DATA SHEET

SA7016

1.3GHz low voltage fractional-N synthesizer

Product specification
Supersedes data of 1999 Apr 20

1999 Nov 04

Philips
Semiconductors

GENERAL DESCRIPTION

The SA7016 BICMOS device integrates programmable dividers, charge pumps and a phase comparator to implement a phase-locked loop. The device is designed to operate from 3 NiCd cells, in pocket phones, with low current and nominal 3 V supplies.

The synthesizer operates at VCO input frequencies up to 1.3 GHz. The synthesizer has fully programmable main and reference dividers. All divider ratios are supplied via a 3-wire serial programming bus.

Separate power and ground pins are provided to the analog and digital circuits. The ground leads should be externally short-circuited to prevent large currents flowing across the die and thus causing damage. V_{DDCP} must be greater than or equal to V_{DD}.

The charge pump current (gain) is set by an external resistance at the R_{SET} pin. Only passive loop filters could be used; the charge pump operates within a wide voltage compliance range to provide a wider tuning range.

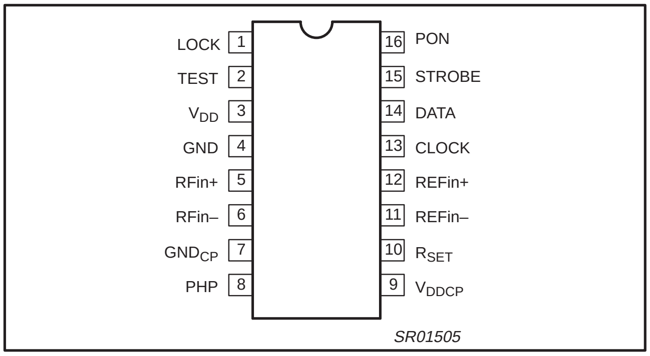


Figure 1. Pin Configuration

FEATURES

- Low phase noise
- Low power
- Fully programmable main divider
- Internal fractional spurious compensation
- Hardware and software power down
- Split supply for V_{DD} and V_{DDCP}

APPLICATIONS

- 350–1300 MHz wireless equipment
- Cellular phones
- Portable battery-powered radio equipment.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
V_{DD}	Supply voltage		2.7	–	5.5	V
V_{DDCP}	Analog supply voltage	$V_{DDCP} \geq V_{DD}$	2.7	–	5.5	V
$I_{DDCP}+I_{DD}$	Total supply current		–	6.2	7.3	mA
$I_{DDCP}+I_{DD}$	Total supply current in power-down mode		–	1	–	µA
f_{VCO}	Input frequency		350	–	1300	MHz
f_{REF}	Crystal reference input frequency		5	–	40	MHz
f_{PC}	Maximum phase comparator frequency		–		4	MHz
T_{amb}	Operating ambient temperature		–40	–	+85	°C

ORDERING INFORMATION

TYPE NUMBER	PACKAGE		
	NAME	DESCRIPTION	VERSION
SA7016DH	TSSOP16	Plastic thin shrink small outline package; 16 leads; body width 4.4 mm	SOT403–1

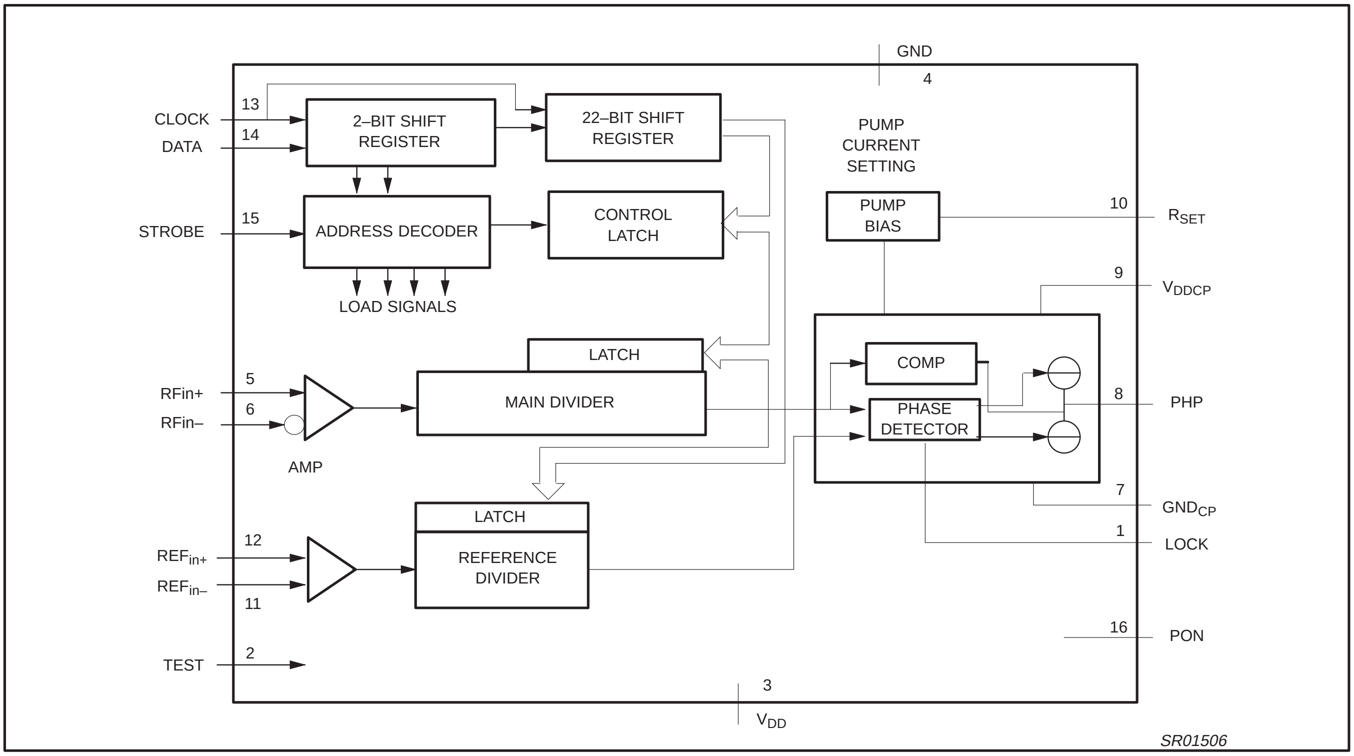


Figure 2. Block Diagram

PINNING

SYMBOL	PIN	DESCRIPTION
LOCK	1	Lock detect output
TEST	2	Test (should be either grounded or connected to V_{DD})
V_{DD}	3	Digital supply
GND	4	Digital ground
RFin+	5	RF input to main divider
RFin–	6	RF input to main divider
GND_{CP}	7	Charge pump ground
PHP	8	Main normal chargepump
V_{DDCP}	9	Charge pump supply voltage
R_{SET}	10	External resistor from this pin to ground sets the chargepump current
REFin–	11	Reference input
REFin+	12	Reference input
CLOCK	13	Programming bus clock input
DATA	14	Programming bus data input
STROBE	15	Programming bus enable input
PON	16	Power down control

