19-1999; Rev 4; 7/04

3.2Gbps Adaptive Equalizer

General Description

The MAX3801 is a +3.3V adaptive cable equalizer designed for coaxial and twin-axial cable point-to-point communications applications. The equalizer includes differential CML data inputs and outputs, a loss-of-signal ($\overline{LOS}$) output, and a cable integrity monitor (CIM) output.

The adaptive cable equalizer is capable of equalizing differential or single-ended signals at data rates up to 3.2Gbps. It automatically adjusts to attenuation caused by skin-effect losses of up to 30dB at 1.6GHz. The equalizer effectively extends the usable length of copper cable in high-frequency interconnect applications.

The MAX3801 is available in a 24-pin QFN package with exposed pad and consumes only 125mW at +3.3V.

Applications

High-Speed Links in Communications and Data Systems

Backplane and Interconnect Applications

SDH/SONET Transmission Equipment

Features

- ♦ **Single +3.3V Operation**
- ♦ **Typical Power Dissipation = 125mW at +3.3V**
- ♦ **Data Rates Up to 3.2Gbps**
- ♦ **Equalizer Automatically Adjusts for Different Cable Lengths**
- ♦ **0dB to 30dB Equalization at 1.6GHz (3.2Gbps)**
- ♦ **Loss-of-Signal ($\overline{LOS}$) Indicator**
- ♦ **Cable Integrity Monitor (CIM)**
- ♦ **On-Chip Input and Output Terminations**
- ♦ **Low External Component Count**
- ♦ **Operating Temperature Range = 0°C to +85°C**
- ♦ **ESD Protection on Inputs and Outputs**

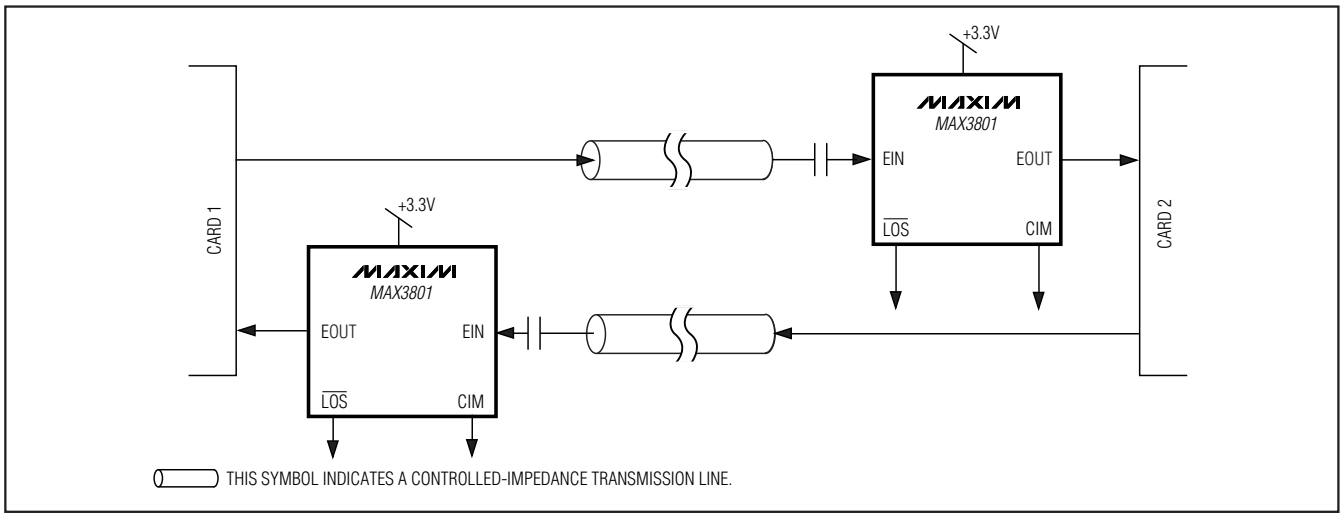
Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	PACKAGE CODE
MAX3801UGG	0°C to +85°C	24 QFN	G2444-1
MAX3801UTG	0°C to +85°C	24 Thin QFN	T2444-2
MAX3801UTG+	0°C to +85°C	24 Thin QFN	T2444-2

+Denotes lead-free package.

Pin Configuration appears at end of data sheet.

