Audio precision Application note 1 in a series

COMPACT DISC PLAYER TESTING WITH AUDIO PRECISION SYSTEM ONE

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The author wishes to thank Bart Locanthi, Dr. Richard Cabot, and Bruce Hofer for their review of the manuscript and helpful suggestions.

NOTE ON TESTING SPEED

Although the necessary testing functions and adequate performance levels are perhaps the two most important criteria for test equipment to be used with CD players, the time required to perform a useful battery of tests is also important. CD player testing speed with System One is often more limited by the track-to-track access speed of the player than by the actual measurement times. As a practical example of the testing speed available by use of the test files stored on the diskette, a System One procedure was created to prompt the operator through a rather comprehensive set of measurements. The table below shows the measured time for a run through this procedure on Unit A (which has quite rapid access times). The procedure saves the results of each test to disk before it loads the next test. The Technics test disc was used for all tests.

The total time, beginning to end, for this series of tests (including saving the results to disk) was 9 minutes 7 seconds with an AT-compatible computer with hard disk. Any test result can be recalled and printed on an Epson FX or EX series dot matrix printer in 25 to 50 seconds per graph.

Measurement Type	Test File Name	Start Time	Finish Time	Fig. No.
Start of procedure		0:00		
Freq. Resp.	FRQRSPDA.TST	0:07	0:59	2
Phase	PHASE.TST	1:09	2:09	71
Noise Spectr.	NOISSPEC.TST	2:18	3:08	16
THD+N vs Freq.	THDFREQ.TST	3:18	4:14	21
SMPTE imd (spectr. analy)	SMPTSPEC.TST	4:25	5:08	60
THD+N vs Ampl	THDAMPL.TST	5:19	6:38	25
Linearity	LINEARTY.TST	6:48	8:08	43
Separation L to R	SEP_LRA.TST	8:18	8:36	75
Separation R to L	SEP_RLA.TST	8:44	9:02	--
End of procedure			9:07	

COMPACT DISC PLAYER TESTING WITH AUDIO PRECISION SYSTEM ONE

Revision 2 January 1989

Bob Metzler

Introduction

Compact Disc player performance is relatively fast and easy to measure with System One. The signal from Compact Disc players reproducing a variety of available test discs is high quality (better than many audio test oscillators), with none of the noise, flutter, and drop-out problems that plague analog tape machine measurements. In addition to common tests such as frequency response, harmonic and intermodulation distortion, and signal-to-noise ratio, Compact Disc player testing also brings up the opportunity to measure quantization distortion and noise (mechanisms not present in analog audio devices) plus ultra-wide-range linearity.

Test Discs

The Compact Disc test discs which Audio Precision has significant experience with include:

- CBS CD-1 Standard Test Disc
- Denon Audio Technical CD 38C39-7147
- EIAJ CD-1 Standard Test Disc (YGDS 13)
- Japan Audio Society test disc CD-1 (YDDS-2)
- Philips Test Sample 3 (410 055-2)
- Sony Test CD Type 3 YEDS-7
- Technics CD Test Disc 1 SH-CD001

All contain signals appropriate for measuring frequency response, THD+N versus frequency, and at least one form of intermodulation distortion. Most contain signals suitable for inter-channel phase, stereo separation, noise, and signal-to-noise ratio measurements. Most contain unique signals not found on the others.

The Japan Audio Society disc has the most tracks of discrete frequencies at maximum level (31), permitting THD+N versus frequency measurements with the best frequency resolution of any of the discs. The CBS, Denon, EIAJ, Philips, and JAS have analog-swept signals across the spectrum, permitting frequency response and interchannel phase versus frequency measurements with the greatest resolution. The CBS and EIAJ discs have the best signals for measuring de-emphasis error of a CD player. The CBS, EIAJ, Technics, Sony, and Philips discs all provide fixed-frequency signals over a wide amplitude range for measuring distortion versus amplitude and linearity; the CBS provides the most amplitude levels, and the Technics provides more amplitude levels than the remaining discs. The CBS is unique among these discs in providing two sets of amplitude-stepped or amplitude-swept signals with dither. The CBS disc thus permits much more thorough exploration of the low-amplitude linearity of CD players than any of the other discs. Most of the tracks on the Philips disc have signals on only the left or right channel at any one time, limiting its usefulness for phase versus frequency measurements and increasing its utility for stereo separation versus frequency.

Representative CD Players

To provide illustrations for this applications note, several CD players were subjected to testing with the methods described below. Their different design architectures and price levels lead to interesting performance variations. They include:

- Unit A: single 16-bit D-to-A multiplexed between channels, double oversampling (88.2 kHz clock). Typical U.S. retail price range $375-$420.

- Unit B: single 16-bit D-to-A multiplexed between channels, single sampling (44.1 kHz clock), portable unit approximately the size of several CD "jewel cases" stacked together, used with ac power supply. Typical U.S. retail price range $150-$200.
- Unit C: dual 16-bit D-to-A converters, quadruple oversampling (176.4 kHz clock). Typical U.S. retail price range $170-$250.
- Unit D: single 16-bit D-to-A converter, single sampling (44.1 kHz), price at U.S. discount store $88.

"SWEEP TESTING" ACROSS A SERIES OF TRACKS

Certain tracks lend themselves to a single "spot" measurement, such as intermodulation distortion at a fixed set of frequencies. Many measurements, however, are best made and graphed as a set of measurements versus frequency or amplitude. Examples are frequency response, THD+N versus frequency, interchannel phase versus frequency, and distortion versus amplitude.

All of these test discs were designed to be usable with manual test equipment. They have sets of tracks or indexed segments within a track with sequential frequency or amplitude steps, typically with from 30 seconds to 1 minute of continuous signal at each available frequency or level. To obtain graphs of sets of measurements requires that the CD player reproduces a series of tracks or indexed segments while System One measures and graphs the data. System One typically requires only 1 to 3 seconds of signal to perform a two-channel pair of measurements. Most of the tests described here are most efficiently made by manually advancing the Compact Disc player from track to track or from index point to index point as System One acquires the data. The plotted graph thus results from a "sweep" across perhaps a dozen adjacent tracks or indexed segments. The total time required for the "sweep" is typically more dependent on the Compact Disc player's track-to-track access time than on System One's measurement speeds. Tracks 8-38 on the JAS disc are only 10 seconds each, and it may be simpler to allow the player to run through these tracks than to advance it manually.

The CBS, EIAJ, and Philips discs in many cases have from 2 to 13 separately-indexed segments within a single track. This reduces the total track count, which may simplify testing with CD players which cannot directly select more than 16 to 20 tracks. On the other hand, use of these discs will significantly slow the testing of any players which do not have indexing capability. In general, each indexed segment is one minute long and a player without indexing facilities must simply be permitted to play through them. A faster alternate, though less automatic, is to press the F10 key to toggle the computer into "pause" mode each time it signifies data acquisition by a "beep". The CD player "fast forward" control may then be used to advance to a time indicating it is in the next segment and F10 pressed again to toggle back to data acquisition mode. Repeating this cycle across the series of indexed sections will acquire all the data.

EXTERNAL FREQUENCY SWEEPS

Since Compact Discs are a playback-only medium, Compact Disc players are principally tested in the EXTERNal FREQuency and EXTERNal LEVEL sweep modes of System One.

Setup

Figure 1 shows the LVF1 panel, SWEEP TEST DEFINITION panel, and SWEEP SETTLING panel for EXTERNal FREQuency sweeps across a series of tracks where the frequency increases from track to track. Examples include tracks 4-16 of the Technics disc, 2-13 of the Sony disc, 46-55 of the Denon disc, and 8-38 of the Japan Audio Society disc. Tracks 6-10 of the CBS disc and 6-10

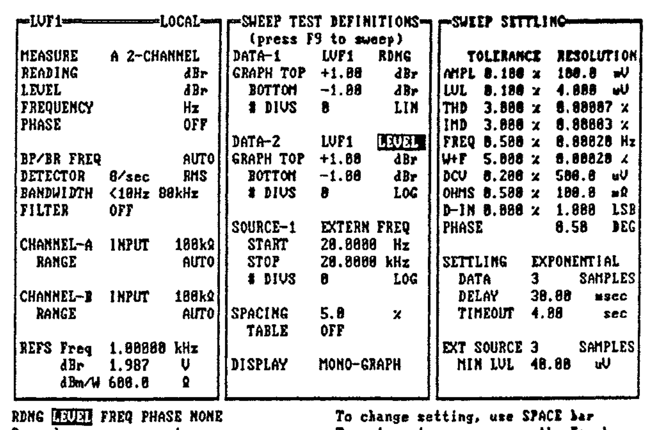

Figure 1 Setup Panels, Frequency Response Testing with A-Version Hardware, Discrete Tracks

of the EIAJ disc are also tested with this setup, but require index advances at some points and track advances at others since they contain four indexed segments within each track except track 10. The key parameters and factors are:

a. Select SOURCE-1 as EXTERNal FREQ with 20 Hz as the START and 20 kHz as the STOP frequency. The direction of "sweep" of the signals on the disc must be matched by the direction implied by these START and STOP frequencies; all of these test discs have tracks in sequence from low to high frequency. The SPACING parameter determines the minimum percentage change in the external source frequency before System One will acquire and plot another point. A 3% value is satisfactory for any of the series of tracks with discrete frequencies.

b. Select the fastest reading rate (on the DETECTOR line of the LVF1 panel) which will produce the desired accuracy. In EXTERNal sweep modes, the reading rate selected on the LVF1 panel is used throughout the test. This differs from GENerator-based sweeps where the reading rate is automatically changed during the sweep as a function of the generator frequency. AUTO reading rate selection produces a 16/second rate during EXTERNal FREQuency and LEVEL sweeps. A 32/sec rate guarantees System One's specified amplitude measurement accuracy down to 50 Hz. The 16/sec rate will produce rated accuracy at 30 Hz and higher, with perhaps 0.1 dB additional error at 20 Hz. Eight readings per second provides specified accuracy to 20 Hz.

FREQUENCY RESPONSE

Setup

The following are the key setup conditions:

a. With A-version hardware (shipped since January 1987), the most rapid testing will result from selecting 2-CHANNEL function, choosing RDNG at DATA-1 (channel A), and LEVEL at DATA-2 (not STEREO mode). Measurements will then be made simultaneously on both channels, with the READING meter measuring the selected channel (usually A, connected to the left channel) while the LEVEL meter measures the alternate (B, or right) channel. This panel setup is illustrated in Figure 1 and stored as FRQRSPDA.TST (**FR**e**Q**uency **R**e**SP**onse, **D**iscrete tone tracks, **A** version hardware) on the companion diskette.

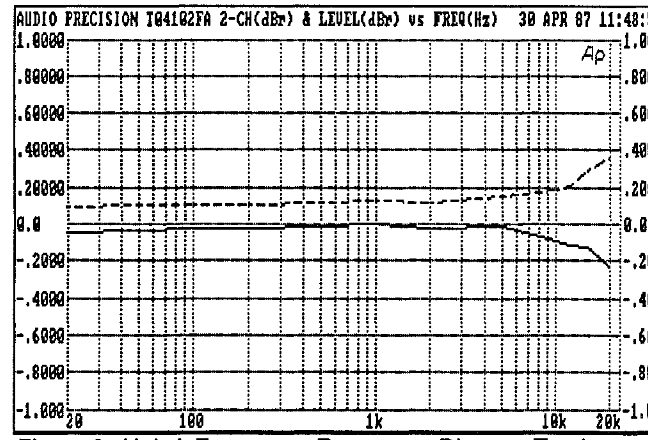

Figure 2 Unit A Frequency Response, Discrete Tracks, A-version Hardware.

Note that any combination of three panels may be simultaneously displayed with System One by using the <Ctrl><PgDn> key to rotate all off-panel screens with the panel where the cursor is located. Figure 2 is a graph of a measurement made with this setup on Unit A.

b. With original version hardware, STEREO mode must be selected instead of DATA-2. Frequency response measurements may be made with either the LEVEL meter or with the principal (READING) meter in its AMPLITUDE mode. Whichever meter is used must be selected at both DATA-1 and STEREO/DATA-2. The selected meter sequentially measures first channel A and then channel B at each frequency, with both points plotted simultaneously. Figures 3 and 4 illustrate the panel setup and graphed results with original version hardware, again measuring Unit A. The graph differs from the previous graph only in the top line labeling, since the AMPLitude

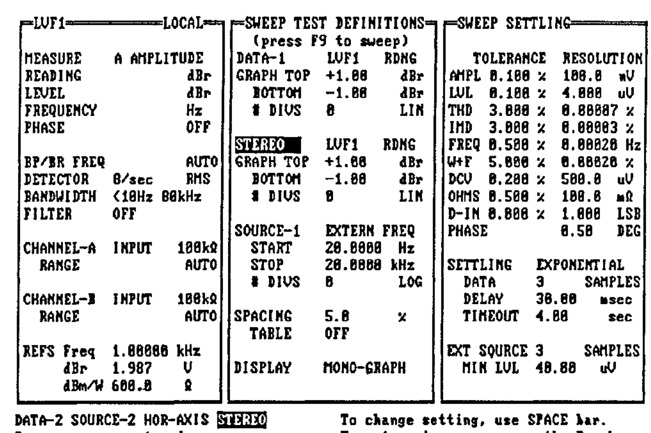

Figure 3 Setup Panels, Frequency Response Testing, Original Hardware, Discrete Tracks.

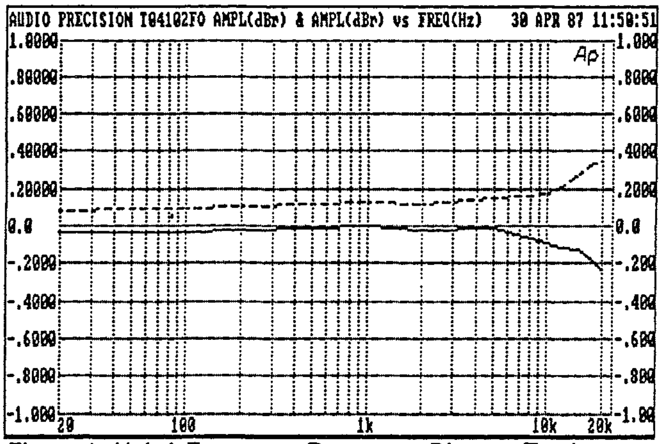

Figure 4 Unit A Frequency Response, Discrete Tracks, Original Hardware.

function of the READING meter is used for both channels. In the previous graph, the 2-Channel function of the READING meter was used for one channel while the LEVEL meter was used for the other. This test is stored as FRQRSPDO.TST (FReQuency ReSPonse, Discrete tracks, Original hardware) on the diskette.

c. When the READING meter is used, no high-pass filter and no low-pass filter lower than the 80 kHz selection should be selected since they would affect the measured response. The AVG detector, which is slightly more accurate at low frequencies, may be selected if desired since the signal is a very pure sine wave.

d. Select a detector reading rate no faster than 8/second for full specified accuracy at 20 Hz, though AUTO (16/sec in EXTERNal FREQ mode) will produce only about 0.1 dB additional potential error at 20 Hz.

e. Since response flatness of 0.1 dB and better is not unusual in good CD players, the settling tolerances of System One's SWEEP SETTLING panel should be tightened from their usual default value of 1% (0.1 dB). Values of 0.1% to 0.5% (0.01 to 0.05 dB) are appropriate for both AMPLITUDE and LEVEL at 8 readings per second.

f. If you wish the displayed response of the left channel to go through 0 dB at 1 kHz, select the dBr (relative dB) units at DATA-1 and DATA-2. Advance the player to a 1 kHz reference level track and press the F4 key while this track is playing. This automatically stores the player's output level (on the channel connected to System One's A input) as the dBr REFerence value.

Testing

Sequence to the lowest-frequency track, press F9, and start the player. The computer will "beep" each time it acquires a set of data; it will then wait for the frequency to change by more than the SPACING value. While the player could simply be allowed to play through the series of tracks, the fastest testing will result from advancing the player one track (or to the next index point in the cases of the CBS, EIAJ, and Philips discs) after each "beep" from the computer. After acquiring data from the last track, save the test to disk under an appropriate name. You may also wish to change the GRAPH TOP and BOTTOM units to better display the particular measurements.

HIGH-RESOLUTION FREQUENCY RESPONSE MEASUREMENTS

The series of fixed-frequency tracks on the various test CDs limits the frequency resolution to between 10 and 31 points across the spectrum. The CBS, EIAJ, Denon, JAS, and Philips test discs permit much higher resolution measurements since each of them has a continuous analog sweep (glide tone) from 20 Hz or lower to 20 kHz or higher. Note that these continuously-changing tones cannot be used for THD+N measurements. Tracks 11 on the CBS and EIAJ and 65 on the Denon are continuous stereo sweeps from 5 Hz to 22 kHz. Tracks 41 and 44 on the JAS disc are stereo sweeps from 20 Hz to 20 kHz; track 41 lasts for 50 seconds, while track 44 lasts for 150 seconds. Track 45 on the JAS disc is a low-frequency sweep from 4 Hz to 125 Hz. Tracks 2 and 3 on the Philips disc are 20 Hz-20 kHz analog sweeps, with track 2 left channel only and track 3 right channel only. These tracks on the Philips disc thus cannot be used for stereo measurements.

Setup

In order to make successful EXTERNal FREQuency sweep tests with a continuously-changing sweep signal, the SWEEP SETTLING panel must be changed. The test setups previously described have software settling algorithms in use for both the data (AMPLITUDE or LEVEL) and the source (FREQUENCY). These algorithms require that frequency and data measurements be stabilized before they are stored and graphed. The default value of EXT SOURCE 3 SAMPLES requires that 3 consecutive frequency measurement samples must agree within the FREQuency TOLERANCE, multiplied by the EXPONENTIAL tolerance weighting, before the system will acquire data. The default value of DATA 3 SAMPLES specifies that 3 consecutive measurement samples of the data parameter (AMPLITUDE or LEVEL) must agree within the TOLERANCE percentage as multiplied by the EXPONENTIAL tolerance weighting before they are captured and plotted. For a glide-tone test, key setup points are:

a. Since the frequency (EXT SOURCE) is continuously changing on a "glide tone" track, 3 consecutive frequency samples will never be equal and the System One software will not acquire data. For measurements to be taken, the EXT SOURCE SAMPLES value must be changed from its default value of 3 samples to 1 sample. This disables the settling algorithm for the EXTERNal SOURCE (frequency) measurement.

b. Depending on the rate of change of the measured parameter (AMPLITUDE or LEVEL) and the tightness of the TOLERANCE for this parameter, it may also be desirable to change DATA SAMPLES from 3 to 2, or to loosen the TOLERANCE somewhat from values which are acceptable on the steady-signal tracks. If data is not taken smoothly and continuously all the way to 20 kHz, it is normally because the response is varying rapidly at high frequencies. The settling must consequently be loosened if data is to be obtained.

c. With the continuous "glide" sweeps, the SPACING value on the SWEEP TEST DEFINITION panel will determine how many points are taken across the audio spectrum.

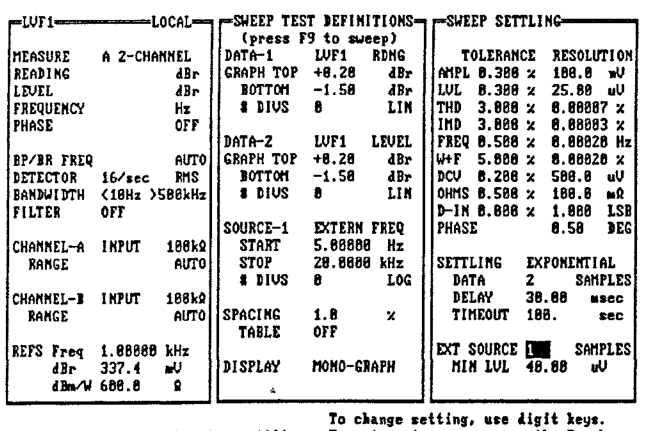

Figure 5 Setup Panels, Frequency Response Testing with Glide-Tone Track and A-version Hardware.

Values as low as 1% to 2% may be selected for maximum data points, except when in STEREO mode.

d. The detector reading rate of 16/sec (selected by AUTO) may compromise accuracy below 30 Hz, but produces more samples and thus more detail at high frequencies.

e. The panels for a stereo frequency response measurement with A-version hardware and a stereo "glide" track are shown in Figure 5. 2-CHANNEL function is used, RDNG (channel A) is displayed at DATA-1 and LEVEL (channel B) at DATA-2. Figure 6 shows the results of a test on Unit B. This setup and data are stored as FRQRSPGA.TST (**F**Re**Q**uency **R**e**SP**onse, **G**lide tone track, **A** version hardware) on the accompanying diskette.

f. With original version hardware, STEREO mode must be selected instead of DATA-2 on the SWEEP TEST DEFINITION panel. AMPLITUDE may be selected on the LVF1 panel and RDNG chosen at DATA-1 (channel A) and STEREO/DATA-2 (channel B), or LEVEL may be selected at DATA-1 and STEREO/DATA-2.

The SPACING parameter must be set to a larger value in order to obtain right channel data with original version hardware. In EXTERNal sweeps and STEREO mode, the software commences each point of data acquisition when the SOURCE (frequency, in this case) has changed by more than the SPACING value from the previous point. It then acquires a DATA-1 reading from the selected channel (usually left), switches to the alternate channel (right) and acquires a DATA-2 reading, and then again measures the SOURCE. If the SOURCE measurement is not still within the SPACING percentage of the value which started the ac-

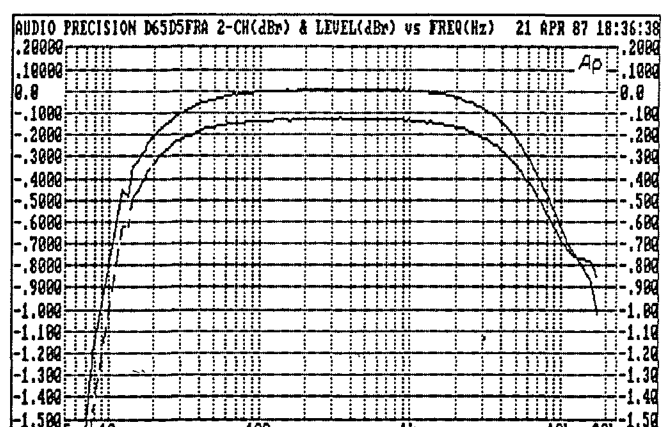

Figure 6 Unit B Frequency Response, Glide-Tone Track.

quisition, DATA-2 will not be kept or plotted. The assumption is that the test disc or tape had moved on to the next section sometime during the DATA-2 measurement. Figures 7 and 8 are this panel setup and a graph made of Unit A. The graph may be compared to Figures 2 or 4, measured on the same player but using fixed-frequency tracks, to see the effect of the increased frequency resolution. The amplitude scales have also been expanded to show detail including the ripple due to the low-pass filters in the CD player. This setup and data are saved as FRQRSPGO.TST on the diskette.

