



# 47MHz to 870MHz Analog CATV Transimpedance Amplifier

MAX3654

## General Description

The MAX3654 analog transimpedance amplifier (TIA) is designed for CATV applications in fiber-to-the-home (FTTH) networks. This high-linearity amplifier is intended for 47MHz to 870MHz subcarrier multiplexed (SCM) signals in passive optical networks (PON). A gain-control input supports AGC operation with optical inputs having -6dBm to +2dBm average power. With 62dBΩ maximum gain at 47MHz and 18dB gain control range, the minimum RF output level is 14dBmV/channel at -6dBm optical input. A compact 4mm x 4mm package includes all of the active RF circuitry required to convert analog PIN photocurrent to a 75Ω CATV output.

This 700mW SiGe RF IC provides a low-cost, low-power integrated analog CATV receiver solution for FTTH ONTs.

## Features

- ◆ 47MHz to 870MHz Operation
- ◆ -6dBm to +2dBm Optical Input Range
- ◆ 21dBm OIP3, 47dBm OIP2
- ◆ 5.5pA/√Hz EIN (Amplifier Alone)
- ◆ 62dB Gain at 47MHz
- ◆ 18dB Transimpedance (Gain) Control
- ◆ Integrated +4dB Gain Tilt (with Typical Photodiode)
- ◆ +5V Single-Supply Operation
- ◆ 700mW Power Dissipation
- ◆ -40°C to +85°C Operating Temperature Range
- ◆ 4mm x 4mm TQFN Package

## Applications

FTTH Optical Network Termination (ONT)

## Ordering Information

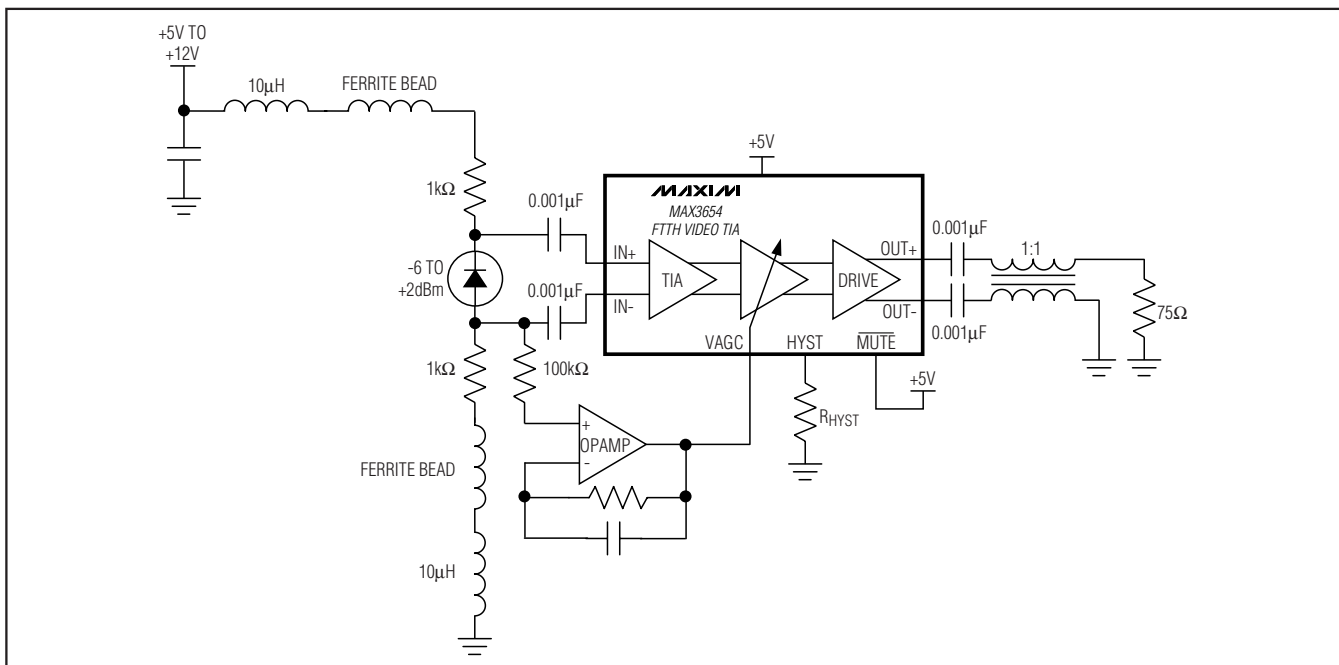
PART	TEMP RANGE	PIN-PACKAGE	PKG-CODE
MAX3654ETE+	-40°C to +85°C	16 TQFN-EP*	T1644F-4-A

