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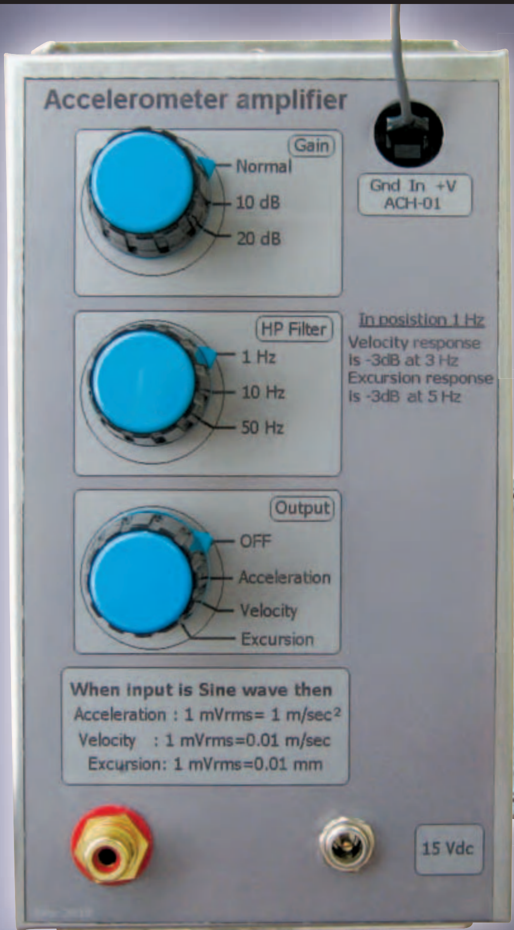

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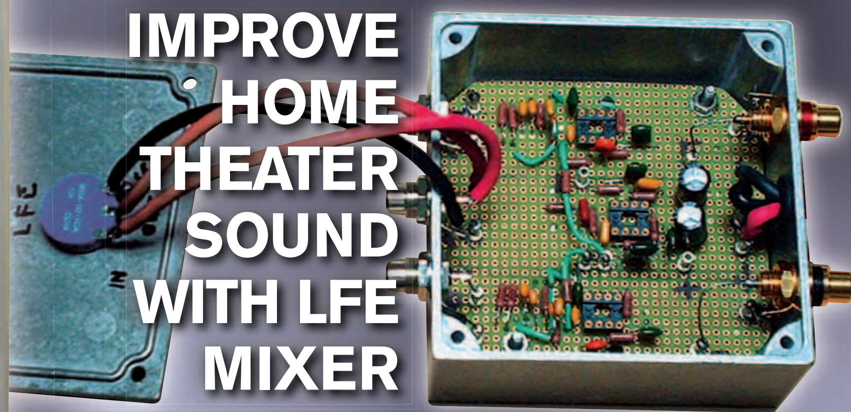

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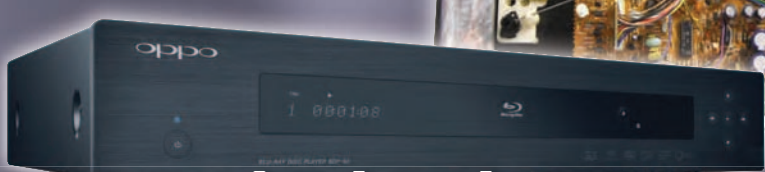

REVIEW OF OPPO BLU-RAY PLAYER

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By George Danavaras

Accelerometer Testing of Loudspeaker Drivers

Test your speakers' performance with this do-it-yourself measurement system.

PHOTO 1: The Accelerometer amplifier.

In this article, I will describe the design and operation of a system consisting of the ACH-01 accelerometer and a preamplifier with an integrated analog signal processor (**Photo 1**). With this system, it will be possible to measure at the low frequencies the acceleration, the velocity, and the excursion of a loudspeaker cone. Also the panel vibrations of a loudspeaker cabinet will be very easily obtained.

THE ACH-01-03 ACCELEROMETER

The ACH-01 (**Photo 2**) manufactured by the Measurement Specialties (www.meas-spec.com) is an inexpensive, general-purpose, linear single axis accelerometer with a very wideband response (specified within 3dB from 2Hz to 20kHz) and internally buffered for low output impedance. It can measure up to ±150g and has a high resonant frequency at 35kHz. The output voltage of the accelerometer is directly analogous to the acceleration that it measures. The ACH-

PHOTO 2: The ACH-01 accelerometer.

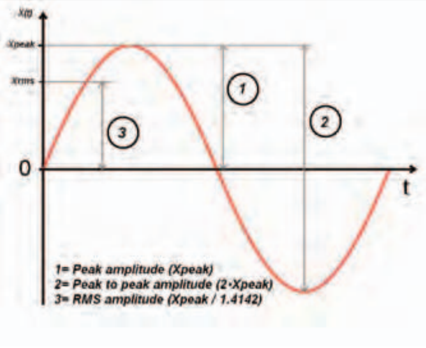

FIGURE 1: Sine wave amplitude definitions.

