“Tiny” Audio DSP Core & Tools

and

MajEq Auto-Tuning System

An introduction and overview

Oxford Digital

1. About Oxford Digital Limited

1.1 Background

- Oxford Digital Limited (ODL) is an independent company that was spun out of Sony's Oxford Pro-Audio Lab in June 2006. Sony has no retained interest in ODL.
- ODL's core strength is in its engineering team of highly experienced audio design engineers with a diverse skills set that provides end-to-end project coverage
- ODL's core businesses:
  - Technology Licensing:
    - Tiny DSP Core and Toolset – an end-to-end audio DSP solution
    - Oxford Digital EQ – for real-time arbitrary frequency response creation
  - Contract Research and Development
    - Problem solving and development of new Intellectual Property for clients
    - Accelerating Time to Market
    - Provision of specialist skills
    - Integration/customisation of TinyCore and Oxford Digital EQ for client applications

1.2 The ODL Team

Team skills include:

- Processor architecture development
- Firmware and HDL for FPGAs and ASICs
- Maths and signal processing algorithm development
- DSP effects and algorithms
- System Architecture/System Level design
- Hardware design
- All types of software (including real-time embedded)
- Core Research and Development
- Collaboration with our clients and their customers (where required)

These broad skills allow us to handle, as required, all parts of a project from concept through to customer support for our clients

1.3 Customer Base

Customers who have kindly released us from our NDA for the client list include:

(USA) [Denon, Marantz, …]	www.dm-holdings.com
(Germany / UK)	www.dialog-semiconductor.com
(UK)	www.sadie.com
Sony Ericsson Mobile Company (Japan)	www.sonyericsson.co.jp
Sony Semiconductor (Japan)	www.sony.net
(USA)	www.srslabs.com
(USA)	www.ti.com/audio
(UK)	www.warwickaudiotech.com
Commercial Audio (Japan)	www.yamaha.com

2 TinyCore and Tools

2.1 Concept and Unique Selling Points (USPs)

Provision of a “world class” end-to-end solution for audio DSP that provides:

- A comprehensive design environment and toolset
- Very fast work-flow through the use of high-level front-end hierarchical Graphical Programming Environment, Core Synthesis and back-end “Tuning” tools
- Very low gate count solutions for FPGA and ASIC
- Very efficient execution (e.g. only 5 instructions for a bi-quad filter with saturating arithmetic)
- Compact code: the high level compiler produces code that on average is 10% smaller than that produced by an expert Assembly Level programmer
- A scalable solution in bit-width, sampling frequency, instructions per sample and number of channels
- Automatic software re-use for different configurations of the TinyCore; no changes are required at the top design level as the compiler produces the required executable code automatically
- Support for encrypted code to allow effects manufacturers (e.g. SRS Labs Inc.) to provide library items that remain private (i.e. it is not possible to push down through the hierarchy to see the internal workings)
- HDL that is easily portable across different FPGAs and ASIC processes and geometries
- Audio DSP Effects library
- Real-time adjustment of parameters (whilst listening) on either evaluation boards or target hardware
- Real-time injection of test signals and ‘scope probe’ type debugging/audio monitoring
- Provision of Test Bench and Test Vectors for the Core including the ability to simulate the DSP output from the Graphical Programming front-end. Semiconductor manufacturers can validate their results by simulating the TinyCore including the desired effect pre- and post- synthesis as part of the sign-off process
- Extremely fast Time to Market for both FPGA and ASIC implementations through the use of the Tiny Toolset (e.g. delivery of DSP code for an application together with HDL for a custom core in 6 days)
- Provision of programmability (as opposed to fixed architecture) by use of the TinyCore de-serialises development of algorithms and silicon and allows substantial overlap in the process, thus reducing time to market even further

2.2 Typical Applications

The TinyCore is scalable and can be used in numerous applications including:

CE Equipment Sound Quality Improvement

Addition of DSP in a Class-D Amp or ASIC elsewhere can improve the sound quality of:

- Accessory Speakers
- Headphones
- Flat Panel TVs
- Personal and Handheld Devices:
- Cell Phones
- Flash and HDD MP3 Players
- PDAs
- Digital Still Cameras
- Portable Gaming Consoles
- Portable Navigation Systems

by:

▪ Removing loudspeaker and cabinet resonances	*for a clear and natural sound*
▪ Extending Bass Frequency Response	*for richer bass*
▪ Increasing Loudness with low voltage drivers	*for stronger performance*
▪ Restoration of MP3 compressed music	*for better sound quality*
▪ Dynamic Range Control	*to assist listening in noisy environments*
▪ Stereo Widening on devices such as Cell Phones	*to give a wide image*
▪ Dialogue Processing	*to improve speech intelligibility*

High End Equipment

FPGA solutions for higher end consumer and professional equipment that provide the ultimate in quality DSP audio processing are extremely practical and cost-effective platforms. Examples include Pro-Audio speaker management and cross-over networks and processing in recording consoles.

2.3 The TinyCore

The TinyCore supports stream-based processing of time domain audio samples including single cycle multiply-adds, and multiply-subtracts. With built in support for sample delay memory of varying size and automatically saturating arithmetic instructions, the TinyCore makes it possible to design a bi-quad filter in five instructions.

TinyCore is a reconfigurable RTL model that permits synthesis of FPGA and ASIC gate-level netlists with these parameters:

- 1 - 32 audio I/O channels
- data path bit width from 16 to 48 bits (in steps of 2 bits)

- 128 - 8192 instructions per audio sample period to process all I/O channels
- 1 - 3 data storage RAMs each independently containing between 2^5 and 2^12 data words
- optional external memory interface for large delays (e.g. sparse FIR filters, reverbs)
- support for encrypted code (so that effects manufacturers (e.g. SRS Labs Inc.) can allow their effects to be used securely and remain private)

The core makes no assumptions on master clock frequency and so is independent of audio sample rate. It is optimised for low power and low gate count through a configurable memory access method and a split multiplier design.

A Gate Count Calculator is available (under NDA) that allows examination of various options of key parameters

2.4 Graphical Programming Environment

The Graphical Programming Environment (GPE) is a fully hierarchical design tool that allows rapid design and prototyping of DSP and algorithms with the ability to control parameters and hear/measure results in real-time.

The GPE includes:

- **TinyDraw**
  A hierarchical schematic entry tool
- **TinyNice**
  Optimising compiler (18 passes in the blink of an eye)
- **TinyGCon**
  A GUI Control interface that provides real-time parameter adjustment
- **Evaluation Board**
  Both ASIC- and FPGA-based evaluation boards are available. These allow DSP algorithms and effects to be developed and used in real-time either connected to the development environment or stand-alone in prototype equipment for evaluation purposes.

Figures 1 to 3 show some of these features.