Testing

Testing with the continuously-swept tracks does not require the operator to advance the player after each "beep"

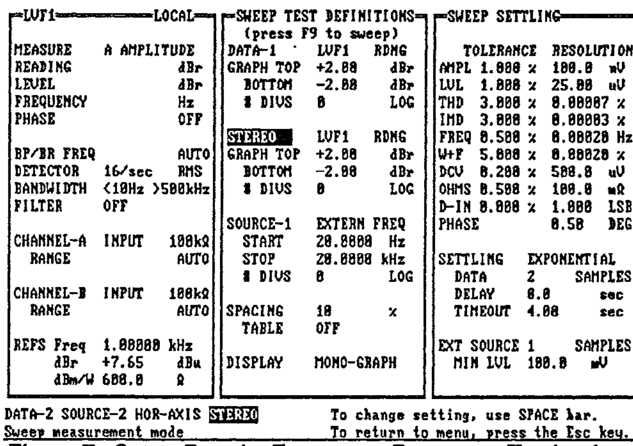

Figure 7 Setup Panels, Frequency Response Testing from Glide-Tone Track, Original Hardware.

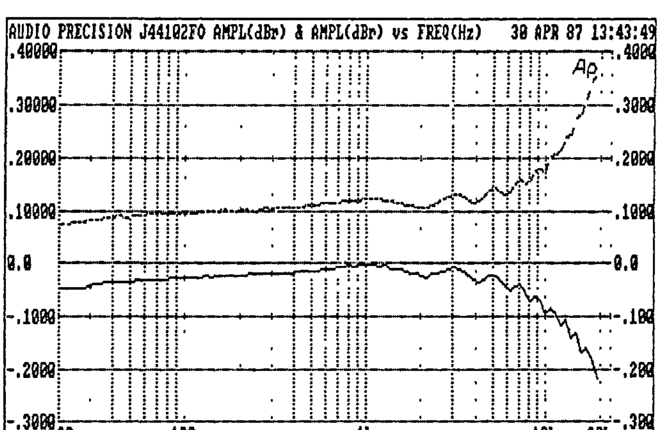

Figure 8 Unit A Frequency Response (Expanded), Glide Tone Track, Original Hardware.

as the discrete tracks do. THD+N measurements cannot be made on these continuously-changing frequencies.

Note that the 1 kHz tone at the beginning of track 65 on the Denon disc is not at the same level as the swept tone. The dBr REFerence may be set to the midband value for the CD player by first playing track 65 while watching the FREQUENCY measurement on the LVF1 panel. As the measured frequency reaches the 1 kHz area, press F4 to store the level measurement from channel A as the dBr REF. Then, reset the CD player to the start of the track, press F9, and start the player. On the Denon disc, the 1 kHz tone lasts for about 8 seconds and data is usually not acquired until the frequency has swept upwards several Hz from the 5 Hz start. Therefore, the first "beep" will typically not occur for 10 to 12 seconds. Either 5 or 10 Hz is an appropriate START selection at SOURCE-1 with the CBS, EIAJ, and Denon discs, while the others start at 20 Hz.

Results

Figure 9 is the graph of the measurement on Unit C using the 2-CHANNEL (A-version) setup. Note that a highly-expanded scale of 0.05 dB per division can be used due to the excellent response flatness of this player. The graph shows a channel imbalance of about 0.075 dB and high-frequency ripple of about 0.04 dB peak-to-peak due to the low-pass filtering of the player. The response below 20 Hz cannot be attributed purely to the player, due to the 16/sec reading rate and because System One flatness is not specified below 10 Hz.

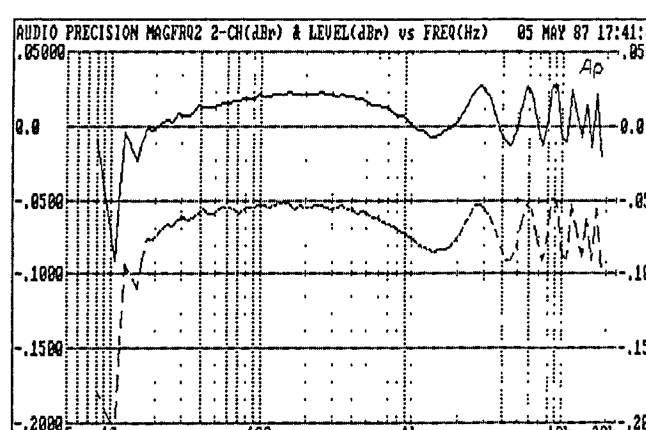

Figure 9 Unit C Frequency Response (Expanded).

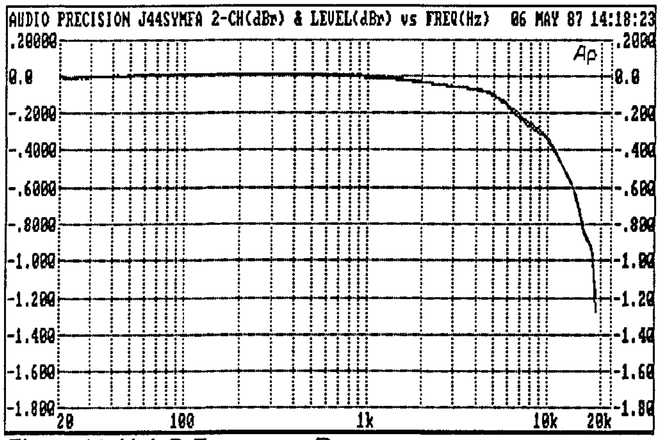

Figure 10 Unit D Frequency Response.

Figure 10 is a graphed measurement of Unit D, using the same setup and track 44 of the JAS disc. The response of this player is down more than 1.2 dB at 20 kHz.

Tracks 2 and 3 on the Philips disc are continuous 20 Hz-20 kHz sweeps of left channel only and right channel only, respectively. Each may be tested separately and the data stored as a separate test, using DATA-1 only (set DATA-2 to NONE). If desired, the two tests may then be graphically overlaid for comparison, using System One's <Alt>F8/F8 image storing and overlay capability. They can also be combined into a single file using the APPEND TEST command.

FREQUENCY RESPONSE WITH DE-EMPHASIS

Compact Discs may be recorded with or without pre-emphasis. When pre-emphasis is used, a "flag" is also digitally recorded which tells the CD player to switch in de-emphasis circuitry in order to provide overall flat frequency response. Perhaps one-third of commercially-available CDs are recorded with pre-emphasis.

Two different methods are provided on the various discs for testing de-emphasis accuracy. The simplest tests are made with the EIAJ and CBS discs. They each have a track (track 12 in both cases) with five frequencies recorded using pre-emphasis. If the player de-emphasis is perfectly accurate, all five frequencies will be reproduced as a flat graph at -20 dB. The same test setups (FRQRSPDO.TST for original hardware or FRQRSPDA.TST for A-version hardware) used for other frequency response tests may also be used for the de-emphasis accuracy tests. Start the player at the beginning of the track (1 kHz reference) and press the F4 key. Advance the index to 2 (125 Hz) and press F9 to start the test. When the computer beeps, index back to 1 (1 kHz) for the next point. When the computer beeps, index to 3 (4 kHz), then 4 (10 kHz), and finally 5 (16 kHz). This index sequence of 1, 2, 1, 3, 4, 5 is necessary because System One software requires a monotonically-increasing or decreasing signal to properly graph and the frequencies in track 12 on these discs are not in monotonic order. The final graph is a measurement of the player's deviation from perfect de-emphasised frequency response.

The Technics (tracks 48 through 50) and Sony (tracks 39 through 41) discs use a different technique. Each has a series of three tracks for testing the accuracy of the player's de-emphasis circuitry. These tracks consist of signals at 1 kHz, 5 kHz, and 16 kHz, recorded at constant 0 dB amplitude (without pre-emphasis) but with the flag set which causes the player to switch in de-emphasis. An ideal player will measure the three signals as follows, when the dBr REF has been set on a 1 kHz 0 dB level signal without emphasis:

1.000 kHz	-0.37 dB
5.000 kHz	-4.53 dB
16.000 kHz	-9.04 dB

A procedure EMPHCORR.PRO has been set up to expedite de-emphasis accuracy measurements with the Technics and Sony discs. It uses EMPHASIS.TST, which is very similar to FRQRSPDA.TST except for choice of the tabular display to better display small deviations. It also differs in that the GEN1 panel frequency setting has been changed from 1 kHz, since an EXTERN FREQ test will not start collecting data until it sees a frequency differing from the generator panel frequency. This change is necessary since the Sony and Technics discs start their de-emphasis testing at a 1 kHz frequency. For original version hardware, the test FRQRSPDO.TST could similarly be changed to DISPLAY TABLE with 500 Hz as the generator frequency and then be saved under the name EMPHASIS.TST.

EMPHCORR.PRO will automatically correct the measurements by subtracting reference data (perfect de-emphasis) from a test result, so that a perfect player would show 0.00 dB at all three frequencies. The key steps of the procedure are as follows:

```
PROCEDUREv1.60;              EMPHCORR.PRO
LOAD TEST EMPHASIS/R;
UTIL PROMPT;                 instructions to select 0 dB
;                            non-emphasized track
/F4/E;                       sets LVF1 dBr REF
LOAD DATA EMPH-REF/R;        loads reference data
;                            to take on dBr REF value
SAVE TEST EMPH-REF/RY;       saves ref. data as test with
;                            proper dBr REF value
UTIL PROMPT;                 instructions to run test
/F9/E;                       run the test
NAMES DELTA EMPH-REF/R;
;                            specifies reference file to
;                            be subtracted
COMPUTE DELTA 1,1/R;         subtracts DATA-1 values
COMPUTE DELTA 2,2/R;         subtracts DATA-2 values
SAVE TEST EMPHCORR/RY;       saves corrected result
/F7/F10/E;                   display and pause
UTIL END
```

Figure 11 shows the corrected test results for Unit C. This data shows the total deviation from perfect flatness due both to de-emphasis error and to imperfect flatness of the basic player circuitry even when de-emphasis is not in use. It also shows any level imbalance between left and right channels, since the dBr REF was set while measuring the left channel in both cases.

If it is desired to further examine only the de-emphasis circuit accuracy without influence of basic frequency response and channel imbalance, the COMPUTE DELTA function can be used to subtract a previously-made frequency response measurement on the same unit from the EMPHCORR.TST data. Figure 12 shows Unit C data after the DELTA operation to subtract the basic player frequency response and channel imbalance.

```
EMPHCORR   05 MAY 87   17:25:43
FREQ(Hz)        2-CH(dBr)       LEVEL(dBr)
1.00001 kHz    -0.00     dBr    -0.09     dBr
5.00005 kHz    -0.05     dBr    -0.15     dBr
16.0002 kHz    -0.02     dBr    -0.11     dBr
```

Figure 11 Unit C De-emphasized Response

```
460-DIFF   05 MAY 87   17:25:43
FREQ(Hz)        2-CH(dBr)       LEVEL(dBr)
1.00001 kHz    -0.01     dBr    -0.01     dBr
5.00005 kHz    -0.05     dBr    -0.07     dBr
16.0002 kHz    -0.01     dBr    -0.02     dBr
```

Figure 12 Unit C De-emphasis Circuitry Response After Subtraction of Basic Response

PROPER SETUP FOR NOISE AND DISTORTION MEASUREMENTS

The 90 to 100 dB dynamic range of CD players places more stringent requirements on the quality of interconnections between player and System One than when measuring many other audio devices. Poor shielding of the interconnect cables and lack of proper grounding between the player and System One can create a noise "floor" which artificially limits many of the measurements described below.

Noise from poor connections or shielding plus analog reproduce channel noise level can be measured on the quiet ("infinity zero") tracks. Noise can be expressed as signal-to-noise ratio by first using F4 to set the dBr REF on a maximum level track, then playing a quiet track. Quiet tracks include 24 and 23 (with and without emphasis) on the Sony disc, 18 (emphasis not stated) on the Philips disc, 18 and 19 (with and without emphasis) on the Technics disc, 4 (without emphasis) on the CBS disc, 4 (emphasis not stated) on the EIAJ disc, and tracks 34 and 35 (emphasis not stated) on the Denon disc. The JAS disc does not have "infinity zero" tracks. Figure 13 shows the panel setup after a 0 dB track has been played and F4 pressed to set the dBr REF value. A GEN NONE setup is used for SOURCE-1 to produce a spot pair of measurements and automatically provide the tabular display format. Figure 14 is the data display resulting from then pressing F9 while a quiet track is being played. This test is stored as NOISEWB.TST (NOISE, Wide-Band) on the diskette. Note that this test produces no information on the digital portions of the system since the D-to-A converter is not being exercised.

```
LVF1             LOCAL   SWEEP TEST DEFINITIONS       SWEEP SETTLING
                            (press F9 to sweep)
MEASURE   A AMPLITUDE    DATA-1     LVF1    RDNG         TOLERANCE  RESOLUTION
READING           dBr    GRAPH TOP  -80.00   dBr      AMPL 10.00 %  100.0   mV
LEVEL             dBr      BOTTOM   -110.00  dBr      LVL  10.00 %  25.00   uV
FREQUENCY         Hz       # DIVS   0        LIN      THD  3.000 %  0.00007 %
PHASE             OFF                                 IMD  3.000 %  0.00003 %
                         STEREO     LVF1    RDNG      FREQ 0.500 %  0.00020 Hz
BP/BR FREQ        AUTO   GRAPH TOP  -80.00   dBr      W+F  5.000 %  0.00020 %
DETECTOR  AUTO    RMS      BOTTOM   -110.00  dBr      DCV  0.200 %  500.0   uV
BANDWIDTH 22Hz  22kHz      # DIVS   0        LIN      OHMS 0.500 %  100.0   mΩ
FILTER    "A"WTG                                      D-IN 0.000 %  1.000   LSB
                         SOURCE-1   GEN1    NONE      PHASE         0.50    DEG
CHANNEL-A INPUT  100kΩ     START             OFF
  RANGE           AUTO     STOP              OFF      SETTLING   EXPONENTIAL
                           # DIVS   0        LOG        DATA     2      SAMPLES
CHANNEL-B INPUT  100kΩ                                  DELAY    30.00    msec
  RANGE           AUTO   # STEPS    0                   TIMEOUT  4.00      sec
                           TABLE    OFF
REFS Freq 1.00000 kHz                                 EXT SOURCE 3      SAMPLES
     dBr  1.988   V      DISPLAY    MONO-GRAPH          MIN LVL  10.00    mV
     dBm/W 600.0  Ω

OFF #1 #2 #3 #4 #5 EXTERN CCIR CCIR-2K "A"WTG
Optional Filters                         To return to menu, press the Esc key.
```

Figure 13 Setup Panels, Integrated Noise Measurement, A-weighted.

```
T10102WB   02 MAY 87   15:26:39
NONE(OFF)        AMPL(dBr)        AMPL(dBr)
      OFF    -100.02  dBr    -99.63    dBr
```

Figure 14 Unit A, Integrated Noise, Tabular Display.

A spectral analysis of the CD player's output while playing a quiet ("infinity zero") track will quickly show a great deal of information on potentially limiting noise problems. On an infinity zero track, the D-to-A converter is quiescent and contributes no noise due to conversions (this is the only testing value from an infinity zero track). The analysis will show whether the CD player's power supply is adequately filtered. It will also show whether other noise sources are coupling into the CD player or cables, such as the magnetic field from the deflection circuits of the computer CRT monitor used with System One. If the analysis extends to sufficiently high frequencies, it will also show signal leakage from the clock at 44.1 kHz, 88.2 kHz (double oversampling), or 176.4 kHz (quadruple oversampling) frequencies.

Setup

Figure 15 shows the setup panels for such a spectral analysis to 20 kHz using the BANDPASS mode of System One. Key factors are:

a. Select BANDPASS mode as the measurement function.

b. SOURCE-1 is selected as an LVF1 BP/BR sweep from 20 kHz to 30 Hz.

c. No high-pass or low-pass filters are selected.

```
LVF1               LOCAL      SWEEP TEST DEFINITIONS       SWEEP SETTLING
                                (press F9 to sweep)
MEASURE     A BANDPASS        DATA-1      LVF1    RDNG       TOLERANCE  RESOLUTION
READING              V        GRAPH TOP   -60.00   dBr     AMPL 10.00 %  100.0  mV
LEVEL                V          BOTTOM    -130.00  dBr     LVL  10.00 %  25.00  uV
FREQUENCY           Hz          # DIVS    0        LIN     THD  3.000 %  0.00007 %
PHASE              OFF                                     IMD  3.000 %  0.00003 %
                              STEREO      LVF1    RDNG     FREQ 0.500 %  0.00020 Hz
BP/BR FREQ        AUTO        GRAPH TOP   -60.00   dBr     W+F  5.000 %  0.00020 %
DETECTOR    AUTO   AVG          BOTTOM    -130.00  dBr     DCV  0.200 %  500.0  uV
BANDWIDTH   <10Hz >500kHz       # DIVS    0        LIN     OHMS 0.500 %  100.0  mΩ
FILTER      OFF                                            D-IN 0.000 %  1.000  LSB
                              SOURCE-1    LVF1    BPBR     PHASE         0.50   DEG
CHANNEL-A   INPUT  100kΩ        START     20.0000 kHz
  RANGE            AUTO         STOP      30.0000  Hz      SETTLING    EXPONENTIAL
                                # DIVS    0        LOG       DATA      2      SAMPLES
CHANNEL-B   INPUT  100kΩ                                     DELAY     30.00    msec
  RANGE            AUTO       # STEPS     80                 TIMEOUT   4.00      sec
                                TABLE     OFF
REFS Freq   1.00000 kHz                                    EXT SOURCE 3       SAMPLES
     dBr    1.938      V      DISPLAY     MONO-GRAPH         MIN LVL   10.00     mV
     dBm/W  600.0      Ω

                                           To change setting, use digit keys.
dB Reference                               To return to menu, press the Esc key.
```

Figure 15 Setup Panels, Spectrum Analysis of Noise.

d. STEREO is selected instead of DATA-2, so that both channels will be swept in sequence on the same test. Channel A (normally left channel) will be plotted with a solid line (green on a color monitor) and Channel B (right) with a dashed (yellow) line. DATA-1 and STEREO/DATA-2 are selected as RDNG, which is the bandpass-filtered signal.

e. dBr is selected for the units at DATA-1 and STEREO/DATA-2, to plot the noise in dB below the output of the player when playing a maximum-level track. To set the dBr REF value on the LVF1 panel correctly, select a track on the test CD with a 1 kHz maximum amplitude (0 dB) signal. Press F4 while this track is playing.

f. The noise levels being measured may not repeat accurately from sample to sample due to the random nature of noise. For faster settling and to avoid TIMEOUT flags (a T displayed at the bottom of the graph), set the AMPL TOLERANCE on the SWEEP SETTLING panel to a relatively loose value such as 10% (1 dB). This test setup is stored as NOISSPEC.TST on the accompanying diskette.

Testing and Results

Select a track with an "infinity zero" signal, without emphasis if available. Press F9. Figure 16 is a graph from such a test on Unit A. On the left channel graph (solid line), a signal at 120 Hz is visible, indicating less-than-perfect filtering of a full-wave rectified power supply (60 Hz power line frequency). The right channel (dashed line) shows 60 Hz and 180 Hz components indicative of magnetic coupling from the power transformer. However, the magnitude of all these signals at about -110 dB means that they will have little effect on wideband measurements such as quantization distortion and quantization noise at levels from -90 to -100 dBr.

Figure 17 shows results of the same test conducted on Unit B. Power line related noise is higher, in the -105 to -110 dBr area. Even more interesting but less easy to explain is the peak above 7 kHz, at about -99 dBr on the left channel. Later analysis (see the SMPTE IMD section below) shows this frequency to be about 7.35 kHz, or 1/6 the 44.1 kHz clock frequency. Signals in the -99 to -105 dBr area begin to have an effect on wideband measurements such as quantization distortion and quantization noise, and become quite significant in more narrowband measurements such as SMPTE IMD.

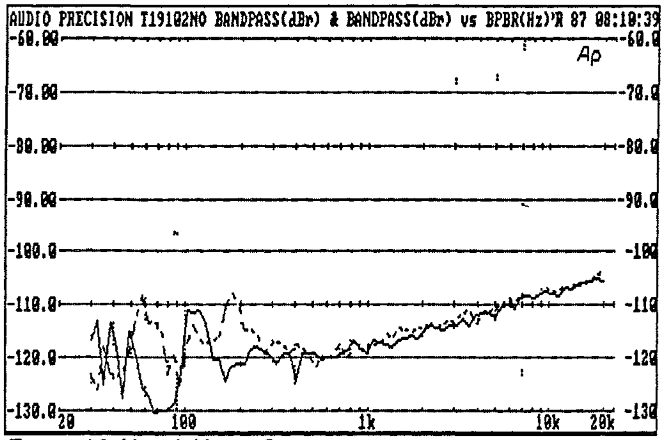

Figure 16 Unit A Noise Spectrum.

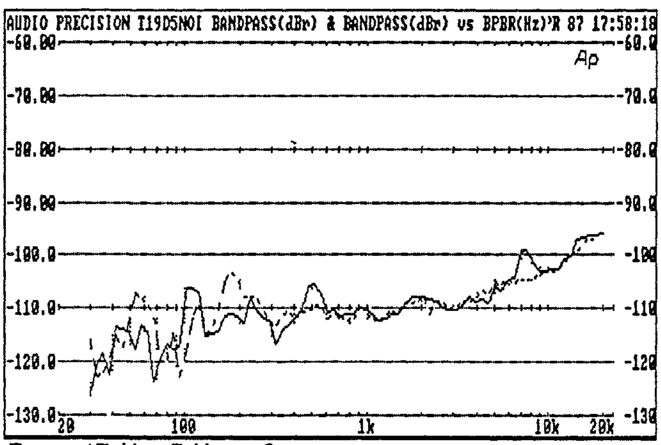

Figure 17 Unit B Noise Spectrum.

Unit C measurements are shown in Figure 18. The noise level is extremely low.

Figure 19 is a measurement of Unit D. Note that the right channel noise is about 10 dB higher than the left channel across most of the high frequency spectrum. Magnetically coupled hum at 180 Hz is significant on both channels. The hum plus other noise acts to set a wideband measurement floor of about -96 dBr on the left channel, while a wideband noise measurement of the right channel shows about -87 dBr due to the integrated effect of the noise across the top 4-5 octaves. These factors become quite limiting in many measurements.

Note that the graphs shown were made with A-version System One hardware. The A-version bandpass filter is sharper than in the original version. The amplitude of the measured peaks will be essentially the same with either version, but the A-version has better ability to discriminate between closely-spaced signals.