+ Denotes lead-free package.

\*EP = Exposed pad.

Pin Configuration appears at end of data sheet.

## Typical Application Circuit



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## ABSOLUTE MAXIMUM RATINGS

Supply Voltage, VCC ..... -0.3V to +6.0V  
 IN+, IN-, VAGC, OUT+, OUT-, MUTE, HYST ..... -0.3V to +5.5V  
 TEST1, TEST2 ..... -0.3V to +5.5V  
 Output Current (OUT+, OUT-) ..... 56mA

Continuous Power Dissipation, 16-Lead TQFN-EP Package  
 (TA = +70°C) (derate 16.9mW/°C above +70°C).... 1349.1mW  
 Operating Temperature Range ..... -40°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

(VCC = +4.75V to +5.25V, typical values at VCC = +5.0V, TA = +25°C, unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Current	ICC			136	170	mA
Gain Control Input Current		VAGC = 1.4V		50	200	μA
Mute Input High	VIH		2.0			V
Mute Input Low	VIL				0.8	V
Mute Input Current	IIH, IIL				30	μA

## AC ELECTRICAL CHARACTERISTICS

(VCC = +4.75V to +5.25V, output ZL = 75Ω, typical values at VCC = +5.0V, TA = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
Operating Frequency Range	f		47		870	MHz	
Frequency Response Flatness		47MHz to 870MHz (Notes 2, 6)		±0.3	±0.75	dB	
Transimpedance, Differential (ZT)		47MHz	VAGC ≤ 0.175V	60.5	62	63.5	dBΩ
			VAGC = 0.500V	51.5	53	54.5	
			VAGC = 1.400V	42	43.5	45	
Gain Control Stability		VAGC = 0 to 1.4V, RHYST = open (Note 3)		±0.75	±1.6	dB	
Gain Tilt		Linear, 870MHz compared to 47MHz (Notes 4, 6)	3	4	5.5	dB	
Output Second-Order Intercept	OIP2	(Note 5)		>47		dBm	
Output Third-Order Intercept	OIP3	(Notes 4, 5)	18	21		dBm	
Equivalent Input Noise Including Photodiode	EIN	VAGC ≤ 0.175V (Notes 4, 6)			8	pA/√Hz	
Gain Hysteresis, Optical		RHYST = open		±0.13		dB	
		RHYST = GND		±0.65			
Differential Output Level, Mute		MUTE ≤ 0.8V, 50MHz		-58	-45	dBc	
RF Output Return Loss	-S22	47MHz to 870MHz		13		dB	

**Note 1:** DC parameters are tested at +25°C, and guaranteed by design and characterization at -40°C and +85°C.

**Note 2:** Maximum difference between frequency response at any point and a straight line connecting frequency response at end points.

**Note 3:** Gain control stability is the maximum variation in transimpedance (over process, voltage, and temperature) for any VAGC control voltage.