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	MIN.	MAX.	UNIT
V_{DD}	Digital supply voltage	–0.3	+5.5	V
V_{DDCP}	Analog supply voltage	–0.3	+5.5	V
$\Delta V_{DDCP}–V_{DD}$	Difference in voltage between $V_{DDCP\ and}$ V_{DD} ($V_{DDCP} \geq V_{DD}$)	–0.3	+2.8	V
V_n	Voltage at pins 1, 2, 5, 6, 11 to 16	–0.3	V_{DD} + 0.3	V
V_1	Voltage at pin 8, 9	–0.3	V_{DDCP}+ 0.3	V
ΔV_{GND}	Difference in voltage between GND_{CP} and GND (these pins should be connected together)	–0.3	+0.3	V
T_{stg}	Storage temperature	–55	+125	°C
T_{amb}	Operating ambient temperature	–40	+85	°C
T_j	Maximum junction temperature		150	°C

Handling

Inputs and outputs are protected against electrostatic discharge in normal handling. However, to be totally safe, it is desirable to take normal precautions appropriate to handling MOS devices.

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	VALUE	UNIT
$R_{th\ j–a}$	Thermal resistance from junction to ambient in free air	120	K/W

CHARACTERISTICS

V_{DDCP} = V_{DD} = +3.0V, T_{amb} = +25°C; unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
Supply; pins 3, 9						
V_{DD}	Digital supply voltage		2.7	–	5.5	V
V_{DDCP}	Analog supply voltage	V_{DDCP} = V_{DD}	2.7	–	5.5	V
$I_{DDTotal}$	Synthesizer operational total supply current	V_{DD} = +3.0V	–	6.2	7.3	mA
$I_{Standby}$	Total supply current in power-down mode	logic levels 0 or VDD	–	1	TBD	µA
RFin main divider input; pins 5, 6						
f_{VCO}	VCO input frequency		350	–	1300	MHz
$V_{RFin(rms)}$	AC-coupled input signal level	R_{in} (external) = R_S = 50Ω; single-ended drive; max. limit is indicative @ 500 to 1300 MHz	–18	–	0	dBm
Z_{IRFin}	Input impedance (real part)	f_{VCO} = 1.2 GHz	–	625	–	Ω
C_{IRFin}	Typical pin input capacitance	f_{VCO} = 1.2 GHz	–	1.0	–	pF
N_{main}	Main divider ratio		512	–	65535	
f_{PCmax}	Maximum loop comparison frequency	indicative, not tested	–	–	4	MHz
Reference divider input; pins 11, 12						
f_{REFin}	Input frequency range from TCXO		5	–	40	MHz
VRFin	AC-coupled input signal level	single-ended drive; max. limit is indicative	360	–	1300	mV_{PP}
Z_{REFin}	Input impedance (real part)	f_{REF} = 20 MHz	–	10	–	kΩ
C_{REFin}	Typical pin input capacitance	f_{REF} = 20 MHz	–	1.0	–	pF
R_{REF}	Reference division ratio		4	–	1023	
Charge pump current setting resistor input; pin 10						
R_{SET}	External resistor from pin to ground		6	7.5	15	kΩ
V_{SET}	Regulated voltage at pin	R_{SET}=7.5 kΩ	–	1.25	–	V
Charge pump outputs (including fractional compensation pump); pin 8; R_{SET} =7.5kΩ, FC=80						
I_{CP}	Charge pump current ratio to I_{SET}[1]	Current gain I_{PH}/I_{SET}	–15		+15	%
I_{MATCH}	Sink-to-source current matching	V_{PH}=1/2 V_{DDCP}.	–10		+10	%
I_{ZOUT}	Output current variation versus V_{PH}[2]	V_{PH} in compliance range	–10		+10	%
I_{LPH}	Charge pump off leakage current	V_{PH}=1/2 V_{CC}	–10		+10	nA
V_{PH}	Charge pump voltage compliance		0.7	–	V_{DDCP}–0.8	V

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
Phase noise (R_{SET} = 7.5 kΩ, CP=00)						
$\mathcal{L}_{(f)}$	Synthesizer's contribution to close-in phase noise of 900 MHz RF signal at 1 kHz offset.	GSM f_{REF} = 13MHz, TCXO, f_{COMP} = 1MHz indicative, not tested	–	–90	–	dBc/Hz
	Synthesizer's contribution to close-in phase noise of 800 MHz RF signal at 1 kHz offset.	TDMA f_{REF} = 19.44MHz, TCXO, f_{COMP} = 240kHz indicative, not tested	–	–85	–	dBc/Hz
Interface logic input signal levels; pins 13, 14, 15, 16						
V_{IH}	HIGH level input voltage		$0.7{*}V_{DD}$	–	V_{DD}+0.3	V
V_{IL}	LOW level input voltage		–0.3	–	$0.3{*}V_{DD}$	V
I_{LEAK}	Input leakage current	logic 1 or logic 0	–0.5	–	+0.5	μA
Lock detect output signal (in push/pull mode); pin 1						
V_{OL}	LOW level output voltage	I_{sink}=2mA	–	–	0.4	V
V_{OH}	HIGH level output voltage	I_{source}=–2mA	V_{DD}–0.4	–	–	V

NOTES:

1. $I_{SET} = \frac{V_{SET}}{R_{SET}}$ bias current for charge pumps.
2. The relative output current variation is defined as:

$$\frac{\Delta I_{OUT}}{I_{OUT}} = 2\cdot\frac{(I_2 - I_1)}{|(I_2 + I_1)|};\ \text{with } V_1 = 0.7V,\ V_2 = V_{DDCP} - 0.8V\ \text{(See Figure 3.)}$$