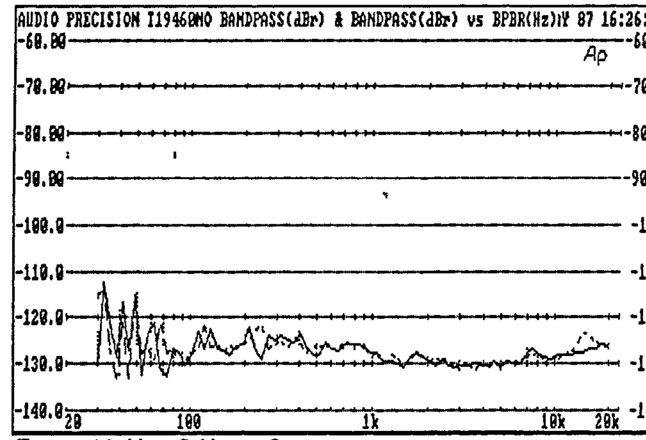

Figure 18 Unit C Noise Spectrum.

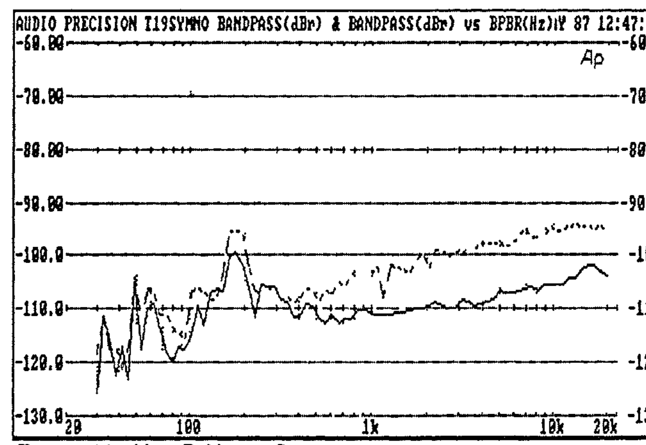

Figure 19 Unit D Noise Spectrum.

DISTORTION AND LINEARITY MEASUREMENTS

Sources contributing to distortion and noise in a CD player include:

- Nonlinearities and noise in the analog sections.
- The theoretical quantization distortion and noise of the D-to-A conversion process. This is a direct function of the number of bits in a linear PCM systems such as CD, with -98.08 dB being the theoretical value. Dither in the recording process can eliminate quantization distortion by redistributing the quantization error energy from specific harmonics into a broad distribution similar to white noise. Only the CBS test disc includes dithered signals.
- Distortion due to practical imperfections of the D-to-A converter such as unequal bit weighting.

- Distortion and noise of the sample and hold circuitry.

Most of these mechanisms cannot be cleanly separated from one another by measurements of a complete CD player, but inferences can often be made. Analog section distortion is likely to make the greatest contribution at maximum signal levels. Analog noise can be separated from digitally-generated noise sources by measuring an infinity zero track, as described earlier. Measuring THD+N vs amplitude can show unequal bit weighting.

THD+N VERSUS FREQUENCY

Setup

a. Select THD+N mode on the LVF1 panel, with dB or percent as units. Select the RMS detector. Make an appropriate choice of low-pass filter frequency. The 22 kHz selection will produce maximum rejection of the CD player clock and out-of-band components. Even more rejection of such signals could be obtained by use of the optional FLP-20000 20 kHz low pass filter plugged into an option socket.

b. Select STEREO instead of DATA-2 so that both channels will be sequentially measured and simultaneously plotted at each step of the frequency sweep. Select RDNG (THD+N) as the displayed function at both DATA-1 and STEREO (DATA-2). Appropriate values of GRAPH TOP and BOTTOM for most CD players are 0.1% and 0.001% or -60 dB and -100 dB, respectively. Figure 20 shows the panels for this test.

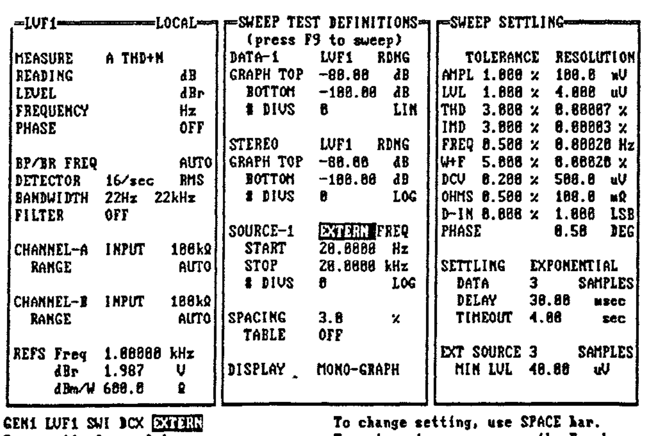

Figure 20 Setup Panels, THD+N vs Frequency.

Testing

Select the first track (lowest frequency) of the series of tracks recorded at 0 dB level. Press F9 and start the CD player in play mode. When measurements have been made on both channels, the computer will "beep". Each time the beep is heard, advance the player to the next track (or the next index point if the test disc used has multiple indexed sections within a track). Following the final track in the series, you may save the test setup and results or re-graph via F7 after improving the selection of graph top and bottom values or units. Figure 21 is a THD+N measurement from Unit A, using System One's 22 kHz low-pass filter. This test setup and data are stored as THDFREQ.TST on the diskette available as a companion to this applications note.

Results

Note that the levels of THD+N obtainable from good CD players (0.0025% to 0.003%, or -90 to -92 dB) are lower than those measurable through a complete digital recording (A-to-D) and playback (D-to-A) cycle with professional 16-bit PCM or 16-bit consumer machines such as RDAT. This is because most of the signals on the test CDs never existed as an analog signal and thus never passed through the theoretical and practical imperfections of A-to-D conversion. Instead, the test CDs contain computer-generated signals whose total RMS quantization error is at the theoretical levels. Dither is not used on any of the high amplitude tracks on any of these test discs. The distortion measured thus results from theoretical quantization distortion and noise in the D-to-A conversion plus imperfections in the D-

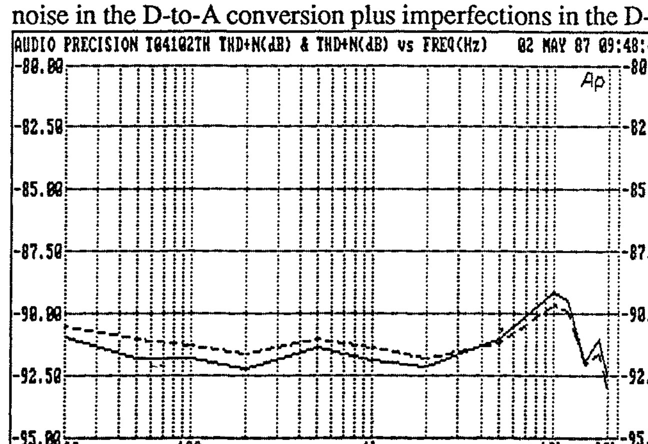

Figure 21 Unit A, THD+N vs Frequency, 22 kHz Low-Pass Filter.

to-A conversion and nonlinearities in the analog sections of the player.

Figures 22 and 23 are measurements made under identical System One conditions on Units B and C, respectively. A rise in THD+N at the higher frequencies is frequently measured, particularly on players with relatively poor reconstruction (low-pass) filters. The cause of this increase in measurement may be demonstrated by use of a hardware feature of System One. The final analog signal which feeds System One's detector is also buffered and connected to the front-panel BNC connector labeled READING MONITOR OUTPUT (on A-version hardware) or PROCESSED SIGNAL MONITOR OUTPUT (on original version hardware). This signal follows all System One filtering--the notch filter in THD+N function plus any high-pass, low-pass, and optional filters selected.

Connect an oscilloscope, audio spectrum analyzer, or frequency counter to this connector while playing a 20 kHz track on a CD player which exhibits higher readings at high frequencies. It will probably be seen that the signal being measured is not a harmonic distortion product, but the beat frequency between the CD player clock and the recorded signal. With a single-sampling player (44.1 kHz clock), for example, this signal being measured will be exactly 24.100 kHz while playing a 20.000 kHz track. Players with two-times and four-times oversampling typically exhibit less of this problem since the clock frequency is farther removed from the signal frequency and more effective filtering can be used without excessive response rolloff or phase shift within the audio band.

The magnitude of this measured beat-frequency product is profoundly influenced by low-pass filtering used in the test equipment. It is a philosophical question whether a high-rejection filter should be used when measuring, or whether the deficiencies of the CD player's own filtering should be allowed to show through by using only the 80 kHz low-pass in System One. Some recent standards call for use of a steep low-pass, with a separate measurement of spurious components made with a high-pass filter. System One's standard 22 kHz low pass filter, used in these tests, has only about 4.5 dB attenuation at 24.1 kHz. Audio Precision's FLP-20K plug-in option filter with steeper rejection characteristics (typically 20 dB at 24.1 kHz) could be used, or an external filter with still sharper cutoff could be used via the external filter capability of an A-version System One.

THD+N VS AMPLITUDE

Quantization distortion and noise are due to errors ("binary round-off") when converting an analog signal amplitude to the nearest available binary number during the digitization process. If all other forms of distortion were negligible, quantization noise and distortion would set a floor (-98.08 dB for the 16-bit linear system of CDs) which would be constant in absolute magnitude across the entire dynamic range of the Compact Disc player. Some players show a rise in distortion at high signal amplitudes, most likely due to distortion in their analog amplifier sections and/or high order bit weighting errors in their D-to-A converters adding to the intrinsic quantization distortion. Steps in the measured distortion across amplitude usually indicate

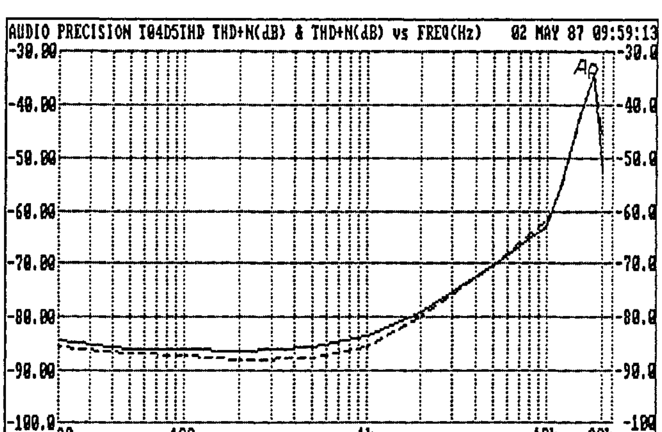

Figure 22 Unit B, THD+N vs Frequency, 22 kHz Low-pass Filter.

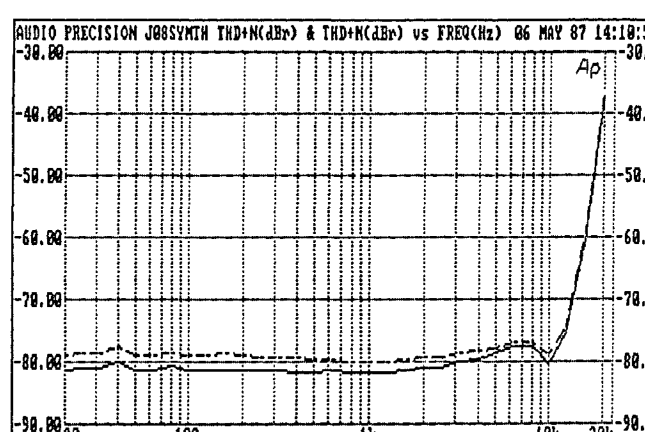

Figure 23 Unit D, THD+N vs Frequency, 22 kHz Low-pass Filter.

weighting errors in the bits which come into more frequent use at a particular amplitude.

Note that some test discs (Sony, Technics) use a 1.000 kHz frequency which is synchronous with the clock frequency at a ratio of 44.1:1. The CBS, EIAJ, and Philips discs use 997 Hz and the Denon 1001 Hz to avoid the synchronous relationship. A synchronous relationship between signal and clock will not test linearity of every state of the player's D-to-A converter, since the points at which the signal waveform will be sampled repeat after a relatively small number of cycles. The non-synchronous relationships are theoretically preferable since the waveform "wanders" through a variety of timing relationships with the clock, causing every state of the converter to be exercised.

Distortion across the 90 dB dynamic range of a Compact Disc player is impossible for most distortion analyzers to measure, since measurement requires holding the fundamental rejection notch fixed at the signal fundamental frequency even when the signal amplitude is as low as approximately 60 microvolts (90 dB below the usual 2 Volt maximum output). Other analyzers with a notch lock-up feature may not maintain the correct setting for the time required to make this test. System One's architecture makes this straightforward, since the notch frequency may be programmed at any desired frequency. The other operational modes include the notch filter frequency being steered by the LVF1 frequency counter, tracking the GEN1 frequency, or being swept as an independent variable.

Stereo distortion-versus-amplitude measurements can be made using track 18 (13 indexed segments) of the CBS disc, track 14 (10 indexed segments) of the EIAJ disc, tracks 22 through 33 (12 levels) of the Technics disc or tracks 14 through 22 (9 levels) of the Sony test disc. Tracks 7 and 8 of the Philips disc are left only and right only, respectively, with the sequence of decreasing amplitudes all taking place within one track. All of these sets of tracks start with a high amplitude signal (0 dB or 1 dB below maximum output) and move downwards to the -90 dB level. All have closely-spaced amplitudes at the higher levels and move to larger steps at lower levels. The CBS and Technics discs have the highest resolution, with -10 dB steps from -10 to -90 dB. The CBS disc starts at 0; the Technics at -1 dB. The Sony and Philips discs have combinations of -10, -12, and -20 dB steps.

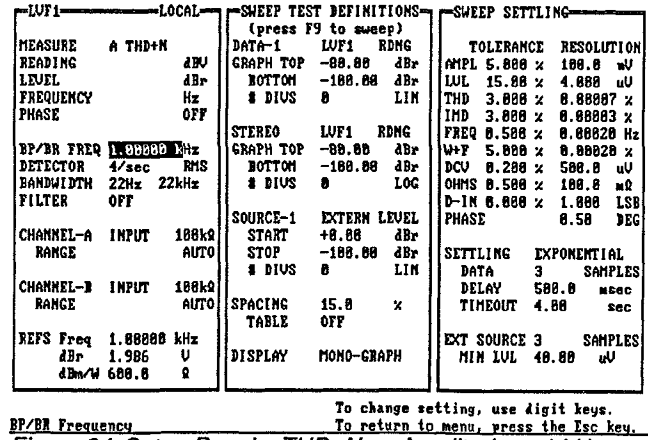

Figure 24 Setup Panels, THD+N vs Amplitude at 1 kHz

Setup

Figure 24 shows the LVF1, SWEEP TEST DEFINITION, and SWEEP SETTLING panels for a distortion versus amplitude test. The key factors and parameters in making these measurements on Compact Disc players are:

a. Select EXTERNal LEVEL sweep mode at SOURCE-1, with the START and STOP points implying a downwards sweep. The most useful horizontal axis calibration is dB relative to maximum output. To accomplish this calibration, set 0 dBr for START and -100 dBr for STOP. Enter the measured maximum output amplitude of the CD player on channel A as the dBr REF value near the bottom of the LVF1 panel by playing a track with a 1 kHz tone at 0 dB and pressing the F4 key. Absolute calibrations are also possible for the horizontal axis. Most CD players have an output amplitude of about 2 Volts at maximum recorded signal level. To calibrate the horizontal axis of the graph in Volts, select 2.0 Volts for START and 50 microvolts for STOP. To calibrate in dBV, select +6 dBV for START and -84 or -90 dBV for STOP.

b. In EXTERNal LEVEL sweeps, the test is driven by and horizontal axis data obtained from the LEVEL voltmeter. The LEVEL voltmeter does not have low-amplitude performance equal to the principal (READING) voltmeter, but its resolution is maximized by selecting the 4/sec reading rate instead of AUTO on the DETECTOR line of the LVF1 panel.

In EXTERnal sweeps, System One collects a new set of data each time the SOURCE-1 parameter changes to a new settled value which differs from the previous settled value by at least the SPACING value. Enter a SOURCE-1 SPAC-

ING value (at the bottom of SWEEP TEST DEFINITION panel) only slightly smaller than the smallest percentage change in voltage between tracks. On the CBS, EIAJ, Philips, and Sony discs, the 0 dB to 1 dB step is the smallest change (approximately 10%) and a SPACING value of 8% or 9% is appropriate. The 2 dB change from the -1 dB track to the -3 dB track is the smallest step on the Technics CD. Two dB is,approximately 20%, so a value of 15% is satisfactory. The SPACING value should be set as large as possible to improve functioning on the -90 dB track, since the quantization steps of the LEVEL meter are slightly over 3 microvolts at the lowest amplitudes. At the nominal level of about 60 microvolts on the -90 dB track, sample-to-sample variations of one bit (3.1 microvolts at 4 readings per second) will fall within the 9% SPACING value. Two-bit repeatability (6.2 microvolts) will fall within a 15% SPACING. Repeatability is necessary since, in EXTERNal LEVEL mode, System One re-checks the SOURCE-1 value after acquiring the right channel (STEREO/DATA-2) data at each step. If the SOURCE-1 value is not within the SPACING percentage of its earlier reading at that step, the right channel data will not be plotted. The system assumes that the track may have ended before the right channel reading was completed.

On the SWEEP SETTLING panel, set the LEVEL TOLERANCE to 15% and the LEVEL RESOLUTION to 4 microvolts. This permits the LEVEL meter measurements (EXT SOURCE) to be accepted as settled even with one or two bits of variation when the -90 dB track is being played.

CD players with large amounts of clock signal leakage may prevent EXTERNal LEVEL sweeps to the -90 dB area, since the LEVEL meter is a wideband voltmeter and will "see" the clock signal the same as the recorded signal. CD players have been measured with clock signal as high as -60 dB, preventing distortion vs amplitude and linearity measurements at low amplitudes.

The desired end product of both linearity and THD+N vs amplitude (quantization distortion) tests is a graph whose horizontal axis is the amplitudes recorded on the test CD. These cannot be measured, since the signal available to System One is both a function of the test disc and the linearity of the CD player. Linearity errors of 3 to 10 dB are not unusual at low amplitudes (see the Linearity section below). Furthermore, full performance of the LEVEL meter is specified only at 10 millivolts and above. Though useful as SOURCE-1 for quantization distortion and linearity tests, the LEVEL meter may show linearity errors (plus wideband noise effects) of 1-2 dB at 50-200 microvolts amplitude (-80 and -90 dB levels relative to maximum output from the player). The distortion (vertical axes) will not be in error since distortion is measured with the wide-range READING voltmeter. However, the readings may be plotted a few dB horizontally from the -80 dB and -90 dB lines on the graph. Since the amplitudes recorded on the CD are stated by the test disc manufacturer, the SOURCE-1 data may be corrected by running a procedure as described below (see Replacing Horizontal Axis Data with Actual Amplitudes).

c. Select THD+N mode and the RMS detector. For the READING units, select an absolute unit (Volts, dBu, dBV, etc.) rather than % or dB which are typically used for other forms of distortion measurements. Both % and dB express distortion products relative to the total signal amplitude at each measurement point. At very low amplitudes in a digital or other noise-limited system, distortion expressed as a percentage approaches 100% (0 dB). This obscures the fact that the fundamental quantization distortion and noise mechanism (on linear PCM converter systems) is essentially independent of signal amplitude. Measuring and graphing THD+N in an absolute unit will help separate the fixed quantization distortion mechanism and show steps in distortion due to weighting errors which occur at particular bit levels.

d. Fix the BP/BR (notch) filter frequency at 1 kHz. Select the 400 Hz high-pass and 22 kHz low-pass filters for minimum noise bandwidth.

e. CD players have some finite value of noise output even when muted during their transitions from track to track. If possible, the MIN LVL parameter on the SWEEP SETTLING panel should be set to a value above this "inter-track noise" output (as measured by the LEVEL voltmeter of the specific System One in use) to prevent System One from mistaking that noise as a legitimate low-amplitude signal track. In EXTERNal sweep mode, System One suspends data acquisition and plotting whenever the signal level measured by the LEVEL voltmeter drops below the MIN LVL value.

To determine the noise level from the player during transitions from track to track, use PANEL mode to observe the LEVEL (in Volts) on the LVF1 panel while operating the track advance control of the player. Enter a value 4 to 8 microvolts (one to two bits of resolution of the LEVEL meter) higher than this inter-track noise level into the MIN LVL field of the SWEEP SETTLING panel. On players with rapid track change, it may be difficult to obtain a good reading of this value. When this is the case, observe the LEVEL reading while playing the -90 dB track (index 13 of track 19 on the CBS disc, index 10 of track 14 on the EIAJ disc, 33 on the Technics, 22 on the Sony, last section of tracks 7 or 8 on the Philips test discs). Since it is desired to measure this track, enter a value about 4 microvolts lower than this reading into the MIN LVL field.

Some CD players have been measured in which the "inter-track noise" is actually higher than the recorded signal on the -90 dB (or even -80 dB) tracks. If MIN LVL is set higher than this value, those tracks cannot be measured. With 1.50A software and later, SETTLING DELAY may be used to disable data acquisition for a sufficient period each time the CD player is sequenced to the next track, permitting MIN LVL to be set to a value lower than the player output on the -90 dB track. Set SETTLING DELAY on the SWEEP SETTLING panel to a value somewhat longer than the time required by the CD player to provide output on the next track when the track advance control is operated. Each time System One software finds the EXT SOURCE value to be settled, it invokes this SETTLING DELAY before it attempts to find settled data. Thus, even if System One accepts the noise level between tracks as a legitimately-settled EXT SOURCE value, SETTLING DELAY prevents immediately taking data. The next track then begins with a new value of EXT SOURCE amplitude, the settling algorithm discards the value from the inter-track noise, and the algorithm starts again to obtain settled measurements on the desired signal from the track. SETTLING DELAY is also invoked after changing channels on a STEREO test, so the measurement time per track will be increased by approximately twice the SETTLING DELAY value. See the SPECIAL PROBLEMS section at the end of this note for an alternate technique with very slow-seeking players.

f. Select RDNG for DATA-1 (and DATA-2 if STEREO mode is desired). Select the desired absolute unit at DATA-1 and DATA-2. Volts, dBu, dBV, or dBr may be used. Since the dBr REF value has already been set (subparagraph (a) of this section) to the output of the player on a 0 dB track, dBr has the advantage of being easily related to the theoretical levels of quantization distortion.

Testing

Set the CD player to the first track of the series intended for distortion versus amplitude and press F9. Each time the computer beeps, advance the CD player one track or to the next index point if the track contains multiple indexed amplitudes. On the Philips disc, simply allow the player to play through the series of 15-second amplitudes on the track. Figure 25 is a graph of distortion versus amplitude of Unit A measured using tracks 22 through 33 of the Technics test disc. The test setup and data are stored as THDAMPL.TST on the companion diskette to this applications note.