**Note 4:** AC parameters guaranteed by design and characterization.

**Note 5:** OIP2 and OIP3 measured using two tones at f1 = 800MHz and f2 = 850MHz, POUT = -16dBm, VAGC = 1.4V.

**Note 6:** Includes the effects of a packaged photodiode having the characteristics shown in Figure 2.

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**MAX3654**

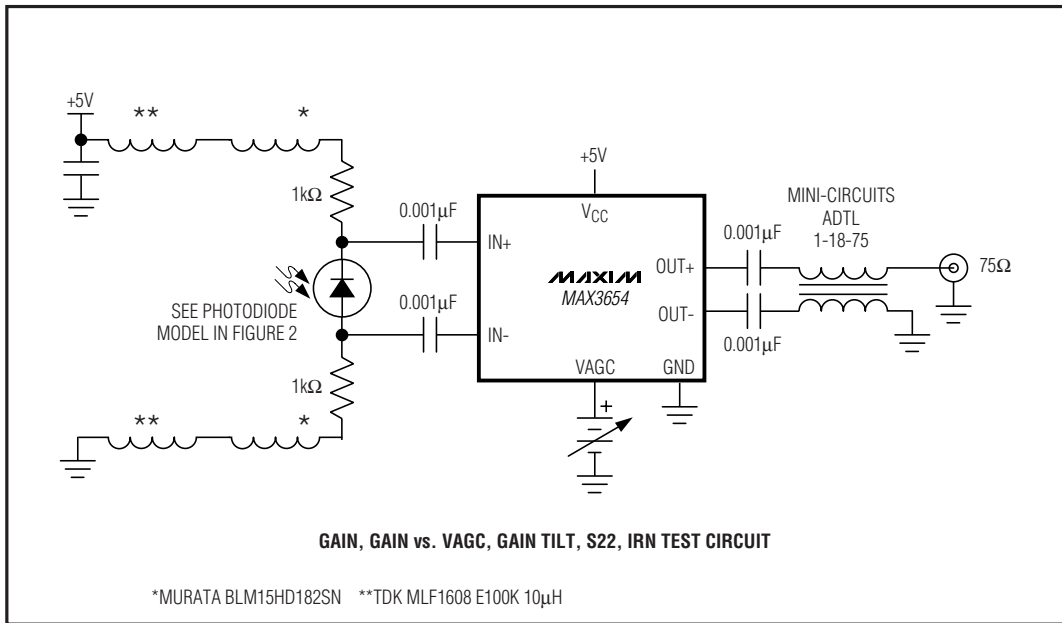
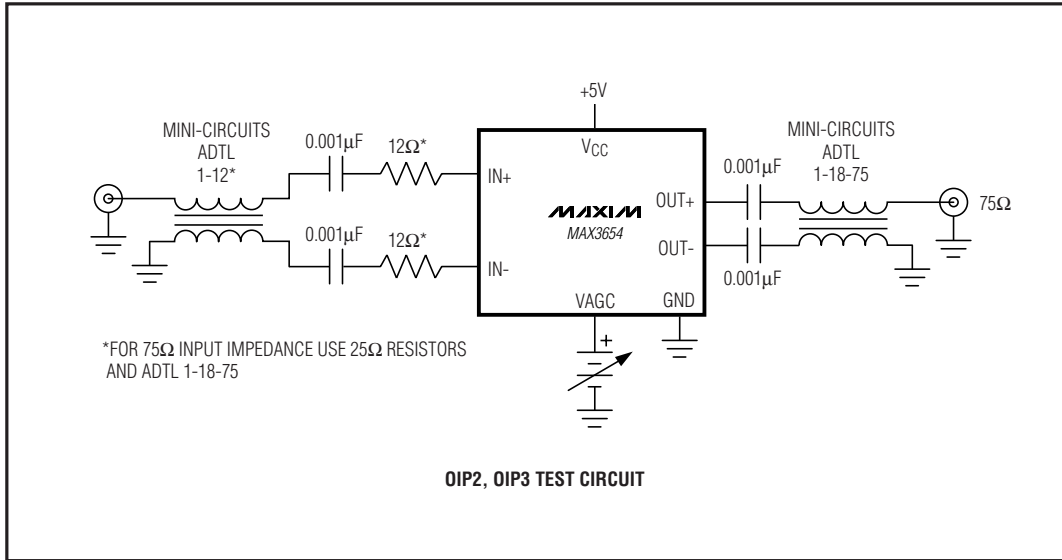