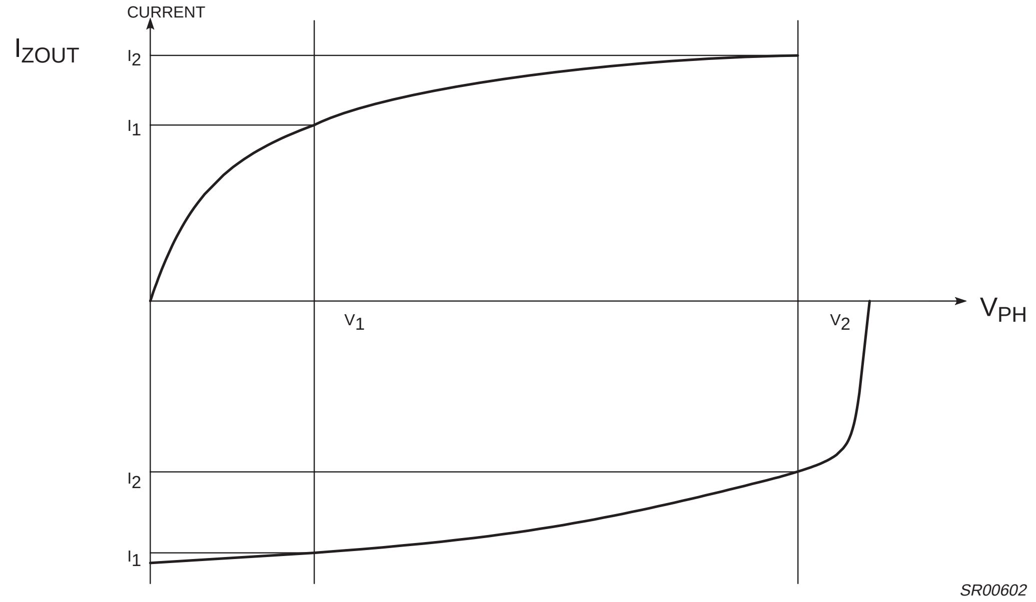


Figure 3. Relative Output Current Variation

FUNCTIONAL DESCRIPTION

Main Fractional-N divider

The RFin inputs drive a pre-amplifier to provide the clock to the first divider stage. For single ended operation, the signal should be fed to one of the inputs while the other one is AC grounded. The pre-amplifier has a high input impedance, dominated by pin and pad capacitance. The circuit operates with signal levels from –18 dBm to 0 dBm, and at frequencies as high as 1.3 GHz. The divider consists of a fully programmable bipolar prescaler followed by a CMOS counter. Total divide ratios range from 512 to 65536.

At the completion of a main divider cycle, a main divider output pulse is generated which will drive the main phase comparator. Also, the fractional accumulator is incremented by the value of NF. The accumulator works with modulo Q set by FMOD. When the accumulator overflows, the overall division ratio N will be increased by 1 to N + 1, the average division ratio over Q main divider cycles (either 5 or 8) will be

$$\mathrm{Nfrac} = \mathrm{N} + \frac{\mathrm{NF}}{\mathrm{Q}}$$

The output of the main divider will be modulated with a fractional phase ripple. The phase ripple is proportional to the contents of the fractional accumulator and is nulled by the fractional compensation charge pump.

The reloading of a new main divider ratio is synchronized to the state of the main divider to avoid introducing a phase disturbance.

Reference divider

The reference divider consists of a divider with programmable values between 4 and 1023 followed by a three bit binary counter. The 3 bit SM (SA) register (see Figure 4) determines which of the 5 output pulses are selected as the main (auxiliary) phase detector input.

Phase detector (see Figure 5)

The reference and main (aux) divider outputs are connected to a phase/frequency detector that controls the charge pump. The pump current is set by an external resistor in conjunction with control bits CP0 and CP1 in the C-word (see Charge Pump table). The dead zone (caused by finite time taken to switch the current sources on or off) is cancelled by forcing the pumps ON for a minimum time at every cycle (backlash time) providing improved linearity.