Typical Application Circuit



For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

3.2Gbps Adaptive Equalizer

ABSOLUTE MAXIMUM RATINGS

Supply Voltage, V_{CC}.....-0.5V to +6.0V
Voltage at $\overline{LOS}$, CIM+, CIM-.....-0.5V to (V_{CC} + 0.5V)
Voltage at EIN+, EIN-.....(V_{CC} - 1V) to (V_{CC} + 0.5V)
Current Out of EOUT+, EOUT-.....25mA
Continuous Power Dissipation (T_A = +85°C)
24-Lead QFN-EP (derate 25.1mW/°C above +85°C) .1630mW
Operating Ambient Temperature Range .....0°C to +85°C
Storage Temperature Range.....-55°C to +150°C
Lead Temperature (soldering, 10s).....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.14V to +3.46V, T_A = 0°C to +85°C. Typical values are at V_{CC} = +3.3V and T_A = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Current	I_{CC}	Includes external load current		37	60	mA
INPUT SPECIFICATIONS						
Minimum Cable Input (Differential)		3.2Gbps, 30dB cable loss at 1.6GHz (Note 1)		650	700	MV_{P-P}
Maximum Cable Input (Differential)				1100		mV_{P-P}
Input Impedance		Single-ended	40	53	62.5	Ω
OUTPUT SPECIFICATIONS						
Output Voltage (Differential)		(Note 2)	500		1000	mV_{P-P}
Output Impedance		Single-ended	50	65	75	Ω
Voltage at CIM Output (Differential)	V_{CIM}	No external load, V_{CIM} = (V_{CIM+}) - (V_{CIM-})	-0.5		+0.5	V_{P-P}
Voltage at CIM Output (Single-Ended)	V_{CIM+}, V_{CIM-}	No external load	0.5		V_{CC} - 0.5	V
Voltage at $\overline{LOS}$		Output high (Note 3)	2.4			V
		Output low (Note 3)			0.4	
Output Common-Mode Voltage		Each output DC-coupled 50Ω to V_{CC}		V_{CC} - 0.2		V

AC ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.14V to +3.46V, T_A = 0°C to +85°C. Typical values are at V_{CC} = +3.3V and T_A = +25°C, unless otherwise noted.) (Note 4)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Maximum Input Data Rate			3.2			Gbps
Residual Jitter (Note 5)		0dB cable loss (Note 6)		120	240	mUI_{P-P}
		24dB cable loss (Note 6)		140	240	
		30dB cable loss (Note 6)		100	200	
Output Edge Speed		20% to 80%		64	90	ps
Input Return Loss (Single-Ended)		≤3.2GHz		15		dB
Output Return Loss (Single-Ended)		≤3.2GHz		15		dB
Equalization Compensation		1.6GHz (skin-effect losses only)	30			dB
Equalization Time Constant				5		µs

Note 1: Minimum cable input for $\overline{LOS}$ to assert high.

Note 2: Input voltage within specification limits, 50Ω to V_{CC} at each output.

Note 3: 100kΩ load to ground.

Note 4: AC electrical characteristics are guaranteed by design and characterization.

Note 5: Includes random jitter and deterministic jitter.

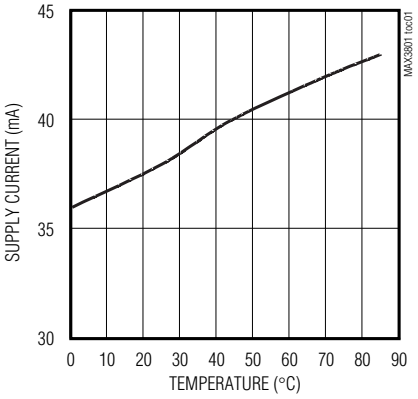
Note 6: Differential cable input voltage = $700mV_{P-P}$, 3.2Gbps 2^{13} - 1PRBS with 100 consecutive ones and 100 consecutive zeros substituted. Cable loss is due to skin effect only.

3.2Gbps Adaptive Equalizer

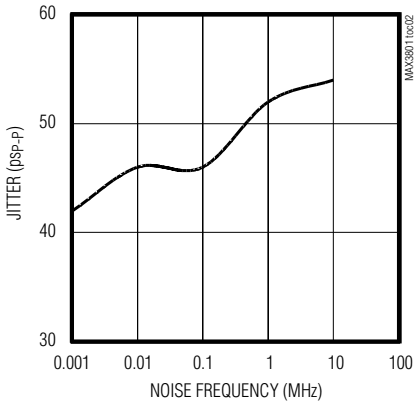
Typical Operating Characteristics

(V_{CC} = +3.3V, all jitter measurements done at 3.2Gbps, 700mV cable input with 2^{13} - 1 PRBS pattern with 100 consecutive ones and 100 consecutive zeros substituted, T_A = +25°C. **Note:** Test pattern produces near worst-case jitter results. Results vary with pattern, unless otherwise noted.)

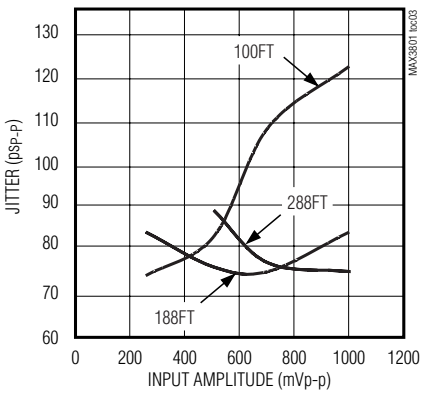
SUPPLY CURRENT vs. TEMPERATURE



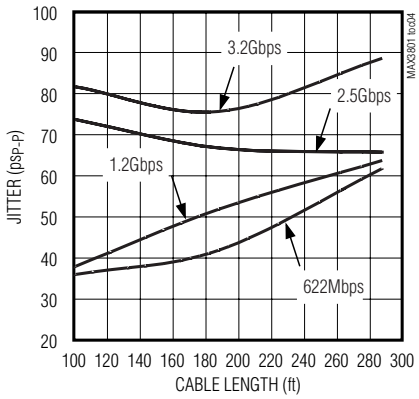
EQUALIZER RESIDUAL JITTER vs. POWER-SUPPLY NOISE (100mVP-P SINE WAVE) (85FT OF GORE 89 CABLE)