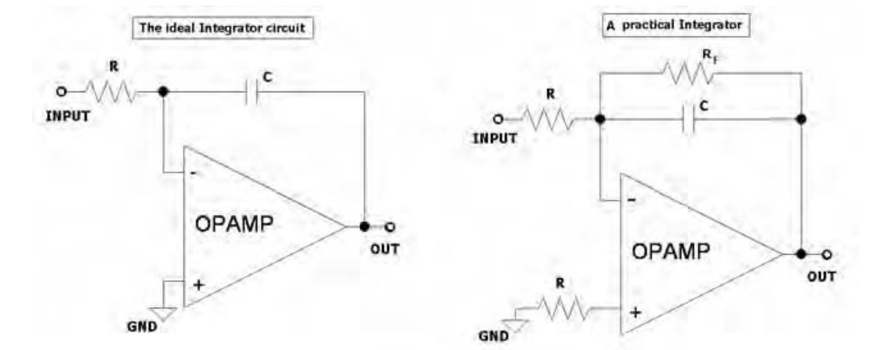

FIGURE 2: The op amp integrator circuit.

01-03 version of the accelerometer is housed in a small, rugged, flat package and is supplied with a shielded cable.

SIMPLE HARMONIC MOTION THEORY

Before I proceed to the description of the preamplifier, I think that it will be very helpful to refresh your knowledge about the theory of the simple harmonic motion. So here is a brief description.

Suppose that you have an ideal loudspeaker cone that is driven with a sinusoidal signal as shown in **Fig. 1**. The instantaneous value of the displacement (=excursion) of the cone can be written in the following form as a function of time t:

$x(t) = Xpeak \times \sin(\omega \times t)$

Where Xpeak is the maximum value of the displacement and $\omega = 2 \times \pi \times f$ is the angular frequency.

The velocity of the piston as a function of time is the first derivative of the displacement and is given by:

$$v(t) = \frac{dx(t)}{dt} = \omega \times Xpeak \times \cos(\omega \times t)$$

Similarly, the acceleration is the first derivative of the velocity (or the second derivative of the displacement) and is given by:

$$a(t) = \frac{dv(t)}{dt} = -\omega^2 \times Xpeak \times \sin(\omega \times t)$$

From the above relations you see that the peak velocity of the cone is:

$Vpeak = \omega \times Xpeak$

And the peak acceleration is:

$Apeak = -\omega \times Vpeak = -\omega^2 \times Xpeak$.

The RMS values of the above are defined as follows: (see also **Fig. 1**)

For the displacement:

$$Xrms = \frac{Xpeak}{\sqrt{2}}$$

For the velocity:

$Vrms = \omega \times Xrms$ and

For the acceleration:

$Arms = \omega \times Vrms = -\omega^2 \times Xrms$

For example, assume that you have a loudspeaker cone, which is driven by a sinusoidal signal with a frequency of 20Hz and the peak-to-peak displacement of the cone is 10mm. Then the peak value of the displacement is 5mm and the RMS value of the displacement is: $Xrms = 3.53$mm.

The RMS value of the velocity is $Vrms = 0.444 \frac{m}{sec}$ and the RMS value of the acceleration is $Arms = 55.83 \frac{m}{sec^2}$

Now what you need for your design is to apply the reverse procedure and compute the displacement and the velocity of the simple harmonic motion when the acceleration is known. Suppose that the acceleration of a piston is $a(t)$ as a function of time t.

Then by reversing the above, the velocity can be calculated by the following:

$v(t) = \int a(t)\mathrm{d}t$

And similarly, the displacement can be calculated by the following:

$x(t) = \int v(t)\mathrm{d}t$

The above means that we can use an integrator circuit to compute the velocity from the acceleration and then one more integrator circuit to compute the displacement from the velocity. This is exactly how the Analog processor of the accelerometer preamplifier operates.

THE INTEGRATOR CIRCUIT

The integrator forms the basis of the accelerometer preamplifier processor. Two integrator circuits that are based on an op amp are shown in **Fig. 2**. The left is an ideal integrator and the right is a more practical circuit. The main component of these circuits is the operational amplifier, configured in such a way that its output voltage is proportional to the integral of its input voltage.

