorphosis.

As the vertical scale of the pictures depends on the angle of the scanner head, it is necessary to stretch them to ensure the same groove fragments from consecutive rings are located at the same place.

The direction of the decoding of the disc is chosen (depending on if the grooves go from the rim to the centre or vice versa). Also the tangential shift is adjusted if necessary, together with the anamorphosis.

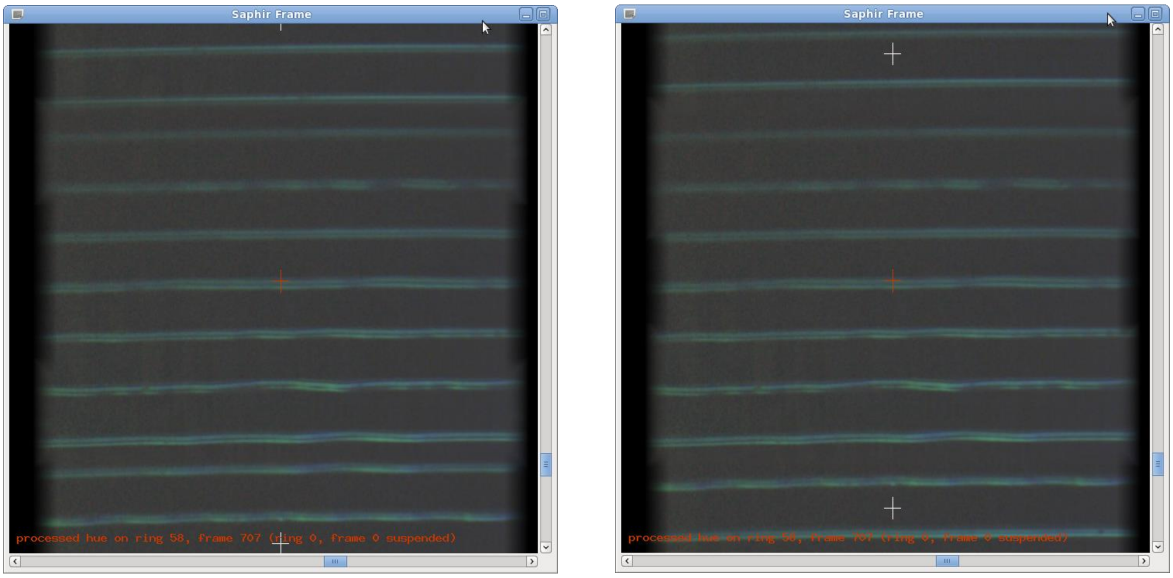


Fig. 36 – 37: on the figure on the left the spacing between some grooves is not regular. Some parts of the same groove turn appear twice. On the figure on the right the anamorphosis has been correctly adjusted and the picture of each ring overlaps perfectly.

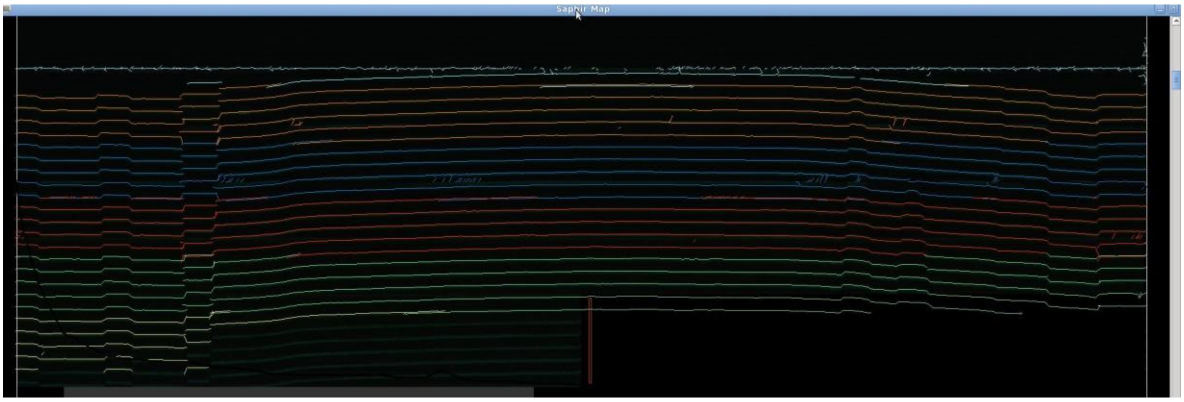


Fig. 38: when decoding is started, it can be seen that on each ring (represented here by each colour), the groove overlaps well on itself at the start and end of each ring.

The next step is to achieve the best possible tracking of the groove. On the Saphir Frame display, the crosses indicate the detected starts and ends of fragments (cf. fig. 39). The yellow and green lines indicate the part of the groove that will be decoded. These parameters can be adjusted by changing the values of the 'seeds' fields and the maximum and minimum luminance thresholds shown in the screenshots below. The goal is to follow the groove without losing any part, but not to set the thresholds too low to avoid generating audio fragments where there is no groove.

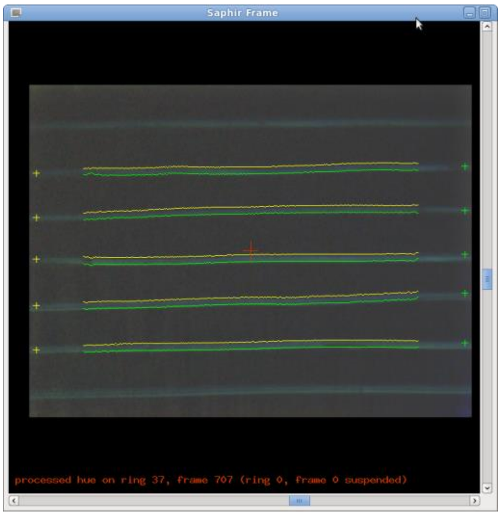
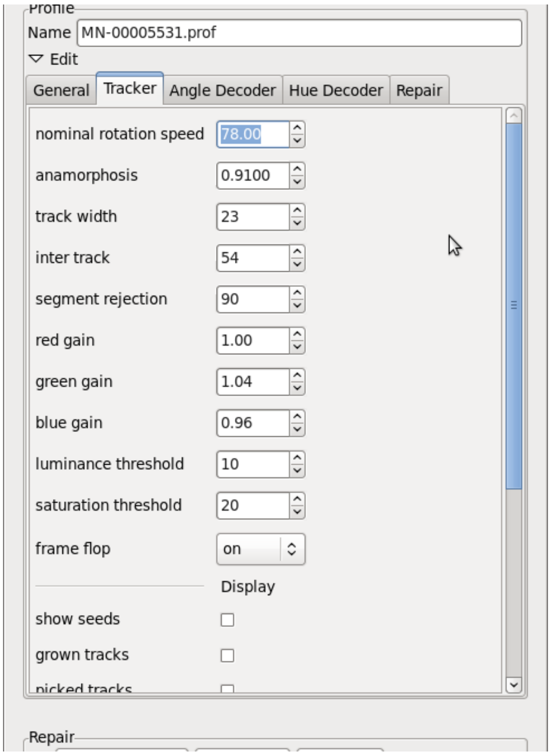


Fig. 39: the cross indicates the detected groove. The yellow and green lines indicate the part of the groove that will be decoded.



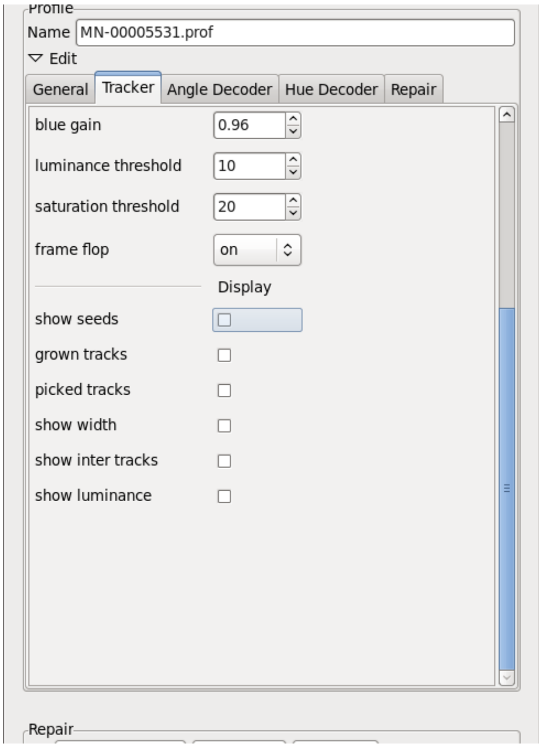


Fig. 40 - 41: settings tab in the Saphir Play interface indicating parameters to track the groove in the picture.

The next step in the process is the actual decoding. Two settings tabs are dedicated for the two types of decoding provided by Saphir: ‘angle decoding’ and ‘colour hue decoding’.

5.3.1. Colour hue decoding

This step is used to extract the audio signal from the groove. First we focus on colour hue decoding, as this is the main particularity of Saphir compared to its competitors. In theory it should allow for a much better audio signal resolution (wide bandwidth, high SNR, low distortion).

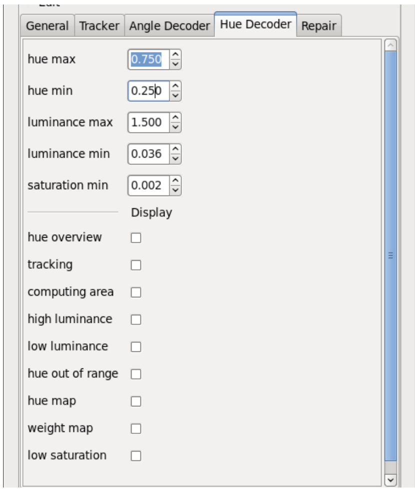


Fig. 42: Hue Decoder tab of the settings tab in the Saphir Play interface

The parameters which will have an effect on the extraction of the signal are as follows:

- the width of the decoded groove
- the gain of blue, green and red colours
- luminance (in particular minimum luminance threshold)
- minimum and maximum Hue thresholds (Hue range)

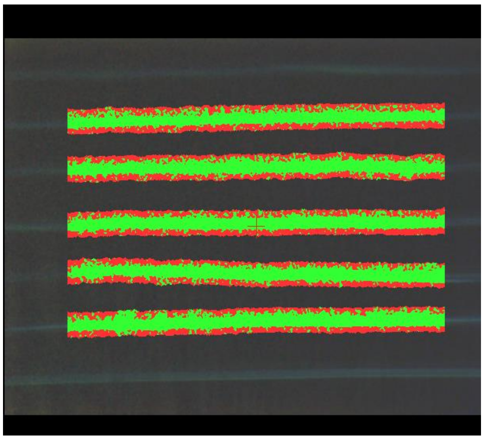


Fig. 43: The 'show luminance' display in the Tracker tab allows on the one hand to adjust the luminance but also to visualise the width of the groove to be decoded, in order to limit the rendering to a defined area and to avoid areas where no signal is present.