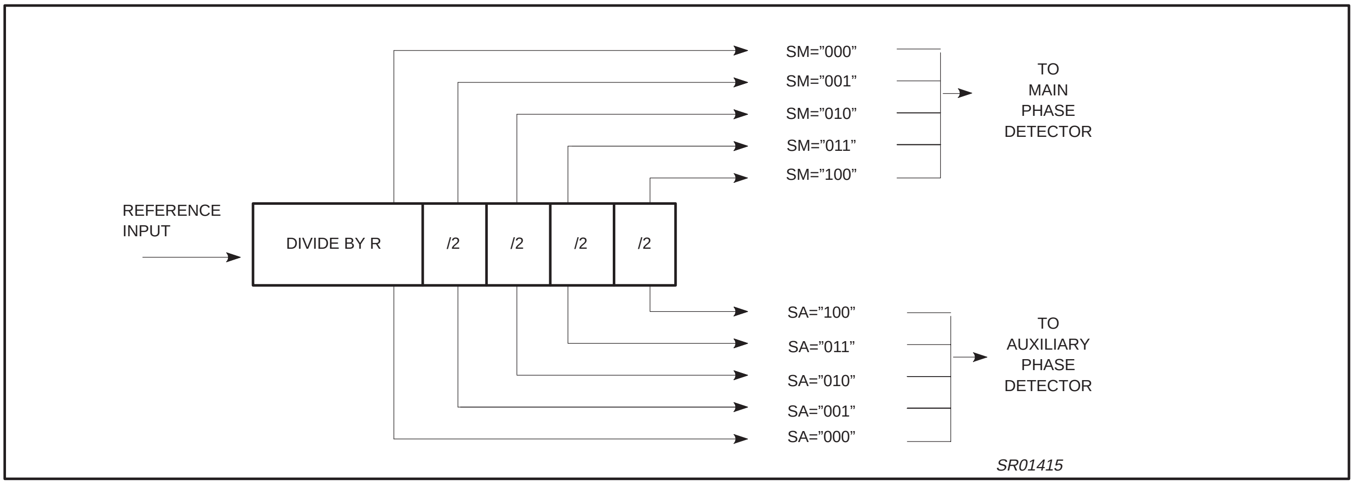


Figure 4. Reference Divider

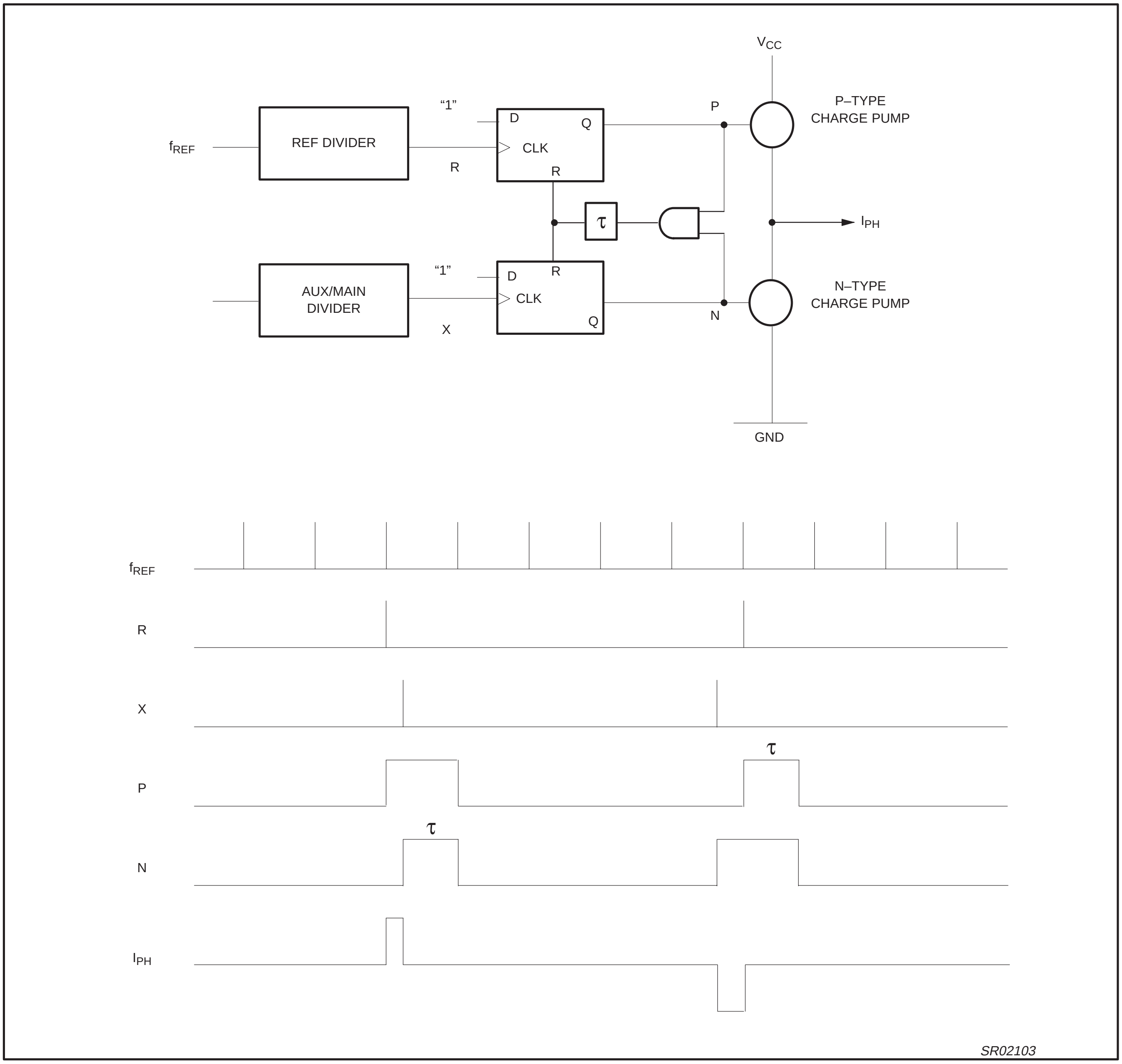


Figure 5. Phase Detector Structure with Timing

Main Output Charge Pumps and Fractional Compensation Currents (see Figure 6)

The main charge pumps on pins PHP and PHI are driven by the main phase detector and the charge pump current values are determined by the current at pin R_{SET} in conjunction with bits CP0, CP1 in the B-word (see table of charge pump ratios). The fractional compensation is derived from the current at R_{SET}, the contents of the fractional accumulator FRD and by the program value of the FDAC. The timing for the fractional compensation is derived from the main divider. The main charge pumps will enter speed up mode after the A-word is set and strobe goes High. When strobe goes Low, charge pump will exit speed up mode.

Principle of Fractional Compensation

The fractional compensation is designed into the circuit as a means of reducing or eliminating fractional spurs that are caused by the fractional phase ripple of the main divider. If I_{COMP} is the compensation current and I_{PUMP} is the pump current, then for each charge pump:

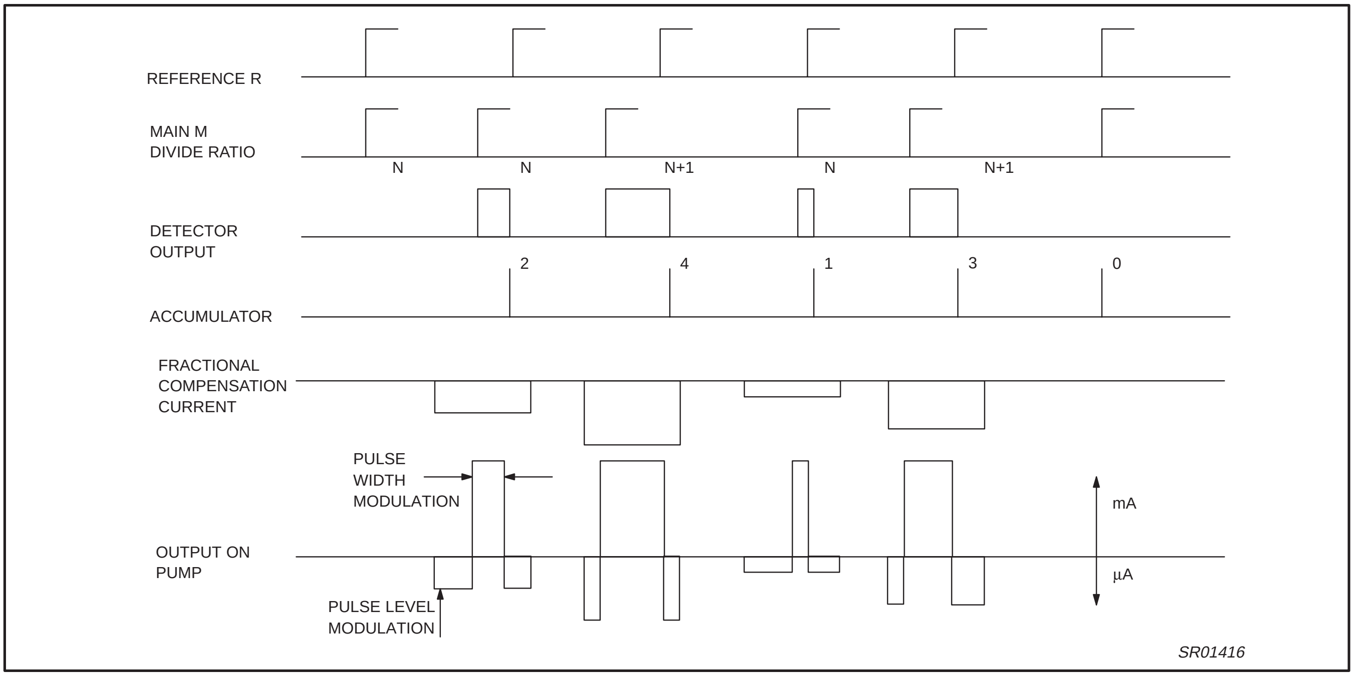
$$I_{PUMP\_TOTAL} = I_{PUMP} + I_{COMP}.$$

The compensation is done by sourcing a small current, I_{COMP}, see Figure 7, that is proportional to the fractional error phase. For proper fractional compensation, the area of the fractional compensation current pulse must be equal to the area of the fractional charge pump ripple. The width of the fractional compensation pulse is fixed to 128 VCO cycles, the amplitude is proportional to the fractional accumulator value and is adjusted by FDAC values (bits FC7–0 in the B-word). The fractional compensation current is derived from the main charge pump in that it follows all the current scaling through external resistor setting, R_{SET}, programming or speed-up operation. For a given charge pump,

$$I_{COMP} = (I_{PUMP} / 128) * (FDAC / 5*128) * FRD$$

FRD is the fractional accumulator value.

The target values for FDAC are: 128 for FMOD = 1 (modulo 5) and 80 for FMOD = 0 (modulo 8).



NOTE: For a proper fractional compensation, the area of the fractional compensation current pulse must be equal to the area of the charge pump ripple output.

