

FEATURES

- Automatic gate voltage adjustment (no calibration)
- Supply voltage (5 V to 16.5 V)
- Bias enhancement or depletion mode devices
- Adjustable drain current up to 1.6 A
- Sink or source gate current
- Optional internal negative voltage generation
- Fast enable/disable
- TRIGOUT output for daisy chain
- Power-up and power-down sequencing
- Overcurrent/undercurrent alarm with hysteresis
- 24-lead, 4 mm × 4 mm LFCSP package: 16 mm²

APPLICATIONS

- Microwave radio and very small aperture terminals (VSATs)
- Military and space
- Test instrumentation
- Fiber optic modulator driver biasing
- CATV laser driver biasing
- Cellular base station
- Wireless infrastructure equipment

GENERAL DESCRIPTION

The HMC980LP4E is an active bias controller that can automatically adjust the gate voltage of an external amplifier to achieve constant drain current. Using an integrated controller, the HMC980LP4E allows safe power-up/power-down, and disable/enable of an external amplifier, ensuring the safe powering of the amplifier. The HMC980LP4E can be used to bias any enhancement or depletion type Class A amplifier operating with drain voltages from 5 V to 16.5 V and drain currents up to 1.6 A, thus offering a complete biasing solution.

FUNCTIONAL BLOCK DIAGRAM

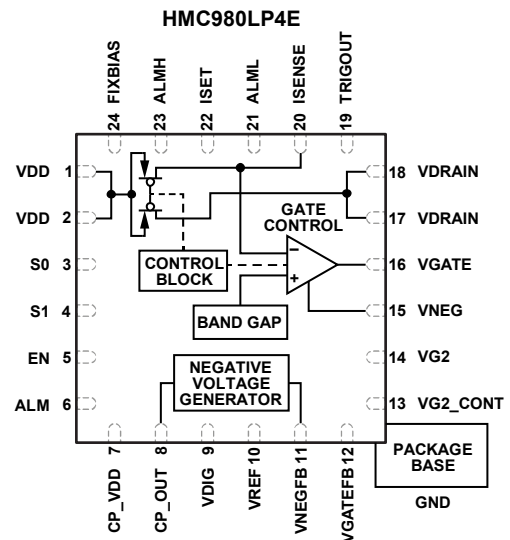


Figure 1.

20370-001

The HMC980LP4E allows stable RF amplifier biasing over supply, temperature, and process variations, and eliminates the required calibration procedures usually employed to prevent RF performance degradation due to variations in amplifier drain current.

The HMC980LP4E is housed in an RoHS compliant 4 mm × 4 mm LFCSP leadless package with an exposed backside pad to improve thermal characteristics.

TABLE OF CONTENTS

Features	1	Controlling Depletion Mode RF Amplifiers	14
Applications	1	Supply Voltages	14
Functional Block Diagram	1	Supply Sequencing	15
General Description	1	Drain Voltage Output.....	15
Revision History	3	Setting the Target Drain Current.....	15
Specifications	4	MOSFET Series Resistance	15
Electrical Specifications.....	4	Enable Input.....	16
Absolute Maximum Ratings	5	VG2 Voltage Adjustment.....	16
Thermal Resistance	5	Self Protection.....	16
Electrostatic Discharge (ESD) Ratings.....	5	Overcurrent/Undercurrent Alarm	17
ESD Caution.....	5	Negative Voltage Generator	18
Pin Configuration and Function Descriptions	6	Disabling the Internal Negative Voltage Generator.....	18
Interface Schematics	8	Changing the Default VNEG Voltage.....	19
Typical Performance Characteristics.....	9	Changing the VGATE Threshold Voltage	20
Theory of Operation	13	Design Examples	21
Overview.....	13	Enhancement Mode Operation	22
Power-Up and Power-Down	13	Recommended HMC980LP4E Circuits.....	22
Negative Voltage Generator	13	Daisy-Chain Operation	23
VGATE Output Control Loop	13	Higher Drain Current Applications.....	23
Stability	13	Reducing External Component Count	25
Secondary Gate Control	13	Evaluation Board Circuit.....	26
External Amplifier Power Sequencing.....	13	Outline Dimensions.....	28
Overcurrent/Undercurrent Alarm	13	Ordering Guide	28
Self Protection.....	13		
Applications Information.....	14		

REVISION HISTORY

This Hittite Microwave Products data sheet has been reformatted to meet the styles and standards of Analog Devices, Inc.

2/2021—Rev. 01.0911 to Rev. B

Updated Format	Universal
Changes to Features Section and General Description Section ..	1
Changes to Electrical Specifications Section and Table 1	3
Changes to Table 2	5
Added Thermal Resistance Section, Table 3, Electrostatic Discharge (ESD) Ratings Section, and Table 4; Renumbered Sequentially	5
Added Figure 2; Renumbered Sequentially	6
Changes to Table 5	6
Changes to Figure 16, Figure 17, Figure 19, and Figure 20	9
Added Figure 21 and Figure 24	10
Added Theory of Operation Section, Overview Section, Power-Up and Power-Down Section, Negative Voltage Generator Section, VGATE Output Control Loop Section, Stability Section, Secondary Gate Control Section, External Amplifier Power Sequencing Section, Overcurrent/Undercurrent Alarm Section, and Self Protection Section	13
Deleted Detailed Description Section, Digital Power Supply (VDIG) Section, and Supply and Drain Voltage (VDD and VDRAIN) Section	13
Changed Application Notes Section to Applications Information Section	14
Added Controlling Depletion Mode RF Amplifiers Section and Supply Voltages Section	14
Deleted Negative Voltage Generator (VNEGOUT) Section and Active Bias Control Loop Section	14
Changes to Figure 34	14
Added Supply Sequencing Section, Drain Voltage Output Section, and Setting the Target Drain Current Section, and MOSFET Series Resistance Section	15
Deleted VNEG Fault Detection Feature Section	15
Changes to Figure 35	15

Changed Enable/Disable (EN) Section to Enable Input Section and Self Protection Feature Section to Self Protection Section	16
Changes to Table 6 and VG2 Voltage Adjustment Section	16
Added Figure 36	16
Deleted Operation Modes Section	17
Changes to Overcurrent/Undercurrent Alarm Section	17
Added Figure 37	17
Added Negative Voltage Generator Section, Figure 39, and Disabling the Internal Negative Voltage Generator Section	18
Changes to Table 7	18
Deleted Table 3; Renumbered Sequentially	19
Added Changing the Default VNEG Voltage, Figure 40, and Figure 41	19
Added Changing the VGATE Threshold Voltage Section, Figure 42, and Figure 43	20
Added Design Examples Section, Controlling a Depletion Mode RF Amplifier Using the Internal Negative Voltage Generator Section, and Controlling a Depletion Mode RF Amplifier Using an External Negative Voltage Section	21
Added Enhancement Mode Operation Section and Recommended HMC980LP4E Circuits Section	22
Changes to Figure 44	22
Added Higher Drain Current Applications Section	23
Changes to Daisy-Chain Operation Section and Figure 45	23
Added Figure 46	24
Added Reducing External Component Count Section, ALM Resistors Section, VNEG/VGATE Feedback Resistors Section, VG2 Set Resistors Section, Negative Voltage Generator Section, and Decoupling Capacitors Section	25
Added Evaluation Board Circuit Section	26
Changes to Figure 47	26
Changes to Table 8	27
Updated Outline Dimensions	28
Changes to Ordering Guide	28

SPECIFICATIONS

ELECTRICAL SPECIFICATIONS

$T_A = 25^\circ\text{C}$, $V_{DD} = 12\text{ V}$, V_{DIG} , $EN = 3.3\text{ V}$, biasing a depletion mode amplifier using the internal negative voltage generator, V_{NEGFB} and V_{GATEFB} pins left floating, unless otherwise noted.

Table 1.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
SUPPLY VOLTAGE	V_{DD}		5		16.5	V
QUIESCENT CURRENT						
VDD	I_{DD}	$V_{DD} = 5\text{ V}$, $EN = V_{DIG}$		19		mA
		$V_{DD} = 5\text{ V}$, $EN = \text{ground}$		7.5		mA
		$V_{DD} = 12\text{ V}$, $EN = V_{DIG}$		20		mA
		$EN = \text{ground}$		9		mA
V_{DIG}	I_{DIG}	$V_{DIG} = 3.3\text{ V}$		3.5		mA
		$V_{DIG} = 5\text{ V}$		6.5		mA
CHARGE PUMP OSCILLATOR FREQUENCY	f_{OSC}			300		kHz
VOLTAGE REFERENCE (PIN 10)	V_{REF}			1.44		V
DIGITAL INPUT THRESHOLDS						
$S0, S1, EN$		Input voltage (V_{IN}) = low			1	V
		$V_{IN} = \text{high}$	1.4			V
VDRAIN CHARACTERISTICS						
Voltage Range	V_{DRAIN}		5		16.5	V
Current Adjustment Range	I_{DRAIN}	$S1 = S0 = \text{ground}$		0.05 to 0.3		A
		$S1 = \text{ground}, S0 = V_{DIG}$		0.3 to 0.6		A
		$S1 = V_{DIG}, S0 = \text{ground}$		0.6 to 1.2		A
		$S1 = V_{DIG}, S0 = V_{DIG}$		1.2 to 1.6		A
Current Change Over Digital Voltage	ΔI_{DRAIN}	V_{DRAIN} set to 12 V, I_{DRAIN} set to 400 mA		0.4		%/V
Current Change Over Temperature				0.023		%/C
Voltage Change Over Temperature	ΔV_{DRAIN}	V_{DRAIN} set to 12 V, I_{DRAIN} set to 400 mA		0.02		%/C
INTERNAL NEGATIVE VOLTAGE GENERATOR CHARACTERISTICS						
Negative Voltage Output	V_{NEG}			-2.46		V
Current Capability	I_{NEG}		0		60	mA
VGATE CHARACTERISTICS						
Gate Current Supply	I_{GATE}		-4		+4	mA
VG2 CHARACTERISTICS						
$VG2$ Current Supply	I_{G2}	$VG2 < 2\text{ V}$	-0.1		+0.1	mA
		$6\text{ V} > VG2 > 2\text{ V}$	-1		+1	mA
		$VG2 > 6\text{ V}$	-5		+5	mA
$VG2$ Adjustment Range	V_{G2}		1		$V_{DD} - 1.3$	V
V_{DIG} CHARACTERISTICS						
Voltage Range	V_{DIG}		3.3		5	V
V_{DIG} Quiescent Current	I_{DIG}	$V_{DD} = 12\text{ V}$, $V_{DIG} = EN = 3.3\text{ V}$		3.5		mA
SWITCH CHARACTERISTICS						
Internal Switch Resistance	R_{DS_ON}	$S1 = S0 = \text{ground}$		2.8		Ω
		$S1 = \text{ground}, S0 = V_{DIG}$		1.55		Ω
		$S1 = V_{DIG}, S0 = \text{ground}$		0.85		Ω
		$S1 = V_{DIG}, S0 = V_{DIG}$		0.7		Ω

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter ¹	Rating
VDD	18 V
S0, S1, EN, VREF, VNEGFB, VGATEFB, TRIGOUT, ISENSE, ALML, ISET, ALMH, FIXBIAS	–0.5 V to VDIG + 0.5 V
CP_VDD	VDD – 0.5 V to VDD + 0.5 V
VG2_CONT	–0.5 V to VDD + 0.5 V
VDIG	5.5 V
VNEG	–4 V to ground
Junction Temperature	125°C
Continuous Power Dissipation (P _{DISS}) (T = 85°C, Derate 94.79 mW/°C Above 85°C)	3.8 W
Peak Reflow Solder (Moisture Sensitivity Level 3 (MSL3))	260°C
Storage Temperature Range	–65°C to +150°C
Operating Temperature Range	–40°C to +85°C

¹ Note that there are two different voltage domains on the HMC980LP4E: a high voltage domain, V_{DD}, and a low voltage domain, V_{DIG}. Take necessary precautions not to violate the absolute maximum ratings of each subdomain.