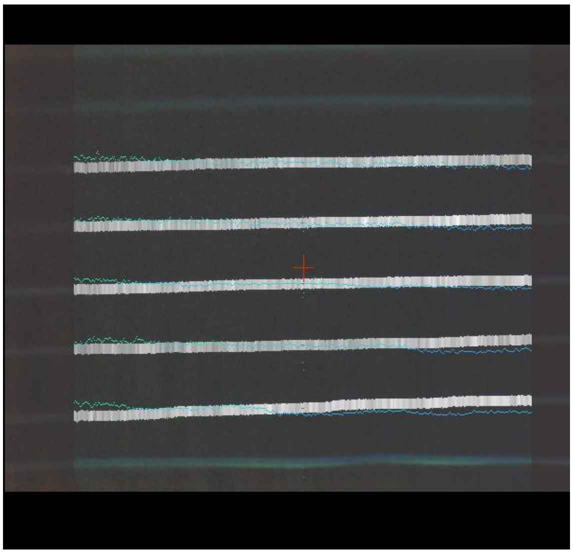


Fig. 44: With the 'hue overview' display, the colour gains can be adjusted. The goal is to find a picture of a ring where a signal is clearly visible, without being too strong, then to adjust the blue and green gains.

When these gains are perfectly centred, as it is the case in the picture above, the signal should vary around a zero centre point in the middle and the blue and green colour representations are represented on either side of the signal.

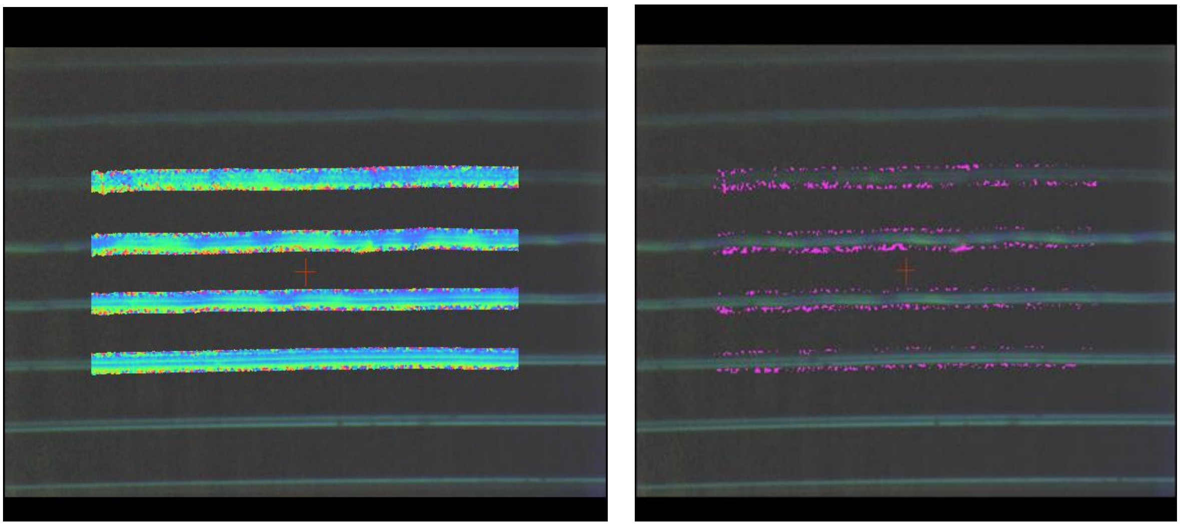


Fig. 45 – 46: on the left, we see all the colours reflected by the groove wall. As mentioned earlier, the downward and upward shape of the waveform should alternate between blue and green. It is therefore necessary to avoid, as much as possible, everything that is not part of the signal. Dust, cracks, etc. therefore appear in other colours.

On the right, in purple dots show the parts of the picture which will not be decoded because they are not considered a part of the signal. The amount of these purple dots can be adjusted with the 'hue min' and 'hue max' parameters.

The 'hue map' and 'hue out of range' displays allow to set the decoding processing range.

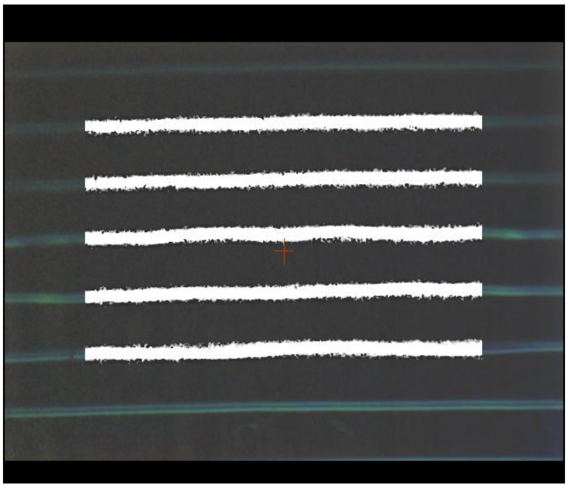
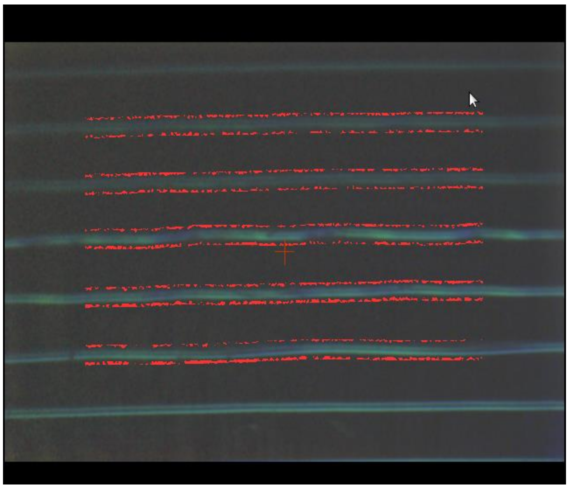
 

Fig. 47 – 48: 'weight map' and 'low luminance' displays of the Saphir Play software.

The 'weight map' and 'low luminance' displays make it possible to separate what is part of the groove wall and what is outside. On fig. 47 the white represents what is considered to be the useful signal. On fig. 48, the red shows the entire surface below the luminance threshold which will not be decoded (inside the selected groove width zone). This threshold is adjusted with the 'low luminance' parameter and corresponds to the background noise below which is considered as not containing any signal.

There is an equivalent parameter called 'high luminance', corresponding to the maximum luminance threshold that will be decoded. It can be used to remove exudates or too bright spots on the surface of the disc, but in the majority of cases it should simply remain high enough not to flag any useful signal from the image.

All these parameters are set by testing different pictures of different rings of the disc side, trying to find the best visual compromise on the whole disc. At this stage of operations, it is not possible to check the audio resulting from the settings.

The operator then triggers the decoding of the disc side with the 'Restart Disk' function. The decoding starts and is represented on the screen by coloured rings which appear as the audio fragments are created. After a few minutes, it is possible to test-play the incomplete out-of-order audio track.

On a heavily loaded machine these decoding renderings can take up to eight hours for one side. During the decoding rendering it is possible to work on the decoding or the repair of another side on the same workstation, or to prepare a new scan.

The experiment on SIRDUKE, with the workstation supplied to Gecko, showed that up to 4 to 6 decoding sessions could run at the same time without overloading the workstation's RAM.

5.3.2. Angle decoding

Angle decoding (via the 'angle decoder' tab) is not based on colour variations but on the slopes of the groove, as measured from the picture. The horizontal engraving signal is therefore extracted according to the angle of the groove.

This decoding method is slower and gives poorer audio results (particularly reduced bandwidth), but can succeed in obtaining a signal in certain cases where this was not possible via hue decoding because of a too weak signal or too much exudate.

In the framework of the SIRDUKE project, only one side out of the 52 was decoded using the angle decoding method. It is expected that in the future the two methods can be applied in combination in the Saphir software, but this is not yet the case.

5.4. Reconstruction phase (repair)

The repair phase consists in linking in the right order the audio fragments generated during the decoding phase, in order to reconstruct the entire recording over the entire duration of the side.

This operation is pretty simple on a disc in good condition of which groove is not damaged, but much more difficult on a disc with retracted, cracked or partially missing lacquer.

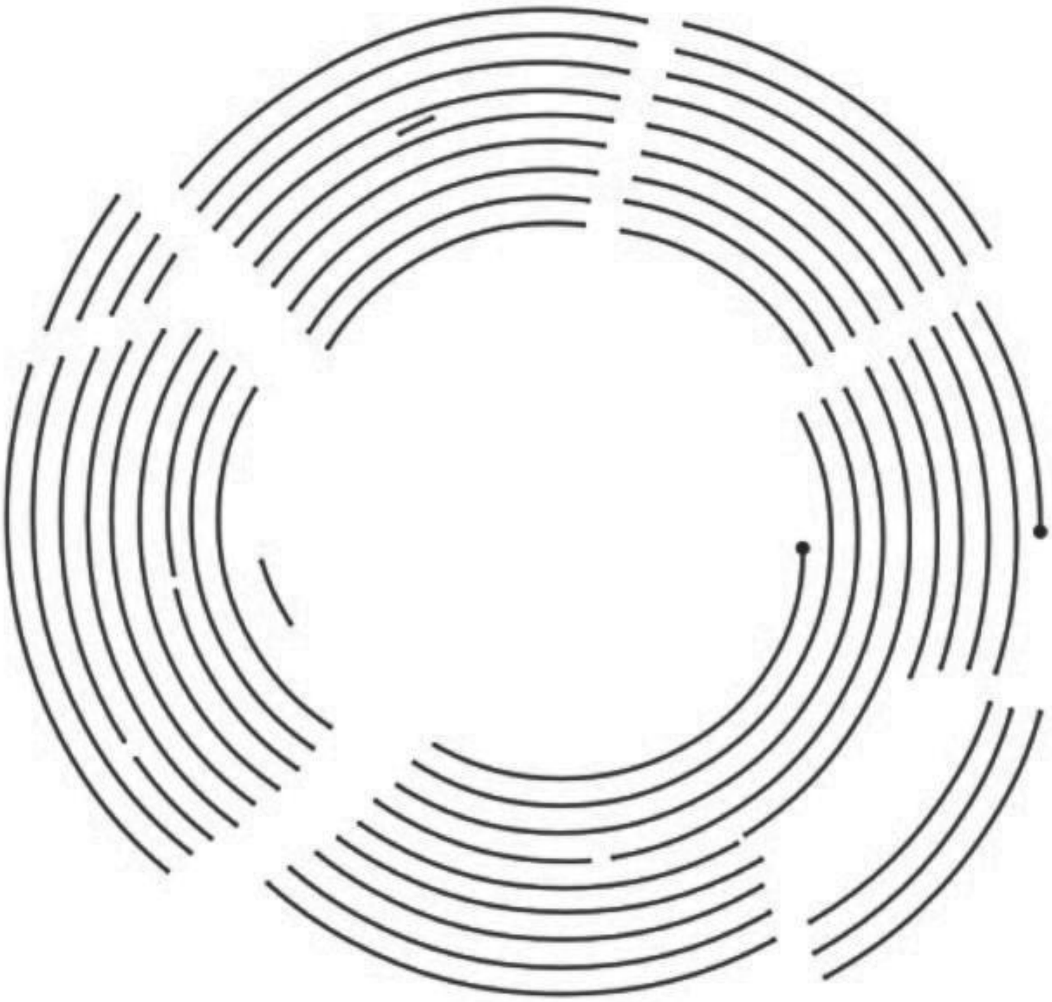


Fig. 49: *this picture schematically represents the audio fragments resulting from the decoding on a side with cracked lacquer, clearly also visualising the problem: the pieces have to be connected correctly together if we want to reconstruct the continuity of the groove.*

