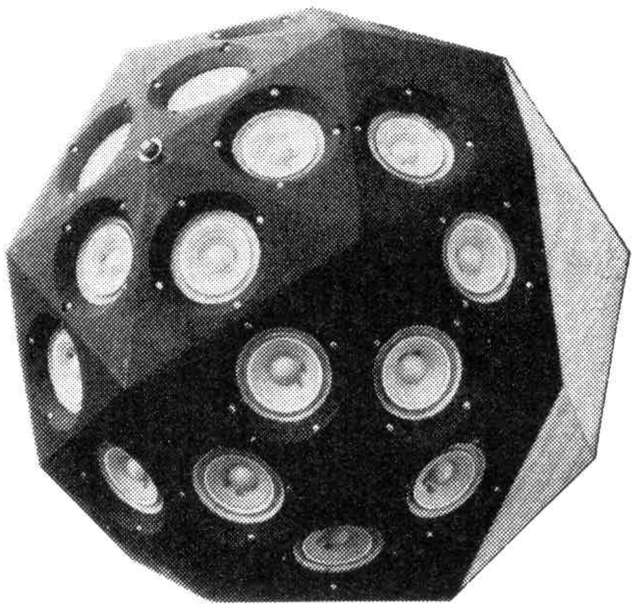
Building a Dodecapentagon

by Chris Huntley



Before the Dodecapentagon was conceived, it was my aim to acquire a speaker system capable of reproducing in a conventional living-room the same peak sound pressure levels that one would hear in a good theater seat during symphony concert fortissimos; and to do so with as little distortion and tonal coloration as feasible. At this point, the cost and size involved were not of concern; but in fact they turned out to be quite reasonable – and certainly not limiting factors. Determination of the peak sound pressure levels involved took considerable research, for such figures are not common in the technical literature – probably due to the lack, until very recently, of peak-reading sound-level meters. The best estimate from published studies give average level readings of 95 to 105 dB, with peak factors guessed at 15 dB – indicating true peaks of 110 to 120 dB. Measurements made later with a true peak-reading meter at Vancouver Symphony concerts have confirmed the validity of this estimate. The zero reference for the sound-pressure dB scale is 10^{-12} watts/m^2; so, to sustain 120 dB in a typical living room with a room-constant of $30m^2$, requires a source of 30 acoustic watts, In this manner, it was determined that the speaker system should be capable of generating 3 to 30 acoustic watts in the low- to mid-frequency range where the fundamental power of musical instruments is located. Though a wide frequency-response covering the range of audibility is a worthwhile goal, the range from 200 to 1,000 Hz is particularly critical, as the ear is most sensitive to tonal colorations in this range. Therefore, any system design should keep coloration sources, such as crossover frequencies and cone- breakups, out of this range.

Bookshelf Systems

The bookshelf speaker has been very popular in recent years, due to its compact size and the commendably wide frequency range that has been achieved. Unfortunately, this has been obtained at the expense of efficiency, which is typically about 0.3% at midband for very good units. To produce 3 to 30 watts output, one would therefore need 1 to 10 kilowatts input – somewhat above their power handling capability. But these figures do show why owners of these units are now buying kilowatt amplifiers in an attempt to reproduce realistic listening levels.

Horn Systems

The acoustical impedance matching of a horn structure gives these systems a much higher efficiency – typically about 10%. Furthermore, the matching greatly reduces the diaphragm excursion and, hence, the AM- and FM-caused distortion products. However, several horns are needed to cover the whole spectrum (since one unit should only cover four octaves), the resultant complex and different-length acoustic paths, plus the crossover networks, may be expected to cause problems with the transient performance and tonal coloration. Maybe some systems are good but how can one find out?

Console Systems

Compared to a "bookshelf" system, a console system has a much larger internal volume that allows the designer to increase the system's efficiency, lower the low-frequency cutoff, or a combination of both. A resonant port may also be used to extend the bass cutoff, but the net results are often of dubious merit. A real problem with these systems is that the lower crossover frequency and cone-breakup of the woofer both lie in the critical 200 to 1,000 Hz range and, as with horn systems, such information is hard to find.

