DMSI
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2006 April 30

To: Kevin Semcken, CEO
Able Planet Inc.

From: D. Michael Shields, Principal
DMSI Consulting

Re: Able Planet LINX Technology in connection with Solitude ANR headset

EXECUTIVE SUMMARY

The attached data and analysis are intended to establish objectively measurable effects due to the application of LINX technology in connection with the receiver transducers of noise-canceling headphones. The data and analysis are largely confined to measurement of electrical modification of the signal although some acoustic measurements are presented for contextual clarity.

While this report does not necessarily establish the existence or extent of collateral psychoacoustic effects, some attempt is made to explain why these may occur. At the time of this report there is extensive testimonial evidence that they do occur and that they are highly effective with respect to improved intelligibility.

BACKGROUND

The LINX technology as applied to headphone speakers consists of placing a specially designed passive device in series with the speaker. On the face of it, this seems too simple to produce the striking improvements, which have been widely reported.

The selection and specification of this device is not arbitrary however. While the invention was originally empirically discovered and optimized, it is nevertheless susceptible to objective quantitative characterization.

The effects of the LINX technology were measured in connection with Solitude stereo noise-canceling headphones. Acoustic measurements will show a slight roll off at high frequencies in accordance with the predicted response.

A small increase in the noise level when the LINX technology is applied. This is not due to thermal noise but rather to an effect, which will be discussed below.

In addition to frequency response and noise level, there is a third identifiable effect, which is the creation of harmonic energy (distortion) at high signal levels. This is likely the dominant effect where the resulting harmonic energy increases the spectral density at high frequencies. Because this redistributed energy is by definition coherent with the stimulus, it is likely to improve intelligibility or the impression of clarity.

PRELIMINARY QUALIFICATION

In the testing of transducers and related systems, it is necessary to qualify the basic parameters in order to design the test procedure. In this instance the first items, which must be determined, are the impedance characteristics and operating voltage level of the speaker.

The test setups are shown on Page 8.

The flat-plate coupler used for the acoustic measurements is not an exact fit to the speakers but considerable care was taken to establish the repeatability of the data.

The impedance of the retrofitted unit (not shown) indicates the expected rise with frequency. The slight rise in impedance is above the operating region of the ANR loop and does not affect its operation.

- The complete electroacoustic transfer of the standard unit from the external input (including the amplifier & ANR function) is shown on Page 9 for both channels.
- Page 10 shows the response of a second sample.

One purpose in showing this data is to illustrate why the following presentations will be confined to the electrical measurements. The (comparatively) gross defects in the electroacoustic response are likely to mask what we are trying to see in terms of what the LINX device does to the electrical signal. Also, the acoustic noise level in the laboratory does not permit reliable observation of low-level acoustic phenomena.

In both response curves, the mid-band response of the speaker alone is about 20dB above 94dB SPL/V, or about 114 dB SPL/V. The subsequent tests are conducted at input levels of 200 and 630 mV rms corresponding to nominal SPL of 100 dB and 110 dB.

HARMONIC DISTORTION

The production of harmonic energy may well be the primary mechanism, which underlies the subjective effectiveness of the LINX technology.

The harmonic energy is produced as a function of the onset of core saturation in the LINX device. Therefore the optimization of the device depends on the operating level (i.e. sensitivity) of the speaker and the SPL requirements of the listener.

In the following showings, measurements were made exclusively at 1 kHz. As far as LINX device performance is concerned, there is no appreciable variation in the saturation characteristic as a function of frequency over the range of frequencies involved.

Referring to the first test setup drawing, P.8, it will be seen in the 1kHz Distortion Setup that there is a 1 kHz trap introduced at the input to the FFT analyzer. This trap reduces the fundamental (1kHz) tone by a little more than 30dB so that the dynamic range of the analyzer is not wasted accommodating it. This technique extends the useful dynamic range of the measurement to about 110dB.

It is also important to note the presence of the attenuator following the power amplifier in the test setup. The purpose of this attenuator is twofold: first, it reduces the signal to a convenient level while also reducing the noise of the amplifier; and second, it presents a source impedance of only 3 Ohms. This prevents any interaction between the source impedance and the impedances of the LINX device and the speaker.

Assuming the reference level of 200 mV will correspond to the peak level of average music, it seems prudent to look 10dB higher as well to see what the effects will be on the maximum peak levels. Harmonic data will be presented at both 0dB ref and +10dB ref with and without the LINX device.

- Voice-coil harmonics with and without LINX at 200mV is shown on Page 11
- Voice-coil harmonics with and without LINX at 630mV is shown on Page 12
- The response of the 1 kHz measurement filter is shown on Page 13

The response of the 1 kHz trap in the harmonic distortion setup referred to earlier shows that the trap has no influence on the amplitude of the harmonics, only the 1 kHz fundamental tone.

The harmonic distortion, which is evident, shows that it is due to symmetrical light saturation of the LINX device. The absence of DC makes this so. If DC is present the saturation will become asymmetrical and even order harmonics will appear. In the AC coupled case, only odd harmonics will be generated.

It is important to understand that the word "distortion" in this application does not necessarily have a negative connotation. The increased high-frequency spectral density, which results, is thought to improve intelligibility.

The magnitude of this effect can be seen in the spectrum plots. At 200 mV drive, the 3rd harmonic increases by about 10dB and the 5th harmonic appears. The harmonics in the "no LINX" plots are generator residuals. It is the increment we are interested in. At 630 mV drive the 3rd harmonic increases by 15 dB and components appear at the 5th and 7th harmonics with significant amplitude. An important aspect is that the effect is smoothly monotonic with signal level and is not analogous to amplifier distortion.

It is also important to note that an enriched harmonic content, which is progressive with signal level, increases the perception of "loudness". This helps the user to achieve sufficient subjective loudness without having to resort to excessive SPL.

MAGNETOSTRICTION

Earlier work with the LINX technology has concerned itself with the magnetostrictive attributes of the core material used in the LINX device. Magnetostriction in the core will produce an acoustic output from the device when current passes through it. The measurement procedures in this report do not evaluate the magnitude of this effect or its acoustic or structural coupling. It is at least worth noting that any such effect will be synchronous with the signal and therefore may contribute to the intelligibility as has been reported.

BARKHAUSEN NOISE AND STOCHASTIC RESONANCE

As mentioned earlier, there is a small increase in noise with the application of the LINX device. It cannot be attributed to thermal noise. Thermal noise due to the LINX device can only arise in the real part of the impedance, which is the resistance of about 2 Ohms. The Johnson noise is proportional to the square root of the resistance and given that the voice-coil resistance of the speaker is typically >30 Ohms, the incremental thermal noise due to the LINX device will be negligible.