On a real disc, there can be up to 12.000 audio fragments and many more possible paths. Even if this number varies greatly depending on the condition of the disc, the problem can be posed as follows:

'What is the best path between the outer fragment and the inner fragment of the disc?'

This path must have the following characteristics :

- start from the first outer fragment and end on the last at centre,
- each fragment must have only one entry and one exit chosen,
- each fragment should only appear once, no loop is allowed in the path,
- as many groove fragment as possible have to be used,
- excessive jumps should be avoided.

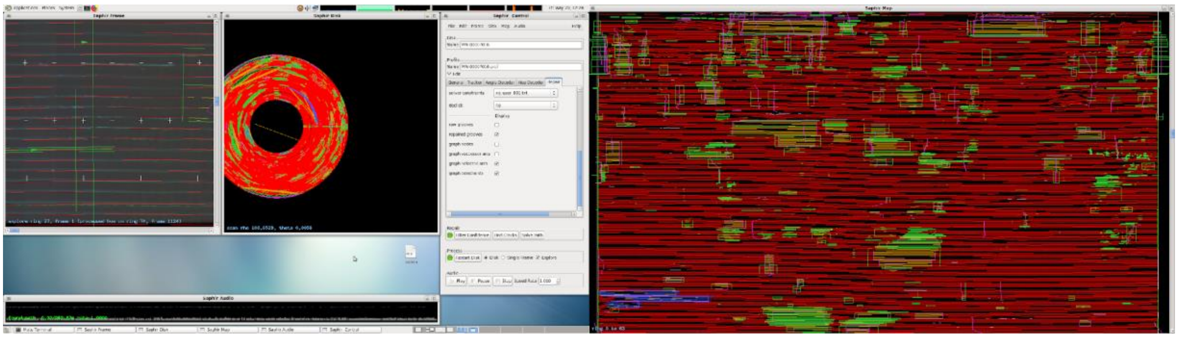
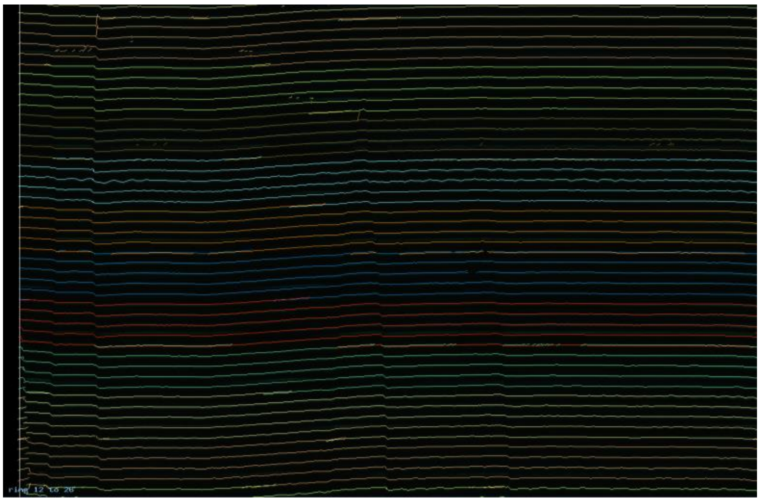


Fig. 50: on this screenshot we see the different Saphir Play windows used during the Repair phase:

- Saphir Control: settings and controls window
- Saphir Frame: this window displays one picture of a ring, we can move around the entire disc
- Saphir Disk: a visualisation of the side seen from above, we can zoom in and move around the entire disc
- Saphir Map (right picture): a visualisation of the entire path of the groove, we can also zoom in and move around. This is the main window used during the reconstruction.
- Saphir Audio: the window presents the waveform of the resulting audio, in which we can move and listen.



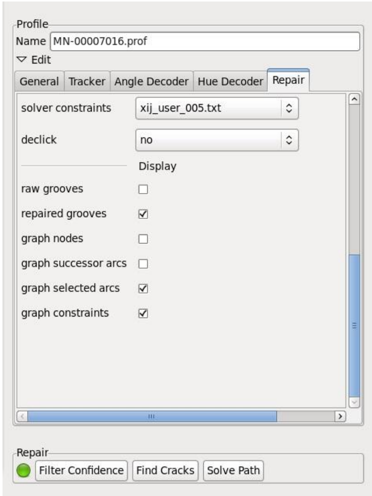


Fig. 51 – 52: at the end of the Decoding phase, the fragments appear in colour for each ring. In Saphir these raw fragments are called 'raw grooves'. They can be displayed or hidden by checking the corresponding box in the Repair tab of the Saphir Control window.

The first step is to identify the lacquer cracks and find a confidence threshold beyond which the fragments must be cut. These parameters are accessible in the Saphir control window: 'find confidence' and 'find cracks'.

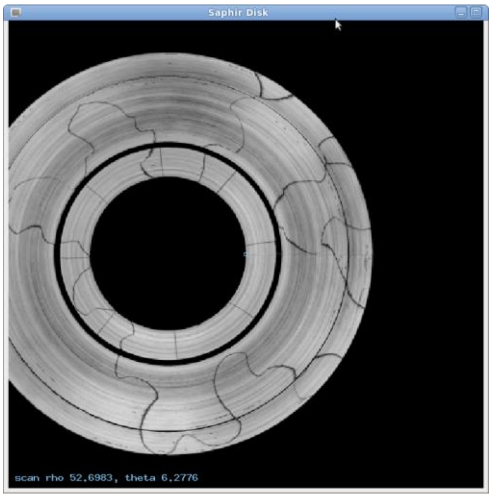


Fig. 53: screenshot from the Saphir 'disc window'. The confidence (parts in which the tracks are complete) is displayed in white. The lower the confidence (black), the more the fragments will be cut and will need to be connected correctly. The confidence threshold is adjusted in the Saphir Control window.

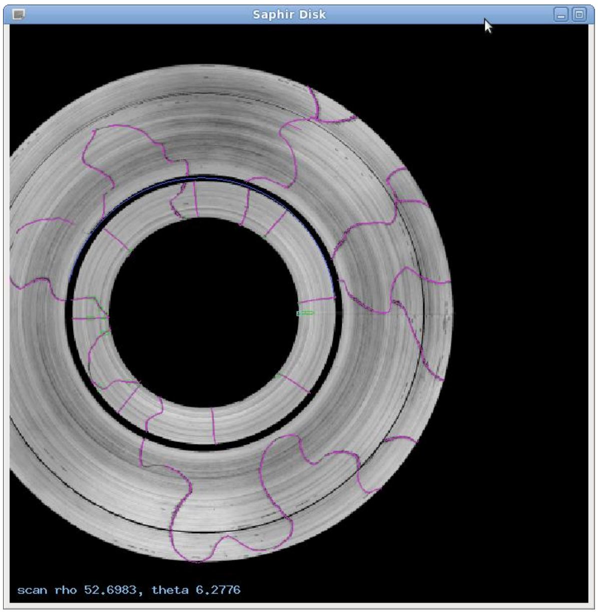


Fig. 54: screenshot from the Saphir 'disc window' featuring the detected cracks in purple.

The 'find cracks' function allows the disc cracks to be detected and displayed in purple, according to a configurable threshold. The goal is to detect enough cracks to cut the fragments in the right place, without having to draw them by hand afterwards, but at the same time avoid detecting cracks when unnecessary (i.e. when the path must continue straight) which would cost time and computing resources.

Once the confidence and the number of cracks have been determined, the operator uses the 'find path' function, which starts the reconstruction of the path of the groove. The rendering time can be long, so it is preferable not to render the entire side on the first try. The operator can select a number of rings to resolve. It is useful to start from the centre of the disc side, on a few rings, then to progress until the edge, before relaunching one last time the reconstruction on the whole disc side.

Once a path has been (partially) found by the software. The 'raw grooves' checkbox can be ticked off and the 'repaired grooves' can be displayed. These repaired grooves are fragments of reconstituted grooves linked together by links called 'arcs', represented by arrows of different colours.

The repaired groove fragments appear in red when they have been integrated into the path, in blue when they are isolated and could not be included as is in the path and in yellow when a fragment is part of an isolated loop. At the end of the repair step, the goal is to have all fragments in red, leaving only irrelevant fragments in blue.

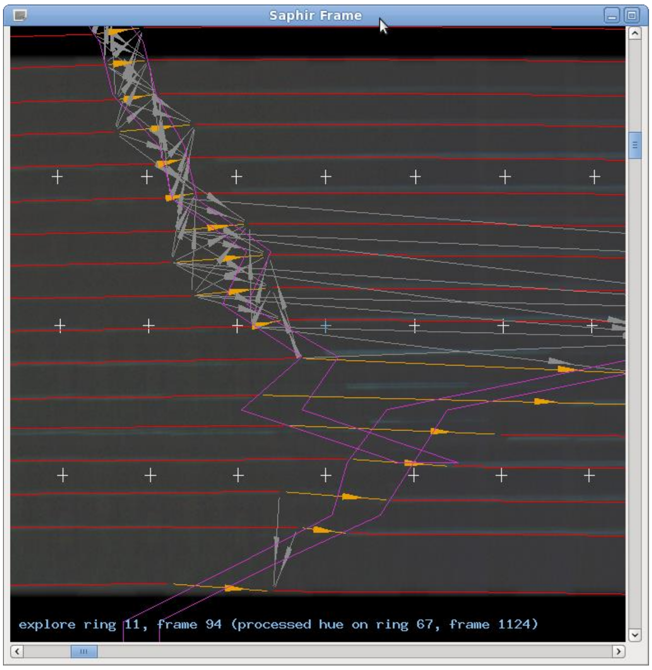


Fig. 55: screenshot from the Saphir 'arcs window' featuring arrows in grey and orange.

