High Performance 2007 CD-4 Demodulator

By
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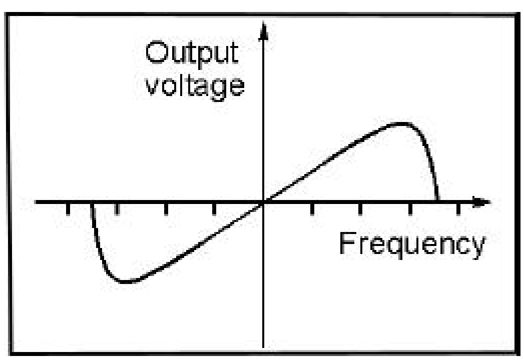
Installment IV

Now that we have a good clean sub-carrier signal, a low distortion detector system is needed to convert the FM-PM-SSBFM signal into the Front minus Back difference audio. FM and Phase modulation techniques were invented by Major Edwin H. Armstrong in 1938. He was responsible for the ratio detector and the differential pulse counting detector. He also discovered the ability to detect FM signals by using an AM detector slightly off tuned (slope detection). A few years later the FM discriminator detector was developed by Foster and Sealy.

Edwin H. Armstrong

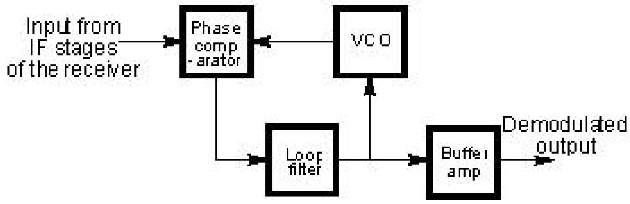
All of these detectors have linearity which is measured by the S curve. The diagonal line of the S curve indicates the linearity of the detector. The straighter the line, the better the linearity. The longer the straight portion, the wider deviation can be linearly detected. Most FM detectors have good linearity around the center of the curve, but start to round (deviate from linear) at the edges. Figure 26 shows the S curve of a typical ratio detector.

Figure 27 is a block diagram of a typical Phase Lock Loop (PLL) FM detector. The PLL consists of a phase detector which is fed the FM signal to be detected as well as the output of the voltage controlled oscillator (VCO). The output of the phase detector feeds a low pass filter, which removes any input carrier frequency, leaving only the modulation signal. This signal (referred to as the frequency error correction signal) is fed to the voltage control connection of the VCO, which forces the VCO to track the input FM signal. This same signal is the detected audio output signal. The Phase Lock Loop (PLL) has an absolutely linear section from the lock to lock frequencies. These frequencies are the upper and lower ones where the PLL unlocks from the signal it is tracking. The curve for the PLL is a Z curve, which makes it more linear for a wider FM frequency range. Figure 28 is the Z curve of the PLL



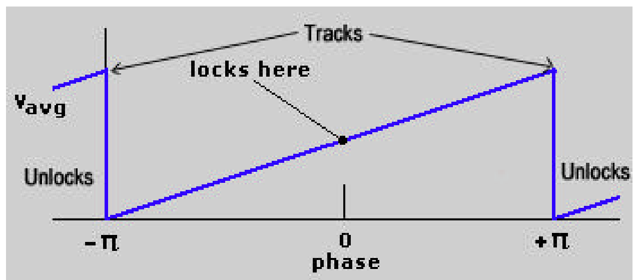
FM RATIO DETECTOR S CURVE **Figure 26**

The PLL has another advantage over other FM detectors. This is it's ability to detect the full information bandwidth with poor carrier-to-noise (CNR) ratio. This becomes very useful in CD-4 demodulation (US patent 3,886,312). The carrier level of the CD-4 sub-carriers is 20 dB (100 times) below the peak level of the main channel audio. This makes the raw CNR under the worst conditions, 20 dB. The PLL for the QSI5022 worked well with a CNR of 7dB. The PLL for the new CD-4 demodulator will work well with a CNR of 3.5dB.



