19-1470; Rev 1; 6/00

MAXIM

900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

General Description

The MAX2232/MAX2233 low-voltage, silicon RF power amplifiers (PAs) are designed for use in the 900MHz ISM band. They operate from a single +2.7V to +5.5V supply, allowing them to be powered directly from a 3-cell NiCd or a 1-cell Lithium-Ion battery. The devices typically deliver 250mW (+24dBm) of output power at 915MHz from a single +3.6V supply, or 150mW (+22dBm) from a single +2.7V supply. At +24dBm output power, power-added efficiency (PAE) is 44%.

The MAX2232/MAX2233 provide 24dB of gain, which is adjustable over a continuous 24dB span via the analog gain-control pin of the MAX2232 or in two 10dB steps via the 2-bit programmable gain-control DAC of the MAX2233. An external capacitor sets the RF output power envelope ramp time, reducing spurious emissions during power-up and power-down by providing a gradual change in output power (MAX2232).

The MAX2232/MAX2233 feature a low-power shutdown mode, which typically draws less than 1µA of supply current, saving power during "idle slots" in time-division multiple-access (TDMA) systems. The ΔVSWR of the RF input in shutdown mode relative to normal operation is 1.2:1. The devices also feature a thermal shutdown function, enabling the PA to protect itself from excessive temperature conditions that could damage the IC. A capacitor to ground limits thermal cycling by setting a thermal shutdown timeout period.

The MAX2232/MAX2233 are available in a space-saving, thermally enhanced 16-pin power-QSOP (PQSOP) package.

Applications

900MHz ISM Band

Digital Cordless Phones

Wireless Data

FM Analog Transmitters

868MHz European ISM Band

Functional Diagrams appear at end of data sheet.

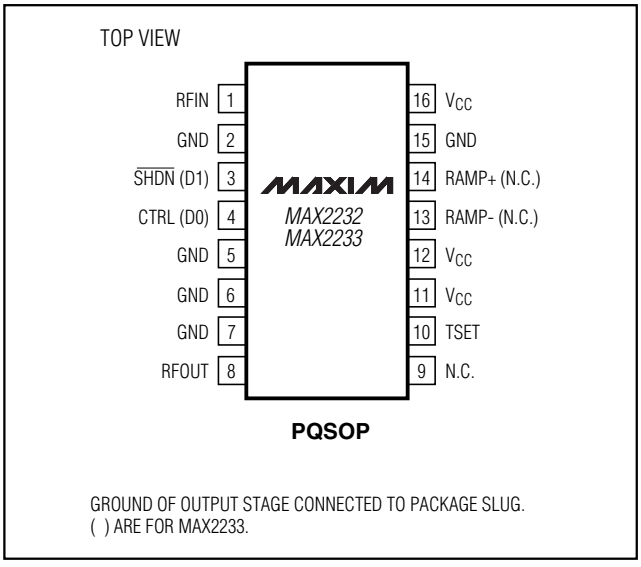
Features

- **800MHz to 1000MHz Frequency Range**
- **250mW (+24dBm) Output Power at 915MHz from +3.6V Supply**
- **+2.7V to +5.5V Single-Supply Operation**
- **44% Power-Added Efficiency**
- **24dB Power Gain**
- **24dB Analog Gain-Control Range (MAX2232)**
- **Three Levels of Digitally Programmed Power Gain in 10dB Steps (MAX2233)**
- **Programmable RF Power Envelope Ramping (MAX2232)**
- **Thermal Shutdown**
- **Programmable Thermal Shutdown Timeout Period**
- **0.2µA Low-Power Shutdown Mode**
- **Low ΔVWSR in Standby and Shutdown Modes**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX2232EEE	-40°C to +85°C	16 PQSOP
MAX2233EEE	-40°C to +85°C	16 PQSOP

