

Designing Audio Circuits and Systems

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- Key Parameters and Types of Crossfeed
- Implementation Issues
- Benjamin Bauer Crossfeed Circuit
- Sigfried Linkwitz Crossfeed Circuit
- Chu Moy Crossfeed Circuit
- Adding Delay
- Jan Meier Crossfeed Circuit
- Active Crossfeed Circuits
- Relative Benefit of Crossfeed

21.8 Low-Frequency Equalization Circuits

- The Linkwitz Transform

21.9 Hearing Loss Protection

- Hearing Loss SPL Levels
- Noise Exposure Computation
- Accounting for Headphone Sensitivity
- Hearing Loss Protection Circuits

22. Volume, Balance, Fader and Panning Controls

22.1 Potentiometer Volume Controls and Faders

- Faders
- Resistance Elements
- Tapers
- Wiper Noise
- Wiper Resistance
- Wiper Loading Effect on Attenuation
- Wiper Loading Distortion
- Output Impedance and Thermal Noise vs. Rotation
- Tracking, Matching and Trimming
- Changing the Taper Law
- Motorized Potentiometers

22.2 Baxandall Active Volume Control

22.3 Switched Attenuators

- Granularity
- Relay Switches
- Ladder attenuators
- Active Switched Attenuators

22.4 Integrated Circuit CMOS Volume Controls

- Zipper Noise
- LM1972 μ Pot 2-Channel 78 dB Audio Attenuator
- PGA2311 Stereo Audio Volume Control
- PGA2320 Stereo Audio Volume Control
- MAX5486 Stereo Audio Volume Control

22.5 Voltage Controlled Amplifiers (VCA)

22.6 Balance Controls

- Balance Control Behavior
- Wiper Crosstalk

22.7 Pan Pots

- The Pan Law

Voltage Controlled Pan Pot

22.8 Loudness Controls

23. Digital-to-Analog Converters

- DAC Design
- How Audio DACs Work
- The DAC

23.1 The Analog Interface

- Output Amplifier
- Voltage-Output DACs
- Current-Output DACs
- DC Servo for Common-Mode Offset Control
- Common-Mode Rejection
- Other DAC Chips
- TIA Noise and Speed
- TIA Distortion
- Output Filtering
- DAC Output Capacitance

23.2 Power Supplies, References and Grounding

- Op Amp Power supply
- DAC Chip Analog Power Supply
- Reference Supply
- Grounding

23.3 Clock Recovery and Jitter

- Phase-Locked Loops
- Clock Recovery
- Jitter
- Transition Density Jitter
- VCO Phase Noise
- Re-Clocking I²S Signals
- Clocking the DAC Chip with a Fixed Clock
- Asynchronous Sample Rate Converters
- S/PDIF Manchester Coding

23.4 Digital Audio Interfaces

- I²S Digital Audio Interface
- Digital Audio Interface Receivers
- USB Digital Audio Inputs

23.5 Digital Audio Sampling and Transmission

- Sampling and Reconstruction
- The sinc Function and Zero-Order Hold

23.6 Interpolation and Decimation

- Interpolation
- Decimation
- Up-Sampling and Down-Sampling

23.7 R2R DACs

- Quantization Noise
- Oversampling to Increase Effective Bits
- Segmented DACs

23.8 Sigma-Delta ADCs

- Sampling Theorem, Interpolation and Decimation
- Delta Modulation
- Sigma-Delta Modulator and Noise Shaping
- Second-Order $\Sigma\Delta$ Modulator
- Higher-Order $\Sigma\Delta$ ADCs
- Multibit $\Sigma\Delta$ ADCs
- Conversion to PCM

23.9 Sigma-Delta DACs

- Reconstruction Filter
- Imaging
- Intra-Sample Signal Peaks

23.10 Control Interfaces

- I²C Bus
- SPI Bus

24. Active Crossovers and Loudspeaker Equalization

24.1 Subwoofer Crossovers

- Crossover Frequency and Slope
- Phase Control

24.2 Advantages of Active Crossovers

- Active Crossover Example
- Reduced Dependence on Amplifier Performance
- Amplifiers Tailored to the Drivers
- Improved Driver Control
- Reduced Distortion in the Crossover
- Reduced Impedance Interactions
- Crossover Flexibility, Precision and Channel Matching
- Active Circuit Phase Correction
- Improved Imaging
- System Voicing and Driver Equalization
- Isolation of Clipping Events
- Active Baffle Step Compensation
- Bass Response Extension
- Absence of Speaker Cables

