



## 1.5 Ω On Resistance, ± 15 V / +12 V / ± 5 V, Quad SPST Switches

### DESCRIPTION

The DG1411E, DG1412E, DG1413E are ± 15 V precision monolithic quad single-pole single-throw (SPST) CMOS analog switches. Built on a new CMOS process, the Vishay Siliconix DG1411E, DG1412E, and DG1413E offer low on-resistance of 1.5 Ω. The low and flat resistance over the full signal range ensures excellent linearity and low signal distortion. The new CMOS platform provides low power dissipation, minimized parasitic capacitance, and low charge injection.

The devices operate from either a single 4.5 V to 24 V power supply, or from dual ± 4.5 V to ± 15 V power supplies. The analog switches do not require a V<sub>L</sub> logic supply, while all digital inputs have 0.8 V and 2 V logic thresholds to ensure low voltage TTL / CMOS compatibility.

The DG1411E, DG1412E, and DG1413E are bi-directional and support analog signals up to the supply voltage when on, and block them when off. The devices each feature four independently selectable SPST switches. The DG1411E is normally closed, while the DG1412E is normally open. The DG1413E has two normally open and two normally closed switches with guaranteed break-before-make operation.

Combined with fast 70 ns switching time, low and flat switch resistance. The devices are ideal for signal switching and relay replacement in data acquisition, industrial control and automation, communication, and A/V systems, in addition to medical instrumentation and automated test equipment.

The switches are available in RoHS-compliant, halogen-free TSSOP16 and QFN16 4 mm by 4 mm packages.

### FEATURES

- 35 V supply max. rating
- On-resistance: 1.5 Ω
- On-resistance flatness: 0.2 Ω
- Channel to channel on-resistance match: 0.04 Ω
- Supports single and dual supply operation
- Fully specified at ± 15 V, ± 5 V, and +12 V
- Integrated V<sub>L</sub> supply
- 3 V logic compatible
- Low parasitic capacitance: C<sub>S(OFF)</sub>: 24 pF, C<sub>D(ON)</sub>: 87 pF
- Rail to rail signal handling
- Material categorization: for definitions of compliance please see [www.vishay.com/doc?99912](http://www.vishay.com/doc?99912)



**RoHS**  
COMPLIANT  
**HALOGEN**  
**FREE**

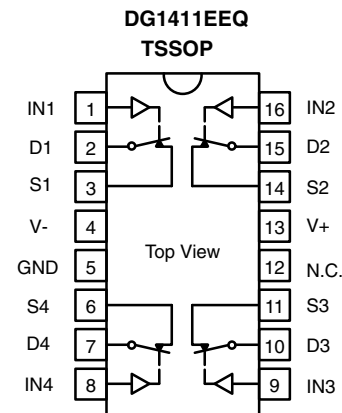
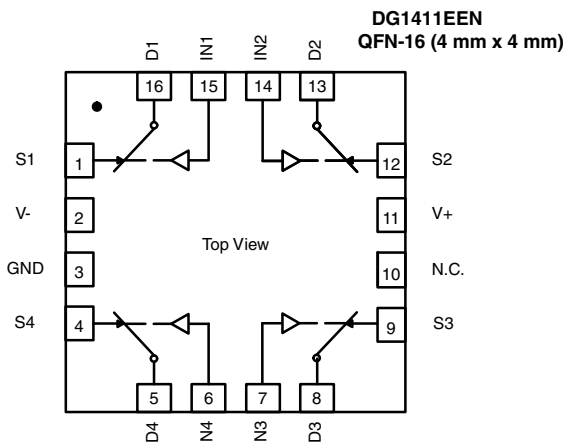
### BENEFITS

- Low insertion loss
- Low distortion
- Break-before-make switching
- Low charge injection over the full signal range

### APPLICATIONS

- Medical and healthcare equipment
- Data acquisition system
- Industrial control and automation
- Test and measurement equipment
- Communication systems
- Battery powered systems
- Sample and hold circuits
- Audio and video signal switching
- Relay replacement

### FUNCTIONAL BLOCK DIAGRAM AND PIN CONFIGURATION - DG1411E



TRUTH TABLE - DG1411E	
LOGIC	SWITCH
0	On
1	Off

### Notes

- QFN exposed pad tied to V-
- N.C. = no connect
- Switches shown for logic "0" input

## FUNCTIONAL BLOCK DIAGRAM AND PIN CONFIGURATION - DG1412E

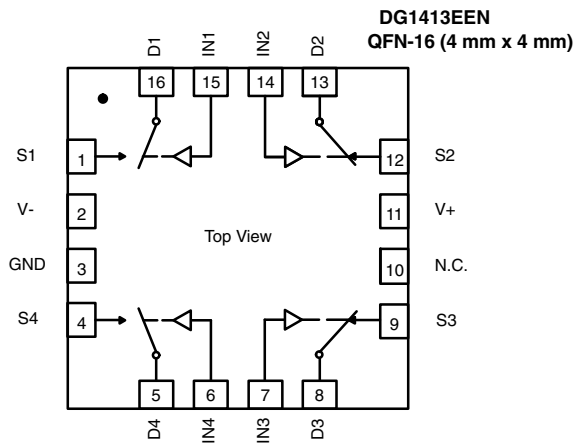


TRUTH TABLE - DG1412E	
LOGIC	SWITCH
0	Off
1	On

### Notes

- QFN exposed pad tied to V-
- N.C. = no connect
- Switches shown for logic "0" input