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

THERMAL RESISTANCE

Thermal performance is directly linked to printed circuit board (PCB) design and operating environment. Careful attention to PCB thermal design is required.

θ_{JA} is the natural convection junction to ambient thermal resistance measured in a one cubic foot sealed enclosure. θ_{JC} is the junction to case thermal resistance.

Table 3. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
HCP-24-2 ¹	49.4	10.6	°C/W

¹ Thermal impedance simulated values are based on a FR4 type PCB.

ELECTROSTATIC DISCHARGE (ESD) RATINGS

The following ESD information is provided for handling of ESD sensitive devices in an ESD protected area only.

Human body model (HBM) per ANSI/ESDA/JEDEC JS-001.

ESD Ratings for HMC980LP4E

Table 4. HMC980LP4E, 24-Lead LFCSP

ESD Model	Withstand Threshold (V)	Class
HBM	1000	1C

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

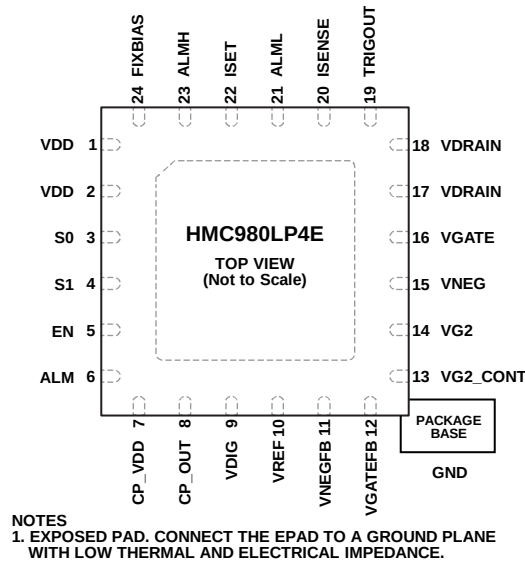


Figure 2. Pin Configuration

Table 5. Pin Function Descriptions

Pin No.	Mnemonic	Description
1, 2	VDD	Supply Voltage Pins. The voltage applied to VDD must be higher than the intended voltage on the VDRAIN output to account for the drop across the series resistance of the internal metal-oxide semiconductor field effect transistor (MOSFET). The expected voltage drop can be calculated as shown in the MOSFET Series Resistance section. See Figure 34, Figure 35, and Figure 44 for examples of appropriate voltage levels. Power up VDIG (Pin 9) before powering VDD. Decouple VDD with parallel 4.7 μ F and 10 nF capacitors.
3, 4	S0, S1	Control Pins. S0 and S1 set the R_{DS_ON} of the VDD to VDRAIN MOSFET. Refer to Table 6 for recommended settings. S0 and S1 have internal pull-up resistors to VDIG.
5	EN	Enable Pin. Bias control loop is enabled when the voltage on the EN pin is pulled above 1.4 V and disabled when pulled below 1 V. EN has an internal pull-up resistor to VDIG.
6	ALM	Overcurrent/Undercurrent Alarm Output. Provides an active high signal referenced to VDIG if the drain current exceeds the upper threshold setting or drops below the lower threshold setting. Refer to the Overcurrent/Undercurrent Alarm section for more details.
7	CP_VDD	Supply Voltage Pin for the Negative Voltage Generator. Connect this pin to VDD and decouple with a 100 pF capacitor.
8	CP_OUT	Negative Voltage Generator Charge Pump Output. The negative voltage generator requires a 1 μ F flying capacitor, a 10 μ F reservoir capacitor, and two diodes to operate. See the Negative Voltage Generator section for more details.
9	VDIG	Supply Voltage Pin for the Digital Sections of the HMC980LP4E. Connect a supply voltage to VDIG between 3.3 V and 5 V. Power VDIG before powering VDD (Pin 1 and Pin 2) or VNEG (Pin 15). Decouple VDIG with parallel 4.7 μ F and 10 nF capacitors.
10	VREF	1.44 V Reference Voltage Output from the Internal Low Dropout (LDO) Regulator. VREF is used to alter the voltages on the VNEG and VGATE pins. See the Changing the Default VNEG Voltage and the Changing the VGATE Threshold Voltage sections for more details.
11	VNEGFB	Feedback Pin for Enabling and Regulating the Output of the Negative Voltage Generator. Float VNEGFB to activate the negative voltage generator, and short VNEGFB to ground to disable the negative voltage generator. VNEGFB can also be used to adjust VNEG with an external resistor. See the Changing the Default VNEG section for more details.
12	VGATEFB	Feedback Pin for Regulating the VGATE threshold. Float VGATEFB when a depletion mode amplifier is being biased, or short VGATEFB to ground when an enhancement mode amplifier is being biased. VGATEFB can also be used to adjust the VGATE threshold voltage. See the Changing the VGATE Threshold Voltage section for more details.
13	VG2_CONT	Control Voltage Input. VG2_CONT sets the level for the second gate output pin, VG2. Use a resistor divider between VDD and ground to set the voltage. VG2 is typically 1.3 V lower than VG2CONT. See the VG2 Voltage Adjustment section for more details.

Pin No.	Mnemonic	Description
14	VG2	Second Gate Control Output Pin. VG2 is used to drive the secondary gate voltage for amplifiers that require multiple gate voltages. This voltage is fixed and therefore not controlled by the bias loop controller. Note that VG2 can only provide a positive voltage between 1 V and $V_{DD} - 1.3$ V.
15	VNEG	Negative Supply Voltage Input to the Chip. VNEG is supplied from the CP_OUT pin when the negative voltage generator is enabled (see the Negative Voltage Generator section). When the negative voltage generator is disabled, connect VNEG to an external voltage. If using an external voltage, power VNEG after first powering VDIG (Pin 9) and then VDD (Pin 1 and Pin 2). Decouple VNEG with a 10 μ F capacitor.
16	VGATE	Gate Voltage Output Control Pin for Amplifier Under Control. Connect VGATE to the gate or base of the external amplifier. To guarantee stability, a 2.2 μ F capacitor must be connected between the gate or base terminal of the external amplifier and ground as close to the amplifier as possible.
17, 18	VDRAIN	Drain Voltage Output Pins. Connect VDRAIN to the supply terminal of the amplifier under control. Decouple the controlled amplifier with a minimum 10 nF capacitor to ground placed as closely as possible to the VDRAIN or VDD pin of the external amplifier.
19	TRIGOUT	Trigger Output Signal. TRIGOUT generates an active high signal referenced to VDIG when the active bias loop stabilizes at the targeted drain current. This signal can be used to trigger the next HMC980LP4E device to turn on if more than one HMC980LP4E is used in a daisy chain. See the Daisy-Chain Operation section and Figure 45 for more details.
20	ISENSE	Amplifier Drain Current Set Pin. Adjust the drain current of the controlled amplifier by connecting a resistor (R_{SENSE}) from ISENSE to ground. A high precision resistor (for example, 0.5% or ± 25 ppm temperature coefficient resistance (TCR) is recommended to ensure optimal bias accuracy.
21	ALML	Low Current Alarm Setting Pin. A precision resistor (for example, 0.5%, ± 25 ppm TCR) connected to ISET determines the undercurrent limit at which the ALM output goes high. If the alarm feature is not used, ALML must be shorted to ISET (Pin 22). See Figure 47 for an example circuit with $\pm 6\%$ alarm thresholds.
22	ISET	Bias Current Set Pin. The total external resistance from ISET pin to ground must always be within 1% of 5 k Ω . If the ALM feature is used, there must be an extra resistor from ALML (Pin 21) to ground for a total resistance from ISET to ground of 5 k Ω . If the ALML feature is not used, connect ALML (Pin 21) and ALMH (Pin 23) to ISET and connect a 5 k Ω resistor to ground from ISET. See Figure 47 for an example circuit with $\pm 6\%$ alarm thresholds.
23	ALMH	High Current Alarm Setting Pin. A precision resistor (for example, 0.5%, ± 25 ppm TCR) connected to ISET determines the overcurrent limit at which the ALM output goes high. If the alarm feature is not used, ALMH must be shorted to ISET (Pin 22). See Figure 47 for an example circuit with $\pm 6\%$ alarm thresholds.
24	FIXBIAS	Bias Adjustment Pin. Connect a precision 10 k Ω resistor (for example, 0.5%, ± 25 ppm TCR) to ground to ensure optimal bias accuracy.
	EPAD	Exposed Pad. Connect the EPAD to a ground plane with low thermal and electrical impedance.

INTERFACE SCHEMATICS

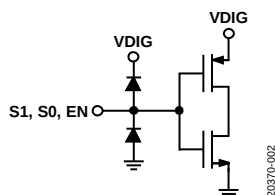


Figure 3. S1, S0, and EN Interface Schematic (Input)

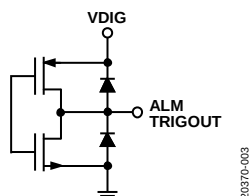


Figure 4. ALM, TRIGOUT Interface Schematic (Output)

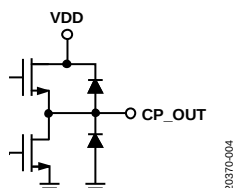


Figure 5. CP_OUT Interface Schematic (Output)

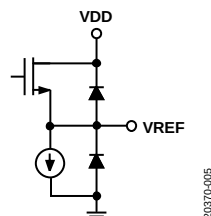


Figure 6. VREF Interface Schematic (Output)

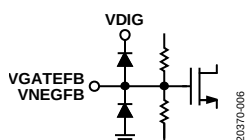


Figure 7. VGATEFB, VNEGFB Interface Schematic (Input)

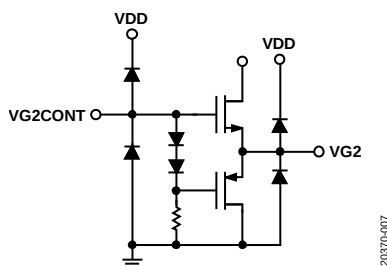


Figure 8. VG2 (Output) and VG2_CONT (Input) Interface Schematic

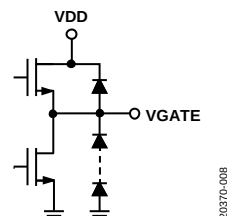


Figure 9. VGATE Interface Schematic (Output)

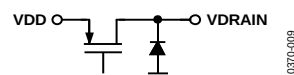


Figure 10. VDD (Input) and VDRAIN (Output) Interface Schematic

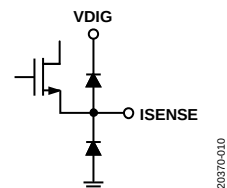


Figure 11. ISENSE Interface Schematic (Input)

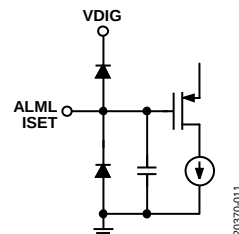


Figure 12. ALML, ISET Interface Schematic (Input)

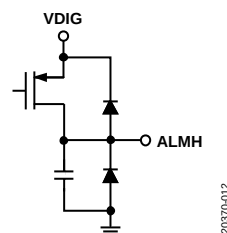


Figure 13. ALMH Interface Schematic (Input)

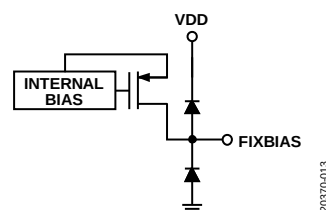


Figure 14. FIXBIAS Interface Schematic (Input)

