

DOKUMENTATION- SUNSCREENPI

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ANNA HOEHNKE (MT), ANJA BRAUN (MT), HANNES HERDA (MT) UND BRITTA WALTER (MS)

Inhaltsverzeichnis

1 Einleitung	2
2 Projektbeschreibung	2
2.1 Ziel des Projekts	2
3 Technische Umsetzung der Hardware – Raspberry Pi	3
4 Technische Umsetzung der Software	5
5 Fazit	8
6 Literaturverzeichnis	10
7 Anhang	10

1 Einleitung

Im Rahmen der Vorlesungen Mobile Systeme der Media Systems-Studenten und IT-Systeme der Medientechnik-Studenten entstand ein interaktives Projekt namens „Internet of Things“, welches an der diesjährigen Jahresausstellung der HAW Hamburg präsentiert wurde.

Einzelne Gruppen kreierten jeweils eine Internet of Things-Anwendung mit einem Raspberry Pi und einer dazugehörigen App, die zum Ausprobieren für die Besucher ausgestellt wurden. Um das Ausprobieren möglichst einfach zu gestalten, wurde ein Server (mobile.mt.haw-hamburg.de) zur Verfügung gestellt.

2 Projektbeschreibung

Unser Projekt SunScreenPi bietet den Usern sicheren Schutz vor Sonnenbränden. Mit dem Nutzen unserer SunScreenPi-App kann man sich mit dem aktuellen UV-Index, seinem angegebenen Hauttypen und dem gewählten Lichtschutzfaktor die Zeit berechnen lassen, die man ohne einen Sonnenbrand zu bekommen in der Sonne verbringen kann.

2.1 Ziel des Projekts

Das Ziel unseres Projektes ist es, etwas Nützliches für uns und unsere Mitmenschen zu entwickeln.

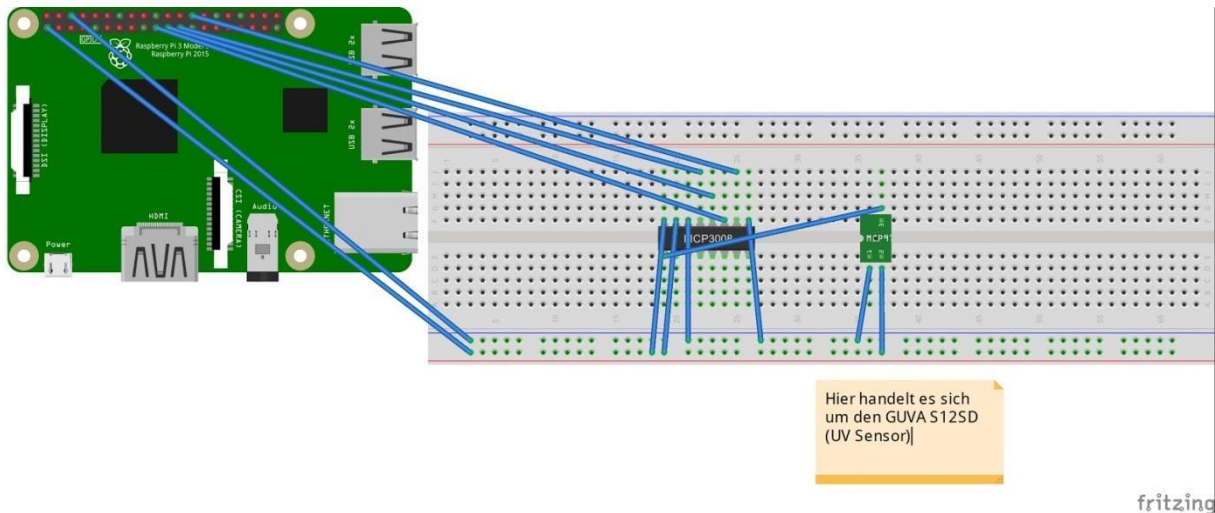
Hier der Soll-Zustand des Projektes, wie wir es in unserem anfänglichen Konzept festlegten:

