Subwoofers

Accurately Set Up a Subwoofer With (Almost) No Test Instruments

Bass frequencies are extremely important to sound reproduction. Everyone is interested in getting their bass right, but most people haven't a clue how to proceed. This article will help to settle the process of integrating an active subwoofer with an existing "satellite" system. If your room and loudspeakers are good, you'll only need two test CDs and your ears to adjust your subwoofer. If your room is not so good, or you want to refine the sound even further, then we'll discuss the best way to integrate test equipment measurements with your hearing. The simple listening test will also reveal if your room has problems and if it's time to hire an acoustician.

Let's review the basic requirements for smooth, extended bass response.

Conquering the Room

Many people are proud of the "ideal dimensions" of their listening room. In general, the larger the room, the fewer audible problems with low frequency standing waves (nodes and antinodes). To get smooth and even bass requires ceilings taller than 10 feet, width greater than 12 feet, and length greater than 25 feet (30 or more for deep bass). Dimensions (including diagonals) should not be multiples of identical wavelengths, to avoid buildup at octave resonances. Of course, larger rooms may need absorption to keep the reverberation time down, but standing waves don't tend to build up awkwardly in larger rooms. It's also important to use absorption so that the decay time at low frequencies is roughly similar to that at mid and high frequencies. This is called a "neutral room."

Lightweight, flexible walls act as *diaphramatic absorbers,* where some bass frequencies will escape out the walls, never to return. In my opinion, the ideal is a solid concrete (block) wall, but proper construction with plaster lathe, wood, and/or double sheet rock can accomplish similar results. But solid walls create problems of their own; a world-class room usually requires some absorption and/or diffusion to deal with resonances and echos. Watch out for cavities within the walls, which can cause resonances. Creating a large room with good bass response, interior acoustics, and outside isolation, is the role of a professional acoustician. This article will share some secrets in the fine tweaking of systems in good rooms; don't dream of building a room from scratch without hiring an acoustician.

Speaker Mounting - Spikes or Isolators?

Soffit-mounting involves recessing loudspeakers into a cavity in the wall, with the edge of the loudspeaker flush to the wall. Soffit-mounting requires the expertise of an experienced acoustician, and is beyond the scope of this article. The main loudspeakers must be decoupled from the floor. Heavy, rigid stands should have a top no larger than the bottom of the loudspeaker to avoid diffraction (a form of comb filtering). I've had great success spiking speaker stands (using spikes, or "tiptoes") through holes in the carpet. Some authorities recommend a damping pad underneath a heavy, full range speaker instead of spikes. Whichever mounting method, the goal is to reduce sympathetic vibrations or traveling waves in cabinets, floor and walls. The resonant frequency of the box and stand should be extremely low. Hit the box with your fist and confirm it does not have a resonant character; sweep a sine wave through the system and listen for vibrations. I've had great success with a very thin isolator (Dr. Scholl's) between the speaker and the stand which compresses almost completely under the speaker's weight.

Listener position

If you're sitting in an antinode, there's always going to be a dip at that frequency, and no amount of equalization will correct the acoustic problem.

Speaker position

Ironically, solid walls aggravate the interaction of loudspeaker position and frequency response. The closer

the loudspeaker to walls and especially corners, the greater the bass level. You may have the "smoothest," most accurate satellite (main) speakers in the world, but they must be positioned to avoid side wall reflections and must be far enough from all walls to reduce resonances.

Near Field Monitoring?

I wouldn't master with near-field monitors, but I will mix with them. Near-field monitoring was devised to reduce the effects of adverse room acoustics, but if your room acoustics are good, then "Mid-field" or "Far-field" will provide a more accurate depth and spatial picture. There must be an obstruction-free path between the monitors and the listener. **What is the biggest impediment to good sound reproduction in a recording studio? The console.** No matter how you position the monitors, the console's surface reflects sound back to your ears, which causes *comb filtering*, the same tunnel effect you get if you put your hand in front of your face and talk into it. Or if you wear a wide-brimmed hat, which produces an irregular dip around 2 kHz. It amazes me that some engineers aren't aware of the deterioration caused by a simple hat brim! Similarly, I shudder when I see a professional loudspeaker sitting on a shelf inches back from the edge, which compromises the reproduction. The acoustic compromise of the console can only be minimized, not eliminated, by positioning the loudspeakers and console to increase the ratio of the direct to reflected path. Lou Burroughs' 3 to 1 rule can be applied to acoustic reflections as well as microphones, meaning that the reflected path to the ear should ideally be at least 3 times the distance of the direct path.