Pin Configuration



900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

ABSOLUTE MAXIMUM RATINGS

V_{CC} to GND .....-0.3V to +6.5V
$\overline{SHDN}$, CTRL, D0, D1 to GND .....-0.3V to (V_{CC} +0.3V)
I_{RFIN} 10mA
RFIN Power (50Ω AC-coupled source). .....+10dBm
Output Load VSWR. 6:1
Continuous Power Dissipation (T_A = +70°C)
16-Pin PQSOP (derate 80mW/°C above +70°C) 3W
Operating Temperature Range .....-40°C to +85°C
Storage Temperature Range .....-65°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} = +2.7V to +5.5V, V_{CTRL} = +2.2V, $V_{\overline{SHDN}}$ = V_{D0} = V_{D1} = +2V, T_A = -40°C to +85°C. No input signal applied, unless otherwise noted. Typical values are at V_{CC} = +3.6V and T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Supply Voltage Range	V_{CC}			2.7		5.5	V
Shutdown Supply Current	I_{CC}	$V_{\overline{SHDN}}$ = 0.6V, V_{D0} = V_{D1} = 0.6V	V_{CC} ≤ 3.6V		0.2	10	µA
			V_{CC} = 5.5V		120		
Standby Supply Current	I_{CC}	V_{CTRL} ≤ 0.4V (MAX2232)			20.3	25	mA
Logic Input High	V_{IH}	$\overline{SHDN}$ (MAX2232), D0, D1 (MAX2233)		2.0			V
Logic Input Low	V_{IL}	$\overline{SHDN}$ (MAX2232), D0, D1 (MAX2233)				0.6	V
CTRL Input for Standby Mode	V_{CTRL}	MAX2232				0.4	V
CTRL Input for Gain-Control Mode	V_{CTRL}	MAX2232		0.6			V
Logic Input Current	I_{IH}	$V_{\overline{SHDN}}$ = 2.0V (MAX2232), V_{D0} = V_{D1} = 2.0V (MAX2233)		-1		10	µA
	I_{IL}	$V_{\overline{SHDN}}$ = GND (MAX2232), V_{D0} = V_{D1} = GND (MAX2233)		-1		1	
CTRL Input Current		V_{CTRL} = GND		-1.5		1	µA
		V_{CTRL} = 2.2V				1.5	

AC ELECTRICAL CHARACTERISTICS

(MAX2232/MAX2233 Evaluation Kit, V_{CC} = +3.6V, V_{CTRL} = +2.2V, $\overline{SHDN}$ = V_{CC} (MAX2232), D0 = D1 = V_{CC} (MAX2233), P_{RFIN} = 0dBm, f_{RFIN} = 915MHz, T_A = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Frequency Range	f_{IN}	(Notes 1, 2)	902		928	MHz
Power Gain	G_P			23.9		dB
Output Power	P_{OUT}	V_{CC} = 4.8V		25.4		dBm
		V_{CC} = 3.6V (Note 1)	22.9	23.9	24.9	
		V_{CC} = 3.0V		22.5		
		V_{CC} = 2.7V		21.6		
Output Power Variation Over Temperature	ΔP_{OUT}	T_A = T_{MIN} to T_{MAX} (Note 1)		1.9	3.2	dB
Output Power, Medium-Power Mode	P_{OUT}	D0 = GND, D1 = V_{CC} (MAX2233 only)		15.8		dBm

AC ELECTRICAL CHARACTERISTICS (continued)