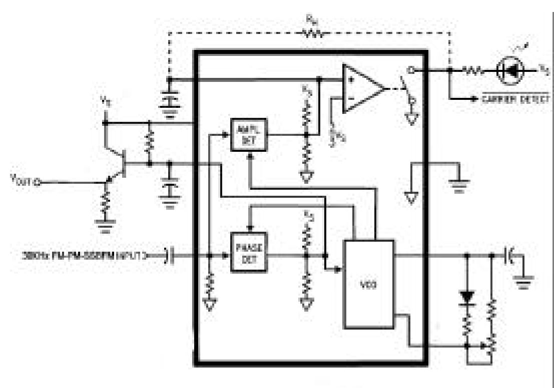
BASIC PLL BLOCK DIAGRAM **Figure 27**

The basic PLL has no means of detected carrier indication. This is useful in identifying a valid incoming carrier. It requires an additional phase detector (Quadrature phase detector) which senses when the VCO output has a 90 degree phase shift with regards to the input frequency. When this condition exists, the PLL is locked to the input frequency. The output from the Quadrature phase detector is feed to a low pass filter and then drives a DC amplifier to turn on an LED indicator.



PLL Z-CURVE **Figure 28**

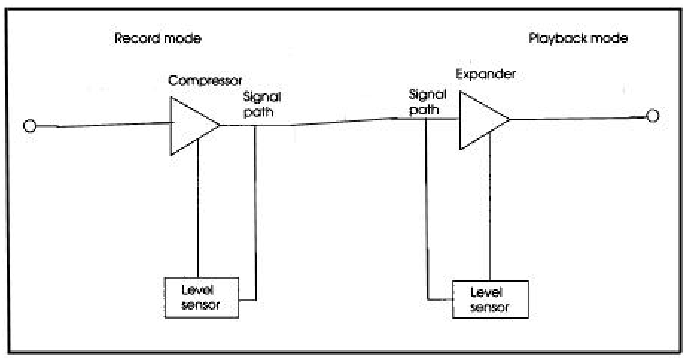
When no 30 KHz carrier is detected, the PLL audio output will be a loud random noise signal similar to an FM receiver not tuned in to a radio station. The LED control signal is used to control an audio mute circuit that shuts off the two difference audio feeds when no 30 KHz signal are present. Figure 29 is a block diagram of the PLL for the new CD-4 demodulator. The Front minus Back audio output from the PLL is fed to a passive, precision FM-PM-SSBFM de-emphasis network. This network uses high temperature grade capacitors and resistors to insure no characteristic variance over –40 to +125 degrees



NEW CD-4 DEMODULATOR PLL **Figure 29**

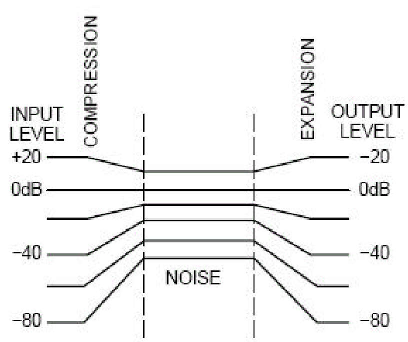
Centigrade. By keeping this passive, small amplifier drift does not affect the EQ performance. As in the main channel, there is an identical 15.5KHz low pass filter after the FM-PM-SSBFM de-emphasis network. Like the main channel, this filter performs the tasks of removal of ultrasonic PLL artifacts, phase and amplitude matching to the main channel, and delay signal matching to the main channel.

The Front minus Back signal is now almost reconstructed. The last audio processing in the sub-channel is the Audio Noise Reduction System (ANRS). This sub system increases the dynamic range of the sub-channel, while reducing the noise in the sub-channel. The ANRS is a closed loop audio signal companding system. Companding is a composite word for compression-expansion. At the record end a level compressor is used to compress a large dynamic range into a smaller one. When the audio signal gets to the playback end, an expander takes the smaller compressed dynamic range and expands it to its original one. Dynamic range is the level range from the loudest audio signal to the softest one based on the system involved. Figure 30 is a basic companding system.



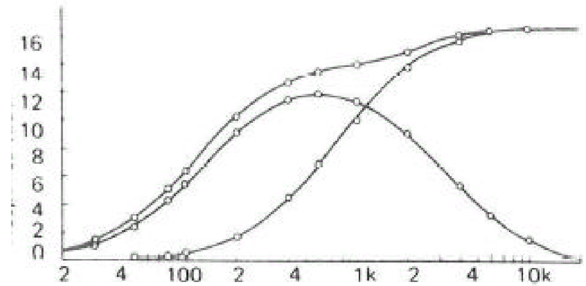
BASIC AUDIO COMPANDING SYSTEM **Figure 30**

High amounts of companding have some undesirable audio artifacts. Tracking linearity for the compressor and expander gets worse as a wider dynamic range is companded. Large companding also has audio pumping effect from the gain control elements in the compressor-expander. The input-output graph for the basic compander is shown in Figure 31.