## FUNCTIONAL BLOCK DIAGRAM AND PIN CONFIGURATION - DG1413E



TRUTH TABLE - DG1413E		
LOGIC	SWITCHES 1, 4	SWITCHES 2, 3
0	Off	On
1	On	Off

### Notes

- QFN exposed pad tied to V-
- N.C. = no connect
- Switches shown for logic "0" input



DEVICE OPTIONS				
PART NUMBER	CONFIGURATION	SWITCH FUNCTION	TEMPERATURE RANGE	PACKAGE
DG1411EEN-T1-GE4	Quad SPST	NC	-40 °C to +125 °C	QFN (4 mm x 4 mm) 16L (variation 2)
DG1412EEN-T1-GE4	Quad SPST	NO	-40 °C to +125 °C	QFN (4 mm x 4 mm) 16L (variation 2)
DG1413EEN-T1-GE4	Quad SPST	NC / NO	-40 °C to +125 °C	QFN (4 mm x 4 mm) 16L (variation 2)
DG1411EEQ-T1-GE4	Quad SPST	NC	-40 °C to +125 °C	TSSOP-16
DG1412EEQ-T1-GE4	Quad SPST	NO	-40 °C to +125 °C	TSSOP-16
DG1413EEQ-T1-GE4	Quad SPST	NC / NO	-40 °C to +125 °C	TSSOP-16

ABSOLUTE MAXIMUM RATINGS			
ELECTRICAL PARAMETER	CONDITIONS	LIMITS	UNIT
V+	Reference to GND	-0.3 to +25	V
V-	Reference to GND	+0.3 to -25	
V+ to V-		+35	
Analog inputs (S or D)		(V-) - 0.3 to (V+) + 0.3	
Digital inputs		GND - 0.3 to (V+) + 0.3	
Maximum continuous switch current	TSSOP-16, T <sub>A</sub> = 25 °C	190	mA
	QFN (4 mm x 4 mm) 16L, T <sub>A</sub> = 25 °C	250	
	TSSOP-16, T <sub>A</sub> = 125 °C	90	
	QFN (4 mm x 4 mm) 16L, T <sub>A</sub> = 125 °C	100	
Maximum pulse switch current	Pulse at 1 ms, 10 % duty cycle	500	
Thermal resistance	TSSOP-16	130	°C/W
	QFN (4 mm x 4 mm) 16L	32	
ESD / HBM	JS-001	2000	V
ESD / CDM	JS-002	750	
Latch up	JESD78	300	mA
Temperature			
Operating temperature		-40 to +125	°C
Max. operating junction temperature		150	
Operating junction temperature		125	
Storage temperature		-65 to +150	

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.



ELECTRICAL CHARACTERISTICS - ± 15 V supply							
PARAMETER	SYMBOL	TEST CONDITIONS UNLESS OTHERWISE SPECIFIED V+ = 15 V, V- = -15 V VINH = 2 V, VINL = 0.8 V	+25 °C	-40 °C to +85 °C	-40 °C to +125 °C	TYP. / MAX.	UNIT
<b>Analog Switch</b>							
Analog signal range	V <sub>ANALOG</sub>		V- to V+			-	V
Drain-source on-resistance	R <sub>DS(on)</sub>	V <sub>S</sub> = ± 10 V, I <sub>S</sub> = -10 mA V+ = 13.5 V, V- = -13.5 V	1.5	-	-	Typ.	Ω
			1.8	2	2.3	Max.	
On-resistance flatness	R <sub>flat(on)</sub>	V <sub>S</sub> = ± 10 V, I <sub>S</sub> = -10 mA	0.2	-	-	-	Ω
			0.42	0.45	0.48	Max.	
On-resistance matching	ΔR <sub>DS(on)</sub>		0.04	-	-	Typ.	Ω
			0.22	0.23	0.24	Max.	
Switch off leakage current	I <sub>S</sub> /I <sub>d(off)</sub>	V+ = 16.5 V, V- = -16.5 V V <sub>S</sub> = ± 10 V, V <sub>D</sub> = ± 10 V	± 0.01	-	-	Typ.	nA
			± 0.5	± 2	± 12	Max.	
Channel on leakage current	I <sub>d(on)</sub>	V <sub>S</sub> = V <sub>D</sub> = ± 10 V	± 0.05	-	-	Typ.	nA
			± 1	± 3	± 40	Max.	
<b>Digital Control</b>							
Input, high voltage	V <sub>INH</sub>		-	-	2	V <sub>min.</sub>	V
Input, low voltage	V <sub>INL</sub>		-	-	0.8	V <sub>max.</sub>	
Input leakage	I <sub>IN</sub>	V <sub>IN</sub> = V <sub>GND</sub> OR V+	0.001	-	-	Typ.	μA
			-	-	± 0.1	Max.	
Digital input capacitance	C <sub>IN</sub>		3.5	-	-	Typ.	pF
<b>Dynamic Characteristics</b>							
Break-before-make time	t <sub>OPEN</sub>	V <sub>S1</sub> = V <sub>S2</sub> = 10 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	24	-	-	Typ.	ns
			-	-	10	Min.	
Turn-on time	t <sub>ON</sub>	V <sub>S</sub> = 10 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	70	-	-	Typ.	ns
			110	130	140	Max.	
Turn-off time	t <sub>OFF</sub>		50	-	-	Typ.	ns
			90	100	110	Max.	
Charge injection	Q <sub>inj</sub>	C <sub>L</sub> = 1 nF, R <sub>GEN</sub> = 0 Ω, V <sub>S</sub> = 0 V	-41	-	-	Typ.	pC
Off isolation	OIRR	C <sub>L</sub> = 5 pF, R <sub>L</sub> = 50 Ω, 100 kHz	-78	-	-	Typ.	dB
Cross talk	X <sub>TALK</sub>	C <sub>L</sub> = 5 pF, R <sub>L</sub> = 50 Ω, 1 MHz	-104	-	-	Typ.	
Insertion loss		f = 1 MHz, R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF	-0.16	-	-	Typ.	
Total harmonic distortion	THD	R <sub>L</sub> = 110 Ω, 15 V <sub>p-p</sub> , f = 20 Hz to 20 kHz	0.0039	-	-	Typ.	%
Bandwidth, -3 dB	BW	C <sub>L</sub> = 5 pF, R <sub>L</sub> = 50 Ω	150	-	-	Typ.	MHz
Source off capacitance	C <sub>S(off)</sub>	f = 1 MHz, V <sub>S</sub> = 0 V	24	-	-	Typ.	pF
Drain off capacitance	C <sub>D(off)</sub>		23	-	-	Typ.	
Drain on capacitance	C <sub>D(on)</sub>		87	-	-	Typ.	
<b>Power Requirements</b>							
Power supply range		GND = 0 V	± 4.5 V min. / ± 16.5 max.				V
Power supply current	I+	Digital inputs 0 or V+ V+ = 16.5 V, V- = -16.5 V	0.001	-	-	Typ.	μA
			-	-	1	Max.	
	I-	Digital inputs 0 or V+	113	-	-	Typ.	
			-	260	290	Max.	