What about measurements?

Can't we just measure, adjust the crossovers and speaker position for flattest response, then sit down and enjoy? Well, since no room or loudspeaker is perfect, measurements are open to interpretation, and frequency response measurements will always be full of peaks and dips, some of which are more important to the ear than others. Which of those many peaks and dips in the display are important and which ones should we ignore?

I've found the ear to be the best judge of what's important, especially in the bass region. The ear will detect there's a bass problem faster than any measurement instrument. The measurement instrument will help to pinpoint the specific problem frequencies, whether they're peaks or dips, and by supplying numbers, aid in making changes. The whole process is very frustrating, and it's inspired my search for setup and test methods that use the ear. A perfect setup still requires a multistep process: listen, measure, adjust, listen again, and repeat until satisfied, but it's possible to streamline that process. Here's a listening test for adjusting subwoofer crossovers that uses simple, readily obtainable and cheap test materials, and that's generally as precise as most more formal measurement techniques! If you're setting up a permanent system, dedicate a day to the process; even the easy doesn't come easy. Some brands of subwoofer amplifiers have all the controls or connectors you need; you may have to adapt the process described below to your particular woofer system.

Polarity is not Phase

This is still a confusing topic, perhaps because people are too timid to say *polarity* when they mean it. The *polarity* of a loudspeaker refers to whether the driver moves outward or inward with positive-going signal, and can be corrected by a simple wire reversal. Remember that *phase* means *relative time*; phase shift is actually a time delay. The so-called *phase* switches on consoles are actually *polarity* switches, they have no effect on the time of the signal! Sometimes this is referred to as *absolute phase*, but I recommend avoiding the use of the term *phase* when you really mean *polarity*. If two loudspeakers are working together, their polarity must be the same. If they are separated by space, or if a crossover is involved, there may be a *phase* difference between them, measured in time or degrees (at a specific frequency). I have a pair of *Genesis* subwoofers with separate servo amplifiers. There are three controls on the crossover/amplifier: volume (gain), phase (from 0 to 180 degrees), and low pass crossover frequency (from 35 Hz to over 200 Hz). Notice there is no high pass adjustment. The *natural* approach to subwoofer nirvana assumes that your (small) *satellite* loudspeakers have clean, smooth response down to some bass frequency, and gradually roll

off below that. It's logical to use the natural bass rolloff of the satellites as the high pass portion of the system and to avoid adding additional electronics that will affect the delicate midrange frequencies. So we use a combination of lowpass crossover adjustment and subwoofer positioning to fine-tune the system.

A good subwoofer crossover/amplifier usually provides more than one method of interconnection with the satellite system. The best is the one which has the least effect on the sound of the critical main system. I prefer not to interfere with the line level connections to the (main) power amp feeding the satellites. If your preamplifier does not have a spare pair of buffered outputs, I recommend using the speaker-level outputs of the main power amp. The *Genesis* provides high-impedance transformer-coupled balanced inputs on banana connectors designed to accept speaker-level signals. Connect the main power amp's output to the sub amp's input with simple zip cord with bananas on each end. No real current is being drawn, so wire gauge does not have to be heavy. Double-bananas make it easy to reverse the polarity of the subwoofer, a critical part of the test procedure. Some subwoofers use a 12 dB/octave crossover, others 18 or more. Interestingly, for reasons we will not discuss here, a 12 dB crossover slope requires woofers that are wired out of polarity with the main system. My new sub crossover uses a 24 dB lowpass slope, which also requires polarity reversal, but to make it easy on the mindless, the internal connections are reversed, and you're supposed to connect "hot to hot" between the main power amplifier and woofer amplifier. Leave nothing to doubt-we must confirm the correct polarity. Steep slopes like 18 and 24 dB are good choices to get the subwoofer to roll off before it interferes with the midrange response.

You have to sit in the "sweet spot" for the listening evaluation. If your subwoofers have an integrated amplifier, you'll need a cooperative friend to make adjustments. Since the Genesis amplifier is physically separate, I was able to move the subwoofer amplifiers to the floor in front of the sweet spot, and make my own adjustments. Here are the two test CDs:

1. The Mix Reference Disc, Deluxe Edition, MRD2A. Since this disc is now out of print, Mix Editor George Petersen has kindly given me permission to put the test tones up on our site so you can make your own custom **Subwoofer test CD**. You can also print a traycard from the PDF file I've provided. You can also use any source of 1/3 octave filtered pink noise.
2. Rebecca Pidgeon, *The Raven*, Chesky JD115, available at record stores, high-end stereo stores, or from Chesky Records.

