Advanced analog console modeling

Multi-channel mixing architecture with authentic circuit emulation

Technical paper explaining methods used in Sonic Sweep 2 plugin
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Abstract

This paper presents a comprehensive digital implementation of a classic analog mixing console, specifically designed to capture the workflow and sonic characteristics of legendary hardware desks. Our approach combines multiple DSP techniques including cascaded biquad filters for authentic EQ curves, op-amp slew rate limiting, dynamic noise modeling, and sophisticated routing architectures. The implementation features three independent channels with serial/parallel routing capabilities, each equipped with 4-band EQ, authentic fader laws, and multiple stages of analog-modeled processing. We demonstrate how these techniques combine to create not just the frequency response, but the unpredictable behaviors, subtle non-linearities, and musical character that define the analog console sound.

1. Introduction

The transition from analog to digital mixing has brought unprecedented precision and recall, but often at the cost of the organic, musical qualities that made analog consoles beloved by engineers. Digital mixing tools frequently lack the subtle interactions, harmonic enrichment, and "happy accidents" that occur when multiple analog stages interact. This paper describes our implementation of Sonic Sweep 2, a digital mixing plugin that meticulously models these analog characteristics through several key innovations:

1. Authentic channel strip architecture with proper gain staging and signal flow
2. Op-amp slew rate limiting based on NJM4560 specifications
3. Multi-stage parametric EQ with analog-style curves
4. Dynamic noise generation with thermal drift and modulation
5. Sophisticated routing options including serial (daisy-chain) and parallel topologies
6. ALPS fader law emulation for authentic control response

2. Console architecture and signal flow

2.1 Channel strip design

Each of the three channels in Sonic Sweep 2 follows the classic analog console signal path. The trim control operates globally on all channels when engaged, mimicking a console's master trim. Each channel then has independent gain control (0-40dB) that drives subsequent stages, creating natural saturation at high settings.

2.2 Serial vs Parallel processing modes

A unique feature of our implementation is the morphable routing topology. Users can blend between:

- Serial (Daisy-Chain) Mode: Signal flows sequentially through channels 1→2→3
- Parallel Mode: All three channels process the input simultaneously and sum at the output

2.3 Gain staging and headroom management

Proper gain staging is essential for analog authenticity. The implementation includes:

- Input gain with drive-dependent saturation: Higher gain settings increase harmonic distortion
- Adaptive signal conditioning: Prevents digital artifacts at extreme EQ settings
- Compensation gains: Carefully calibrated to maintain unity gain through the signal path

3. Parametric EQ implementation

3.1 Four-band architecture

Each channel features a sophisticated 4-band EQ system:

1. Low Cut: 18dB/octave Chebyshev-inspired filter at 75Hz
2. Low Mid: 45-3000Hz parametric with variable Q
3. High Mid: 500-18000Hz parametric with variable Q
4. Low/High Shelves: First-order shelves at 80Hz and 12kHz

3.3 Dynamic pre-dip compensation

A unique innovation in our High Mid band is dynamic pre-dip compensation. When boosting frequencies, a complementary dip is created at a dynamically calculated lower frequency. This mimics the behavior of analog EQs where boost operations naturally affect neighboring frequencies.

3.4 Shared shelf filters

To accurately model how analog consoles apply cumulative frequency shaping, shelf filters are implemented as shared processors applied post-mix rather than per-channel. This creates the characteristic "console sound" where all channels contribute to an overall tonal signature.

4. Analog non-linearity modeling

4.1 Op-amp slew rate limiting

A defining characteristic of analog consoles is slew rate limiting in op-amp stages. We model the NJM4560 op-amp used in many classic consoles:

```
class NJM4560_SlewLimiter {
    double maxDeltaPerSample;

    double processSample(double sample, uint channel) {
        double delta = sample - prevSample[channel];
        if (delta > maxDeltaPerSample) delta = maxDeltaPerSample;
        else if (delta < -maxDeltaPerSample) delta = -maxDeltaPerSample;
        prevSample[channel] += delta;
        return prevSample[channel];
    }
};
```

Slew limiting is applied at four critical stages:

- Post-EQ (channel strip)
- Post-fader (channel output)
- Summing bus
- Master output

5. Dynamic noise and modulation

5.1 Pink noise generation

Console noise is modeled using a six-stage filter creating authentic 1/f spectrum.

5.2 Noise modulation system

The noise floor is modulated by multiple sources to create organic movement:

1. Slow drift (0.17 Hz)
2. Power ripple (50 Hz)
3. Harmonic (100/150 Hz)
4. Random walk

6. Control response and parameter mapping

6.1 ALPS Fader law implementation

Channel and bus faders use authentic ALPS D-taper response curves.

6.2 Parameter smoothing

All gain controls use time-constant smoothing to prevent zipper noise.

6.3 EQ frequency and Q mapping

EQ parameters use carefully tuned non-linear mappings:

- Frequency: Logarithmic scaling
- Q: Exponential scaling from 0.25 to 15
- Gain: ±15dB range

7. Performance optimizations

7.2 Channel muting logic

Muted channels bypass processing entirely, with special handling for serial mode where early channel muting affects downstream channels.

7.3 Safety mechanisms

Signal clamping, adaptive limiting, clip detection with LED feedback and DC blocking.

8. Conclusion

Sonic Sweep 2 demonstrates that careful attention to analog circuit behavior, combined with modern DSP techniques, can create a plugin that not only sounds like analog hardware but feels like it in use. The combination of accurate EQ curves, slew rate limiting, dynamic noise, and proper gain staging creates a mixing tool that adds the desirable imperfections and musical character of classic consoles while maintaining the reliability and recall of digital systems.

Future development will explore:

- Transformer saturation modeling
- Channel crosstalk simulation
- Expanded console aging models
- Additional filter types

References

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