APPENDIX 1

RULE BASE: FUZZY CONTROL OF QUASI-RESONANT BUCK CONVERTER

[System]
Name='stndp'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=49
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='mom'

[Input1]
Name='error'
Range=[-1 1]
NumMFs=7
MF1='NB':'gaussmf',[0.1416 -1]
MF2='NM':'gaussmf',[0.1416 -0.6666]
MF3='NS':'gaussmf',[0.142 -0.333]
MF4='ZE':'gaussmf',[0.1416 0]
MF5='PS':'gaussmf',[0.1416 0.3332]
MF6='PM':'gaussmf',[0.1416 0.6668]
MF7='PB':'gaussmf',[0.1416 1]
[Input2]
Name='chinerror'
Range=[-1 1]
NumMFs=7
MF1='NB':'gaussmf',[0.1416 -1]
MF2='NM':'gaussmf',[0.1416 -0.6666]
MF3='NS':'gaussmf',[0.1416 -0.3334]
MF4='ZE':'gaussmf',[0.1416 0]
MF5='PS':'gaussmf',[0.1416 0.3334]
MF6='PM':'gaussmf',[0.1416 0.6666]
MF7='PB':'gaussmf',[0.1416 1]
[Output1]
Name='control_signal'
Range=[-1 1]
NumMFs=7
MF1='NB':'gaussmf',[0.1416 -1]
MF2='NM':'gaussmf',[0.1416 -0.6664]
MF3='NS':'gaussmf',[0.1416 -0.3334]
MF4='ZE':'gaussmf',[0.1416 0]
MF5='PS':'gaussmf',[0.1416 0.3334]
MF6='PM':'gaussmf',[0.1416 0.6666]
MF7='PB':'gaussmf',[0.142 1]
[Rules]
1 1, 1 (1) : 1
1 2, 1 (1) : 1
1 3, 1 (1) : 1
1 4, 1 (1) : 1
1 5, 2 (1) : 1
1 6, 3 (1) : 1
1 7, 4 (1) : 1
2 1, 1 (1) : 1
2 2, 1 (1) : 1
2 3, 2 (1) : 1
2 4, 2 (1) : 1
2 5, 3 (1) : 1
2 6, 4 (1) : 1
2 7, 5 (1) : 1
3 1, 1 (1) : 1
3 2, 2 (1) : 1
3 3, 3 (1) : 1
3 4, 3 (1) : 1
3 5, 4 (1) : 1
3 6, 5 (1) : 1
3 7, 6 (1) : 1
4 1, 2 (1) : 1
4 2, 2 (1) : 1
4 3, 3 (1) : 1
4 4, 4 (1) : 1
4 5, 5 (1) : 1
4 6, 6 (1) : 1
4 7, 7 (1) : 1
5 1, 2 (1) : 1
5 2, 3 (1) : 1
5 3, 4 (1) : 1
5 4, 5 (1) : 1
5 5, 5 (1) : 1
5 6, 6 (1) : 1
5 7, 7 (1) : 1
6 1, 3 (1) : 1
6 2, 4 (1) : 1
6 3, 5 (1) : 1
6 4, 6 (1) : 1
6 5, 6 (1) : 1
6 6, 7 (1) : 1
6 7, 7 (1) : 1
7 1, 4 (1) : 1
7 2, 5 (1) : 1
7 3, 6 (1) : 1
7 4, 7 (1) : 1
7 5, 7 (1) : 1
7 6, 7 (1) : 1
7 7, 7 (1) : 1
APPENDIX 2

RULE BASE: NEURO-FUZZY CONTROL OF QUASI-RESONANT BUCK CONVERTER

[System]
Name='nf_sys'
Type='sugeno'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=49
AndMethod='prod'
OrMethod='probor'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='wtaver'

[Input1]
Name='error'
Range=[-1 1]
NumMFs=7
MF1='NB':'gaussmf',[0.1416 -1]
MF2='NM':'gaussmf',[0.1416 -0.6667]
MF3='NS':'gaussmf',[0.142 -0.333]
MF4='ZE':'gaussmf',[0.1416 0]
MF5='PS':'gaussmf',[0.1416 0.3333]
MF6='PM':'gaussmf',[0.1416 0.6667]
MF7='PB':'gaussmf',[0.1416 1]

[Input2]
Name='chinerror'
Range=[-1 1]
NumMFs=7
MF1='NB':'gaussmf',[0.1416 -1]
MF2='NM':'gaussmf',[0.1416 -0.6666]
MF3='NS':'gaussmf',[0.1416 -0.3334]
MF4='ZE':'gaussmf',[0.1416 0]
MF5='PS':'gaussmf',[0.1416 0.3334]
MF6='PM':'gaussmf',[0.1416 0.6666]
MF7='PB':'gaussmf',[0.1416 1]