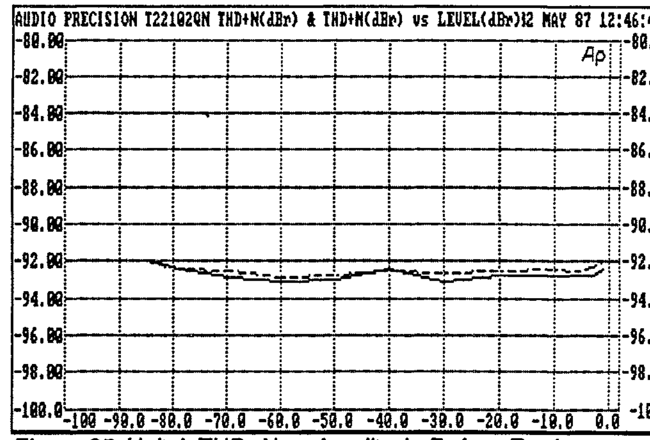

Figure 25 Unit A THD+N vs Amplitude Before Replacement of Measured Amplitudes with Known Amplitudes on Test Disc

Replacing Horizontal Axis Data with Actual Amplitudes

As noted earlier, the desired end result of the test includes a horizontal axis consisting of the actual amplitudes recorded on the test disc. There is no theoretical way in which these amplitudes can be measured, since they are recoverable only through the CD player which is being tested and which may be to some extent non-linear. Furthermore, LEVEL voltmeter performance is specified only down to 10 millivolts. It may have several dB of linearity error at the 60 microvolt level. Wideband noise also contributes error since the LEVEL meter has a bandwidth in excess of 500 kHz.

Since the amplitudes on the test CD tracks are stated by the CD manufacturer, EDIT DATA mode may be used to manually substitute them for the measured values. For even more automatic operation, an Audio Precision-furnished program may be run which in approximately two seconds will replace the LEVEL meter-measured values

```
----!----1----!|---2----!----3----!----4----!----5----!----6----!--|-7----!----8
          dBr                  dBr                  dBr
    -1.00372251,          -92.4299926,          -91.9128189
    -3.00671226,          -92.7742156,          -92.2890397
    -5.99715198,          -92.8298339,          -92.5822984
    -9.98930341,          -92.7419281,          -92.4122466
    -20.0042401,          -92.8205335,          -92.4990996
    -29.9932513,          -93.0942076,          -92.6891555
    -40.0099529,          -92.4633638,          -92.5304872
    -49.9846723,           -93.017045,          -92.7973402
    -59.8415493,          -93.1712418,          -92.8787917
    -69.4644815,          -92.8437959,          -92.5642468
    -78.8467101,          -92.3702471,          -92.4589081
    -84.0719676,          -91.9442595,          -92.0371321

----!----1----!|---2----!----3----!----4----!----5----!----6----!--|-7----!----8
INSERT MODE — press INSERT for Overtype mode.                 Esc = return to menu.
F6 = Block Delete to buffer.                           F5 = copy from Delete Buffer.
```

Figure 26 Data Editor Contents Before Correction

```
----!----1----!|---2----!----3----!----4----!----5----!----6----!--|-7----!----8
          dBr                  dBr                  dBr
    -1.00072251,          -92.4299926,          -91.9128189
    -3.00071226,          -92.7742156,          -92.2890397
    -6.00015198,          -92.8298339,          -92.5822984
   -10.00030341,          -92.7419281,          -92.4122466
    -20.0002401,          -92.8205335,          -92.4990996
    -30.0002513,          -93.0942076,          -92.6891555
    -40.0009529,          -92.4633638,          -92.5304872
    -50.0006723,           -93.017045,          -92.7973402
    -60.0005493,          -93.1712418,          -92.8787917
    -70.0004815,          -92.8437959,          -92.5642468
    -80.0007101,          -92.3702471,          -92.4589081
    -90.0009676,          -91.9442595,          -92.0371321

----!----1----!|---2----!----3----!----4----!----5----!----6----!--|-7----!----8
INSERT MODE — press INSERT for Overtype mode.                 Esc = return to menu.
F6 = Block Delete to buffer.                           F5 = copy from Delete Buffer.
```

Figure 27 Data Editor Contents After Correction

with the theoretical values furnished by the test disc manufacturer.

To manually correct the data, press <Esc> EDIT DATA at the conclusion of a test. A screen display similar to Figure 26 should be seen, with the SOURCE-1 data (from the LEVEL meter) in column 1, Channel A (normally left channel) data in column 2, and Channel B data in column 3. Columns 2 and 3 were measured with the READING meter which has specified accuracy to much lower levels than the lowest from CD players. At the higher amplitudes, typically down through the -60 dB (about 2 millivolts) track, column 1 should match the values given by the test CD manufacturer except for any systematic offset due to not setting the dBr REF value correctly on a 0 dB track. Increasing errors will typically be seen at still lower levels.

The measured values in Column 1 can be replaced with the values from the test CD documentation. Overtype

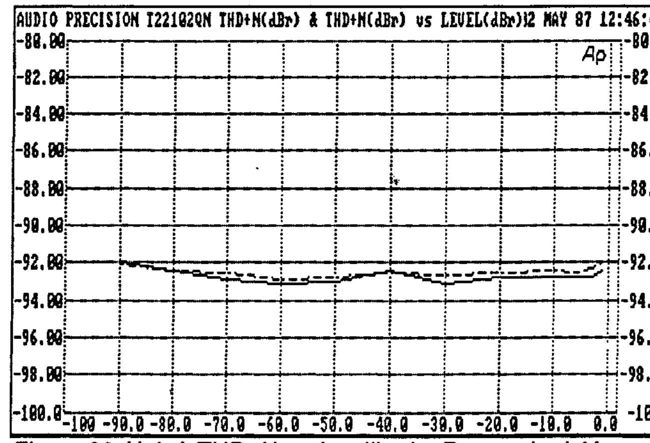

Figure 28 Unit A THD+N vs Amplitude, Re-graphed After Correction

mode, obtained by pressing the <Ins> key, is convenient for replacing these values. Figure 27 is an example of the data editor after the measured values have been replaced in column 1. Digits beyond 0.01 dB are not significant. When the column 1 data has been corrected, press <Esc> and re-save the test. Figure 28 is a re-graph of the Unit A data via F7 after correcting the column 1 data.

For automatic operation, a procedure REPL-xxx.PRO may be run which uses the program COMBINE.EXE to replace the SOURCE-1 (LEVEL voltmeter) data with disk-stored data for the particular CD test disc being used. To run these procedures, sufficient memory space must be reserved at system start-up for COMBINE.EXE to operate while S1.EXE is still in memory. If System One is started with the batch file S1CD.BAT, included on the companion diskette, it will leave sufficient memory for COMBINE.EXE (and CDLINEAR.EXE--see below) to run. To do this, copy S1CD.BAT from the diskette to the directory from which you normally start System One software. Then, type S1CD <Enter> instead of the usual S1 <Enter>.

For track 18 of the CBS test disc, the procedure REPL-CBS.PRO is as follows:

```
PROCEDUREv1.60
SAVE DATA infile2/Ry;          saves test data to infile2.dat
DOS erase infile1.dat/R;        erases any previous version
;                               of infile1.dat
DOS copy cbs18ref.dat infile1.dat/R
;                              copies the CBS track 18
;                              reference data to infile1.dat
```

```
DOS combine -4/R;          runs the compiled program
;                          COMBINE.EXE which
;                          creates a new file outfile.dat
;                          consisting of SOURCE-1
;                          data from infile1.dat and
;                          DATA-1 and DATA-2
;                          values from infile2.dat
LOAD DATA outfile/R;       loads the newly-combined
;                          data back into the test file.
UTIL END
```

Since INFILE1.DAT consists of the exact amplitudes of the test disc according to the test disc manufacturer and INFILE2.DAT is the result of the test just run, the resulting OUTFILE.DAT will be the desired plot of THD+N of both channels versus the exact amplitudes of the disc. The test may then be displayed, saved, or further processed as desired. Procedures stored on the companion diskette include REPL-SON.PRO for tracks 14-22 of the Sony disc, REPL-TEC.PRO for tracks 22-33 of the Technics disc, REPL-PHI.PRO for tracks 7 (left) and 11 (right) of the Philips disc, REPL-CBS.PRO for track 18 of the CBS disc, and REPL-EIA.PRO for track 14 of the EIAJ disc. Each copies the appropriate xxxxxref.dat file to infile1.dat; they are otherwise identical. Each may be inserted into user-written procedures as required.

Complete THD+N vs amplitude testing procedures are included on the diskette for use with the CBS and Technics test discs. They are named CBSTHDAM.PRO and TECTHDAM.PRO, respectively. Operator assistance is normally involved to advance the CD player track or index number as the computer beeps, and to press <Enter> after the final data point is acquired. The appropriate REPL-xxx.PRO procedure then replaces the amplitude data as described above, and the resulting corrected test is displayed. The procedure then pauses for the operator to examine the data. An <Enter> or <Esc> will cause the procedure to save the result as TESTNAME (change this name to whatever name you prefer). The procedure would then normally proceed to the next test on the CD player.

Figure 29 is a measurement of Unit D, after correction, with the same test. The right-channel noise shown earlier in Figure 19 sets a floor for the right channel distortion measurements below -10 dBr. Both channels show an increase in distortion at the higher levels.

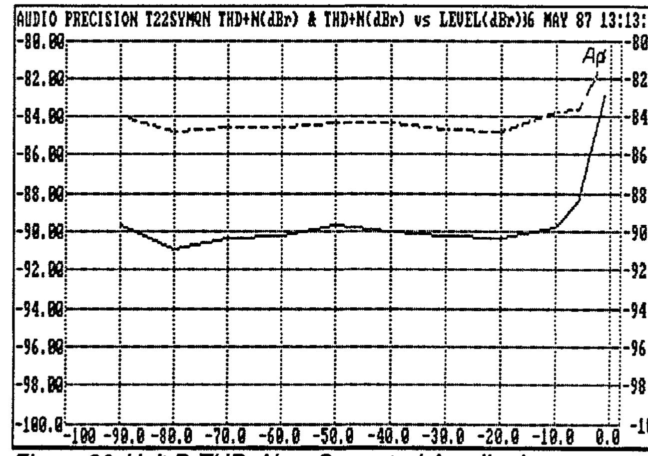

Figure 29 Unit D THD+N vs Corrected Amplitude

Displaying Distortion Relative to Theoretical Values

Since the theoretical minimum total RMS quantization error in a PCM system can be computed (-98.08 dB for 16 bits), some audio engineers like to express distortion as a figure of merit, in terms of "excess distortion" above theoretical. This is easily done with System One, but requires that the horizontal graph axis also be changed if dBr was the initially-selected horizontal calibration.

To display "excess distortion", the dBr REF value on the LVF1 panel must be set to the theoretical value of distortion for the particular CD player. We will assume that the dBr REF value has already been properly set by pressing F4 while playing a 0 dB, 1 kHz track. Change the units for the LVF1 dBr REF from their default setting of Volts to either dBV or dBu. For the measurements and setup example shown above in Figures 24 and 25, the original dBr REF value of 1.986 Volts becomes +5.96 dBV. Subtracting 98.08 dB from this value gives -92.12 dBV. Enter -92.12 dBV in the dBr REF field of the LVF1 panel. The GRAPH TOP and BOTTOM values for both DATA-1 and DATA-2 must now be changed to positive values, to plot as dB above theoretical. For the particular player of this example, +10 dBr and 0 dBr are good choices.

Since the same LVF1 dBr REF value is also the reference for the SOURCE-1 horizontal axis calibration when dBr are the selected units at SOURCE-1 START and STOP, the horizontal axis calibration must be changed. One alternative is to replace the original 0 to -100 dBr values at SOURCE-1 with 0 to +100 dBr. Both vertical and horizontal axes will then be dB above theoretical distortion levels.

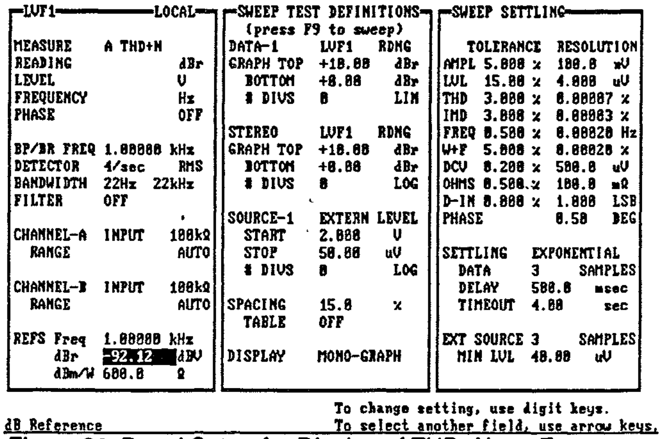

Figure 30 Panel Setup for Display of THD+N as "Excess Distortion"

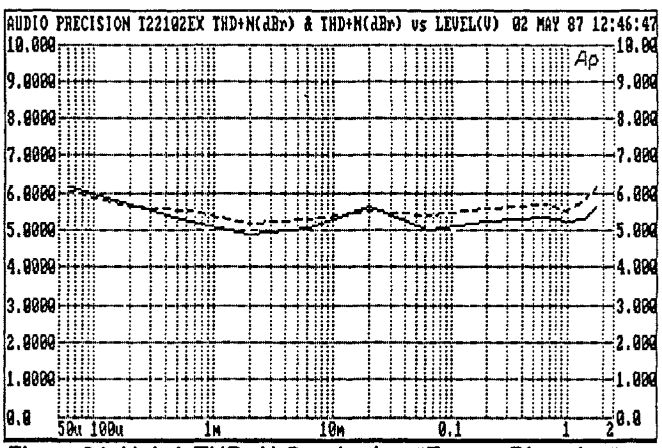

Figure 31 Unit A THD+N Graphed as "Excess Distortion"

This may not be as useful as absolute units such as dBV or Volts for the horizontal axis. Figure 30 shows the same panel setup but with a LOG horizontal scale and 2 Volts and 50 microvolts as START and STOP. Figure 31 shows the same data from Figure 28, now plotted as excess distortion above theoretical.

SPECTRAL ANALYSIS OF LOW AMPLITUDE TRACKS

Another approach to quantization distortion measurement is to perform spectral analysis of the CD player's signal, thereby separating broadband quantization noise from discrete harmonic distortion. System One's BANDPASS function permits selective amplitude measurements, limited by the shape of the 1/3 octave tunable bandpass filter. This capability has been shown earlier in this note to analyze the noise spectrum of a CD player while playing an infinity zero track. The selectivity of a 1/3 octave filter is not sufficient to do useful analysis of high amplitude signals of a CD player, where the dynamic range (measured selectively) exceeds 100 dB. With limited dynamic range signals, however, such as at recorded levels of -70, -80, and -90 dB, BANDPASS function can show very interesting information. The A-version of System One hardware is more useful than the original hardware in this application, since the skirt attenuation of the 1/3 octave filter is considerably increased.

Setup

Figure 32 shows the panel setup for spectrum analysis using tracks with a signal recorded at amplitudes of -60 dB and below. Key actions required include:

a. Select LVF1 BP/BR as SOURCE 1. You may sweep from 20 kHz to 20 Hz, or across narrow portions of the spectrum if desired.

b. To set the dBr REF, select a track with a 1 kHz 0 db (maximum level) signal. Temporarily select AMPLITUDE function and press F4.

c. Select BANDPASS function as READING. Select RDNG and dBr units at DATA-1. If stereo testing is desired, select STEREO instead of DATA-2, RDNG, and dBr units. GRAPH TOP and BOTTOM of -60 dB and -130 dB are a good start, but may be changed after the test to best display the data.

d. Disable any high-pass and low-pass filters.

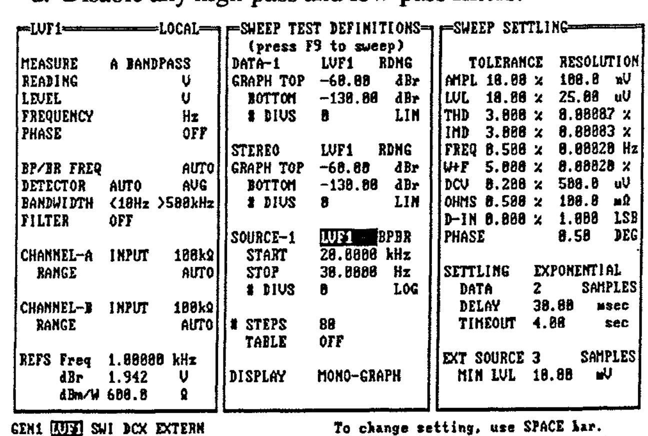

Figure 32 Setup Panels for Spectral Analysis of Low-Amplitude Tracks

This setup is stored as SPECANYL.TST on the diskette.

Testing

Select a low-amplitude track such as tracks 30-33 on the Technics disc, 20-22 on the Sony disc, indexes 8-10 of track 14 on the EIAJ disc, or indexes 11-13 of track 18 on the CBS disc, and press F9. The selected (usually left) channel will be swept and graphed (solid line), followed by the alternate (right) channel (dashed line).

Results

Figure 33 shows a measurement on Unit A of track 31 (1 kHz at -70 dB) of the Technics disc. In addition to the fundamental component at 1 kHz, a third harmonic at 3 kHz is clearly visible at about -103 dB on the left channel and -104 dB on the right channel. Still lower amplitude harmonics are visible at 7 kHz, possibly at 5 kHz, and perhaps several similar-order harmonics just above 10 kHz which are not separated by the selectivity of the bandpass filter. Below the fundamental frequency, the left channel 120 Hz power supply ripple and the right channel magnetically-coupled hum at 60 and 180 Hz are also visible.

Figure 34 shows track 32 (-80 dB) of the same disc on the same player. Note that a second harmonic at -103 and a third harmonic at -100 are clearly visible, plus what are possibly several harmonics not separated by the analyzer in the 6-8 kHz area. It can be seen that the harmonic structure of this player's D-to-A converter is different with a -80 dB signal than it was with a -70 dB signal. At -70 dB, any second harmonic was more than 32 dB down and masked by the fundamental, while the third harmonic was 33 dB down. With a -80 signal, fewer bits of the D-to-A converter are being exercised and the second harmonic is now only 23 dB below the fundamental with the third harmonic at -20 dB.

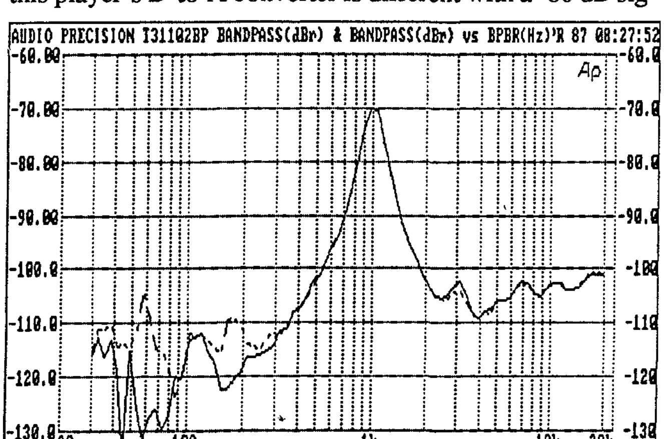

Figure 33 Spectral Analysis of Unit A, -70 dB Track of Technics Disc

Figure 35 is a measurement of track 33 (-90 dB) of the Technics disc on the same player. The fundamental now measures -86 dB instead of the expected -90 due to linearity error of the D-to-A converter. A second harmonic is visible in the left channel at about -107 dB, plus a clustering of several adjacent harmonics from 4th through 7th. On a high resolution heterodyne-type spectrum analyzer connected to the READING MONITOR OUTPUT (PROCESSED SIGNAL OUTPUT) connector, these show

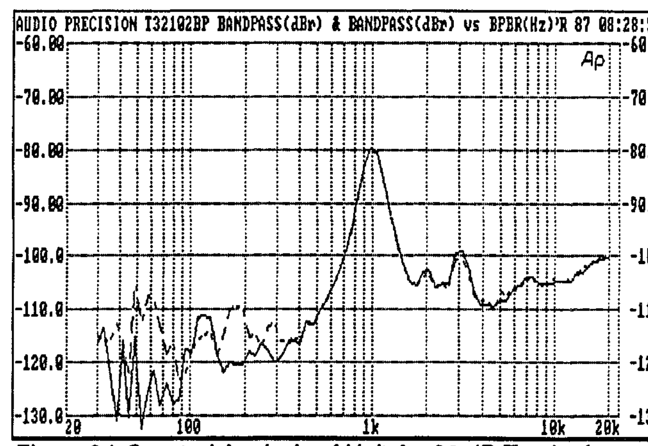

Figure 34 Spectral Analysis of Unit A, -80 dB Track of Technics Test Disc

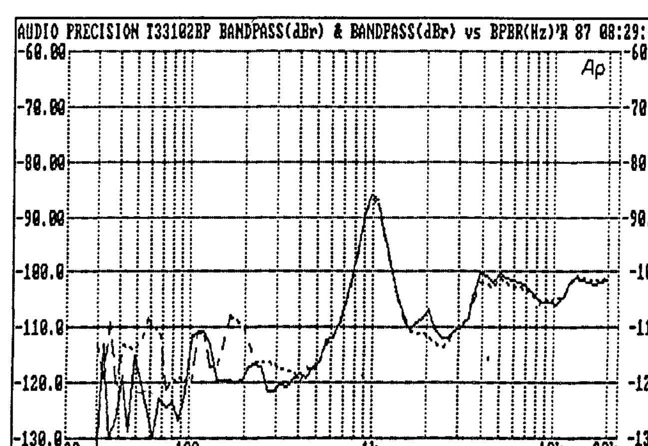

Figure 35 Spectral Analysis of Unit A, -90 dB Track of Technics Test Disc

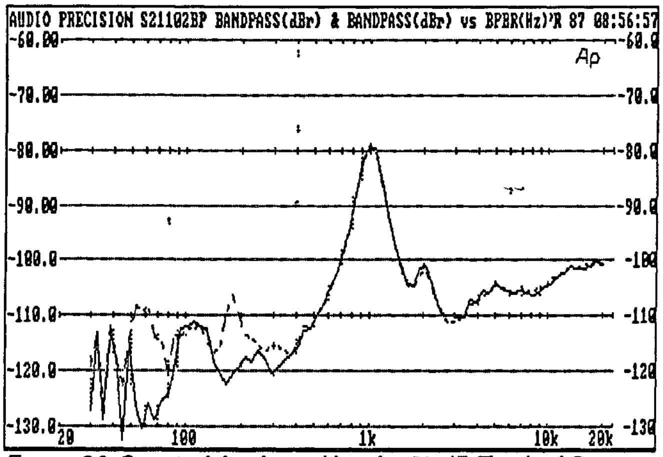

Figure 36 Spectral Analysis, Unit A, -80 dB Track of Sony Test Disc

clearly as 4th, 5th, 6th, and 7th harmonics with approximately equal amplitudes.

