

# *Designing Audio Circuits and Systems*

## Table of Contents

### **1. Introduction**

- 1.1 The Basics
- 1.2 Audio Signal Processing and Control
- 1.3 Line Level Preamplifiers
- 1.4 Phono and Tape Preamplifiers
- 1.5 Microphone Preamps
- 1.6 Mixing Consoles

### **2. A Simple Preamplifier Design**

- 2.1 Preamplifier Block Diagram
- 2.2 Line Level Signal Path
- 2.3 Tone Controls
- 2.4 Muting Circuit
- 2.5 Moving Magnet Phono Preamplifier
- 2.6 Moving Coil Phono Preamplifier
- 2.7 Relay Switching
- 2.8 Power Supply
- 2.9 Testing
- 2.10 Troubleshooting

### **3. Circuit Building Blocks**

- 3.1. Introduction
- 3.2. Transistors
- 3.3 Basic Amplifier Stages
- 3.4 Current Mirrors
- 3.5 Current Sources
- 3.6 Voltage References
- 3.7 Bandgap Voltage References
- 3.8 Complementary Feedback Pair (CFP)
- 3.9  $V_{be}$  Multipliers
- 3.10 Diamond Buffer
- 3.11 Operational Amplifiers
- 3.12 Circuit Simulation

### **4. Passive Components**

- 4.1 Resistors
- 4.2 Potentiometers
- 4.3 Capacitors
- 4.4 Inductors
- 4.5 Transformers
- 4.6 Mechanical Switches
- 4.7 Electromechanical Relays

### **5. Surface Mount Technology**

- 5.1 Advantages
- 5.2 Passive Component Packages and Sizes
- 5.3 Discrete Semiconductor and IC Packages
- 5.4 SMT Assembly
- 5.5 Printed Circuit Board Fabrication
- 5.6 DIP Adapters and Prototyping

5.7 Rework

## **6 Poles, Zeros, Networks and Bode Plots**

- 6.1 Resistance And Resistor Networks
- 6.2 Reactance
- 6.3 Imaginary Numbers and Complex Numbers
- 6.4 Impedance and the Complex Plane
- 6.5 Poles And Zeros
- 6.6 Bode Plots
- 6.7 The  $s$  Plane
- 6.8 Transfer Functions
- 6.9 Resonant Circuits

## **7. Semiconductors**

- 7.1 Bipolar Junction Transistors
- 7.2 Junction Field Effect Transistors
- 7.3 Small-Signal MOSFETs
- 7.4 Diodes and Rectifiers
- 7.5 Zener Diodes
- 7.6 LEDs

## **8. Operational Amplifiers**

- 8.1 The Ideal Op Amp
- 8.2 Inverting Amplifiers and the Virtual Ground
- 8.3 Non-Inverting Amplifiers and the Virtual Short
- 8.4 Differential Amplifier
- 8.5 Instrumentation Amplifier
- 8.6 Noise Gain
- 8.7. Compensation
- 8.8 A Simple Op Amp
- 8.9 Basic Specifications and Performance
- 8.10 FET Op Amps
- 8.11 Composite Op Amps
- 8.12 Op Amp Circuits

## **9. Negative Feedback**

- 9.1 How Negative Feedback Works
- 9.2 Input-Referred Feedback Analysis
- 9.3 Simple Feedback Circuits
- 9.4 Frequency-Dependent Negative Feedback
- 9.5 Feedback Compensation and Stability
- 9.6 Feedback Compensation Principles
- 9.7 Evaluating Loop Gain
- 9.8 Evaluating Stability
- 9.9 Compensation Loop Stability
- 9.10 Slew Rate
- 9.11 Harmonic and Intermodulation Distortion Reduction

## **10. Noise**

- 10.1 Signal-to-Noise Ratio
- 10.2 A-Weighted Noise Specifications
- 10.3 Noise Power and Noise Voltage
- 10.4 Noise Bandwidth
- 10.5 Noise Voltage Density and Spectrum
- 10.6 Relating Input Noise Density to Signal-to-Noise Ratio
- 10.7 Amplifier Noise Sources

- 10.8 Thermal Noise
- 10.9 Shot Noise
- 10.10 Bipolar Transistor Noise
- 10.11 JFET Noise
- 10.12 Op Amp Noise
- 10.13 Noise Simulation
- 10.14 Preamplifier Circuit Noise
- 10.15 Excess Resistor Noise
- 10.16 Zener Diode and LED Noise
- 10.17 Low-Noise Amplifiers for Extremely High-Impedance Sources