- Ein UV-Sensor auf einem Sonnenschirm montiert, der den aktuellen UV-Index misst und alle paar Minuten vom Raspberry Pi ausgelesen wird
- Der Raspberry Pi soll über eine Powerbank betrieben werden
- Personalisierte Empfehlungen für das Sonnenbaden (Jeder bekommt seinen eigenen Timer auf der App)
- Der User kann seinen Hauttypen ermitteln (Test durchführen)
- Mitberücksichtigung eines Lichtschutzfaktors
- Die App soll für sechs verschiedene Hauttypen ausgelegt sein

3 Technische Umsetzung der Hardware – Raspberry Pi

Geräteliste:

- Raspberry Pi 3
- UV-Sensor GUA S12SD
- AD-Wandler MCP3008
- Adafruit T-Coppler Plus für Raspberry Pi
- Steckplatine
- Potentiometer 1k
- Kabel



PDIP, SOIC

CH0	1	16	V _{DD}
CH1	2	15	V _{REF}
CH2	3	14	AGND
CH3	4	13	CLK
CH4	5	12	D _{OUT}
CH5	6	11	D _{IN}
CH6	7	10	CS/SHDN
CH7	8	9	DGND

Der UV – Sensor erfasst Licht mit Wellenlängen zwischen 240 und 370 nm und kann mit 2,7 Volt bis zu 5 Volt betrieben werden. Da der Raspberry Pi ca. 5,5 Volt geliefert hat, haben wir uns entschieden den Sensor mit 3,3 Volt zu versorgen. Der Sensor misst die UV – Strahlung mit einer Photodiode und gibt einen Spannungswert zwischen 0 und 1,1 Volt aus. Dieser Spannungswert kann in einen UV – Index umgerechnet werden, indem man den gelieferten Spannungswert durch 0,1 Volt dividiert:

$$UV - Index = \frac{\text{Spannungswert}}{0,1 V}$$

Da der Raspberry Pi keine analogen Signale verarbeiten kann, ist ein Analog – Digital – Wandler nötig, um das Signal zu digitalisieren und an den Raspberry Pi weiterzuleiten. Der Wandler wird ebenfalls mit einer Spannung von 3,3 Volt versorgt, sowie einer Referenzspannung die ebenfalls 3,3 Volt beträgt. Die Daten werden über das Serial Peripheral Interface – kurz SPI – des Raspberry Pi übertragen, wobei

der AD – Wandler hier als Master fungiert. Dazu muss im Programmcode spidev importiert werden, sowie eine Schnittstellenreferenz und die zu nutzende Schnittstelle definiert und geöffnet werden. Außerdem muss die Taktung bezogen auf die zu senden Bytes laut Datenblatt eingerichtet werden (Vgl. Raspberry Code, Zeile 14 - 21), sodass das digitale Signal korrekt gesendet und empfangen werden kann. Zum Schluss wird die Schnittstelle wieder geschlossen.

Der Raspberry Pi kann nun 10 Bit, also 1024 Werte von dem Wandler empfangen. Bei einer Referenzspannung von 3,3 Volt, entspricht ein Digitaler Wert:

$$\frac{3,3 \text{ Volt}}{1024} = 3.22265625 \text{ mV}$$

Um den digitalen Wert in einen Spannungswert umzurechnen, wird der empfangene Wert mit 3,22265625 multipliziert (Vgl. Raspberry Code, Zeile 22). Diese Spannung wird wie zu Anfang beschrieben in einen UV – Index umgerechnet (Vgl. Raspberry Code, Zeile 23).

Damit verschiedene Nutzer zu jeder Zeit das Programm nutzen können, müssen die UV – Werte in einer Liste gespeichert werden. Für ein möglichst genaues Abbild der Strahlungssituation, haben wir uns für ein Intervall von 6 Sekunden für die Datenspeicherung entschieden. Um die Datenmenge zu begrenzen, wird diese Liste nur für den laufenden Tag gespeichert und dann wieder gelöscht (Vgl. Raspberry Code, Zeile 29 - 31). Damit zwei verschiedene Nutzer zeitlich unabhängig auf die Daten zugreifen können, müssen die UV – Werte mit einem timestamp versehen werden, weswegen die Liste als Dictionary angelegt ist. Soll nun die verbleibende Sonnenzeit ermittelt werden, kann die App für jeden Nutzer mittels des timestamps individuell auf die Daten zugreifen und nur die Daten verarbeiten die für den jeweiligen Nutzer relevant sind. Die Liste l wird über das SocketIO an den Server gesendet, wozu zuvor die IP-Adresse des Ziels sowie der Port angegeben wurde (Vgl. Raspberry Code, Zeile 27 und 10 - 11).