As will be discussed in the LINEARITY section below, supposedly equal signals are not necessarily identical on different test discs. Figures 36 and 37 are the -80 and -90 dB tracks of the Sony disc on the same player. Comparison of the two -80 dB tracks shows only a 1-2 dB difference in amplitude of the second harmonic, but more than a 10 dB difference at third harmonic and significant differences at 4th and 5th harmonics. The nominal -90 dB tracks vary even more. The fundamental of the Sony disc is 5 dB lower than on the Technics disc, second harmonic is about the same, third harmonic is about 13 dB higher on the Sony, and the fifth harmonic is about 5 dB higher on the Sony. Even though the signals on the CD test discs are computer-generated, it is clear that different equations were used in these cases--perhaps in the definition of zero

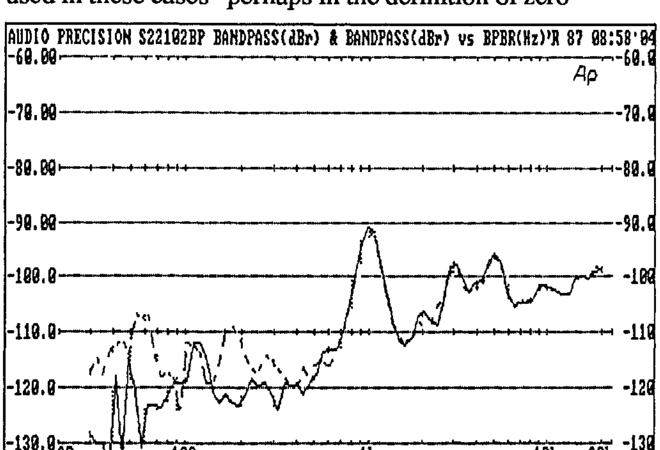

Figure 37 Spectral Analysis, Unit A, -90 dB Track of Sony Test Disc

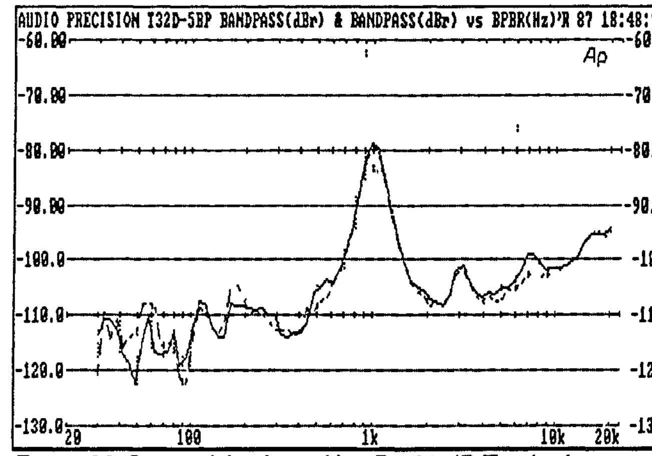

Figure 38 Spectral Analysis, Unit B, -80 dB Track of Technics Test Dis\c

amplitude. The spectra analyzed from the -80 and -90 dB signals of the Philips disc agree with those from the Technics disc.

Figures 38 and 39 are measurements of the -80 and -90 dB tracks of the Technics disc with Unit B. The 7.35 kHz non-harmonic product noted earlier can be seen in both graphs. At -80 dB, Unit B shows only a hint of a second harmonic at about -107 dB and a third harmonic 1-2 dB lower than Unit A in Figure 34. At -90 dB, Unit B shows second and fifth harmonics at -100 dB and a generally different structure from Unit A.

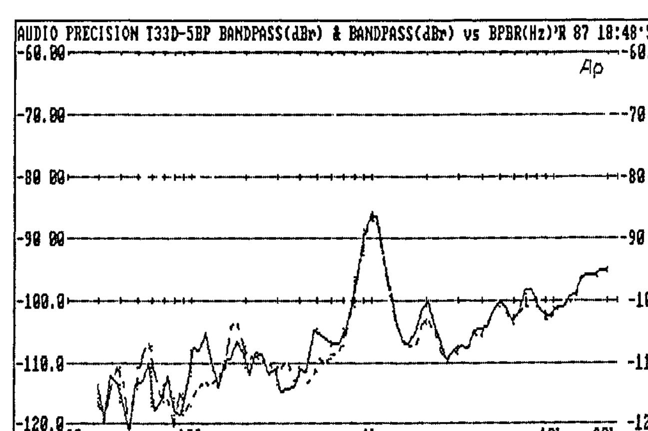

Figure 39 Spectral Analysis, Unit B, -90 dB Track of Technics Test Disc

LINEARITY

Linearity is a measurement of actual output amplitude versus the known amplitudes on the test disc. The same sets of decreasing amplitude tracks at 1 kHz used for distortion versus amplitude may also be used for linearity measurements with System One. Furthermore, two additional tracks on the CBS disc provide still more measurement capabilities at very low amplitudes.

Setup for Full-Range Linearity Tests

a. The SOURCE-1 setup and all settings relative to the LEVEL meter are identical to the distortion versus amplitude setup of Figure 24 above. Note that a detector reading rate of 4/second rather than AUTO is critical.

b. For data, the READING voltmeter function is selected as BANDPASS. At 1 kHz, BANDPASS mode will produce an approximate 20 dB reduction of noise compared to AMPLITUDE mode with the minimum 22 kHz bandwidth, since the bandpass filter Q of approximately 4.32 results in a bandwidth of about 230 Hz when tuned to a 1 kHz center frequency.

c. Change the BP/BR selection on the LVF1 panel from AUTO to 1 kHz to lock the filter at that frequency.

d. To set the 0 dBr REFerence, be sure the units at READING are dBr, play a 1 kHz or 997 Hz 0 dB track on the test CD, and press the F4 key. A dBr REFerence previously set in AMPLITUDE mode or with the LEVEL meter cannot be used in BANDPASS mode, since the bandpass filter may have a gain error as large as 0.5 dB compared to AMPLITUDE mode or the LEVEL meter.

Figure 40 shows the test panel setup, which is stored as LINEARTY.TST on the diskette. Figure 41 shows the resulting data, in DISPLAY TABLE format, from a test of Unit A across tracks 22 through 33 of the Technics disc. EDIT DATA mode or the automatic procedure of the appropriate REPL-xxx.PRO should then be used to correct the SOURCE-1 (first column) data as described above under distortion versus amplitude measurement. After correction, the data will look like Figure 42.

Since deviation from perfect linearity is the desired end measurement, the data should be further operated upon by the COMPUTE LINEARITY function. COMPUTE LINEARITY first calculates a best fit straight line (using

```
LVF1                  LOCAL   SWEEP TEST DEFINITIONS      SWEEP SETTLING
                               (press F9 to sweep)
MEASURE     A BANDPASS        DATA-1      LVF1    RDNG       TOLERANCE  RESOLUTION
READING              dBr      GRAPH TOP   +0.00    dBr    AMPL 5.000 %  100.0  mV
LEVEL                dBr        BOTTOM    -90.00   dBr    LVL  15.00 %  4.000  uV
FREQUENCY            Hz         # DIVS    0        LIN    THD  3.000 %  0.00007 %
PHASE                OFF                                  IMD  3.000 %  0.00003 %
                              STEREO      LVF1    RDNG    FREQ 0.500 %  0.00020 Hz
BP/BR FREQ  1.00000 kHz       GRAPH TOP   +0.00    dBr    W+F  5.000 %  0.00020 %
DETECTOR    4/sec    AVG        BOTTOM    -90.00   dBr    DCV  0.200 %  500.0  uV
BANDWIDTH   22Hz   22kHz        # DIVS    0        LOG    OHMS 0.500 %  100.0  mΩ
FILTER      OFF                                           D-IN 0.000 %  1.000  LSB
                              SOURCE-1    EXTERN LEVEL    PHASE         0.50   DEG
CHANNEL-A   INPUT   100kΩ       START     +0.00    dBr
  RANGE              AUTO       STOP      -90.00   dBr    SETTLING    EXPONENTIAL
                                # DIVS    0        LIN      DATA      3     SAMPLES
CHANNEL-B   INPUT   100kΩ                                   DELAY     500.0   msec
  RANGE              AUTO     SPACING     15.0     %        TIMEOUT   4.00     sec
                                TABLE     OFF
REFS Freq   1.00000 kHz                                   EXT SOURCE 3      SAMPLES
     dBr    1.943    V        DISPLAY     MONO-GRAPH        MIN LVL   40.00   uV
     dBm/W  600.0    Ω

                                       To change setting, use digit keys.
BP/BR Frequency                        To return to menu, press the Esc key.
```

Figure 40 Setup Panels, Linearity Test at 1 kHz.

the least squares method) to a specified section of the data. It then calculates the deviation of every data point from that straight line. The result is a graph of deviation from perfect linearity, which may normally be displayed with a high resolution of only a few dB. This provides much better indication of the actual CD player linearity than attempting to interpret a graph with 90 dB dynamic range.

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LEVEL(dBr)		BANDPASS(dBr)		BANDPASS(dBr)	
-0.82	dBr	-0.99	dBr	-0.87	dBr
-2.82	dBr	-2.98	dBr	-2.87	dBr
-5.81	dBr	-6.00	dBr	-5.87	dBr
-9.80	dBr	-10.00	dBr	-9.88	dBr
-19.81	dBr	-19.99	dBr	-19.87	dBr
-29.81	dBr	-29.99	dBr	-29.87	dBr
-39.82	dBr	-40.00	dBr	-39.88	dBr
-49.80	dBr	-49.96	dBr	-49.85	dBr
-59.67	dBr	-59.85	dBr	-59.75	dBr
-69.24	dBr	-69.53	dBr	-69.53	dBr
-78.54	dBr	-79.14	dBr	-79.39	dBr
-83.88	dBr	-85.83	dBr	-86.40	dBr

Figure 41 Linearity Test of Unit A, Tabular Display Before Correction

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LEVEL(dBr)		BANDPASS(dBr)		BANDPASS(dBr)	
-1.00	dBr	-0.99	dBr	-0.87	dBr
-3.00	dBr	-2.98	dBr	-2.87	dBr
-6.00	dBr	-6.00	dBr	-5.87	dBr
-10.00	dBr	-10.00	dBr	-9.88	dBr
-20.00	dBr	-19.99	dBr	-19.87	dBr
-30.00	dBr	-29.99	dBr	-29.87	dBr
-40.00	dBr	-40.00	dBr	-39.88	dBr
-50.00	dBr	-49.96	dBr	-49.85	dBr
-60.00	dBr	-59.85	dBr	-59.75	dBr
-70.00	dBr	-69.53	dBr	-69.53	dBr
-80.00	dBr	-79.14	dBr	-79.39	dBr
-90.00	dBr	-85.83	dBr	-86.40	dBr

Figure 42 Linearity Test of Unit A After Correction

The COMPUTE LINEARITY command requires three numeric arguments; the data set to compute on (DATA-1 or DATA-2), and the upper and lower horizontal values over which the straight line fitting is to occur. Most CD players are quite linear between the -40 dB amplitude and the -6 dB amplitude. The typical command to calculate deviation from perfect linearity of the left channel (DATA-1) data would thus be:

COMPUTE LINEARITY 1,-45,-4 <Enter>

and for the right channel

COMPUTE LINEARITY 2,-45,-4 <Enter>

The GRAPH TOP and BOTTOM values must now be changed for both DATA-1 and DATA-2 to properly display the resulting curves of deviation from perfect linearity. +5 and -5 dBr is a good starting choice for most players, with additional adjustments necessary on players with unusually good or unusually bad linearity.

Figure 43 is a graph of the corrected linearity test data shown tabularly in Figure 42. While deviation from linearity can be seen at low amplitudes, the information presentation is not optimum. Figure 44 is a graph of the deviation from linearity, after use of COMPUTE LINEARITY and changing the graphic coordinates.

Figures 45 and 46 are the data table and deviation-from-perfect-linearity graph for Unit C, which has a different linearity characteristic at low amplitudes. While Unit C is the most linear of the four units measured for this applications note down through the -80 dBr level, it has the largest linearity error (and in the opposite direction) at -90. The left channel measures about 6.5 dB in error on the -90 dB track; the right channel measures over 8 dB in error.

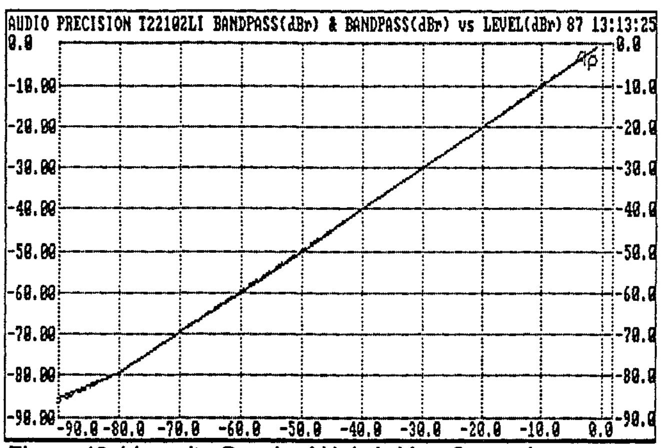


Figure 43 Linearity Graph of Unit A After Correction

T22460LI 05 MAY 87 16:52:54

LEVEL(dBr)		BANDPASS(dBr)		BANDPASS(dBr)	
-1.00	dBr	-1.00	dBr	-1.08	dBr
-3.00	dBr	-2.99	dBr	-3.07	dBr
-6.00	dBr	-6.00	dBr	-6.08	dBr
-10.00	dBr	-9.98	dBr	-10.08	dBr
-20.00	dBr	-19.99	dBr	-20.07	dBr
-30.00	dBr	-30.00	dBr	-30.07	dBr
-40.00	dBr	-40.00	dBr	-40.08	dBr
-50.00	dBr	-50.01	dBr	-50.06	dBr
-60.00	dBr	-60.01	dBr	-60.06	dBr
-70.00	dBr	-70.16	dBr	-70.30	dBr
-80.00	dBr	-80.49	dBr	-80.84	dBr
-90.00	dBr	-96.44	dBr	-98.40	dBr

Figure 45 Linearity Test of Unit C After Correction, Tabular Display.

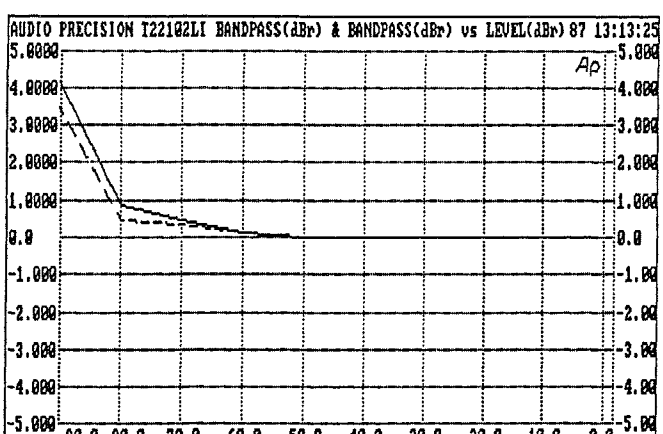


Figure 44 Unit A, Deviation from Perfect Linearity. Obtained by use of COMPUTE LINEARITY command.

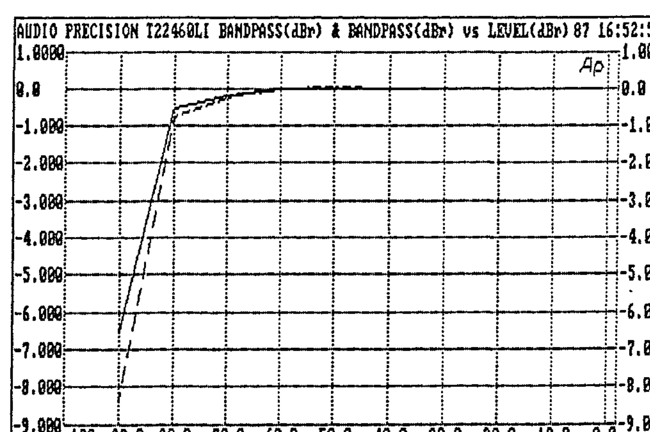


Figure 46 Linearity Test of Unit C After Correction, Graphic Display

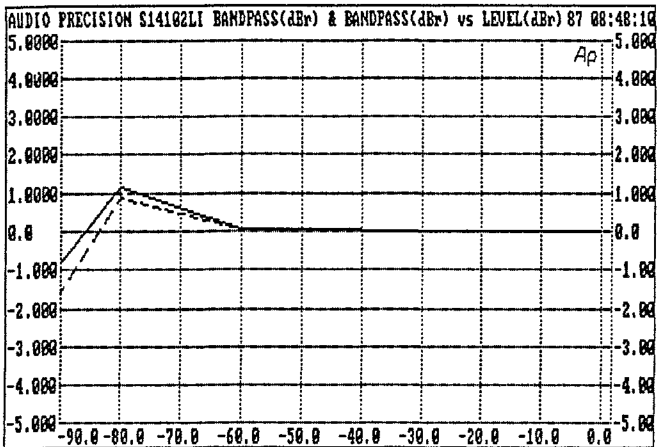


Figure 47 Unit A Linearity Test with Sony Test Disc

Figure 47 is the deviation-from-linearity test of the same CD player graphed in Figure 44 above, but using tracks 14 through 22 of the Sony test disc. Note that the +3.5 to +4 dB reading from the -90 dB track of the Technics disc becomes -1 to -1.5 dB with the Sony disc. The spectral analysis section above showed the differing spectra of the -90 dB tracks on these two discs. The Philips disc -90 dB track measures identically in linearity and spectrum to the Technics disc.

Complete linearity-testing procedures included on the companion diskette are CBS-TR18.PRO and TEC-TR22.PRO. They prompt the operator to take the necessary actions, incorporate the appropriate REPL-xx.PRO to bring the reference amplitude data into SOURCE-1, and automaticaly change the DATA-1 and DATA-2 GRAPH TOP and BOTTOM parameters to display typical values of nonlinearity.

Linearity Tests with Dither

The CBS test disc is unique among those listed in that it contains two test tracks with dither added. Dither is a low-amplitude noise signal of at least +/- 1/2 LSB amplitude. While dither reduces the ultimate signal-to-noise ratio of the system, it effectively reduces distortion (improves linearity) at low amplitudes and extends linear operation below the undithered theoretical limit. Signals below 1/2 LSB in peak amplitude would never be converted (recorded) in a non-dithered system. With dither, signals at arbitrarily low amplitudes are still converted and recorded since the dither acts to assure the LSB is continually being toggled. On a frequency domain basis, dither can be thought of as spreading the quantization noise across the spectrum, rather than having that energy all concentrated at harmonics of the signal frequency. In practice, most digitally recorded program material contains dither--either via deliberate addition, or simply from noise inherent in the analog equipment (pre-amplifiers, consoles, etc.) used prior to the A-to-D conversion.

Track 19 on the CBS disc contains four dithered signal levels for linearity testing at low amplitudes. Three are the same amplitudes as the last three sections of undithered track 18: -70.31, -80.77, and -90.31 dB. The fourth signal on track 19 is at the -100 dB level. Dither is 1/2 LSB with a uniform probability distribution. The procedure CBS-TR19.PRO on the diskette is a complete, operator-prompting procedure to make the measurements and perform the necessary computations. The key portions of the procedure (omitting operator-prompting messages) are as follows:

```
PROCEDUREv1.60
LOAD TEST CBS-TR19/R
UTIL PROMPT;                   messages to operator
/F9/E;                         acquire the data
SAVE TEST cbs19raw/Ry;         save in normal test format
SAVE DATA infile2/Ry;          save ASCII data for COM-
;                              BINE.EXE
DOS erase infile1.dat/R;       erase old infile1.dat
DOS erase outfile.dat/R;       erase old outfile.dat
DOS copy cbs19ref.dat infile1.dat/R;
;                              copy reference data to
;                              infile1.dat
DOS combine -4/R;              run COMBINE.EXE as
;                              described earlier
LOAD DATA cbs19ref/R;          load ref. data to assume dBr
;                              REF value from test
SAVE TEST cbs19ref/Ry;         save test to be used as
;                              DELTA file
LOAD DATA outfile/R;           load resulting outfile.dat
SAVE TEST cbs19cor/Ry;         save the corrected test file
NAMES DELTA cbs19ref/R;        attach ref. file for delta
COMPUTE DELTA 1,1/R;           subtract reference data
;                              stored in file cbs19ref.tst
;                              from DATA-1
COMPUTE DELTA 2,2/R;           same for DATA-2
PANEL 10/R;                    change DATA-1 GRAPH
;                              TOP to +10 dBr
-10/R;                         change GRAPH BOTTOM
;                              to -10 dBr
```

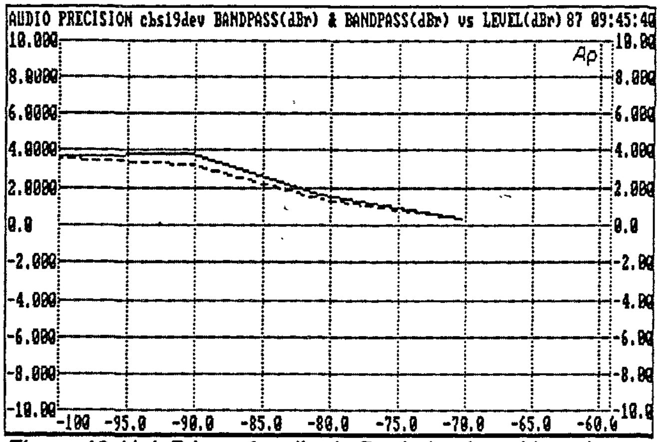


Figure 48 Unit B Low-Amplitude Deviation from Linearity, Dithered Track 19 of CBS Test Disc.

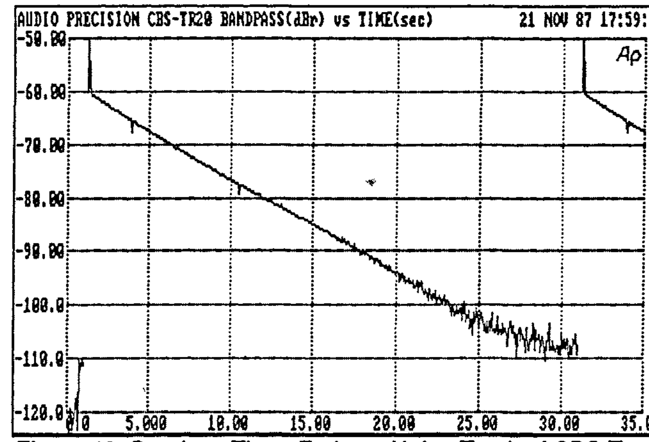


Figure 49 Graph vs Time, Fade-to-Noise Track of CBS Test Disc, Unit B

10/R;	change DATA-1 TOP
-10/R/E;	change DATA-2 BOTTOM
SAVE TEST cbs19dev/Ry;	save the resulting test
;	showing deviation from
;	perfect linearity
/F7/F10/E;	display the graph and pause
UTIL END	

Figure 48 is a graph of the performance of Unit B resulting from the above procedure.