There is another noise mechanism, which is possible. It is called *Barkhausen* noise and it is characteristic of magnetically permeable steel. When a magnetic material is driven through its hysteresis curve by a magnetizing force (H), the magnetic flux density (B) does not vary smoothly with the magnetizing force. Instead it varies in small jumps. Since each jump is a transient phenomenon, there is a noise spectrum associated with it. Observation of this effect is widely used in the steel milling industry to evaluate processing of the steel. In this context fairly high values of B and H are used.

In the context of the LINX device, the values are smaller, but the effect nevertheless exists. It occurs to some degree in all magnetic components. The task is to devise a way of detecting the Barkhausen noise in order to estimate its magnitude.

Referring to Page 14, the test setup shows a low-frequency generator being used to drive a low-frequency current through the winding thus exciting the core. As the flux jumps occur a voltage will be induced in the winding, which will cause a noise current to flow. By measuring the voltage across a fixed resistance in series with the winding, while simultaneously rejecting the excitation (low-frequency) current it is possible to observe the effect.

The low-pass filter after the generator removes any harmonic distortion products from the generator. The high-pass filter ahead of the analyzer ensures that the low-frequency signal will not overload the analyzer. The spectrum is then measured with and without the low-frequency excitation.

On Page 15 , the LINX device is replaced with a wire. The spectra with and without the low-frequency signal are identical. This verifies that there are no noise artifacts due to the excitation in the test setup.

On Page 16, the LINX device is present. The low-frequency excitation is set to 20 Hz. The increase in the noise from 3kHz to 10 kHz can be clearly seen.

On Page 17, the LINX device is present. The low frequency excitation is set to 40 Hz. Again, the noise increase is clear, but it is greater. This is because there are twice as many flux jumps per unit time because of the doubling of the excitation frequency. The increase in the noise floor is significantly large at about 10 dB. This represents a 1000% increase in the noise power.

When the desired signal itself is the source of excitation, it becomes very difficult to analytically separate the noise from the cause of the noise. The noise still occurs, but it is difficult to make a clear presentation. An important aspect of the noise is that it is caused by, and is therefore temporally coherent with the signal.

The noise, which is added to the signal by this mechanism, may play a role in the improvement of hearing threshold through an effect known as *stochastic resonance*.

Stochastic resonance is a general physical phenomenon, which can be observed and demonstrated, in a variety of physical systems. It is demonstrable in a counterintuitive way, namely that adding noise to a system may actually improve the signal-to-noise ratio. This occurs when a system, in this case hearing, receives a signal, which is just below what is required to excite it. By adding a small amount of noise (often astonishingly small) the system responds to the signal which was previously unable to elicit a response.

The role of stochastic resonance in human hearing, impaired or otherwise, is beyond the scope of this report. The availability of Barkhausen noise as a possible source of excitation is established in the foregoing data.

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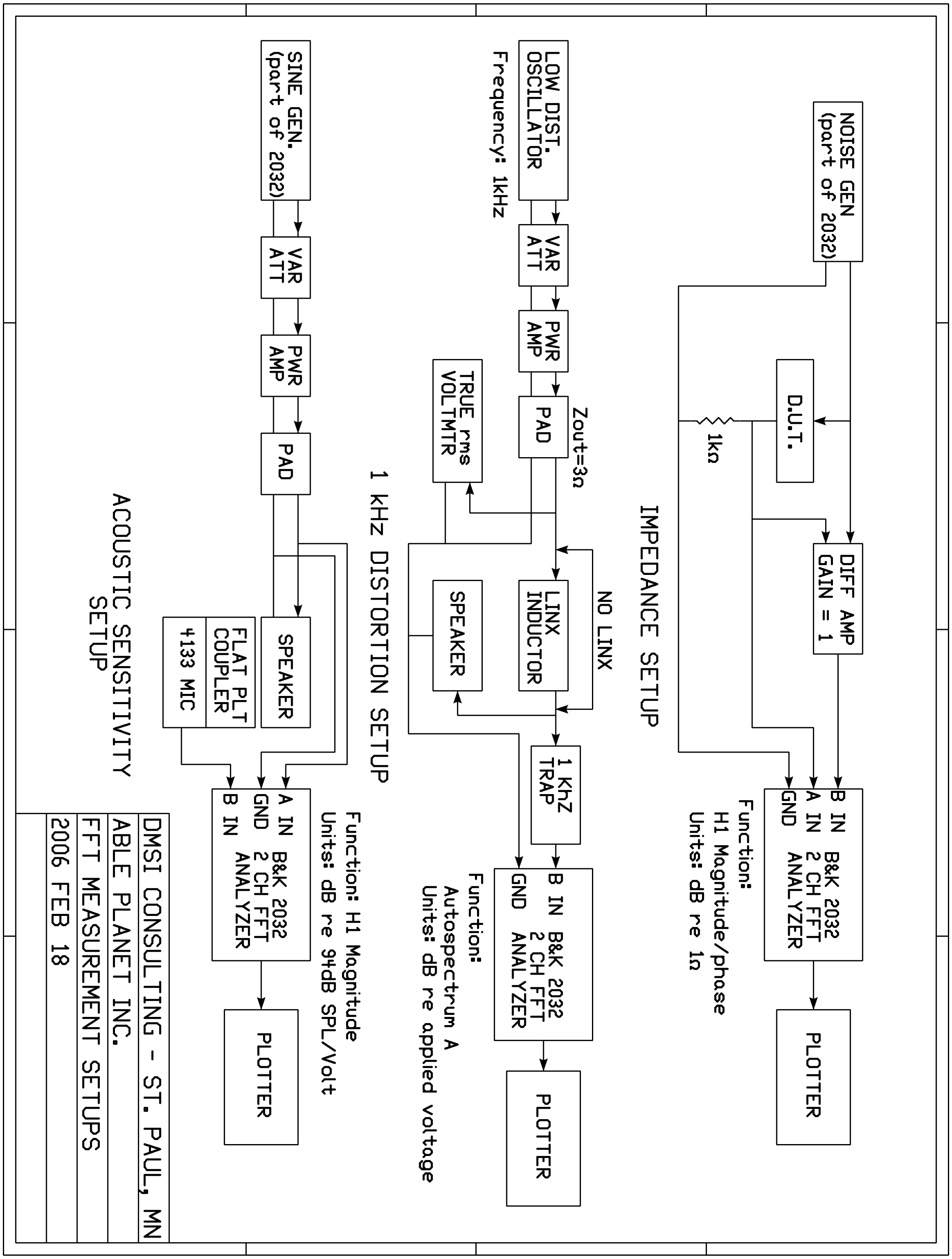
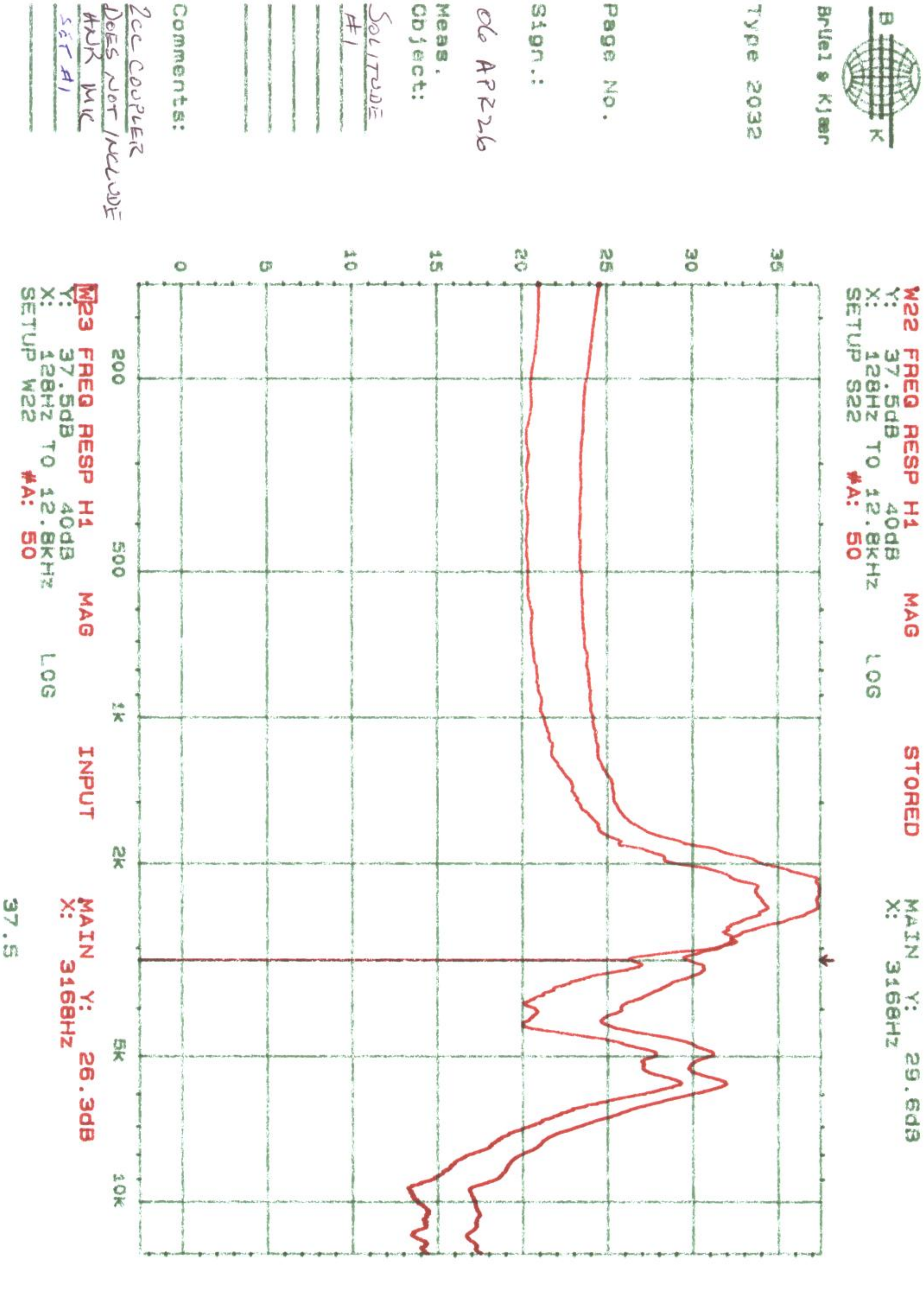
SUMMARY

