Stability Analysis of Linear and PWM Power Amplifiers

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Topics of Discussion

• Operational Amplifiers
• PWM Amplifiers
• Stability Analysis
• Real Life Stability Tests
• Conclusion
Op Amps
Linear Operation Basics

\[ V_m = V_p = 0 \]
\[ I_{IN} = 0 \]
\[ \frac{V_{IN}}{R_I} + \frac{V_{OUT}}{R_F} = 0 \]
\[ V_{OUT} = -V_{IN} \left( \frac{R_F}{R_I} \right) \]

\[ V_m = V_p = V_{IN} \]
\[ I_{IN} = 0 \]
\[ \frac{V_{OUT} - V_{IN}}{R_F} + \frac{0 - V_{IN}}{R_I} = 0 \]
\[ V_{OUT} = V_{IN} \left( 1 + \frac{R_F}{R_I} \right) \]
Class C Output Stages
Simple Class AB Outputs
Complex Amplifier
• More Work
• Less Waste
PWM Power Delivery

![PWM Power Delivery Diagram](attachment:image.png)

- **PWM CONTROL**
- **Switch**
- **Storage/Filter**
- **Load**

95%  
50%  
5%
H-Bridge Providing Bipolar Output from a Single Supply
H-Bridge Waveforms

95% Duty Cycle
or
+90% Output

50% Duty Cycle
or
0 Output

5% Duty Cycle
or
–90% Output

A

0

V_s

B

0

V_s

A-B

+V_s

–V_s
STABILITY & COMPENSATION
Beta ($\beta$) – Feedback Factor

\[ V_{\text{out}} = \frac{A_o \beta}{1 + A_o \beta} = \frac{1}{\beta} \]

(For $A_o \beta \gg 1$)

\[ \beta = \frac{R_i}{R_i + R_f} \]

\[ V_{\text{fb}} = \beta V_{\text{out}} \]
*20db/ decade Rate of Closure → “Stability”

**40db/ decade Rate of Closure → “Marginal Stability”
External Phase Compensation

**SMALL SIGNAL RESPONSE**

- **$C_C = 0\text{pF}$**
- **$C_C = 33\text{pF}$**

1. Stable for any $C_C$
2. Unstable for $C_C = 0\text{pF}$

**Notes:**

- OPEN LOOP GAIN $A_{oL}(\text{dB})$

**Diagram Details:**

- Frequency range: $1 \text{Hz}$ to $10 \text{MHz}$
- Graph showing response at different capacitors ($C_C$)
Stability – Rate of Closure

\[ fp = \frac{1}{2\pi R_f C_f} \]

\[ fz = \frac{R_i + R_f}{2\pi R_i R_f C_f} \]
Stability – Open Loop

\[ fz = \frac{1}{2\pi R_f C_f} \]

\[ fp = \frac{R_i + R_f}{2\pi R_i R_f C_f} \]
Capacitive Loading

Unity Gain Stable Amplifier

Unstable 40db/decade with CL

SMALL SIGNAL RESPONSE

OPEN LOOP GAIN
Aol (db)

Aol  Aol w/ CL
40  40

1/B  Acl

Stable  Unstable
20  20

FREQUENCY, f(Hz)

1  10  100  1k  10k  100k  1M  10M
Capacitive Load Compensation

REQUIRES UNITY GAIN STABLE AMPLIFIER

1. OPEN LOOP GAIN Aol (db)
2. SMALL SIGNAL RESPONSE
3. FREQUENCY, f(Hz)

1/β

1/β

1/β
Noise-Gain Compensation

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Bode Plot

- AoI
- AoI/Cload
- 1/Beta
- Ad
- Signal at Cload
- Fcl

Gain, db vs Frequency, Hz
A Bode Plot showing gain in decibels (dB) versus frequency in Hertz (Hz). The plot includes several curves:
- **Aol**: Blue line
- **Aol/Clod**: Pink line
- **1/Beta**: Dashed black line
- **Ad**: Green line
- **Signal at Clod**: Dotted black line
- **Fcl**: Red line with X marks
Bode Plot

Gain, db vs Frequency, Hz

- AoI
- AoI/Cloud
- 1/Beta
- Ad
- Signal at Cloud
- Fci
PA07/Cloud Riso Phase Components

Phase Shift Components

- P1 Phase
- P2 Phase
- P3 Phase
- PZC Phase
- PNG Phase
- ZNG Phase
- ZCF Phase
- ZcF Phase
- Zriso Phase
- Open Loop

Frequency, Hz

Phase Shift, Degrees

0.1 1.0 10.0 100.0 1,000.0 10,000.0 100,000.0 1,000,000.0 10,000,000.0
Stability and Compensation

- Ground Loops
- Supply Loops
- Local Internal Loops
- Coupling: Internal and External
- Aol Loop Stability
Eliminate Coupling
Internal and External

- Ground the Case
- Reduce Impedances
- Eliminate $I_b$ Compensation Resistor on +IN
- Don’t Run Output Traces Near Input Traces
- Run $I_{out}$ Traces Adjacent to $I_{out}$ Return Traces
Ground Loops

**PROBLEM**

\[ f(\text{osc}) \approx f(\text{unity}) \]

**SOLUTION**

Diagram showing a 'STAR' ground point.
Supply Line Modulation

IL Rs MODULATION FEEDS BACK TO GAIN STATE

Lw & CL FORM “TANK”
Bypassing Supply Lines

C1 = 0.1 to 1µF
C2 = 10µF/Amp out (peak), Electrolytic
Bipolar Output Stages

- FULL COMPLEMENTARY
- QUASI COMPLEMENTARY
- ALL NPN
Fixing Output Stage Oscillations

\[ F(\text{osc}) > f(\text{unity}) \]
Real World Stability Tests
Square Wave Test
AVcl Peaking Test

PEAKING-MEASURED CLOSED LOOP
Avcl(dB) Peaking

\[ \text{Avcl} = \frac{V_{\text{OUT}}}{V_{\text{IN}}} \]

SMALL SIGNAL RESPONSE

OPEN LOOP PHASE MARGIN (DEGREES)

0 5 10 15 20 25

0 10 20 30 40 50

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CONCLUSION
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