[Output1]
Name='control_signal'
Range=[-1 1]
NumMFs=7
MF1='NB':'linear',[0 0 -1]
MF2='NM':'linear',[0 0 -0.66]
MF3='NS':'linear',[0 0 -0.34]
MF4='ZE':'linear',[0 0 0]
MF5='PS':'linear',[0 0 0.34]
MF6='PM':'linear',[0 0 0.66]
MF7='PB':'linear',[0 0 1]

[Rules]
1 1, 7 (1) : 1
1 2, 7 (1) : 1
1 3, 7 (1) : 1
1 4, 7 (1) : 1
1 5, 6 (1) : 1
1 6, 5 (1) : 1
1 7, 4 (1) : 1
2 1, 7 (1) : 1
2 2, 7 (1) : 1
2 3, 6 (1) : 1
2 4, 6 (1) : 1
2 5, 5 (1) : 1
2 6, 4 (1) : 1
2 7, 3 (1) : 1
3 1, 7 (1) : 1
3 2, 6 (1) : 1
3 3, 5 (1) : 1
3 4, 5 (1) : 1
3 5, 4 (1) : 1
3 6, 3 (1) : 1
3 7, 2 (1) : 1
4 1, 6 (1) : 1
4 2, 6 (1) : 1
4 3, 5 (1) : 1
4 4, 4 (1) : 1
4 5, 3 (1) : 1
4 6, 2 (1) : 1
4 7, 1 (1) : 1
5 1, 6 (1) : 1
5 2, 5 (1) : 1
5 3, 4 (1) : 1
5 4, 3 (1) : 1
5 5, 3 (1) : 1
5 6, 2 (1) : 1
5 7, 1 (1) : 1
6 1, 5 (1) : 1
6 2, 4 (1) : 1
6 3, 3 (1) : 1
6 4, 2 (1) : 1
6 5, 2 (1) : 1
6 6, 1 (1) : 1
6 7, 1 (1) : 1
7 1, 4 (1) : 1
7 2, 3 (1) : 1
7 3, 2 (1) : 1
7 4, 1 (1) : 1
7 5, 1 (1) : 1
7 6, 1 (1) : 1
7 7, 1 (1) : 1
APPENDIX 3

IRF 940 DATA SHEET

International Rectifier

PreLIMINARY

IRF9410

HEXFET® Power MOSFET

V_{DSS} = 30V
R_{DS(on)} = 0.030Ω

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The SO-8 has been modified through a customized leadframe for enhanced thermal characteristics and multiple-die capability making it ideal in a variety of power applications. With these improvements, multiple devices can be used in an application with dramatically reduced board space. The package is designed for vapor phase, infra red, or wave soldering techniques.

Absolute Maximum Ratings (TA = 25°C Unless Otherwise Noted)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Maximum</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain-Source Voltage</td>
<td>V_{DS}</td>
<td>30</td>
<td>V</td>
</tr>
<tr>
<td>Gate-Source Voltage</td>
<td>V_{GS}</td>
<td>±20</td>
<td>V</td>
</tr>
<tr>
<td>Continuous Drain Current (Diode Conduction)</td>
<td>l_{D}</td>
<td>7.0</td>
<td>A</td>
</tr>
<tr>
<td>T_A = 70°C</td>
<td>5.6</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Pulsed Drain Current</td>
<td>l_{PD}</td>
<td>37</td>
<td>A</td>
</tr>
<tr>
<td>Continuous Source Current (Diode Conduction)</td>
<td>I_{S}</td>
<td>2.6</td>
<td>A</td>
</tr>
<tr>
<td>Maximum Power Dissipation (Diode Conduction)</td>
<td>P_{D}</td>
<td>2.5</td>
<td>W</td>
</tr>
<tr>
<td>T_A = 70°C</td>
<td>1.8</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>Single Pulse Avalanche Energy</td>
<td>E_{AS}</td>
<td>70</td>
<td>mJ</td>
</tr>
<tr>
<td>Avalanche Current</td>
<td>I_{AP}</td>
<td>4.2</td>
<td>A</td>
</tr>
<tr>
<td>Repetitive Avalanche Energy</td>
<td>E_{AVR}</td>
<td>0.25</td>
<td>mJ</td>
</tr>
<tr>
<td>Peak Diode Recovery dv/dt</td>
<td>dV/dt</td>
<td>5.0</td>
<td>V/ns</td>
</tr>
<tr>
<td>Junction and Storage Temperature Range</td>
<td>T_{J,ST}</td>
<td>-55 to +150</td>
<td>°C</td>
</tr>
</tbody>
</table>