ELECTRICAL CHARACTERISTICS - Single 12 V supply							
PARAMETER	SYMBOL	TEST CONDITIONS UNLESS OTHERWISE SPECIFIED V+ = 12 V, V- = -0 V VINH = 2 V, VINL = 0.8 V	+25 °C	-40 °C to +85 °C	-40 °C to +125 °C	TYP. / MAX.	UNIT
<b>Analog Switch</b>							
Analog signal range	V <sub>ANALOG</sub>		0 to V+				V
Drain-source on-resistance	R <sub>DS(on)</sub>	V <sub>S</sub> = 0 V to 10 V, I <sub>S</sub> = -10 mA; V+ = 10.8 V, V- = 0 V	2.5 3.1	- 3.8	- 4.4	Typ. Max.	Ω
On-resistance flatness	R <sub>flat(on)</sub>	V <sub>S</sub> = 0 V to 10 V; I <sub>S</sub> = -10 mA	0.7 0.9	- 1	- 1.1	Typ. Max.	Ω
On-resistance matching	ΔR <sub>DS(on)</sub>		0.04 0.19	- 0.22	- 0.25	Typ. Max.	
Switch off leakage current	I <sub>S</sub> /I <sub>d(off)</sub>	V+ = 10.8 V, V- = 0 V V <sub>S</sub> = 1 V/10 V; V <sub>D</sub> = 10 V/1 V	± 0.02 ± 0.55	- ± 1.2	- ± 10	Typ. Max.	nA
Channel on leakage current	I <sub>d(on)</sub>	V <sub>S</sub> = V <sub>D</sub> = 3.2 V/10 V	± 0.01 ± 1	- ± 2	- ± 35	Typ. Max.	
<b>Digital Control</b>							
Input, high voltage	V <sub>INH</sub>		-	-	2	Min.	V
Input, low voltage	V <sub>INL</sub>		-	-	0.8	Max.	
Input leakage	I <sub>IN</sub>	V <sub>IN</sub> = V <sub>GND</sub> or V+	0.001 -	- -	- ± 0.1	Typ. Max.	μA
Digital input capacitance	C <sub>IN</sub>		3.5	-	-	Typ.	pF
<b>Dynamic Characteristics</b>							
Break-before-make time	t <sub>OPEN</sub>	V <sub>S1</sub> = V <sub>S2</sub> = 8 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	90 -	- -	- 50	Typ. Min.	ns
Turn-on time	t <sub>ON</sub>	V <sub>S</sub> = 8 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	150 190	- 230	- 260	Typ. Max.	
Turn-off time	t <sub>OFF</sub>		60 100	- 110	- 120	Typ. Max.	
Charge injection	Q <sub>INj</sub>	C <sub>L</sub> = 1 nF, R <sub>GEN</sub> = 0 Ω, V <sub>S</sub> = 6 V	6	-	-	Typ.	
Off isolation	OIRR	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF, 100 kHz	-78	-	-	Typ.	dB
Cross talk	X <sub>TALK</sub>	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF, 1 MHz	-106	-	-	Typ.	
Insertion loss		f = 1 MHz, R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF	-0.23	-	-	Typ.	
Bandwidth, -3 dB	BW	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF	150	-	-	Typ.	MHz
Source off capacitance	C <sub>S(off)</sub>	f = 1 MHz, V <sub>S</sub> = 6 V	31	-	-	Typ.	pF
Drain off capacitance	C <sub>D(off)</sub>		29	-	-	Typ.	
Drain on capacitance	C <sub>D(on)</sub>		93	-	-	Typ.	
<b>Power Requirements</b>							
Power supply range		GND = 0 V, V- = 0 V	± 5 V min. / ± 16.5 max.				V
Power supply current	I+	Digital inputs 0 or V+ V+ = 13.2 V	0.001	-	-	Typ.	μA
			-	-	1	Max.	
		IN1 = IN2 = IN3 = IN4 = 5 V	54	-	-	Typ.	
			-	150	190	Max.	