BASIC AUDIO COMPANDER **Figure 31**
INPUT OUTPUT CHARACTERISTIC

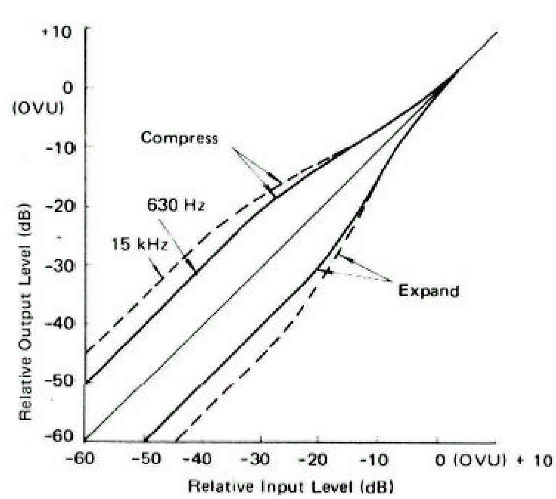
The ANRS has a variation on the basic compander. It divides the companding scheme into two frequency bands. This technique is similar to Dolby C noise reduction with the exception that the frequency bands for CD-4 ANRS are different than Dolby C. The CD-4 has a low mid compressor that has a mid band peak at 630 Hz and a high band compressor with a peak at 15KHz. Figure 32 shows the two compressor response curves. These curves actually yield a noise reduction of 10 dB at mid range and 15 dB at high



CD-4 ANRS MID AND HIGH COMPRESSOR RESPONSE CURVES **Figure 32**

Courtesy of JVC

Frequency. These curves are the frequency response parameters that drive the dual band compander. Splitting the companding into 2 bands greatly reduces the audio artifacts from the compressor-expander subsystems. At the same time it increases the mid and high frequency dynamic range of the Front minus Back audio signals and improves the signal to noise ratio of the sub-channels. Figure 33 is the input-output characteristic of the CD-4 ANRS. In this graph, the centerline is the result of compression at the record end followed by expansion at the playback end.