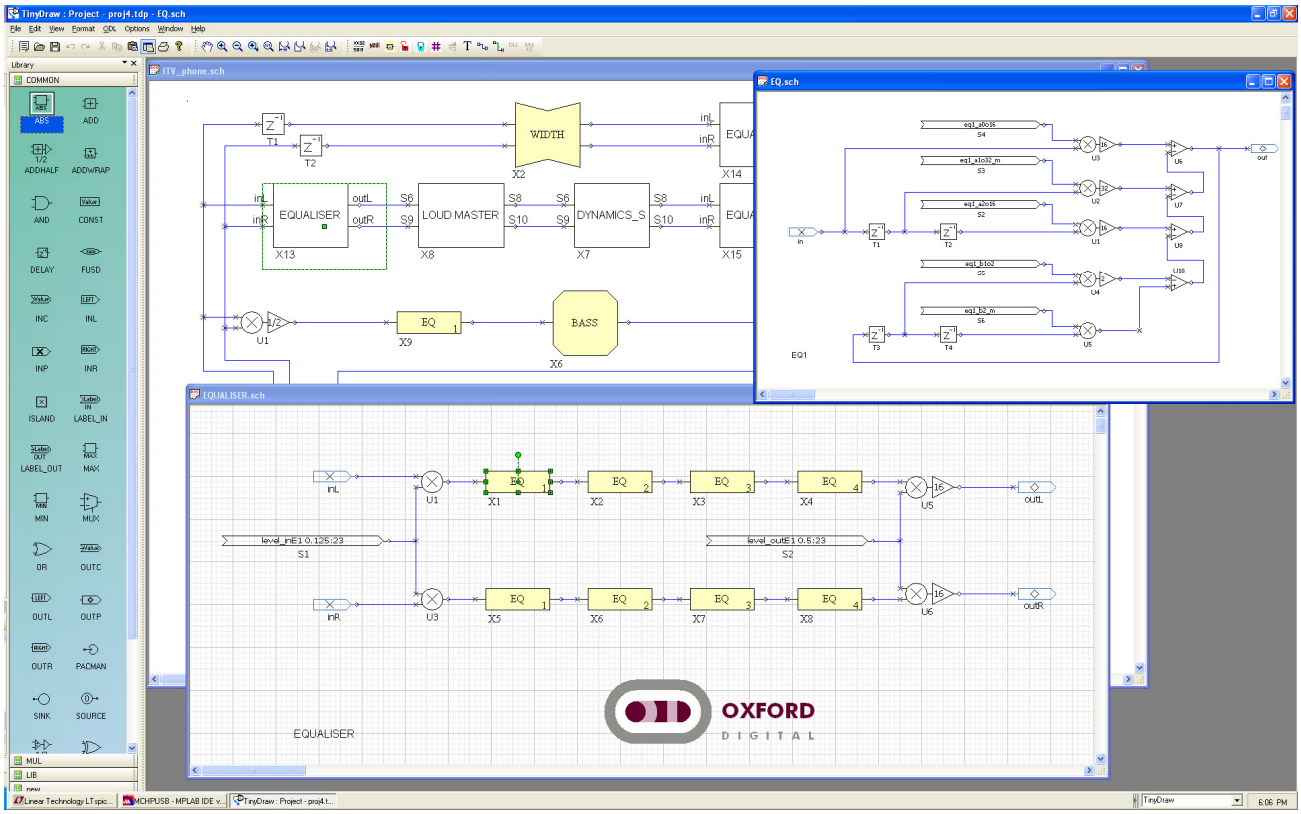

Fig. 1 *TinyDraw Screen:* Component selection Left, high-level Cell Phone application in background, expansion of EQ block in mid-ground and detail of an EQ element in foreground (3 levels of hierarchy shown here)