Figure 1. Test Circuits for Characterization

# 47MHz to 870MHz Analog CATV Transimpedance Amplifier

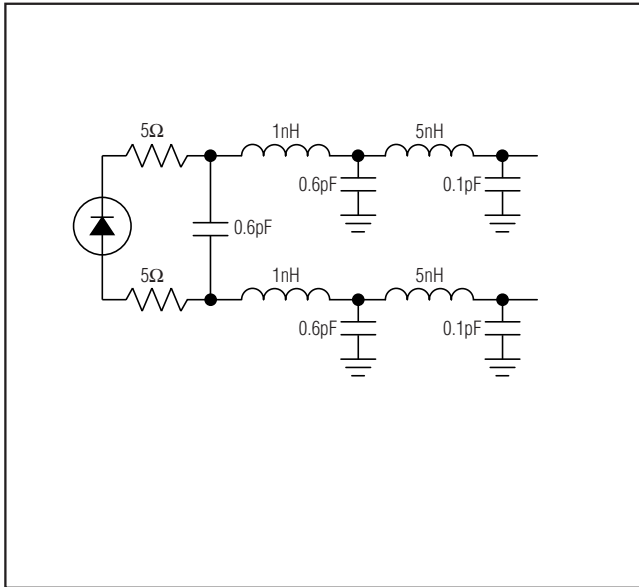


Figure 2. Photodiode and Header Model

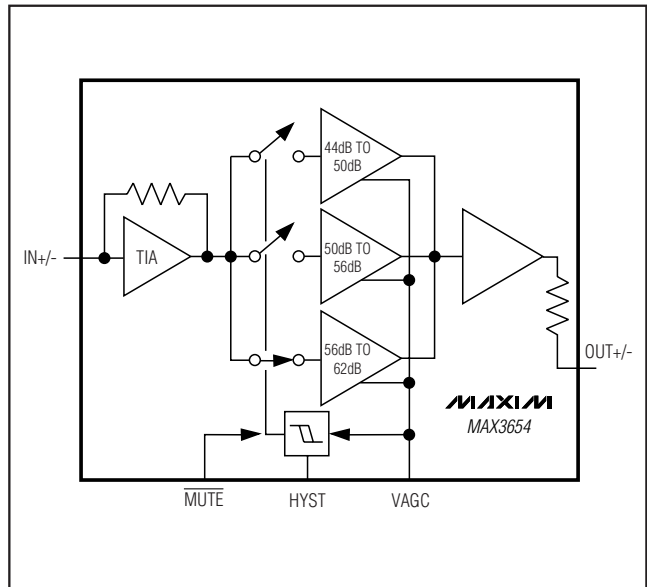
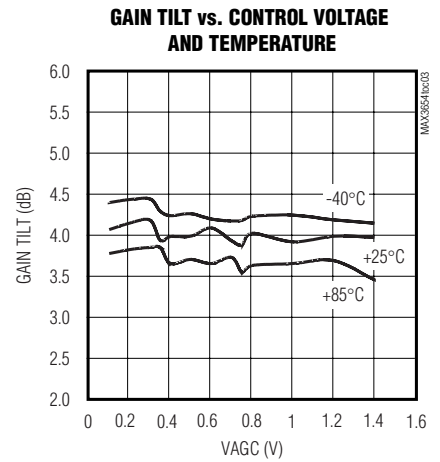
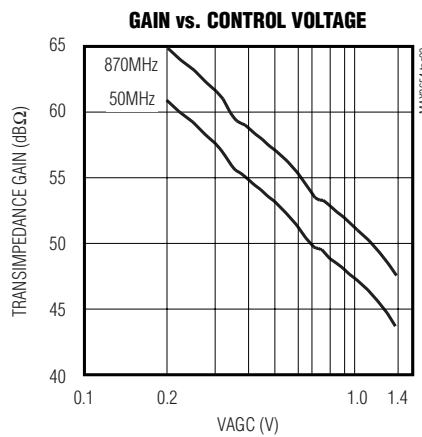
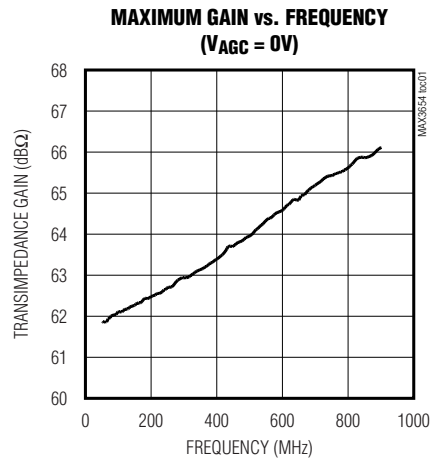