Figure 6. Waveforms for NF = 2 Modulo 5 → fraction = $^{2}/_{5}$

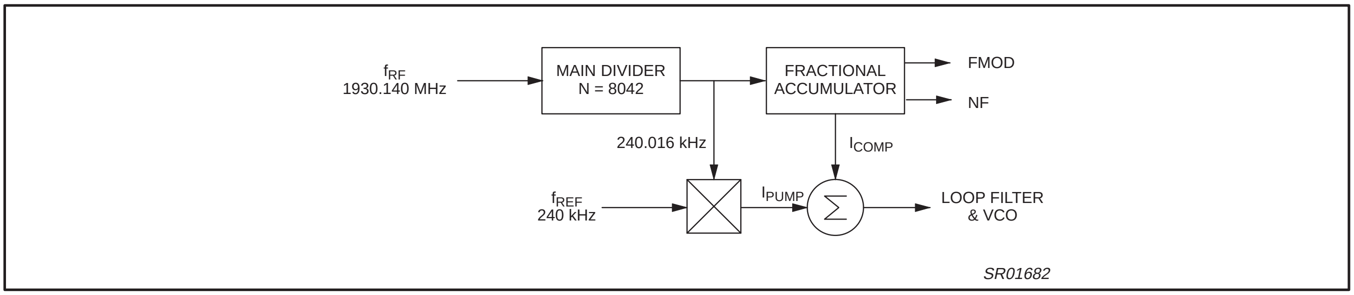


Figure 7. Current Injection Concept

Charge pump currents

CP0	I_{PHP}	I_{PHP-SU}
0	$3xI_{SET}$	$15xI_{SET}$
1	$1xI_{SET}$	$5xI_{SET}$

NOTES:

1. $I_{SET}=V_{SET}/R_{SET}$: bias current for charge pumps.
2. I_{PHP-SU} is the total current at pin PHP during speed up condition.

Lock Detect

The output LOCK maintains a logic ‘1’ when the auxiliary phase detector ANDed with the main phase detector indicates a lock condition. The lock condition for the main and auxiliary synthesizers is defined as a phase difference of less than ±1 period of the frequency at the input REFin+, –. One counter can fulfill the lock condition when the other counter is powered down. Out of lock (logic ‘0’) is indicated when both counters are powered down.

Power-down mode

The power-down signal can be either hardware (PON) or software (PD). The PON signal is exclusively ORed with the PD bits in B-word. If PON = 0, then the part is powered up when PD = 1. PON can be used to invert the polarity of the software bit PD. When the synthesizer is reactivated after power-down, the main and reference dividers are synchronized to avoid possibility of random phase errors on power-up.

Serial programming bus

The serial input is a 3-wire input (CLOCK, STROBE, DATA) to program all counter divide ratios, fractional compensation DAC, selection and enable bits. The programming data is structured into 24 bit words; each word includes 2 or 3 address bits. Figure 8 shows the timing diagram of the serial input. When the STROBE goes active HIGH, the clock is disabled and the data in the shift register remains unchanged. Depending on the address bits, the data is latched into different working registers or temporary registers. In order to fully program the synthesizer, 3 words must be sent: C, B, and A. Table 1 shows the format and the contents of each word. The D word is normally used for testing purposes. When sending the B-word, data bits FC7–0 for the fractional compensation DAC are not loaded immediately. Instead they are stored in temporary registers. Only when the A-word is loaded, these temporary registers are loaded together with the main divider ratio.

Serial bus timing characteristics. See Figure 8.

$V_{DD} = V_{DDCP} = +3.0V$; $T_{amb} = +25°C$ unless otherwise specified.

SYMBOL	PARAMETER	MIN.	TYP.	MAX.	UNIT
Serial programming clock; CLK					
t_r	Input rise time	–	10	40	ns
t_f	Input fall time	–	10	40	ns
T_{cy}	Clock period	100	–	–	ns
Enable programming; STROBE					
t_{START}	Delay to rising clock edge	40	–	–	ns
t_W	Minimum inactive pulse width	$1/f_{COMP}$	–	–	ns
$t_{SU;\overline{E}}$	Enable set-up time to next clock edge	20	–	–	ns
Register serial input data; DATA					
$t_{SU;DAT}$	Input data to clock set-up time	20	–	–	ns
$t_{HD;DAT}$	Input data to clock hold time	20	–	–	ns

Application information

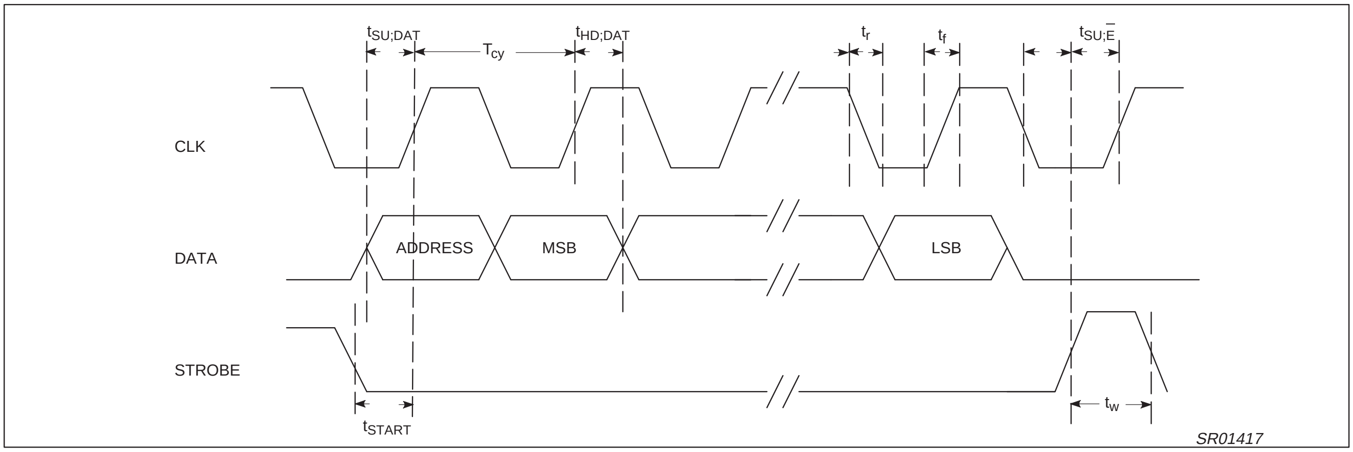


Figure 8. Serial Bus Timing Diagram

Data format

Table 1. Format of programmed data

LAST IN		MSB	SERIAL PROGRAMMING FORMAT				FIRST IN LSB
p23	p22	p21	p20	../..	../..	p1	p0

Table 2. A word, length 24 bits

LAST IN						**MSB**															**LSB**	**FIRST IN**	
Address		fmod	Fractional-N			Main Divider ratio																Spare	
0	**0**	**FM**	**NF2**	**NF1**	**NF0**	**N15**	**N14**	**N13**	**N12**	**N11**	**N10**	**N9**	**N8**	**N7**	**N6**	**N5**	**N4**	**N3**	**N2**	**N1**	**N0**	**SP1**	**SP2**
Default:		0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0

A word select	Fixed to 00.
Fractional Modulus select	FM 0 = modulo 8, 1 = modulo 5.
Fractional-N Increment	NF2..0 Fractional N Increment values 000 to 111.
N-Divider	N0..N15, Main divider values 512 to 65535 allowed for divider ratio.