The arcs come are shown as arrows of two colours:

- in grey the 'successors arcs', which show the possible paths between two fragments, depending on adjustable parameters of angle, distance and number of jumps.
- in orange the 'selected arcs', which show the connections chosen automatically during the rendering to follow the path.

These two types of arcs may or may not be displayed independently, using checkboxes in the Saphir control window. After the rendering launched during the 'find path' step, it is unlikely that the path is entirely red, meaning that the selected arcs are the correct ones when resolving a crack for example.

The main reasons for poor or incomplete reconstruction are :

- An arc, needed to solve the pass, does not exist (does not appear in grey).
- The desired path intersects with itself, which is not permitted.
- A groove fragment jumps over a crack, connecting different turns. It should be cut to allow for the correct linking.
- A fragment of a groove is missing. Bypassing it would require jumping further than allowed by the parameters.
- Computation is stopped by the user, delivering sub-optimal results.
- Directives (constraints) given by the user hold an error.

These problems are solved by the operator applying different kinds of constraints. These constraints can be considered as guidelines about the path that the reconstructed signal should take.

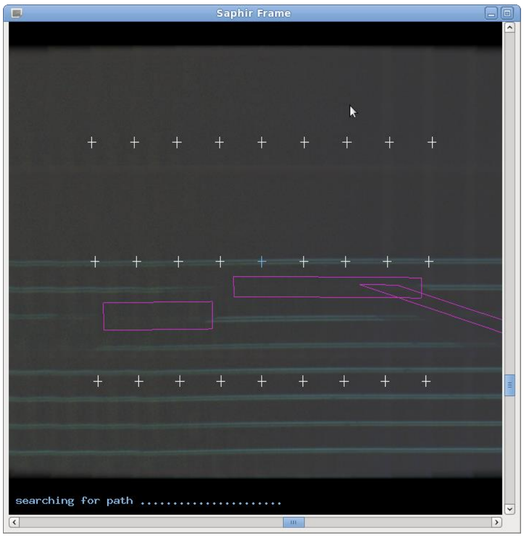


Fig. 56: screenshot of the 'cut box' in purple on the Saphir software

The 'cut box', a purple rectangle is used to cut a fragment of a groove. It behaves like the cracks detected in the previous step. Cutting out fragments can be necessary when a crack has not been detected automatically and/or when a fragment must be cut, or ignored (e.g. if a small crack is identified as a groove fragment for example).

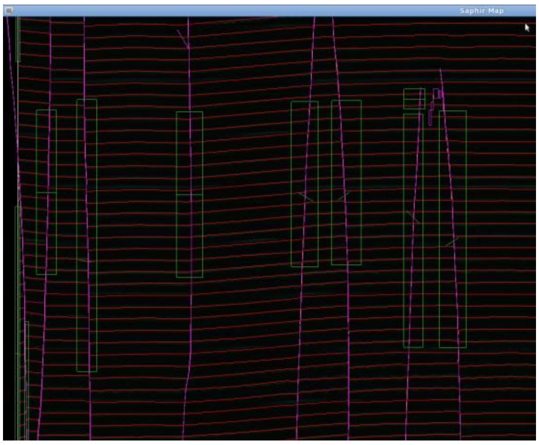


Fig. 57: screenshot of the 'recommended box' in green on the Saphir software.

The 'recommended box' is a green rectangle with an adjustable direction arrow. It corresponds to the following directive: for each groove fragment that ends in the Box, only the arcs that correspond to the arrow's direction must be used. This typically makes it possible to compensate for a radial shift across a crack between lacquer patches.

There is also the 'mandatory box', which looks the same, but in yellow. It is used to force the passage of the path and is not used very often.

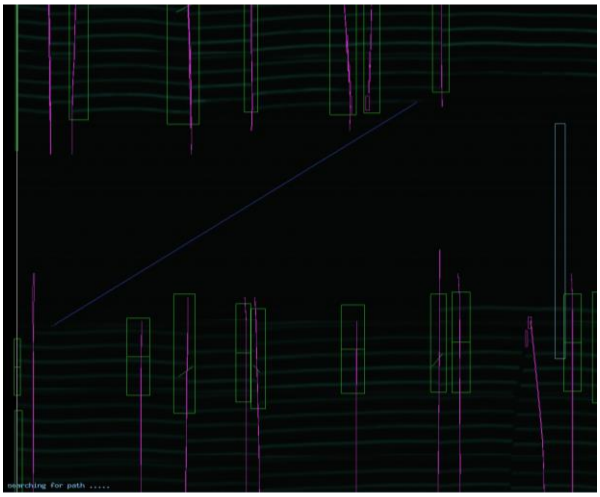


Fig. 58: screenshot of the 'shortcut arc' in blue on the Saphir software.

The 'shortcut arc' is a blue arrow that is drawn from the desired starting point to the end point. This newly created arc is allowed to cross any arc or fragment. It can be used to connect across missing lacquer flakes, uncut sections, or to solve complex cases where lacquer fragments overlap or where the desired path auto-intersects.

All these constraints can be displayed or hidden from all Saphir windows by checking the 'graph constraints' box in the Saphir control window. Fig. 59 and 60 show some examples of the use of graph constraints during the repair phase.

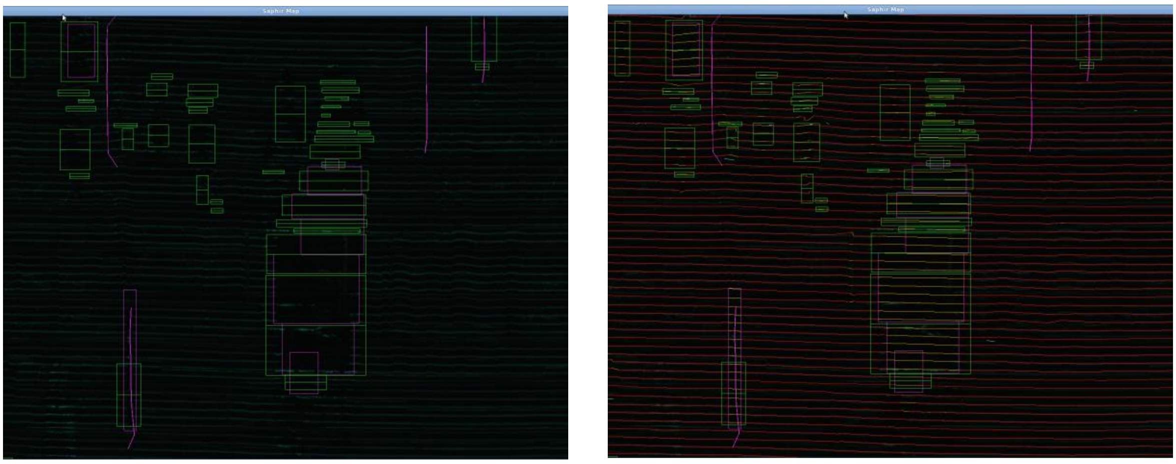


Fig. 59 – 60: screenshots of the Saphir software showing in the green boxes the missing groove areas before and after reconnection.

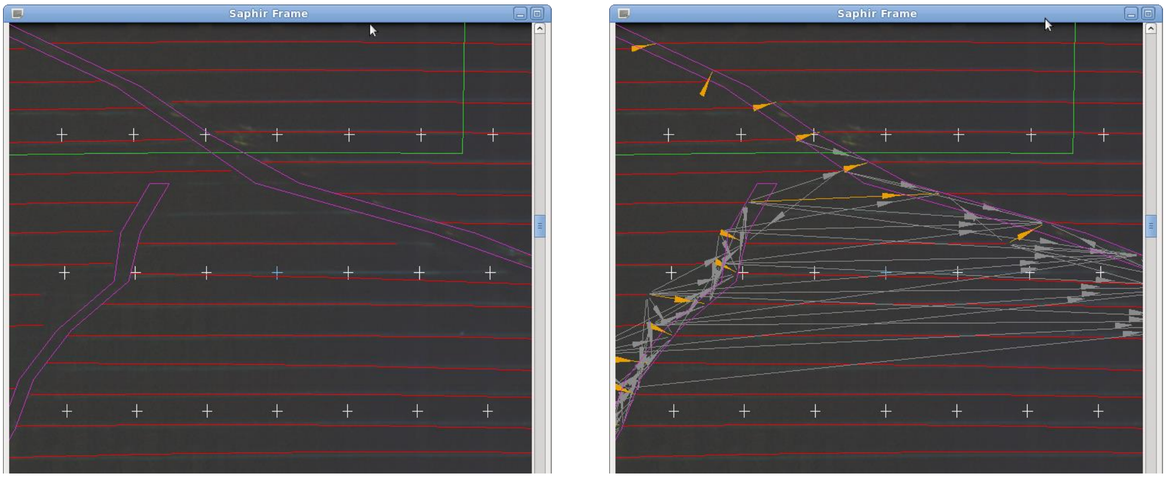


Fig. 61 – 62: fragments cut by cracks as shown by the Saphir software. On the right picture, we see 'successor arcs' in grey and 'selected arcs' in orange. We partially see a 'recommended box' at the top of the picture, which allowed to correctly link the fragments on a part of the crack.