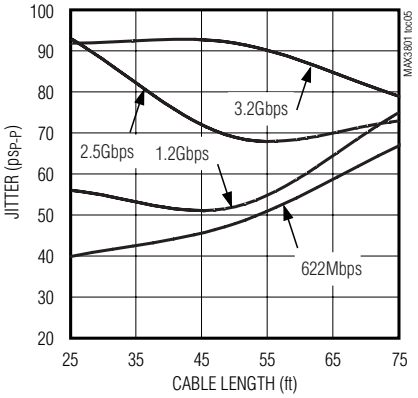
EQUALIZER RESIDUAL JITTER vs. INPUT AMPLITUDE AT 3.2GHz (RG59 – 75Ω COAXIAL CABLE – SINGLE-ENDED)



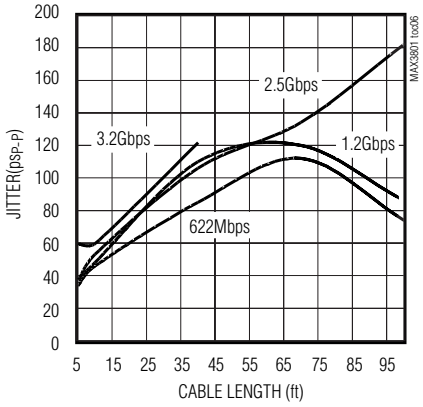
EQUALIZER RESIDUAL JITTER vs. CABLE LENGTH (RG59 – 75Ω COAXIAL CABLE – SINGLE-ENDED) INPUT LEVEL OF 500mVP-P



EQUALIZER RESIDUAL JITTER vs. CABLE LENGTH (RG179B – 75Ω COAXIAL CABLE – SINGLE-ENDED) INPUT LEVEL OF 700mVP-P



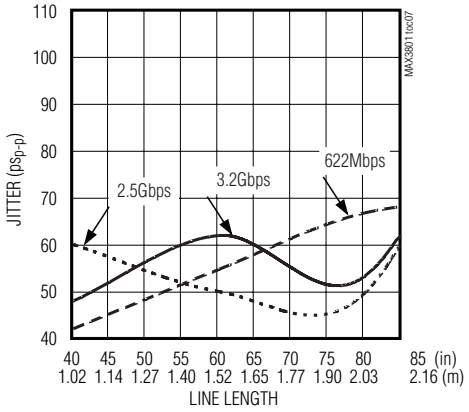
EQUALIZER RESIDUAL JITTER vs. CABLE LENGTH (CATEGORY 5E – TWISTED PAIR) INPUT LEVEL OF 700mVP-P



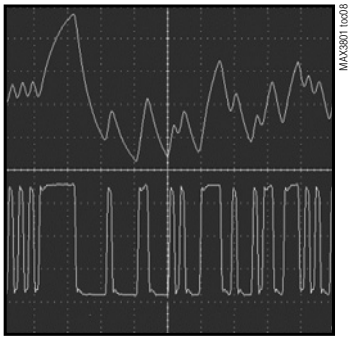
Typical Operating Characteristics (continued)

(V_{CC} = +3.3V, all jitter measurements done at 3.2Gbps, 700mV cable input with 2^{13} - 1 PRBS pattern with 100 consecutive ones and 100 consecutive zeros substituted, T_A = +25°C. **Note:** Test pattern produces near worst-case jitter results. Results vary with pattern, unless otherwise noted.)

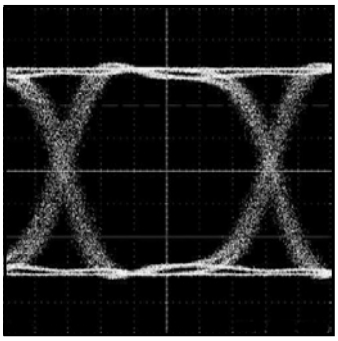
EQUALIZER RESIDUAL JITTER vs. LINE LENGTH (FR-4 6MIL STRIPLINE – SINGLE-ENDED)



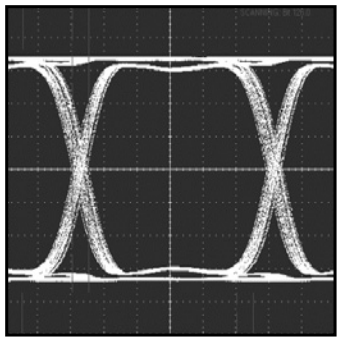
EQUALIZER INPUT AFTER 115FT OF CABLE (TOP) EQUALIZER OUTPUT (BOTTOM)



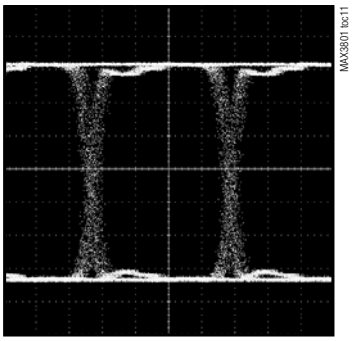
EQUALIZER OUTPUT EYE DIAGRAM AFTER 288 FT OF RG59 CABLE (INPUT OF 1000mVP-P, 3.2Gbps, 2^{23} - 1PRBS)



