Analog Secrets Your Mother Never Told You

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123rd AES Convention
New York, October 2007
## Seminar Outline

- New ICs
- Microphone preamplifiers
- Log math
- Balanced outputs
- Q & A
- Door prizes!
Department: Engineering

Chapter: New ICs

Name: Bob Moses

Address: 123rd AES Convention
          New York, October 2007
New ICs

- **THAT 2162 Dual VCA**
  - Pre-trimmed
  - Current-in, current-out
  - VCAs are completely independent
  - QSOP-16 package
  - $2.98 (1,000’s) -- $1.49 per channel
  - Samples available now
  - Production quantities this quarter (4Q07)
## New ICs

- **THAT 1280-Series**
  - Dual Balanced Line Receiver
  - Three gain versions
    - THAT 1280: 0dB (pin compatible w/ TI INA2134)
    - THAT 1283: ±3dB
    - THAT 1286: ±6dB (pin compatible w/ TI INA2137)
  - SO-14 package
  - $1.98 (1,000's) -- $0.99/channel
  - Samples available now
  - Production quantities this quarter (4Q07)
Department  Engineering

Chapter  Mic Preamps

Name  Rosalfonso “Ros” Bortoni

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Mic Preamp - Highlights

- One chip solution
  - Wide gain range
  - High bandwidth
  - Low noise
  - Low power

- Two gain options
  - 1510: $G = 1 + 10k/Rg$ (0dB min)
  - 1512: $G = 0.5 + 5k/Rg$ (-6dB min)
  - Accepts +24dBu @ +/- 15V rails
Continuously Adjustable Gain Mic Preamp

- Uses potentiometer (R3) to control gain
- 60dB+ gain range
- Output dc offset changes with gain
- Will thump if changed quickly
Cure Thump with a Capacitor

- $C_1$ avoids output dc variations
- Sets dc gain to 1
- Avoids thump
- Disadvantages
  - + PCB Area
  - Antenna (RFI)
  - Cost of cap
Switched Gain Mic Preamp

- Uses switches to control gain
- 60dB+ gain range
- Output dc offset still changes with gain
- Will click when gain is changed
Cure Click with a Capacitor

• **C1 avoids output dc variations**
• **Sets dc gain to 1**
• **Avoids click**
• **Disadvantages**
  - Same as with pot