Track 20 on the CBS disc contains a 500 Hz signal plus dither. Dither is with a triangular probability distribution. The signal fades linearly from -60 dB to -120 dB during 30 seconds (2 dB per second rate); the cycle is then completed. This is the only CD track known to Audio Precision which permits linearity measurement with better than 10 dB resolution at low amplitudes.

This track cannot be measured with an EXTERNal LEVEL sweep selection at SOURCE-1. EXTERNal LEVEL sweeps use amplitude changes as measured by the LEVEL voltmeter to drive the data acquisition process. The LEVEL voltmeter has a bandwidth of greater than 500 kHz, unaffected by the bandpass filter or any other filter selection in System One. On the lower portions of the fade-to-noise signal on track 20, the signal is below the wideband noise level and changes thus will not be detected by the LEVEL meter. Instead, this track is measured with an EXTERNal TIME test. Since the signal fade rate is linear with time, the horizontal axis may then be interpreted or recalibrated in signal amplitude.

Figure 49 shows a graph of the initial measurement of a CD player using track 20 of the CBS disc and CBSTR20L.TST (left channel) or CBSTR20R.TST (right channel) from the companion diskette. Figure 50 shows the key setup panels for CBSTR20L.TST. The BANDPASS filter is fixed at the 500 Hz signal frequency. The LVF1 dBr REF value must be correctly set by playing the 0 dB 499 Hz section of the CBS disc (track 7 index 04) and pressing F4. 625 steps are chosen (high sample density) to minimize the time at the beginning of the test before the first data point is taken. Settling is OFF and the INPUT range is set to 80 mV fixed, rather than AUTO, for the same reason. Only one channel is tested during each test for optimum timing and data resolution. To run this test manually, cue the player to track 20 in the pause mode. Press F9 to start the test and wait until the graph and titles are completely drawn, then put the player in play mode. The beginning of the ramp will thus be a second or two into the graph. Note that brief transient spikes may appear on

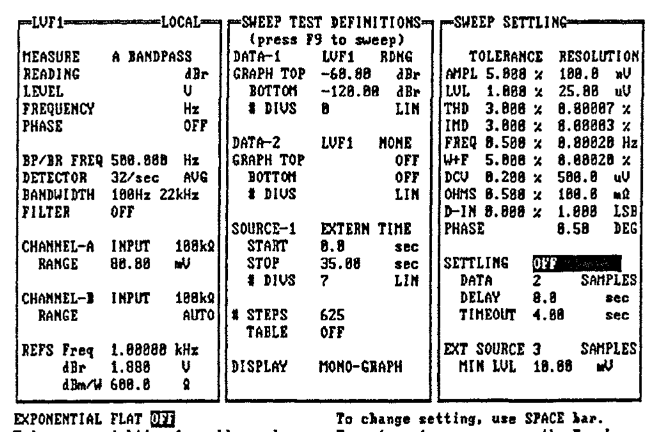


Figure 50 Setup Panels for Fade-to-Noise Track 20 of CBS Test Disc

the graph at range switch points of the reading meter since settling is off, but they will not affect the linearity measurement.

The test diskette contains a special compiled program named CDLINEAR.EXE which searches a data file resulting from the above test for the beginning of the first ramp. It then discards all data from before and after this ramp and replaces the SOURCE-1 data (time in seconds) with the -60 to -120 dBr amplitude data, since it is known that the amplitude fades at the rate of exactly 2 dB per second. Figure 51 shows a graph of the previous data after CDLINEAR.EXE has been run and the SOURCE-1 units and START and STOP points changed appropriately. Note that for CDLINEAR.EXE to operate, sufficient memory space must be reserved at System One start-up. Starting S1 via the batch file S1CD.BAT, included on the companion diskette, is one way to accomplish this.

This data cannot be properly processed by use of the COMPUTE LINEARITY command discussed earlier, since player non-linearity at the -60 dB amplitude would prevent there being any truly linear data to which to fit the straight line. A more rigorous approach is to use the COMPUTE DELTA command to subtract from the test data the -60 to -120 dB reference file stored on the diskette as CBS20REF.DAT.

Two complete procedures on the diskette named CBSTR20L.PRO (left channel) and CBSTR20R.PRO (right channel) automate all the above operations plus operator prompts and graph top and bottom value changes to display typical values of non-linearity.

Before running either procedure, the test files which they use must be calibrated to the output level (on each channel) of the specific CD player being tested. A procedure named CALCBS20.PRO has been created to simplify this calibration. CALCBS20.PRO prompts the operator to load a test disc with a 499 Hz or 500 Hz 0 dB signal and start the player. The procedure loads the test for left channel measurement, changes to autoranging and turns settling on, sets the dBr reference (<F4>key), turns settling off, changes the input range back to 80 mV fixed, and saves the test to disc with the new dBr reference. It then does the same thing for the right channel linearity test.

After CALCBS20.PRO has been run for the specific player to be tested, CBSTR20L.PRO and CBSTR20R.PRO may be run. They operate as follows (be sure enough meory was reserved for CDLINEAR.EXE):

```
PROCEDUREv1.60 ;              CBSTR20L.PRO
LOAD TEST cbstr20l/R;         load the time-sweep test
UTIL PROMPT;                  instructions to operator
/F9/E;                        acquire data (amplitude vs
;                             time
SAVE TEST cbs20rwl/Ry;        save as test before proces-
;                             sing
SAVE DATA infile/Ry;          save ASCII data for use by
                              CDLINEAR.EXE
DOS cdlinear/R;               run CDLINEAR
LOAD OVERLAY cbs-tr20/R;      load an overlay which
;                             preserves the dBr REF
;                             value, but changes
;                             SOURCE-1 from EXTERN
;                             TIME to EXTERN LEVEL
;                             in dBr
PANEL ç/E;                    go to panel and <Alt>R to
;                             restore punched-out field of
;                             overlay
LOAD DATA CBS20REF/R;         load ASCII form of -60 to
;                             -120 dB reference data so
;                             that it becomes referred to
;                             present dBr REF value
SAVE TEST CBS20REF/Ry;        save reference data referred
;                             to correct dBr REF
LOAD DATA outfile/R;          load result of CDLINEAR
;                             computation
NAMES DELTA cbs20ref/R;       specify ref. file to be
;                             subtracted
COMPUTE DELTA 1/R;            subtract CBS20REF.TST
;                             from data in memory
PANEL 10/R;                   set DATA-1 graph top to
;                             +10 dBr
-10/R/E;                      set graph bottom to -10 dBr
SAVE TEST 20resu-l/Ry;        save result as a test file
/F7/F10/E;                    display result and pause
UTIL END
```

Figure 51 is a graph of the data from unit B after the procedure was run. Note the non-linearity of 3-4 dB occurring between -70 and -90 dB. Non-linearity then levels off below -90 dB, since only the LSB is being exercised by the dither. At lower amplitudes, the signal grows noisier and noiser. The upwards trend of the deviation-from-linearity curve at the low-amplitude end of the graph is not non-linearity in the normal sense, but simply the noise floor of the dither signal and CD player as viewed through the approximately 120 Hz bandwidth (at -3 dB) of System One's bandpass filter when tuned to 500 Hz. Use of still more

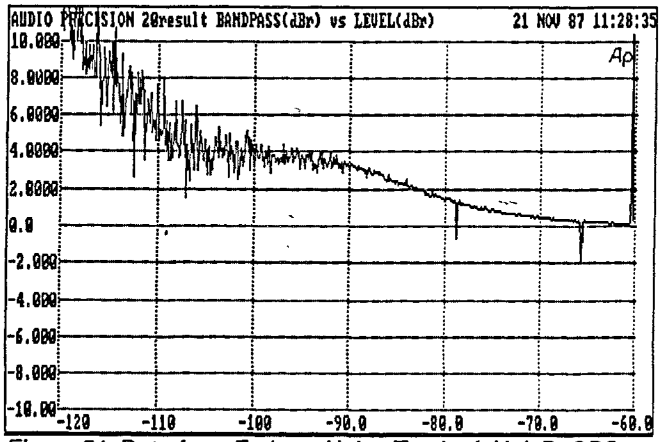


Figure 51 Data from Fade-to-Noise Track of Unit B, CBS Disc, after CDLINEAR.EXE Operation and Re-graph.

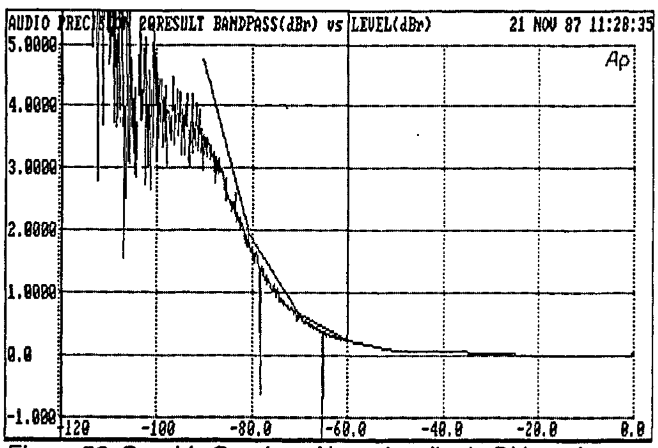


Figure 52 Graphic Overlay of Low-Amplitude Dithered Linearity Data with Full-Range Undithered Data, Unit B

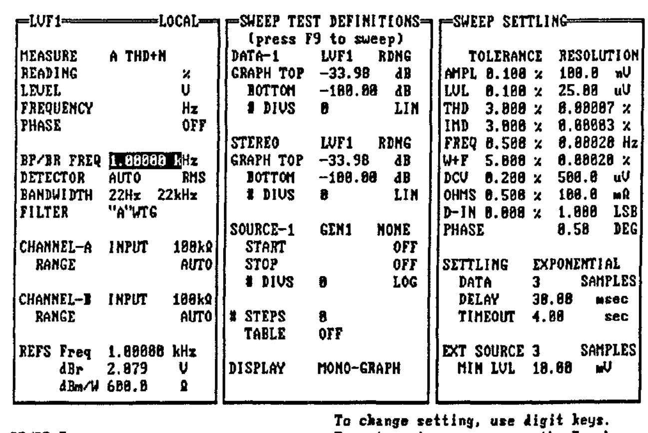
selective bandpass filtering at 500 Hz could reduce the noise floor still further. This would not give additional information on linearity of the CD player, however, since only the LSB is being exercised at signal amplitudes below -98 dB.

Figure 52 is a graphic overlay comparing the low-amplitude linearity test from track 20 with the undithered full-range linearity test from track 18 of the CBS disc, both on Unit B. Note the improvement in linearity at the -90 dBr level brought about by the dithering.

DYNAMIC RANGE

Some testing methods, such as document CP-307 of the Electronic Industries Association of Japan (EIAJ), define dynamic range measurement of a CD player as a THD+N measurement on a -60 dB track, corrected by adding 60 dB. This method eliminates any distortion introduced at higher levels in the CD player. It also allows use of distortion analyzers which lack the low residual noise and distortion floors to directly verify the specifications of CD players on the higher output amplitude tracks. Analyzers other than System One, however, will require a voltage amplifier to be connected following the CD player output, since the nominal 2 millivolt signal at -60 dB is insufficient for them to measure directly.

Figure 53 shows the test setup to make such a measurement directly (no amplifiers required) with System One. The BP/BR filter frequency is fixed at the frequency recorded on the disc (normally 1 kHz), the dB unit selected at READING on the LVF1 panel and for DATA-1, and GEN NONE selected at SOURCE-1 for a single-point measurement. The 22 kHz low-pass filter and RMS detector should be selected. The A-weighting filter is specified by the EIAJ for this test, since it is really more akin to a noise measurement than a distortion measurement and it is desired that the results be directly comparable to A-



```
LVF1                LOCAL    SWEEP TEST DEFINITIONS     SWEEP SETTLING
                              (press F9 to sweep)
MEASURE    A THD+N           DATA-1     LVF1   RDNG       TOLERANCE  RESOLUTION
READING              %       GRAPH TOP  -33.98   dB     AMPL 0.100 %  100.0  nV
LEVEL                V         BOTTOM   -100.00  dB     LVL  0.100 %  25.00  uV
FREQUENCY            Hz        # DIVS   0       LIN     THD  3.000 %  0.00007 %
PHASE                OFF                                IMD  3.000 %  0.00003 %
                             STEREO     LVF1   RDNG     FREQ 0.500 %  0.00020 Hz
BP/BR FREQ 1.00000 kHz       GRAPH TOP  -33.98   dB     W+F  5.000 %  0.00020 %
DETECTOR   AUTO      RMS       BOTTOM   -100.00  dB     DCV  0.200 %  500.0  uV
BANDWIDTH  22Hz   22kHz        # DIVS   0       LIN     OHMS 0.500 %  100.0  mΩ
FILTER     "A"WTG                                       D-IN 0.000 %  1.000  LSB
                             SOURCE-1   GEN1   NONE     PHASE         0.50   DEG
CHANNEL-A  INPUT    100kΩ      START           OFF
  RANGE              AUTO      STOP            OFF      SETTLING   EXPONENTIAL
                               # DIVS   0       LOG       DATA     3     SAMPLES
CHANNEL-B  INPUT    100kΩ                                 DELAY    30.00  msec
  RANGE              AUTO    # STEPS    0                 TIMEOUT  4.00    sec
                               TABLE    OFF
REFS Freq  1.00000 kHz                                  EXT SOURCE 3     SAMPLES
     dBr   2.079     V       DISPLAY    MONO-GRAPH        MIN LVL  10.00  mV
     dBm/W 600.0     Ω

                                      To change setting, use digit keys.
BP/BR Frequency                       To return to menu, press the Esc key.
```

Figure 53 Setup Panels, Dynamic Range Test

```
T30102DY   30 APR 87   08:25:58
NONE(OFF)        THD+N(dB)       THD+N(dB)
     OFF      -33.50    dB    -33.22    dB
```

Figure 54 Dynamic Range Test of Unit A, Tabular Display Resulting from "GEN NONE" Test.

weighted noise measurements. This test is stored as DYN-RANGE.TST. Results of a measurement on Unit A, using the -60 dB 1 kHz track 30 of the Technics disc, are shown in Figure 54. This measurement must then be corrected by adding 60 dB, resulting in dynamic range measurements of 93.5 dB left channel and 93.2 dB right channel.

QUANTIZATION NOISE

Quantization noise measurement in a digital system differs fundamentally from noise measurement on a quiet (infinity zero) track. On a quiet track, the D-to-A converter is not being exercised. Any noise that might result from its conversions is thus not being generated. A maximum-amplitude (zero dB) signal track must be played to properly measure quantization noise. To remove the fundamental component of this signal, THD+N function is selected. In order to prevent actual harmonic distortion products from also obscuring the quantization noise measurement, all low-to-moderate order harmonics are also removed with a high-pass filter. A zero dB level track with a low frequency signal, preferably 20 Hz, must be selected, such as track 2 on the Sony disc, 8 on the JAS disc, 4 on the Technics disc, track 6 index 3 on the CBS or EIAJ discs (17 Hz), or 26 (L) or 27 (R) on the Denon disc.

Figure 55 shows the panel setup. The 400 Hz high-pass filter attenuates low and moderate order harmonics of the 20 Hz signal; any signals below 200 Hz will be attenuated by 20 dB or more. Quantization noise across the audio spectrum above 400 Hz will be measured. A GEN NONE selection at SOURCE-1 provides a single spot measurement on each channel, as shown in Figure 56 for Unit A. This test is stored as QNTZNOIS.TST on the diskette.

```
LVF1                        LOCAL
MEASURE      A THD+N
READING                  dBr
LEVEL                    V
FREQUENCY                Hz
PHASE                    OFF

BP/BR FREQ               AUTO
DETECTOR     AUTO        RMS
BANDWIDTH    400Hz  22kHz
FILTER       OFF

CHANNEL-A    INPUT      100kΩ
  RANGE                  AUTO

CHANNEL-B    INPUT      100kΩ
  RANGE                  AUTO

REFS Freq    1.00000 kHz
     dBr     2.015     V
     dBm/W   600.0     Ω
```

```
SWEEP TEST DEFINITIONS
  (press F9 to sweep)
DATA-1       LVF1     RDNG
GRAPH TOP    -80.00   dBr
  BOTTOM     -95.00   dBr
  # DIVS     15       LIN

STEREO       LVF1     RDNG
GRAPH TOP    -80.00   dBr
  BOTTOM     -95.00   dBr
  # DIVS     15       LIN

SOURCE-1     GEN1     NONE
  START               OFF
  STOP                OFF
  # DIVS     0        LOG

# STEPS      0
  TABLE      OFF

DISPLAY      MONO-GRAPH
```

```
SWEEP SETTLING
     TOLERANCE   RESOLUTION
AMPL 1.000 %     100.0   mV
LVL  1.000 %     25.00   uV
THD  3.000 %     0.00007 %
IMD  3.000 %     0.00003 %
FREQ 0.500 %     0.00020 Hz
W+F  5.000 %     0.00020 %
DCV  0.200 %     500.0   uV
OHMS 0.500 %     100.0   mΩ
D-IN 0.000 %     1.000   LSB
PHASE            0.50    DEG

SETTLING     EXPONENTIAL
  DATA       3        SAMPLES
  DELAY      30.00    msec
  TIMEOUT    4.00     sec

EXT SOURCE 3          SAMPLES
  MIN LVL    10.00    mV
```

```
<10Hz 22Hz 100Hz 400Hz                    To change setting, use SPACE bar.
High Pass Filter                          To return to menu, press the Esc key.
```

Figure 55 Setup Panels, Quantization Noise Test.

```
QNTZNOIS  20 MAY 87  11:31:40
NONE(OFF)      THD+N(dBr)       THD+N(dBr)
     OFF    -92.31   dBr    -92.28   dBr
```

Figure 56 Quantization Noise Test, Unit A, Using 20 Hz Tone from technics Disc, "GEN NONE" Test.

INTERMODULATION DISTORTION

System One can measure most of the intermodulation distortion test signals on the discs discussed. With IMD signals of fixed frequency and amplitude, a "spot" measurement of both channels is appropriate. This provides an integrated measurement of all imd products within System One's analysis bandwidth. This is most easily accomplished by selecting GEN NONE at SOURCE-1, even though the generator will not be used. GEN NONE automatically uses the DISPLAY TABLE format even though MONO-GRAPH or COLOR-GRAPH may be selected, and produces a single point measurement on one or both channels.

SMPTE/DIN/IEC IMD Measurements

Figure 57 shows the panel setups for measuring a SMPTE-like or DIN-like pair of signals with one low-frequency tone (40 Hz to 500 Hz) and one high-frequency tone (2.5 kHz or higher), with the amplitude ratio of the signals anywhere below 5:1 (low-frequency amplitude to high-frequency amplitude). Example tracks include 46 on the JAS disc, 25 and 26 on the Sony disc, track 13 index 1 on the CBS and EIAJ discs, 16 and 17 on the Philips disc, 42 and 43 on the Technics disc, and 40-42 on the Denon disc.. Figure 58 is an example of the measurement made on Unit A with track 43 of the Technics test CD. This setup is stored as SMPTSPOT.TST on the diskette. The Philips tracks are separately recorded on left and right channel, so the test must be changed to single channel and separate tests made for each channel.

```
LVF1 ─────────── LOCAL   SWEEP TEST DEFINITIONS     SWEEP SETTLING
                          (press F9 to sweep)
MEASURE   A SMPTE        DATA-1     LVF1   RDNG       TOLERANCE  RESOLUTION
READING           dB     GRAPH TOP  -80.00   dB     AMPL 1.000 %  100.0  mV
LEVEL             V        BOTTOM   -120.00  dB     LVL  1.000 %  25.00  uV
FREQUENCY         Hz       # DIVS   0       LIN     THD  3.000 %  0.00007 %
PHASE             OFF                               IMD  5.000 %  0.00003 %
                         STEREO     LVF1   RDNG     FREQ 0.500 %  0.00020 Hz
BP/BR FREQ        AUTO   GRAPH TOP  -80.00   dB     W+F  5.000 %  0.00020 %
DETECTOR  AUTO    RMS      BOTTOM   -120.00  dB     DCV  0.200 %  500.0  uV
BANDWIDTH 30Hz  700Hz      # DIVS   0       LIN     OHMS 0.500 %  100.0  mΩ
FILTER    OFF                                       D-IN 0.000 %  1.000  LSB
                         SOURCE-1   GEN1   NONE     PHASE         0.50   DEG
CHANNEL-A INPUT ' 100kΩ    START            OFF
  RANGE           AUTO     STOP             OFF     SETTLING    EXPONENTIAL
                           # DIVS   0       LOG       DATA      2   SAMPLES
CHANNEL-B INPUT   100kΩ                               DELAY     30.00  msec
  RANGE           AUTO   # STEPS    0                 TIMEOUT   4.00   sec
                           TABLE    OFF
REFS Freq 1.00000 kHz                               EXT SOURCE 3    SAMPLES
     dBr  387.3   mV     DISPLAY    MONO-GRAPH        MIN LVL   10.00  mV
     dBm/W 600.0  Ω

FREQ AMPL TB-ON TB-INT TB-LVL NONE        To change setting, use SPACE bar.
Sweep stimulus                            To return to menu, press the Esc key.
```

Figure 57 Setup Panels, "Spot" Measurement of SMPTE or DIN Intermodulation Distortion.

```
T43102WB   02 MAY 87   13:58:47
NONE(OFF)        SMPTE(dB)      SMPTE(dB)
    OFF     -86.83    dB    -85.21    dB
```

Figure 58 "Spot" (Integrated) SMPTE IMD Measurement of Unit Using 400 Hz--7 kHz Track of Technics Disc.

Spectral Analysis of Intermodulation Products

More information on IMD is available by doing a spectral analysis of the signal following the amplitude modulation detector which is part of the SMPTE analysis mode. Normal SMPTE analysis mode integrates and measures all signals falling into the 30 Hz-700 Hz spectral range after AM detection. By selecting SOURCE-1 as an LVF1 BP/BR sweep across this range, the identity and amplitudes of individual IMD products may be measured. Figure 59 shows the panel setups for spectral analysis of SMPTE IMD.