Figure 3. Functional Diagram

## Typical Operating Characteristics

( $V_{CC} = +5.0V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



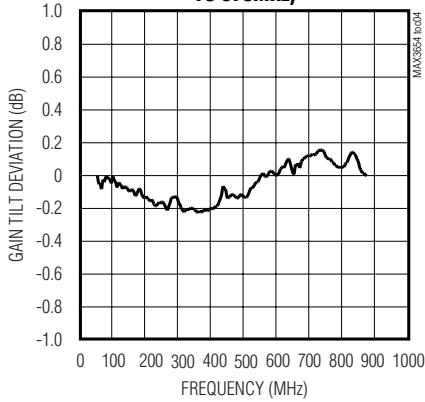
# 47MHz to 870MHz Analog CATV Transimpedance Amplifier

MAX3654

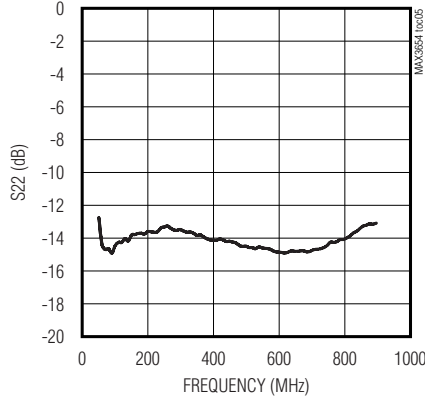
## Typical Operating Characteristics (continued)

( $V_{CC} = +5.0V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)

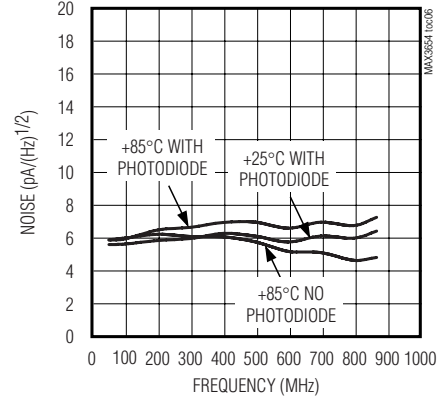
**GAIN TILT DEVIATION vs. FREQUENCY  
(REFERRED TO A LINE FROM 50MHz TO 870MHz)**



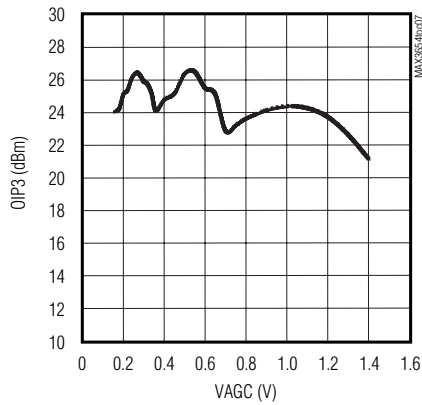
**DIFFERENTIAL S22  
(NORMALIZED TO 75Ω)**



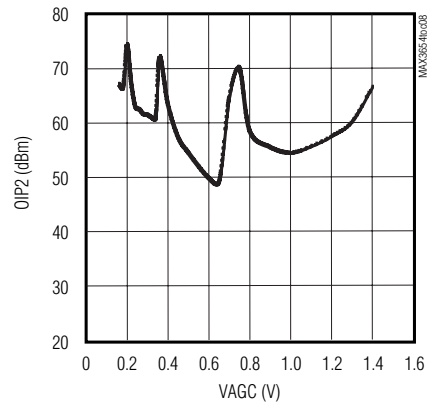
**INPUT REFERRED NOISE vs. FREQUENCY  
(MAXIMUM GAIN, VGA = 0V)**