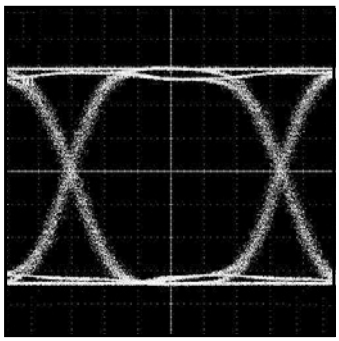
EQUALIZER OUTPUT EYE DIAGRAM AFTER 100FT OF 75Ω RG179 CABLE (2.5Gbps, SINGLE-ENDED, 2^7 - 1PRBS)



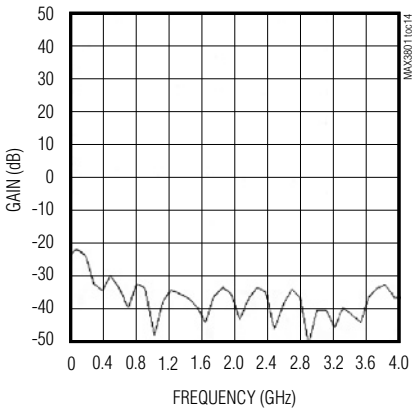
EQUALIZER OUTPUT EYE DIAGRAM AFTER 70FT OF CATEGORY 5E CABLE (INPUT OF 1000mVP-P, 1.25Gbps)



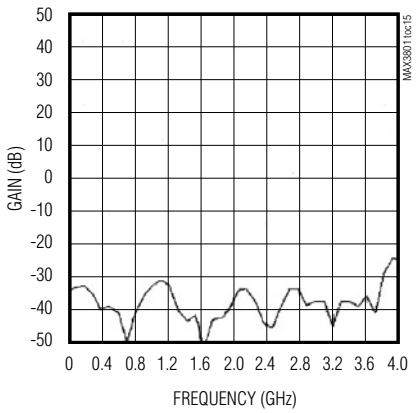
EQUALIZER OUTPUT EYE DIAGRAM AFTER 115FT OF 50Ω GORE 89 CABLE (INPUT OF 1000mVP-P, 3.2Gbps)



EQUALIZER INPUT RETURN LOSS (S11)



EQUALIZER OUTPUT RETURN LOSS (S22)



3.2Gbps Adaptive Equalizer

Pin Description

PIN	NAME	FUNCTION
1, 3, 7, 12, 16, 18, 19, 24	GND	Ground
2, 4, 8, 11, 17, 20, 23	V_{CC}	Power Supply
5	CIM-	Negative Cable Integrity Monitor (CIM) Output
6	CIM+	Positive Cable Integrity Monitor (CIM) Output
9	EOUT-	Negative Equalizer Output, CML
10	EOUT+	Postive Equalizer Output, CML
13, 14	N.C.	No connection. Leave unconnected.
15	$\overline{LOS}$	Equalizer Loss-of-Signal Output, Active-Low
21	EIN+	Postive Equalizer Input, CML
22	EIN-	Negative Equalizer Input, CML
EP	Exposed Pad	Ground. The exposed pad must be soldered to the circuit board ground for proper thermal and electrical operation.

Detailed Description

The adaptive cable equalizer accepts differential CML input data at rates up to 3.2Gbps and is capable of equalizing differential or single-ended signals. It automatically adjusts to attenuation levels of up to 30dB at 1.6GHz (because of skin-effect losses in copper cable). The equalizer consists of a CML input buffer, a loss-of-signal detector, a flat response amplifier, a skin-effect compensation amplifier, a current-steering network, a dual power-detector feedback loop, an output limiting amplifier, and a CML output buffer (Figure 1).

General Theory of Operation

The shape of the power spectrum of a random bit stream can be described by the square of the sinc function, where sinc f = (sin πf) / πf. For sufficiently long bit patterns (nonrandom bit streams), $sinc^2(f)$ is a good approximation. From the shape of the $sinc^2(f)$ function, we can estimate the ratio of the power densities at any two frequencies. The MAX3801 adaptive equalizer employs this principle by incorporating a feedback loop that continuously monitors the power at two frequencies and dynamically adjusts the equalizer to maintain the correct power ratio.

CML Input and Output Buffers

The input and output buffers are implemented using current-mode logic (CML). Equivalent circuits are shown in Figures 2 and 3. For details on interfacing with CML, refer to Maxim application note HFAN-1.0, Introduction to LVDS, PECL, and CML.

Flat Response and Skin-Effect Compensation Amplifiers

The buffered input waveform is fed equally to two amplifiers—the flat response amplifier and the skin-effect compensation amplifier. The flat response amplifier has a constant gain over the entire frequency range of the device, and the skin-effect compensation amplifier has a gain characteristic that approximates the inverse of the skin-effect attenuation inherent in copper cable. The skin-effect attenuation, in dB per unit length, is proportional to the square root of the frequency. The output currents from the two amplifiers are supplied to the current-steering network. Note that, when $\overline{LOS}$ asserts low, equalization is minimized.