(MAX2232/MAX2233 Evaluation Kit, V_{CC} = +3.6V, V_{CTRL} = +2.2V, $\overline{SHDN}$ = V_{CC} (MAX2232), D0 = D1 = V_{CC} (MAX2233), P_{RFIN} = 0dBm, f_{RFIN} = 915MHz, T_A = +25°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output Power, Low-Power Mode	P_{OUT}	D0 = V_{CC}, D1 = GND (MAX2233 only)		6.5		dBm
Gain-Control Range (Note 3)	ΔG_P	0.6V < V_{CTRL} < 2.2V (MAX2232 only)		23.6		dB
Power-Added Efficiency	PAE			44		%
Power-Added Efficiency at +21dBm Output Power	PAE	CTRL adjusted to give P_{RFOUT} = +21dBm (MAX2232 only)		29		%
Supply Current, Medium-Power Mode	I_{CC}	D0 = GND, D1 = V_{CC} (MAX2233 only)		78.5		mA
Supply Current, Low-Power Mode	I_{CC}	D0 = V_{CC}, D1 = GND (MAX2233 only)		44.0		mA
Input VSWR	VSWR	Z_{SOURCE} = 50Ω (Note 1)		1.5:1		
Input VSWR Change, Shutdown Mode (Notes 1, 4)	ΔVSWR			1.4:1		
Input VSWR Change, Standby Mode (Notes 1, 4)	ΔVSWR	MAX2232 only		1.2:1		
Off-Isolation		$\overline{SHDN}$ = D0 = D1 = GND		52		dB
		CTRL = GND (MAX2232 only)		38		
Maximum Nonharmonic Spurious Output Due to Load Mismatch		V_{CC} = +2.7V to +5.5V, 6:1 VSWR at any phase angle, P_{RFIN} = +5dBm		-60		dBc
Maximum Output Load VSWR Without Damage (Note1)		Any load phase angle, P_{RFIN} = +5dBm, T_A = T_{MIN} to T_{MAX}	6:1			
Harmonic Suppression		(Note 5)		29		dBc
Autoramping Rise Time		C_{RAMP} = 0.22µF (Notes 1, 6) (MAX2232 only)		0.9		ms
Autoramping Fall Time		C_{RAMP} = 0.22µF (Notes 1, 7) (MAX2232 only)		3.2		ms
Output Power Rise Time		RAMP+ = RAMP- = unconnected (Note 6)		0.4		µs
Thermal Shutdown Temperature	T_{TH}	P_{RFIN} = 0dBm, V_{CC} = +3.6V		145		°C
Thermal Shutdown Timeout Period	t_{TH}	C_{TSET} = 0.22µF (Note 8)		900		ms

Note 1: Guaranteed by design.

Note 2: Operation outside this range is possible, but not characterized.

Note 3: Gain is monotonic with V_{CTRL}.

Note 4: Input VSWR relative to input impedance in operating mode.

Note 5: Harmonics measured on evaluation kit, which provides some harmonic attenuation in addition to the rejection provided by the IC. The combined suppression is specified.

Note 6: Time measured from $\overline{SHDN}$ (MAX2232) low-to-high transition to when output power is within 1dB of final value. Includes effects of 1% tolerance capacitor.

Note 7: Time measured from $\overline{SHDN}$ (MAX2232) high-to-low transition to when output power is -20dB of final value. Includes effects of 1% tolerance capacitors.

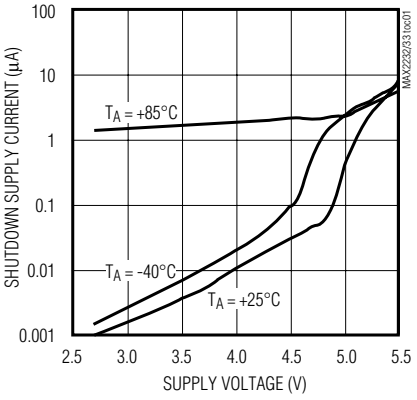
Note 8: Time from die temperature dropping below Thermal Shutdown Temperature, T_{TH}, to when the device turns itself back on.

900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

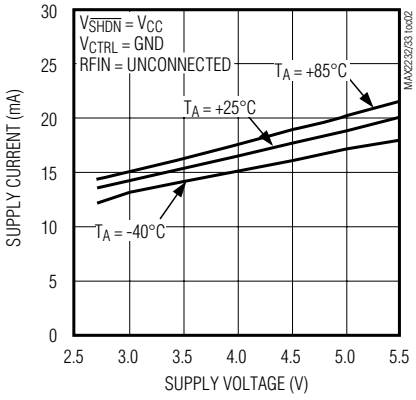
Typical Operating Characteristics

(MAX2232/MAX2233 Evaluation Kit, V_{CC} = +3.6V, CTRL = V_{CC}, $\overline{SHDN}$ = D0 = D1 = V_{CC}, P_{RFIN} = 0dBm, f_{RFIN} = 915MHz, T_A = +25°C, unless otherwise noted.)