Table 3. B word, length 24 bits

Address		**REFERENCE DIVIDER**										**LOCK**	**PD**	**CP**	**FRACTIONAL COMPENSATION DAC**								**SPARE**
0	**1**	**R9**	**R8**	**R7**	**R6**	**R5**	**R4**	**R3**	**R2**	**R1**	**R0**	**LO**	**MAIN**	**CP0**	**FC7**	**FC6**	**FC5**	**FC4**	**FC3**	**FC2**	**FC1**	**FC0**	**SP3**
Default:		0	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0

B word select	Fixed to 01
R-Divider	R0..R9, Reference divider values 4 to 1023 allowed for divider ration.
Charge pump current Ratio	CP0: Charge pump current ratio, see table of charge pump currents.
Lock detect output	L0 0 Main lock detect signal present at the LOCK pin (push/pull). 1 Main lock detect signal present at the LOCK pin (open drain). When main loop is in power down mode, the lock indicator is low.
Power down	Main = 1: power to main divider, reference divider, main charge pumps, Main = 0 to power down.
Fractional Compensation	FC7..0 Fractional Compensation charge pump current DAC, values 0 to 255.

Table 4. D word, length 24 bits

Address			**SYNTHESIZER TEST BITS**						**SYNTHESIZER TEST BITS**														
1	1	0	–	–	–	–	–	Tspu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Default:			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Tspu: Speed up = 1	Forces the main charge pumps in speed-up mode all the time. **NOTE**: All test bits must be set to 0 for normal operation.

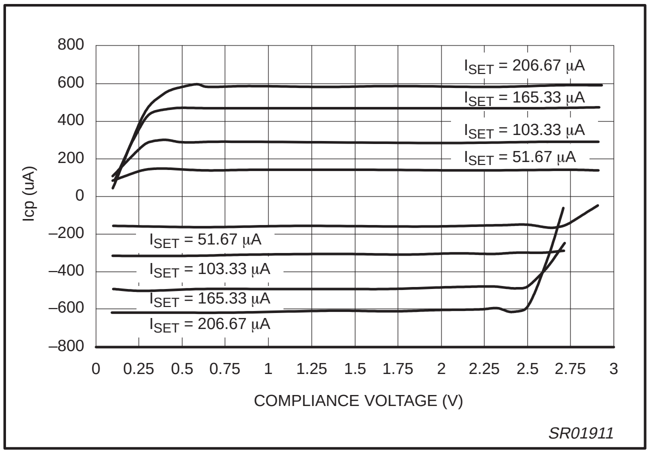


Figure 9. Php Charge Pump Output vs. I_{SET} (CP = 0, TEMP = 25°C)

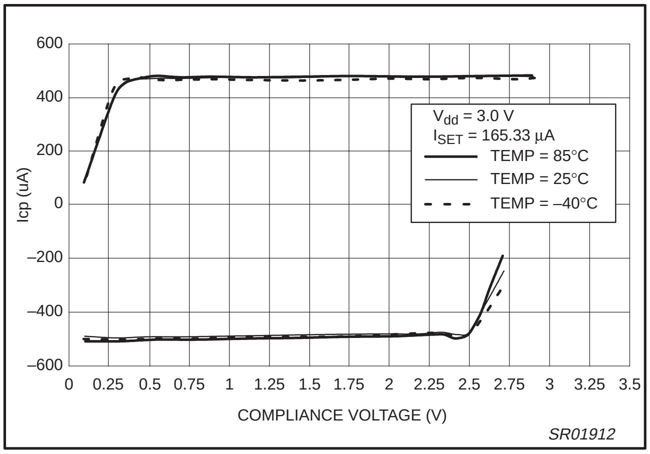


Figure 10. Php Charge Pump Output vs. Temperature (CP = 0; V_{DD} = 3.0 V; I_{SET} = 165.33 µA)

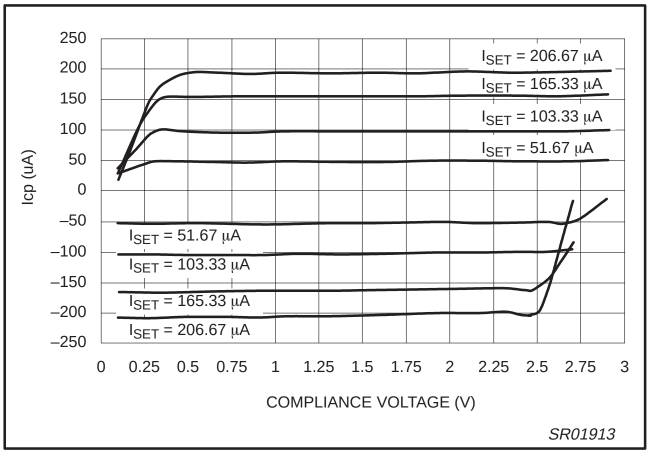


Figure 11. Php Charge Pump Output vs. I_{SET} (CP = 1; TEMP = 25°C)

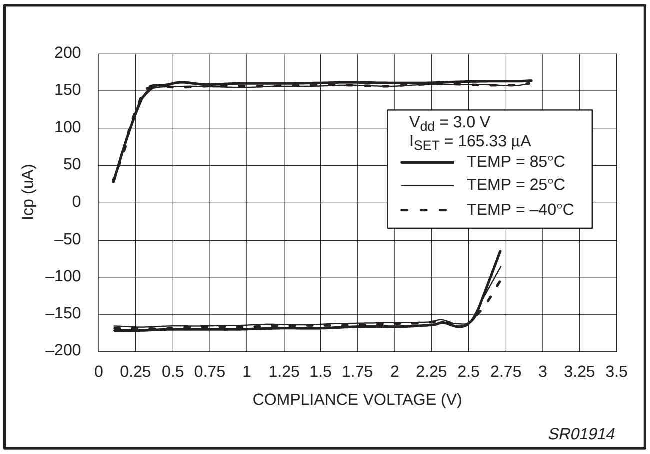


Figure 12. Php Charge Pump Output vs. Temperature (CP = 1; V_{DD} = 3.0 V; I_{SET} = 165.33 µA)