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Cure Click with a Capacitor

• C1 avoids output dc variations
• Sets dc gain to 1
• Avoids click
• Disadvantages
  - Same as with pot
```

![Diagram of the circuit](image)
Mic Preamps – Choosing the Cap

- First, choose minimum $R_g$ based on max gain
- Second, choose highest allowed LF cutoff
- Then: $C_g = 1 / (2\pi f R_g)$
- For max gain = +60dB & LF cutoff = 5Hz
  - For 1510: $R_g = 10\,\Omega$, $C_g \approx 3300\mu F$
  - For 1512: $R_g = 5\,\Omega$, $C_g \approx 6800\mu F$
- For max gain = +40dB & LF cutoff = 5Hz
  - For 1510: $R_g = 100\,\Omega$, $C_g \approx 330\mu F$
  - For 1512: $R_g = 50\,\Omega$, $C_g \approx 680\mu F$
- Etc.
Mic Preamp with Output Servo

- Reduces steady-state output offset
- Doesn’t fix transient offset
  - Likely to click
  - Adds PCB area
  - Increases cost
Mic Preamp with Input Servo

- Reduces steady-state output offset
- Reduces transient offset, too

- Requires high-performance opamp
  - Low input offset voltage
  - Low input bias current
Recommended Circuit for Digital Control

- Use C-MOS switches to change Rg
- Splitting Rg to minimize charge injection (pops)

• 1512 lowers charge injection pop by 6dB
Unbalanced Capacitance at Rg1, Rg2

- Lowers CMRR @ HF
- Caused by
  - PCB stray capacitances
  - Different loading on Rg1 vs Rg2
- Effect is surprisingly large
Common-Mode Gain vs. Freq., 1~10pf Imbalance
Common-Mode Gain vs. Capacitive Imbalance, 20kHz
Department: Engineering
Chapter: VCA/RMS & Log Math
Name: Les Tyler
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### THAT VCAs, RMS, & Log Math

- (Very) basic Voltage Controlled Amplifiers (VCAs)
- (Very) basic RMS Detectors
- (Very) basic Analog Engines®
- Cool “log math” simplifies designs using the above
Blackmer® VCAs Offer “Deci-Linear” Control

- Linear control voltage causes Exponential gain (direct dB control)
- Typically -100~+40dB
- ~ ±6mV per dB gain
- Positive- & negative-sense control ports
- Current in & out
- Singles: 2180/1-series
  - SO-8 & SIP-8
- Dual: 2162
  - QSOP-16
THAT Level Detectors Are “Deci-Linear”

- Logarithmic output Voltage (direct dB) reading
- Good linearity over >60dB
- Current in, voltage out
- RMS-responding
- Time response mimics ear’s time-weighting
  - Less sensitive to phase shifts than peak or average.
- Single: 2252
  - SIP-8
- SO-packages
  - See Analog Engines®

THAT Corporation
Analog Engines®: VCAs + RMS Detector

- Compressor/limiter on a single chip
- Versatile 4320/4301
  - Includes several opamps and other useful stuff
- Basic 4305/4315
  - Just VCA and RMS detector
- 4301/4305
  - High voltage (±15V)
- 4315/4320
  - Low voltage, low power (+5V, 1.6mA)
Analog Engines® Are Deci-Linear, Too

- VCAs offer Deci-Linear control law
  - Direct dB control of gain
- Detectors offer Deci-Linear output law
  - Direct dB reading of RMS level
- Makes designing complex dynamics processors easy
  - Compressors/Limiters
  - Expanders/Gates
- Feedforward possible
  - VCA control law matches RMS-detector output law
- Deci-Linear characteristic makes “log-math” useful for side chain design
- Easily produces repeatable, predictable results
Linear Math Approach

- VCA gain law: \[ A_V = e^{\frac{-E_C}{2VT}} \]

- Detector output law: \[ V_{OUT} = 2VT \ln(V_{inrms}) \]

- “Linear” math leads to exponentials & logs
- Combining these two theoretically predicts gain trajectory
- But, do you really want to deal with this math?
“Log Math” Approach

• Express signal levels as their dB levels
• Express all gains in dB

• VCA gain law: $A_{db} = -166.7E_c$
• Detector output law: $V_{OUT} = 0.006 \text{ dB}_{RMS}$

• “Log” math reduces the exponentials and logs to simple, linear relationships
• Much easier to deal with!
Feedforward Processors - Log Math

- We can combine the previous two equations, and get:

\[ dB_{OUT} = dB_{IN} + \left[ -166.7 \cdot (G \cdot 0.006 dB_{IN}) \right] = (1 - G) dB_{IN} \]

- Compression (Expansion) ratio is:

\[ \frac{dB_{IN}}{dB_{OUT}} = \frac{1}{(1 - G)} \]

- Sign of gain determines compress or expand

- Lots of variations possible
  - Infinite compression
  - Negative compression
Feedback Processors - Log Math

- The VCA control voltage depends on the detector’s level reading and G:

\[ E_C = G \cdot 0.006 \text{ dB}_{OUT} \]

- But, the output signal depends on the input and the VCA gain:

\[ \text{dB}_{OUT} = \text{dB}_{IN} + [166.7 \cdot (G \cdot 0.006\text{dB}_{OUT})] = \text{dB}_{IN} - G\text{dB}_{OUT} \]