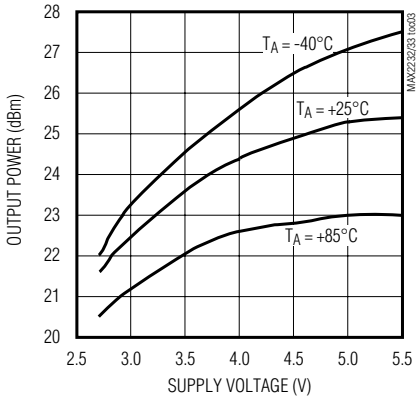
SHUTDOWN SUPPLY CURRENT vs. SUPPLY VOLTAGE



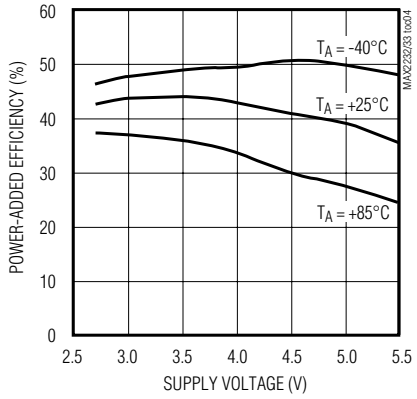
MAX2232 STANDBY SUPPLY CURRENT vs. SUPPLY VOLTAGE



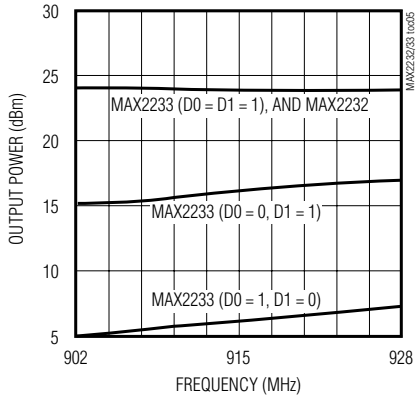
OUTPUT POWER vs. SUPPLY VOLTAGE



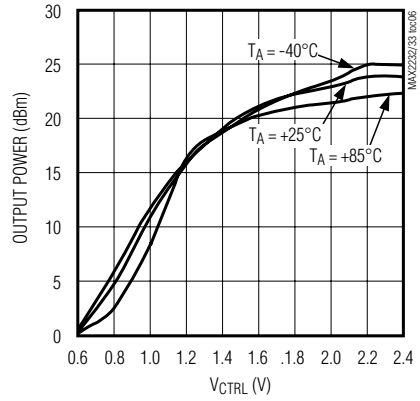
POWER-ADDED EFFICIENCY vs. SUPPLY VOLTAGE



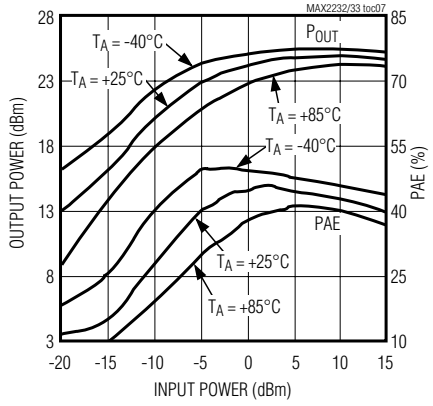
OUTPUT POWER vs. FREQUENCY



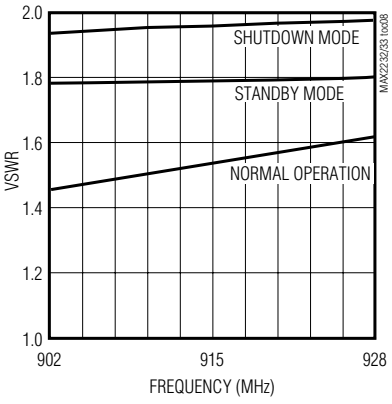
MAX2232 OUTPUT POWER vs. GAIN CONTROL VOLTAGE



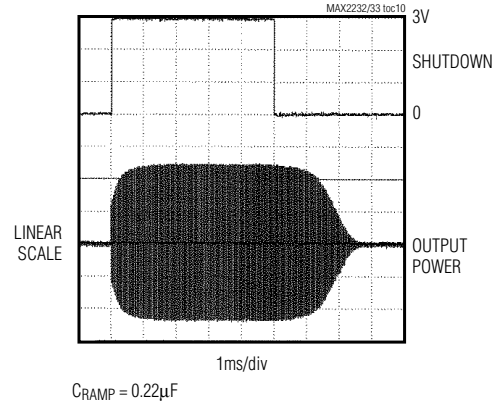
OUTPUT POWER AND POWER-ADDED EFFICIENCY vs. INPUT POWER