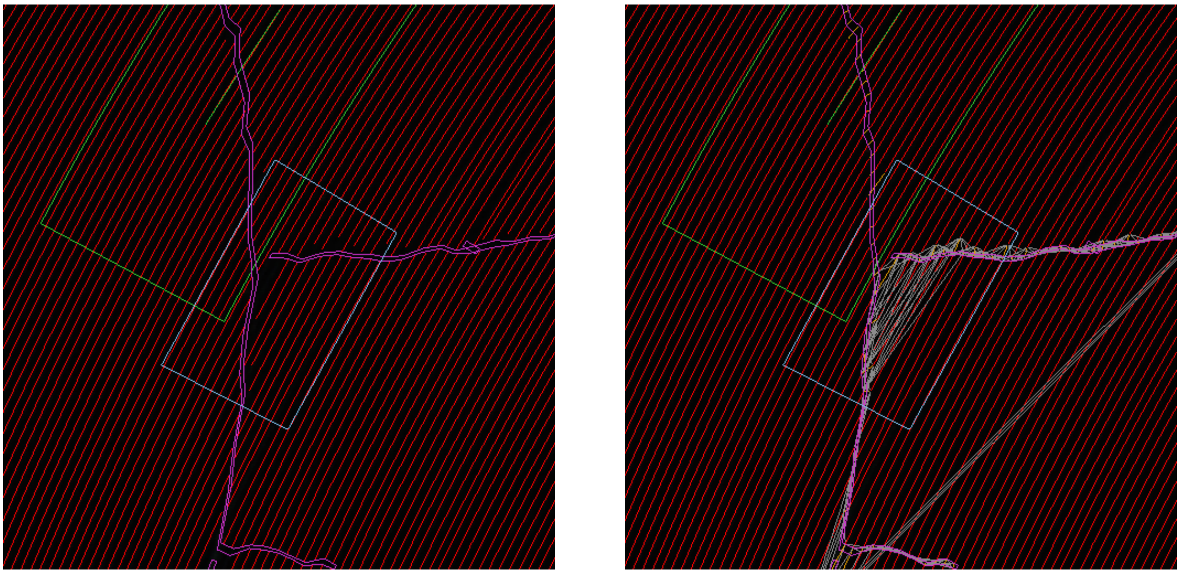


Fig. 63 – 64: the same region as in fig. 59 and 60, but seen from the Saphir Disk window. The light blue rectangle shows what is displayed on the Saphir Frame.

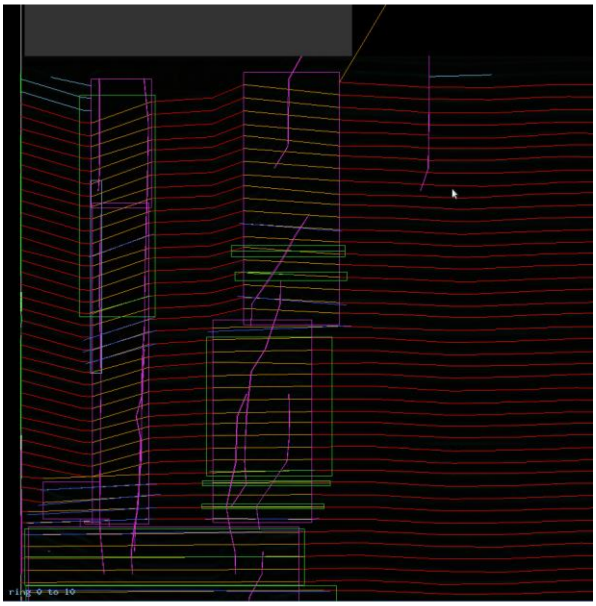


Fig. 65: on this disc, the lacquer is lifted and stretched around the edge (periphery of the side). It appears to be very distorted, in addition to having missing pieces of lacquer. Many constraints were required, including shortcut arcs (dark blue) to reconstruct the path.

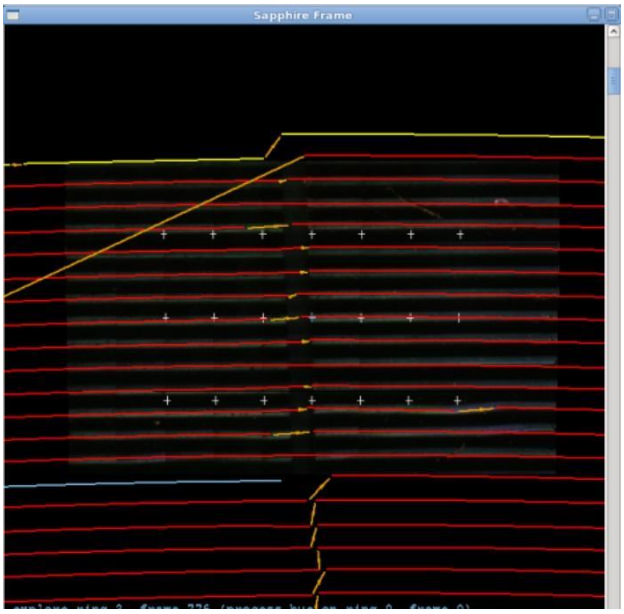


Fig. 66: a blue groove fragment which was not included in the path. This is due to the fact that the groove is not cut across the thin crack, generating several spurious skips between turns. In this case it was necessary to add a 'cut box' along the crack, creating new Arcs that will allow the correct path to be followed.

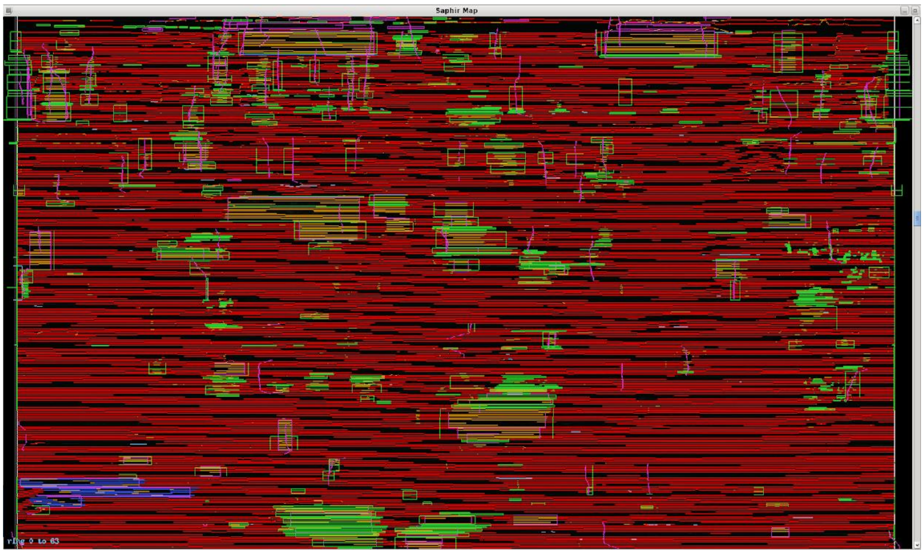


Fig. 67: the whole display of a side with many complex connections, in the Saphir Map window.

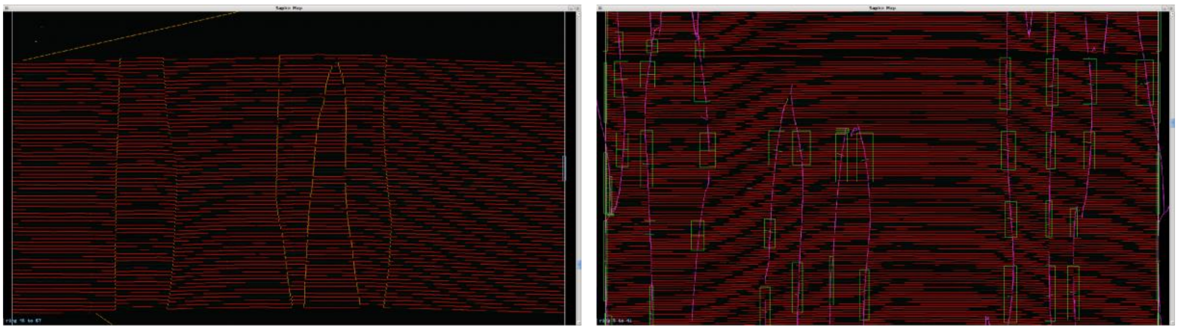


Fig. 68 – 69: Once the reconstruction is finished, the path appears mostly in red. These figures show a reconstructed disc on the Saphir 'map window', with and without the display of Graph Constraints.

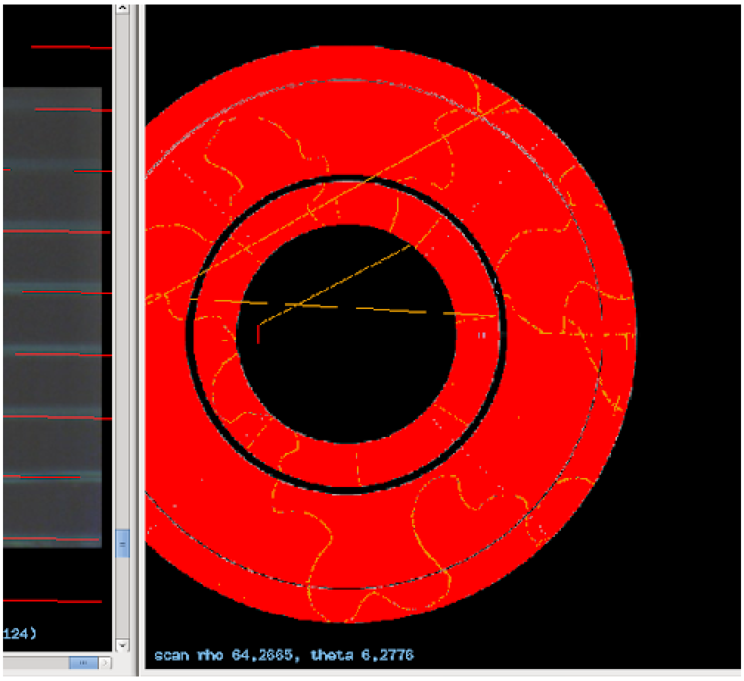


Fig. 70: screenshot of a fully reconstructed disc on the Saphir 'disc window'.

We can summarise the repair phase with these three following simplified diagrams:

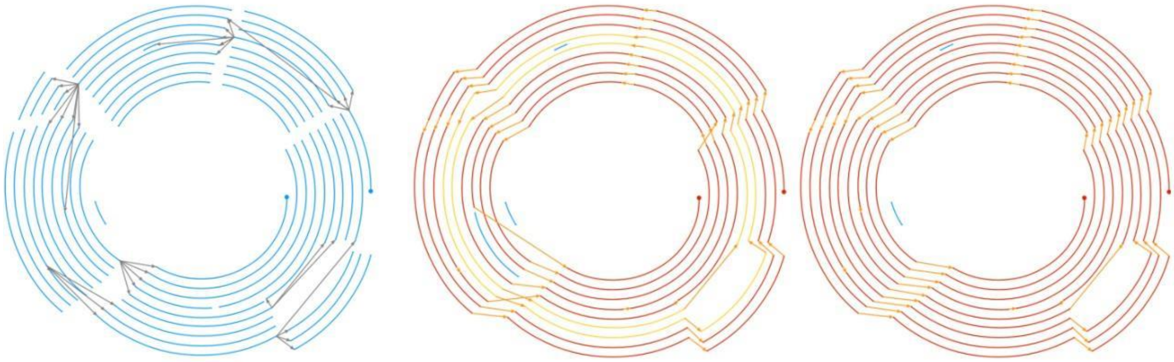


Fig. 71: three simplified diagrams summing up the main track guiding operations possible during the repair phase.