I recorded Rebecca's disc in 1994. Track 12 is *Spanish Harlem,* which has a slow, deliberate acoustic bass part that makes it easy to identify notes that "stick out" too far and covers the major portion of the bass spectrum. This record has never failed to reveal the anomalies of different rooms and loudspeakers in several years of use as a musical reference. The ear is better with instant comparisons than absolute judgments, and this test relies on our ear's ability to make comparisons. All musical instruments and transducers produce harmonics as well as fundamentals. To the best of our ability to discriminate, we will be concentrating on the fundamental tones in this piece of music. If your loudspeakers have significant harmonic distortion, they can complicate or confuse the test. Many studio loudspeakers are designed for high power handling at the expense of tonal accuracy or distortion. This test is not for them. If you want accurate bass, it's time to replace the loudspeakers and probably hire an acoustician with a distortion analyzer.

Start by evaluating the satellite system with the subs turned off. Listen to the bass at a moderate level equal to or slightly louder than the natural level of an acoustic bass. Listen for harmonic distortion: if it doesn't sound like a "transparent" acoustic bass, fix the problem with the satellites, first. Listen for uneven notes. If the lower note(s) of the scale are successively softer in level than the higher notes, then you have a perfect candidate for a subwoofer. If intermediate bass notes are weak or strong (uneven bass), the satellite loudspeakers may be too close to the corners, in a node or antinode, the listening position may be

in a standing wave, or the satellites themselves poorly designed. It may be time to bring in an acoustician. But if the satellite bass is even, you can move on to the next step, adjusting the subwoofers.
Spanish Harlem, in the key of G, uses the classic 1, 4, 5 progression. Here are the frequencies of the fundamental notes of the bass. If your loudspeaker has sufficiently low harmonic distortion, it will not affect your judgment of the power of the bass notes, which are already affected by the natural harmonics of the instrument.

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                                                  49   62       73           65
82       98             73       93       110
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As you can see, this covers most of the critical bass range. If the lowest note(s) is weaker than the rest, then you are a candidate for a subwoofer. My satellites behave in the classic manner, with the lowest note (G, 49Hz) slightly low in level, but the rest fall in a balanced line. I've been in small rooms where one or more of the intermediate notes are emphasized or weak, which suggests standing wave problems. Repositioning the satellites may help. Avoid equalization, which is a nasty band aid...proper acoustic room treatment is the cure. You could conceivably add a subwoofer out of phase at the frequencies in question, but that's a technique that should remain confidential between you and your analyst. Fix the acoustic problems first and you'll be happier.

If your satellite system passed the initial examination, next step is to decide on a starting (approximate) subwoofer location. A satellite-subwoofer system has tremendous flexibility, offering in theory the best of two worlds. The satellites can be placed on rigid stands at ear level, far from corners and side walls, reducing floor and wall reflections and comb-filtering in the midband. And the subs can be placed on the floor, in the position that gives the most satisfactory bass response, integrated with the satellites. If you only have one (mono) subwoofer, start by placing it in the middle between the stereo speakers. Contrary to popular belief, stereo subwoofers are important, they can improve the sense of "envelopment", the concert hall realism that bass waves are passing by you. Authorities are split on the issue whether a mono or stereo subwoofer setup is more forgiving of room modes. I prefer the sound of stereo subwoofers. A complete discussion of how to place the satellites would require another article, but let's start by saying that you may have to deal with reflections from the side walls by placing absorbers in critical locations. Consider consulting a competent acoustician.

Assuming your satellite system passes the listening test, it's time to find the right crossover frequency, phase and woofer amplitude that will just supplement the lower notes of the scale. Start by placing the subwoofers next to and slightly in front of the satellites. First we must determine the proper polarity for the subwoofers. If your system uses XLR input connectors, build a polarity reversing adapter for this part of the test. This is easier with only one channel playing. Put on the **MRCD** with full bandwidth pink noise, at a moderate level (70-80 dB SPL). Adjust the crossover to its highest frequency, the phase to 0, and turn up the subwoofer gain until you're sure you can hear the woofer's contribution. Reverse the polarity of the sub. The polarity which produces the loudest bass is the *correct polarity*. Mark it on the plugs, and don't forget it!