The output of the circuit is given by

$Vout = \frac{1}{RC} \int Vin \times \mathrm{d}t$

The resistor Rf reduces the gain of

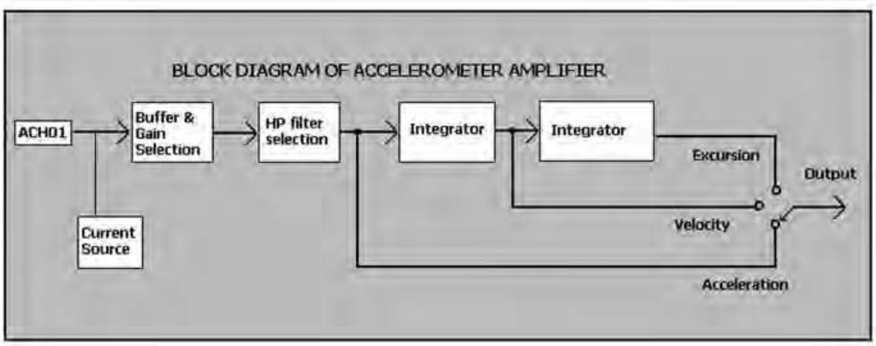

FIGURE 3: The block diagram of the Accelerometer preamplifier.

the circuit at the very low frequencies (theoretically the gain of the ideal integrator at DC is infinite) because otherwise the output of the op amp will saturate after some time.

The integrator can also be seen as an active low-pass filter with a very low cutoff frequency.

THE ELECTRONIC DIAGRAM

The preamplifier is based on the block diagram of **Fig. 3**. The first stage buffers the signal from the ACH accelerometer and can provide a gain of 10 or 20dB when the output of the accelerometer is very low. The next stage is a high-pass filter with a user selectable cutoff frequency. An integrator follows and has as output the velocity of the input while the next integrator has as output the excursion (or displacement).

The complete electronic diagram of the voltmeter is shown in **Fig. 4**. At the input of the circuit, there is a three-pin connector for the connection of the ACH accelerometer to the amplifier. One pin is used for the voltage supply to the Accelerometer, the second is the output of the accelerometer, and the third is the Ground pin.

The voltage that supplies the accelerometer should have a very low ripple and for this reason a RC low pass filter consisting of the resistor 24kΩ and the capacitor 470μF filters additionally the voltage.

Transistor Q1 with the components R1, R2 and Led1 bias the internal FET of the Accelerometer with a constant current of 20μA. The jumper JP4 is used to connect or to disconnect the bias circuit to the input pins. This is helpful for the calibration of the circuit, as you will see later.

The op amp IC1A and the components around it buffer the output of the accelerometer and provide with the switch S1 a selectable gain of 0 or 10 or 20dB. It is very important that for the measurement of the velocity and the excursion the S1 switch should be set to the 0dB gain (indicated as Normal position on the front panel).

The components C13, C15, C16, and R24 with the op amp IC1B form a first-order high-pass filter and the switch S2 selects the cutoff frequency between 1, 10, or 50Hz. The op amp IC2A with R3, R5, and C11 form the first integra-