Thermal Resistance Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Limit</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Junction-to-Ambient</td>
<td>R_{J,A}</td>
<td>50</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

RECOMMENDED UPGRADE: IRF7403 or IRF7413

LITERAL TECHNICAL DATA APPLICABLE: IRF7005

9/15/97
### Electrical Characteristics @ $T_J = 25^\circ$C (unless otherwise specified)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{BRDSS}$</td>
<td>30</td>
<td>----</td>
<td>----</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$I_{BRDSS}$</td>
<td>0.024</td>
<td>----</td>
<td>----</td>
<td>µA</td>
<td>$V_{GS} = 0V, I_{D} = 250\mu A$</td>
</tr>
<tr>
<td>$R_{DS(\text{on})}$</td>
<td>0.022</td>
<td>0.040</td>
<td>----</td>
<td>Ω</td>
<td>Reference to $25^\circ$C, $I_D = 1mA$</td>
</tr>
<tr>
<td>$V_{GS(on)}$</td>
<td>1.0</td>
<td>----</td>
<td>----</td>
<td>V</td>
<td>$V_{GS} = V_{GS}, I_{D} = 250\mu A$</td>
</tr>
<tr>
<td>$g_{m}$</td>
<td>14</td>
<td>----</td>
<td>----</td>
<td>S</td>
<td>$V_{GS} = 15V, I_{D} = 7.0A$</td>
</tr>
<tr>
<td>$I_{DSS}$</td>
<td>2.0</td>
<td>----</td>
<td>----</td>
<td>µA</td>
<td>$V_{GS} = 24V, V_{GS} = 0V$</td>
</tr>
<tr>
<td>$I_{SS}$</td>
<td>25</td>
<td>----</td>
<td>----</td>
<td>µA</td>
<td>$V_{GS} = 24V, V_{GS} = 0V, T_J = 55^\circ$C</td>
</tr>
<tr>
<td>$Q_{gs}$</td>
<td>100</td>
<td>----</td>
<td>----</td>
<td>nA</td>
<td>$V_{GS} = 20V$</td>
</tr>
<tr>
<td>$Q_{ds}$</td>
<td>-100</td>
<td>----</td>
<td>----</td>
<td>nA</td>
<td>$V_{GS} = -20V$</td>
</tr>
<tr>
<td>$Q_{gs}$</td>
<td>18</td>
<td>27</td>
<td>----</td>
<td>nC</td>
<td>$V_{GS} = 2.0A$</td>
</tr>
<tr>
<td>$Q_{ds}$</td>
<td>3.6</td>
<td>----</td>
<td>----</td>
<td>nC</td>
<td>$V_{GS} = 15V$</td>
</tr>
<tr>
<td>$t_{on}$</td>
<td>4.9</td>
<td>7.4</td>
<td>----</td>
<td>ns</td>
<td>$V_{GS} = 10V, \text{See Fig. 10}$</td>
</tr>
<tr>
<td>$t_{off}$</td>
<td>7.3</td>
<td>15</td>
<td>----</td>
<td>ns</td>
<td>$V_{GS} = 25V$</td>
</tr>
<tr>
<td>$t_{r}$</td>
<td>6.3</td>
<td>17</td>
<td>----</td>
<td>ns</td>
<td>$I_D = 1.0A$</td>
</tr>
<tr>
<td>$t_{f}$</td>
<td>23</td>
<td>46</td>
<td>----</td>
<td>ns</td>
<td>$R_D = 6.0\Omega, V_{GS} = 10V$</td>
</tr>
<tr>
<td>$t_{d/dt}$</td>
<td>17</td>
<td>34</td>
<td>----</td>
<td>ns</td>
<td>$R_D = 25\Omega$</td>
</tr>
<tr>
<td>$C_{GD}$</td>
<td>550</td>
<td>----</td>
<td>----</td>
<td>pF</td>
<td>$V_{GS} = 0V$</td>
</tr>
<tr>
<td>$C_{GS}$</td>
<td>260</td>
<td>----</td>
<td>----</td>
<td>pF</td>
<td>$V_{GS} = 25V$</td>
</tr>
<tr>
<td>$C_{RSS}$</td>
<td>100</td>
<td>----</td>
<td>----</td>
<td>pF</td>
<td>$f = 1.0\text{MHz}, \text{See Fig. 9}$</td>
</tr>
</tbody>
</table>