TYPICAL PERFORMANCE CHARACTERISTICS

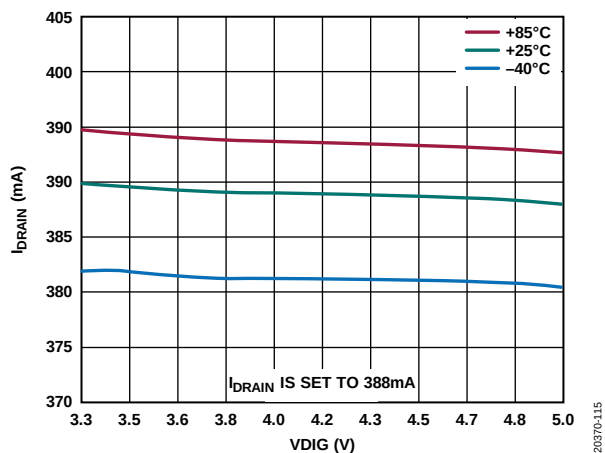


Figure 15. I_{DRAIN} vs. $VDIG$, HMC637ALP5E Used as External Amplifier, $S0 = VDIG$, $S1 = \text{Ground}$

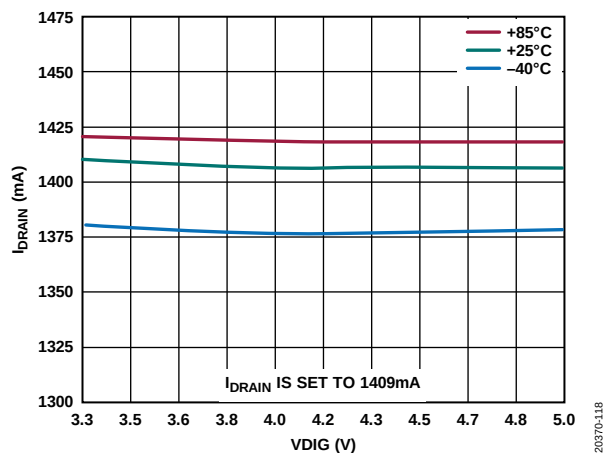


Figure 18. I_{DRAIN} vs. $VDIG$, HMC637ALP5E Used as External Amplifier, $S0 = VDIG$, $S1 = VDIG$

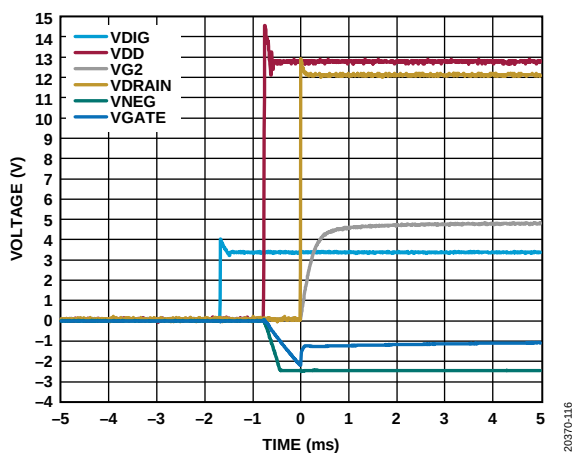


Figure 16. Power-Up Waveform (Negative Voltage Generator Used and EN Left Floating, HMC637ALP5E Used as External Amplifier)

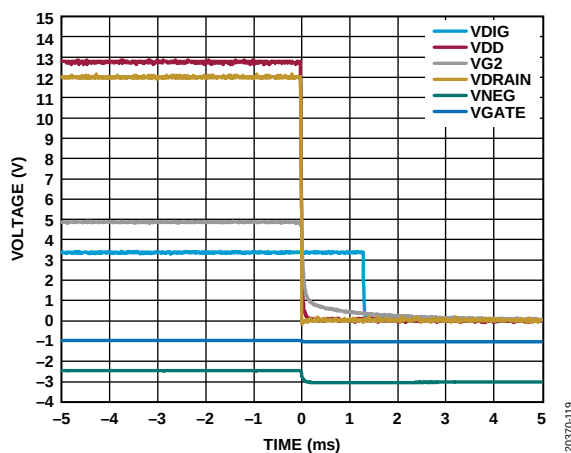


Figure 19. Shutdown Waveform (Negative Voltage Generator Used and EN Left Floating, HMC637ALP5E Used as External Amplifier)

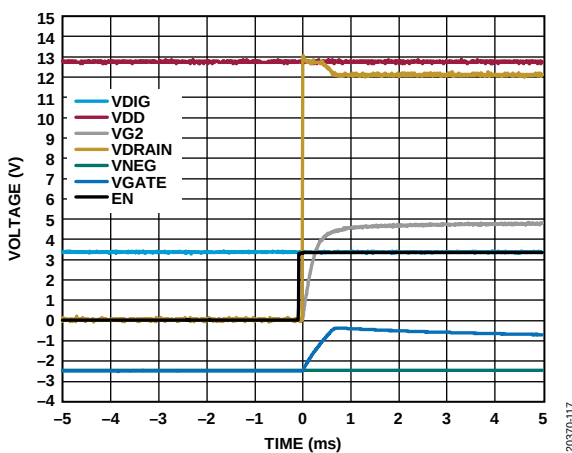


Figure 17. Enable Waveform (Negative Voltage Generator Used, HMC637ALP5E Used as External Amplifier)

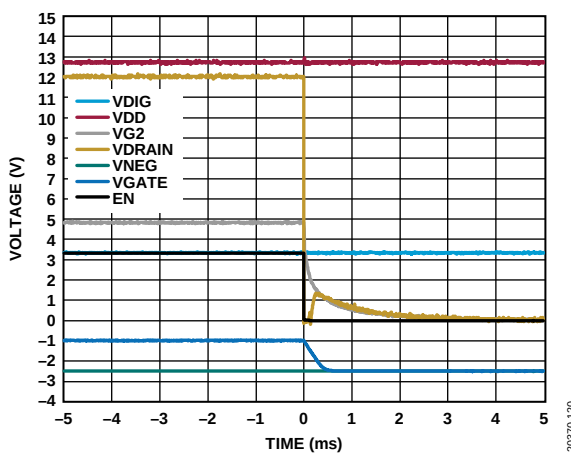


Figure 20. Disable Waveform (Negative Voltage Generator Used, HMC637ALP5E Used as External Amplifier)

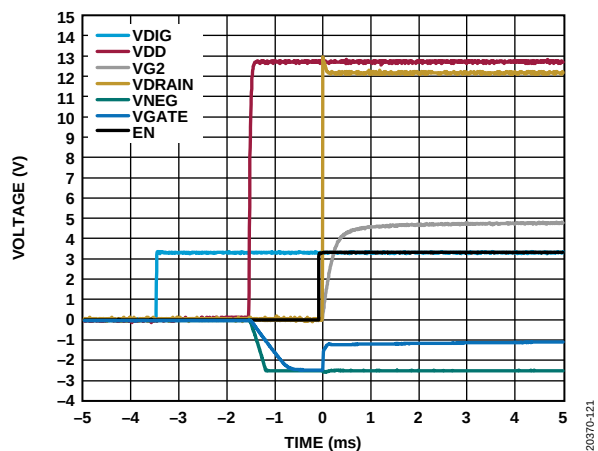


Figure 21. Power-Up Waveform (Negative Voltage Generator Used and EN Controlled, HMC637ALP5E Used as External Amplifier)

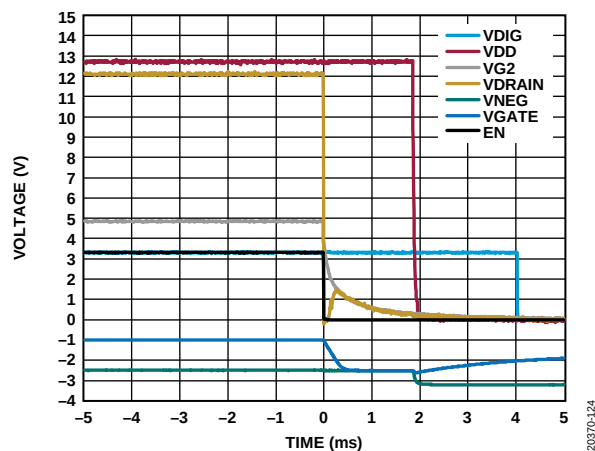


Figure 24. Shutdown Waveform (Negative Voltage Generator Used and EN Controlled, HMC637ALP5E Used as External Amplifier)

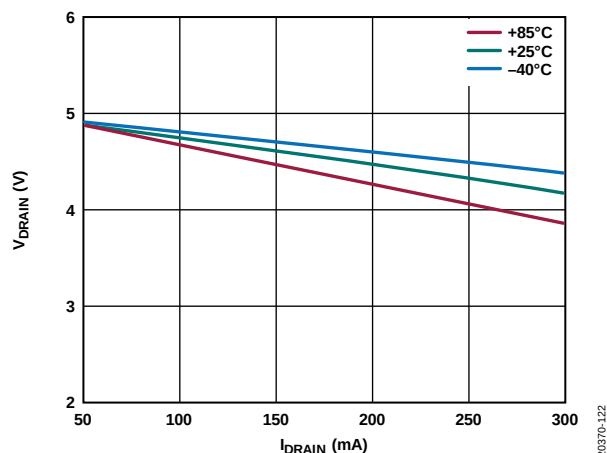


Figure 22. V_{DRAIN} vs. I_{DRAIN} Across Temperature, $V_{DD} = 5\text{ V}$, $V_{DIG} = 3.3\text{ V}$, $S_0 = \text{Ground}$, $S_1 = \text{Ground}$

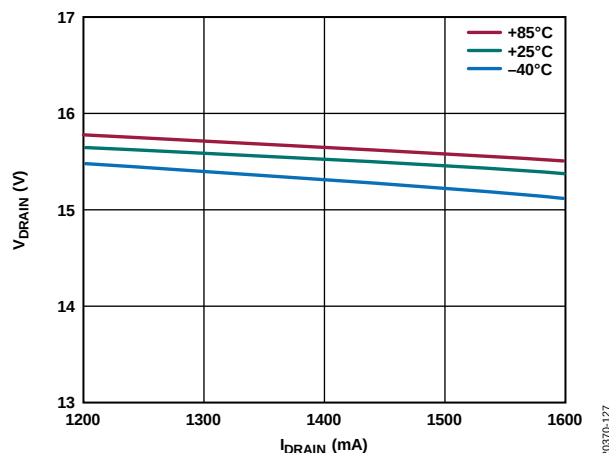


Figure 25. V_{DRAIN} vs. I_{DRAIN} Across Temperature, $V_{DD} = 16.5\text{ V}$, $V_{DIG} = 5.0\text{ V}$, $S_0 = V_{DIG}$, $S_1 = V_{DIG}$

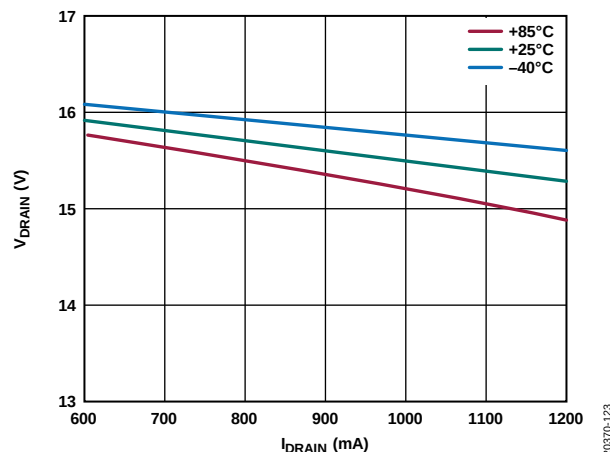


Figure 23. V_{DRAIN} vs. I_{DRAIN} Across Temperature, $V_{DD} = 16.5\text{ V}$, $V_{DIG} = 5.0\text{ V}$, $S_0 = \text{Ground}$, $S_1 = V_{DIG}$