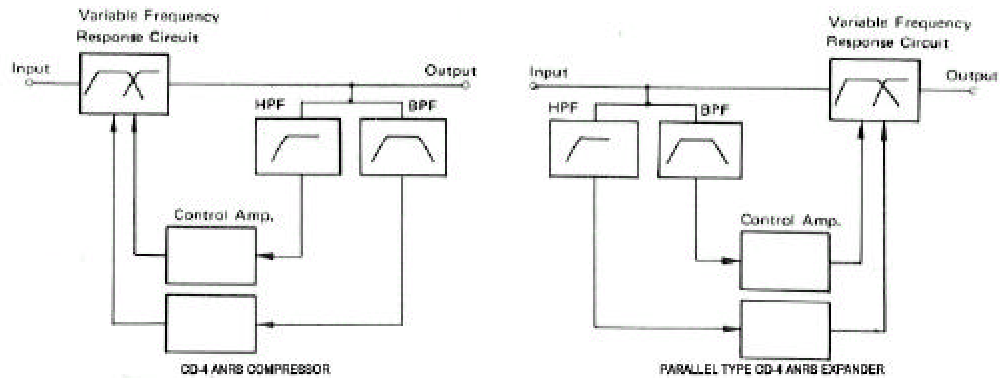


CD-4 ANRS INPUT-OUTPUT CHARACTERISTIC **Figure 33**

Courtesy of JVC

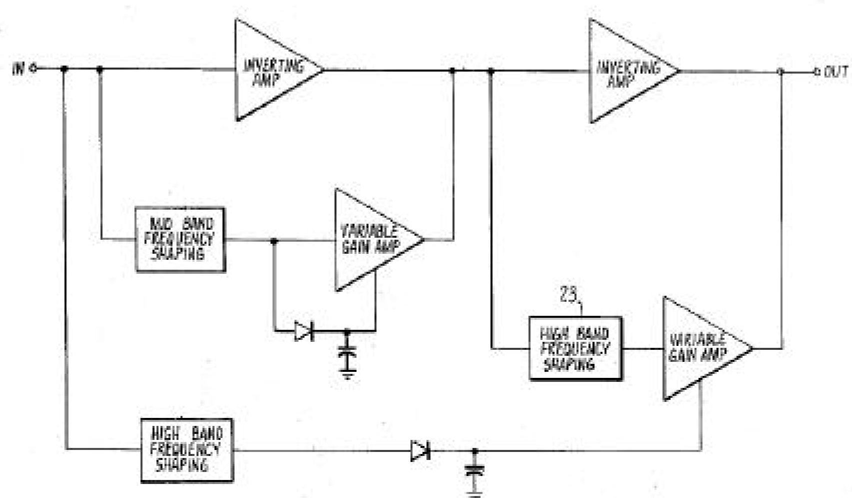
A problem does exist in the original CD-4 ANRS expander. The configuration of the expander is known as a parallel dual band expander. Figure 34 is a block diagram of this type of expander. This type expander has variable phase distortion introduced into the difference signal by the additive controlled frequency response networks. The result is Front to Back separation that does not remain stable. As the ANRS changes its expansion, the phase of the Front minus Back signal gets distorted. The result is that when this signal is applied to the sum and difference matrix, its phase does not match for proper addition or subtraction. This means that some Front audio is in the Back and visa versa.

In evaluating the problem, I came up with a new type of expansion system (US patent 3902131) which uses algebraic subtraction for both CD-4 ANRS frequency bands. This ANRS sub-system was the one used in the QSI5022. Figure 35 is a block diagram of my tandem CD-4 ANRS expander. In the tandem expander, the main signal path is straight through two inverting amplifiers. An inverting amplifier is one where the output signal is 180 out of phase with input signal. With two amplifiers in tandem the output is now in phase with the input. The control inputs are taken from the main input to the tandem expander. The 630 Hz mid expander is achieved by taking the control signal after the mid band frequency shaping



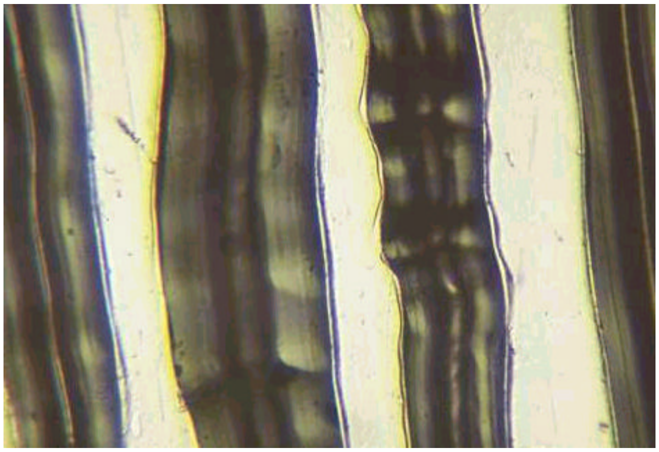
CD-4 ANRS PARALLEL DUAL BAND EXPANDER **Figure 34**
Courtesy of JVC

network. The output of the shaping network is also fed to the audio input of the first gain controlled amplifier. This amplifier is a non-inverting type (the output phase is the same as the input phase). Its output is subtracted from the output of the first inverting amplifier providing the mid band expander. The high band (15KHz) expander has two identical frequency shaping networks. The first one is driven from the main input of the expander and is the control drive. The second frequency shaping network is fed from the output of the mid band expander. It feeds the audio input of the second non-inverting variable gain amplifier. This output is subtracted from the second inverting amplifier, providing the high band (15KHz) expander. This tandem configuration improves the Front to Back separation by 8dB. Figure 35 is the block diagram of my CD-4 ANRS tandem expander.