### Source-Drain Ratings and Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_D$</td>
<td>----</td>
<td>----</td>
<td>2.8</td>
<td>A</td>
<td>MOSFET symbol showing the integral reverse p-n junction diode.</td>
</tr>
<tr>
<td>$I_{SM}$</td>
<td>----</td>
<td>----</td>
<td>37</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$V_{DSS}$</td>
<td>0.78</td>
<td>1.0</td>
<td>----</td>
<td>V</td>
<td>$T_J = 25^\circ$, $I_D = 2.0A, V_{GS} = 0V$</td>
</tr>
<tr>
<td>$t_{r}$</td>
<td>40</td>
<td>80</td>
<td>----</td>
<td>ns</td>
<td>$T_J = 25^\circ$, $I_D = 2.0A$</td>
</tr>
<tr>
<td>$Q_{r}$</td>
<td>63</td>
<td>130</td>
<td>----</td>
<td>nC</td>
<td>$dV/dt = 100\mu A/s$</td>
</tr>
</tbody>
</table>

**Notes:**

- Repetitive rating: pulse width limited by max. junction temperature. (See Fig. 11)
- $I_{D} \leq 4.0A$, $dV/dt \leq 120\mu A/s$, $V_{DD} \leq V_{BRDSS}$, $T_J \leq 150^\circ$C
- Starting $T_J = 25^\circ$, $L = 6.6\mu H$, $R_S = 25\Omega$, $I_{DSS} = 4.8A$.
- Pulse width $\leq 300\mu s$, duty cycle $\leq 2\%$.
- Surface mounted on FR-4 board, $t \leq 10$ sec.
Fig 1. Typical Output Characteristics

Fig 2. Typical Output Characteristics

Fig 3. Typical Transfer Characteristics

Fig 4. Typical Source-Drain Diode Forward Voltage
**Fig 5.** Normalized On-Resistance Vs. Temperature

**Fig 6.** Typical On-Resistance Vs. Drain Current

**Fig 7.** Typical On-Resistance Vs. Gate Voltage

**Fig 8.** Maximum Avalanche Energy Vs. Drain Current
Fig 9. Typical Capacitance Vs. Drain-to-Source Voltage

Fig 10. Typical Gate Charge Vs. Gate-to-Source Voltage

Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Ambient
IRF9410

Package Outline

SO8 Outline

Part Marking Information

EXAMPLE: THIS IS AN IRF7101

000

INTERNATIONAL REC 312
ITER
F7101
TOP

DATE CODE (YWW)
Y = LAST DIGIT OF THE YEAR
WWW = WEEK

WAFFER
LOT CODE
(LAST 4 DIGITS)

XXXX

PART NUMBER

BOTTOM

NOTES:
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS ARE SHOWN IN MILLIMETERS (INCHES).
4. OUTLINE CONFORMS TO JEDEC OUTLINE MS-012AA.
5. DIMENSIONS DOES NOT INCLUDE MOLD PROTRUSIONS.
6. MOLD PROTRUSIONS NOT TO EXCEED 0.32 (0.8).
7. DIMENSIONS IS THE LENGTH OF LEAD FOR SOLDERING TO A SUBSTRATE.
Tape & Reel Information
S08
Dimensions are shown in millimeters (inches)

NOTES:
1. CONTROLLING DIMENSION: MILLIMETER.
2. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS (INCHES).
3. OUTLINE CONFORMS TO EIA-481 & EIA-541.

NOTES:
1. CONTROLLING DIMENSION: MILLIMETER.
2. OUTLINE CONFORMS TO EIA-481 & EIA-541.
APPENDIX 4

LM 324 DATA SHEET

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description
The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off the standard ±5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics
- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage
- The unity gain crossover frequency is temperature compensated
- The input bias current is also temperature compensated

Advantages
- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows direct sensing near GND and V_{out} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features
- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range: 3V to 35V or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA)—essentially independent of supply voltage
- Low input biasing current 45 nA (temperature compensated)
- Low input offset voltage 2 mV and offset current 5 nA
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0V to V^+ − 1.5V

Connection Diagram

Dual-In-Line Package

Connection Diagram (Continued)

Order Number LM124AW/892, LM124AWG/893, LM124AW/993 or LM124WG/893
LM124AW/RQML and LM124AW/RQML2 (Note 3)

See NS Package Number W148
LM124AW/Q12QML and LM124AW/Q12QML2 (Note 2)

See NS Package Number WS144A

Schematic Diagram (Each Amplifier)
### Absolute Maximum Ratings (Note 12)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office or Distributors for availability and specifications.