MAX2232 RFIN PORT VSWR vs. FREQUENCY



MAX2232 OUTPUT POWER vs. SHUTDOWN CONTROL



Pin Description

PIN		NAME	FUNCTION
MAX2232	MAX2233		
1	1	RFIN	RF Input Port. Requires external matching network and blocking capacitor.
2	2	GND	Input Stage Ground. Connect directly to low-inductance ground plane. If vias are used, separate them from other GND pin vias.
3	—	$\overline{SHDN}$	Shutdown Control Input. Drive $\overline{SHDN}$ low to place the device in shutdown mode. Drive high for normal operation.
—	3	D1	Digital Gain/Shutdown Control Input. MSB of the 2-bit digital output power control. D0 and D1 set the output power to one of three discrete levels. To place the device in shutdown, drive D0 and D1 low (Table 2).
4	—	CTRL	Analog Gain-Control Input. Apply a voltage between 0.6V and 2.2V to vary the gain of the PA. Drive CTRL below 0.4V to place the device in standby mode. Drive CTRL above 2.2V to place the device in peak output power mode.
—	4	D0	Digital Gain/Shutdown Control Input. LSB of the 2-bit digital output power control. D0 and D1 set the output power to one of three discrete levels. To place the device in shutdown, drive D0 and D1 low (Table 2).
5, 6	5, 6	GND	Second Stage Ground. Connect directly to low-inductance ground plane. If vias are used, separate them from other GND pin vias.
7	7	GND	Output Stage Ground. Connect directly to low-inductance ground plane. If vias are used, separate them from other GND pin vias.
8	8	RFOUT	Open-Collector, RF Output Port. Connect output matching network to this pin.
9	9, 13, 14	N.C.	No Connection. Do not make a connection to this pin.
10	10	TSET	Thermal Shutdown Timeout Capacitor Terminal. Connect a capacitor from TSET to ground to limit thermal cycling.
11	11	V_{CC}	Second Stage Supply Voltage. Bypass with appropriate capacitors to GND.
12	12	V_{CC}	Input Stage Supply Voltage. Bypass with appropriate capacitors to GND.
13	—	RAMP-	Negative Terminal of Output Power Ramp Capacitor. Connect capacitor, C_{RAMP}, between RAMP+ and RAMP- to control the rise and fall time of the output power ramp.
14	—	RAMP+	Positive Terminal of Output Power Ramp Capacitor. Connect capacitor, C_{RAMP}, between RAMP+ and RAMP- to control the rise and fall time of the output power ramp.
15	15	GND	Bias Circuitry Ground. Connect directly to low-inductance ground plane. If vias are used, separate them from other GND pin vias.
16	16	V_{CC}	Bias Circuitry Supply Voltage. Bypass with appropriate capacitors to GND.
SLUG	SLUG	GND	Output Stage Ground. Provides additional thermal conduction, as well as a low-inductance path to ground. Connect directly to low-inductance ground plane.

900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

Detailed Description

The MAX2232/MAX2233 are nonlinear power amplifiers (PAs) intended for constant envelope applications (FM, FSK, GMSK). The devices operate over the 902MHz to 928MHz frequency range and provide typically 250mW of output power and 44% efficiency from a single +2.7V to +5.5V supply. Both devices typically provide 24dB of gain, which is adjustable over a continuous 24dB range through an analog voltage on CTRL of the MAX2232 or in two 10dB steps through the 2-bit programmable gain inputs (D0, D1) on the MAX2233. A low-power shutdown mode on both devices reduces supply current to 0.2µA.

All bias, gain control, and temperature-sensing circuitry is provided on-chip to save board space and reduce component count. The signal path includes a variable gain amplifier (VGA), an output driver, and an output power transistor. On-chip interstage matching networks are provided for optimal loading and power transfer. Internal bias circuitry responds to CTRL and $\overline{SHDN}$ of the MAX2232, or to the 2-bit gain/shutdown control DAC of the MAX2233, providing optimum biasing and efficiency as well as shutdown and ramp control functions. A unique temperature-sensing circuit protects the device from overheating by shutting down the PA until a safe temperature is resumed.

The devices come in a 16-pin PQSOP package, which incorporates a slug on the bottom of the device to increase heat conduction and provide a low inductance path to ground.