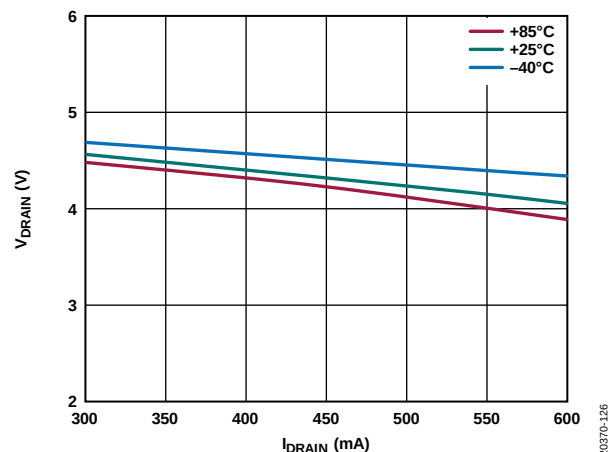


Figure 26. V_{DRAIN} vs. I_{DRAIN} Across Temperature, $V_{DD} = 5\text{ V}$, $V_{DIG} = 3.3\text{ V}$, $S_0 = 3.3\text{ V}$, $S_1 = \text{Ground}$

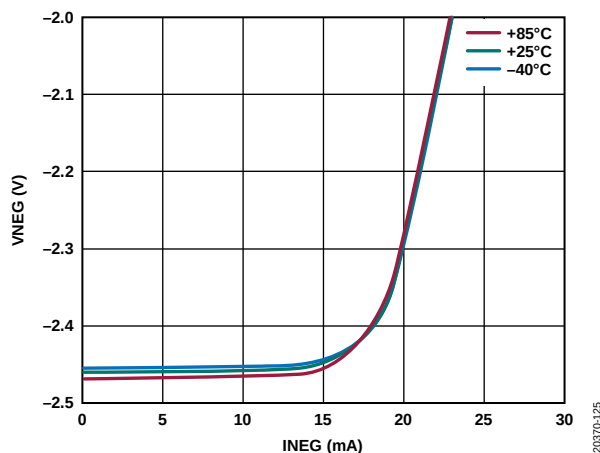


Figure 27. VNEG Load Regulation at VDD = 5 V

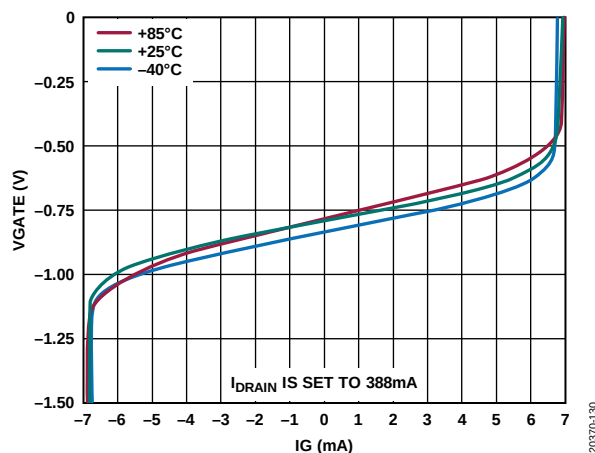


Figure 30. VGATE Load Regulation at VDD = 12 V, HMC637ALP5 Used as External Amplifier

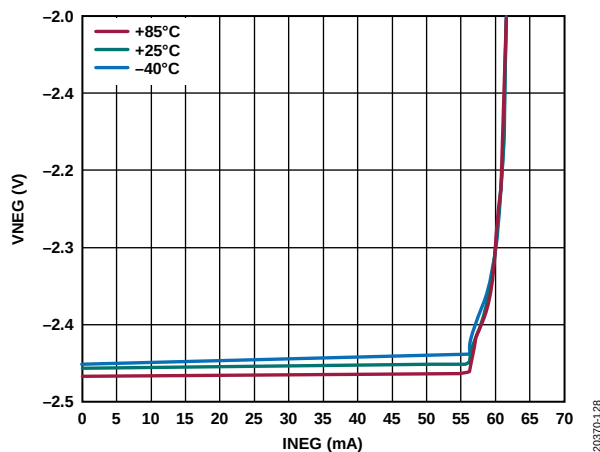


Figure 28. VNEG Load Regulation at VDD = 16.5 V

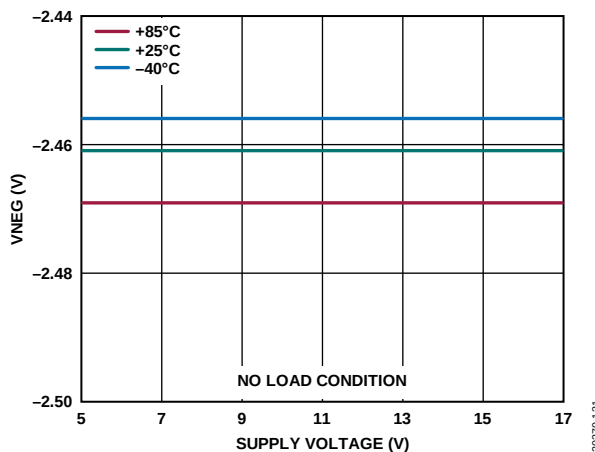


Figure 31. VNEG vs. Supply Voltage

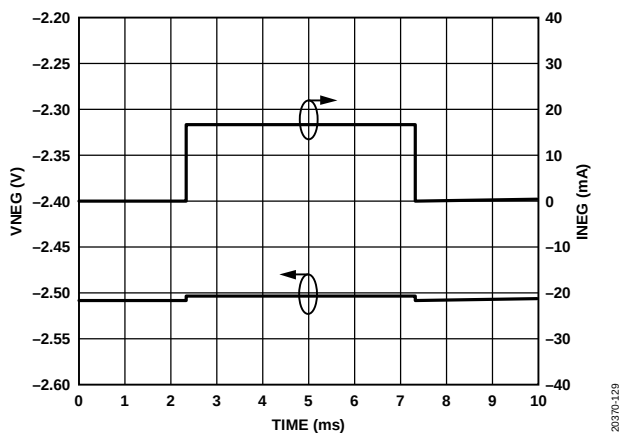


Figure 29. VNEG Load Transient, VDD = 5 V

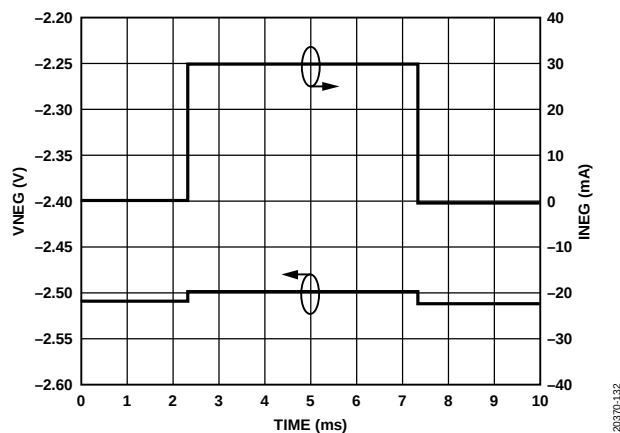


Figure 32. VNEG Load Transient, VDD = 16.5 V

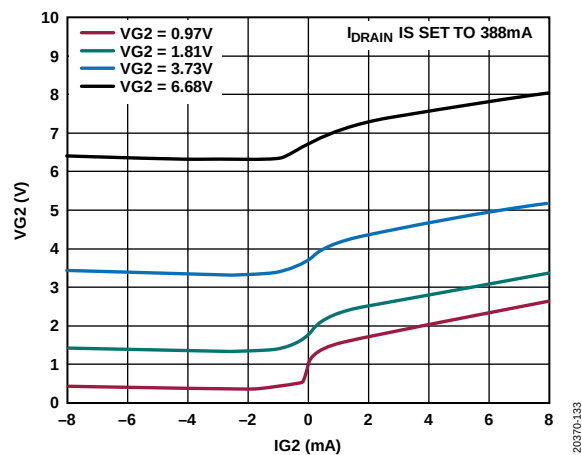


Figure 33. VG2 Load Regulation at VDD = 12 V, [HMC637ALP5E](#) Used as External Amplifier

THEORY OF OPERATION

OVERVIEW

To achieve consistent performance, amplifiers require stable drain current. The HMC980LP4E is a fully integrated biasing solution for amplifiers, which removes the need for discrete biasing. Using an internal feedback loop and a precision external resistor, the automatic gate voltage controller keeps the drain current of the associated amplifier constant over temperature and process variations.

POWER-UP AND POWER-DOWN

The HMC980LP4E also allows safe power-up and power-down sequencing of the targeted amplifier. The HMC980LP4E can provide the ideal bias solution to virtually any amplifier on the market with a drain current up to 1.6 A and a supply voltage between 5 V and 16.5 V.

NEGATIVE VOLTAGE GENERATOR

The HMC980LP4E has an integrated negative voltage generator used to create the negative voltage required to drive depletion mode amplifiers. If an external negative supply is already available or an enhancement mode device is targeted, the negative voltage generator can be disabled.

VGATE OUTPUT CONTROL LOOP

The HMC980LP4E regulates the drain current (I_{DRAIN}) of the amplifier under bias using the VGATE output, which is connected to the gate bias pin of the external amplifier. The drain current passing through the associated amplifier is sampled and used to automatically adjust the voltage on the VGATE pin to achieve constant drain current through the external amplifier.

This control loop continuously adjusts the VGATE pin voltage to achieve consistent drain current over supply, temperature, and process variations, as well as threshold drifts due to aging. The device to device, temperature, and supply variation of the HMC980LP4E is minimal. Thus, by using an accurate sense resistor connected to the ISENSE pin, expensive calibration procedures in high volume production can be avoided.

The gate control of the HMC980LP4E is designed to both sink and source current into the gate of the targeted amplifier, up to ± 4 mA. This unique feature is important to achieve nearly constant drain current through the amplifier while the gate current varies with different input power values.

STABILITY

The HMC980LP4E allows for stable RF amplifier biasing over supply and temperature variations. The gate control can both sink and source current up to ± 4 mA. The gate control is required to compensate for charging the gate current of the amplifier over input power variations.

SECONDARY GATE CONTROL

The HMC980LP4E also generates a second gate voltage, VG2. VG2 is fixed and can be adjusted through a resistor divider connected to VDD for amplifiers that require a second gate voltage.

EXTERNAL AMPLIFIER POWER SEQUENCING

To ensure the safety of the external amplifier, the HMC980LP4E provides automatic power-up sequencing. During startup, VDRAIN and VG2 are kept at ground when VGATE is first reduced to VNEG to ensure that the external amplifier is completely pinched off before VDRAIN is applied. When the EN signal is taken high, VDRAIN is then applied and the active bias loop is enabled. After VDRAIN is applied, VG2 is generated and VGATE is increased linearly until the desired drain current is reached.

For power-down and disabling, the same sequencing is applied in reverse order.

OVERCURRENT/UNDERCURRENT ALARM

The HMC980LP4E has a built in overcurrent and undercurrent alarm feature. If a fault conditions arises, ALM goes high, indicating a problem. The current alarm signal provided in the HMC980LP4E does not affect the operation of the controller. This feature is included for monitoring purposes where a system level protection scheme can be implemented with external control circuitry.

SELF PROTECTION

The HMC980LP4E has a built in sensing feature to protect itself against short-circuit conditions at both the VDRAIN and VNEG pins. When a short-circuit event is detected, VDRAIN and VGATE are both disabled.