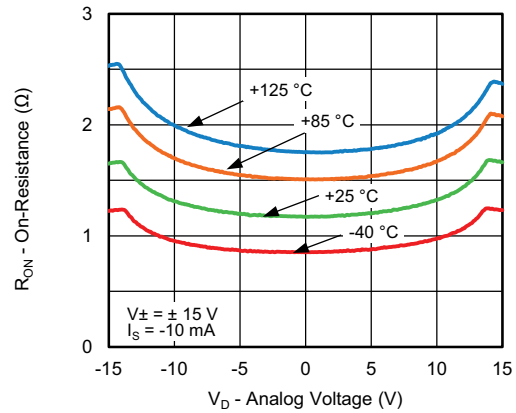
ELECTRICAL CHARACTERISTICS - ± 5 V supply							
PARAMETER	SYMBOL	TEST CONDITIONS UNLESS OTHERWISE SPECIFIED V <sub>+</sub> = 5 V, V <sub>-</sub> = -5 V V <sub>INH</sub> = 2 V, V <sub>INL</sub> = 0.8 V	+25 °C	-40 °C to +85 °C	-40 °C to +125 °C	TYP. / MAX.	UNIT
<b>Analog Switch</b>							
Analog signal range	V <sub>ANALOG</sub>		V <sub>-</sub> to V <sub>+</sub>				V
Drain-source on-resistance	R <sub>DS(on)</sub>	V <sub>S</sub> = ± 4.5 V, I <sub>S</sub> = -10 mA V <sub>+</sub> = 4.5 V, V <sub>-</sub> = -4.5 V	3	-	-	Typ.	Ω
			3.3	4	4.7	Max.	
On-resistance flatness	R <sub>flat(on)</sub>	V <sub>S</sub> = ± 4.5 V, I <sub>S</sub> = -10 mA	0.7	-	-	Typ.	
			0.9	1	1.1	Max.	
On-resistance matching	ΔR <sub>DS(on)</sub>		0.04	-	-	Typ.	
			0.19	0.22	0.25	Max.	
Switch off leakage current	I <sub>S</sub> /I <sub>d(off)</sub>	V <sub>+</sub> = 5.5 V, V <sub>-</sub> = -5.5 V V <sub>S</sub> = ± 4.5 V, V <sub>D</sub> = ∓ 4.5 V	± 0.004	-	-	Typ.	nA
			± 0.5	± 1.5	± 10	Max.	
Channel on leakage current	I <sub>d(on)</sub>	V <sub>S</sub> = V <sub>D</sub> = ± 4.5 V	± 0.003	-	-	Typ.	
			± 0.5	± 2	± 35	Max.	
<b>Digital Control</b>							
Input, high voltage	V <sub>INH</sub>		-	-	2	Min.	V
Input, low voltage	V <sub>INL</sub>		-	-	0.8	Max.	
Input leakage	I <sub>IN</sub>	V <sub>IN</sub> = V <sub>GND</sub> or V <sub>+</sub>	0.001	-	-	Typ.	μA
			-	-	± 0.1	Max.	
Digital input capacitance	C <sub>IN</sub>		3.5	-	-	Typ.	pF
<b>Dynamic Characteristics</b>							
Break-before-make time	t <sub>OPEN</sub>	V <sub>S1</sub> = V <sub>S2</sub> = 3 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	110	-	-	Typ.	ns
			-	-	65	Min.	
Turn-on time	t <sub>ON</sub>	V <sub>S</sub> = 3 V R <sub>L</sub> = 300 Ω, C <sub>L</sub> = 35 pF	280	-	-	Typ.	
			330	400	440	Max.	
Turn-off time	t <sub>OFF</sub>		180	-	-	Typ.	
			220	260	280	Max.	
Charge injection	Q <sub>INj</sub>	C <sub>L</sub> = 1 nF, R <sub>GEN</sub> = 0 Ω, V <sub>S</sub> = 0 V	7	-	-	Typ.	pC
Off isolation	OIRR	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF, 100 kHz	-78	-	-	Typ.	dB
Cross talk	X <sub>TALK</sub>	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF, 1 MHz	-106	-	-	Typ.	
Insertion loss		f = 1 MHz, R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF	-0.26	-	-	Typ.	%
Bandwidth, -3 dB	BW	R <sub>L</sub> = 50 Ω, C <sub>L</sub> = 5 pF	160	-	-	Typ.	MHz
Source off capacitance	C <sub>S(off)</sub>	f = 1 MHz, V <sub>S</sub> = 0 V	34	-	-	Typ.	pF
Drain off capacitance	C <sub>D(off)</sub>		31	-	-	Typ.	
Drain on capacitance	C <sub>D(on)</sub>		94	-	-	Typ.	
<b>Power Requirements</b>							
Power supply range		GND = 0 V	± 4.5 V min. / ± 16.5 max.				V
Power supply current	I <sub>+</sub>	Digital inputs 0 V or V <sub>+</sub> V <sub>+</sub> = 5.5 V, V <sub>-</sub> = -5.5 V	0.001	-	-	Typ.	μA
			-	-	1	Max.	
	I <sub>-</sub>	Digital inputs = 0 V or V <sub>+</sub>	0.001	-	-	Typ.	
			-	-	1	Max.	