Next comes an iterative process ("lather, rinse, repeat until clean"). Here's a summary of the four-steps: (1, 2, & 3) Using filtered pink noise, we'll determine the precise phase, amplitude and crossover dial position for *any one crossover frequency*. (4) Then we'll put Rebecca back on and see if all the bass notes now sound equally loud. If not equally loud, then we'll go back to the filtered pink noise and try a different crossover frequency. We keep repeating this test sequence until the bottom note(s) has been made "even" without affecting the others. With practice you can do this in less than half an hour. Adjust each subwoofer individually, playing one channel at a time.
And now in detail:

1) Crossover frequency (lowpass)

Play filtered pink noise (or the Mix CD's multifrequencies) at your best guess of crossover frequency, say 63 or 80 Hz. Notice that the signal has a *pitch center, or dominant pitch quality.* If the subwoofer is misadjusted, adding the sub to the satellites will slide the pitch center of the satellite's signal. Reverse the sub's polarity (set it to *incorrect polarity).* With the sub gain at a medium level, start at the lowest frequency, and raise the frequency until you hear the dominant pitch begin to rise (literally, the center "note" of the pink noise appears to go sharp, to use musical terms). Back it off slightly (to a point just below where the pitch is affected), and you have correctly set the crossover to this frequency. Recheck your setting. That's it.

2) Phase

The sub should always be on a line with or slightly in front of the satellite. With the woofer a moderate amount in front of the satellites, the phase will generally need to be set something greater than 0 degrees. Return the sub(s) to *the correct polarity.* Play the same frequency of filtered noise and increase the amount of "phase" until you hear the dominant pitch rise. Back it off slightly, recheck your setting, and that's it.

3) Amplitude

The subwoofer's settings are exactly correct when its amplitude is identical to the satellite's at the crossover frequency. The subwoofer gain is the easiest to get right because there will be a clear center point, just like focusing a camera. Play the filtered noise, and discover that the pitch is only correct at a certain gain, above which the pitch goes up (sharp), and slightly below which it goes down (flat). "Focus" the gain for the center pitch, which will match the pitch of the satellites without the sub. Recheck your work by disconnecting and reconnecting the sub. The pitch should not change when you reconnect the sub, otherwise the gain is wrong. To be extremely precise, increase the gain in tiny increments until you find the point where the pitch rises when the sub is connected, then back the gain off by the last increment. This process is extremely sensitive.

4) Rebecca

Play *Spanish Harlem* again. If all the levels of the bass notes are even, you're finished with steps 1-4. If you hear a rise in level below some low note, then the crossover frequency is too high and vice versa. Do not attempt to fix the problem with the subwoofer gain, because that has been calibrated by this procedure, which leaves nothing in doubt except the choice of crossover frequency. Go back to step one and try again. Once all the notes are even, your crossover is perfectly adjusted. Write that frequency down. Then, for complete confidence, check the nearest frequency above and below (go back through steps 1-4), proving you made the right choice. This piece of test music is sufficiently useful that there will be a clear difference between each 1/3 octave frequency choice and it will be comparatively easy to determine the winner. The trick is not to rely on our faulty acoustic memory, but on the ear's ability to make relative comparisons.

More Refinement

Fine tuning the stereo separation (space between the woofers)

If you have stereo subwoofers, their left-right separation must be adjusted. Play *Spanish Harlem*. Listen to the sound of the bass with the subs off. It should be perfectly centered as a phantom image and and its apparent distance from the listener should subtend a line between the satellites. If it is not perfectly centered or its image is vague, the satellites are too far apart. Now add the subwoofers. The bass should not move forward or backward, and its image should not get wider or vaguer. Adjust the physical separation of the subwoofers until the bass image width is not disturbed when they are turned on. This "integrates" the system. Go back to step one, recheck the amplitude and phase settings for the new woofer position. Everything is now spot on.

Congratulations, you've just aligned a world-class reproduction system! A subwoofer should not call attention to itself, either by location or amplitude. When you play music, the combination of the sub and mains will sound like a single, seamless source.

Now, after logging your settings, sit back, listen and enjoy. You've earned the time off. Don't let anyone touch those hard-earned adjustments, for you can be confident that they are about as good as they're going to get. Play several of your favorite recordings, and listen to the bass. The bass on the best recordings will be acceptable on your reference system; the worst recordings will have too much or too little bass. Now you can be reasonably sure the problem is in the recording, not your room or woofers. What a nice feeling!