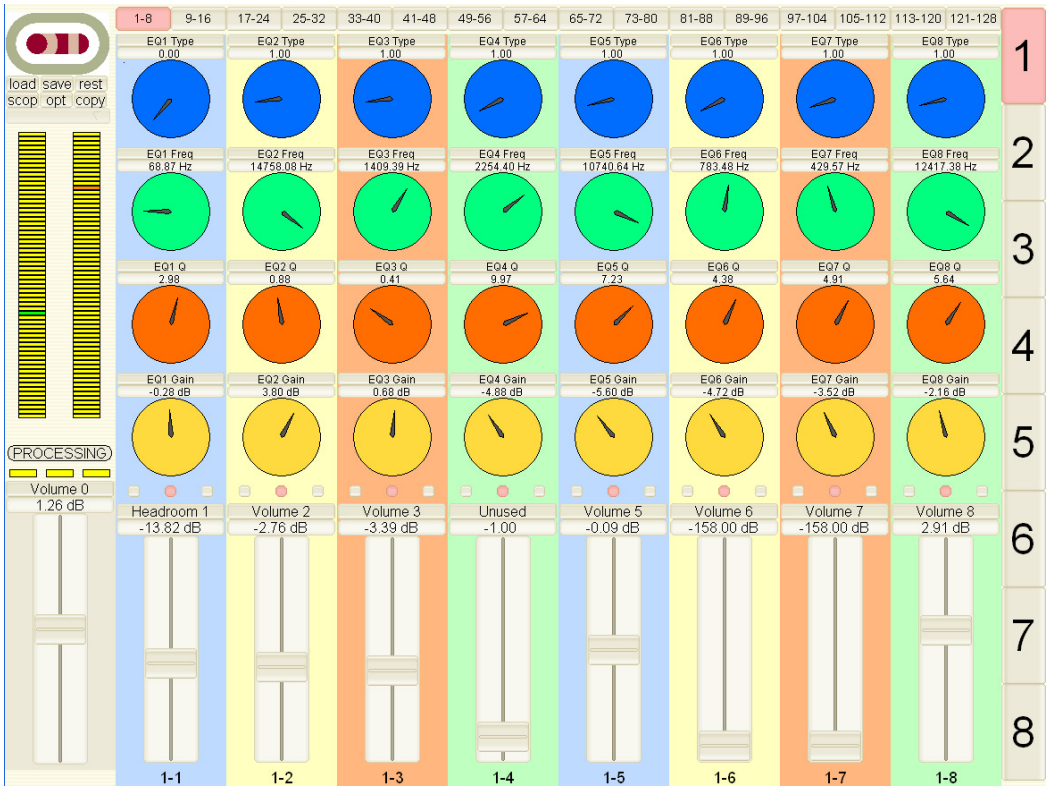

Fig. 2 *TinyGCon GUI Control interface:* This shows 1 of the 16 pages of controls that can be assigned to control parameters in real-time and the 8 scene tabs on the RHS which can be used to compare different settings

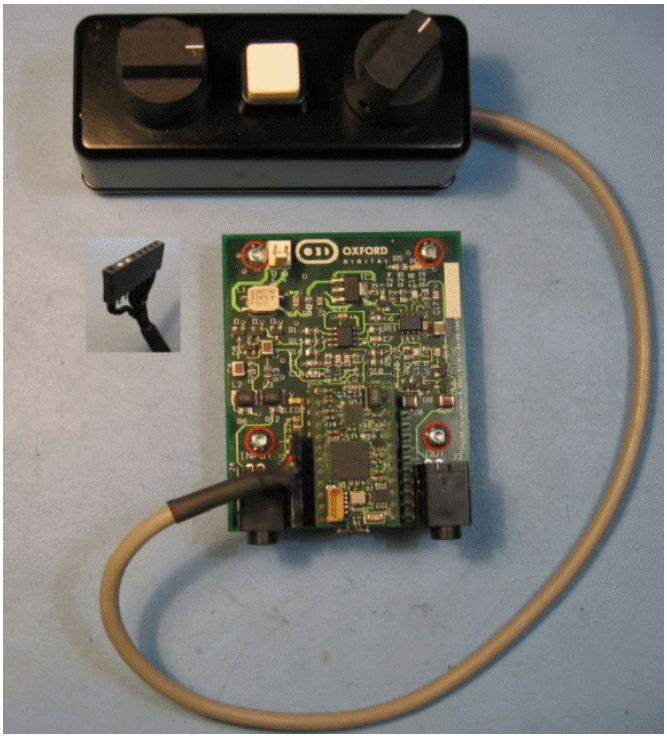

Fig. 3 *Evaluation Board with Control Box for Stand-alone operation.* This can be embedded in equipment to demonstrate the effect on/off and to choose different 'scene' pre-sets.

2.5 Effects Libraries

An Effects Library is available for use with the GPE. It includes effects such as:

- Various Filter and EQ configurations
- Several types of Bass Enhancement that address different speaker deficiencies
- Compressor
- Limiter
- ***LoudMaster*** (an effect to make sounds louder without increasing peak level)
- ***EdgeMaster*** (an effect that modulates transients to add punch (+ve) or reduce transients (-ve))
- Noise Gate

2.6 Third Party Effects

SRS Labs Inc., the industry leader in surround sound, audio, and voice technologies, announced at CES 2010 the availability of SRS StudioSound HD™ for Oxford Digital's TinyCore processor. With a pre-ported and optimized library for StudioSound HD, Oxford Digital licensees and SRS StudioSound HD licensees can quickly and efficiently integrate the remarkable all-in-one audio solution into their TinyCore-based SoCs, multimedia processors and TV designs through simple firmware integration.