- Combining and rearranging, we can solve for the Compression (or Expansion) ratio:

\[ \frac{\text{dB}_{IN}}{\text{dB}_{OUT}} = 1 + G \]

- Sign of gain G determines compress vs. expand

- Fewer variations are possible due to stability considerations
  - Infinite compression is unstable!
Adding Thresholds

• Change $G$ based on detector’s output level
  - Half-wave rectifier
  - OA2/D1/D2
• Vary dc offset (R7) before rectifier
  - Changes the “active region” where detector’s output passes to the VCA control port
  - Corresponds to a dB threshold
Controlling Ratio and Static Gain

- Vary control path gain (R8)
  - Changes $G$ (in the active region)
  - Controls compression/expansion ratio

- Vary dc offset (R12) after clamp circuit
  - Changes static gain
See THAT's app notes for more detail

• AN101a: details about “Log math” involved

• AN100a: side-chain circuit details
  - Compressor application

• Many others for more circuit ideas
Department: Engineering
Subject: Balanced Outputs
Name: Gary Hebert
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Balanced Floating Output Drivers

• Imitate some aspects of output transformers
• High common-mode output impedance (several kΩ)
• Low differential output impedance
• Feedback minimizes common-mode output current (I_{out+} = -I_{out-})
• Output appears across two output terminals
  - Whether or not one is grounded
Clipping Behavior

- Traditional designs can lose control over output current if clipped when one output is grounded
  - CM feedback is lost
  - Output current in grounded leg increases to current limit
  - Can lead to distorted crosstalk
- Outsmarts® CM feedback loop maintains control
  - No current limiting
  - Less sensitive PCB layouts
OutSmarts Demo Board - Block Diagram
Clipping Into Single-ended Loads

• THAT 1606/1646 Behavior

Note: \( f_{\text{IN}} = 1 \text{ kHz}, \ Z_{\text{LOAD}(+)} = 10 \text{ k}\Omega, \ Z_{\text{LOAD}(-)} = 0 \text{ \Omega} \)
Clipping Into Single-ended Loads

- SSM2142 Misbehavior

Note: $f_{IN} = 1\,kHz$, $Z_{LOAD(+)} = 10\,k\Omega$, $Z_{LOAD(-)} = 0\,\Omega$
Clipping Into Single-ended Loads

- DRV134/135 Misbehavior

Note: $f_{IN} = 1$ kHz, $Z_{LOAD(+) } = 10 \, k\Omega$, $Z_{LOAD(-) } = 0 \, \Omega$
CMRR Depends on Impedance Ratios

- Wheatstone Bridge
  - Models Balanced Driver/Receiver
- CMRR is high if ratios match
- CMRR degrades if $\frac{R_{cmo1}}{R_{cmo2}} \neq \frac{R_{cmi1}}{R_{cmi2}}$
- CMRR is unaffected by differential signal level
Signal Balance

• Signal Balance measures match of + and - output levels
  - Using a perfectly balanced load
• Signal Balance affects only headroom
• Might affect crosstalk in multipair cables
• Does not affect CMRR
Discrete Balanced Floating Output Driver

- R1, R11 deliberately increased (nominal 11kΩ)
  - Ensures stability
  - Lowers CM output impedance
Discrete Balanced Floating Output Driver

- R8 is typically trimmed for best signal balance
  - Compensates for resistor mismatches (e.g., R1/R11)
  - But this is not the best solution

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123rd AES Convention, New York, October 6, 2007
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Signal Balance vs. Pot Rotation

- **SBR =** \(20 \log \left( \frac{V_{o+} + V_{o-}}{V_{in}} \right)\)
- Load is 18 kΩ per output
- Null occurs at about 11.5% pot rotation
CMRR vs. Pot Rotation

- Same 18 kΩ loads (perfectly matched)
- CMRR null occurs at about 80% pot rotation
- CMRR after trim is 10 dB worse than no trim at all
CMRR vs. Pot Rotation - 10 MegΩ Zin

- CMRR vs. Pot Rotation with 10 MegΩ CM loads
- With InGenius input this isn’t an issue
Signal Balance vs. Pot Rotation - 10 MΩ Zin

- However, Signal Balance is unchanged with 10 MegΩ loads
THAT Output Driver ICs

- Trimming is complex - let us do it for you
- 1646/06 include all required trims & adjustments
Department  

Chapter  

Name  

Address  

Engineering

Wrap Up

Bob Moses

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Conclusions

• Secret #1: new ICs from THAT!
• Secret #2: Mic Preamps need dc stability
  - Use capacitor in series with Rg
  - Output servo is of limited benefit
  - Input servo can work well, but is expensive
• Secret #3: For digital control, put analog switches inside split pairs of Rg
• Secret #4: Match stray loading on Rg pins
• Secret #5: Log math is easy and fun!
• Secret #6: Cross-coupled balanced outputs misbehave in some real world conditions
• Secret #7: OutSmarts® delivers optimal performance under tortuous conditions