The LINX technology

- Produces coherent harmonic content
- Produces coherent noise content
- Gently filters random system noise
- Does not materially reduce the transducer sensitivity
- Improves the electrical load on the driving amplifier
- Is known to improve intelligibility
- Is the simplest method to implement these results
- Is easily retrofitted to existing products

NOTICE


IMPEDANCE SETUP
NOISE GEN (part of 2032)
D.U.T.
1kΩ
DIFF AMP GAIN = 1
B IN
A IN
GND
B&K 2032 2 CH FFT ANALYZER
PLOTTER
Function: H1 Magnitude/phase
Units: dB re 1Ω
1 kHz DISTORTION SETUP
LOW DIST. OSCILLATOR
Frequency: 1kHz
VAR ATT
PWR AMP
PAD
Zout=3Ω
TRUE rms VOLTMTR
NO LINX
LINX INDUCTOR
SPEAKER
1 KhZ TRAP
B IN
GND
B&K 2032 2 CH FFT ANALYZER
PLOTTER
Function: Autospectrum A
Units: dB re applied voltage
ACOUSTIC SENSITIVITY SETUP
SINE GEN. (part of 2032)
VAR ATT
PWR AMP
PAD
SPEAKER
FLAT PLT COUPLER
4133 MIC
A IN
GND
B IN
B&K 2032 2 CH FFT ANALYZER
PLOTTER
Function: H1 Magnitude
Units: dB re 94dB SPL/Volt
DMSI CONSULTING - ST. PAUL, MN
ABLE PLANET INC.
FFT MEASUREMENT SETUPS
2006 FEB 18