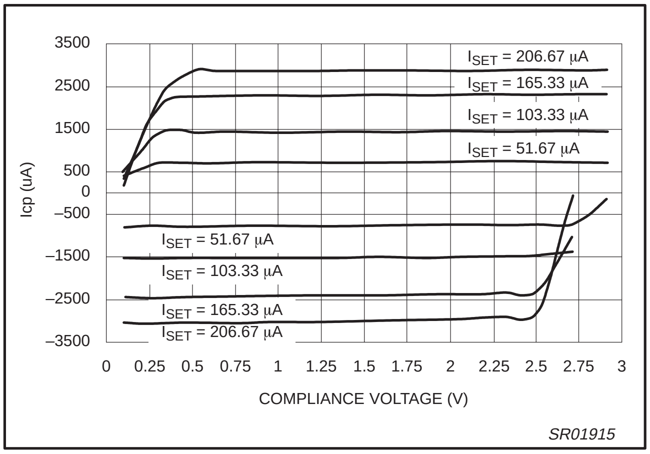


Figure 13. Php–su Charge Pump Output vs. I_{SET} (CP = 0; TEMP = 25°C)

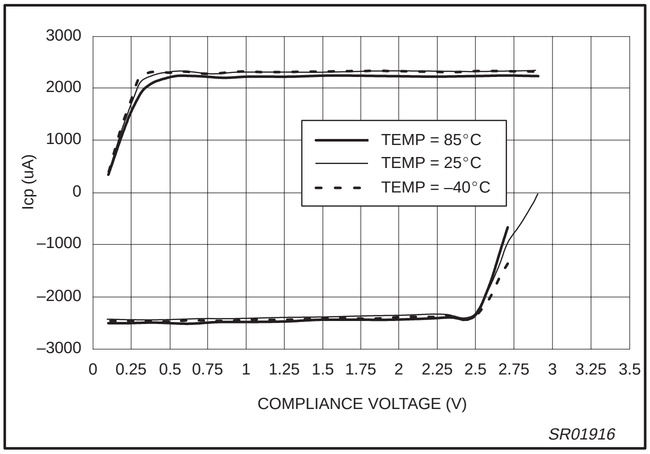


Figure 14. Php–su Charge Pump Output vs. Temperature (CP = 0; V_{DD} = 3.0 V; I_{SET} = 165.33 µA)

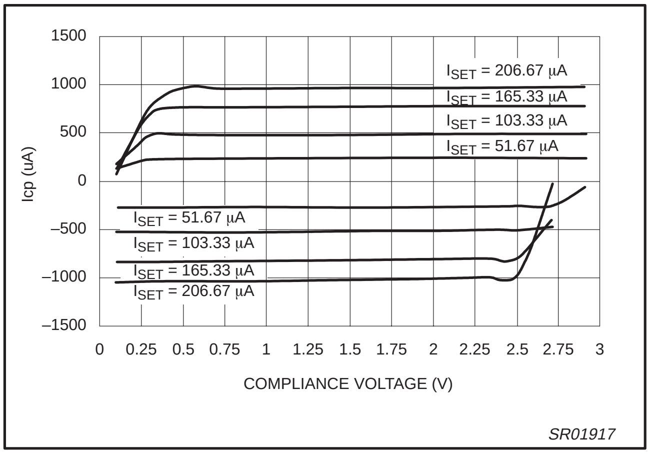


Figure 15. Php–su Charge Pump Output vs. I_{SET} (CP = 1; TEMP = 25°C)

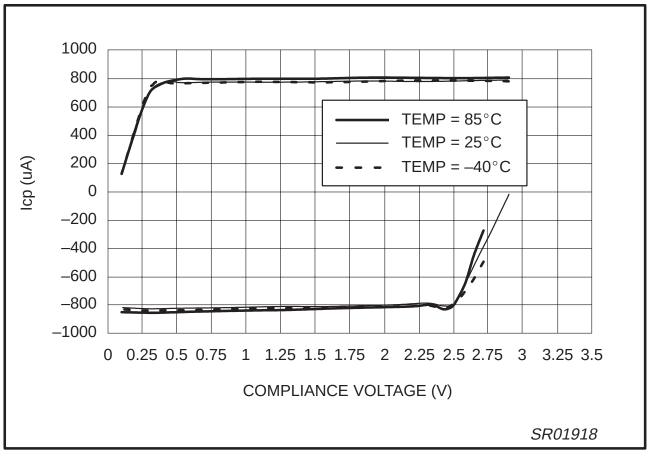


Figure 16. Php–su Charge Pump Output vs. Temperature (CP = 1; V_{DD} = 3.0 V; I_{SET} = 165.33 µA)

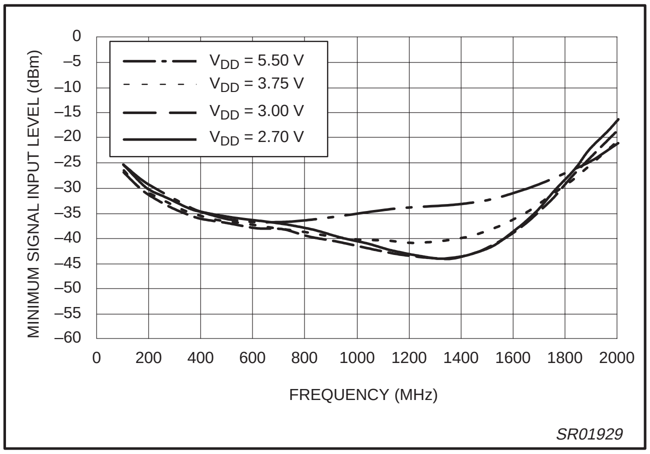


Figure 17. Main Divider Input Sensitivity vs. Frequency and Supply Voltage (TEMP = 25°C)

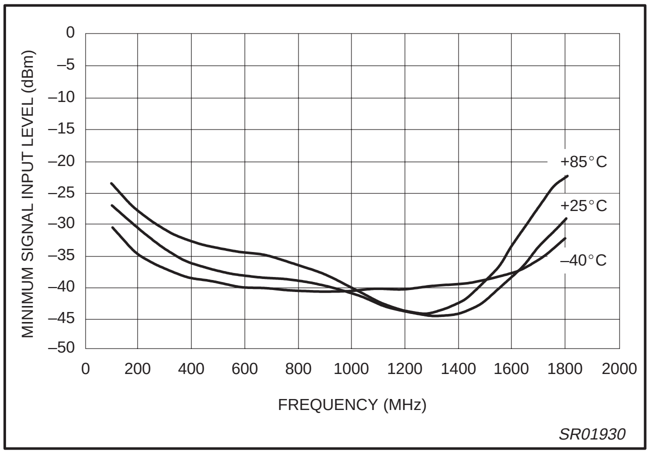


Figure 18. Main Divider Input Sensitivity vs. Frequency and Temperature (V_{DD} = 3.00 V)