The Dodecapentagon

Thinking about these short- comings led to a thorough analysis of the problems involved, so that the facts could be sifted from the wealth of old-wives-tales about speaker design; and this, in turn, resulted in conception of the Dodecapentagon. The Dodecapentagon is a sphere made from sixty identical triangular wooden sections arranged in twelve groups of five (hence the name). Each section would contain a loudspeaker if the system were to be used omnidirectionally; but, for its intended corner application, only the twenty-two forward-facing sections were so equipped. The unit is an infinite baffle type (no ports); and, to prevent internal standing- waves, the interior is filled with 800 grams of Fraser-Valley long-hair sheep's wool, which is renowned for its acoustical absorption properties. The Dodecapentagon has excellent dispersion since the system generates a spherical sound-wavefront. There is no on-axis and off-axis. The cabinet contributes no tonal coloration, as the structure has no flat panels to resonate, and no corners to cause diffraction effects. These are common problems with box structures. Coloration caused by cone-breakup is also reduced – for a conventional system with a 30 to 40 cm (12 to 15") woofer, these resonances show up in the critical 200 to 1,000 Hz range, whereas for the 12 cm (5") units in the Dodecapentagon they are pushed up above 1,500 Hz. Furthermore, normal production tolerances in the twenty-two units will further reduce the audibility of any such effects. Another feature of the system is its high efficiency. The most significant performance improvements stem from the acoustical interaction of the twenty-two units, which causes the efficiency of the system at frequencies below about 1,000 Hz to be twenty-two times the efficiency of an individual unit. This may be intuitively appreciated by considering the pressure at a distant location – when all units are energized, this will be twenty-two times larger than for a single energized driver (the motion of each is mass-controlled, independent of the air load). This is an increase of 484 times in acoustic power, so the efficiency has actually increased by a factor of twenty-two. The frequency response of the system below 1 kHz is well defined by the lumped acoustical constants of the drivers and the enclosure. Above 1 kHz the response will drop because of the loss of efficiency as the shorter wavelengths reduce the acoustical coupling; and further out the response will drop again as a result of the reduced efficiency of the driver units caused by cone losses and a rising voice-coil impedance (on-axis responses stay flat due to a progressively beamed response). Because of this, the Dodecapentagon requires compensation with an active equalizer ahead of the power amplifier. Such an approach is different from the normal one of fiddling the driver units and cabinet to get a flat response; but, as has been shown, it yields very worthwhile improvements in the areas of efficiency, distortion, and tonal coloration.

Construction of the Dodecapentagon

To simplify construction, it was decided to make all the triangular sections identical, though the calculation of the angles involved was quite formidable. The circular cut-outs for speakers were beveled to reduce coloration from that area. All twenty-two speakers were wired in parallel to avoid any potential interaction between units with different impedance characteristics. It thus created a somewhat low (0.4 ohm) load impedance, necessitating the use of electric range cable to connect it to a custom power-amplifier (delivering 25 amps at 10 volts peak). For use with a conventional amplifier, one can obtain satisfactory results using twenty or twenty- four units in a series-parallel array if all units in each series string are matched for resonant frequency. The speakers used were inexpensive 12 cm units with a high-compliant 'acoustic suspension' surround, giving a free-air resonance around 120 Hz and a respectably flat treble response.

Distortion

Followers of loudspeaker reviews will have noticed that IM distortion figures have been conspicuous by their absence. They may also perhaps be forgiven for doubting the credibility of distortion curves that indicate a non-linearity mechanism independent of drive level. Harmonic distortion products *per se* are not audibly detrimental, since all musical instruments themselves generate overtones; but, unfortunately, if more than one note is present, the non-linearity involved will also generate a myriad of intermodulation products, most of which are discordant. Furthermore, there are other considerations, such as the Doppler effect (which causes IM, but not harmonic products), and non-linearities in treble units where the harmonic products fall above cutoff but many of the intermodulation products fall in the more-audible lower frequencies. Paul Klipsch has published many results of 2-tone IM tests to compare his horn system to conventional systems (showing a significant difference); similar tests on the Dodecapentagon indicate a linearity approaching that of the horn.

Conclusion

The increased efficiency and power-handling capability of a spherical array of small speaker units give a considerable performance improvement over conventional systems, and have enabled achievement of the original design objectives in a modest size (70 cm diameter) and for a modest investment (about $100 per system). The system has now been running for over two years, allowing a retrospective evaluation of the original objectives on the basis of my own reactions, and those of others. The design philosophy is valid: a good, clean record of suitable content played at a level peaking at 110 to 120 dB SPL does not sound too loud (in fact it sounds unnaturally quiet if played lower). On the other hand, an increase of distortion, particularly high-frequency IM (which frequently shows up on the inner- band of records), makes such a level unpleasant – females in particular seem to get distressed more quickly under such conditions.