APPLICATIONS INFORMATION

CONTROLLING DEPLETION MODE RF AMPLIFIERS

Figure 34 and Figure 35 show typical circuits for biasing depletion mode amplifiers using the internal VNEG and an external negative voltage (V_{EXT}), respectively. The subsequent sections describe how to configure the circuitry around the HMC980LP4E and how to calculate the correct component values.

SUPPLY VOLTAGES

The HMC980LP4E requires a minimum of two separate supply rails: VDIG and VDD.

VDIG (Pin 9, 3.3 V to 5 V) powers the internal logic circuits for the HMC980LP4E. The current drawn on this rail is approximately 3.5 mA.

VDD (Pin 1 and Pin 2, 5 V to 16.5 V) provides the power for the RF amplifier and some of the HMC980LP4E internal circuitry. Depending on the RF amplifier being controlled, the VDD current can be up to 1.6 A.

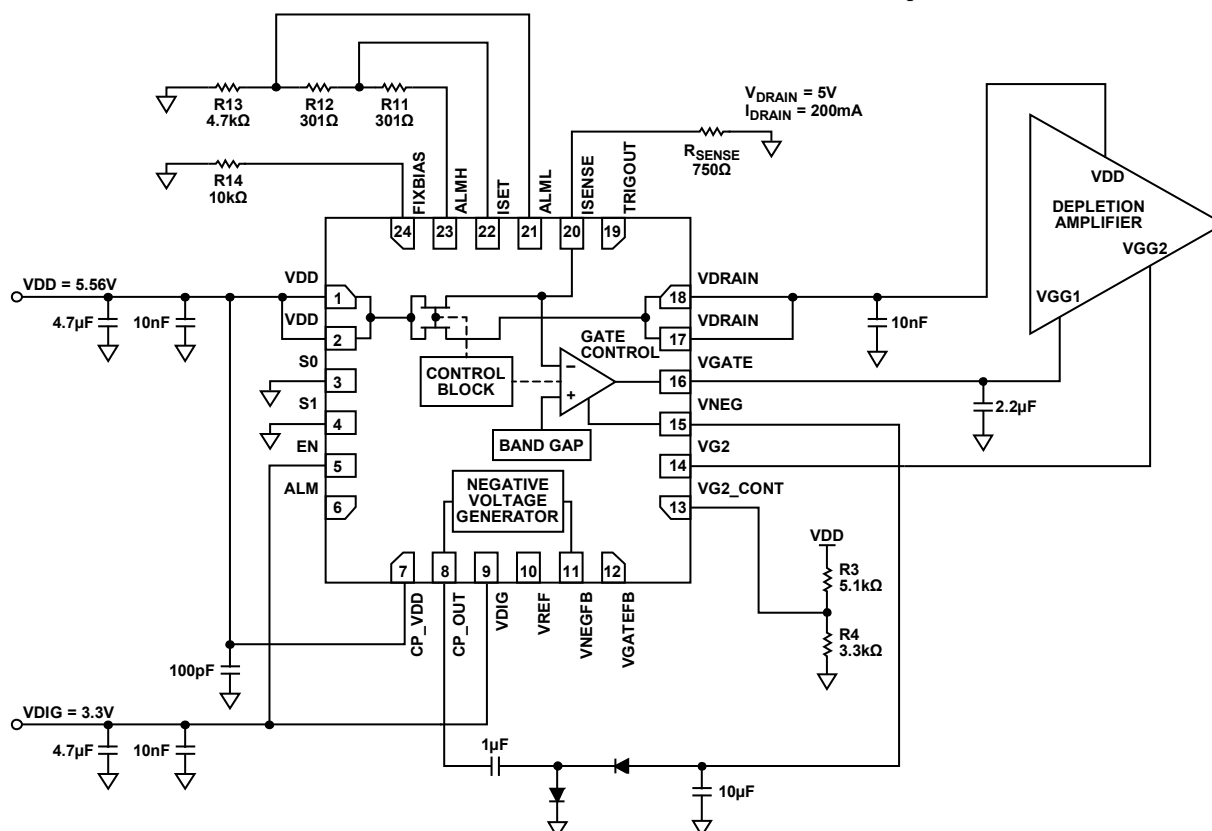


Figure 34. Typical Circuit for Controlling a Depletion Mode Amplifier Using the Internal VNEG

20370-034



SUPPLY SEQUENCING

After all supply voltages are on, the HMC980LP4E can be enabled by asserting EN (Pin 5) to begin biasing the RF amplifier. Note that EN has an internal pull-up to VDIG.

The VDD supply to the HMC980LP4E is connected to the VDRAIN output through an internal MOSFET switch. This MOSFET is controlled through power-up sequencing, which ensures that no voltage is applied to the drain of the RF amplifier until after the gate voltage is pulled down and that the external amplifier is pinched off. Connect the VDRAIN output (Pin 17 and Pin 18) of the HMC980LP4E to the drain (collector) of the RF amplifier.

The target drain current for the RF amplifier is set using a precision resistor, R_{SENSE} (see Figure 35), connected from ISENSE (Pin 20) to ground. Use the following equation to set the desired drain current through the RF amplifier:

Base the target drain current on the current that the RF amplifier requires to deliver the desired performance and not necessarily on the quiescent current of the RF amplifier with no RF signal present.

There is a small voltage drop between VDD and VDRAIN due to the finite R_{DS_ON} of the internal MOSFET. To compensate for this, VDD must be set to the value calculated using the following equation:

where:

V_{DRAIN} is the output voltage from the HMC980LP4E that is applied to the VDD pin of the RF amplifier.

I_{DRAIN} is the desired constant drain current through the RF amplifier.

R_{DS_ON} can be varied and is set by the logic levels of S0 and S1 (Pin 3 and Pin 4). As the target drain current increases, reduce the value of R_{DS_ON} . Use Table 6 to determine the correct settings for S0 and S1. Note that S0 and S1 have pull-up resistors to VDIG. Therefore, if left floating, the S0 and S1 pins default to high.

Using settings other than the recommended values for S0 and S1 may result in increased power consumption and increased device to device performance variation.

Table 6. Recommended S0 and S1 Settings vs. Drain Current Range

Drain Current Range (A)	Condition	R_{DS_ON} Value (Ω)
0.05 to 0.3	S1 = ground, S0 = ground	2.8
0.3 to 0.6	S1 = ground, S0 = VDIG	1.55
0.6 to 1.2	S1 = VDIG, S0 = ground	0.85
1.2 to 1.6	S1 = VDIG, S0 = VDIG	0.7

ENABLE INPUT

The active bias control loop is enabled when the EN pin is pulled up to VDIG. The loop is disabled when the EN pin is pulled down to ground. If EN is left floating, the HMC980LP4E is enabled through a pull-up resistor internally. The operation of the negative voltage generator is independent of the enable condition. The EN signal only controls the operation of the VGATE, VG2, and VDRAIN outputs. When EN is pulled down to ground, the HMC980LP4E discharges VDRAIN and VG2 down to ground and pulls the VGATE pin to VNEG. VGATE goes down to VNEG regardless of the threshold level setting of VGATEFB. When EN is pulled high, the HMC980LP4E enables VDRAIN and VG2 as well as starting the bias control loop to automatically adjust the VGATE output voltage.

VG2 VOLTAGE ADJUSTMENT

The HMC980LP4E generates a second fixed gate voltage, VG2 (Pin 14) for amplifiers that require a second gate bias connection. VG2 can be adjusted through a resistor divider connected to VG2_CONT (Pin 13). VG2 can range between 1 V and $VDD - 1.3$ V. Therefore, VG2 is always positive. VG2 is typically 1.3 V below the voltage present at the VG2_CONT pin. See Figure 36 for an example of how to set VG2.

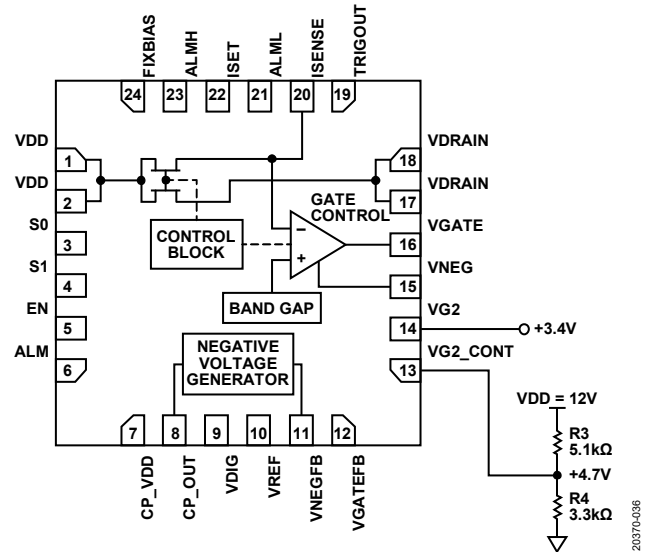


Figure 36. Resistor Divider Used to Set VG2

Use the following equations to calculate the voltage at VG2_CONT (Pin 13) and VG2 (Pin 14):

$$VG2_CONT (V) = VDD \times \frac{R4}{R3 + R4}$$

$$VG2 (V) = VG2_CONT - 1.3 V$$

SELF PROTECTION

Due to the small R_{DS_ON} of the internal MOSFET between VDD and VDRAIN, a large amount of current may flow through the HMC980LP4E. The HMC980LP4E attempts to protect itself by disabling the VDRAIN and VGATE output voltages during a short-circuit event on either pin. The HMC980LP4E remains in this disabled mode until a full power cycle or an enable/disable cycle is applied.

When the HMC980LP4E is controlling depletion mode amplifiers, VNEG is continuously monitored for short-circuit faults to ground. If VNEG rises above a preset value (typically -0.6 V), the VDRAIN and VG2 outputs are pulled to ground while VGATE is pulled to VNEG. The HMC980LP4E stays in this standby mode until the fault condition at VNEG is corrected.

OVERCURRENT/UNDERCURRENT ALARM

The HMC980LP4E provides an overcurrent and undercurrent alarm indicator, ALM (Pin 6). The ALM pin is pulled up to VDIG when the amplifier drain current exceeds the set values for minimum or maximum drain currents. Note that the ALM pin status does not affect the operation of HMC980LP4E and is provided only for monitoring purposes.

The overcurrent and undercurrent limits are set using three resistors, as shown in Figure 37. The resistor values shown in Figure 37 represent alarm thresholds of $\pm 6\%$. However, the thresholds do not need to be symmetrically placed around the target drain current. The threshold values also possess a small built in hysteresis. Note that the total external resistance from the ISET pin to ground ($R12 + R13$) must be within 1% of 5 k Ω . The resistor values for Figure 37 can be calculated using the following equations:

$$I_{UCTH} (A) = I_{DRAIN} \times \left(1 - \frac{R12}{R12 + R13} \right)$$

$$I_{OCTH} (A) = I_{DRAIN} \times \left(1 + \frac{R11}{R12 + R13} \right)$$

where:

I_{UCTH} is the undercurrent alarm threshold.

I_{OCTH} is the overcurrent alarm threshold.

The ALM pin status is shown with a varying I_{DRAIN} value in Figure 38.