4 Technische Umsetzung der Software

Um der Anforderung des Kurses gerecht zu werden, mussten die Projekte mittels Websockets mit dem zur Verfügung gestellten Server kommunizieren.

Es musste also eine Web App her, die zwar aussieht wie eine native App, in Wirklichkeit aber eine einfache Website ist. Daher programmierten wir diese in den Sprachen HTML, CSS und JavaScript.

HTML für die Struktur der Website, CSS für das Aussehen und JavaScript für die Funktionalität.

Die App lässt sich also wie jede andere Website auch über den Browser auf mobilen Geräten wie auch auf PCs aufrufen. Da sie jedoch aussehen soll, wie eine „richtige“ App, ist sie für die kleineren Bildschirme von mobilen Geräten optimiert. Dies spiegelt sich unter anderem darin wider, dass die fünf farbigen Sektionen untereinander angeordnet sind. So passen sie besser auf die Hochkant Bildschirme von Smartphones (siehe Abbildung 2).

Das Prinzip:

Der UV – Sensor am Raspberry Pi ermittelt alle 6 Sekunden den UV-Index. Der Raspberry Pi sammelt die UV-Werte in einem Dictionary und sendet diesen mittels Websocket an den Server. Die Web -App empfängt den Dictionary und kann nun damit rechnen.

Prinzipiell steht eine Formel im Mittelpunkt der ganzen App. Vorher vereinbaren wir folgende Abkürzungen:

ht = Eigenschutzzeit der verschiedenen Hauttypen in Minuten (z.B. Hauttyp 1 mit 7 Minuten Eigenschutzzeit)

uvi = UV - Index

Isf = Lichtschuttfaktor in Minuten

Die Zeit in Minuten, die man sich in der Sonne aufhalten kann, ohne einen Sonnenbrand zu bekommen, ergibt sich aus:

$$(ht * 8) / (uvi) * Isf$$

Zum Nachvollziehen:

Benutzer A sei Hauttyp 1 mit 7 Minuten Eigenschutzzeit. Er hat sich mit Lichtschuttfaktor 20 eingecremt und es sei ein aktueller UV-Index von 5. Dann ergibt sich eine

gefährlose Zeit in der Sonne von : $(7 * 8) / 5 * 20 = 224$ Minuten oder ~ 3,7 Stunden

Da wir aber einen Countdown benutzen, der auch Sekunden anzeigen soll, hängen wir im Script den Faktor 60 an (siehe calculate2.js Zeile 133, 149).

Da nun aber nicht unbedingt jeder Benutzer weiß, welcher Hauttyp er ist, gibt es die Möglichkeit, sich zuerst einmal Informationen über die Hauttypen zu beschaffen. Dies kann der Benutzer über die Schaltfläche „Info“ rechts neben der Hauttypen Auswahl machen (siehe Abbildung 2). Hier gibt es zu jedem Hauttypen einen Bereich, in dem die größten Merkmale als Stichpunkte zusammengefasst aufgelistet sind, sowie jeweils ein Bild des Typs. Die Bilder zeigen Emojis in verschiedenen Haut- und Haarfarben, um möglichst alle Benutzer durch die Einfachheit anzusprechen. Zu den aufgelisteten Merkmalen gehören die Hautfarbe, die Haarfarbe, die Augenfarbe, Hautmerkmale wie Sommersprossen, die Reaktion der Haut auf Sonne und die ungefähre Eigenschutzzeit des jeweiligen Hauttyps.

Falls man sich durch diese Information immer noch nicht sicher ist, welcher Hauttyp man ist, kann der Benutzer noch einen Test machen.