**OIP3 vs. CONTROL VOLTAGE**



**OIP2 vs. CONTROL VOLTAGE**



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## Pin Description

PIN	NAME	FUNCTION
1, 4, 9, 12	VCC	+5.0V Power Supply
2	IN+	Positive Analog Photodiode Input Connection. Typically connected to photodiode cathode.
3	IN-	Negative Analog Photodiode Input Connection. Typically connected to photodiode anode.
5	VAGC	AGC Control Input. Range is 0 to 1.4V. See the <i>Typical Operating Characteristics</i> Gain vs. Control Voltage graph.
6	$\overline{\text{MUTE}}$	Mute Control Input, TTL. $\overline{\text{MUTE}} < 0.8\text{V}$ to mute output.
7	HYST	AGC Hysteresis Control Input. A resistor from HYST to GND controls the hysteresis level.
8, 14, 16	GND	Ground
10	OUT-	Negative RF Output. The voltage on this pin decreases with increasing optical power when IN+ is connected to the photodiode cathode.
11	OUT+	Positive RF Output. The voltage on this pin increases with increasing optical power when IN- is connected to the photodiode anode.
13	TEST1	Reserved for Test. Connect to GND for normal operation.
15	TEST2	Reserved for Test. Connect to GND for normal operation.
EP	EP	Exposed Pad. The exposed pad must be soldered to the circuit-board ground for proper thermal and electrical performance.

### Detailed Description

The MAX3654 is a broadband, high-linearity, low-noise transimpedance amplifier. The transimpedance (gain) can be adjusted between  $43.5\text{dB}\Omega$  and  $62\text{dB}\Omega$  using the voltage at an external control input (VAGC). When connected as shown in the *Typical Application Circuit*, optical input levels from  $-6\text{dBm}$  to  $+2\text{dBm}$  will produce a minimum output of  $14\text{dBmV/channel}$ , and  $4\text{dB}$  tilt compensation. Gain deviation over frequency from  $47\text{MHz}$  to  $870\text{MHz}$  is less than  $\pm 0.75\text{dB}$ .

#### Low-Noise Variable Gain Amplifier

The input stage is a low-noise analog transimpedance amplifier (TIA) connected differentially to the analog photodiode. Desired performance can be achieved with a photodiode having capacitance ( $C_{PD}$ ) up to  $1\text{pF}$ .

#### VAGC and Hysteresis Control

The gain-control pin VAGC sets overall TIA gain implemented as three switchable gain stages, each with a continuously variable gain control, as shown in Figure 3.

This produces a continuously variable gain ranging from  $62\text{dB}\Omega$  (at  $VAGC = 0.175\text{V}$ ) to  $43.5\text{dB}\Omega$  at ( $VAGC=1.4\text{V}$ ). A set of comparators examines the

VAGC input to select a gain stage. As the voltage at VAGC crosses the two locations in the gain vs. VAGC curve, where the gain stage changes ( $350\text{mV}$  and  $700\text{mV}$ ), there will be small deviations in the output which may lead to a brief interruption of CATV signals. See the *Typical Operating Characteristics* for Gain vs. Control Voltage.

A hysteresis control input is provided to limit dithering when the optical level is close to a gain-switching point. The hysteresis level is controlled by the value of  $R_{HYST}$ . Hysteresis is minimum ( $0.13\text{dB}$ ) when this pin is open.

#### RF Output and Cable Tilt Compensation

With a typical photodiode, the gain at  $870\text{MHz}$  is  $4\text{dB}$  higher than at  $47\text{MHz}$ . The overall frequency response of the TIA is within  $\pm 0.75\text{dB}$  of a straight line connecting the values at  $47\text{MHz}$  and  $870\text{MHz}$ .

#### Mute

In normal operation, the TTL  $\overline{\text{MUTE}}$  pin is held high. When  $\overline{\text{MUTE}}$  is low, the output signal is attenuated by more than  $45\text{dB}$ .