## **11. Filters**

- 11.1 Filter Shapes and Characteristics
- 11.2 Sallen-Key Filters
- 11.3 Sallen-Key Third-Order Filters
- 11.4 Filter Sensitivity
- 11.5 Multiple Feedback Filters (MFB)
- 11.6 State Variable Filters
- 11.7 Coupled State Variable Band-Pass Filters
- 11.8 The Biquadratic Filter
- 11.9 Single-Amplifier Biquad and Linkwitz Transform
- 11.10 Gyration
- 11.11 Negative Impedance Converters (NIC)
- 11.12 Frequency-Dependent Negative Resistors (FDNR)
- 11.13 Wien Bridge and Bridged-T Filters
- 11.14 Twin-T Notch Filters
- 11.15 Bainter Notch Filters
- 11.16 Hall Notch Filter
- 11.17 All-Pass Filters
- 11.18 Application-Specific filters

## **12. Distortion**

- 12.1 Nonlinearity and Its Consequences
- 12.2 Total Harmonic Distortion
- 12.3 SMPTE Intermodulation Distortion
- 12.4 CCIF Intermodulation Distortion
- 12.5 Transient Intermodulation Distortion
- 12.6 Phase Intermodulation Distortion
- 12.7 Multitone Intermodulation Distortion (MIM)
- 12.8 Highly Sensitive Distortion Measurement
- 12.9 Input-Referred Distortion Analysis
- 12.10 Other Sources of Distortion
- 12.11 Early Effect Distortion
- 12.12 Junction Capacitance Distortion
- 12.13 Grounding Distortion
- 12.14 Power Rail Distortion
- 12.15 Input Common-Mode Distortion
- 12.16 Resistor Distortion
- 12.17 Capacitor Distortion
- 12.18 Inductor and Magnetic Distortions
- 12.19 EMI-Induced Distortion
- 12.20 Thermally Induced Distortion

## **13. Switches and Relays**

- 13.1 Mechanical Switches and Pushbuttons
- 13.2 Mechanical Relays

- 13.3 JFET Switches
- 13.4 MOSFET Switches
- 13.5 DMOS Switches
- 13.6 CMOS Switches
- 13.7 CMOS/DMOS Switches
- 13.8 Photo-Coupled Switches

## **14. Power Supplies and Grounding**

- 14.1 The Design of the Power Supply
- 14.2 Power Transformer
- 14.3 Reservoir Capacitors
- 14.4 Rectifier Speed
- 14.5 IC Voltage Regulators
- 14.6 Capacitance Multipliers
- 14.7 External Power Supplies
- 14.8 Switch Mode Power Supplies (SMPS)
- 14.9 Grounding Architectures
- 14.10 Radiated Magnetic Fields
- 14.11 Safety Circuits

## **15. Moving Magnet Phono Preamplifiers**

- 15.1 Gain and Equalization
- 15.2 Moving Magnet Cartridge Model and Termination
- 15.3 Noise
- 15.4 Overload
- 15.5 Classic Phono Preamp Circuit
- 15.6 DC Servos
- 15.7 Inverse RIAA Network
- 15.8 Other Phono Preamplifier Architectures
- 15.9 Infrasonic (Subsonic) Filters
- 15.10 Vertical Flutter Reduction
- 15.11 A JFET Phono Preamplifier
- 15.12 Synthetic Cartridge Loading
- 15.13 Balanced Inputs
- 15.14 The VinylTrak Phono Preamp

## **16. Moving Coil Phono Preamps**

- 16.1 Signal Levels and MC Cartridge Characteristics
- 16.2 Moving Coil Transformers
- 16.3 Noise in the Cartridge-Transformer System
- 16.4 Moving Coil Head Amps
- 16.5 Other BJT and Op Amp Head Amps
- 16.6 A JFET Head Amp
- 16.7 Balanced Input Head Amp
- 16.8 The VinylTrak Dedicated MC Preamp

## **17. Tape Preamps and NAB/IEC Equalization**

- 17.1 Signal Levels and Tape Head Characteristics
- 17.2 NAB and IEC Equalization
- 17.3 Other Frequency Response Effects
- 17.4 Noise
- 17.5 NAB Playback Preamplifiers

## **18. Microphone Preamps**

- 18.1 Acoustic and Electrical Signal Levels and Sensitivity
- 18.2 Microphone Types and Characteristics

- 18.3 Console Microphone Preamplifiers
- 18.4 Phantom Powering
- 18.5 Condenser Microphone Preamplifiers
- 18.6 Electret Microphone Preamplifiers
- 18.7 Ribbon Microphone Preamplifiers
- 18.8 Piezoelectric Microphone Preamplifiers
- 18.9 MEMS Microphones

## **19. Balanced Inputs and Outputs**

- 19.1 Common-Mode Rejection
- 19.2 Balanced Input Circuits
- 19.3 Balanced Output Circuits
- 19.4 Transformers
- 19.5 Grounding and Shielding