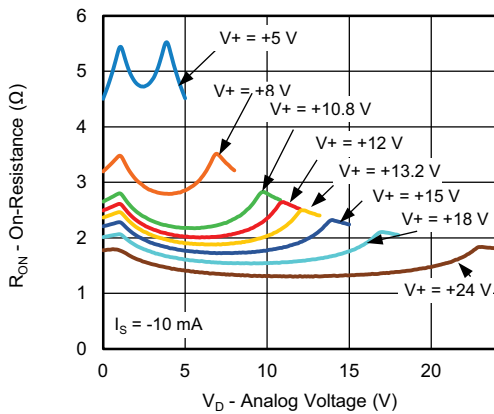
TYPICAL CHARACTERISTICS (T<sub>A</sub> = 25 °C, unless otherwise noted)



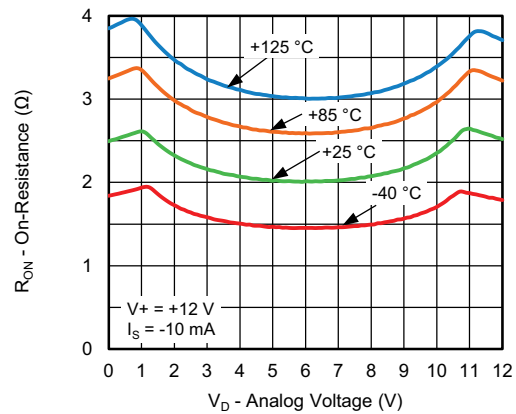
On-Resistance vs. Analog Voltage



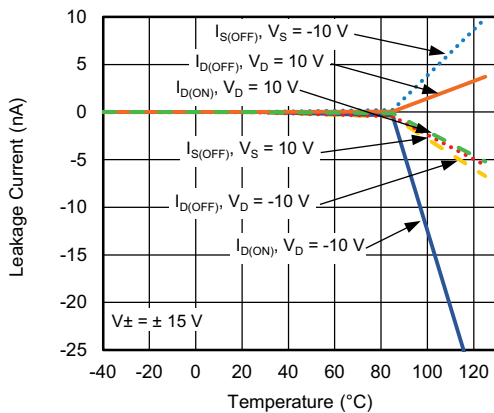
On-Resistance vs. Temperature



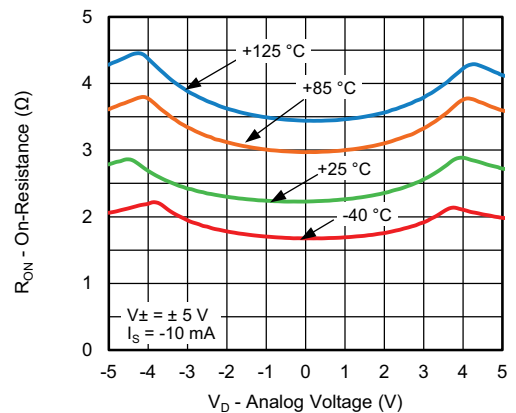
On-Resistance vs. Analog Voltage



On-Resistance vs. Temperature



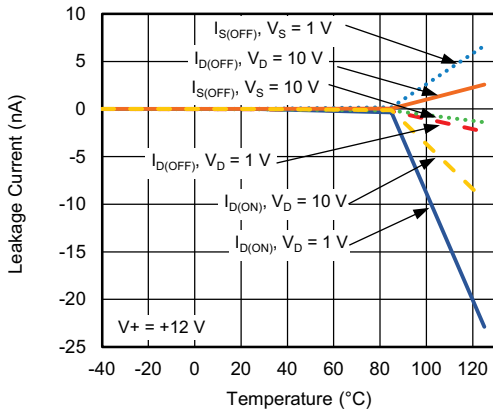
Leakage Current vs. Temperature



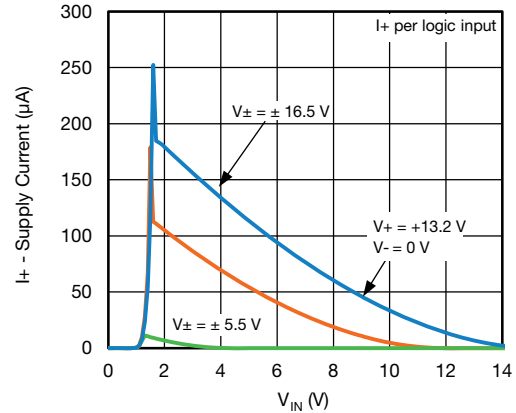
On-Resistance vs. Temperature



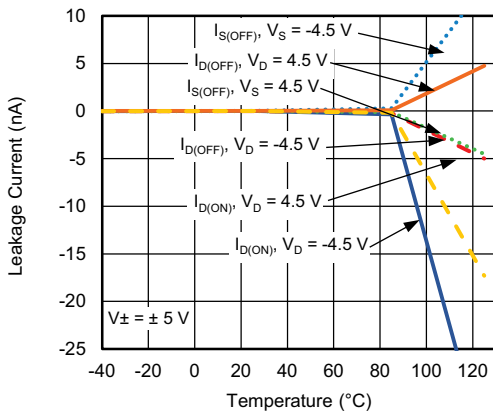