Der User muss dazu die Schaltfläche „Test“ anklicken (siehe Abbildung 2). Er muss hier 10 Fragen beantworten. Die Antworten sind intern je mit Punkten versehen. Die erste Auswahlmöglichkeit entspricht dabei immer Punktzahl 1, die zweite Punktzahl 2 und so weiter. Anschließend werden dann alle Punkte addiert und durch 10 geteilt, sodass die Durchschnittspunktzahl ermittelt werden kann. Diese entspricht dem ungefähren Hauttyp des Benutzers. Bei einer Kommazahl, wird mathematisch auf oder abgerundet. Dem Benutzer wird aber trotzdem die tatsächliche Zahl angezeigt, damit er sich selbst dafür entscheiden kann, welcher Hauttyp eher zu ihm passt, falls er zwischen zweien liegt.

Wenn der Benutzer sich seines Hauttyps sicher ist, wählt er diesen auf der Hauptseite aus und kann sich nun dem Lichtschuttfaktor widmen. Auch hier steht es ihm frei, sich zunächst noch ein paar Informationen über den Lichtschuttfaktor zu holen, indem er auf die Schaltfläche „Info“ klickt (siehe Abbildung 2).

Hier stehen ihm ein paar wissenswerte Fakten zum Lichtschuttfaktor zur Verfügung und wird darauf hingewiesen, dass es ratsam ist, niemals ohne Lichtschuttfaktor sonnenbaden zu gehen, da die Strahlung doch erheblichen Schaden anrichten kann.

Entweder cremt sich der Benutzer nun mit einem Mittel mit LSF ein oder er belässt es bei der ungeschützten Haut. Zurück auf der Hauptseite, muss er ebenfalls wählen, welchen LSF er benutzt (oder keinen).

In dieser ganzen Zeit bekommt die App stetig UV - Werte.

Drückt der User auf Zeit berechnen wird ihm seine individuelle Zeit im blauen Kästchen unter „Zeit berechnen“ angezeigt.

Hierbei wird ein Durchschnittswert aller UV-Werte gebildet, die seit dem Drücken des Buttons gemessen worden sind. So wird ein Verfälschen des Ergebnisses verhindert und für jeden Nutzer die Sonnenzeit individuell berechnet. Es sollen also für den ganzen Tag die Werte gespeichert werden und so jedem Nutzer zu jeder Zeit zugang zur App gesichert werden.

Außerdem wird zu diesem Zeitpunkt ein Counter gestartet, der die Sekunden speichert, die seit des Starts vergangen sind.

Unser größtes Ziel war es jedoch, die Zeit zu verändern, wenn der UV - Index sich ändert. Dies war mit einigen Schwierigkeiten verbunden, die wir letztendlich aber überwunden haben. Sobald der Durchschnittswert sich relevant (ab ca + 0.2 oder – 0.2) ändert, wird eine „aktualisieren-Funktion“ aufgerufen, die einen neuen Countdown setzt (siehe calculate2.js Zeile 140, code.js Zeile 32). Dieser nimmt die gleichen Eingaben des Benutzers (Hauttyp und LSF), subtrahiert davon aber die Zeit, die bereits abgelaufen war, seit der Benutzer auf „Zeit berechnen“ gedrückt hat (siehe oben: Counter, calculate2.js Zeile 151).