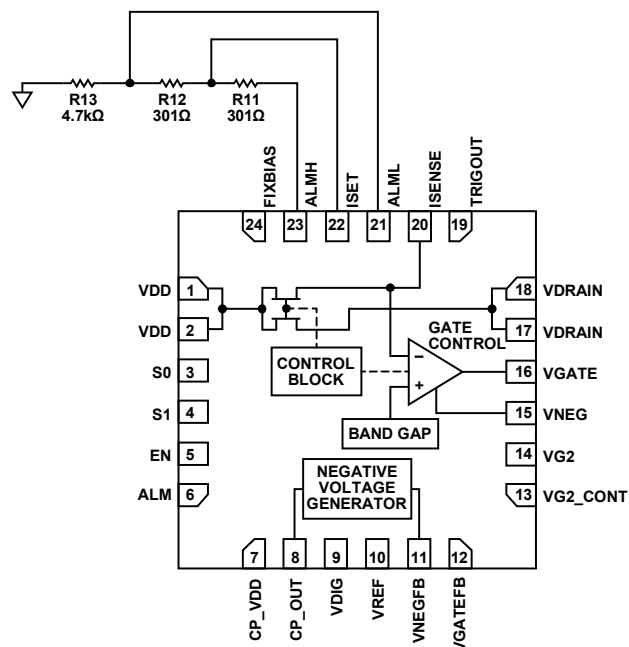


Figure 37. Current Alarm Resistor Configuration for $\pm 6\%$ Thresholds

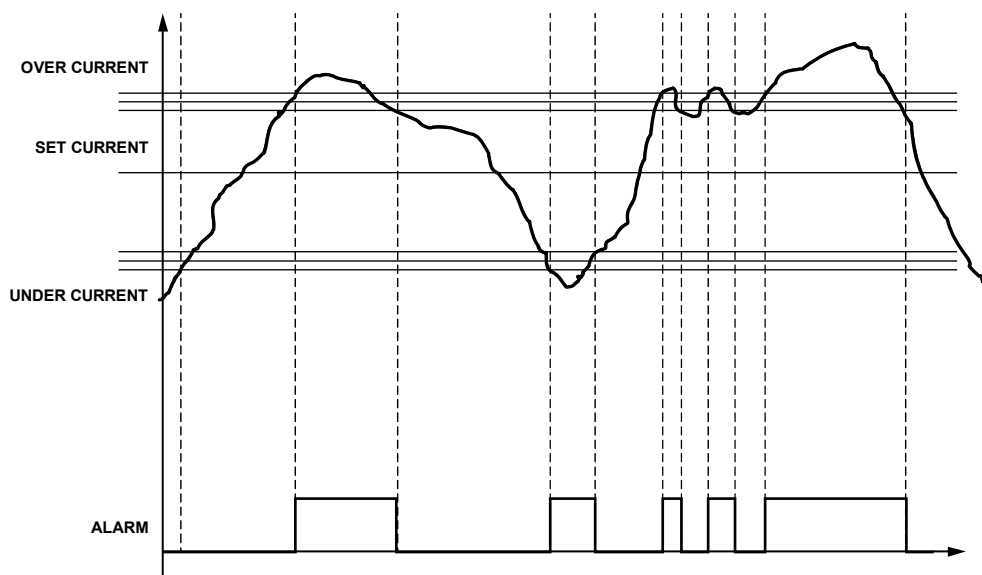


Figure 38. Current Alarm Behavior

NEGATIVE VOLTAGE GENERATOR

The HMC980LP4E has an internal charge pump that generates the negative voltage rail, VNEG, required for biasing depletion mode devices. By default, the HMC980LP4E generates -2.46 V at the CP_OUT pin. This charge pump requires two diodes and two capacitors connected externally, as shown in Figure 39.

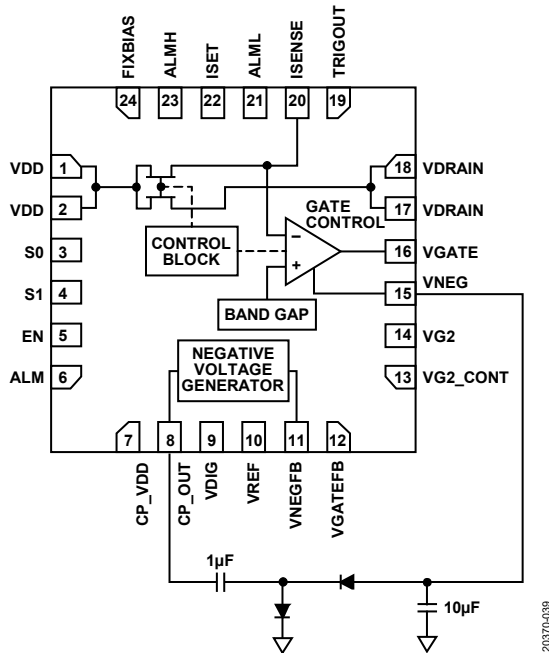


Figure 39. External Components Required for the Negative Voltage Generator

The HMC980LP4E is designed to reject the ripple on the CP_OUT pin by isolating VGATE from the CP_OUT pin. Thus, the noise of the charge pump is effectively isolated from the gate of the RF amplifier.

DISABLING THE INTERNAL NEGATIVE VOLTAGE GENERATOR

The charge pump can be disabled using the VNEGFB pin if an enhancement mode amplifier is being biased or if the desired negative supply is already available in the system. In either case, ground the VNEGFB pin to disable the internal charge pump. If using an external negative voltage, connect the negative supply to VNEG (Pin 15). See Table 7 for more details on selection of the operating modes. When using an external negative voltage for depletion mode amplifiers, the external voltage must be between -2.3 V and -3.5 V for the HMC980LP4E to operate properly.

Table 7. Mode Selection

Mode	VNEGFB	VGATEFB	VNEG	Description
Depletion Mode Amplifier, VNEG = Internal	Float	Float	CP_OUT	Depletion mode amplifier control. Internal negative voltage generator is active and generating -2.46 V . See Figure 34 for an example application schematic.
Depletion Mode Amplifier, VNEG = External	Ground	Float	External	Depletion mode amplifier control. Internal negative voltage generator is disabled. Connect an external voltage between -3.5 V and -2.3 V to VNEG. See Figure 35 for an example application schematic.
Enhancement Mode Amplifier, VNEG = 0 V	Ground	Ground	Ground	Enhancement mode amplifier control. Internal negative voltage generator is disabled. See Figure 44 for an example application schematic.
Invalid	Float	Ground	Not applicable	Invalid configuration. The HMC980LP4E stays in standby.

CHANGING THE DEFAULT VNEG VOLTAGE

VNEG limits the range of the VGATE output voltage. By default, the internal charge pump sets VNEG to -2.46 V. In some cases, VNEG may need to be adjusted to force VGATE to operate over a specific voltage range, for example, when an amplifier requires gate voltages more negative than -2 V to fully shut off, or when the absolute maximum rating of an amplifier for VGATE is less negative than -2 V.

VNEG can be adjusted using an external resistor. To set VNEG to a voltage lower (more negative) than the default, a resistor is connected between VNEGFB and VREF (Pin 11 and Pin 10). Use the following equation to calculate the resistor value:

$$R(k\Omega) = \frac{50}{\left(50 \times \frac{VNEG_{DESIRED} - 0.815}{262 \times (0.815 - VREF)}\right) - 1}$$

where:

$VNEG_{DESIRED}$ is the more negative voltage than the default.

$VREF = 1.44$ V.

This resistor is connected as shown in Figure 40.

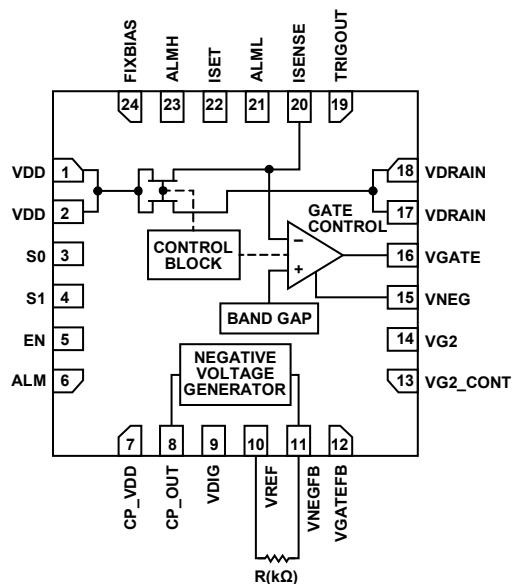


Figure 40. Resistor Used to Reduce VNEG Below -2.46 V (More Negative)

To set VNEG to a voltage higher (less negative) than the default, a resistor must be connected between VNEGFB and VNEG (Pin 11 and Pin 15). Use the following equation to calculate the resistor value:

$$R(k\Omega) = \frac{262}{\left(262 \times \frac{VREF - 0.815}{50 \times (0.815 - VNEG_{DESIRED})}\right) - 1}$$

where:

$VREF = 1.44$ V.

$VNEG_{DESIRED}$ is the less negative voltage than the default.

This resistor is connected as shown in Figure 41.

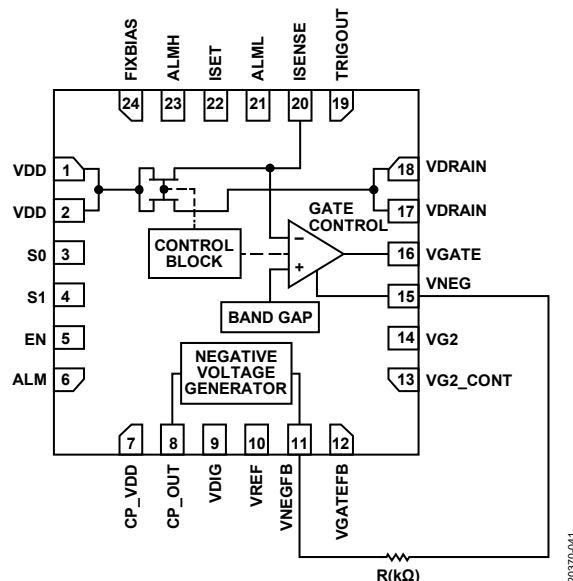


Figure 41. Resistor Used to Increase VNEG Above -2.46 V (Less Negative)

It is important to note that VNEG must always be set lower (more negative) than the VGATE threshold voltage by at least 0.3 V to 0.4 V to ensure a reliable startup. Therefore, the VGATE threshold voltage cannot be equal to VNEG.

CHANGING THE VGATE THRESHOLD VOLTAGE

During startup, VGATE must first pull down to the threshold voltage before the control loop can start, to ensure that the RF amplifier is pinched off before asserting VDRAIN. By default, the VGATE threshold voltage is approximately -2.06 V. In some cases, this threshold voltage may need to be adjusted to safely bias the RF amplifier, for example, when an amplifier requires gate voltages more negative than -2 V to fully shut off, or when the absolute maximum rating of an amplifier for VGATE is less negative than -2 V.

The VGATE threshold voltage can be adjusted using an external resistor. To set the threshold lower (more negative) than the default, a resistor is connected between VGATEFB and VGATE (Pin 12 and Pin 16). Use the following equation to calculate the resistor value:

$$R(k\Omega) = \frac{50}{\left(50 \times \frac{VGATE_{DESIRED} - 0.815}{262 \times (0.815 - VREF)}\right) - 1}$$

where:

$VGATE_{DESIRED}$ is the more negative threshold voltage than the default.

$VREF = 1.44$ V.

This resistor is connected as shown in Figure 42.

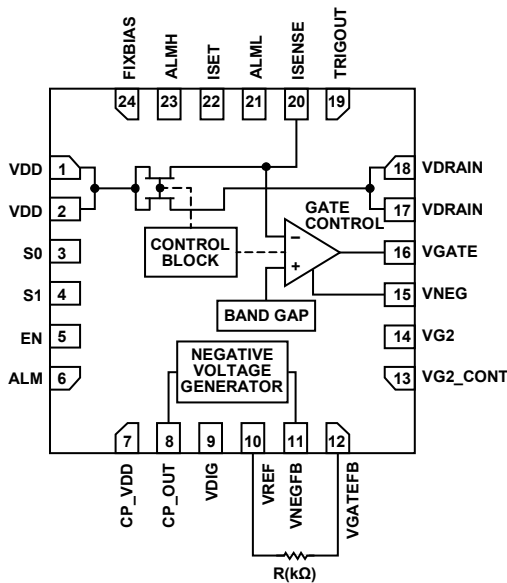


Figure 42. Resistor Used to Reduce VGATE Threshold Voltage Below the Default (More Negative)

To set the threshold higher (less negative) than the default, a resistor must be connected between VGATEFB and VGATE (Pin 12 and Pin 16). Use the following equation to calculate the resistor value.

$$R(k\Omega) = \frac{262}{\left(262 \times \frac{VREF - 0.815}{50 \times (0.815 - VGATE_{DESIRED})}\right) - 1}$$

where:

$VGATE_{DESIRED}$ is the less negative threshold voltage than the default.