RF Input Stage (Variable Gain Amplifier)

The input stage includes a variable gain amplifier (VGA) with 24dB gain-control range. With the appropriate matching network, the input VSWR is nominally 1.5:1 during operation and the change in VSWR is only 1.2:1, relative to normal operation. This stage remains active during standby mode (MAX2232) to provide a constant input impedance but is off during shutdown mode (MAX2232/MAX2233). AC-couple this port with a DC-blocking capacitor.

RF Second Stage (Driver)

The driver provides gain to overcome interstage matching losses and to produce a signal large enough to drive the output power transistor into saturation. The driver stage is off during standby (MAX2232) and shutdown (MAX2232/MAX2233) modes.

RF Output Stage (Output Power Transistor)

The output power transistor delivers +24dBm of output power from a single +3.6V supply. The transistor's open-collector output requires a pull-up inductor to V_{CC} for proper biasing, as well as a proper output matching network to ensure optimum output power. Connect the output matching network to RFOUT (pin 8). See the *Typical Application Circuit* for bias and matching components suitable for 900MHz operation. The ground of the output stage is connected to a metal slug on the bottom of the MAX2232/MAX2233's 16-pin PQSOP package. The metal slug increases heat conduction and provides a low-inductance path to ground. Solder the metal slug to the PC-board ground plane.

MAX2232

Analog Gain Control and Power Management

Shutdown Mode

Drive the shutdown ($\overline{SHDN}$) pin below 0.6V to place the MAX2232 in shutdown mode. The VGA, driver, and output transistor are off in shutdown mode and the supply current is typically reduced to 0.2µA. When $\overline{SHDN}$ is above 2.0V, the device is enabled.

Standby Mode

Drive $\overline{SHDN}$ above 2.0V and CTRL below 0.4V to place the MAX2232 in standby mode. In standby mode, the VGA remains biased while the driver and output transistor are disabled. Supply current is typically 20mA in standby mode. This mode allows the device to maintain a good input VSWR while maintaining 38dB of isolation. This is useful to users who drive the PA with a direct modulated VCO, where pulling of the VCO results from changes in the input VSWR.

Analog Gain Control

The voltage applied to the gain-control (CTRL) pin varies the output power of the MAX2232 continuously over a 24dB range. An internal comparator holds the PA to a constant peak output power if V_{CTRL} is above 2.2V. For V_{CTRL} below 0.4V, the PA is in standby mode. CTRL presents a high input impedance, allowing the V_{CTRL} voltage to be set with a resistor-divider or a voltage output DAC.

Output Power Autoramping

The internal bias circuitry of the MAX2232 automatically ramps the output power of the PA down or up at a constant rate (in W/sec) when switched in or out of shutdown mode. The output power is ramped to the level set by V_{CTRL} on the MAX2232. The output power rise and fall time ramp is set by placing a capacitor, C_{RAMP}, between RAMP+ and RAMP-. This provides an easy means of avoiding spectral splatter and complying with transmit mask requirements, without using a separate controller. The output power rise and fall time is set by the value of C_{RAMP}.

900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

MAX2233

Digital Gain Control and Power Management

The MAX2233 responds to logic-level signals at the device's 2-bit DAC inputs, D0 and D1, placing the device in shutdown mode or into one of three discrete output power levels. See Table 2 for operating modes and output power levels. Setting D0 and D1 to a logic-level low places the device in shutdown mode and reduces supply current to 0.2µA. The VGA, driver, and output stage are off in shutdown mode, while the input impedance is only slightly changed. Setting D0 and D1 to one of the other three modes adjusts the output power to one of three discrete levels in 10dB steps.

Thermal Shutdown

The MAX2232/MAX2233 feature a thermal shutdown mode that helps to protect the device from damage when the die temperature becomes excessive. If the temperature of the die exceeds the thermal shutdown temperature, T_{TH}, the VGA is forced into a low-gain mode and output power is reduced to a minimum. After the PA's die temperature drops below T_{TH}, the device remains in thermal shutdown mode for the thermal shutdown timeout period, t_{TH}. A single capacitor, C_{TSET}, from TSET to ground sets t_{TH}. The thermal shutdown timeout period helps to limit device thermal cycling that results if the source of the excessive temperature is not removed. t_{TH} is set by the value of C_{TSET}.