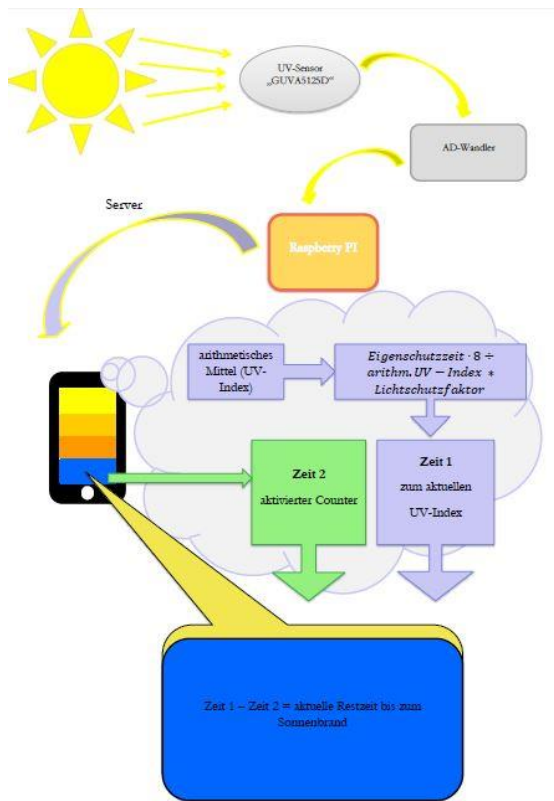


Abbildung 1: Blockschaltbild

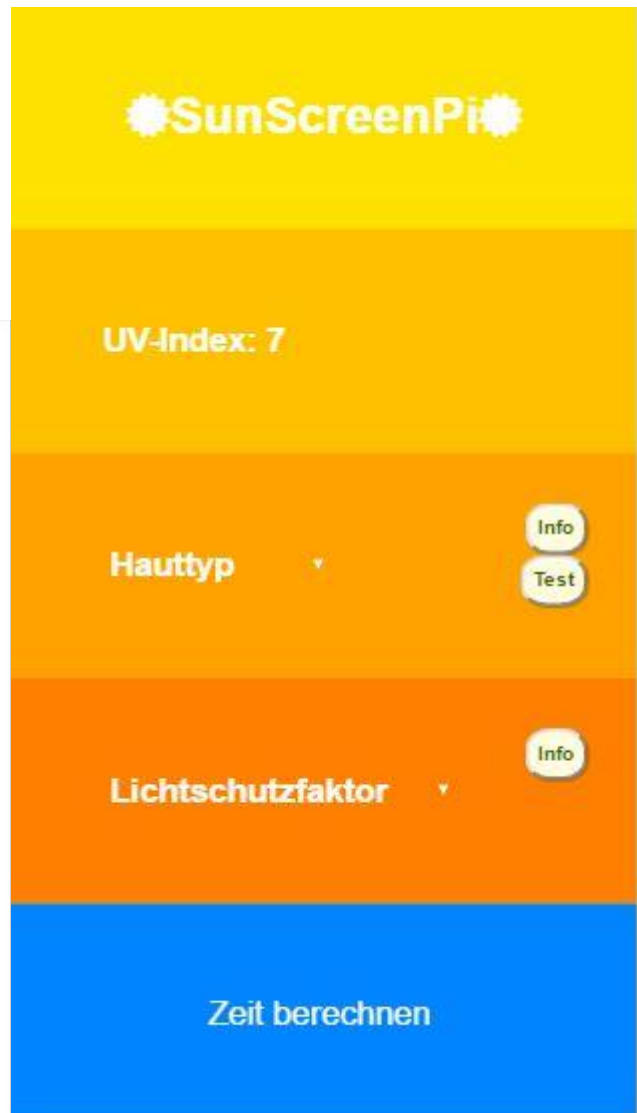


Abbildung 2: Aussehen der Hauptseite

5 Fazit

„Ende gut, alles gut“ ist wohl der abschließende Satz, der einen dicken Schlussstrich der Erleichterung unter unser SunScreenPi-Projekt ziehen lässt. Unsere eigene Gruppe freute sich wohl (neben unseren Professoren) am meisten darüber, dass alles so reibungslos funktionierte. Sind es doch meist die kleinen Probleme, denen man anfangs nicht allzu große Aufmerksamkeit zukommen lässt, diese dann aber im Endeffekt das ganze Unternehmen so ins Wanken bringen können, dass alles wie ein Kartenhaus zusammenzustürzen droht. In unseren Köpfen und auf dem Papier schien zu Beginn des Projekts alles einfach und schnell realisiert, was in der Praxis aber teilweise einfach nicht funktionieren wollte und uns dann oft an den Rand der Verzweiflung manövrierte. Aber da sind wir ganz sicher nicht die Ersten, denen es so ergeht.