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## Applications Information

### Photodiode Parasitics

The MAX3654 TIA is designed to operate with a low-capacitance analog photodiode. Proper system design includes considerations of lead configuration, pad, and through-hole geometry, and PC board layer selection for connections to the IC. The TIA is designed to operate correctly when the total capacitance of the photodiode, package, leads and PC board is between 1.0pF and 2.5pF.

### RF Output

The differential TIA RF output should be connected (AC-coupled) to a balun transformer for normal single-ended output.

### AGC Operation

For AGC operation, the optical average power can be measured from the voltage drop across the lower bias resistor, using high impedance to isolate the photodiode as shown in the EV kit schematic. TIA gain is inversely proportional to the voltage present at VAGC from 0.175V to 1.4V. From 0 to 0.175V, the gain is constant and maximum. The nominal gain is given by:

$$ZT(\text{dB}\Omega) = 62\text{dB}\Omega + 20 \times \log \left[ \frac{175\text{mV}}{\text{VAGC}(\text{mV})} \right]$$

(0.175V ≤ VAGC ≤ 1.4V).

When connected as shown in the *Typical Applications Circuit*, the MAX3654 will maintain the electrical output constant (15dBmV/ch) for optical signals in the -6dBm to +2dBm range.

### Evaluation Kit and PC Board Layout

The factory-assembled EV kit for the MAX3654 provides two versions: optical input and electrical input.

The optical input circuit includes photodiode bias circuitry, an op amp to adjust VAGC according to the DC photodiode current (for AGC operation), an output balun, and a 75Ω output connector. Through-hole pads are provided to attach the triplexer analog photodiode leads. Since photodiode capacitance and package lead inductance affect the amount of up tilt, in configurations where lead inductance is significantly lower than the value shown in Figure 2, the up tilt may be increased by providing discrete inductance on the PC board. When a CPD = 0.5pF (typ) photodiode is mount-

ed with 5mm (nominal) leads into through-hole vias as in the EV kit configuration, a 4dB up tilt will normally be achieved. It is important to configure the layout with capacitance and inductance in the anode and cathode connection as symmetric as possible.

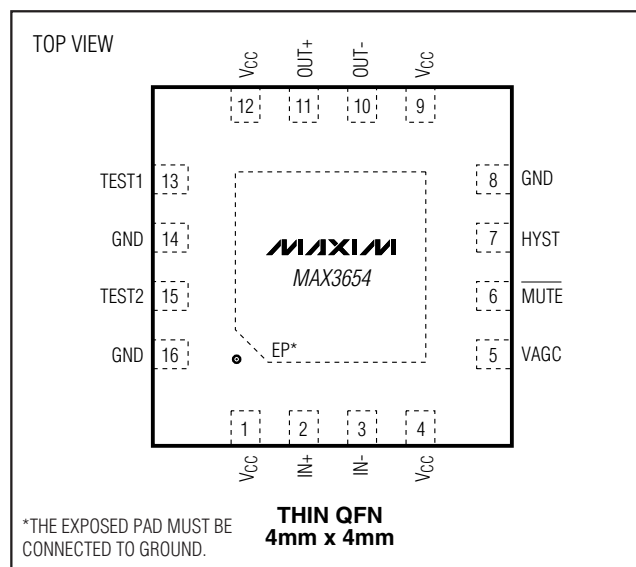
The electrical input circuit is normally configured with a 50Ω input for use with conventional test and measurement equipment. If desired, the MAX3654 input can also be terminated with 75Ω as shown in the EV kit data sheet. The 75Ω EV kit outputs should be connected to 50Ω test and measurement equipment using a minimum loss pad.