Each time we use the 'find path' function, after some rendering time the resulting audio can be listened to in the Saphir audio window. As the decoding always takes place in the same direction, if the disc is engraved from centre to rim, the soundtrack is played backwards (the images having been reversed). A 'reverse play' option would be useful here. Once the reconstruction is complete, the audio can be exported as is, in PCM wave format, 32 bits floating point.

5.5. The digital audio restoration phase

For the SIRDUKE project, it was decided that Gecko would provide restored files in addition to the raw files coming from Saphir. The audio coming out from Saphir is sometimes harsh, very noisy, without equalisation curve. But above all the audio quality and levels vary depending on the discs. A semi-automatic restoration makes it possible to homogenise the audio rendering of the production and make listening more enjoyable.

In order to obtain the most faithful reconstruction of the sound, the following procedure was followed: first of all, we tried to play back some parts of some disc sides with a stylus, when possible, in order to compare the result with the Saphir rendering. Only short parts on 7 of the 52 sides could be played with a stylus, but the sound turned out better than the Saphir rendering. This point will be elaborated in the next chapter, whereas this chapter discusses the applied process.

The first steps of restoration therefore consisted of :

- Reversing all the files resulting from Saphir whenever necessary, i.e. the discs cut from the centre to the edge (35 sides out of 52 sides processed).
- For the 8 sides concerned for which the stylus was used to play back a part of the record: editing in Steinberg's Wavelab software, to combine the parts that could be played with a stylus with the parts that only Saphir could play.

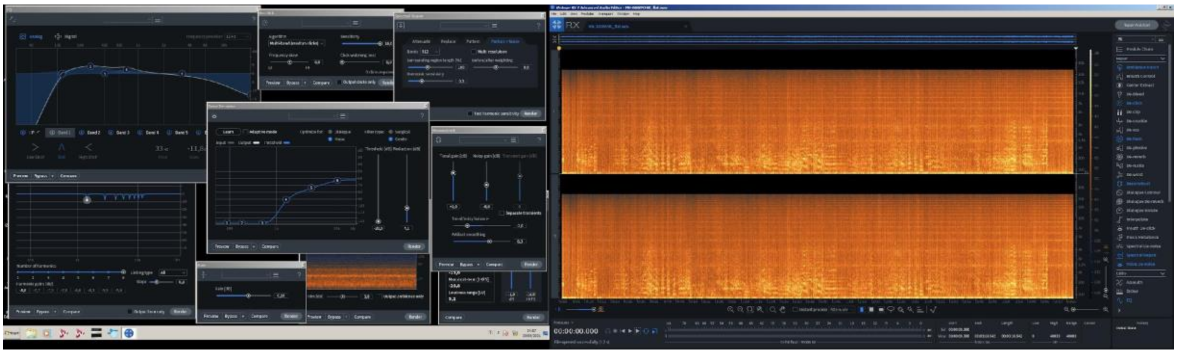
The budget and the interest of the project had to be focused on Saphir. Hence for the SIRDUKE project a more thorough manual restoration, making use of digital restoration tools was out of scope, as this method can be very time consuming.

Besides of that a detailed restoration only makes sense in the context of broadcasting or remastering the complete programs or concert recordings. For the discs in the SIRDUKE project, the other parts of these intellectual entities were absent. The restoration therefore consisted of homogenising production and improving listening comfort. Some restoration steps therefore happened in a semi-automatic way.

First, all files were given a batch run into Cambridge's Cedar software Declicker, with parameters that matched for all sides, determined by trial and error. Then, the other steps were performed in Izotope's RX7 software, mostly manually:

- Repairs of holes and drops in the audio signal
- Attenuation of the strongest distortions
- Attenuation of high unwanted frequencies generated by Saphir decoding
- Extraction of the middle signal (removal of the sides) and mono sum on the parts digitised with a stylus
- Light level follow automation to attenuate the strongest variations
- Level and equalisation matching to attenuate the differences in sound between Saphir parts and stylus parts
- Denoising applied to all sides with specific settings for each side.
- Manual equalisation of each side

After this processing the files were all set to an average level of -18 LUFS and with peaks not exceeding -1dB 'true peak'. These values, in addition to being consistent with a potential broadcast, allow good listening comfort without too much limiting the peaks of the files.



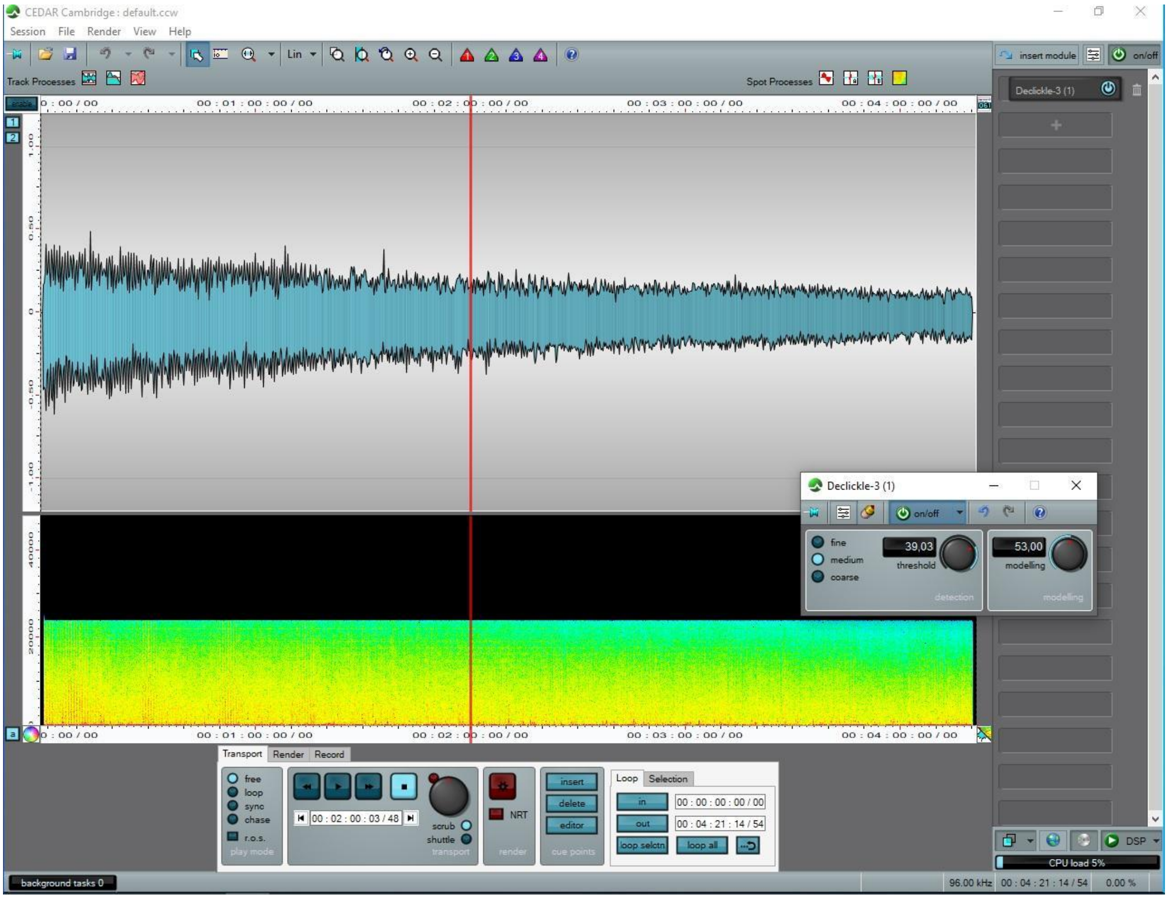


Fig. 72 – 73 : screenshots from the Cambridge Cedar software.

VI. Production overview

6.1. Overview of the project results

6.1.1. Statistical analysis of the digitisation

a) Age of the carriers

During registration, for each lacquer disc side to be digitised, the recording date - if known - was registered in meemoo's AMS database. The recording date was unknown for four sides. The oldest recording was from November 21, 1942 and the youngest from March 15, 1948. Ten recordings were from 1942, two from 1943, 31 from 1944, two from 1945 and three from 1948.

b) Preservation problems as registered pre digitisation

During registration, notes were made for each side about the condition, in particular which preservation problems the side suffered from. A total of 173 preservation problems were noted, or an average of 3,32 per side.

All disc sides suffered from at least one phenomenon – this makes sense as they were selected for this project specifically for the occurrence of at least scratches, cracks or delamination. 51 of the 52 selected disc sides suffered from at least two phenomena, 39 from at least three, 25 from at least four and six disc sides from as many as five phenomena. Figure 70 lists all the preservation phenomena.

c) Disk cores

Of the 52 disc sides involved in the project, 47 were based on a metal core, two were based on a glass core and three were based on a core made of an unknown material.

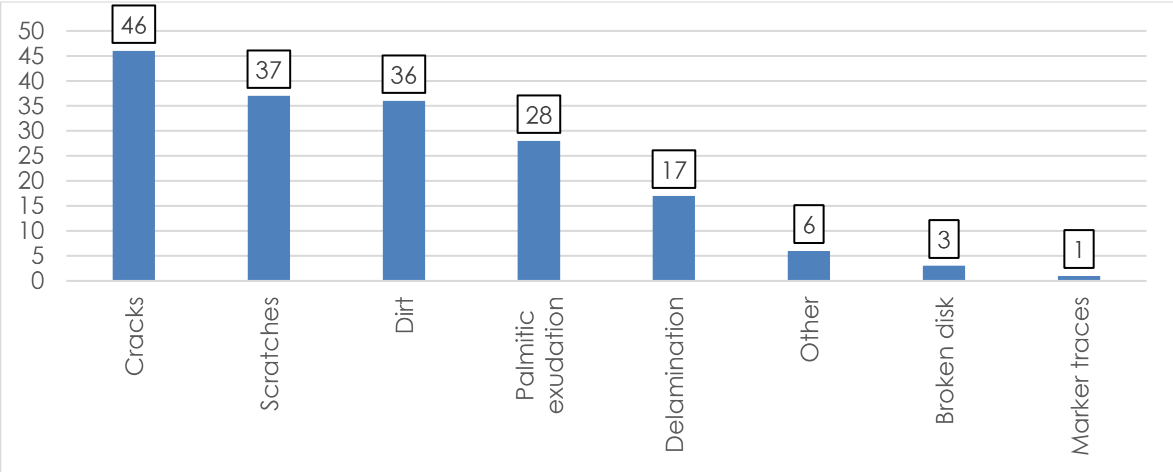


Fig. 74: deterioration phenomena of the disc sides as registered before the digitisation.

d) File duration

The sound that could be recuperated from the 51 digitised sides together had a total duration of 02:53:11, or an average of 00:03:24. The shortest file lasted 00:00:10, the longest 00:05:01. Of 15 disc sides the complete signal could not be digitised, mainly due to missing parts of lacquer.