TYPICAL CHARACTERISTICS (T<sub>A</sub> = 25 °C, unless otherwise noted)



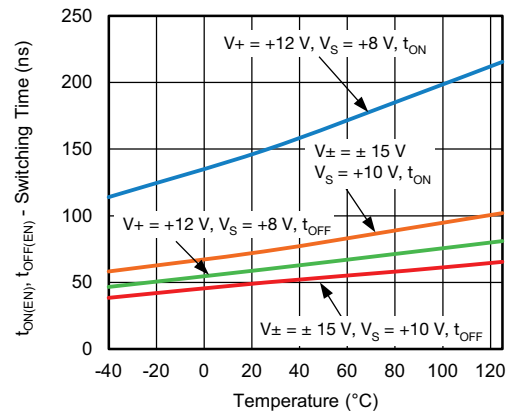
Leakage Current vs. Temperature



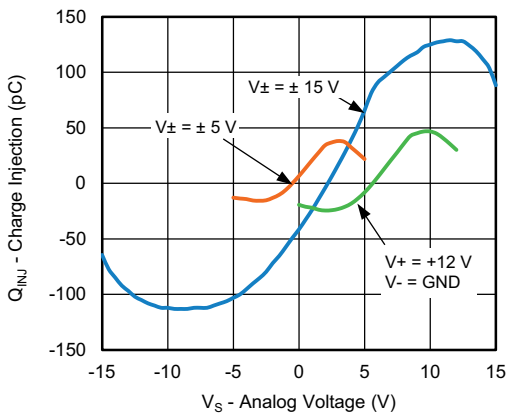
I+ - Supply Current vs. Logic Level



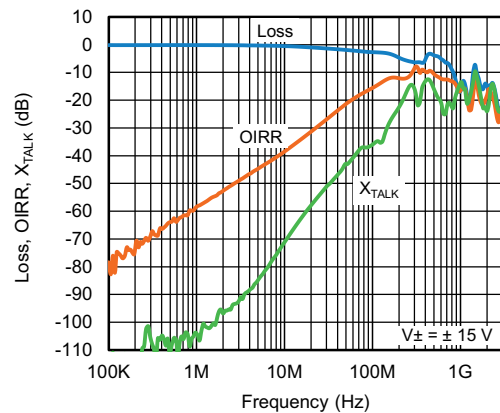
Leakage Current vs. Temperature



Switching Time vs. Temperature



Charge Injection vs. Analog Voltage

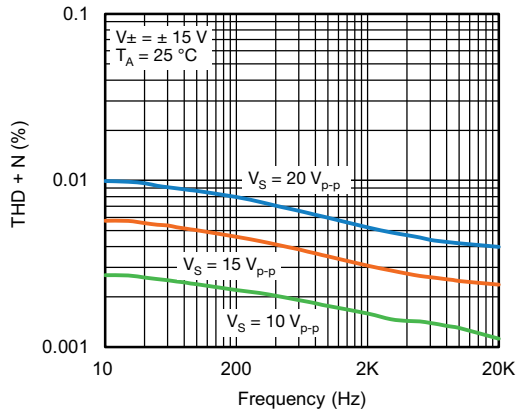


BW, OIRR, X<sub>TALK</sub> vs. Frequency

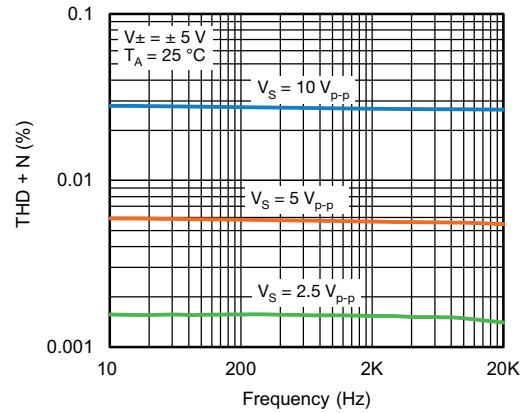




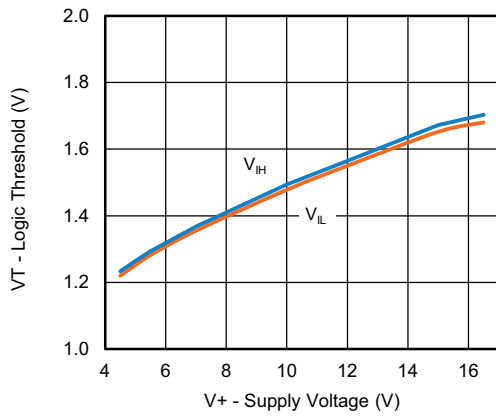
**TYPICAL CHARACTERISTICS** ( $T_A = 25\text{ }^\circ\text{C}$ , unless otherwise noted)