Brüel & Kjær
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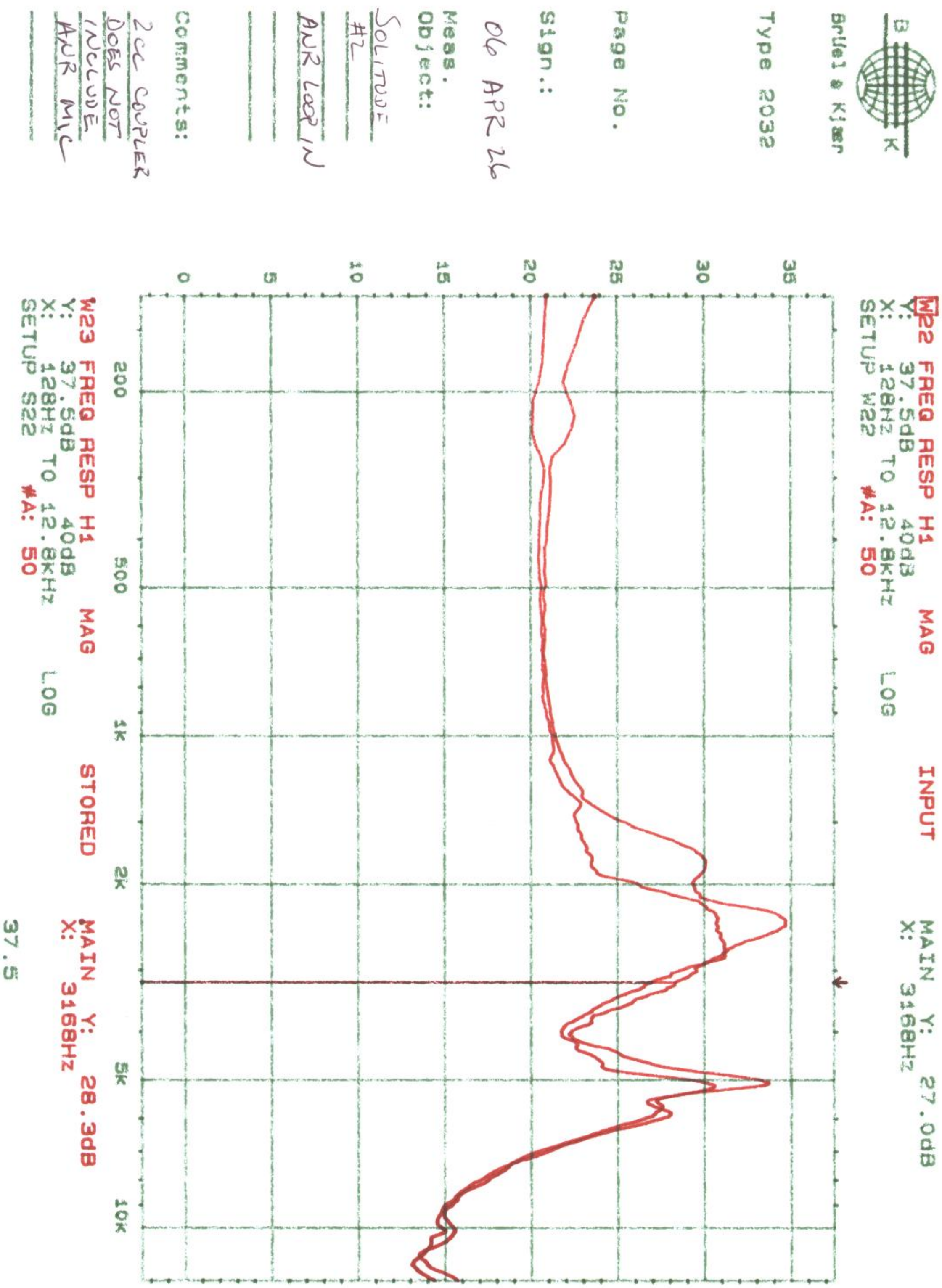
Page No.
Sign.:
06 APR 26
Meas. Object:
SOLITUDE #1
Comments:
2cc COUPLER
DOES NOT INCLUDE
ANR MIC
SET #1
W22 FREQ RESP H1 MAG LOG STORED
Y: 37.5dB 40dB
X: 128Hz TO 12.8kHz
SETUP S22 #A: 50
MAIN Y: 29.6dB
X: 3168Hz
W23 FREQ RESP H1 MAG LOG INPUT
Y: 37.5dB 40dB
X: 128Hz TO 12.8kHz
SETUP W22 #A: 50
MAIN Y: 26.3dB
X: 3168Hz
37.5
0
5
10
15
20
25
30
35
200
500
1k
2k
5k
10k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06 APR 26
Meas. Object:
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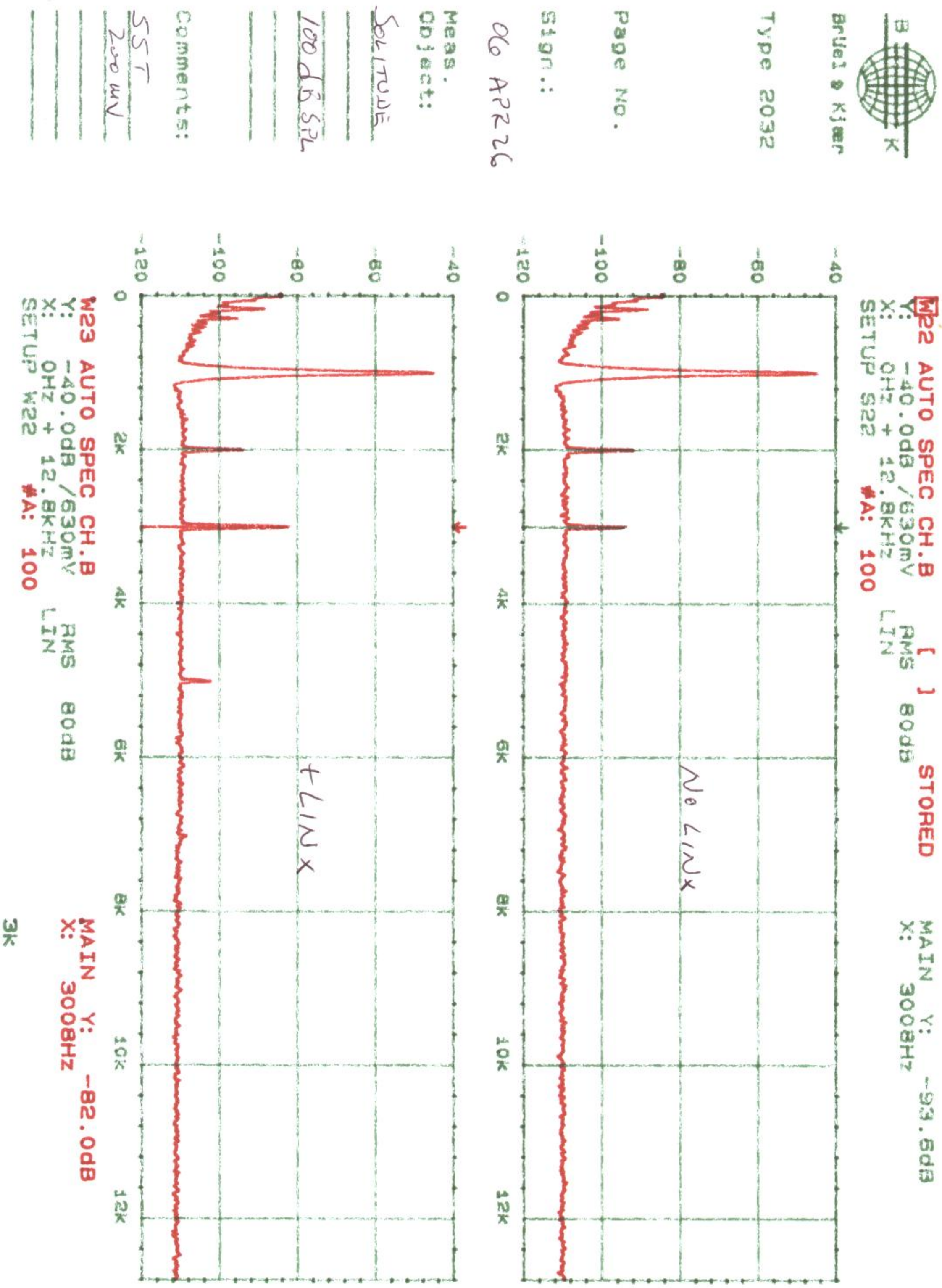
ANR LOOP IN
Comments:
2cc COUPLER DOES NOT INCLUDE ANR MIC
W22 FREQ RESP H1 MAG INPUT
Y: 37.5dB 40dB
X: 128Hz TO 12.8kHz LOG
SETUP W22 #A: 50
MAIN Y: 27.0dB
X: 3168Hz
0
5
10
15
20
25
30
35
200
500
1k
2k
5k
10k
W23 FREQ RESP H1 MAG STORED
Y: 37.5dB 40dB