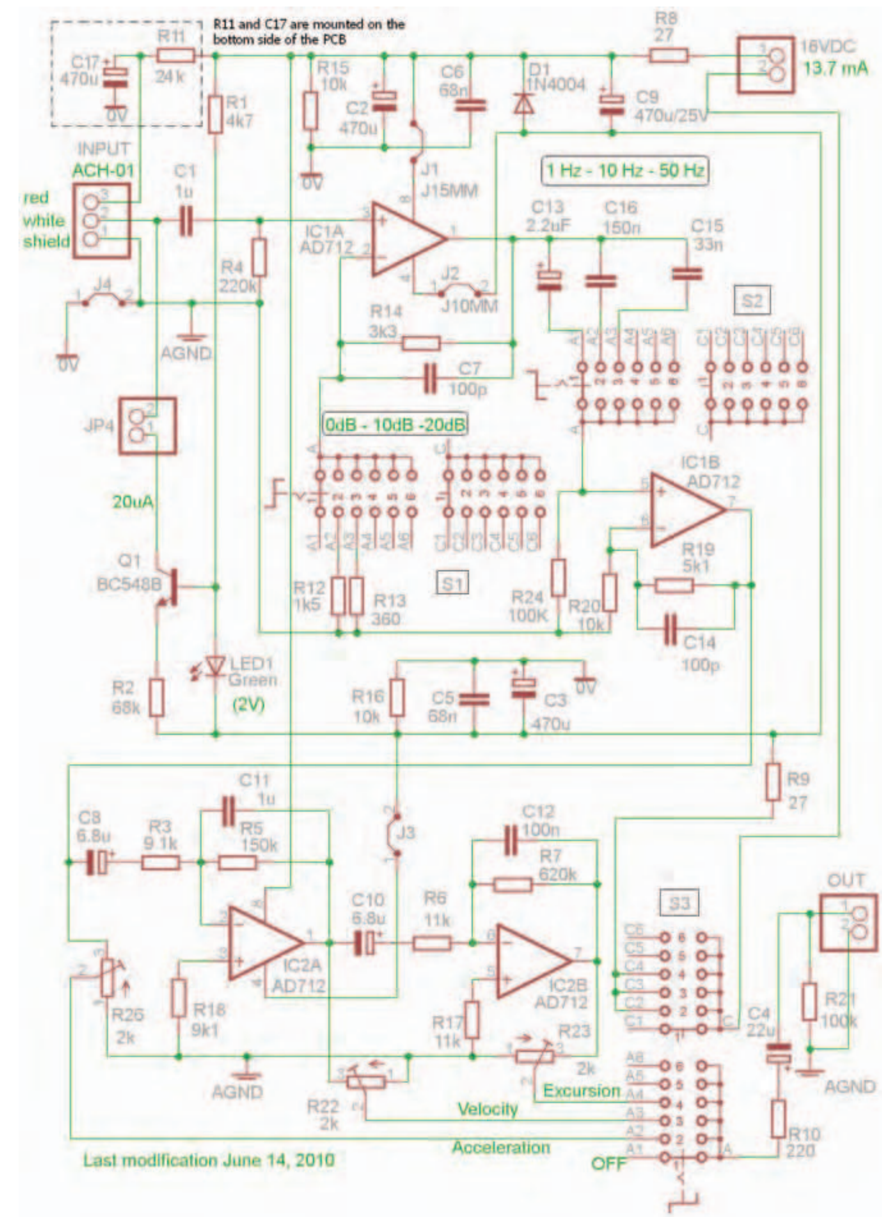

FIGURE 4: The electronic diagram of the Accelerometer preamplifier.

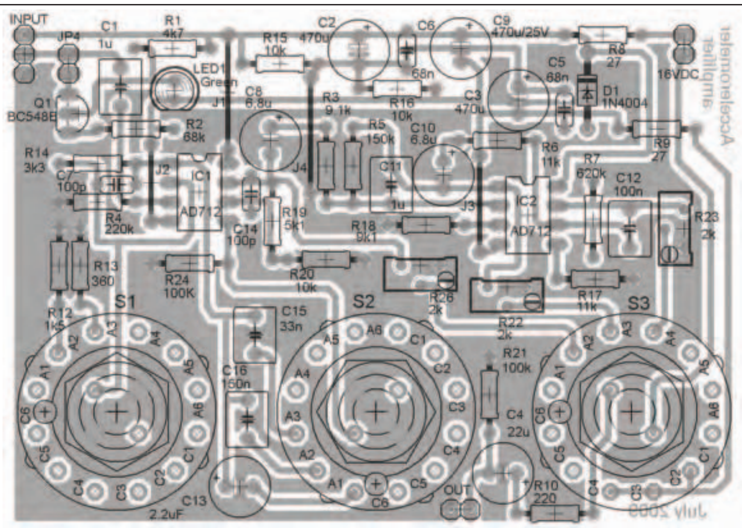

FIGURE 5: The PCB layout of the Accelerometer preamplifier.

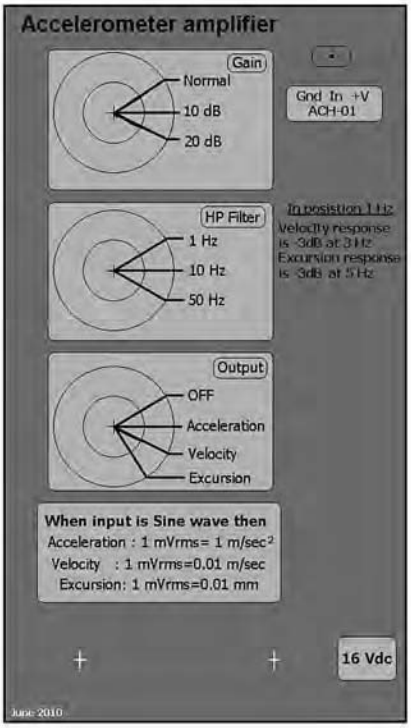

FIGURE 6: The front panel of the Accelerometer preamplifier.

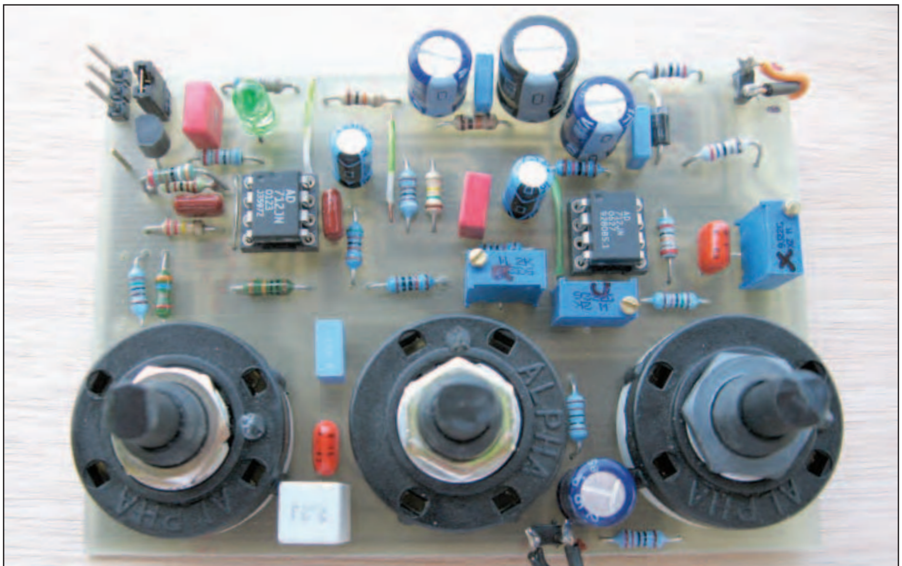

PHOTO 3: The PCB of the accelerometer amplifier.