<table>
<thead>
<tr>
<th></th>
<th>LM124A/LM224A/LM324A</th>
<th>LM3902</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage, $V^*$</td>
<td>32V</td>
<td>28V</td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>32V</td>
<td>28V</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>$-0.3V$ to $+32V$</td>
<td>$-0.3V$ to $+28V$</td>
</tr>
<tr>
<td>Input Current</td>
<td>$50mA$</td>
<td>$50mA$</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>$1130mW$</td>
<td>$1130mW$</td>
</tr>
<tr>
<td>Cavity DIP</td>
<td>$1260mW$</td>
<td>$1260mW$</td>
</tr>
<tr>
<td>Small Outline Package</td>
<td>$800mW$</td>
<td>$800mW$</td>
</tr>
<tr>
<td>Output Short-Circuit to GND</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>V* &lt; 15V and $T_a = 25^\circ C$</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ C$ to $+70^\circ C$</td>
<td>$-25^\circ C$ to $+65^\circ C$</td>
<td>$-25^\circ C$ to $+125^\circ C$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage Temperature Range</th>
<th>$-65^\circ C$ to $+150^\circ C$</th>
</tr>
</thead>
</table>

| Lead Temperature (Soldering, 10 seconds) | $260^\circ C$ |

| Soldering Information | $260^\circ C$ |

<table>
<thead>
<tr>
<th>Dual-In-Line Package</th>
<th>$260^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Outline Package</td>
<td>$260^\circ C$</td>
</tr>
<tr>
<td>Vapor Phase (60 seconds)</td>
<td>$215^\circ C$</td>
</tr>
<tr>
<td>Infrared (15 seconds)</td>
<td>$220^\circ C$</td>
</tr>
</tbody>
</table>

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

ESD Tolerance (Note 13) | $250V$ |

### Electrical Characteristics

$V^* = +5V$, (Note 7), unless otherwise stated.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LM124A</th>
<th>LM224A</th>
<th>LM324A</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>(Note 6) $T_a = 25^\circ C$</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>$I_{OC}$ or $I_{OC}$, $V_{OC} = 0V$</td>
<td>20</td>
<td>50</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>$I_{OC}$ or $I_{OC}$, $V_{OC} = 0V$, $T_a = 25^\circ C$</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Input Common-Mode Voltage Range</td>
<td>$V^* = 30V$, (LM3902, $V^* = 28V$), $T_a = 25^\circ C$</td>
<td>0</td>
<td>$V^* = 1.5$</td>
<td>0</td>
<td>$V^* = 1.5$</td>
</tr>
<tr>
<td>Supply Current</td>
<td></td>
<td>1.5</td>
<td>3</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Large Signal Voltage Gain</td>
<td>$V^* = V^*$, $R_L &gt; 3k$</td>
<td>0.7</td>
<td>1.2</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Common-Mode</td>
<td>$G_{CM}$, $V_{OC} = 0V$ to $V^*$, $T_a = 25^\circ C$</td>
<td>70</td>
<td>85</td>
<td>70</td>
<td>85</td>
</tr>
</tbody>
</table>

Additional notes and specifications are provided in the referenced notes and documents.
## Electrical Characteristics (Continued)