X: 128Hz TO 12.8kHz LOG
SETUP S22 #A: 50
MAIN Y: 28.3dB
X: 3168Hz
37.5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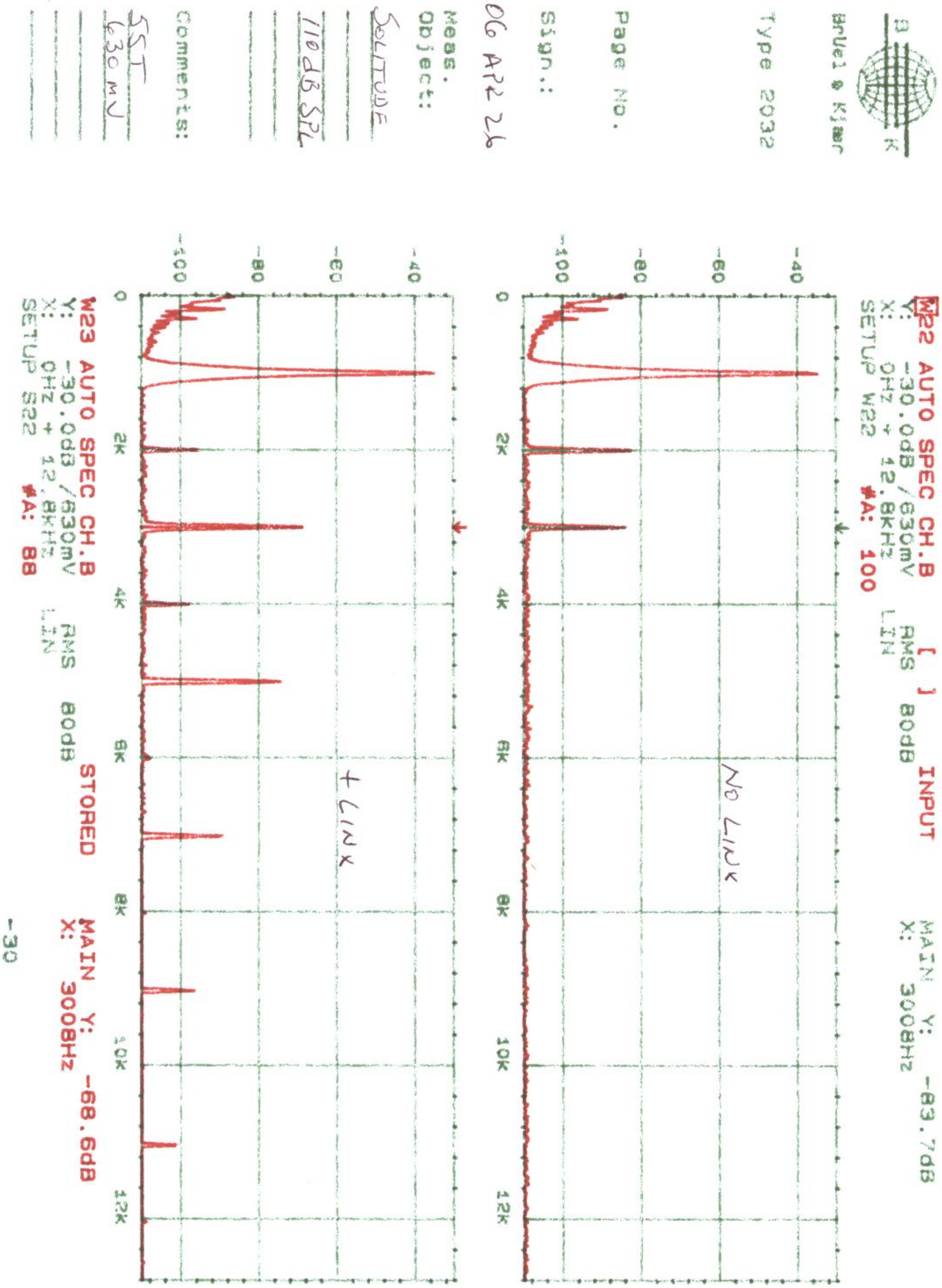
06 APR 26
Meas. Object:
SOLITUDE
100 dB SPL
Comments:
SST
200 mV
W22 AUTO SPEC CH.B [ ] STORED
Y: -40.0dB /630mV RMS 80dB
X: 0Hz + 12.8kHz LIN
SETUP S22 #A: 100
MAIN Y: -93.6dB
X: 3008Hz
No LINX
W23 AUTO SPEC CH.B
Y: -40.0dB /630mV RMS 80dB
X: 0Hz + 12.8kHz LIN
SETUP W22 #A: 100
MAIN Y: -82.0dB
X: 3008Hz
+LINX
3K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Type 2032
Page No.
Sign.:
06 APR 26
Meas. Object:
SOLITUDE
110 dB SPL
Comments:
SST
630 mV
W22 AUTO SPEC CH.B
Y: -30.0dB / 630mV
X: 0Hz + 12.8kHz
SETUP W22 #A: 100
[ ] RMS LIN
80dB
INPUT
MAIN Y: -83.7dB
X: 3008Hz
NO LINK
W23 AUTO SPEC CH.B
Y: -30.0dB /630mV
X: 0Hz + 12.8kHz
SETUP S22 #A: 88
RMS LIN
80dB
STORED
MAIN Y: -68.6dB
X: 3008Hz
+ LINK
-30
-40
-60
-80
-100
0
2K
4K
6K
8K
10K
12K