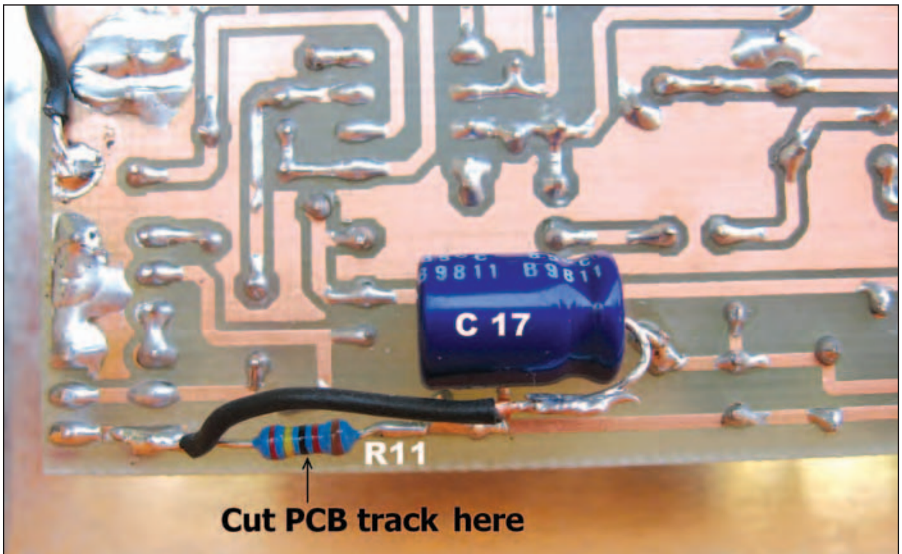

PHOTO 4: The placement of R11 and C17 on the bottom of the PCB.

tor, which gives at its output the velocity.

The op amp IC2B with R6, R7, and C12 form the second integrator that gives as its output the excursion (or displacement) of the input signal. Trimmer R26 calibrates the output signal for the acceleration, trimmer R22 calibrates the output signal for the velocity and trimmer R23 calibrates the output signal for the excursion. Switch S3 selects the type of the signal that will be connected to the output of the preamplifier.

For the supply of the preamplifier I used an external power supply pack with a nominal output voltage of 15V DC and a current capability of 300mA. This gave an actual output voltage of about 16.4V DC but with a very low ripple because the total current consumption of the preamplifier is only 14mA. This is very important for the good operation of the circuit.

THE PCB

The construction of the preamplifier is complicated so I designed a PCB using the Demo version of the Eagle Layout editor. You can download this demo version of the program free from Cadsoft (www.cadsoftusa.com). The demo version is fully operational except a limitation on the maximum dimensions of the PCB, which was not a problem for this project.

The placement of the components on the PCB is shown in **Fig. 5**.

All the components are placed on the topside of the PCB except the resistor R11 (24kΩ) and the capacitor C17 (470μF) that are mounted on the bottom side of the PCB. Before the placement of R11 the PCB track that connects the power supply to the pin 3 of the Input connector should be cut. See **Photo 4** for the details.

The three rotary switches S1, S2, and S3 are placed directly on the PCB to facilitate the construction of the meter.

In **Fig. 6**, the diagram of the front plate that I used for the meter is shown. I printed this diagram to a self-adhesive transparent paper, which then was put on the front panel of the metallic box of the meter. This gave a very attractive look for the meter as shown in **Photo 1**.

I also used the same diagram, printed on normal paper, as a guide for the opening of the holes for the rotary switches, the output connector, and the power supply connector.

CALIBRATION OF THE AMPLIFIER

The sensitivity S of the ACH-01 accelerometer is given in mV/g where g is the Earth's Gravity in $\frac{m}{sec^2}$ (the typical value is g=9.81$\frac{m}{sec^2}$).

Suppose that E (in mV RMS) is the

PHOTO 5: The setup for checking the accuracy of the system.