### V<sup>+</sup> = ±5.0V, (Note 7), unless otherwise stated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LMX238A</th>
<th>LMX239A</th>
<th>LMX240A</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply Rejection Ratio</td>
<td>V&lt;sup&gt;+&lt;/sup&gt; = 5V to 30V (LM2022, V&lt;sup&gt;+&lt;/sup&gt; = 5V to 26V), T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>65 100</td>
<td>65 120</td>
<td>65 100</td>
<td>dB</td>
</tr>
<tr>
<td>Amplifier-to-Amplifier Coupling (Note 11)</td>
<td>f = 1 kHz to 20 kHz, T&lt;sub&gt;θ&lt;/sub&gt; = 25°C (Input Referred)</td>
<td>-120</td>
<td>-120</td>
<td>-120</td>
<td>dB</td>
</tr>
<tr>
<td>Output Current Source</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 5.4V, V&lt;sub&gt;EE&lt;/sub&gt; = 3.6V, V&lt;sub&gt;TH&lt;/sub&gt; = 1.2V, T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>20 40</td>
<td>20 40</td>
<td>20 40</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;TH&lt;/sub&gt; = 1V, V&lt;sub&gt;TH&lt;/sub&gt; = 2V, T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>10 20</td>
<td>10 20</td>
<td>10 20</td>
<td>nA</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 1V, V&lt;sub&gt;TH&lt;/sub&gt; = 6V, V&lt;sub&gt;TH&lt;/sub&gt; = 1.2V, T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>12 50</td>
<td>12 50</td>
<td>12 50</td>
<td>nA</td>
</tr>
<tr>
<td>Short Circuit to Ground</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 15V, T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>40 80</td>
<td>40 80</td>
<td>40 80</td>
<td>mA</td>
</tr>
<tr>
<td>Input Offset Voltage</td>
<td>(Note 8)</td>
<td>4 4 5</td>
<td></td>
<td>kW</td>
<td></td>
</tr>
<tr>
<td>V&lt;sub&gt;CC&lt;/sub&gt; Drift</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 0Ω</td>
<td>7 20</td>
<td>7 20</td>
<td>7 30</td>
<td>μA/V°C</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>I&lt;sub&gt;CC&lt;/sub&gt; = 10μA, V&lt;sub&gt;CC&lt;/sub&gt; = 4V</td>
<td>50 30</td>
<td></td>
<td>75 40</td>
<td>nA</td>
</tr>
<tr>
<td>I&lt;sub&gt;CC&lt;/sub&gt; Drift</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 0Ω</td>
<td>10 200</td>
<td>10 200</td>
<td>10 300</td>
<td>nA</td>
</tr>
<tr>
<td>Input Bias Current I&lt;sub&gt;CC&lt;/sub&gt;</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 0Ω</td>
<td>40 100</td>
<td>40 150</td>
<td>40 200</td>
<td>nA</td>
</tr>
<tr>
<td>Input Common-Mode Voltage Range (Note 10)</td>
<td>V&lt;sup&gt;+&lt;/sup&gt; = ±30V (LM2022, V&lt;sup&gt;+&lt;/sup&gt; = 26V)</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−2</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−2</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−2</td>
<td>V</td>
</tr>
<tr>
<td>Large Signal Voltage Gain</td>
<td>V&lt;sup&gt;+&lt;/sup&gt; = ±18V (V&lt;sub&gt;CC&lt;/sub&gt; = 1V to 11V)</td>
<td>25 26</td>
<td></td>
<td>15 46</td>
<td>V/mV</td>
</tr>
<tr>
<td>Output Voltage Swings</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 30V (LM2022, V&lt;sup&gt;+&lt;/sup&gt; = 26V)</td>
<td>26 26</td>
<td></td>
<td>26 26</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>R&lt;sub&gt;1&lt;/sub&gt; = 10 kΩ</td>
<td>27 27</td>
<td>27 28</td>
<td>27 28</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 3V, R&lt;sub&gt;1&lt;/sub&gt; = 10 kΩ</td>
<td>5 20</td>
<td>5 20</td>
<td>5 20</td>
<td>kV</td>
</tr>
<tr>
<td>Output Current Source</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = 3V</td>
<td>15 75</td>
<td>15 90</td>
<td>15 75</td>
<td>nA</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;TH&lt;/sub&gt; = ±1V, V&lt;sub&gt;TH&lt;/sub&gt; = ±1.5V</td>
<td>15 75</td>
<td>15 90</td>
<td>15 75</td>
<td>nA</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;TH&lt;/sub&gt; = ±1V, V&lt;sub&gt;TH&lt;/sub&gt; = ±1.5V</td>
<td>15 75</td>
<td>15 90</td>
<td>15 75</td>
<td>nA</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;TH&lt;/sub&gt; = ±1V, V&lt;sub&gt;TH&lt;/sub&gt; = ±1.5V</td>
<td>15 75</td>
<td>15 90</td>
<td>15 75</td>
<td>nA</td>
</tr>
</tbody>
</table>

## Electrical Characteristics

### V<sup>+</sup> = ±5.0V, (Note 7), unless otherwise stated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LMX214/LMX214</th>
<th>LMX214</th>
<th>LMX215/2</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>(Note 6)</td>
<td>3 2 7 2 7 2 7</td>
<td>kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Bias Current I&lt;sub&gt;CC&lt;/sub&gt;</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 0Ω</td>
<td>45 150 45 250 45 250</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>I&lt;sub&gt;CC&lt;/sub&gt; = 10μA, V&lt;sub&gt;CC&lt;/sub&gt; = 4V</td>
<td>50 30 5 50 5 50</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Common-Mode Voltage Range (Note 10)</td>
<td>V&lt;sup&gt;+&lt;/sup&gt; = ±26V (LM2022, V&lt;sup&gt;+&lt;/sup&gt; = 26V), T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−1.5</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−1.5</td>
<td>0  V&lt;sup&gt;+&lt;/sup&gt;−1.5</td>
<td>V</td>
</tr>
<tr>
<td>Supply Current Over Full Temperature Range</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 10 kΩ</td>
<td>1.5 3</td>
<td>1.5 3</td>
<td>1.5 3</td>
<td>mA</td>
</tr>
<tr>
<td>Large Signal Voltage Gain</td>
<td>V&lt;sub&gt;TH&lt;/sub&gt; = ±18V, R&lt;sub&gt;S&lt;/sub&gt; = 2kΩ, (V&lt;sub&gt;CC&lt;/sub&gt; = 1V to 11V)</td>
<td>50 100</td>
<td>25 100</td>
<td>25 100</td>
<td>V/mV</td>
</tr>
<tr>
<td>Common-Mode Voltage Range</td>
<td>R&lt;sub&gt;S&lt;/sub&gt; = 10 kΩ</td>
<td>70 89 65 85 50 70</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Supply Rejection Ratio</td>
<td>V&lt;sup&gt;+&lt;/sup&gt; = 3V to 30V (LM2022, V&lt;sup&gt;+&lt;/sup&gt; = 3V to 26V), T&lt;sub&gt;θ&lt;/sub&gt; = 25°C</td>
<td>65 100 65 100 65 100</td>
<td>dB</td>
<td></td>
<td></td>
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</table>