B K
Brüel & Kjær

Type 2032

Page No.

Sign.:
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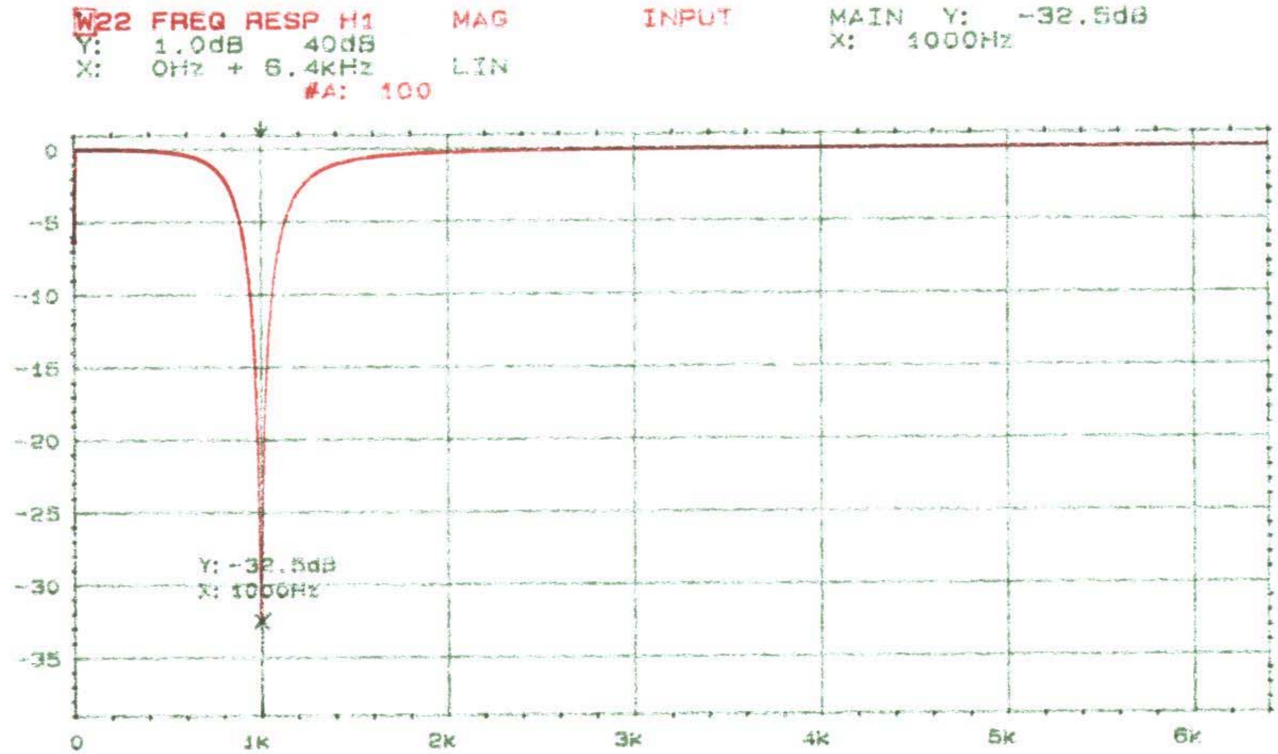
Meas.
Object:
1KHZ
NOTCH FILT.

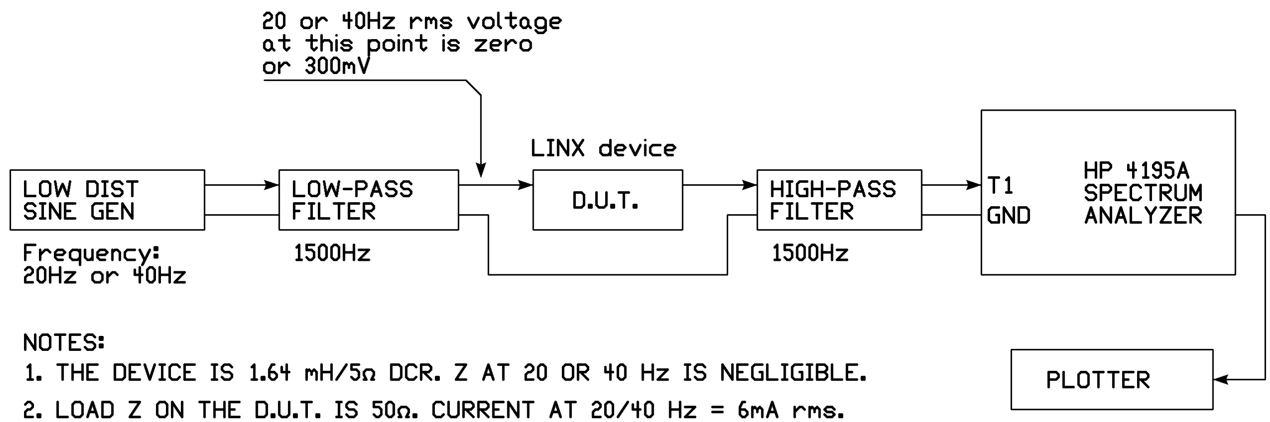
Comments:



SETUP W22

MEASUREMENT:	DUAL SPECTRUM AVERAGING		
TRIGGER:	GENERATOR		
DELAY:	TRIG→A: 0.000ms	CH.A→B: 0.000ms	
AVERAGING:	EXP 100		
FREQ SPAN:	6.4kHz ΔF: 8Hz	T: 125ms	ΔT: 61.0µs
CENTER FREQ:	BASEBAND		
WEIGHTING:	RECTANGULAR		
CH.A:	4V + 3Hz DIR	FILT: 25.6kHz	1V/V
CH.B:	3V + 3Hz DIR	FILT: 25.6kHz	1V/V
GENERATOR:	PSEUDO RANDOM NOISE		
SINE GENERATOR FREQ.:	1000.000Hz		

1K



NOTES:

1. THE DEVICE IS 1.64 mH/5Ω DCR. Z AT 20 OR 40 Hz IS NEGLIGIBLE.
2. LOAD Z ON THE D.U.T. IS 50Ω. CURRENT AT 20/40 Hz = 6mA rms.
3. BASEBAND NOISE IS ANALYZED FROM 3kHz-10kHz.
4. SETUP IS VERIFIED BY SUBSTITUTING A SHORT FOR THE D.U.T. THE NOISE IN THE ANALYSIS BAND IS UNCHANGED IN THE PRESENCE OR ABSENCE OF THE LOW-FREQUENCY TONE.
5. WHEN THE D.U.T. IS INSERTED, THE NOISE BAND IS INCREASED BY AS MUCH AS 10dB IN THE PRESENCE OF THE LOW-FREQUENCY TONE.
6. IN THIS CASE THE ONLY AVAILABLE NOISE SOURCE IS BARKHAUSEN NOISE.
7. THE NOISE INCREASE IS PROPORTIONAL TO EXCITATION FREQUENCY.