How The Pitch Detection Method Works

The 1/3 octave pink noise signal (or the multitone test signal) contains a narrow band of frequencies, whose dominant level is at the center of the band. Thus, you perceive a "pitch" to the signal. When you add a second loudspeaker driver (the subwoofer) driven by the same signal, if the woofer's output does not exactly match the level and distribution of frequencies produced by the main loudspeaker, there will be a shift in the dominance of the multifrequencies, either towards the high end of the band or the low end, perceived as a pitch shift. When the two signals are well-matched in level, freqeuency distribution and phase, you will hear a delicate increase in level, but no change in pitch. By simple comparative listening, taking the woofer in and out of the circuit, you have confirmed that your drivers are matched at the crossover frequency, and that the wavefronts of your main speakers and subs are aligned at the critical crossover frequency.

Of course, we're making certain assumptions...that:

- your satellite system is well designed, linear and rolls off below some defined frequency.
- your subwoofer system is linear and rolls off above some defined frequency.
- the slopes of the two rolloffs are compatible and will integrate.

Your degree of success depends on how closely the two systems meet those requirements.

What To Do When the Results are Less Than Perfect

When interpreting *Spanish Harlem*, don't get too hung up on little "dips" in level. Dips are less objectionable to the ear than peaks. First, attack problems with resonant notes and then look at the dips. Everything may not be rosy the first time around. Supposing that the subwoofer helped the bottom note(s), which means the crossover is at the right frequency, but some upper note in the progression has been affected. This means the subwoofer position is not optimized, or the subwoofer has some frequency response anomaly. As the sub is moved towards the room corners, the low bass response goes up, previous dips become peaks. There's cancellation/reinforcement between the subs and the satellites, which changes complexly as the sub is moved. Thus, adjusting the subwoofer position is a powerful method to even out the bass, but this type of trial and error is too complicated without test equipment. You could slide the woofer slightly, adjust the crossover as above, listen, move it again, readjust, and listen, but our acoustic memory is too short to tell when we've hit the perfect spot.

Advanced Techniques

Integrating the Instruments with the Ears

Here's where it gets complicated. If you are having problems with uneven bass, we can no longer rely strictly on our ears. If you're comfortable with measurement instruments, then let's proceed. First, listen to Rebecca and mark down the problem frequency or frequencies, either peaks or dips. You'll use that knowledge when you bring in the big guns, the 1/3 octave analyser. The good thing is that Rebecca has already told you where the problems are, so you'll know how to separate the forest from the trees in the 1/3 octave display. I used *Spectrafoo* (an excellent analysis program for the Mac) in transfer function mode with wide band pink noise into both satellites and subs (one channel at a time). *Spectrafoo* time aligns the stimulus and response, which helps to separate direct from reflected sound, more accurately representing

what the ear hears. *Spectrafoo* revealed a rising response in my room below 40 Hz, and more important, a little dip in the combined response circa 63 Hz which corresponded with my perception that note was perhaps a little weak. By moving the sub around very slightly and watching the display, I was able to exchange the weakness against the surplus without aggravating any other peaks.

The strength of this method is we're continuously integrating our powerful (almost objective) listening judgments with the "over-powerful" analysis tool. We're using the analyser for general trends, not absolute amplitudes; that's what I mean by separating the forest from the trees. The position of the test microphone should be in the exact listening position. Wear earplugs to keep your ears fresh when you're not required to listen. After moving the woofer, don't forget to readjust the crossover gain and phase with our listening technique.

If all goes well, *Spanish Harlem* will be even better adjusted and we can rest assured that our system is **really really tweaked.** Now sit back and enjoy. Oops, your work is never done. Now that you've adjusted your system, I'll let you in on one more secret: Servo amplifiers have internal adjustments that affect woofer damping, make the bass "tighter" or "looser." but that's another story.

Acknowledgments:

Jon Marovskis of Janis Subwoofers introduced me to the concept of a pitch detection technique many years ago. This article refines and expands on his original idea.

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Acoustician Johnson Knowles suggests a viscoelastic polymer pad material like EAR Isodamp C1002 or C1000. The internal damping characteristics ofthe viscoelastics are exceptionally effective as a speaker to stand interface material.

U.S. Consultant Steve Desper recommends STIK-TAK by Devcon Corporation, available at your local hardware store. It's a cheap solution and works well. Australian Greg Simmons has found a similar product--marketed as *Blue Tak*: "Use enough of it relative to the weight of your speakers. For a small monitor weighing just over 20kg, I used four balls about 15mm in diameter (one under each corner). With 20kg on top of them, these balls squashed down to about 4mm or 5mm thickness, and held the monitor very firmly."