Results

Figures 60 and 61 are measurements of Unit A playing tracks 42 and 43, respectively, of the Technics disc. Track 42 contains 50 Hz and 7 kHz signals in a 4:1 amplitude ratio; track 43 has 400 Hz and 7 kHz signals in the same ratio. The graphs show that the second order products (7 kHz +/- LF tone) are dominant. In Figure 60, the 50 Hz component measures about -89 and -88 dB on left and right

```
LVF1 ─────────── LOCAL   SWEEP TEST DEFINITIONS     SWEEP SETTLING
                          (press F9 to sweep)
MEASURE   A SMPTE        DATA-1     LVF1   RDNG       TOLERANCE  RESOLUTION
READING           dB     GRAPH TOP  -70.00   dB     AMPL 3.000 %  100.0  mV
LEVEL             V        BOTTOM   -120.00  dB     LVL  1.000 %  25.00  uV
FREQUENCY         Hz       # DIVS   0       LIN     THD  3.000 %  0.00007 %
PHASE             OFF                               IMD  5.000 %  0.00003 %
                         STEREO     LVF1   RDNG     FREQ 0.500 %  0.00020 Hz
BP/BR FREQ        AUTO   GRAPH TOP  -70.00   dB     W+F  5.000 %  0.00020 %
DETECTOR  AUTO    RMS      BOTTOM   -120.00  dB     DCV  0.200 %  500.0  uV
BANDWIDTH 30Hz  700Hz      # DIVS   0       LIN     OHMS 0.500 %  100.0  mΩ
FILTER    OFF                                       D-IN 0.000 %  1.000  LSB
                         SOURCE-1   LVF1   BPBR     PHASE         0.50   DEG
CHANNEL-A INPUT   100kΩ    START    1.00000 kHz
  RANGE           AUTO     STOP     30.0000 Hz      SETTLING    EXPONENTIAL
                           # DIVS   0       LOG       DATA      2   SAMPLES
CHANNEL-B INPUT   100kΩ                               DELAY     30.00  msec
  RANGE           AUTO   # STEPS    70                TIMEOUT   4.00   sec
                           TABLE    OFF
REFS Freq 1.00000 kHz                               EXT SOURCE 3    SAMPLES
     dBr  387.3   mV     DISPLAY    MONO-GRAPH        MIN LVL   10.00  mV
     dBm/W 600.0  Ω

GEN1 LVF1 SWI DCX EXTERN                  To change setting, use SPACE bar.
Sweep stimulus module                     To return to menu, press the Esc key.
```

Figure 59 Setup Panels, Spectral Analysis of SMPTE-like or DIN-like IMD Products.

channels with smaller third and fourth order products at 100 Hz and 150 Hz. In Figure 61, the 400 Hz component is about -87 dB on both channels. The source of the 200 Hz signal at -95 dB in Figure 55 is not known.

Figure 62 shows the spectral analysis in the SMPTE mode of Unit D with Technics track 42 (50 Hz and 7 kHz) playing. The second order products at 50 Hz are dominant, at -74 and -72 dB on the two channels. Several odd order products are also visible; third order at 100 Hz, 5th order at 200 Hz, and 7th order at 300 Hz. The 100 Hz product appears broadened due to the 120 Hz power supply hum in the unit.

Figure 63 (Technics track 42, 50 Hz and 7 kHz) and 64 (Technics track 43, 400 Hz and 7 kHz) are spectral analyses of Unit B, whose noise output spectrum was shown in Figure 17 earlier in this note. The -85 dB left channel product at 350 Hz in both figures is not due to IMD

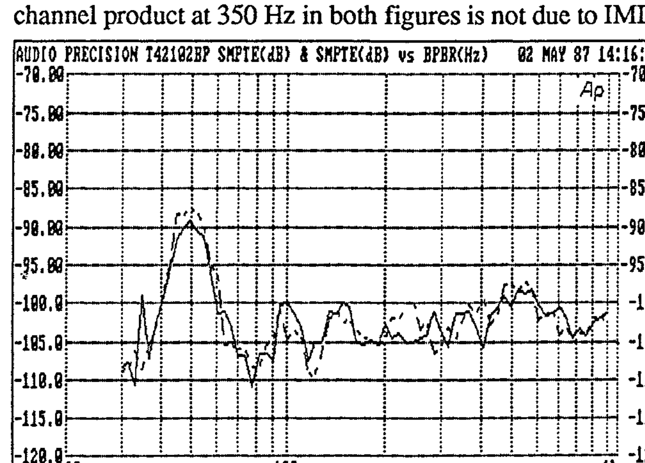


Figure 60 Spectral Analysis of Unit A IMD Products, 50 Hz--7 kHz Signal from Technics Disc.

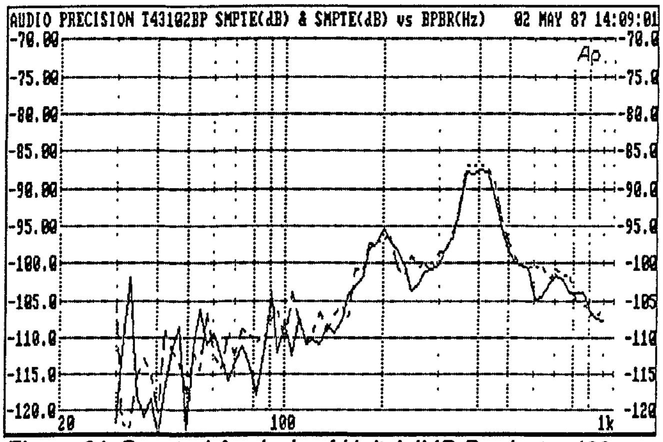


Figure 61 Spectral Analysis of Unit A IMD Products, 400 Hz--7 kHz Signal from Technics Disc.

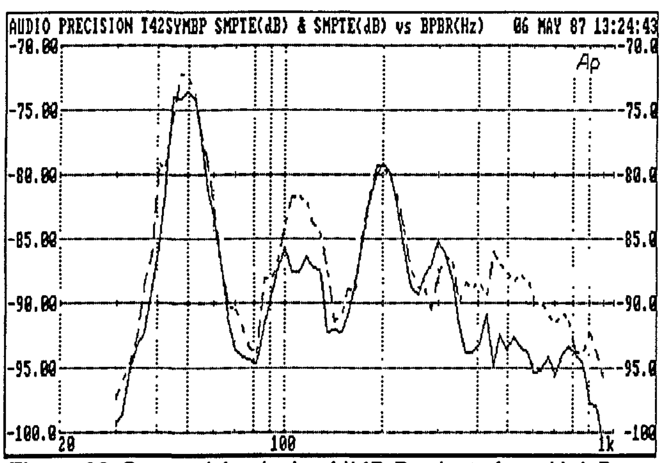


Figure 62 Spectral Analysis of IMD Products from Unit D, 50 Hz--7 kHz Signal from Technics Disc.

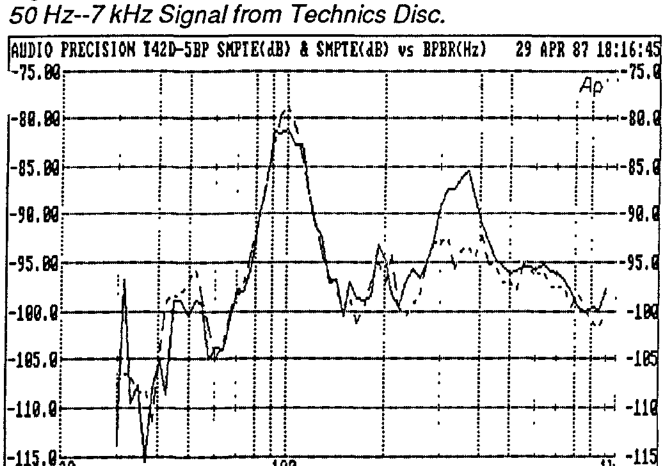


Figure 63 Spectral Analysis of IMD Products of Unit B, 50 Hz--7 kHz Signal from Technics Disc.

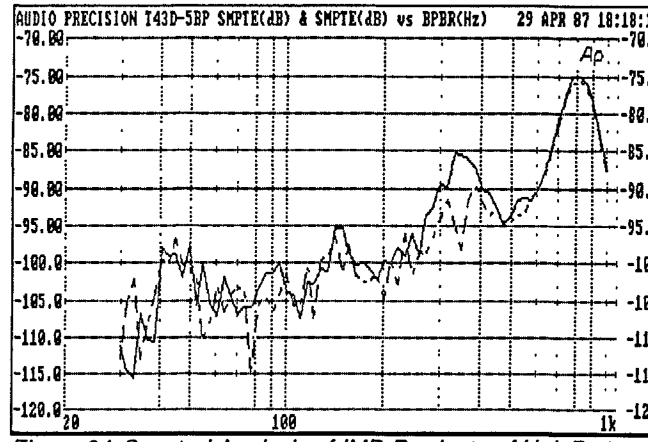


Figure 64 Spectral Analysis of IMD Products of Unit B, 400 Hz--7 kHz Signal from Technics Test Disc.

between the 7 kHz and LF tones on the test disc, but to a beat between the 7 kHz signal on the disc and the 7.35 kHz spurious output of this CD player. The actual IMD products at 100 Hz in Figure 57 and 800 Hz in Figure 58 (7 kHz +/- 2 * LF tone) show that third order products are dominant in this player. Note that the SMPTE mode analysis bandwidth of System One is specified as 30 Hz to 700 Hz at the -3 dB points. At the 800 Hz frequency of the third order product (400 Hz lower tone frequency), the analyzer is down about 4.9 dB. Correction of the measurement by this amount shows Unit B to have IMD about 10 dB higher with the 400 Hz/7 kHz combination than with the 50 Hz/7 kHz signal.

An integrated SMPTE IMD measurement of this player made with the test SMPTSPOT.TST shows results of -79 dB on both channels with the 50 Hz/7 kHz track, indicating that the left channel integrated result is influenced by the 7.35 kHz spurious product at -85 dB in addition to the actual third order IMD product of -81 dB.

CCIF IMD Measurements

Figure 65 is the panel setup for CCIF-type measurements with two equal amplitude, closely-spaced tones at a relatively high frequency. For System One to make accurate measurements, the spacing between the tones should be between 40 Hz and 1 kHz and the center frequency of the two-tone pair should be above 4 kHz. Example tracks include 43-45 on the Denon disc, 44 on the Technics, 27 and 28 on the Sony, 47 on the JAS, track 13 index 2 on the EIAJ and CBS discs, and 14-15 on the Philips.

```
-LVF1---------------LOCAL-  -SWEEP TEST DEFINITIONS-  -SWEEP SETTLING----------
                              (press F9 to sweep)
MEASURE     A CCIF          DATA-1      LVF1   RDNG     TOLERANCE   RESOLUTION
READING              %      GRAPH TOP   -40.00   dB   AMPL 1.000 %  100.0  mV
LEVEL                V        BOTTOM    -106.02  dB   LVL  1.000 %  25.00  uV
FREQUENCY            Hz       # DIVS    0       LIN   THD  3.000 %  0.00007 %
PHASE                OFF                              IMD  3.000 %  0.00003 %
                            STEREO      LVF1   RDNG   FREQ 0.500 %  0.00020 Hz
BP/BR FREQ           AUTO   GRAPH TOP   -40.00   dB   W+F  5.000 %  0.00020 %
DETECTOR    AUTO     RMS      BOTTOM    -106.02  dB   DCV  0.200 %  500.0  uV
BANDWIDTH                     # DIVS    0       LIN   OHMS 0.500 %  100.0  mΩ
FILTER      OFF                                       D-IN 0.000 %  1.000  LSB
                            SOURCE-1    GEN1   NONE   PHASE         0.50   DEG
CHANNEL-A   INPUT    100kΩ    START             OFF
  RANGE              AUTO     STOP              OFF   SETTLING   EXPONENTIAL
                              # DIVS    0       LOG     DATA     3      SAMPLES
CHANNEL-B   INPUT    100kΩ                              DELAY    30.00    msec
  RANGE              AUTO   # STEPS     0               TIMEOUT  4.00      sec
                              TABLE     OFF
REFS Freq   1.00000 kHz                               EXT SOURCE 3      SAMPLES
      dBr   387.3    mV     DISPLAY     MONO-GRAPH      MIN LVL  10.00   mV
      dBm/W 600.0    Ω
AMPLITUDE BANDPASS BANDREJECT THD+N SMPTE CCIF DIM W+F 2-CHANNEL CROSSTALK
Measurement mode                         To select another field, use arrow keys.
```

Figure 65 Setup Panels, CCIF IMD "Spot" Measurement

```
CCIFSPOT   30 APR 87   08:39:00
NONE(OFF)       CCIF(dB)      CCIF(dB)
     OFF    -105.48  dB    -102.78  dB
```

Figure 66 "Spot" CCIF-IMD Measurement, Unit A, 19 kHz--20 kHz Signal from Technics Test Disc.

Results

Figure 66 is an example of the test results from Unit A. This setup is stored as CCIFSPOT.TST on the diskette. Note that System One measures only the low-frequency (second-order) product when performing CCIF IMD tests.

CCIF "Sweeps"

The Philips disc again has separate L and R tracks and thus cannot be tested in stereo. Each track on the Philips disc consists of six sections., each 50 seconds in duration. Each section has a two-tone pair with 70 Hz spacing centered at 5 kHz, 10 kHz, and 15 kHz at 0 dB level, repeating at a -20 dB level. All six sections can be measured and stored in one test by doing an EXTERNal TIME "sweep", showing distortion versus time in chart recorder fashion. Figure 67 shows the panels, which are stored as the CCIF-TIME.TST setup on the diskette. Figure 68 is the graphic result of such a test on Unit A with the Philips disc. The portion from 0-50 seconds is thus from the 4965/5035 Hz tone pair; 50-100 seconds from the 9965/10035 Hz pair, and 100-150 Hz from 14965/15035 Hz tones. The same tone pattern, but at a 20 dB lower amplitude, repeats from 150 seconds to 300 seconds.

```
-LVF1---------------LOCAL-  -SWEEP TEST DEFINITIONS-  -SWEEP SETTLING----------
                              (press F9 to sweep)
MEASURE     A CCIF          DATA-1      LVF1   RDNG     TOLERANCE   RESOLUTION
READING              %      GRAPH TOP   -80.00   dB   AMPL 1.000 %  100.0  mV
LEVEL                V        BOTTOM    -110.00  dB   LVL  1.000 %  25.00  uV
FREQUENCY            Hz       # DIVS    0       LIN   THD  3.000 %  0.00007 %
PHASE                OFF                              IMD  3.000 %  0.00003 %
                            DATA-2      LVF1   NONE   FREQ 0.500 %  0.00020 Hz
BP/BR FREQ           AUTO   GRAPH TOP           OFF   W+F  5.000 %  0.00020 %
DETECTOR    4/sec    RMS      BOTTOM            OFF   DCV  0.200 %  500.0  uV
BANDWIDTH                     # DIVS            LOG   OHMS 0.500 %  100.0  mΩ
FILTER      OFF                                       D-IN 0.000 %  1.000  LSB
                            SOURCE-1    EXTERN TIME   PHASE         0.50   DEG
CHANNEL-A   INPUT    100kΩ    START     0.0     sec
  RANGE              AUTO     STOP      300.0   sec   SETTLING   OFF
                              # DIVS    0       LIN     DATA     3      SAMPLES
CHANNEL-B   INPUT    100kΩ                              DELAY    30.00    msec
  RANGE              AUTO   # STEPS     900             TIMEOUT  4.00      sec
                              TABLE     OFF
REFS Freq   1.00000 kHz                               EXT SOURCE 3      SAMPLES
      dBr   387.3    mV     DISPLAY     MONO-GRAPH      MIN LVL  10.00   mV
      dBm/W 600.0    Ω
EXPONENTIAL FLAT OFF                   To change setting, use SPACE bar.
Tolerance weighting for old samples    To return to menu, press the Esc key.
```

Figure 67 Setup Panels, CCIF IMD vs Time Test for Tracks 14 and 15 of Philips Disc.

Figure 69 is an overlay of the Unit A test (lower traces) with an identical test on Unit D (upper traces). It can be seen that the CCIF im distortion of Unit D increases with frequency, while Unit A decreases. Unit A, at -102 to -105 dB, is somewhat noise limited while the Unit B measurement is clearly distortion at -83 to -84 dB. The 20 dB amplitude decrease from 150 to 300 seconds drops Unit D out of its "high distortion" region into -85 to -90 dB readings. The same amplitude drop increases the measurements from Unit A since it was already partially noise-limited at the higher level.

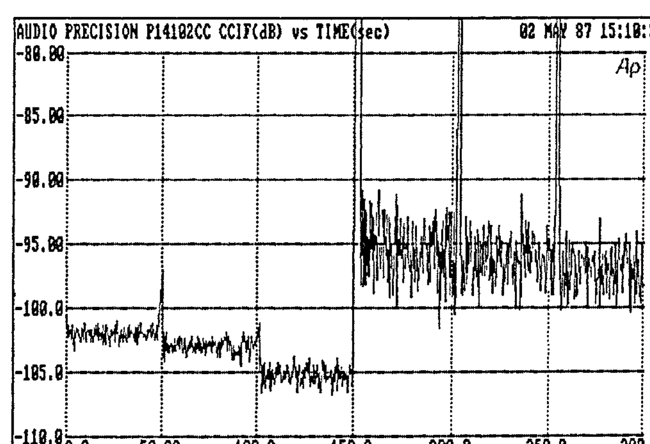


Figure 68 Unit A CCIF IMD vs Time as Philips Disc Sweeps 50 Seconds Each at 5 kHz--10 kHz--15 kHz Center Frequency. First Set of Signals at 0 dB, Second Set -20 dB

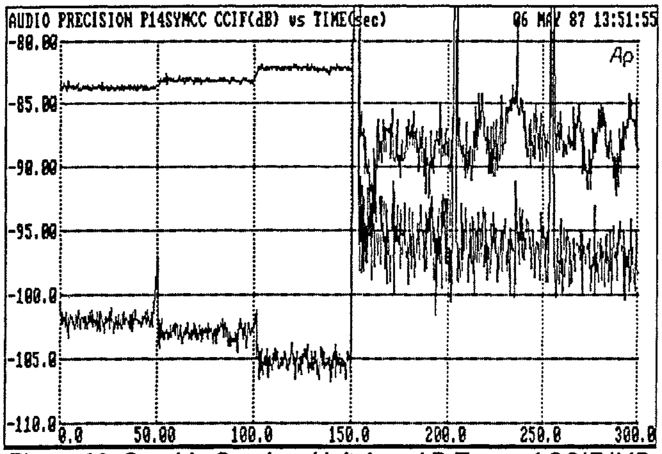


Figure 69 Graphic Overlay, Unit A and D Tests of CCIF IMD ; Time (Frequency) with Philips Disc.

PHASE MEASUREMENTS

Interchannel phase may be measured and displayed as DATA-1 or DATA-2. The phase measurement may give an indication of whether the player has a single D-to-A converter multiplexed between the channels or two separate converters, though a multiplexed player with time delay compensation will obscure that fact. If a single D-to-A converter without delay compensation is used, the amount of measured phase shift at 20 kHz can indicate whether the player is a single sampling (44.1 kHz clock), double oversampling (88.2 kHz clock), or quadruple oversampling (176.4 kHz clock) design. A 44.1 kHz multiplexed unit with no other significant sources of interchannel time or phase delay will show about 82 degrees phase shift at 20 kHz. This number derives from a delay of one-half clock period (11.338 microseconds at the 44.100 kHz clock fre-·iency). At the 50 microsecond period of a 20 kHz signal, ‿ystem One expresses the result as (11.338/50.000)*360 or 81.632 degrees.

An 88.2 kHz clocked converter may show about 41 degrees at 20 kHz (5.7 microseconds delay), and a 176.4 kHz unit about 20 degrees (2.8 microseconds). This delay between channels will cause loss of high frequency response if the two channels are summed for monaural reproduction, as happens often in broadcasting.

Setup

Figure 70 shows the SWEEP TEST DEFINITION and SWEEP SETTLING panels for the inter-channel phase

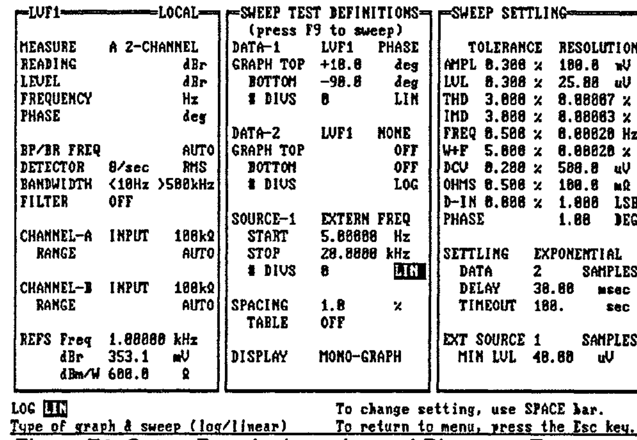


Figure 70 Setup Panels, Interchannel Phase vs Frequency Test.

measurement, assuming that an analog-sweep track will be used. Use of LIN rather than LOG display on the horizontal axis helps make obvious that the effect is a constant time delay (linear phase).

Testing

If LIN display is selected to actually run the test, it may appear that data is not being graphed even though the computer is beeping, since the LIN display with the log sweep on the disc compresses all the low-frequency measurements at the extreme left of the graph. It may thus be more confidence-inspiring to run the test in LOG mode, then to change to LIN and re-display the data via F7 for analysis.

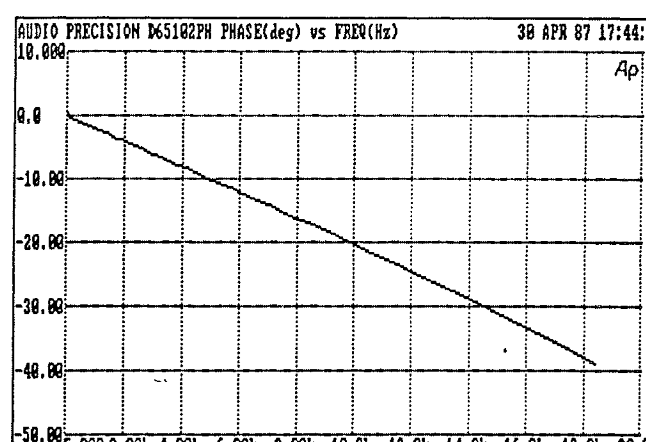


Figure 71 Interchannel Phase vs Frequency, Unit A (Double Oversampling).

Results

Figure 71 is a test graph made with track 65 of the Denon disc, displaying inter-channel phase of a double oversampling player (Unit A). This test setup and data is stored as PHASE.TST on the diskette. Figures 72 and 73, respectively, show the measured phase versus frequency for a single-sampling player (Unit B) and for a player with separate D-to-A converters for each channel plus delay compensation for the interleaved stereo data structure of a Compact Disc (Unit C). If desired, any of these tests may be further processed with the COMPUTE LINEARITY command to show departure from linear phase difference (constant time delay) as a function of frequency. On most players measured, the departure from linear phase difference is less than five degrees at high frequencies.