Current-Steering Network

The function of the current-steering network is to combine adjustable quantities of the output currents from the flat response and skin-effect compensation ampli-

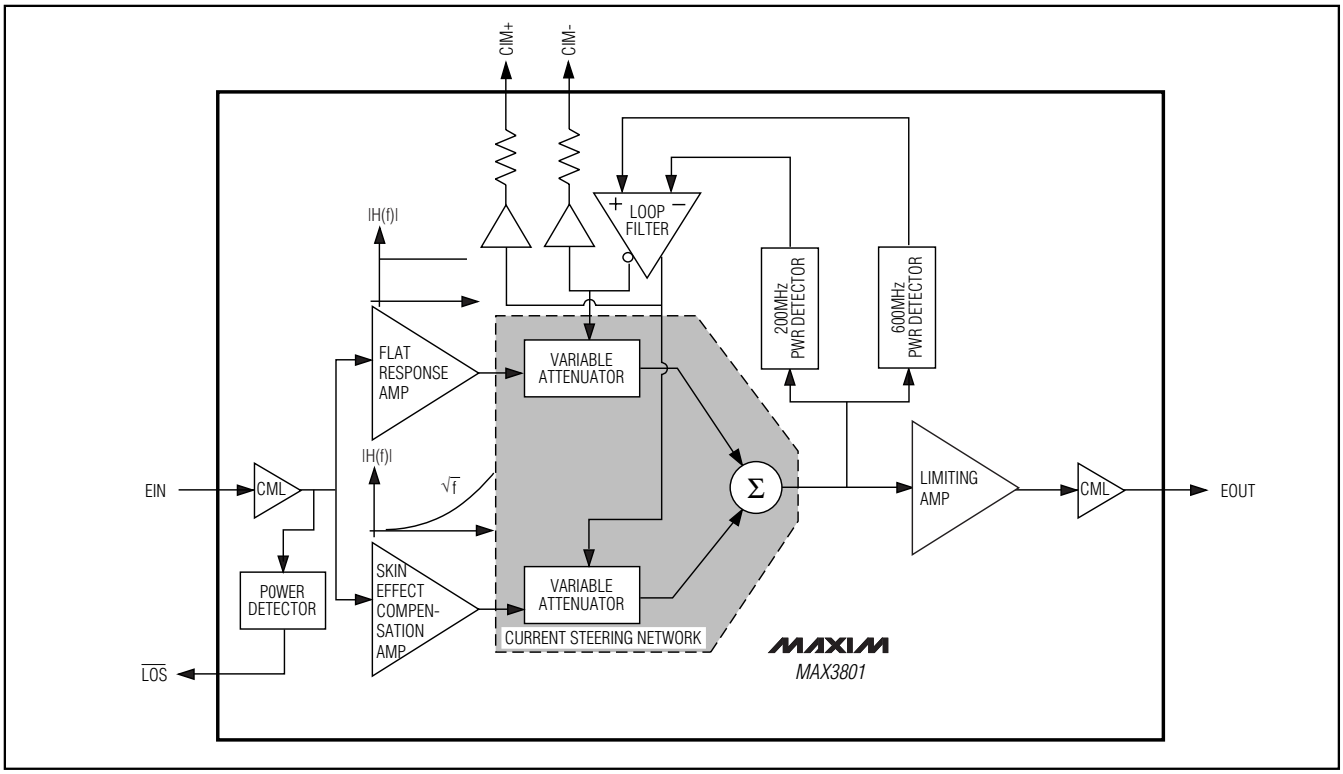


Figure 1. Functional Diagram

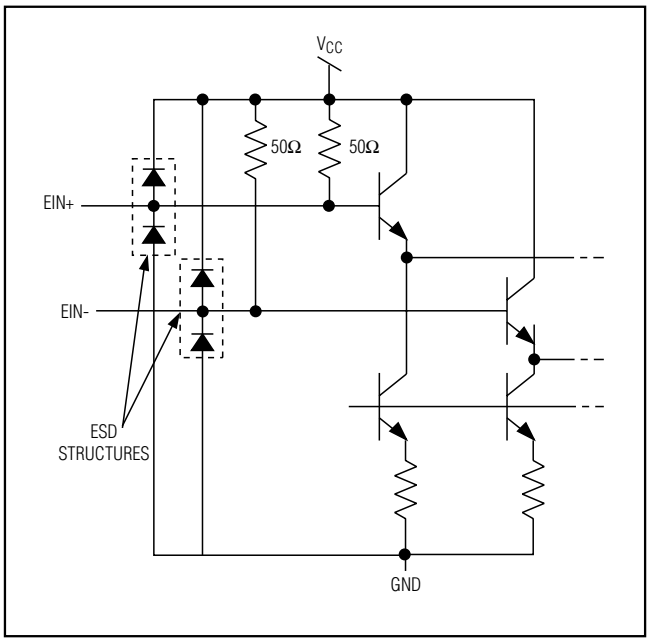


Figure 2. CML Input Equivalent Circuit

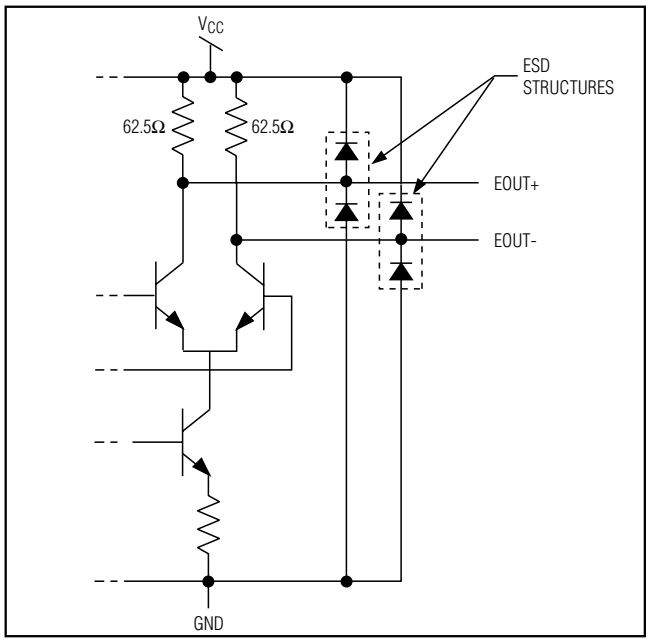


Figure 3. CML Output Equivalent Circuit

fiers to achieve a desired current ratio. The ratio adjustment is controlled by the dual power-detector feedback loop.