$VREF = 1.44$ V.

This resistor is connected as shown in Figure 43.

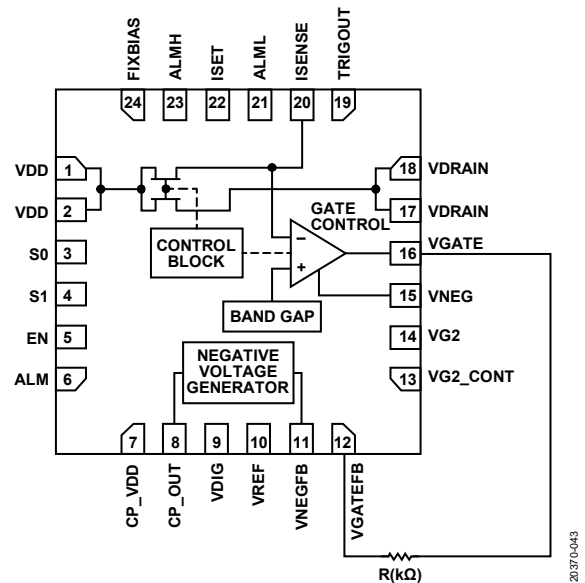


Figure 43. Resistor Used to Increase VGATE Threshold Voltage Above the Default (Less Negative)

DESIGN EXAMPLES**Controlling a Depletion Mode RF Amplifier Using the Internal Negative Voltage Generator**

The following steps describe how to design an HMC980LP4E circuit for controlling the bias current in a depletion mode RF amplifier using the built in negative voltage generator of the HMC980LP4E. For this example, assume that the amplifier requires 10 V for VDD, draws 450 mA, and only has one VGGx pin. Also, note that the VGGx pin of the depletion mode RF amplifier cannot tolerate voltages below -2 V.

1. Choose R_{SENSE} to set the HMC980LP4E target drain current to 450 mA. R_{SENSE} has a 1% tolerance.

$$R_{SENSE} (\Omega) = \frac{150}{0.45 \text{ A}} = 333.33 \Omega \approx 332 \Omega$$

2. Choose S0 and S1 states based on the expected current draw. Table 6 shows that for 450 mA, S0 = VDIG (or left floating due to the internal pull-up resistor) and S1 = ground. Table 6 also shows the R_{DS_ON} value of the internal MOSFET with these switch settings. In this case, $R_{DS_ON} = 1.55 \Omega$.
3. Calculate the voltage required on VDD to set the correct voltage on VDRAIN when the correct current is being drawn.

$$VDD (V) = 10 \text{ V} + (1.55 \Omega \times 450 \text{ mA}) = 10.698 \text{ V} \approx 10.7 \text{ V}$$

4. Adjust the VNEGFB pin to set VNEG to -2 V. This resistor is placed between VNEG (Pin 15) and VNEGFB (Pin 11), and has a 1% tolerance.

$$R (k\Omega) = \frac{262}{\left(262 \times \frac{1.44 \text{ V} - 0.815}{50 \times (0.815 - (-2 \text{ V}))} \right) - 1}$$

$$R (k\Omega) = 1603.33 \text{ k}\Omega \approx 1620 \text{ k}\Omega$$

5. Setting VNEG to -2 V also requires that the VGATE threshold value be changed to maintain a buffer of 0.3 V to 0.4 V by placing a resistor between VGATE (Pin 16) and VGATEFB (Pin 12). This resistor has a 1% tolerance. Calculate the resistor value as follows:

$$R (k\Omega) = \frac{262}{\left(262 \times \frac{1.44 \text{ V} - 0.815}{50 \times (0.815 - (-1.7 \text{ V}))} \right) - 1}$$

$$R (k\Omega) = 867 \text{ k}\Omega \approx 866 \text{ k}\Omega$$

Controlling a Depletion Mode RF Amplifier Using an External Negative Voltage

The following steps describe how to design an HMC980LP4E circuit for controlling the bias current in a depletion mode RF amplifier using an external negative voltage for VNEG (Pin 15). For this example, assume that the amplifier requires 12 V for VDD, draws 200 mA, and has two VGGx pins, one of which requires a positive voltage of 6 V.

1. Choose R_{SENSE} to set the HMC980LP4E target drain current to 200 mA. R_{SENSE} has a 1% tolerance.

$$R_{SENSE} (\Omega) = \frac{150}{0.2 \text{ A}} = 75 \Omega$$

2. Choose S0 and S1 states based on the expected current draw. Table 6 shows that for 200 mA, S0 and S1 = ground. Table 6 also provides the R_{DS_ON} value of the internal MOSFET with these switch settings. In this case, $R_{DS_ON} = 2.8 \Omega$.
3. Calculate the voltage required on VDD to set the correct voltage on VDRAIN when the correct current is being drawn.

$$VDD (V) = 12 \text{ V} + (2.8 \Omega \times 200 \text{ mA}) = 12.56 \text{ V}$$

4. Calculate the resistor values needed to generate the VG2_CONT voltage. VG2_CONT must be set to 1.3 V higher than the desired VG2. Assume the top resistor is 5.1 k Ω to start. R4 has a 1% tolerance.

$$VG2_CONT = 6 \text{ V} + 1.3 \text{ V} = 7.3 \text{ V}$$

$$7.3 \text{ V} = 12.56 \text{ V} \times \frac{R4}{R3 + R4}$$

$$R4 = 7.078 \text{ k}\Omega \approx 7.15 \text{ k}\Omega$$

RECOMMENDED HMC980LP4E CIRCUITS

Many RF amplifier bias control circuits that use the HMC980LP4E have been built and verified for reference. A list of these circuits is available on the Analog Devices wiki. Although this list of circuits is extensive, it is not exhaustive. If a given RF amplifier is not included in this list, that does not mean that it cannot be actively biased using the HMC980LP4E.

Ensure that the proper mode of operation is selected before powering the HMC980LP4E to avoid biasing the external amplifier incorrectly.

Figure 44. Typical Circuit for Controlling an Enhancement Mode Amplifier

HIGHER DRAIN CURRENT APPLICATIONS

Two or more HMC980LP4E devices can be connected in parallel to bias amplifiers that require more current than the 1.6 A that a single HMC980LP4E can provide.

If using the internal negative voltage generator, set up only one HMC980LP4E with the negative voltage generator, and the CP_OUT pin from that device drives the VNEG pins of all parallel devices (up to 10 HMC980LP4E devices).

Connect the VDRAIN outputs from all the HMC980LP4E devices together and apply them to the power supply pin of the amplifier under control.



Figure 45. Daisy-Chain Operation

It is only necessary to use the VGATE output from one HMC980LP4E to drive the VGG1 pin of the amplifier under control. Decouple the VGATE outputs from all other

HMC980LP4E devices with 2.2 μF capacitors and left floating
See Figure 46 for an example of how to bias a depletion mode
amplifier at 12 V and 2 A using two HMC980LP4E devices.

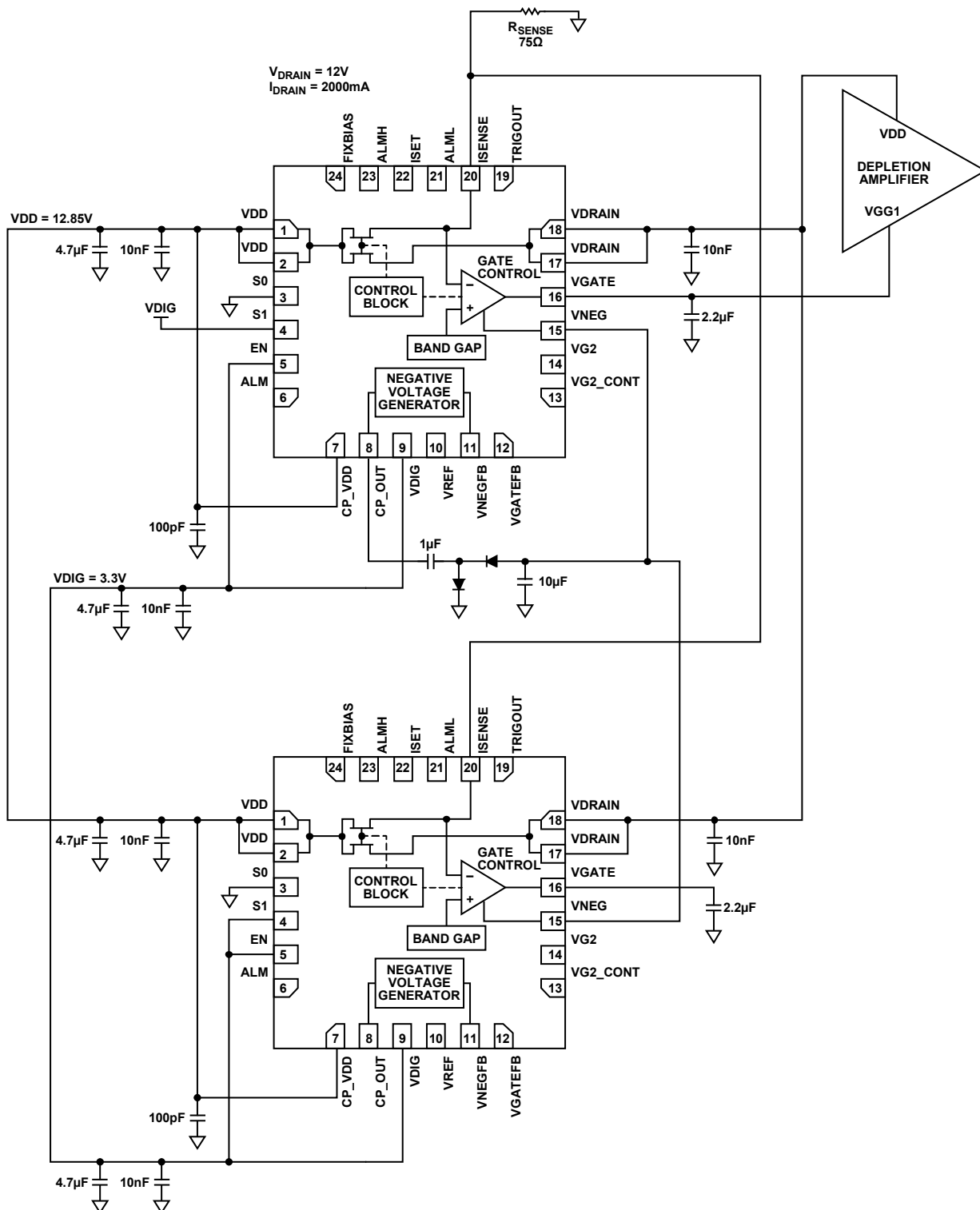


Figure 46. Biasing High Current Amplifiers Using Two HMC980LP4E Devices

REDUCING EXTERNAL COMPONENT COUNT

In space critical applications, it is possible to combine or eliminate some of the external components surrounding the HMC980LP4E. It must be understood that eliminating these components results in some features of the HMC980LP4E becoming inaccessible.