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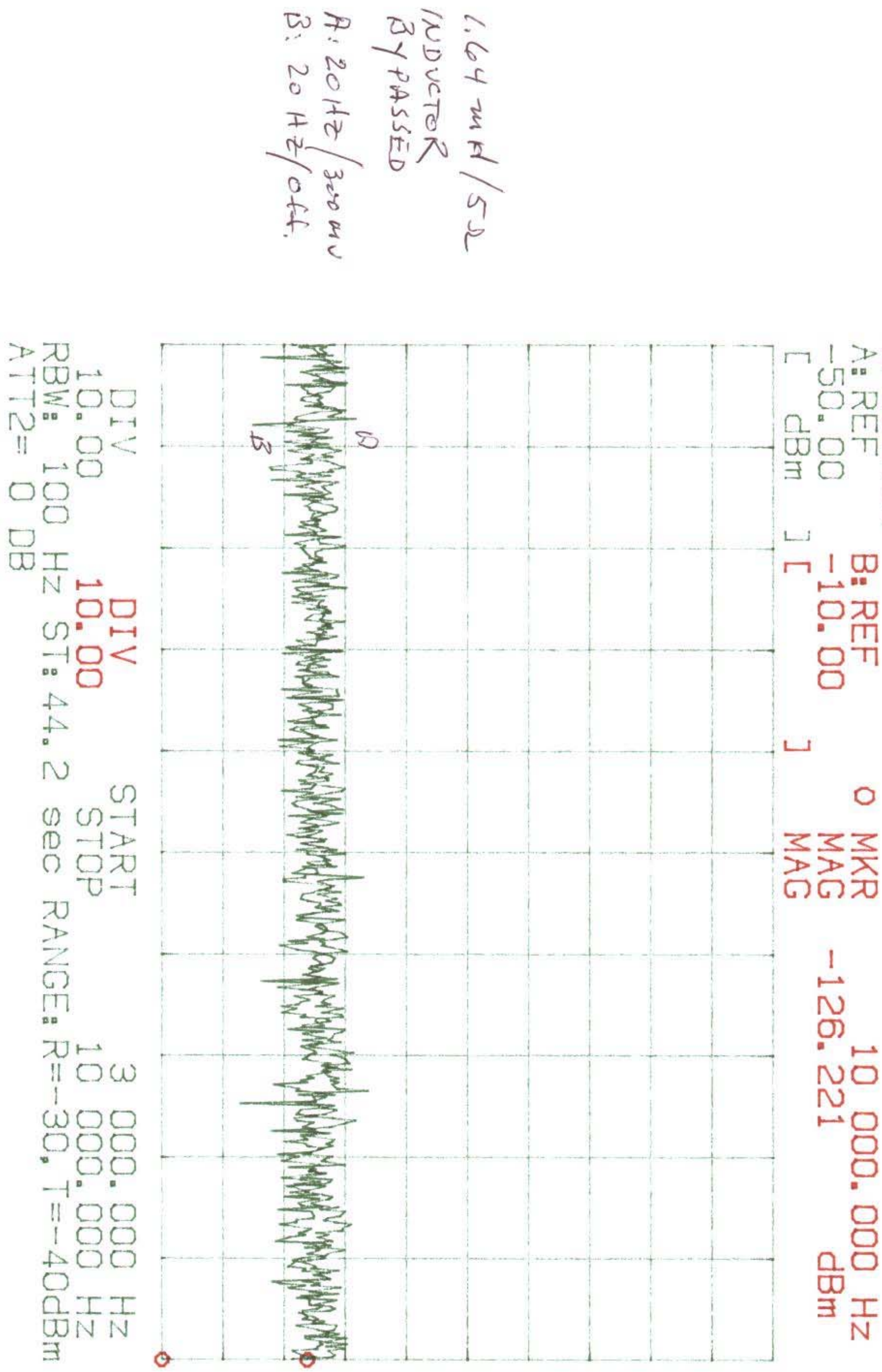
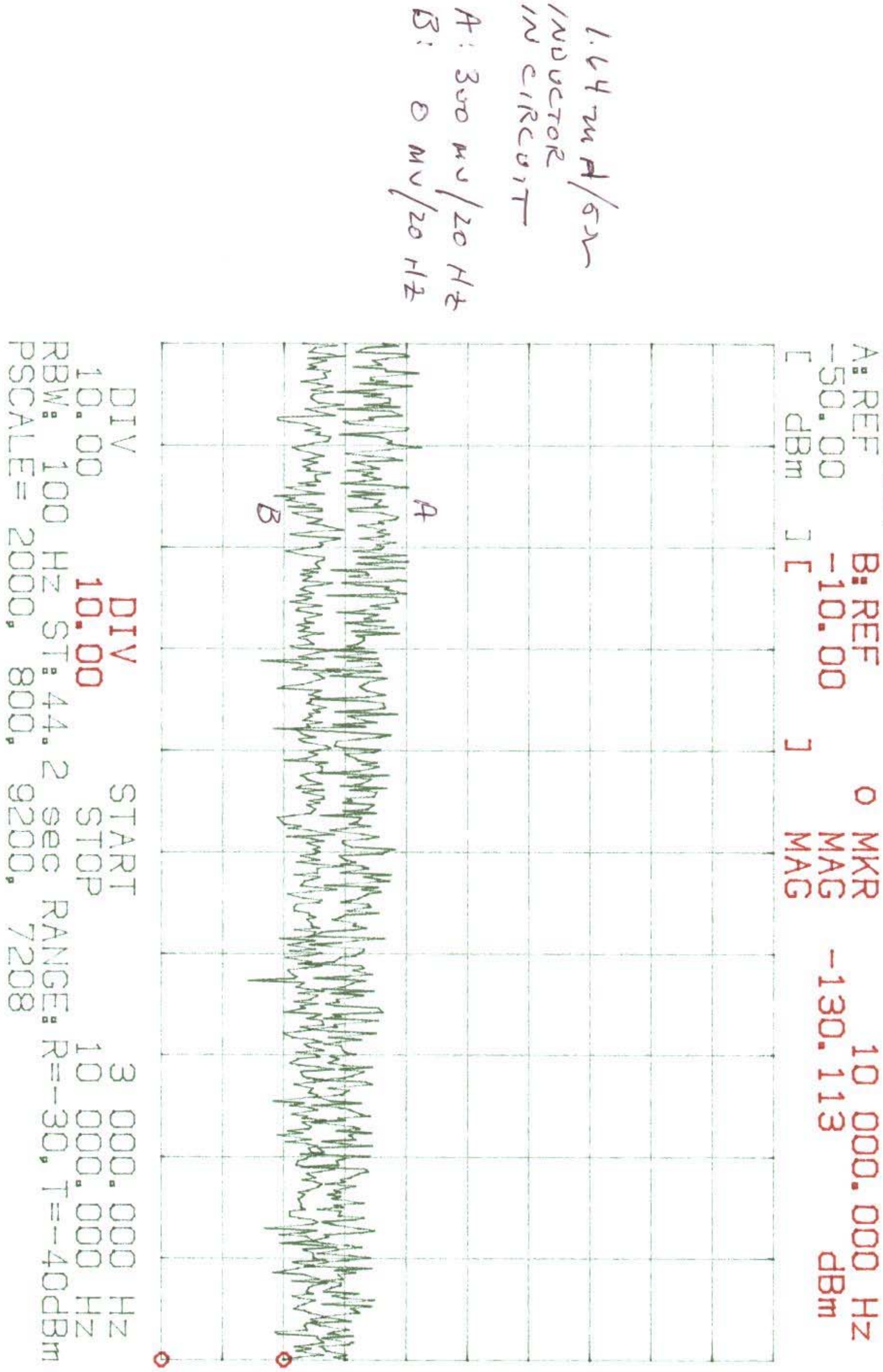
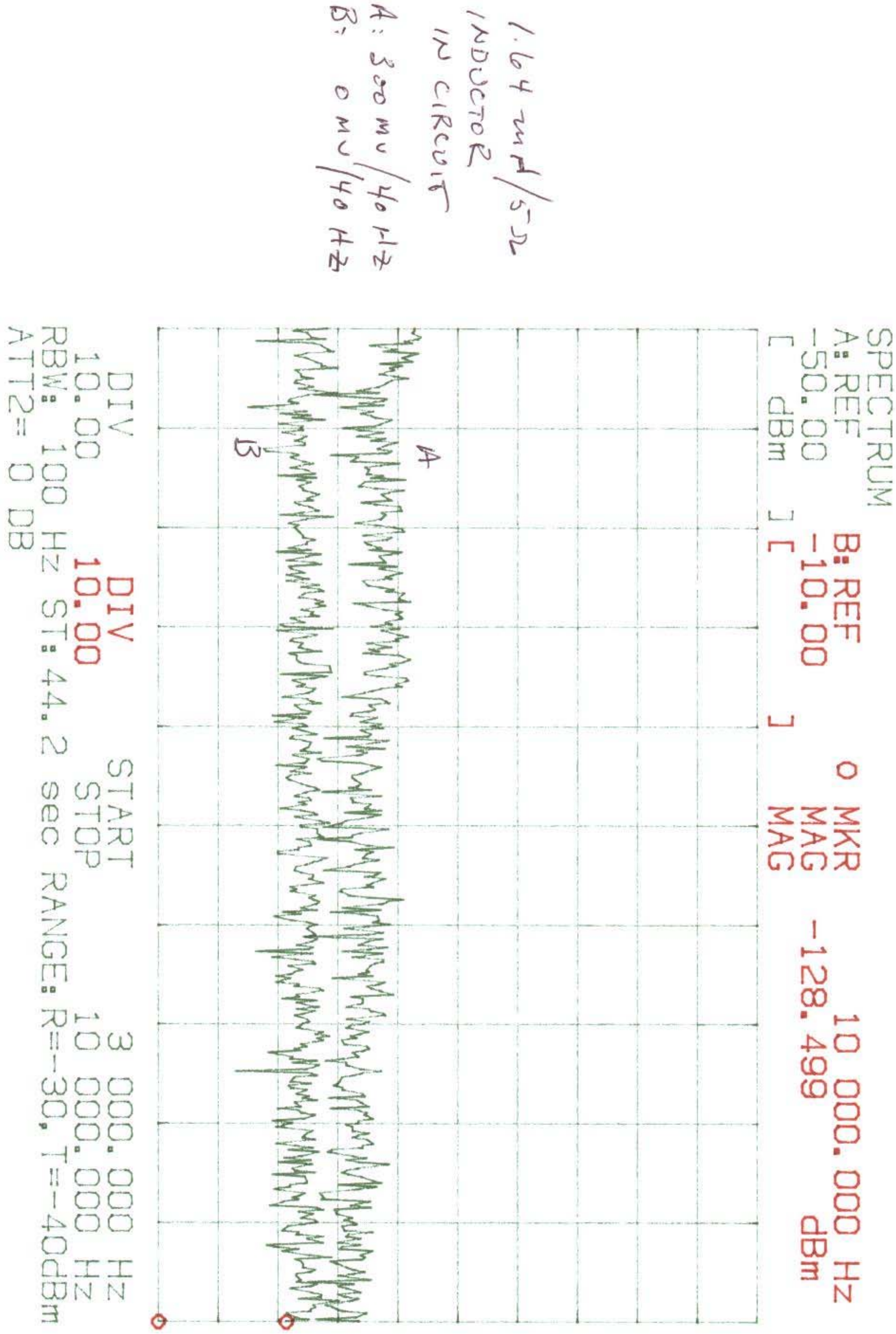
ABLE PLANET INC.
BARKHAUSEN NOISE
TEST SETUP & NOTES
2006 JAN