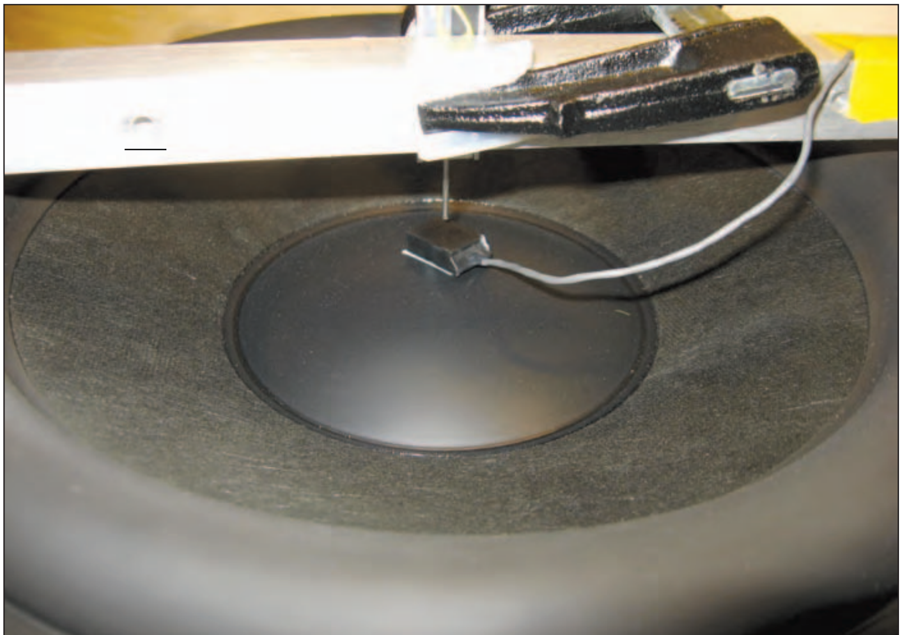

PHOTO 6: Closeup of setup.

actual output voltage of the accelerometer then the acceleration *Arms* that is measured by the accelerometer is given by the following:

$$Arms = \frac{g \times E}{S} \ \frac{m}{sec^2}$$

If you know the acceleration and the frequency ($\omega = 2 \times \pi \times f$), the velocity is computed by:

$$Vrms = \frac{A_{rms}}{\omega} \ \frac{m}{sec}$$

And the displacement is computed by: $xrms = \frac{A_{rms}}{\omega^2}$ in meters. Now, for the calibration of the amplifier we will make some calculations based on the above formulas.

The ACH-01 is provided calibrated from the factory and the one that I used had a sensitivity of S = 9.1mV/g.

If you suppose that the output of the accelerometer is E = 110mVrms at the frequency of 40Hz then you have:

The acceleration is:

$$Arms = \frac{9.81 \times 110}{9.1} \ \frac{m}{sec^2} = 118.58 \ \frac{m}{sec^2}$$

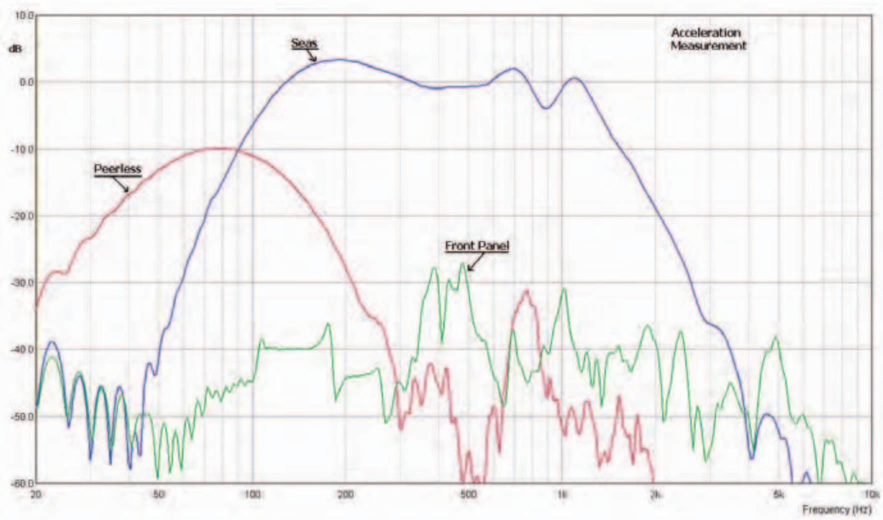

FIGURE 7: Accelerations measurements.

Table 1: Comparison between digital caliper indication and accelerometer amplifier measurements.