24.3 Disadvantages of Active Crossovers

24.4 Self-Powered Loudspeakers

24.5 Types of Crossovers, Roll-Off Slopes and Phase Relationships

- First-Order Crossover
- Time Alignment, Non-Coincident Drivers and Lobing Error
- Vertical Lobing Error
- MTM Driver Arrangement
- Phase Shift and Group Delay
- Crossover Slopes
- Second-Order Butterworth Crossovers
- Third-Order Butterworth Crossovers
- Fourth-Order Butterworth Crossovers

24.6 Conventional Crossovers

- Second-Order Butterworth Crossovers
- Third-Order Butterworth Crossovers
- Fourth-Order Butterworth Crossovers

24.7 Linkwitz-Riley Crossovers

- Second-Order Linkwitz-Riley Crossover
- Fourth-Order Linkwitz-Riley Crossover

24.8 Three-Way Crossover Architectures

24.9 3.5-Way Loudspeakers

24.10 Time Alignment

- Active Delay Networks for Time Alignment

24.11 Crossover Filter Design

- Driver Correction
- Crossover Effect on Imaging

24.12 Active Baffle Step Compensation

24.13 Woofer Equalization – Linkwitz Transform

24.14 Equalized Quasi-Sealed System

- A Vented System Acting Like a Sealed System
- Equalizing the Quasi-Sealed System
- Achieving Higher SPL at Low Frequencies
- The Equalizer

24.15 DSP Crossovers

24.16 SPICE Simulation

25. Voltage Controlled Amplifiers (VCAs)

25.1 Translinear Circuits

- Emitter-Driven VCA
- Transconductance Paradigm
- Base-Driven VCA
- Distortion
- Noise
- Control Linearity
- Control Feedthrough

25.2 VCA Circuits

- Baskind and Rubin VCA
- Feedback VCA
- Frey VCA
- Blackmer VCA

25.3 VCA Applications

- Volume Control
- Balance Control
- Panpot
- Compressors
- AGC Circuit
- Autoscaling
- AC Voltmeter with Linear dB Readout
- Tunable State Variable Filters and Oscillators
- Automation

26. Compressors and Other Dynamic Processors

26.1 Compressors

- Versatility
- Dynamically Changing the Gain

26.2 A Simple Compressor

- Makeup Gain
- Usage Context

26.3 Compressor Attributes

- Compression Ratio
- Compressor Threshold
- Attack and Release Time
- Compression Knee
- Breathing and Pumping
- Threshold Circuit and Attack/Release Timing

26.4 Compressor Architecture

- Feedback and Feedforward Compressors
- Feedforward Compressors and Side-Chains
- The Side-Chain

- Decilinear Compressors and Log Domain Processing
- Generalized Compressors
- Limiters
- Feedback vs. Feedforward Compressors
- External Side-Chain Inputs
- Linked Compressors

26.5 Voltage Controlled Gain

- Required Gain Range of Control Element
- Voltage Controlled Amplifiers (VCA)
- JFET Gain Control Elements
- Optical Gain Control Elements
- Vacuum Tube Gain Control Elements

26.6 Amplitude Detection

- Log-Responding RMS Detector
- VCA-Based Amplitude Detection

26.7 Frequency-Dependent Compression

26.8 Multiband Compression

26.9 Dynamic Equalization

- Common Filter Dynamic Equalizer

26.10 De-Essers

26.11 Expandors and Upward Compression

- Upward Compression

26.12 Companders

- Frequency-Dependent Companders and Noise Reduction

26.13 Other Types of Dynamic Gain Control

- AGC and AGC Hold
- Noise Gating
- Ducking

26.14 Clippers Hard and Soft

26.15 The Klever Klipper

- Soft Clipping with Dynamic Threshold

27. Level Displays and Metering

27.1 The VU Meter

- Zero-VU Reference Level
- Meter Ballistics and Response Time
- Response to Peaks and Maximum Signal Level
- Typical Passive VU Meter Circuit
- Electronic Ballistics and Bar-Graph Displays
- Microcontroller-Based VU Meters