2.7 CE Tuning Tool

This tool allows the sonic performance of CE equipment such as Flat Panel TV, AV, Accessory Speakers, Cell Phones, GPS systems to be improved with the objectives stated in 2.2 above. The Tuning Tool includes pre-configured DSP that runs on a TinyCore and includes the following effects:

- Many EQ sections for control of cabinet and speaker resonances
- Two different types of BassMaster Bass Frequency extension to cope with the different problems inherent in a wide range of equipment
- LoudMaster which increases subjective loudness without the need to increase peak drive voltage. This is extremely useful in portable and mobile equipment with low PSU voltage.
- Effects to restore richness of mp3 and other compressed music
- LevelMaster which is able to seamlessly adapt the dynamic range to make sounds clear in a noisy environment
- Stereo Widening

The parameters in the DSP are set up for each particular model produced using a simple one page real-time GUI shown in Fig 4.

Once the optimum parameters are identified for a particular model of CE equipment that has a chip incorporating the TinyCore designed in, the parameters can be exported for inclusion in ROM in the production line.

Training is available to allow engineers with good listening ability to become expert in Tuning the CE equipment with the (EasyTune) Tuning Tool.

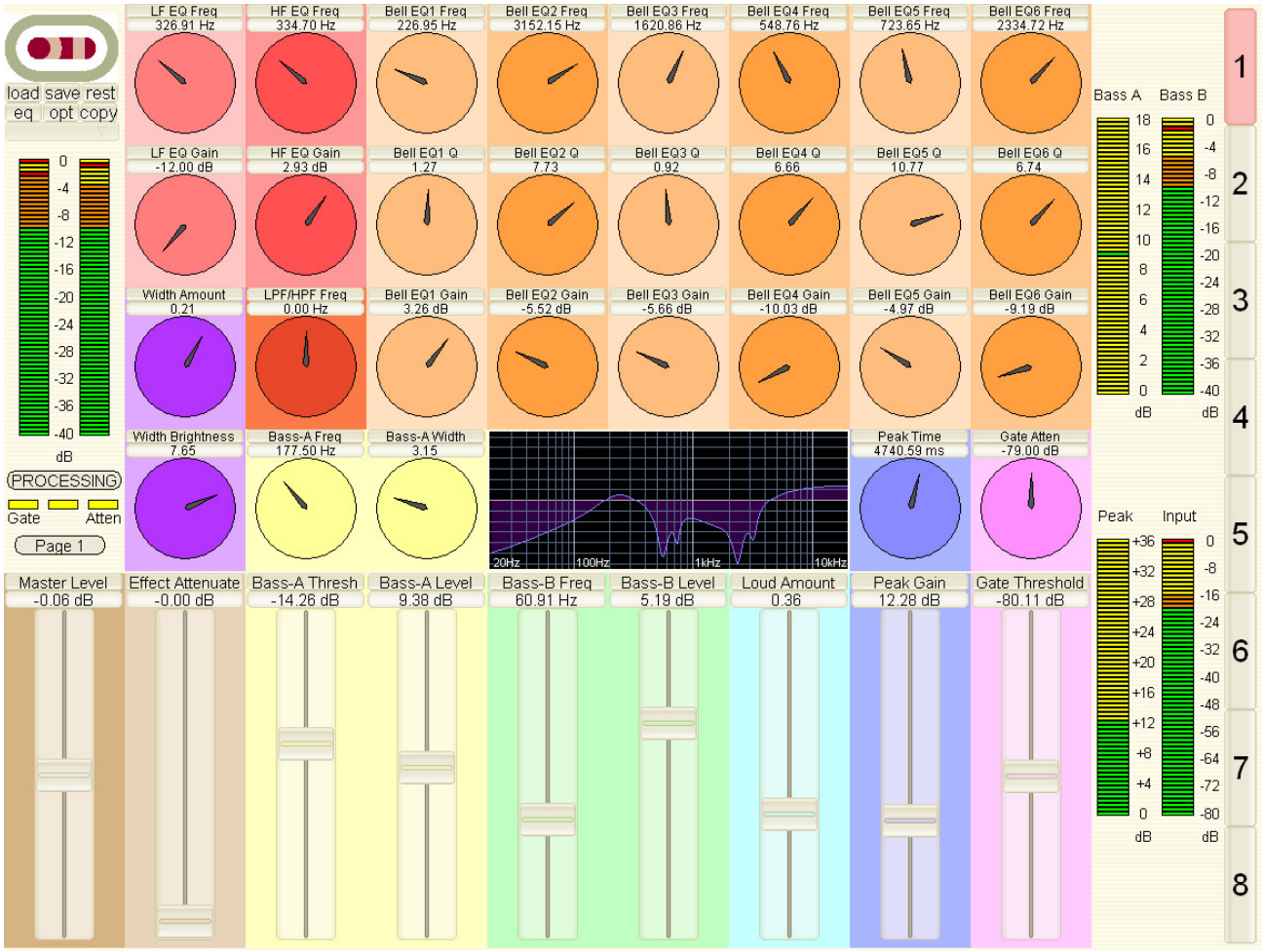

Fig. 4 *Tuning Tool GUI* – Frequency Display can be enlarged by clicking on it.

3 MajEq Auto-Tuning Tool

3.1 Concept

The MajEq system incorporates the following:

- Measurement system to capture the frequency response of CE devices including speakers and headphones
- Alternatively, measurements can be imported from external systems (e.g. SMAART, SysTune)
- Means to produce a correcting “target” EQ curve
- Means to select the useful band where correction should be applied (so as not to over-drive speakers outside their useful range thus avoiding nasty noises and damage)
- Means to define a fixed DSP budget (e.g. 5 bi-quads)
- More efficient use of the DSP budget than conventional parametric EQs – up to 40% fewer poles
- Means to automatically produce the correcting EQ curve with guaranteed convergence within a few seconds
- Means to “edit” the correcting response via familiar EQ controls (filters, parametric EQs) if it is desired to over-ride the measurement system – all within the same defined DSP budget
- Means to layer additional EQ (e.g. Classical, Pop, Jazz, Rock curves &/or regional sounds) – all within the same defined DSP budget

A typical result produced by the MajEq system is shown below in Fig. 5:

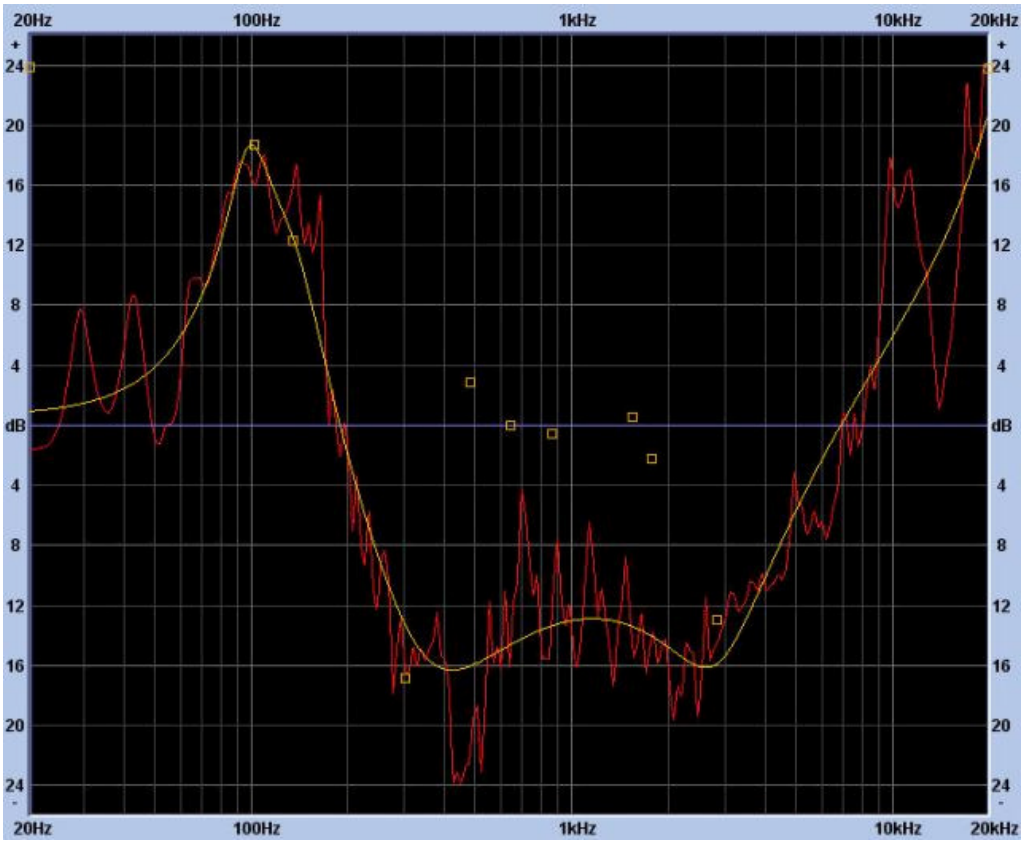

Fig. 5 *Using the MajEq system*: Use of 5 bi-quads produces this curve within a few seconds