Digital Caliper Indication 5 mm			Digital Caliper Indication 15 mm			Digital Caliper Indication 10 mm		
Frequency	Positive peak cone excursion	Negative peak cone excursion	Frequency	Positive peak cone excursion	Negative peak cone excursion	Frequency	Positive peak cone excursion	Negative peak cone excursion
(HZ)	(mm)	(mm)	(HZ)	(mm)	(mm)	(HZ)	(mm)	(mm)
15	4.9	5.14	15	14.7	15.05	15	10.1	10.41
20	5.05	5.24	20	14.7	15.6	20	10.27	10.9

The velocity is:

$$Vrms = \frac{A_{rms}}{\omega}\ \frac{m}{sec} = \frac{118.58}{251.32} = 0.472\ \frac{m}{sec}$$

And the excursion is:

$$Xrms = \frac{A_{rms}}{\omega^2} = \frac{118.58}{63165.46} = 0.1.877\text{mm}$$

Now you can proceed with the calibration of the amplifier. For this, I used a low distortion audio frequency generator, a digital frequency meter, and my true RMS digital Voltmeter (*audioXpress*, July 2009, p. 12).

I set the frequency of the audio generator at exactly 40.00Hz and the level at 110.0mV RMS. I removed the jumper JP4 (to disconnect the bias circuit) and connected the generator to the input of the amplifier (pin 2 for the + and pin 3 for the – of the input connector).

I connected the RMS Voltmeter to the output of the preamplifier and I set the switch S3 to the acceleration and I adjusted the trimmer R26 so that the Voltmeter indication was 118.6mV RMS (which means that 1mV RMS = $1\ \frac{m}{sec^2}$).

Then I set the switch S3 to the Velocity position and I adjusted the trimmer R22 so that the RMS Voltmeter indication was 47.2mV RMS (which means that 1mV RMS = $0.01\ \frac{m}{sec}$).

Finally I set the switch S3 to the Excursion position and adjusted the trimmer R23 so that the RMS Voltmeter indication was 187.7mV RMS (which means that 1mV RMS = 0.01mm). This completes the calibration of the preamplifier.

CHECKING THE SYSTEM

After the calibration of the preamplifier, I was thinking of a method to check the measurement accuracy of the accelerometer and the calibrated preamplifier. **Photo 5** shows the setup that I used:

A Peerless 830500, which is a 12″ loudspeaker.

A power amplifier for driving the loudspeaker.

A Fluke 289 True RMS multimeter which can measure the peak (positive and negative) values of a signal and

A digital caliper.

The demo version of the ARTA software (http://www.fesb.hr/~mateljan/arta/).

I mounted the accelerometer on the middle of the loudspeaker cone (**Photo 6**) using double-sided tape. The digital caliper was firmly mounted perpendicular with the cone of the loudspeaker using thick aluminum bars. The depth probe of the caliper was moved down until it touched the surface of the accelerometer and the indication of the digital caliper was set to zero (0.00mm).

Then the depth probe was moved up some millimeters to allow the loudspeaker cone to move and I increased very slowly the voltage level to the loudspeaker until I just heard the accelerometer hit the edge of the depth probe. This means that the positive peak excursion of the loudspeaker cone was equal to the indication of the digital caliper.

The measurements were performed for two different frequencies (15 and 20Hz) and for three different peak cone excursions (5mm, 10mm, and 15mm). The results are indicated in **Table 1**.

For the 5mm excursion at 15Hz the indication of the preamplifier was 4.9mm for the positive excursion and 5.14 for the negative excursion.

At 20Hz the indication of the preamplifier was 5.05mm for the positive excursion and 5.24 for the negative excursion.

For the 10mm excursion at 15Hz the indication of the preamplifier was 10.1mm for the positive excursion and 10.41 for the negative excursion.

At 20Hz the indication of the preamplifier was 10.27mm for the positive excursion and 10.9 for the negative excursion.

For the 15mm excursion at 15Hz the indication of the preamplifier was 14.7mm for the positive excursion and 15.05 for the negative excursion.

At 20Hz the indication of the preamplifier was 14.7mm for the positive excursion and 15.6 for the negative excursion.

The above results prove that the measurements of the accelerometer are very close to the indication of the digital caliper.

SOME INTERESTING MEASUREMENTS

I used the accelerometer and the preamplifier to perform some measurements on my current four-way loudspeaker system. Each channel consists of a separate closed box subwoofer with an Infinity 12″ speaker which operates up to 62Hz, two Peerless 830452 woofers as open baffle dipoles that operate from 62 to 162Hz, a SEAS ER18 mid/woofer on an open baffle dipole that operates from 162 to 2.2kHz and a SEAS H1499 DXT tweeter.

The measurements that I performed are shown in **Figs. 7-10**. For the measurements of **Figs. 7 and 8**, the loudspeaker was driven with pink noise and the accelerometer was mounted in the center of the loudspeaker's cones. I used the acceleration and the excursion output of the preamplifier.

In **Fig. 7**, I measured the acceleration of the Peerless cone, the acceleration of the SEAS ER18 cone, and the acceleration of the front panel, which supports the loudspeaker units to examine their relative amplitudes. The drive voltage to the loudspeaker was the same in all measurements. It seems from this measurement that from the 350Hz to 500Hz the level of the front panel is about –30dB down from the level of the loudspeaker cone. This indicates that more damping of the front panel is necessary for this range.