For more information, see the Maxim website:

MAX3654 EV Kit data sheet—  
<http://www.maxim-ic.com/Fiber.cfm>

Minimum Loss Pad—  
[http://www.maxim-ic.com/appnotes.cfm/appnote\\_number/972](http://www.maxim-ic.com/appnotes.cfm/appnote_number/972)

## Pin Configuration



## Chip Information

TRANSISTOR COUNT: 3376

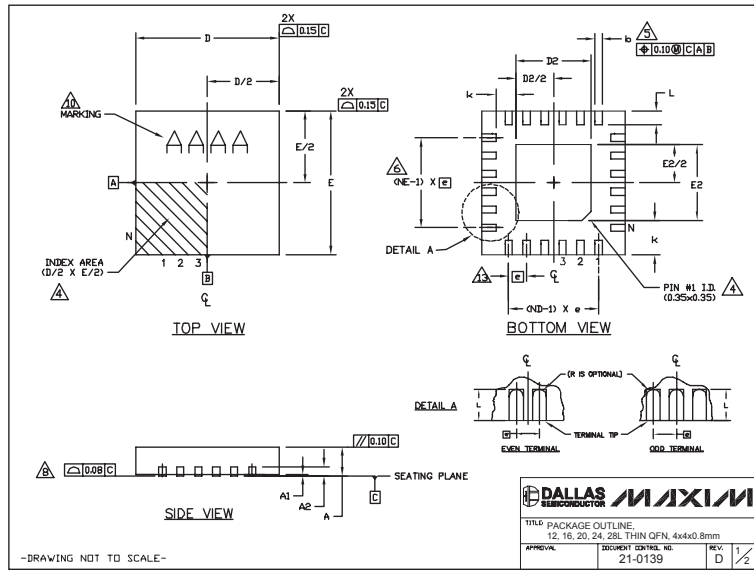
PROCESS: SiGe Bipolar

SUBSTRATE: SOI

# 47MHz to 870MHz Analog CATV Transimpedance Amplifier

## 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](http://www.maxim-ic.com/packages).) For the latest package outline information, go to [www.maxim-ic.com/packages](http://www.maxim-ic.com/packages).) (TQFN 4mm x 4mm x 0.8mm, Package Code: T1644.)



COMMON DIMENSIONS													EXPOSED PAD VARIATIONS										
PKG REF.	1PL 4x4			1GL 4x4			2PL 4x4			24L 4x4			2PL 4x4			PKG CODES	E2		24L OFN THINLEPS ALLOWED				
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	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	T1644-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
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	T1644-3	1.95	2.10	2.25	1.95	2.10	2.25	NO
A2	0.20 REF			0.20 REF			0.20 REF			0.20 REF			0.20 REF			T1644-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
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	T1644-2	1.95	2.10	2.25	1.95	2.10	2.25	NO
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	T1644-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
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	T1644-4	1.95	2.10	2.25	1.95	2.10	2.25	NO
e	0.80 BSC.			0.85 BSC.			0.90 BSC.			0.95 BSC.			1.00 BSC.			T2044-1	1.95	2.10	2.25	1.95	2.10	2.25	NO
k	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-	T2044-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
L	0.45	0.55	0.65	0.45	0.55	0.65	0.45	0.55	0.65	0.40	0.50	0.30	0.40	0.50	T2044-3	1.95	2.10	2.25	1.95	2.10	2.25	NO	
N	1E			16			20			24			28			T2444-1	2.45	2.60	2.63	2.45	2.60	2.63	NO
ND	3			4			5			6			7			T2444-2	1.95	2.10	2.25	1.95	2.10	2.25	YES
NE	3			4			5			6			7			T2444-3	2.45	2.60	2.63	2.45	2.60	2.63	YES
NSDC	VGG3			VGGC			VGGD-1			VGGD-2			VGGE			T2444-4	2.45	2.60	2.63	2.45	2.60	2.63	NO
NSD	VGG3			VGGC			VGGD-1			VGGD-2			VGGE			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 JEDEC 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 L APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TP.  
 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 T2444-1, T2444-3, T2444-4 AND T2844-1.  
 10. MARKING IS FOR PACKAGE ORIENTATION REFERENCE ONLY.  
 11. COPLANARITY SHALL NOT EXCEED 0.08mm.  
 12. WARRAGE SHALL NOT EXCEED 0.10mm.  
 13. LEAD CENTERLINES TO BE AT TRUE POSITION AS DEFINED BY BASIC DIMENSION "e", ±0.05.

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