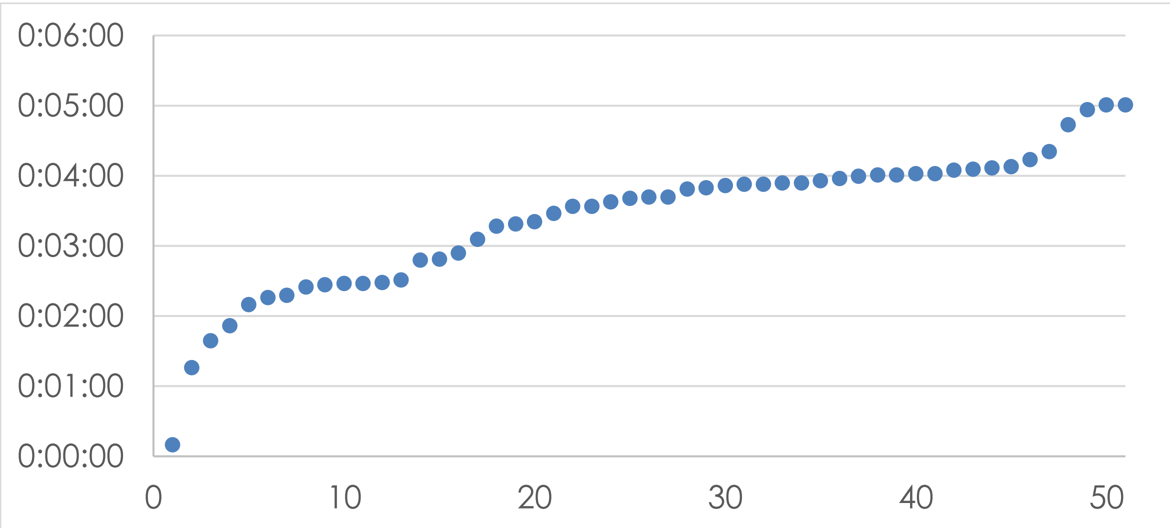


Fig. 75: division of the durations of the sound files resulting from the digitisation in the SIRDUKE project.

e) Groove direction

16 sides were recorded from the edge towards the inside, the 35 others were recorded from the inside to the edge. For the non-digitisable side, this direction could not be established.

f) Digitisation with stylus

For some disc sides, stylus playback was considered possible for a part of the side, as those parts were considered in a good enough condition to withstand the movement of the stylus. In those cases, stylus based digitisation was preferred over optical digitisation because of the advantages described under 6.3. Seven out of 51 digitized disc sides were partially digitised in this project making use of a stylus. In total 00:17:21 or 10,01% of the sound resulting from this project was digitised via stylus playback.

6.1.2. Further project goals

As mentioned under 6.1.2 the objective of the project went further than the actual digitisation and the recovery of historical sound material thought lost. The project partners also wished to contribute to and to learn more about the possibilities of optical digitisation in a broader sense:

Gecko it was important to learn how high the productivity of optical digitisation could be. The answer to this question is discussed under 6.2.

INA wanted to learn about the daily use of the Saphir technology in the context of a commercial provider of digitisation services. Although the productivity was not as high as desired, INA was proud of having demonstrated that INA-Saphir was able to deliver soundtracks from nearly all the provided disc sides, which would have been lost otherwise. The user feedback from Gecko has very much helped them to focus on urgently needed improvements, which were made during, or soon after the end of the project, progressing towards a better productivity:

- improved stability of the software and reducing the crashes frequency,

- protection of the input fields against unintentional value changes,
- better synchronisation between windows,
- reverse play, allowing centre-to-rim disc sides to be played directly,
- generating a complete picture of the disc side, for optional display in the Map and Disk windows.

At INA, the work continues on improving the number of available scanners, the quality of the results, and the system productivity.

Finally, meemoo wanted to contribute to the development of an innovative technology for the rescue of audiovisual heritage. Considering the positive evaluation of this project by the other project partners, meemoo considers this mission as accomplished. This was the first time INA-Saphir was used by a service provider and this is auspicious for the future of exploitation of the technology.

6.2. Estimated productivity

Meemoo and VRT financed a part of the project costs. Gecko planned to dedicate 250 man-hours to the project and INA provided the Saphir equipment and know-how. Gecko's Adrien Bailly spent 220 hours, including training (25 hours) on the Saphir production and about 50 hours on the sound digital restoration, editing the XMLs and writing this report. As this timeframe did not allow to complete all the phases of the SIRDUKE disc batch, INA's Jean-Hugues Chenot worked on Saphir at Gecko's facilities for about 90 hours in addition to the 25 hours of training. The total human time spent on Saphir (without restoration or other tasks) for the SIRDUKE project thus reached 320 hours.

It is very difficult to establish the average processing time per disc side, as the following parameters must be taken into account :

- Saphir requires a significant amount of time to get used to before it can be mastered by a sound technician who is used to handling audio and playing these carriers in the traditional way.
- the time spent on reconstructing the groove of one side can vary a lot, depending on the difficulty of the disc side. Time spent goes from a few hours to several days.
- It is necessary to separate machine time (rendering) and human time.

For example, only one scanner is available, but this step requires only 15 minutes of human time, whereas decoding operations on another disc side can be performed simultaneously with the scanning.

For the decoding phase - although this can take quite long for some sides - this time is compensated by the fact that one decoding session can be running while the operator is preparing another disc side. Depending on the power of the workstation, several sessions may thus run in parallel.

The repair phase is the most difficult to estimate, as it consists largely of human time, it is extremely dependent on the disc side difficulty and it is better to do it in parallel for several sides.

On average, it can be estimated that seven operator-hours per disc side were used over the course of the project.

6.3. Saphir compared to traditional playback methods

Given the complexity of Saphir, the processing time and the audio quality of the exported files, it seems obvious that stylus playback appears to be the preferred solution when possible. Indeed, for lacquer discs of the same age, the productivity of an experienced technician ranges from 15 to 60 sides per day, depending on the condition of the discs, with an average of 40 à 50.

On some difficult sides, particularly those with retracted and cracked lacquer, the techniques mentioned in the previous chapters allow to recover a majority of the content.

A stylus playback also has the advantage of better sound quality. Depending on the condition of the groove, a suitable stylus size and shape can be selected for a particular record and the digitisation can be performed in stereo. The best channel (choice of groove wall) can then be chosen. The Gecko experience shows that there is often a very big difference in sound quality (signal to noise ratio) between one wall of the groove and the other, but selecting the groove wall is more complex in Saphir.

Moreover, digitising with a stereo stylus, i.e. vertical and horizontal, allows to obtain both a 'middle signal' and a 'side signal'. For digital restoration, extracting this middle signal allows to attenuate the background noise located mainly in the sides.

This attenuation sounds relatively natural and is a good first step before using denoising plug-ins that quickly bring unpleasant digital artefacts on sources as noisy as lacquer discs. Saphir however only works in mono and cannot take advantage of this technique.

Still it is obvious that for the discs involved in the SIRDUKE project the application of the Saphir technology is relevant. Attempting to play this collection of discs with a stylus would have been extremely time-consuming in some cases (very difficult to track) and simply impossible in the vast majority of cases. The proof of this is in the fact that only a few parts of the sides of the project were played with a stylus and that no other attempt was made at the risk of permanently damaging the lacquer.

These discs had been rejected from a classic digitisation workflow and Saphir was able to process 51 out of 52 sides.

Saphir is already an operational system and it can extract a signal in all the encountered cases – although with very diverse results. In most cases, the audio quality resulting from the process is satisfactory, or at least exploitable, considering that without Saphir, the content would have simply been lost.

6.4. Difficulties encountered during the production phase

6.4.1. First approach of Saphir, scanning and decoding

Saphir is still under development, future evolutions are planned. They will focus on the correction of bugs, the improvement of the detection and the management of cracks and the possibility of mixing the two decoding methods, angle and hue.

The main difficulty at the beginning of the use of Saphir by a technician used to traditional digitisation was undoubtedly the lack of an immediate relationship with the sound. Learning the techniques of digitising an instantaneous disc by a sound technician is done to a large extend based on audible feedback. The choice of the stylus, the cleanliness, the condition of the disc and other adjustments have a direct influence on the sound rendering and allow adjustments in real time.

With Saphir there is no ‘real time’ and the numerous decoding parameters are based on units that are very different from those used in the sound industry, making the first approach to Saphir difficult. It takes a long time to learn which effect a decoding parameter will have on the final output.

The Saphir Control interface is functional and usable after some exercise. However, it could be improved visually and ergonomically:

- classification of parameters by most frequent usage,
- reorganisation and reduction of the numerous parameters, some of which are no longer useful,
- protection of the input fields against unintentional value changes
- management of sessions and files requiring a minimum of basic knowledge of the Linux system and its command prompt.

6.4.2. Repair

The repair phase allows for a visualisation of how Saphir reconstructs the path. The graph constraints that can be added are designed for all cases and work well. But there are some difficulties:

- In the Saphir map window, editing the graph constraints is difficult, synchronisation of focus with other windows needs improvement and features around the dateline should be better rendered.
- Some path parts are difficult to solve despite several attempts, without being able to see where the problem lies.
- Problems in the path appear on parts that have been solved during the rendering of the previous rings.
- Difficulty in ignoring areas that, from experience, are not useful, like the passage from one track to another, or the very first and last rotations, or areas that are too damaged. This point is a source of loss of time.
- The special case of discs cut from centre to rim. Saphir always decodes in the same way and does not allow the audio to be reversed. Once the audio is exported, it is not a problem to reverse it in a few seconds in any digital audio editor, but for the Repair phase, it would be useful to be able to listen to the audio forward or backward, in order to check by listening to the content, if the reconstructed path seems coherent.

Experience shows that on the instantaneous discs of the 1930s to 1950s, cases of engraved disc from the centre to the rim are frequent. On the SIRDUKE project, 35 sides out of 52 were engraved in this direction.

6.3.3. Stability

The PC on which the SIRDUKE project has been running has been able to handle all possible cases. However, there were several system crashes, especially during the decoding phases.

Sessions crashes during decoding were mostly due to inappropriate settings, requiring too much RAM until the machine froze. In some cases, however, we were not able to determine where these bugs were coming from, nor how to know in advance if a particular session will require more resources. These crashes seemed to be independent of the number of sessions running on the machine. These crashes were one of the most important wastes of time, firstly because the decoding step could only be done in one shot (and it was necessary to start again in case of a problem) and secondly because the workstation slowed down on all the sessions in progress. Moreover, the terminal output is usually too complex to provide useful information to an inexperienced technician.