**THD + N vs. Frequency**

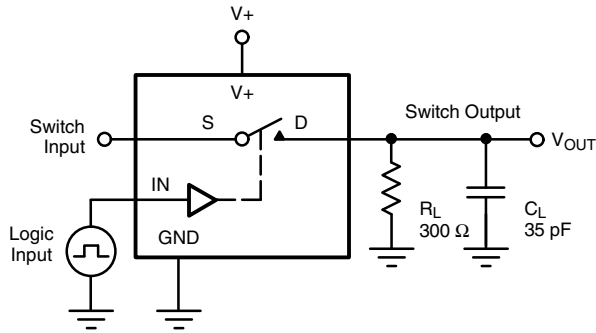


**THD + N vs. Frequency**



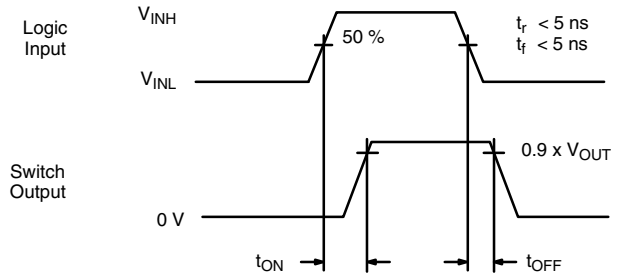
**Logic Threshold vs. Supply Voltage**

TEST CIRCUITS



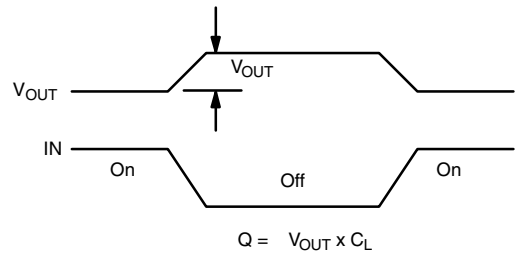
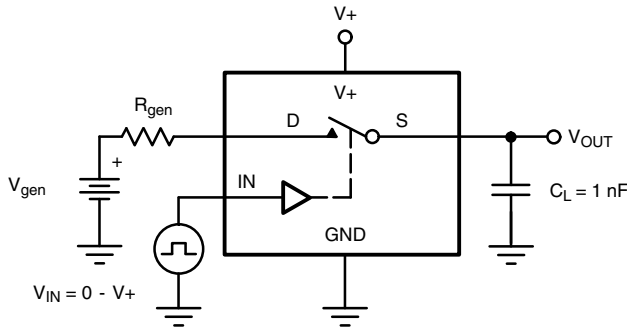
$C_L$  (includes fixture and stray capacitance)

$$V_{OUT} = V_D \left( \frac{R_L}{R_L + R_{ON}} \right)$$



Logic "1" = Switch On  
Logic input waveforms inverted for switches that have the opposite logic sense.

Fig. 1 - Switching Time



IN depends on switch configuration: input polarity determined by sense of switch.