It can be used with the TinyCore Tuning Tool or else used stand-alone with any bank of standard bi-quad sections.

3.2 Unique Selling Points

The USPs associated with the Oxford Digital *MajEq* system and tuning methodology are:

- *MajEq* can be used stand-alone or integrated into the CE Tuning Tool to provide a complete solution for both automated frequency response equalisation of Enclosure/Driver and for adding corrective effects (e.g. Bass Enhancement), assistive effects (e.g. Dynamic Range Control for increased intelligibility in noisy environments) and aesthetic audio effects (e.g. Stereo Widening)
- The Measurement System is included
- Measurements can also be taken by external systems (e.g. SMAART, SysTune) and imported into the system
- A fixed DSP budget for equalisation and aesthetic tonal correction can be defined (i.e. the number of bi-quads available)
- It makes extremely efficient use of the limited equalisation DSP in the device – up to 40% more efficient in terms of poles than a conventional parametric EQ
- Ability to modify frequency response via familiar controls (like filters, tone controls & parametric EQs) with no extra DSP
- Ability to layer additional EQ (Rock, Classical, Pop, Jazz, regional sound preferences) with no extra DSP
- Fast workflow (hours or even days using conventional parametric EQs for response equalisation can be reduced to minutes)
- It allows deskilling of the task as relatively unskilled people can produce good results
- It's a low latency, low processing budget solution
- Aspects of the *MajEq* system is covered by UK Patent Application Publication No: GB 2 458 631 A, International Patent Application Publication No: WO2009/112825 and UK Patent Application No: 0922702.6 .

4 Marketing Activities

4.1 Technical Papers

Oxford Digital has presented technical papers at several conferences worldwide (see Appendix A).

4.2 Conventions and Exhibitions

Oxford Digital has sponsored and exhibited at many conferences and exhibitions alongside other leading brands – see selection below.

Fig. 6 *Examples of Trade Shows, Exhibitions and Conference Sponsorship*

5 Contact Information

We are happy to discuss any of the issues above (or indeed any other audio-related issues) in more depth. Please contact:

Name: John Richards, CEO

E: john.richards@oxford-digital.com

T: +44-845-450-5664
F: +44-845-450-5663

W: www.oxford-digital.com

APPENDIX A

Selected Oxford Digital Technical Papers

1. P. Eastty, “Digital Audio Processing on a Tiny Scale: Hardware and Software for Personal Devices”, Paper Number 7207, AES 123rd Convention, New York, October 2007.
2. N. Bentall, P. Eastty and D. Stott, “An Efficient, Low-Noise Filter Architecture for Bass Processing on a DSP Core”. Paper Number 7351, AES 124th Convention, Amsterdam, May 2008.
3. N. Bentall, P. Eastty and D. Stott, “Tiny DSP: DSP Core, Algorithm Development and 'Device Mastering’”. Paper Number 6 AES 34th International Conference: New Trends in Audio for Mobile and Handheld Devices, Jeju Island, South Korea, August 2008.
4. P. Eastty, “Accurate IIR Equalisation to an Arbitrary Frequency Response, with Low Delay and Low Noise Real-Time Adjustment”, Paper 7639, AES 125th Convention, San Francisco, October 2008.
5. UK Patent Application Publication No: GB 2 458 631 A, “Improving audio equalisation and filtering to address problems of disruptive phase response in graphic equalizers”.
6. International Patent Application Publication No: WO2009/112825, “Improving audio equalisation and filtering to address problems of disruptive phase response in graphic equalizers”.
7. UK Patent Application No: 0922702.6, “Determining a configuration for an audio processing operation”.