[www.national.com](http://www.national.com)
### Electrical Characteristics (Continued)

![Image](120x208 to 504x704)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LM324/LM234</th>
<th>LM304</th>
<th>LM2902</th>
<th>Units</th>
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<tr>
<td></td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Min</td>
<td>Typ</td>
</tr>
<tr>
<td>(I_{o, m})</td>
<td>-120</td>
<td>-120</td>
<td>-120</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Output Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>(V_{o, h} = 1V, V_{o, l} = -2V, V^+ = 15V, V^+ = 2V, T_o = 25^\circ C)</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Sink</td>
<td>(V_{o, h} = 1V, V_{o, l} = -2V, V^+ = 15V, V^+ = 2V, T_o = 25^\circ C)</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>(I_{o, h} = 125\mu A, V_{o, l} = 300, mV, T_o = 25^\circ C)</td>
<td>12</td>
<td>50</td>
<td>12</td>
<td>50</td>
<td>(\mu A)</td>
</tr>
<tr>
<td>Short-Circuit to Ground (Note 5)</td>
<td>(V^+ = 15V, T_o = 25^\circ C)</td>
<td>40</td>
<td>60</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Input Offset Voltage (Note 6)</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Input Offset Current (</td>
<td>I_{o, h}</td>
<td>,</td>
<td>I_{o, l}</td>
<td>)</td>
<td>100</td>
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<tr>
<td>Input Bias Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(\mu A)</td>
</tr>
<tr>
<td>Input Common-Mode Voltage (V_{c, m})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large-Signal Voltage Gain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V/V</td>
</tr>
<tr>
<td>Output Voltage (V_o)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swing</td>
<td>(V^+ = 30V) (LM2062, (V^+ = 26V))</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>V</td>
</tr>
<tr>
<td>(R_o = 2, k\Omega)</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>(\mu V/V)</td>
<td></td>
</tr>
<tr>
<td>(R_{o, h} = 10, k\Omega)</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>(V_{o, h} = 2V, R = 10, k\Omega)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Output Current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>(V_{o, h} = -1V, V_{o, l} = 2V, V^+ = 15V)</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Sink</td>
<td>(V_{o, h} = -1V, V_{o, l} = 2V, V^+ = 15V)</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

**Note 6:** For operating at high temperatures, the LM324/LM304/LM2902 must be derated based on a +150°C maximum junction temperature and thermal resistance of 80°C/watt which applies for the device sold in a plastic circuit board, operating in still air ambient. The LM324/LM304 and LM324/LM2902 can be derated based on a +125°C maximum junction temperature. The diodes are the total of all four amplifiers—use external diodes, where possible, to allow the amplifier to saturate or to reduce the power which is dissipated in the integrated circuit.

**Note 8:** Short circuits from the output to \(V^+\) can cause excessive heating and eventual destruction. When combining short circuits to ground, the maximum output current is approximately 63mA independent of the magnitude of \(V^+\). At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Protective devices can result from failures among all amplifiers.

**Note 3:** This input current will only exist when the voltage at any of the input leads is driven negative; it is due to the collector-base junction of the input NPN transistor becoming forward biased and thereby acting as an input diode clamp. In addition to this diode action, there is also a large input parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the supply to drift to the supply voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output signals will be re-established when the input voltage, which was negative, again returns to a value greater than -0.3V (at 25°C).

**Note 10:** The input baseline voltage of either input signal is not allowed to be more than +5.2V (at 25°C). The upper end of the common-mode voltage range is \(-1.8V\) (at 25°C), but either or both inputs can go to +7V before damage (20mA) for LM324/LM304, independent of the magnitude of \(V^+\).

**Note 11:** Due to proximity of external components, beware that coupling is notshielding via stray capacitance between these external parts. This typically can be detuned as this type of capacitance is destructive at higher frequencies.

**Note 12:** Refer to RETS16AX for LM124A military specifications and refer to RETS124R for LM124 military specifications.