27.2 Peak Program Meter (PPM)

- Attack and Release Time
- Type I and Type IIb PPMs

27.3 Dual-Scale LED Meters

27.4 The Dorrrough Meter

27.5 Digital Peak Meter

27.6 True Peak Meters

27.7 Loudness Metering – the LU, the LUFS and LKFS

- Terminology
- K Weighting
- The LUFS Measurement
- Measurement Duration and Timing
- Gating
- Program Loudness and Loudness Range

27.8 Broadcast vs. Cinema Loudness Models

27.9 Other Audio Level Displays

- Peak-Average Meter
- Power Amplifier Metering
- Bar Graph Spectrum Displays

28. Microcontrollers and Microcomputers

- Embedded Systems
- System-on-Chip (SoC)
- Microcomputers (μ C)
- Board-Level MCUs and μ Cs

28.1 CPU Architectures, Instructions and Execution

28.2 Clocks

28.3 General Purpose I/O (GPIO)

- Analog-to-Digital Conversion
- Digital-to-Analog Conversion

28.4 Microcontroller Examples

- Microchip Technology PIC
- Arduino UNO
- Arduino Nano
- Raspberry Pi Pico
- In-situ* Programming

28.5 Microcomputers

- Raspberry Pi 3 Model B
- Raspberry Pi Zero
- Operating Systems

28.6 FPGAs and Embedded Processors

- Configuration
- Soft and Hard IP
- Xylinx Spartan 6
- Verilog

28.7 Microcontroller Resources

- RAM Memory
- Flash Memory
- EEPROM Memory
- Analog-to-Digital Converter
- PWM Outputs
- Timers
- Serial Ports
- SPI and I²C Bus Interfaces
- Other Resources

28.8 SPI Bus

- SPI Operating Modes
- SPI Payload Throughput

28.9 I²C Bus

- The Address Space Conundrum

28.10 SPI Bus Peripherals

- I/O Expander
- A/D Converters
- D/A Converters
- FLASH
- EEPROM
- SD Card
- RAM

28.11 I²C Bus Peripherals

- I/O Expander
- A/D and D/A Converters
- FLASH
- EEPROM
- RAM

29. Mixers and Recording Consoles

29.1 A Mixer in its Simplest Form

- Microphone Preamp
- Phantom Power
- Low-Cut Filter
- Equalizer
- Fader
- Pan Pot
- The Mixing Bus and the Master Section
- Stereo Mix Buss
- Master Fader and Line Output Amplifier
- Headphone Output
- Level Meters

29.2 Operating Levels, Headroom and Overload

29.3 A Generic 16-Channel Mixer – The Channel Strip

- The Channel Strip
- Alternate Left and Right Busses
- Solo Monitoring Bus
- Auxiliary Sends
- Pre-Fade Listen (PFL)
- Monitor Bus
- Channel Inserts
- Mute
- Overload Indicators

29.4 A Generic 16-Channel Mixer – The Master Section

- Mixing Amplifiers
- Main Stereo Outputs
- Master Insert
- Auxiliary Outputs
- Return Inputs
- Foldback

29.5 More Capable Mixers

- Stereo Channel Strip
- Direct Channel Outputs
- VCA Faders
- Number of Auxiliary Sends and Flexibility
- Channel Grouping and Subgroups
- VCA Groups
- Simple Matrix Mixer
- Metering

29.6 More Capable Filters and Equalizers

- Variable Frequency Low-Cut Filter

- Steeper Shelving Equalizers
- Series-Resonant Midband Equalizers
- Wien Bridge Equalizers
- Quasi-Parametric Equalizers
- Parametric Equalizers
- Constant-Q Equalizers

29.7 Monitor Mixers

29.8 Matrix Mixers

29.9 Broadcast Consoles

- Microphone Inputs
- Line Level Inputs
- Busses
- On-Location Live Broadcasts
- Loudness Metering

29.10 Recording Consoles

- Multitrack Recording
- Mixdown

29.11 Mix Bus Technical Challenges

- Noise Gain
- Other Problems Mixing Many Channels

30. DI Boxes and Microphone Splitters

30.1 Passive DI Boxes

30.2 Active DI Boxes

30.3 Passive Microphone Splitter

30.4 Active Microphone Splitters