ALM Resistors

If the ALM function is not needed, the three resistors used to set the ALM limits (see the Overcurrent/Undercurrent Alarm section) can be combined into one 5 k Ω resistor. The ALML and ALMH pins (Pin 21 and Pin 23) must be tied directly to the ISET pin (Pin 22). Pin 22 still requires a 5 k Ω resistor to ground.

VNEG/VGATE Feedback Resistors

Depending on the absolute maximum limits of the RF amplifier being biased, it is possible to eliminate the resistors used to limit the range of VNEG and VGATE.

Assuming the internal negative voltage generator is being used (see the Negative Voltage Generator section) and the amplifier being biased can safely tolerate -2.46 V on the gate pin, Resistors R5, R6, R7, and R8 can be removed.

VG2 Set Resistors

If the amplifier being biased requires only one gate control voltage, the resistor divider used to set the voltage on VG2 (R3 and R4) can be removed. The VG2_CONT and VG2 pins (Pin 13 and Pin 14) must be left floating.

Negative Voltage Generator

If the desired VNEG voltage is available externally, the negative voltage generator can be disabled and the associated components removed. See the Negative Voltage Generator section. In this case, C6, C7, and D1 can be safely removed from the circuit. The externally available VNEG supply must be applied to the VNEG pin (Pin 15) while CP_OUT (Pin 8) must be left to float.

Decoupling Capacitors

Depending on the required power supply rejection ratio (PSRR) of the application, the minimal noise of the VDD and VDIG supplies, and the decoupling requirements of the amplifier being biased, some of the decoupling capacitors on the HMC980LP4E can be removed. It is recommended to start by removing the large value capacitors and leaving the small value capacitors for high frequency decoupling.

EVALUATION BOARD CIRCUIT

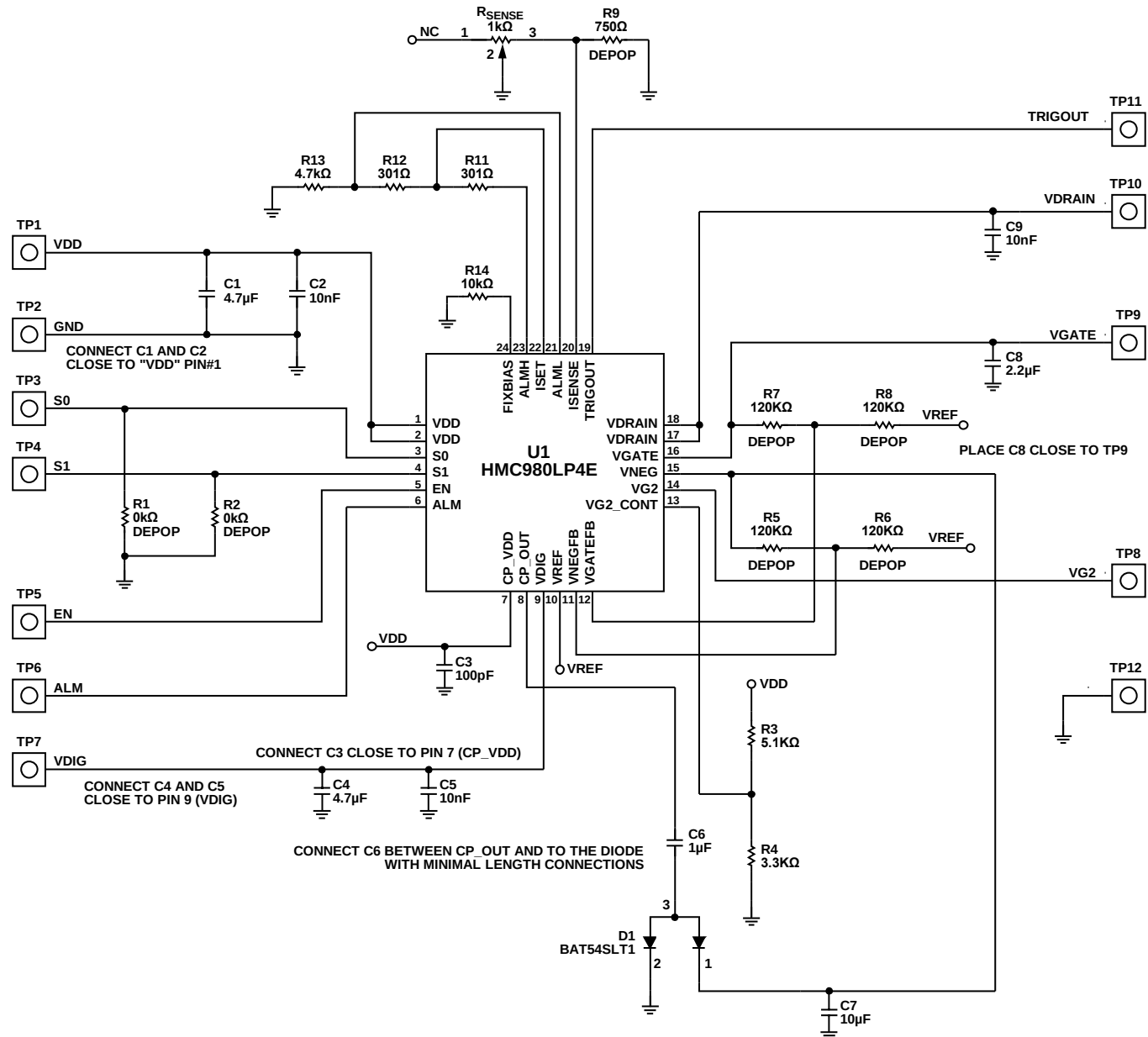


Figure 47. Evaluation Board Schematic

20370-Q47

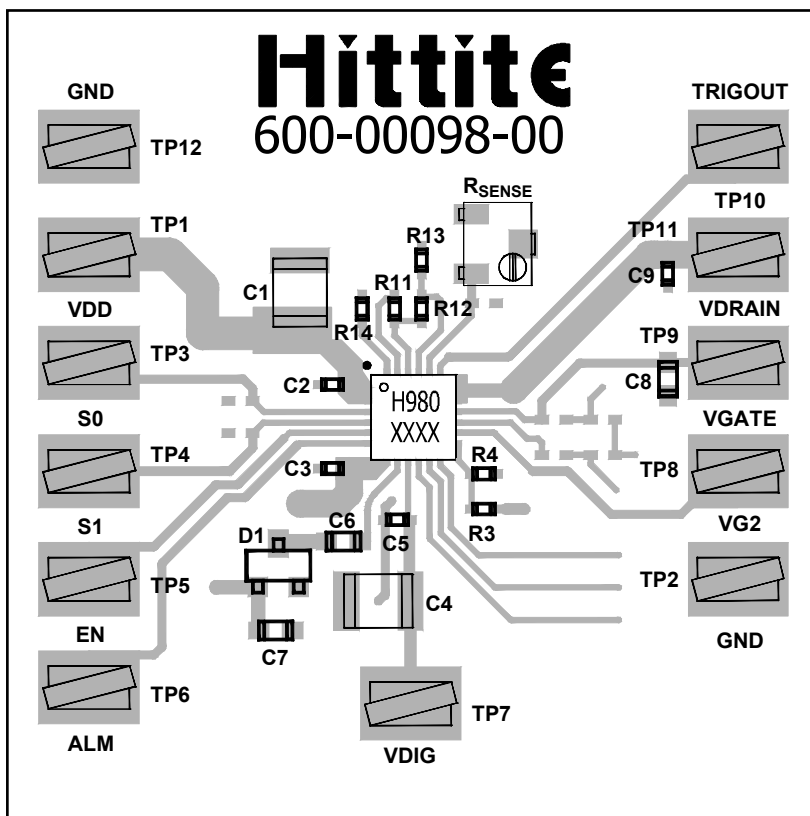


Figure 48. Evaluation Board Component Side Layout

Table 8. Bill of Materials for Evaluation PCB EVAL01-HMC980LP4E

Reference Designator	Description	Default Value
TP1 to TP12	Test points	Not applicable
C1, C4	VDD and VDIG decoupling capacitors	4.7 μ F (1210)
C2, C5	VDD and VDIG decoupling capacitors	10 nF (0402)
C9	VRAIN decoupling capacitor	10 nF (0402)
C3	CP_VDD decoupling capacitor	100 pF (0402)
C6	Charge pump output flying capacitor	1 μ F (0603)
C7	Charge pump output storage capacitor	10 μ F (0603)
C8	VGATE decoupling capacitor	2.2 μ F (X5R)
D1	Dual series Schottky barrier diode	BAT54SLT1
R3	Top resistor to set VG2	5.1 k Ω (0402)
R4	Bottom resistor to set VG2	3.3 k Ω (0402)
R5, R6	VNEG voltage adjustment resistors	Open (0402)
R7, R8	VGATE threshold voltage adjustment resistors	Open (0402)
R_SENSE	Potentiometer for setting target drain current	1 k Ω
R9	Fixed resistor for setting target drain current	Open (0402)
R11, R12	Alarm threshold setting resistors	301 Ω (0402)
R13	ISET resistor	4.7 k Ω (0402)
R14	FIXBIAS resistor	10 k Ω (0402)
R1, R2	S0, S1 pull-down resistors	Open (0402)
U1	Device under test	HMC980LP4E
PCB ¹	EVAL01-HMC980LP4E evaluation PCB	Not applicable

¹ Circuit board material: FR4.

OUTLINE DIMENSIONS

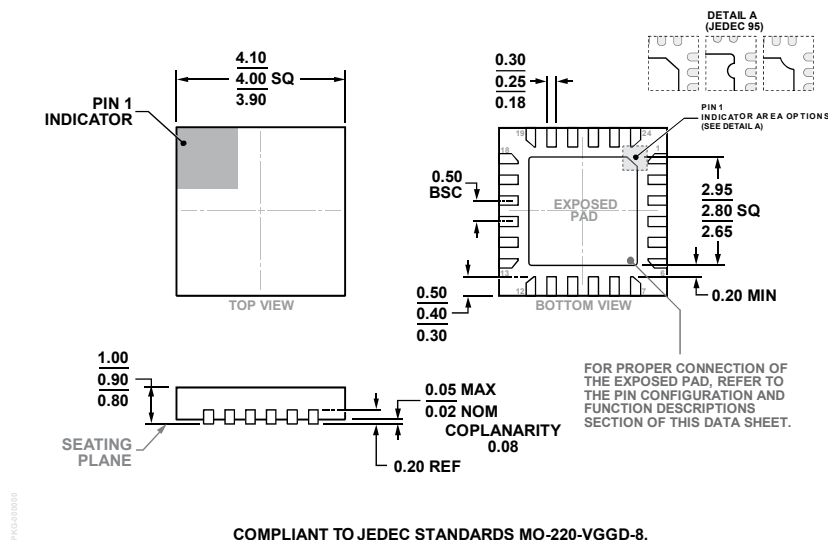


Figure 49. 24-Lead Lead Frame Chip Scale Package [LFCSP]
4 mm × 4 mm Body and 0.90 mm Package Height
(HCP-24-2)

Dimensions shown in millimeters

ORDERING GUIDE

Model ¹	MSL Rating ²	Temperature Range	Package Description	Package Option	Marking Code ³
HMC980LP4E	MSL3	−40°C to +85°C	24-Lead LFCSP	HCP-24-2	H980 XXXX
HMC980LP4ETR	MSL3	−40°C to +85°C	24-Lead LFCSP	HCP-24-2	H980 XXXX
EVAL01-HMC980LP4E			Evaluation Board		

¹ All models are RoHS compliant, low stress injection molded plastic, and 100% matte Sn lead finish.

² Maximum peak reflow temperature of 260°C. See Table 2 in the Absolute Maximum Ratings section.

³ 4-digit lot number XXXX.