1.64 mH / 5Ω
INDUCTOR
BYPASSED
A: 20 Hz / 320 mV
B: 20 Hz / off.
SPECTRUM
A: REF
-50.00
[dBm]
B: REF
-10.00
[ ]
MKR 10 000.000 Hz
MAG -126.221 dBm
MAG
DIV
10.00
DIV
10.00
START 3 000.000 Hz
STOP 10 000.000 Hz
RBW: 100 Hz ST: 44.2 sec RANGE: R=-30, T=-40dBm
ATT2= 0 DB


1.64 mH/6Ω
INDUCTOR
IN CIRCUIT
A: 300 mV/20 Hz
B: 0 mV/20 Hz
SPECTRUM
A: REF
-50.00
[dBm]
B: REF
-10.00
[ ]
MKR 10 000.000 Hz
MAG -130.113 dBm
MAG
A
B
DIV
10.00
DIV
10.00
START 3 000.000 Hz
STOP 10 000.000 Hz
RBW: 100 Hz ST: 44.2 sec RANGE: R=-30, T=-40dBm
PSCALE= 2000, 800, 9200, 7208


1.64 mH / 5 Ω
INDUCTOR
IN CIRCUIT
A: 300 mV / 40 Hz
B: 0 mV / 40 Hz
SPECTRUM
A: REF -50.00 [dBm]
B: REF -10.00 [ ]
o MKR 10 000.000 Hz
MAG -128.499 dBm
MAG
A
B
DIV 10.00
DIV 10.00
START 3 000.000 Hz
STOP 10 000.000 Hz
RBW: 100 Hz ST: 44.2 sec RANGE: R=-30, T=-40dBm
ATT2= 0 DB