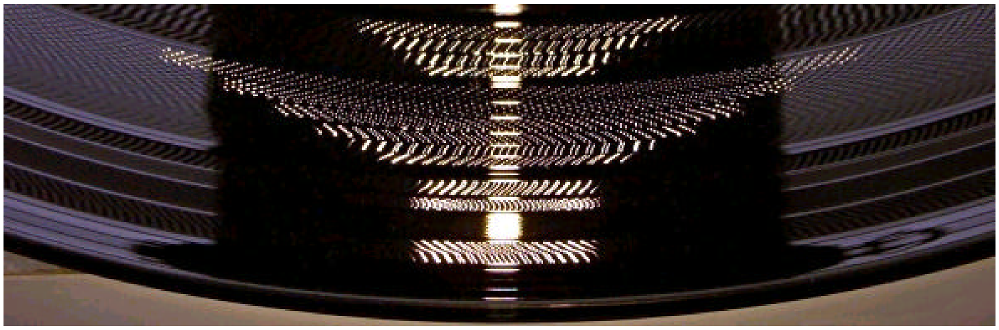
CD-4 ANRS TANDEM EXPANDER **Figure 35**

And now for the humorous story…let me set the stage. JVC and its parent company Panasonic (Masushita Electric Corp) are in the process of trying to woo RCA and Warner Brothers records to endorse and use the CD-4 quadraphonic record system. The problem that had arisen was that of the number of disk plays before the record was unusable. RCA had set the standard in the stereophonic disk (Figure 36) and expected the same results from the quadraphonic disk. The standard was to play the record 100 times with a conventional low-quality record player using a ceramic cartridge, tracking at 4½ grams. Once the record had been played this many times, then it should be able to be played back correctly on a four-channel turntable with quadraphonic cartridge and the performance should be the same as an unplayed quadraphonic record. The problem was that in the Japanese tests, they were getting 30 plays and in RCA's tests, they were getting about 45 plays. This was unsatisfactory and the problem was insurmountable. I was notified by one of the people from Panasonic, that this problem existed and I requested that they send me some of the disks from RCA Indianapolis, that had been played 100 times or more for me to evaluate.



STANDARD STEREO GROOVE **Figure 36**
Courtesy of Micrographia

When I received the disks, I visually inspected them and noticed something wrong. As a mastering engineer having cut many master disks, there's a certain pattern and sheen that you expect to see from a record and the quality of the sheen changes as the record is worn. The change, however, is very gradual and goes from a very high-polished mirror appearance to a soft gray appearance. This is what you expect from a standard stereo LP. The CD-4 LP, however, has a slightly different look to it. An unplayed CD-4 disk has what is known as a Beckman-Meyer (Figure 37) appearance. This is because there are two 30 KHz dub-carriers in the record groove. The Beckman-Meyer pattern has been used for years to give the mastering engineer a good idea of how well his cutting system is performing without having to actually play back the disk.

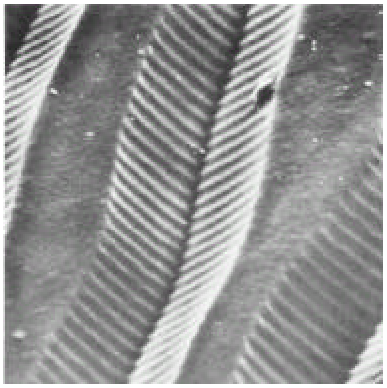


BECKMAN-MEYER DISK PATTERN **Figure 37**
Courtesy of Micrographia

When you cut a master LP, you cannot play the disk so it will remain virgin going to the record pressing plant. A 12" LP is mastered on a 14" blank and the mastering engineer will generally run a Beckman-Meyer pattern at about 13½" to confirm the quality of this cutter before actually cutting the master.

When I looked at the disks sent to me from RCA, I noticed that the disks didn't look like a CD-4 disk that had been worn. They looked more like pavement that had been traveled on by trucks many times, having a light gray appearance of used gravel. This, I thought, was quite strange. I took one of the disks and put it on my CD-4 playback system with our new high-quality demodulator and a Technics 451C Semiconductor Strain Gauge cartridge, tracking at two grams with a Shibata stylus. The result was awful, nothing but horrible breakup noise, very little carrier, and no quadraphonic reproduction. The characteristic of the noise was different from the noise that you hear from a destroyed CD-4 groove. It was more like the noise that you would hear if the Carrier Level Control (CLC) had gone bad in the cutting system. I had experienced this at the JVC cutting center during some test masters, so I was familiar with the sound. I thought for a moment, how could this be? Production disks would have never gotten this far with that problem existing (Figure 38).

I asked the chief engineer of my company, Gil Gibson, whose background is in chemical engineering, to create a cleaning solution that I could use to clean the disk. I had indicated to him that I thought there may be some cracks in the actual disk surface, where dirt adhered and I needed some form of solution that would either liquefy the dirt or elevate it from the cracks. About two hours later he brought me a test solution and I applied to the surface of the disk with a lint-free cloth we use in the laboratory called a Chem-Wipe. I cleaned about one inch of the diameter of the beginning surface of the disk. I dried the disk off with another Kimwipe and put the stylus down on the disk to let it play. Playback was awful,