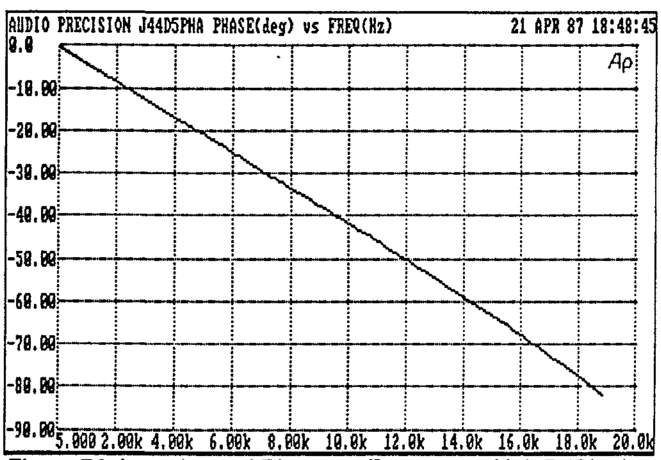


Figure 72 Interchannel Phase vs Frequency, Unit B (Single Sampling).

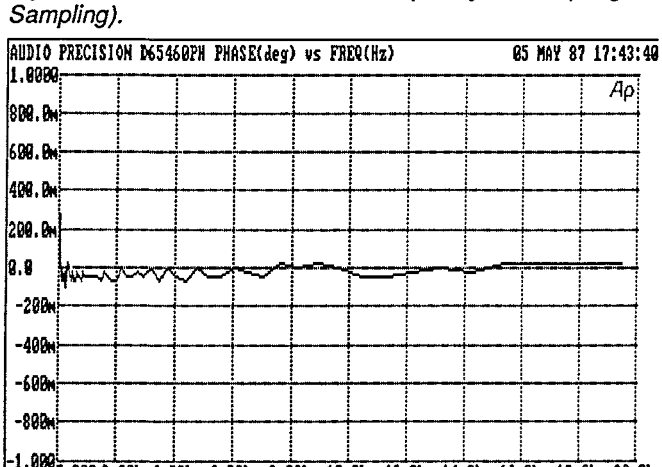


Figure 73 Interchannel Phase vs Frequency, Unit C (ual D-to-A Converters).

STEREO SEPARATION

Stereo separation can be measured on any track or series of tracks with test frequencies recorded at maximum level on only one channel. Examples are tracks 4 and 8 on the Philips disc, 34-41 on the Technics disc, tracks 2 and 3 index 1-5 on the EIAJ and CBS discs, and 29-36 on the Sony disc.

Setup

CROSSTALK function may be used with A-version hardware, or BANDPASS function and STEREO mode with either original or A-version hardware.

a. A-Version. Figure 74 shows the setup panels for separation tests with A-version hardware. The SOURCE-1 settings are nearly identical to all the other EXTERnal FREQuency sweeps across a series of fixed-frequency tracks described earlier, but SPACING has been reduced to 2% in order to capture the change from 19.001 kHz to 19.997 kHz which is the smallest step of tracks 4 and 8 on the Philips disc.

1. For the data measurements, select CROSSTALK function *and the channel (track) which does not have signal recorded.* For example, assuming that the CD player left channel is connected to System One's A input and right channel to the B input, select B CROSSTALK while playing tracks recorded on the left channel only. In CROSSTALK function, the READING meter in BANDPASS mode is connected to the selected channel, while the LEVEL meter and frequency counter are connected to the alternate channel. The frequency counter can thus steer the bandpass filter to the frequency of the recorded signal on the driven track, the LEVEL meter measures the amplitude of the driven track, and the READING meter measures the non-driven track with the bandpass filter selectivity discriminating against wideband noise.

2. Select an AMPLITUDE TOLERANCE on the SWEEP SETTLING panel such as 10% (1 dB) to provide rapid settling on the noisy signal on the non-driven channel.

3. BP/BR must be AUTO to permit the filter to be steered by the counter.

4. The dB unit can be selected at READING on the LVF1 panel and for display at DATA-1, to directly display

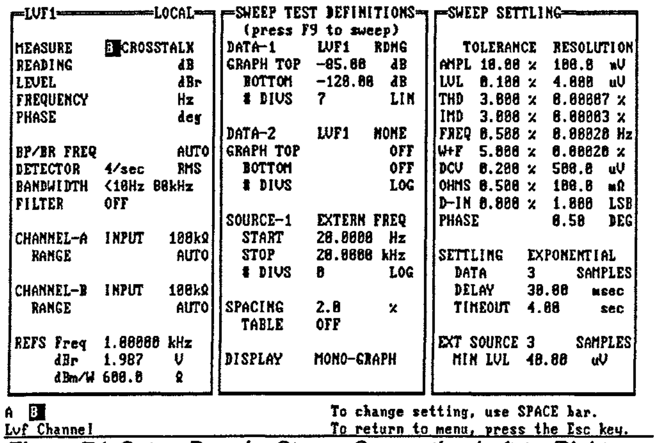


Figure 74 Setup Panels, Stereo Separation Left-to-Right, A-Version Hardware.

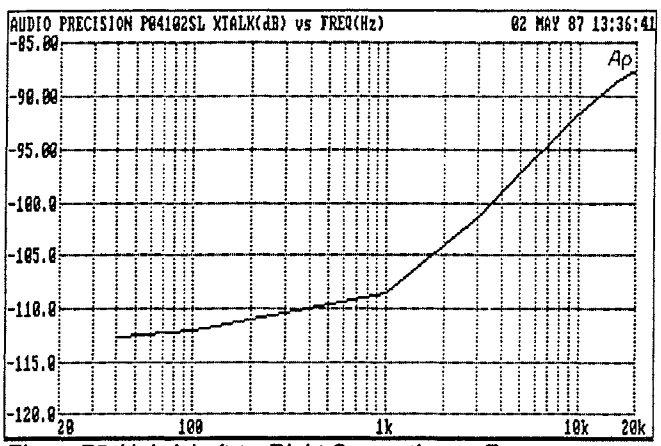


Figure 75 Unit A Left-to-Right Separation vs Frequency, A-version Hardware.

the difference in amplitude between the READING and LEVEL meters. Figure 75 is a graph of left-to-right separation of Unit A using the signals of track 4 of the Philips disc and the setup just described. SEP_L-RA.TST (SEParation Left-Right, A version hardware) on the companion diskette has the test setup and data shown.

5. To measure separation from right to left, change the channel selection at the top of the LVF1 panel from B to A. This test is stored as SEP_R-LA.TST.

b. Original or A-version. With either original or A-version hardware, separation can also be measured in BANDPASS function. Figure 76 shows the panel setup.

1. The channel selected at the top of the LVF1 panel must now be *the driven channel.*

2. RDNG must be selected at both DATA-1 and DATA-2, and DATA-2 must be changed to STEREO. With this

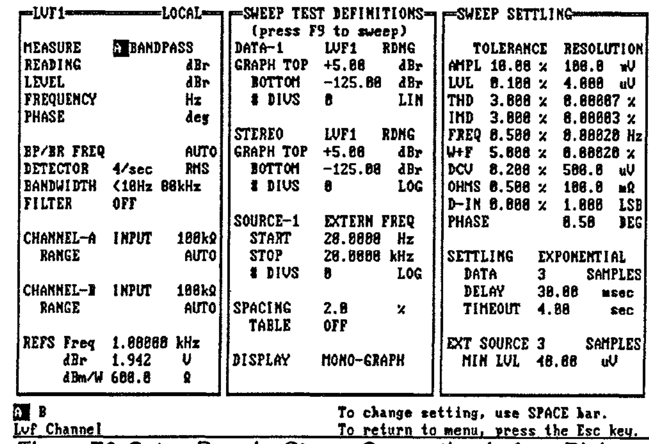


Figure 76 Setup Panels, Stereo Separation Left-to-Right, Original Hardware.

setup, System One will first measure frequency plus amplitude through the selectivity of the bandpass filter on the selected channel. The filter will be automatically tuned to the frequency measured by the counter. After this data settles, System One will then automatically switch to the alternate channel but will leave the bandpass filter frequency unchanged, and will measure settled data on the alternate channel. It then switches back to the selected channel and verifies that the frequency has not changed, "beeps" to signify that the pair of measurements is completed, and waits for the frequency (SOURCE-1) to change by more than the SPACING value.

3. The amplitude of the driven channel will be plotted as a solid line (green on a color monitor) and the non-driven channel will be plotted as a dashed line (yellow on a color monitor). Separation is the difference between the two lines. If dBr units are used and the dBr REF value was set at midband on the driven channel, the solid line will not deviate significantly from zero on most good quality CD players. The dashed (yellow) line thus closely represents separation.

Figure 77 is a sample graph, also of Unit A, made with original version hardware and the setup described. It is stored as SEP_L-RO.TST (SEParation Left-Right, Original hardware) on the diskette. An identical setup except for the channel selection is SEP_R-LO.TST. Figure 78 is an overlaid graph of the measurements of Unit B (top trace at 20 kHz), Unit D (second trace), Unit A (third trace), and Unit C (best separation at 20 kHz).

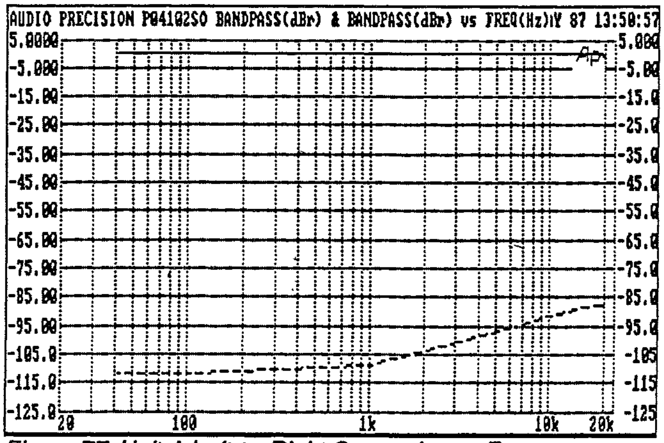


Figure 77 Unit A Left-to-Right Separation vs Frequency, Original Hardware

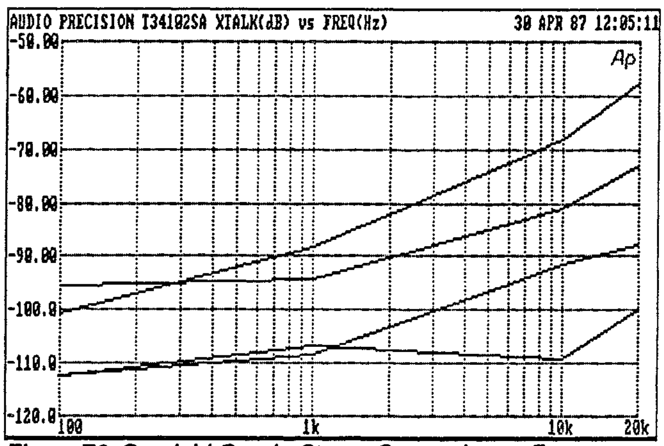


Figure 78 Overlaid Graph, Stereo Separation vs Frequency of Four CD Players. Top Line is Unit B, 2nd Line Unit D, 3rd Line Unit A, Bottom Line Unit C.

FREQUENCY ACCURACY

The measured frequency accuracy of most tracks, test discs, and CD players is quite high. However, either the Philips disc or its documentation is in error on one segment of track 4 where the frequency is specified as 6363 Hz but measures 6373 Hz.

The Technics disc provides one track (52) specifically for frequency accuracy measurement. This track contains a 20 kHz signal at +/- 2 Hz accuracy. Figure 79 shows the panel setup to measure the CD player frequency accuracy on this track, using System One's relative frequency measurement capability. This test is stored on the disc as FREQACUR.TST. The EIAJ and CBS discs both contain a track 10 with a precision 19997 Hz signal. The same test

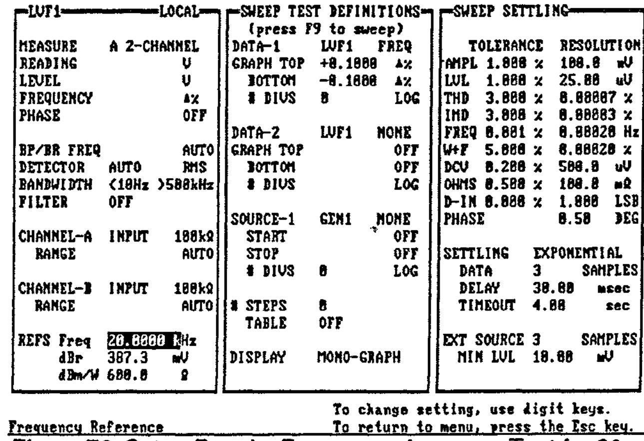


Figure 79 Setup Panels, Frequency Accuracy Test for 20 kHz Frequency Reference.

could be used with them by first changing the LVF1 Freq REF field to 19.997 kHz.

Setup

a. Enter 20 kHz (19.997 kHz for CBS and EIAJ discs) into the Freq REF field near the bottom of the LVF1 panel.

b. Select LVF1 FREQ at DATA-1, with delta % as the units. This expresses the measured frequency in terms of percentage deviation from the Freq REF value, rather than in absolute terms.

c. Select GEN NONE at SOURCE-1 for a single point measurement with automatic tabular display.

d. Enter a tight TOLERANCE such as 0.001% for FREQuency on the SWEEP SETTLING panel.

Testing

Play track 52 on the Technics disc and press F9. Figure 80 is the result of this test on Unit D. The accuracy of the internal crystal oscillator of the CD player is the variable in this test. It is understood that some low-cost players have used resistor-capacitor oscillators instead of crystals.

```
T52SYMFR  06 MAY 87  13:35:09
NONE(OFF)     FREQ(Δ%)
     OFF     +0.0070  Δ%
```

Figure 80 Frequency Accuracy, Unit D.

WOW AND FLUTTER TESTS

The fundamental physical mechanisms which produce wow and flutter in analog tape machines and turntables do not exist in CD players. Even if there were instantaneous short-term variations in the speed of the disc rotation, they would not translate into pitch (frequency) changes since data is actually clocked into the D-to A converter(s) at a quartz-crystal-based rate. However, the EIAJ has detailed a test procedure for wow and flutter. The EIAJ and CBS test discs have a track especially for this test (track 14 on EIAJ and track 15 on CBS), and some other discs have tracks with either a 3 kHz or 3.15 kHz signal compatible with many flutter meters.

Figure 81 shows the setup panels for WOW&FLUT.TST on the companion diskette which will make the measurement as specified by the EIAJ standard. The standard in turn refers to the IEC 386 standard (peak detector, weighted). WOW&FLUT.TST is a time chart recording for 20 seconds. The EIAJ specifies measurements to be made for at least 5 but not more than 30 seconds. Note that the long time constant required of a wow and flutter detector will produce a decaying transient at the beginning of most wow and flutter tests. It is thus normally desirable to set the time chart axis to not begin until perhaps five seconds after the beginning of the test so that this transient can die away. Figure 82 is a graph of such a measurement made with this test. A graph below the System One guaranteed residual of 0.001% is typical for high quality players, unless an isolated noise impulse causes a spike. The EIAJ specifies that spikes occurring less than twice in ten seconds should be ignored. At least one player reportedly

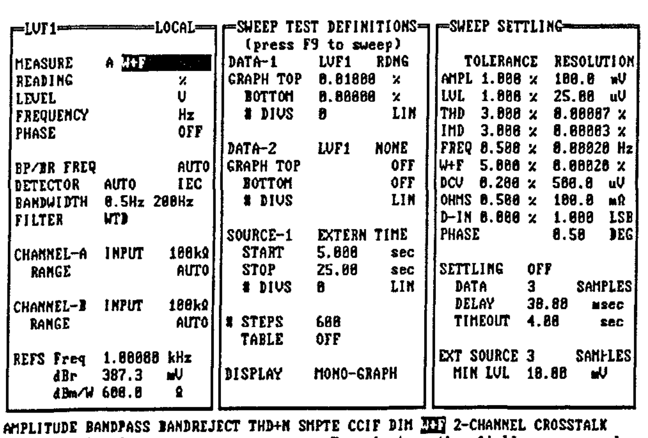


Figure 81 Setup Panels, Wow and Flutter Test.

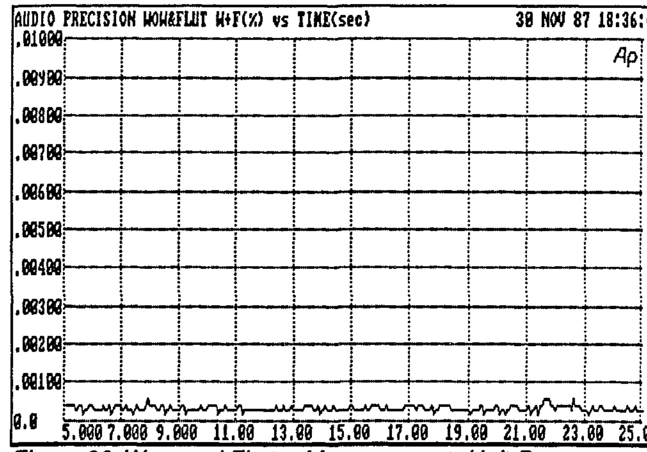


Figure 82 Wow and Flutter Measurement, Unit B

has an RC clock oscillator instead of a crystal, with resulting wow and flutter of about 0.002%. An alternate to manual interpretation of the graph is use of the COMPUTE 2-SIGMA function. COMPUTE 2-SIGMA will replace the measured data with the value which was exceeded for not more than 5% of the time.

SPECIAL PROBLEMS

Occasionally compact disc players are found with defects which require special measurement techniques in order to obtain data.

Excessive Inter-Track Noise

As noted earlier, some CD players have noise output while seeking between tracks that is larger than their signal output on low amplitude tracks such as -80 and -90 dB. This condition makes it more difficult for System One to perform linearity and THD+N versus amplitude tests, since the system may interpret the inter-track noise as a legitimate low-amplitude signal. One solution described earlier is to increase the SETTLING DELAY beyond the time required for the player to seek from track to track. System One software will then discard data during that interval, and will then capture and plot properly the measurement from the next track.

A disadvantage of this approach is overall measurement speed. SETTLING DELAY is invoked at every measurement, on both stereo channels. If (for example) the CD player is relatively slow in track seeking and requires a 5 second SETTLING DELAY to function properly in a linearity test, the cumulative effect will be 130 seconds of delay while testing both channels of a player across 13 amplitude levels. An alternate technique which may be faster is use of the F10 (pause) key. F10 is a toggle key; pressing it causes data acquisition to pause, and pressing it again causes data acquisition to commence. The player may be started on the first of the decreasing-level tracks and F9 pressed to begin the test. As soon as the computer beeps, press F10 and advance the player to the next track or index point. As soon as the signal from the player stabilizes, press F10 again to take data. When the computer beeps, press F10, advance the player, and so forth.

Excessive Clock Signal Leakage

Several CD players have been measured with a rather high level of leakage at the double oversampled clock frequency of -88.2 kHz. In at least two cases, this signal (at the audio output connectors) was only 60 dB below full output. In EXTERNal LEVEL tests such as linearity and THD+N vs amplitude, the LEVEL voltmeter sees this signal since the LEVEL voltmeter bandwidth is greater than 500 kHz. The LEVEL voltmeter will thus be unable to drive the test as the recorded amplitudes go below the -60 level, making it impossible to test linearity and quantization distortion at the lower amplitudes.

With version 1.60 and later software, the <Ctrl>F9 capability can solve this problem. <Ctrl>F9 appends new data to the data already in memory, rather than erasing previous data as F9 does. When the problem is encountered, change the SOURCE-1 selection from EXTERNal LEVEL to GEN NONE. Select the first track of the decreasing-amplitude series to be measured and press F9. Data will be taken and tabularly displayed, since GEN NONE automatically selects this display mode. Advance the player to the next track or index point and press <Ctrl>F9 when the player output stabilizes. Continue to advance through the tracks or indices, pressing <Ctrl>F9 after the signal appears.

At the end of the series of tracks, press <Esc> Edit Data. You should see a display similar to Figure 83. The first column (SOURCE-1) is meaningless, but will be replaced with the theoretical disc amplitudes supplied by the test disc manufacturer when REPL-xxx.PRO is run. The second and third columns (DATA-1 and DATA-2) will consist of good data, interspersed with rows of the value -1.000000e+32. This value signifies to System One that, during a re-graphing operation, it should move to the following point but should not draw a vector between the points. These -1.0000000e+32 rows must be edited out of the data or no graphing at all can take place. They are easily deleted by using the arrow keys to move the editor cursor to the first character in the row to be deleted, pressing F6, moving the cursor down one row, and pressing F6 again. Following the deletion of all these rows, the display should look similar to Figure 84. You can now press <Esc>, go to the panel, and change SOURCE-1 back to EXTERNal LEVEL. Then, move to the menu and load and run the appropriate REPL-xxx.PRO which will substitute the disc manufacturer's known amplitude data for the SOURCE-1 column.

```
---|----1----|‖--2----|----3----|----4----|----5----|----6----|--‖-7----|----8
            OFF                  dBr                   dBr
           1000,                  0.,          -0.337067586
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -1.00279002,           -1.33839192
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -3.00520925,           -3.34184354
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -5.99917654,           -6.33539751
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -9.99465557,           -10.3319631
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,          -20.007931,           -20.3415527
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -30.0070067,           -30.3331122
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -39.9940131,           -40.3230814
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -49.9594052,           -50.2913161
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
           1000,         -59.8072746,           -60.1618125
 -1.00000003e+32,    -1.00000003e+32,       -1.00000003e+32
---|----1----|‖--2----|----3----|----4----|----5----|----6----|--‖-7----|----8
INSERT MODE — press INSERT for Overtype mode.               Esc = return to menu.
F6 = Block Delete to buffer.                           F5 = copy from Delete Buffer.
```

Figure 83 Edit Data Display After a Series of <Ctrl>F9 Operations

```
---|----1----|‖--2----|----3----|----4----|----5----|----6----|--‖-7----|----8
            OFF                  dBr                   dBr
           1000,                  0.,          -0.337067586
           1000,         -1.00279002,           -1.33839192
           1000,         -3.00520925,           -3.34184354
           1000,         -5.99917654,           -6.33539751
           1000,         -9.99465557,           -10.3319631
           1000,          -20.007931,           -20.3415527
           1000,         -30.0070067,           -30.3331122
           1000,         -39.9940131,           -40.3230814
           1000,         -49.9594052,           -50.2913161
           1000,         -59.8072746,           -60.1618125
           1000,         -69.7498234,           -70.1550985
           1000,         -78.8761609,           -79.5087554
           1000,         -85.7038338,           -86.5687581
---|----1----|‖--2----|----3----|----4----|----5----|----6----|--‖-7----|----8
INSERT MODE — press INSERT for Overtype mode.               Esc = return to menu.
F6 = Block Delete to buffer.                           F5 = copy from Delete Buffer.
```

Figure 84 Data Editor After Deleting Undesired Rows