Applications Information

Proper attention to voltage supply bypassing is essential for high-frequency RF circuit stability. Bypass V_{CC} with 0.1µF, 10nF, and 100pF capacitors in parallel with each other to ground. Use separate vias to the ground plane for each of the bypass capacitors and minimize trace length to reduce inductance. Use separate vias to the ground plane for each ground pin. Use low-inductance ground connections.

Decouple $\overline{SHDN}$, CTRL, D0, and D1 with 0.1µF capacitors to ground to minimize noise on the internal bias cell. Use a series resistor (typically 100Ω) to further reduce coupling of high-frequency signals into the control pins.

Table 1. MAX2232 Operating Modes

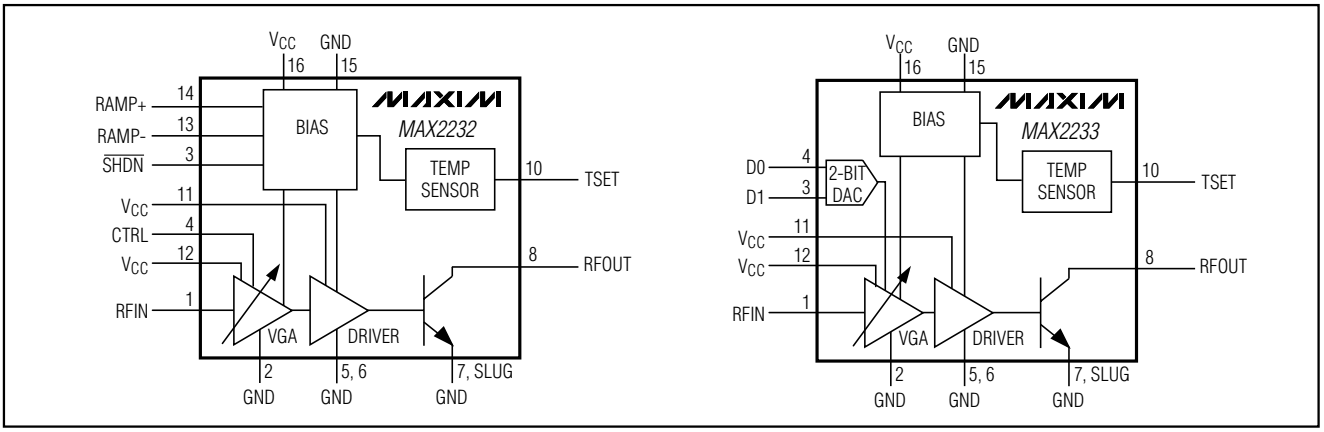
MODE	$V_{\overline{SHDN}}$	V_{CTRL}	OUTPUT POWER (P_{RFIN} = 0dBm, V_{CC} = +3.6V)
Shutdown	< 0.6V	X	< -35dBm
Standby	> 2.0V	≤ 0.4V	< -35dBm
Variable Gain	> 2.0V	0.6V ≤ V_{CTRL} < 2.2V	0dBm to +24dBm
Maximum Gain	> 2.0V	> 2.2V	+24 dBm