The current-steering network is implemented with two variable attenuators that feed into a current-summing node. The variable attenuators attenuate the output currents of the flat response and skin-effect compensation amplifiers under control of the dual power-detector feedback loop. The outputs of the two attenuators are combined at the summing node and then fed to the output limiting amplifier and the feedback loop.

Dual Power-Detector Feedback Loop

The output of the current-steering network is applied to the inputs of two frequency-specific power detectors. One of the power detectors is tuned to 200MHz, and the other is tuned to 600MHz. The outputs of the two power detectors are applied to the inverting (200MHz power detector) and noninverting (600MHz power detector) inputs of the differential loop amplifier. The differential outputs of the loop amplifier control the variable attenuators in the current-steering network.

Output Limiting Amplifier

The output limiting amplifier amplifies the signal from the current-steering network to achieve the specified output voltage swing.

Applications Information

Refer to Maxim application note HFAN-10.0, *Equalizing Gigabit Copper Cable Links with the MAX3800* (available at www.maxim-ic.com) for additional applications information.

Cable Integrity Monitor (CIM)

The differential CIM output current is directly proportional to the output current of the loop amplifier (which controls the current-steering network—see the *Detailed Description*). This is an analog current output that indicates the amount of equalization being applied. A convenient way to monitor the CIM current is to connect a 100kΩ resistor from each of the CIM outputs to ground, and then measure the voltage at the CIM pins.

The amount of equalization (and thus the CIM output level) is affected by various factors, including cable type, cable length, signal bandwidth, etc.

Loss-of-Signal ($\overline{LOS}$) Output

Loss-of-signal is indicated by the $\overline{LOS}$ output. A low level on $\overline{LOS}$ indicates that the equalizer input signal power has dropped below a threshold. The $\overline{LOS}$ output indicates a loss of signal. When the equalizer no longer detects a signal from the channel, the $\overline{LOS}$ output goes low. When there is sufficient input voltage to the channel (typically greater than 650mV), $\overline{LOS}$ is high. The $\overline{LOS}$ output is suitable for indicating problems with the transmission link caused by, for example, a broken cable, a defective driver, or a lost connection to the equalizer.

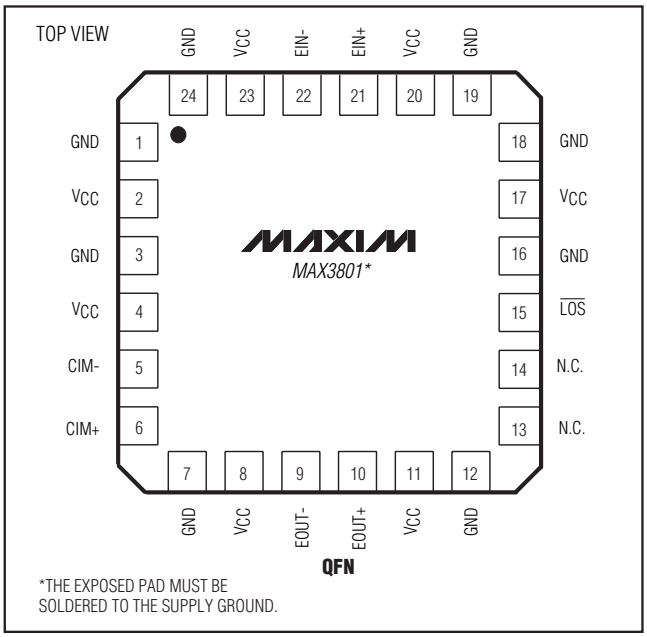
Single-Ended Operation

For single-ended operation of the equalizer, connect the unused input to ground through a series combination of a capacitor (of equal value to other AC-coupling capacitors) and a 50Ω resistor. Note that the MAX3801 is specified for differential operation. The effective range of equalization for single-ended use is approximately 4dB to 30dB at 1.6GHz.

Layout Considerations

The MAX3801's performance significantly can be affected by circuit-board layout and design. Use good high-frequency design techniques, including minimizing ground inductance and using fixed-impedance transmission lines for the high-frequency data signals. Place power-supply decoupling capacitors as close as possible to V_{CC}.