On the workstation used for SIRDUKE, running one scan session simultaneously with two decode sessions and two to six repair sessions worked well. Running four to eight decoding sessions while the technician was away (at night, for example) worked, but in some cases several sessions crashed during the night, forcing a restart of the process.

6.5. Suggestions for improvement

The main notion of improvement of the whole system, according to the point of view of a sound technician at Gecko, would be the relationship to the sound. This would certainly involve very large changes to the way the Saphir system currently works, but it could be featured as follows:

- On the scan step, a function to preview a quick decoding of a part of the groove. This could allow the technician to select the best wall of the groove and to adjust the scan parameters according to the audio rendering.
- At the decoding step, similarly, the possibility of listening, in real time or by rapid rendering on a few rings, to the influence of this or that

parameter on the audio rendering. This would make it possible to avoid decoding a side entirely and then returning to it with other parameters to make a second attempt.

On the repair phase, the following points could make the productivity more efficient:

- Better visualisation of the groove pictures on the Saphir Frame and especially Saphir Map windows,
- Increasing the visibility of the grooves on the Saphir Map when the Graphs Constraints are not displayed,
- Visualising the ‘real’ groove can help to take a step back and solve the path.
- Improving the behaviour of Shortcut Arcs on the dateline.
- Allowing the display or hiding of Cut Boxes and Cracks independently of other constraints, to improve visibility.
- Creating a system to manage a work history, to make it easier to undo. The system of saving Graphs Constraints at a given time is functional, but not very practical.
- Creating a system of entry and exit points. This system would allow to force and choose where the path starts and where it ends and thus to lock these points without taking into account the first grooves if one wishes. It would also allow to isolate parts that one does not want to solve, to work on tracks only or to ignore non-engraved parts.

Finally, a last suggestion would be to make it possible to manage pre-sets in Saphir. We can imagine pre-sets according to the type of disc, the state of the lacquer and its difficulty. The SIRDUKE project has shown that the settings were often similar from one glass disc to another, from one retracted disc to another, etc. Combined with a pre-decoding system as mentioned above, this pre-set management tool could be very efficient to start the work on each side.

VII. References

The text, the diagrams and the pictures in this report are all based on those obtained during the SIRDUKE project, at the Gecko facilities in Montreuil, France, except :

- fig. 5: https://en.wikipedia.org/wiki/RIAA_equalization
- fig. 29, 49, 66 and 71: *Saphir: Optical Playback of Damaged and Delaminated Analogue Audio Disc Records*, ACM Journal on Computing and Cultural Heritage (JOCCH) vol.11, no. 3, August 2018.

The screenshots originate from the Saphir tool from INA as used by Gecko for the SIRDUKE project. The statistics were drafted based on the XML-based reporting per disc side.

The following written sources were used:

- *Saphir: Optical Playback of Damaged and Delaminated Analogue Audio Disc Records*, ACM Journal on Computing and Cultural Heritage (JOCCH) vol.11, no. 3, August 2018
- Rochat, Rebecca, *Typology guide Lacquer discs collection of Radio-Lausanne and Radio-Genève*, 2019.

Annex 1: list of disc sides digitised in the SAPHIR project

PID	Original carrier ID	Title	Recording date	Preservation problems
zg6g18974n	niet ingevuld_5171/1	Part 01/01: Montage Anniversaire	23/03/1945	Palmitic exudation | Cracks
7940s22r90	GW.207_32726	Part 01/02: 16 landen conferentie in Parijs / Bevin	15/03/1948	Delamination | Other | Dirt
959c55wn80	niet ingevuld_2981-19	Part 06/06: Pastorales Wallonnes Pour Soli Et Petit Orchestre/Evocation De Saint Hubert	21/11/1942	Delamination | Scratches
rj48p8b475	niet ingevuld_2981-17	Part 05/06: Pastorales Wallonnes Pour Soli Et Petit Orchestre / Evocation De Saint Hubert	21/11/1942	Delamination | Scratches
f766421w16	GW.207_32727	Part 02/02: 16 landen conferentie in Parijs / Bevin	15/03/1948	Delamination | Palmitic exudation
4q7qn8c294	60/6_2981-9	Part 02/02: Chansons de Wallonie (pour choeurs et orchestre)	21/11/1942	Scratches | Cracks | Delamination | Dirt
dv1ck0nh8w	60/6_2981-12	Part 01/02: Suite Pastorale / componist: Jean Absil	21/11/1942	Scratches | Cracks | Delamination | Other | Dirt
4q7qn8c28t	60/6_2981-11	Part 02/02: Suite Pastorale / componist: Jean Absil	21/11/1942	Scratches | Cracks | Delamination | Other | Dirt
086350w817	60/6_2981-10	Part 01/02: Chansons de Wallonie (pour choeurs et orchestre)	21/11/1942	Cracks | Delamination | Scratches
zp3vt3v15q	niet ingevuld	Part 01/02: Medeeling	6/09/1944	Palmitic exudation | Cracks
bv79s3xq6s	niet ingevuld	Part 02/02: Medeeling	6/09/1944	Palmitic exudation | Cracks
zs2k66p56f	niet ingevuld	Part 01/02: Medeeling	6/09/1944	Palmitic exudation | Delamination | Cracks
z02z340z31	niet ingevuld	Part 01/02: Medeeling	6/09/1944	Palmitic exudation | Delamination | Cracks
6m3322461v	niet ingevuld	Part 02/02: Medeeling	6/09/1944	Cracks

PID	Original carrier ID	Title	Recording date	Preservation problems
ks6j127b2n	niet ingevuld	Part 01/02: Medeeling	6/09/1944	Palmitic exudation | Cracks
gb1xd3313m	niet ingevuld_115759	Part 01/01: Comité tegen het alcoholisme	uuuu-uu-uu	Palmitic exudation | Cracks
610vq5487q	niet ingevuld	Part 01/03: Medeeling N.B.R. (origineel)	uuuu-uu-uu	Palmitic exudation | Delamination | Cracks
9w08w5fv0r	ZB. 60_1934/5	Part 05/10: Beiaard Mechelen 3-3-42	3/03/1942	Scratches | Cracks | Palmitic exudation | Dirt
z60bv9hw9h	niet ingevuld	Part 06/10: Brugge Beiaard 31-5-42	31/03/1942	Scratches | Cracks | Palmitic exudation | Dirt
7p8tb34h4f	ZB. 60_1934/4	Part 04/10: Beiaard Mechelen 3-3-42	3/03/1942	Scratches | Cracks | Palmitic exudation | Dirt
bk16m5717q	ZBD14_3155/3	Part 02/02: Jeugdlied (van Wies Moens en Gaston Feremans) / componist: Gaston Feremans	8/12/1942	Palmitic exudation | Cracks
ws8hd9rn71	ZB36_5915-7	Part 02/02: Droom (R. Peeters) + Preludium (A. De Boeck)	7/02/1944	Scratches | Cracks | Palmitic exudation | Other | Dirt
xs5j98359b	ZB38_5927/11	Part 02/02: Vl. R. K.	13/02/1944	Scratches | Cracks | Palmitic exudation | Dirt
qj77s9mm6h	ZB38_5927/9	Part 01/02: Vl. R. K.	13/02/1944	Scratches | Cracks | Palmitic exudation | Marker traces | Dirt
j09w110453	ZB43_5909/9	Part 03/04: Omroeporkest 07/02/1944	7/02/1944	Scratches | Cracks | Palmitic exudation | Dirt
pv6b29sj6f	ZB43_5909/8	Part 02/04: Omroeporkest 07/02/1944	7/02/1944	Scratches | Cracks | Other | Dirt

PID	Original carrier ID	Title	Recording date	Preservation problems
db7vm65h46	ZB43_5909/11	Part 04/04: Omroeporkest 07/02/1944	7/02/1944	Scratches | Cracks | Palmitic exudation | Dirt
zc7rn5332z	ZB43_5909/6	Part 01/04: Omroeporkest 07/02/1944	7/02/1944	Scratches | Cracks | Palmitic exudation | Dirt
cr5n894j0n	ZB64_7331/6	Part 01/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
xs5j98239j	ZB64_niet ingevuld	Part 06/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
1v5bc5vb95	ZB67_5864/2	Part 03/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
4q7qn80r2t	ZB64_7331/11	Part 09/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
4x54f3p237	ZB64_7331/7	Part 03/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
qv3bz83066	ZB67_5864/5	Part 05/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Other | Dirt
vq2s48jw8j	ZB67_5864/4	Part 04/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
0g3gx6670g	ZB67_5864/6	Part 07/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
804xh1gr9f	ZB67_5864/9	Part 09/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
hd7np3z483	ZB64_7331/2	Part 07/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
n58cg1kw91	ZB67_5864/8	Part 08/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt

PID	Original carrier ID	Title	Recording date	Preservation problems
r785h9dm02	ZB28_5519/2	Part 04/09: 22/12/1943	22/12/1943	Scratches | Cracks | Broken | Delamination | Dirt
5h7bs0nz6f	ZB64_7331/17	Part 10/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
mp4vh7f460	niet ingevuld	Part 11/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Delamination | Dirt
qr4nk57v14	ZB64_7331/3	Part 08/10: Beiaard 06/08/1944	6/08/1944	Scratches | Cracks | Palmitic exudation | Dirt
ff3kw7935g	ZB67_5864/3	Part 02/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Palmitic exudation | Dirt
wm13n4287m	ZB67_5864/10	Part 10/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
xk84j2cs56	ZB67_5864/1	Part 01/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Palmitic exudation | Dirt
hh6c26s88h	niet ingevuld	Part 05/09: 22/12/1943	22/12/1943	Scratches | Cracks | Broken | Delamination | Dirt
9z90884s52	ZB67_5864/7	Part 06/11: Kwartet voor strijkinstrumenten op.10 / componist: Peter Benoit	31/01/1944	Scratches | Cracks | Dirt
m61bk3525c	N181/2_9255	Part 02/02: Léopoldville (Congo)	11/05/1945	Scratches | Broken | Dirt
5t3fx9232c	niet ingevuld_23.24	Part 02/04: / Lode BACKX	uuuu-uu-uu	Delamination | Cracks
5t3fx92312	niet ingevuld_23.24	Part 01/04: / Lode BACKX	uuuu-uu-uu	Delamination | Cracks
b27pp0p94z	1782_73293	Part 03/04: Montage Oudenaarde, 1948	2/04/1948	Delamination | Dirt