X = Don't care

Table 2. MAX2233 Operating Modes Truth Table

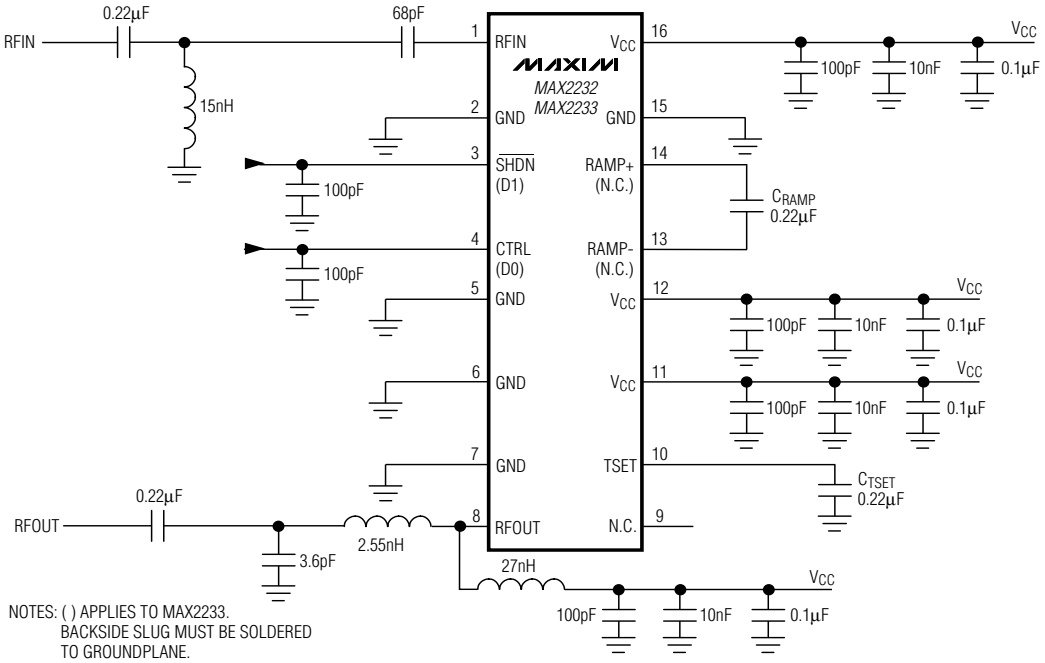
MODE	D1	D0	OUTPUT POWER (P_{RFIN} = 0dBm, V_{CC} = +3.6V)
Shutdown	0	0	< -35dBm
Low Power	0	1	+6.5dBm
Medium Power	1	0	+15dBm
High Power	1	1	+24dBm

Functional Diagrams

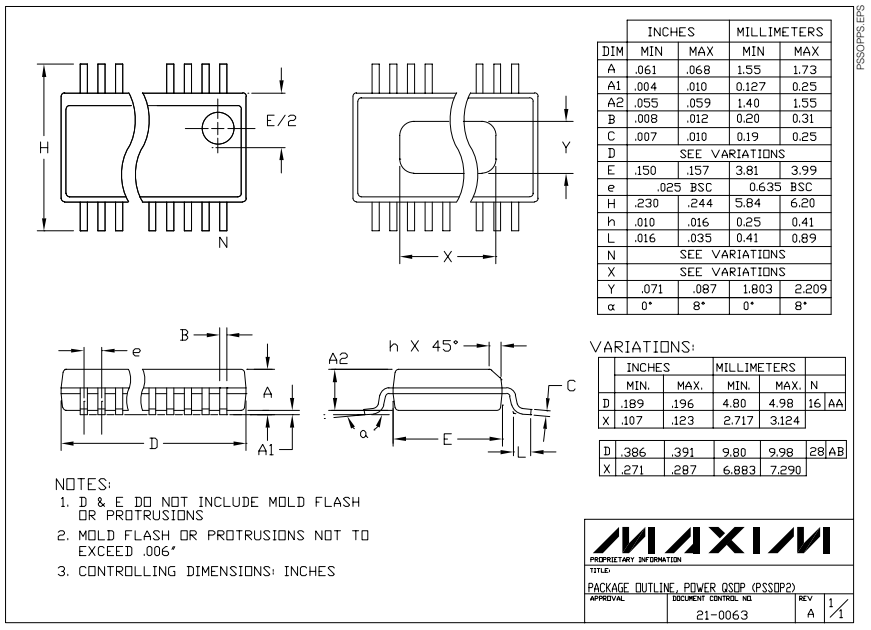


900MHz ISM-Band, 250mW Power Amplifiers with Analog or Digital Gain Control

Typical Application Circuit



Package Information



DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	.061	.068	1.55	1.73
A1	.004	.010	0.127	0.25
A2	.055	.059	1.40	1.55
B	.008	.012	0.20	0.31
C	.007	.010	0.19	0.25
D	SEE VARIATIONS			
E	.150	.157	3.81	3.99
e	.025 BSC		0.635 BSC	
H	.230	.244	5.84	6.20
h	.010	.016	0.25	0.41
L	.016	.035	0.41	0.89
N	SEE VARIATIONS			
X	SEE VARIATIONS			
Y	.071	.087	1.803	2.209
α	0°	8°	0°	8°

	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	N	
D	.189	.196	4.80	4.98	16	AA
X	.107	.123	2.717	3.124		
D	.386	.391	9.80	9.98	28	AB
X	.271	.287	6.883	7.290		

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