In **Fig. 8**, I kept the same drive voltage to the loudspeaker and measured the excursion of the Peerless cone and the excursion of the SEAS ER18 cone to examine their relative amplitudes. For the measurements of **Fig. 9**, I put the accelerometer on the center of the cone of the Peerless woofer and kept the drive voltage to the loudspeaker constant at 20V RMS. I measured the distortion of the acceleration output signal at different frequencies and then the positive and negative peak excursion of the loudspeaker cone.

For the measurements of **Fig. 10**, I increased the drive voltage to the loudspeaker until the distortion of the cone acceleration output voltage was about 10%. Then I measured the drive voltage to the loudspeaker and the peak-to-peak excursion of the loudspeaker cone.

Unfortunately my test amplifier had a maximum output voltage of about 22V RMS, so it was not possible to continue the measurements in higher frequencies that demand much more output voltage drive.

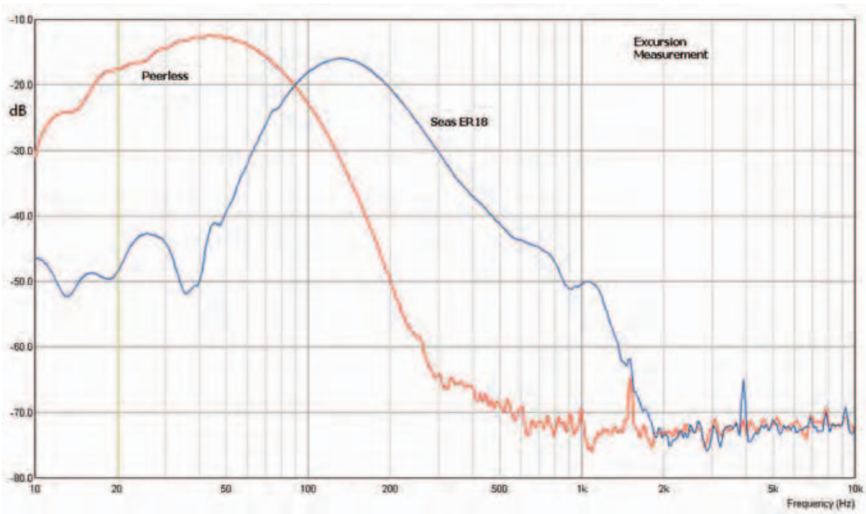

FIGURE 8: Cone excursion measurements.

Frequency	Cone acceleration Distortion	Positive peak cone excursion	Negative peak cone excursion	RMS cone excursion	Positive peak cone acceleration	Negative peak cone acceleration	RMS cone acceleration	Peak to peak excursion as measured at the Excursion output
(Hz)	(%)	mV peak	mV peak	mVrms	mV peak	mV peak	mV rms	mm
20	14	1300	1350	931	262	240	150	26.5
40	4.5	621	648	445	428	403	266	12.7
55	3.6	430	446	299	540	518	367	8.8

FIGURE 9: Peerless 830452 measurements at 20V RMS.

Peerless 830452 in an H-frame dipole				Cone Acceleration distortion = 10 %				
Frequency	Positive peak cone excursion	Negative peak cone excursion	RMS cone excursion	Positive peak cone acceleration	Negative peak cone acceleration	RMS cone acceleration	Loudspeaker Voltage drive	Peak to peak excursion as measured at the Excursion output
(Hz)	mV peak	mV peak	mVrms	mV peak	mV peak	mV rms	Vrms	mm
16	1100	1054	725	134	133	78	13.2	21.54
30	1165	1208	831	220	203	131	18	23.73

FIGURE 10: Peerless 830452 cone excursion and voltage drive for 10% cone acceleration distortion.

CONCLUSION

This is a very useful test and measurement system. It measures the acceleration, the velocity, and the excursion of a loudspeaker cone or a loudspeaker panel with good accuracy. It is easy to use and the cost to build is very reasonable. If you don't have such equipment in your lab, here is a good opportunity to build one. *aX*

Parts list of the Accelerometer preamplifier

Part	Value
C1, C11	1µ, MKT
C2, C3, C9, C17	470µ/25V, electrolytic
C4	22µ/25V bipolar
C5, C6	68n
C7, C14	100p
C8, C10	6.8µ/25V, electrolytic
C12	100n
C13	2.2µF/MKT
C15	33n
C16	150n
D1	1N4007
IC1, IC2	AD712
LED1	Green LED 5MM
Q1	BC548B
R1	4k7
R2	68k
R3	9.1k
R4	220k
R5	150k
R6, R17	11k
R7	620k
R8, R9	27
R10	220
R11	24k
R12	1k5
R13	360
R14	3k3
R15, R16, R20	10k
R18	9k1
R19	5k1
R21, R24	100k
R22, R23, R26	2k, Multi-turn trimmer
S1, S2, S3	Switch CK102X06