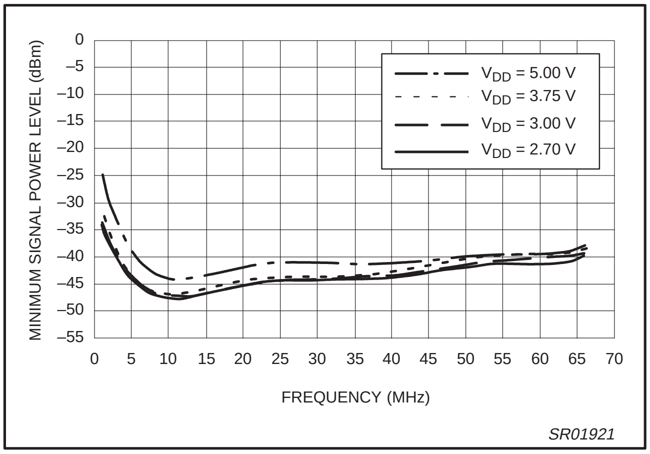


Figure 19. Reference Divider Input Sensitivity vs. Frequency and Supply Voltage (TEMP = 25°C)

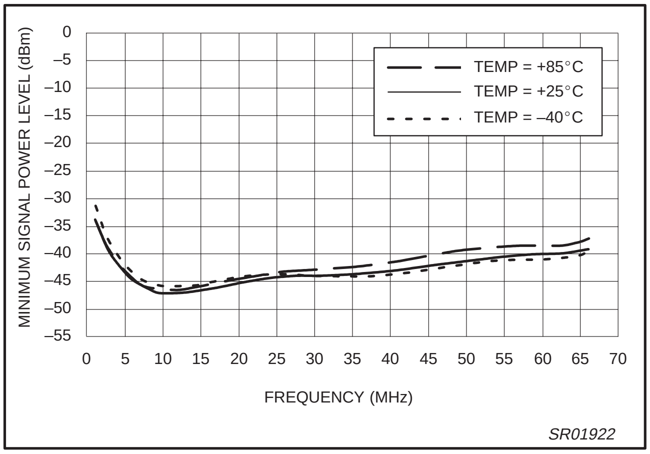


Figure 20. Reference Divider Input Sensitivity vs. Frequency and Temperature (V_{DD} = 3.00 V)

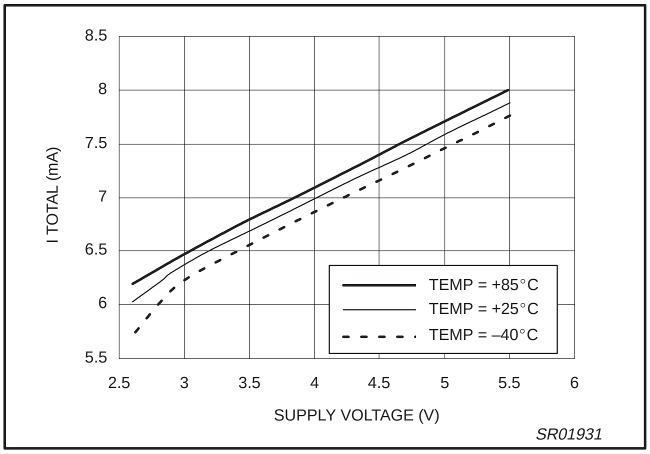
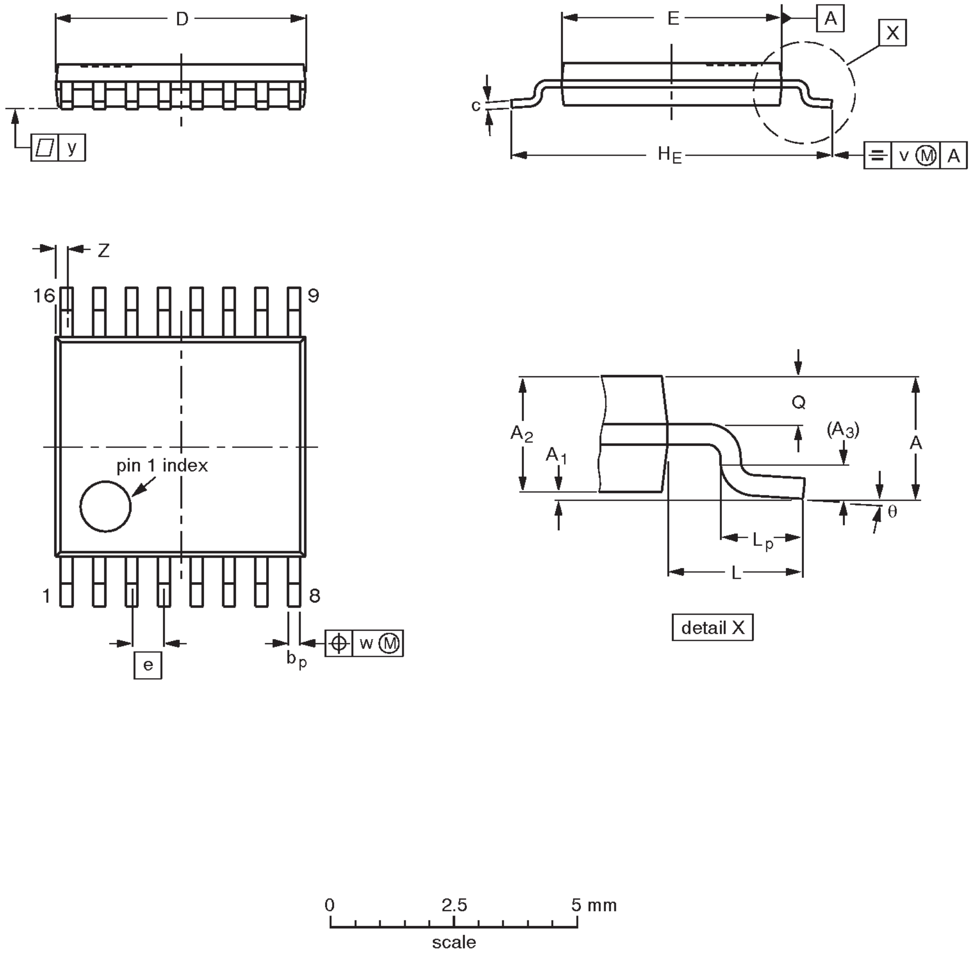


Figure 21. Current Supply Over V_{DD}

TSSOP16: plastic thin shrink small outline package; 16 leads; body width 4.4 mm SOT403-1



DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	$D^{(1)}$	$E^{(2)}$	e	H_E	L	L_p	Q	v	w	y	$Z^{(1)}$	θ
mm	1.10	0.15 0.05	0.95 0.80	0.25	0.30 0.19	0.2 0.1	5.1 4.9	4.5 4.3	0.65	6.6 6.2	1.0	0.75 0.50	0.4 0.3	0.2	0.13	0.1	0.40 0.06	8° 0°

Notes

1. Plastic or metal protrusions of 0.15 mm maximum per side are not included.
2. Plastic interlead protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT403-1		MO-153				~~94-07-12~~ 95-04-04

NOTES

Data sheet status

Data sheet status	Product status	Definition [1]
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[1] Please consult the most recently issued datasheet before initiating or completing a design.

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Date of release: 11-99

Document order number: 9397 750 06565

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