## **20. Equalizers and Tone Controls**

- 20.1 Baxandall Tone Control
- 20.2 Three-Band Tone Control
- 20.3 Four-Band Equalizer
- 20.4 Equalizer Topologies
- 20.5 Wien Bridge Equalizer
- 20.6 Equalizer Q
- 20.7 Graphic (Multiband) Equalizers
- 20.8 Parametric Equalizers
- 20.9 Semi-Parametric Equalizers
- 20.10 Shelving Equalizers
- 20.11 Low-Cut and High-Cut Filters

## **21. Headphone Amplifiers**

- 21.1 Headphone Types
- 21.2 Sound Levels and Load Impedance
- 21.3 Headphone Sensitivity and Drive Requirements
- 21.4 Headphone Amplifier Design Considerations
- 21.5 Power Supply Requirements
- 21.6 Headphone Amplifier Designs
- 21.7 Crossfeed Circuits
- 21.8 Low-Frequency Equalization Circuits
- 21.9 Hearing Loss Protection

## **22. Volume, Balance, Fader and Panning Controls**

- 22.1 Potentiometer Volume Controls and Faders
- 22.2 Baxandall Active Volume Control
- 22.3 Switched Attenuators
- 22.4 Integrated Circuit CMOS Volume Controls
- 22.5 Voltage Controlled Amplifiers (VCA)
- 22.6 Balance Controls
- 22.7 Pan Pots
- 22.8 Loudness Controls

## **23. Digital-to-Analog Converters**

- 23.1 The Analog Interface

- 23.2 Power Supplies, References and Grounding
- 23.3 Clock Recovery and Jitter
- 23.4 Digital Audio Interfaces
- 23.5 Digital Audio Sampling and Transmission
- 23.6 Interpolation and Decimation
- 23.7 R2R DACs
- 23.8 Sigma-Delta ADCs
- 23.9 Sigma-Delta DACs
- 23.10 Control Interfaces

## **24. Active Crossovers and Loudspeaker Equalization**

- 24.1 Subwoofer Crossovers
- 24.2 Advantages of Active Crossovers
- 24.3 Disadvantages of Active Crossovers
- 24.4 Self-Powered Loudspeakers
- 24.5 Types of Crossovers, Roll-Off Slopes and Phase Relationships
- 24.6 Conventional Crossovers
- 24.7 Linkwitz-Riley Crossovers
- 24.8 Three-Way Crossover Architectures
- 24.9 3.5-Way Loudspeakers
- 24.10 Time Alignment
- 24.11 Crossover Filter Design
- 24.12 Active Baffle Step Compensation
- 24.13 Woofer Equalization – Linkwitz Transform
- 24.14 Equalized Quasi-Sealed System
- 24.15 DSP Crossovers
- 24.16 SPICE Simulation

## **25. Voltage Controlled Amplifiers (VCAs)**

- 25.1 Translinear Circuits
- 25.2 VCA Circuits
- 25.3 VCA Applications

## **26. Compressors and Other Dynamic Processors**

- 26.1 Compressors
- 26.2 A Simple Compressor
- 26.3 Compressor Attributes
- 26.4 Compressor Architecture
- 26.5 Voltage Controlled Gain
- 26.6 Amplitude Detection
- 26.7 Frequency-Dependent Compression
- 26.8 Multiband Compression
- 26.9 Dynamic Equalization
- 26.10 De-Essers
- 26.11 Expandors and Upward Compression
- 26.12 Compandors
- 26.13 Other Types of Dynamic Gain Control
- 26.14 Clippers Hard and Soft
- 26.15 The Klever Klipper

## **27. Level Displays and Metering**

- 27.1 The VU Meter
- 27.2 Peak Program Meter (PPM)
- 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
- 27.8 Broadcast vs. Cinema Loudness Models
- 27.9 Other Audio Level Displays

## **28. Microcontrollers and Microcomputers**

- 28.1 CPU Architectures, Instructions and Execution
- 28.2 Clocks
- 28.3 General Purpose I/O (GPIO)
- 28.4 Microcontroller Examples
- 28.5 Microcomputers
- 28.6 FPGAs and Embedded Processors
- 28.7 Microcontroller Resources
- 28.8 SPI Bus
- 28.9 I<sup>2</sup>C Bus
- 28.10 SPI Bus Peripherals
- 28.11 I<sup>2</sup>C Bus Peripherals

## **29. Mixers and Recording Consoles**

- 29.1 A Mixer in its Simplest Form
- 29.2 Operating Levels, Headroom and Overload
- 29.3 A Generic 16-Channel Mixer – The Channel Strip
- 29.4 A Generic 16-Channel Mixer – The Master Section
- 29.5 More Capable Mixers
- 29.6 More Capable Filters and Equalizers
- 29.7 Monitor Mixers
- 29.8 Matrix Mixers
- 29.9 Broadcast Consoles
- 29.10 Recording Consoles
- 29.11 Mix Bus Technical Challenges

## **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