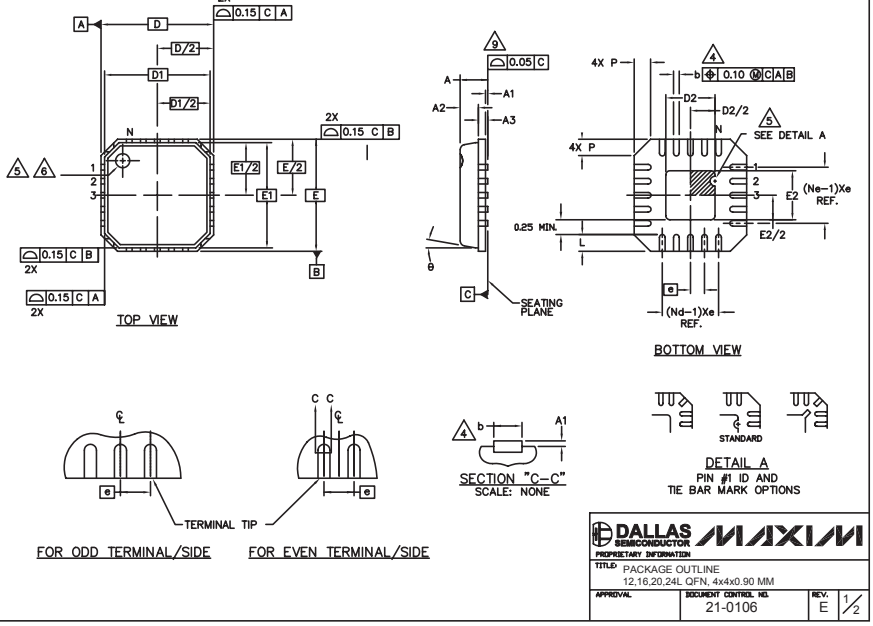
Pin Configuration



Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

12,16,20,24L QFN.EPS



NOTES:

1. DIE THICKNESS ALLOWABLE IS 0.305mm MAXIMUM (.012 INCHES MAXIMUM).
2. DIMENSIONING & TOLERANCES CONFORM MUST TO ASME Y14.5M. – 1994.
3. N IS THE NUMBER OF TERMINALS.
   Nd IS THE NUMBER OF TERMINALS IN X-DIRECTION &
   Ne IS THE NUMBER OF TERMINALS IN Y-DIRECTION.
4. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.20 AND 0.25mm FROM TERMINAL TIP.
5. THE PIN #1 IDENTIFIER MUST BE EXISTED ON THE TOP SURFACE OF THE PACKAGE BY USING INDENTATION MARK OR INK/LASER MARKED. DETAILS OF PIN #1 IDENTIFIER IS OPTIONAL, BUT MUST BE LOCATED WITHIN ZONE INDICATED.
6. EXACT SHAPE AND SIZE OF THIS FEATURE IS OPTIONAL.
7. ALL DIMENSIONS ARE IN MILLIMETERS.
8. PACKAGE WARPAGE MAX 0.05mm.
9. APPLIED FOR EXPOSED PAD AND TERMINALS.
   EXCLUDE EMBEDDING PART OF EXPOSED PAD FROM MEASURING.
10. MEETS JEDEC MO220; EXCEPT DIMENSION "b".
11. THIS PACKAGE OUTLINE APPLIES TO PUNCHED QFN (STEPPED SIDES).

SYMBOL	COMMON DIMENSIONS MIN.	NOM.	MAX.	NOTE
A	0.80	0.90	1.00	
A1	0.00	0.01	0.05	
A2	0.00	0.65	0.80	
A3		0.20 REF.		
D		4.00 BSC		
D1		3.75 BSC		
E		4.00 BSC		
E1		3.75 BSC		
θ	0°	–	12°	
P	0.24	0.42	0.60	

SYMBOL	PITCH VARIATION A MIN.	NOM.	MAX.	NOTE	SYMBOL	PITCH VARIATION B MIN.	NOM.	MAX.	NOTE	SYMBOL	PITCH VARIATION C MIN.	NOM.	MAX.	NOTE	SYMBOL	PITCH VARIATION D MIN.	NOM.	MAX.	NOTE
e		0.80 BSC			e		0.65 BSC			e		0.50 BSC			e		0.50 BSC		
N		12		3	N		16		3	N		20		3	N		24		3
Nd		3		3	Nd		4		3	Nd		5		3	Nd		6		3
Ne		3		3	Ne		4		3	Ne		5		3	Ne		6		3
L	0.50	0.60	0.75		L	0.50	0.60	0.75		L	0.50	0.60	0.75		L	0.30	0.40	0.50	
b	0.28	0.33	0.40	4	b	0.23	0.28	0.35	4	b	0.18	0.23	0.30	4	b	0.18	0.23	0.30	4

PKG. CODE	EXPOSED PAD VARIATION D2 MIN.	NOM.	MAX.	E2 MIN.	NOM.	MAX.
G1244-2	1.95	2.10	2.25	1.95	2.10	2.25
G1644-1	1.95	2.10	2.25	1.95	2.10	2.25
G2044-3	1.95	2.10	2.25	1.95	2.10	2.25
G2044-4	1.55	1.70	1.85	1.55	1.70	1.85
G2444-1	1.95	2.10	2.25	1.95	2.10	2.25