**Note 13:** Human body model, 1.5 kΩ in series with 100 pF.
Typical Performance Characteristics (Continued)

![Graphs showing Input Current and Voltage Gain characteristics for LM2902 and LM2902 only.]

Application Hints

The LM124 series are op amps which operate with only a single power supply voltage, have true differential inputs, and remain in the linear mode with an input common-mode voltage of 0 VDC. These amplifiers operate over a wide range of power supply voltages with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 2.3 VDC.

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14). Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause burning of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than Vcc without damaging the device. Protection should be provided to prevent the input voltages from going negative more than ~0.3 VDC (at 25°C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply drain, the amplifiers have a class B output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion.

Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

The bias network of the LM124 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from 3 VDC to 30 VDC. Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels. If not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers, the larger value of output source current which is available at 25°C provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of Vcc/2) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground in most cases. Input biasing is not required and input voltages which range to ground can easily be accommodated.
Typical Single-Supply Applications \((V^* = 5.0 \ V_{DC})\)

Non-Inverting DC Gain (0V Input = 0V Output)

DC Summing Amplifier \((V_{IN} < 0 \ V_{DC} \text{ and } V_{O} > 0 \ V_{DC})\)

Power Amplifier

Where \(V_{O} = V_{1} + V_{2} - V_{3} = V_{4}\)
\(\left|V_{1} + V_{2}\right| \leq \left|V_{3} + V_{4}\right|\) to keep \(V_{O} > 0 \ V_{DC}\)

\(V_{I} = 5 \ V_{DC} \text{ for } V_{O} = 0 \ V_{DC}\)
\(A_{O} = 10\)
Typical Single-Supply Applications  \( (V^* = 5.0 \, V_{IN}) \) (Continued)

Current Monitor

\[ V_I = \frac{V_{OUT}}{1 + \frac{R_2}{R_1}} \]

\[ V_O = V_I - V^* \]

*(increase R1 for 0V, small)*

Driving TTL

Voltage Follower

Pulse Generator
Typical Single-Supply Applications \((V^* = 5.0 \ V_{\text{cc}})\) (Continued)

Squarewave Oscillator

```
R1 10k
R2 10k
R3 10k

\(V^*\) 0.001F
```

Pulse Generator

```
R1 10k
R2 10k
R3 10k

\(V^*\) 0.001F
```

High Compliance Current Sink

```
R1 10k

\(i_s\) 0.1A
```

\(i_s = 1\) amp limit \(V_{\text{cc}}\)

(increase \(R_2\) for \(i_s\) small)
Typical Single-Supply Applications (V* = 5.0 V_{ref}) (Continued)

Low Drift Peak Detector

Comparator with Hysteresis

Ground Referencing a Differential Input Signal

V0 = V1
Typical Single-Supply Applications  \((V^* = 5.0 \, V_{cc})\) (Continued)

Voltage Controlled Oscillator Circuit

Photo Voltaic-Cell Amplifier

AC Coupled Inverting Amplifier

\(A_v = \frac{R_2}{R_1}\) (As shown, \(A_v \approx 10^3\)
**Typical Single-Supply Applications**  \((V^* = 5.0 \; V_{\text{ref}})\)  (Continued)

**AC Coupled Non-Inverting Amplifier**

\[ A_v = 1 + \frac{R_2}{R_1} \]
\[ A_{v_p} = 11 \quad \text{(as shown)} \]

**DC Coupled Low-Pass RC Active Filter**

\[ f_c = 1 \; \text{MHz} \]
\[ Q = 1 \]
\[ A_v = 2 \]
Typical Single-Supply Applications ($V^* = 5.0 \, V_{DC}$) (Continued)

High Input Z, DC Differential Amplifier

For $R_1 = R_4$, $R_2 = R_3$ (NMR depends on this resistor ratio match)

$V_0 = 1 + \frac{R_4}{R_2} (V_2 - V_1)$

As shown $V_0 = 2(V_2 - V_1)$

High Input Z Adjustable-Gain
DC Instrumentation Amplifier

If $R_1 = R_3, R_2 = R_4, R_5 = R_6, R_7$ (NMR depends on match)

$V_0 = 1 - \frac{R_1}{R_2} (V_2 - V_1)$

As shown $V_0 = 121 (V_2 - V_1)$
Typical Single-Supply Applications \((V^* = 5.0 \, V_{DD})\) (Continued)

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)

Bridge Current Amplifier

For \( \delta < 1 \) and \( R_i > R \),

\[ V_0 = V_{pp} \left( \frac{R_i}{R} - \frac{1}{2} \right) \]

Bandpass Active Filter

\[ f_c = 1 \, \text{kHz} \]
\[ Q = 25 \]
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

LIFE SUPPORT POLICY

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