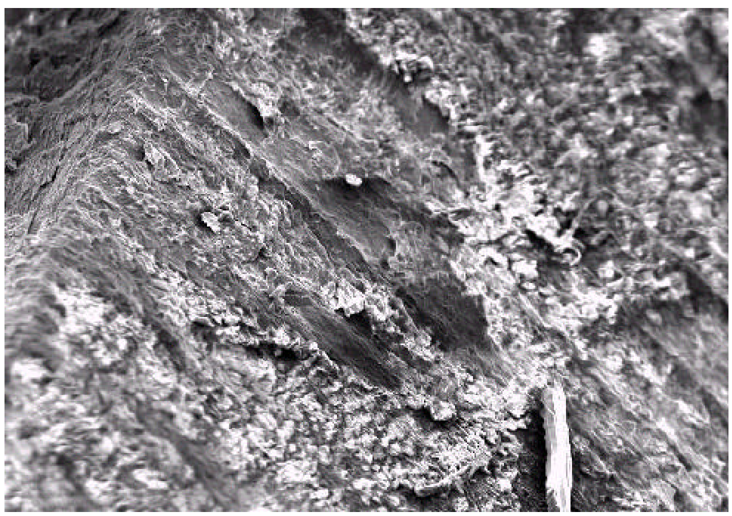


CD-4 RECORD GROVE **Figure 38**

just as bad as before cleaning. As I was doing this, I got a phone call in the lab, so I turned the volume of the audio amplifier down and took the phone call. While I was talking on the phone, I was watching the turntable and all of a sudden about ¾" into the record, the stylus popped out of the record and skidded all the way to the middle of the disk. Concerned about damaging my Shibata stylus, I Quickly lifted up the tone arm and put it in the tone arm holder and finished my phone call. When I went back to see what had happened, I noticed a gigantic dirtball around the stylus. I removed the dirt so that the stylus was clean and put it back at the beginning of the record, turned up the volume, and low and behold the record played perfectly, until it got to the spot where it jumped out of the groove. I then applied the cleaning solution to the entire surface of the disk and carefully dried it off with another Kimwipe and played the whole disk with the volume down. After every two tracks on the disk, I would lift up the arm and clean off the dirtball from the stylus. Completing the first cleaning play, I decided I would play it one more time to see if there was any more residual dirt remaing. The second play had a little ball at the very end. Now the final test, I turned the volume up and played the whole record. It was perfect! There were no carrier dropouts, no burst noise, and fantastic front-to-back separation.

I knew there was something going on, but I needed to investigate further. RCA had sent me a number of disks. I cleaned two more and the result was the same. I then took one of the clean disks, and one disk that had never been cleaned and went to see a friend of mine, Bob Maddox, at Stanford University.

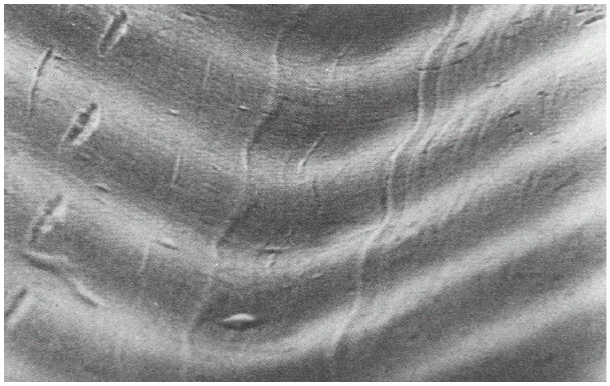
Bob was a Professor of Chemical Engineering and he had access to a very nice electron scan microscope. I told him that I wanted to see what was going on in the grooves to get an idea of exactly what was happening. The process of doing the electron scan microscopy is very complex. You must first make a sample to be scanned. That sample then needs to be metal sputtered with a one-or-two molecule thick layer of metal. The sample is then put in to the scanning chamber and is scanned in various magnifications. We did that and saw what the dirt was doing to the CD-4 record groove. Records, by their nature, are made of vinyl or some form of polycarbonate plastic. When a stylus is playing this groove, it acts like a young person rubbing his feet on a rug floor or holding a plastic rod and rubbing a cloth on the rod, creating static electricity. This static electricity continues to build a charge on the disk surface. The static charge attracts all of the dirt and dust that is in the air to the surface of the record. Because the wavelength of the 30 KHz sub-carriers is so short, it makes very rapid hills and valleys in the groove wall. As the stylus from the regular phono player plays this groove, it pushes the dirt into the valleys of the sub-carrier like a pavement steamroller. With each additional play, more dirt fills up the valleys until the dirt is as high as the peaks, essentially hiding the sub-carrier from the playback stylus (Figure 39). When the disk is cleaned, the Shibata stylus, because of its shape in the front, acts like a snowplow and physically digs the dirt out of the valleys. This returns the groove to its normal condition, allowing it to play perfectly.