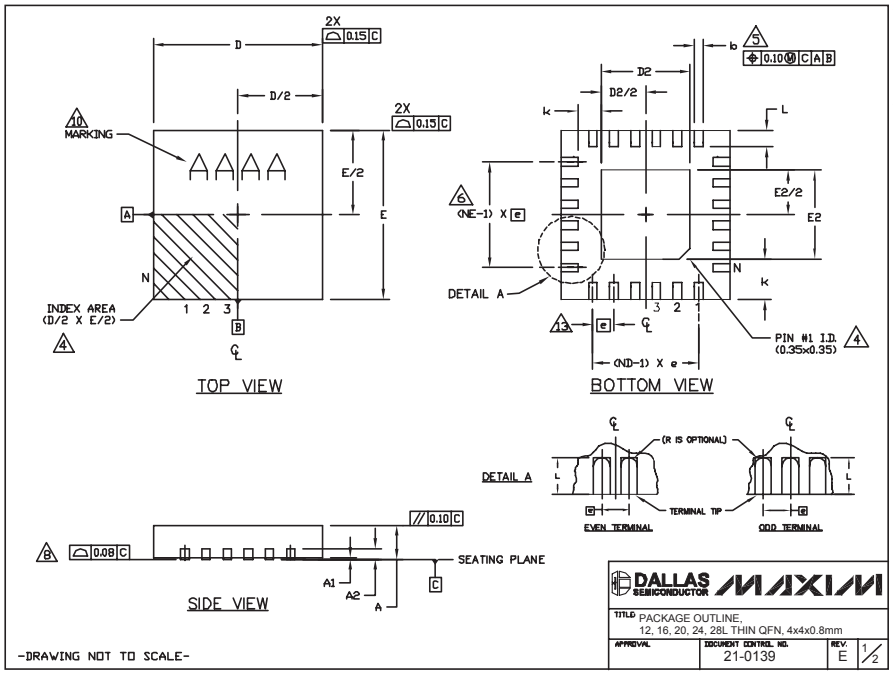
DALLAS SEMICONDUCTOR MAXIM
PROPRIETARY INFORMATION
TITLE: PACKAGE OUTLINE
12,16,20,24L QFN, 4x4x0.90 MM
APPROVAL
DOCUMENT CONTROL NO.
21-0106
REV.
E
2/2

3.2Gbps Adaptive Equalizer

Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

24L QFN THIN.EPS



COMMON DIMENSIONS

PKG	12L 4x4			16L 4x4			20L 4x4			24L 4x4			28L 4x4		
REF.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80
A1	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05	0.0	0.02	0.05
A2	0.20 REF			0.20 REF			0.20 REF			0.20 REF			0.20 REF		
b	0.25	0.30	0.35	0.25	0.30	0.35	0.20	0.25	0.30	0.18	0.23	0.30	0.15	0.20	0.25
D	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
E	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10	3.90	4.00	4.10
e	0.80 BSC.			0.65 BSC.			0.50 BSC.			0.50 BSC.			0.40 BSC.		
k	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-
L	0.45	0.55	0.65	0.45	0.55	0.65	0.45	0.55	0.65	0.30	0.40	0.50	0.30	0.40	0.50
N	12			16			20			24			28		
ND	3			4			5			6			7		
NE	3			4			5			6			7		
Jedec Var.	WGGB			WGGC			WGGD-1			WGGD-2			WGGE		

EXPOSED PAD VARIATIONS

PKG. CODES	D2			E2			DOWN BONDS ALLOWED
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	
T1244-3	1.95	2.10	2.25	1.95	2.10	2.25	YES
T1244-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
T1644-3	1.95	2.10	2.25	1.95	2.10	2.25	YES
T1644-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
T2044-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
T2044-3	1.95	2.10	2.25	1.95	2.10	2.25	NO
T2444-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
T2444-3	2.45	2.60	2.63	2.45	2.60	2.63	YES
T2444-4	2.45	2.60	2.63	2.45	2.60	2.63	NO
T2844-1	2.50	2.60	2.70	2.50	2.60	2.70	NO

NOTES:

1. DIMENSIONING & TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
3. N IS THE TOTAL NUMBER OF TERMINALS.
4. THE TERMINAL #1 IDENTIFIER AND TERMINAL NUMBERING CONVENTION SHALL CONFORM TO JESD 95-1 SPP-012. DETAILS OF TERMINAL #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE TERMINAL #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE.
5. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TIP.
6. ND AND NE REFER TO THE NUMBER OF TERMINALS ON EACH D AND E SIDE RESPECTIVELY.
7. DEPOPULATION IS POSSIBLE IN A SYMMETRICAL FASHION.
8. COPLANARITY APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
9. DRAWING CONFORMS TO JEDEC MO220, EXCEPT FOR T2444-3, T2444-4 AND T2844-1.
10. MARKING IS FOR PACKAGE ORIENTATION REFERENCE ONLY.
11. COPLANARITY SHALL NOT EXCEED 0.08mm
12. WARPAGE SHALL NOT EXCEEND 0.10mm
13. LEAD CENTERLINES TO BE AT TRUE POSITION AS DEFINED BY BASIC DIMENSION "e", ±0.05.
14. NUMBER OF LEADS SHOWN ARE FOR REFERENCE ONLY

-DRAWING NOT TO SCALE-

DALLAS SEMICONDUCTOR MAXIM
TITLE PACKAGE OUTLINE, 12, 16, 20, 24, 28L THIN QFN, 4x4x0.8mm
APPROVAL
DOCUMENT CONTROL NO. 21-0139
REV. E
2/2

Maxim cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim product. No circuit patent licenses are implied. Maxim reserves the right to change the circuitry and specifications without notice at any time.

© 2004 Maxim Integrated Products Printed USA MAXIM is a registered trademark of Maxim Integrated Products.