Fig. 2 - Charge Injection

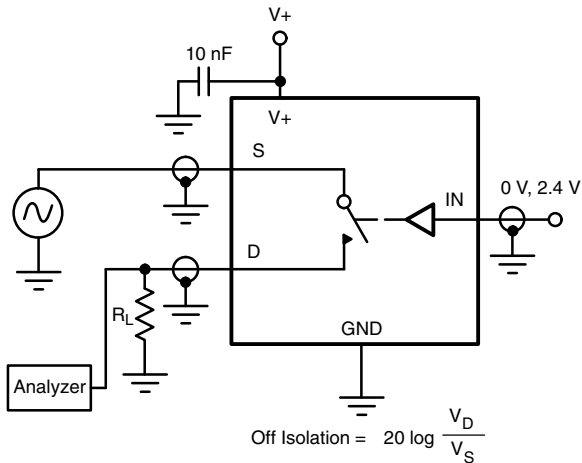


Fig. 3 - Off-Isolation

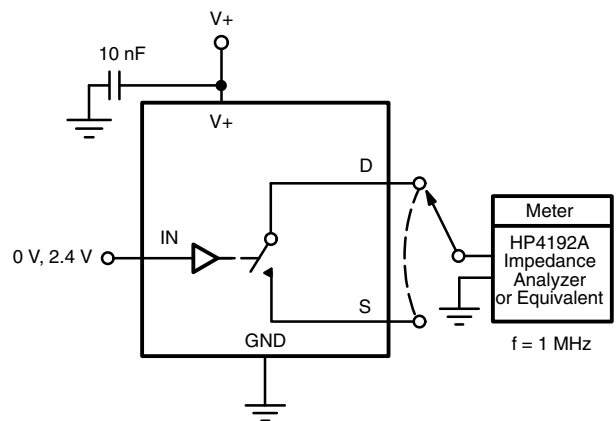
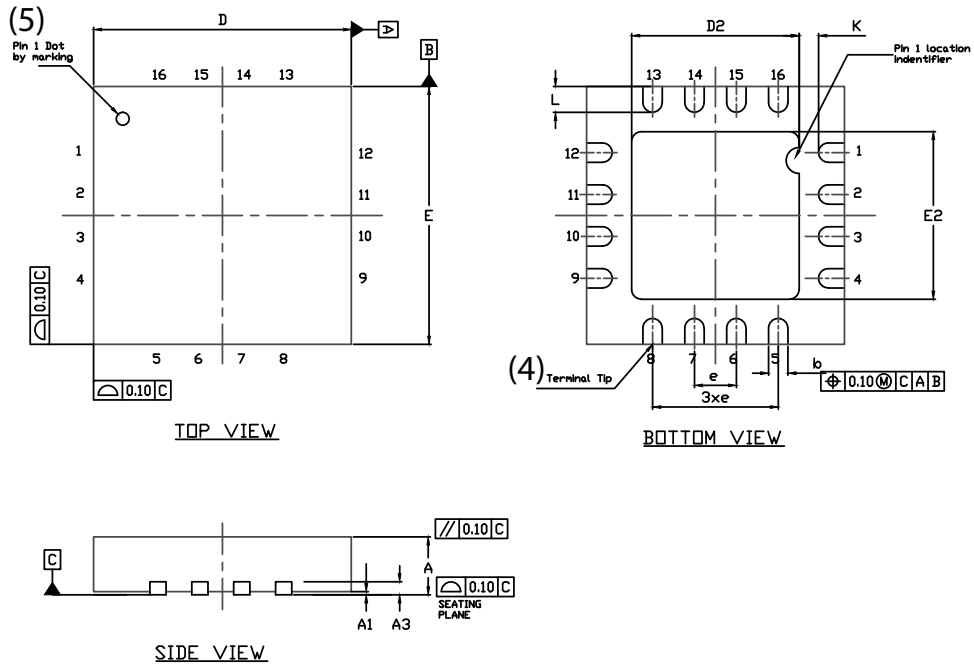


Fig. 4 - Channel Off/On Capacitance

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### QFN 4x4-16L Case Outline



DIM	VARIATION 1						VARIATION 2					
	MILLIMETERS <sup>(1)</sup>			INCHES			MILLIMETERS <sup>(1)</sup>			INCHES		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.75	0.85	0.95	0.029	0.033	0.037	0.75	0.85	0.95	0.029	0.033	0.037
A1	0	-	0.05	0	-	0.002	0	-	0.05	0	-	0.002
A3	0.20 ref.			0.008 ref.			0.20 ref.			0.008 ref.		
b	0.25	0.30	0.35	0.010	0.012	0.014	0.25	0.30	0.35	0.010	0.012	0.014
D	4.00 BSC			0.157 BSC			4.00 BSC			0.157 BSC		
D2	2.0	2.1	2.2	0.079	0.083	0.087	2.5	2.6	2.7	0.098	0.102	0.106
e	0.65 BSC			0.026 BSC			0.65 BSC			0.026 BSC		
E	4.00 BSC			0.157 BSC			4.00 BSC			0.157 BSC		
E2	2.0	2.1	2.2	0.079	0.083	0.087	2.5	2.6	2.7	0.098	0.102	0.106
K	0.20 min.			0.008 min.			0.20 min.			0.008 min.		
L	0.5	0.6	0.7	0.020	0.024	0.028	0.3	0.4	0.5	0.012	0.016	0.020
N <sup>(3)</sup>	16			16			16			16		
Nd <sup>(3)</sup>	4			4			4			4		
Ne <sup>(3)</sup>	4			4			4			4		

**Notes**

- (1) Use millimeters as the primary measurement.
- (2) Dimensioning and tolerances conform to ASME Y14.5M. - 1994.
- (3) N is the number of terminals. Nd and Ne is the number of terminals in each D and E site respectively.
- (4) Dimensions b applies to plated terminal and is measured between 0.15 mm and 0.30 mm from terminal tip.
- (5) The pin 1 identifier must be existed on the top surface of the package by using identification mark or other feature of package body.
- (6) Package warpage max. 0.05 mm.

ECN: S13-0893-Rev. B, 22-Apr-13  
 DWG: 5890

## TSSOP: 16-LEAD



Symbols	DIMENSIONS IN MILLIMETERS		
	Min	Nom	Max
A	-	1.10	1.20
A1	0.05	0.10	0.15
A2	-	1.00	1.05
B	0.22	0.28	0.38
C	-	0.127	-
D	4.90	5.00	5.10
E	6.10	6.40	6.70
E1	4.30	4.40	4.50
e	-	0.65	-
L	0.50	0.60	0.70
L1	0.90	1.00	1.10
y	-	-	0.10
theta1	0°	3°	6°

ECN: S-61920-Rev. D, 23-Oct-06  
DWG: 5624



**RECOMMENDED MINIMUM PAD FOR TSSOP-16**



Recommended Minimum Pads  
Dimensions in inches (mm)



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