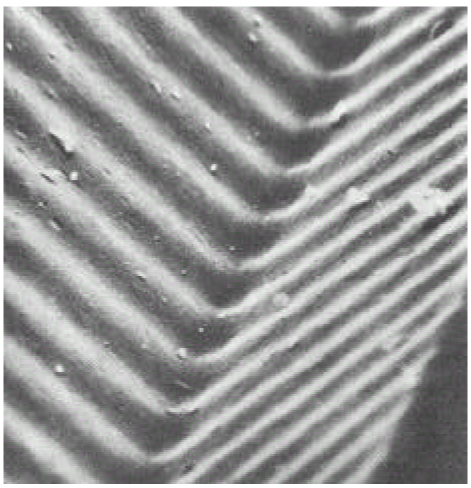
CD-4 GROOVE WALL FULL OF DIRT AFTER 100 PLAYS @ 4.5 GRAMS **Figure 39**

After confirming this, I wrote a paper that I delivered to Panasonic, RCA and Warner Brothers, as well as the IEEE, titled "The Dorren Effect of Carrier Recovery Amplitude Perturbations." I then called RCA and Panasonic and let them know that I had figured out the problem and I could demonstrate the solution. We all met one week later at RCA's plant in Indianapolis. We set up all of our equipment, and I brought out the disks that RCA had sent me to demonstrate. The head of RCA's engineering division, Rex Isom, said, "No, I don't want you to use those disks, I want you to use these" and handed me a new set of disks. I was the only one in the room who was confident. All of the people from Panasonic had facial expressions of "deer in the headlights". I was sure they were convinced that this would not work and they would not gain acceptance from Warner Brothers or RCA. Also watching this demonstration were Jack Holtzman and his brother Keith, from Warner, Electra, Atlantic Records (WEA). Jack was the Chairman of Board. I told everyone to have a cup of coffee and a donut while I prepared the demonstration. I took one of RCA's records, cleaned it, put it on the turntable, played it with the volume off, and removed the expected dirtballs from the stylus.

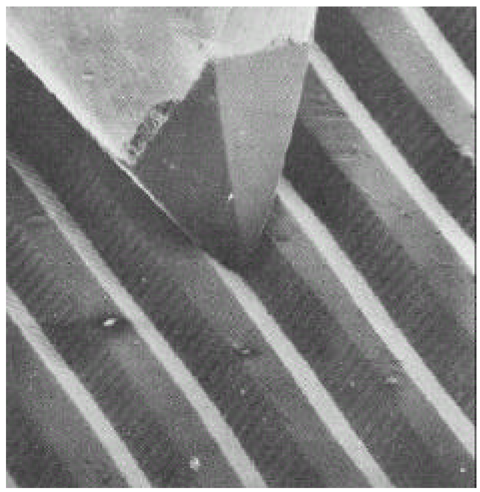
In about ten minutes I said to everyone, "Ok, let me demonstrate CD-4 to you." I took one of the records that had not been cleaned and played it and it sounded awful. I then took the disk that I had cleaned, put it on the turntable and played it. It was perfect! Rex then asked me to clean a disk that he was holding. I said "sure" and proceeded. After the cleaning play, I turned up the volume and the disk also played perfectly. Rex announced to all of us that this disk had been played 500 times at 4.5 grams. Everybody from Panasonic and JVC had a big smile of relief on their faces and the people from RCA and Warner Brothers were shaking everyone's hands. That's where the agreement was made to support the CD-4 Quadraphonic disk system.



BOTTOM OF CD-4 GROOVE AFTER CLEANING TECHNIQUE **Figure 40**



CD-4 GROOVE **Figure 41**



SHIBATA STYLUS IN CD-4 GROOVE **Figure 42**

Well that is the story. You are probably saying "interesting, but where is the humor?" Well it is hidden in the story. Read it again and see if you can find it. If you think you found it send me a private email with the answer. In two weeks I will reveal it.

Well that is it for installment 4. Next time I will discuss the sum-difference matrix and the RSSI system.

Lou Dorren