Ausgegangen waren wir zunächst davon, dass der aktuelle UV - Wert des Sensors nur maximal alle zehn Minuten oder sogar nur einmal in der Stunde abgegriffen werden müsse. Entweder scheint die Sonne oder nicht. Entweder sind Wolken am Himmel oder nicht, dachten wir. Wenn mal eine kleine Wolke am blauen Himmel vorüberzieht, dann wird das unseren durchschnittlichen UV - Wert nur unmerklich verändern, so dass wir davon ausgehen wollten, dass eine hohe Anzahl von Daten des Sensors absolut nicht nötig sei. Glücklicherweise gab es diesbezüglich auch kritische Bemerkungen in unserer Gruppe, weswegen wir uns letztlich darauf einigten, die Testwerte alle sechs Sekunden an den Server zu senden. Zu diesem Zeitpunkt sprach auch nichts dagegen, dass wir den Server mit zu viel Informationen „zumüllen“ würden. Außerdem haben wir eine tägliche Löschung der Liste programmiert. Das würde genügen, dachten wir. Am Tag der Jahresausstellung sollte sich dann allerdings zeigen, dass in beiden Fällen genau das Gegenteil der Fall war. Der Server wurde von unserer Datenflut so sehr zugemüllt, dass es ihn nach einer Stunde im Betrieb zum Absturz brachte und der UV - Index wechselte sehr wohl innerhalb von nur Minuten zwischen fünf verschiedenen UV-Indizes, wenn der Himmel urplötzlich für zwanzig Minuten von einem riesigen Wolkenteppich bedeckt war und sich anschließend die Sonne aus voller Kraft ein Loch durch die Wolkendecke brannte. Mit solch einem dynamischen Wechsel hatte von uns niemand gerechnet. Wir waren sogar davon ausgegangen, dass es aufgrund des gleichbleibenden UV -Index für den Standbesucher beim Ausprobieren des SunScreenPi langweilig werden könnte und planten daher, den sich verändernden UV-Index mit einem angeschlossenen Potentiometer zu verändern. Dieses Vorhaben wurde damit überflüssig. Die hohe Anzahl von Daten des Sensors ist somit nicht nur zu empfehlen, sondern dringend angebracht, um einen möglichst realistischen UV - Wert abbilden und dementsprechend eine gute Empfehlung für den User der App aussprechen zu können. Verändern müssten wir noch im Code des Raspberry Pi, dass jede an den Server gesendete Liste (alle sechs Sekunden), die vorherige Liste im Server überschreibt, um so ein „zumüllen“ des Servers zu verhindern. Ein weiter auftretendes Problem, was uns nahe der Verzweiflung brachte bestand darin, dass jedes Mal, wenn ein User in der App durch Drücken des Startbuttons einen Countdown startete, der alte Countdown weiterlief, beide parallel zählten und somit auch beide übereinander angezeigt wurden. Die Zahlen sprangen, wodurch die Darstellung, in Form von kryptisch anmutenden Zahlen, sehr verwirrend wirkte. Die Ästhetik konnten wir dann noch durch ein wenig professionelle Hilfe retten. Anfangs hatten wir sechs Hauttypen eingeplant. Bei der Befragung der potenziellen Hauttypen V und IV zeigte sich dann aber, dass diese sich fast nie eincremten und auch kein wirkliches Interesse für unser Projekt bestand. In den seltensten Fällen hatte je einer der Hauttypengruppe V oder VI die Erfahrung mit einem Sonnenbrand gemacht. Vier verschiedene Hauttypen sollten uns also genügen. Die zu Beginn eingeplante Powerbank als Energiequelle für den Raspberry Pi ließen wir letztlich weg und zogen ein Stromkabel aus dem Hochschulgebäude hinüber zum Sonnendeck des Neubaus. Wir wollten einfach jede mögliche Fehlerquelle ausgrenzen und wollten nicht riskieren, dass wir während des Betriebs auf einmal eine neue Stromquelle organisieren hätten müssen, hätte der Raspberry Pi doch mehr Strom benötigt und

die Powerbank schneller leergesogen, als eingeplant. Ausserdem benötigten wir eine Stromquelle für den Laptop, mit welchen wir auf den Raspberry Pi zugriffen und Strom für die Lautsprecher, da wir unseren Stand mit entspannter Reggeamusik bespielen wollten.

Die Platzwahl unseres Projekt-Standes auf dem Sonnendeck war nicht optimal, da sich die meisten Besucher der Jahresausstellung im Innenhof der Finkenau tummelten. Aber damit konnten wir beim Aufbau unseres Standes nicht rechnen.

Unser Projekt kam bei den Standbesuchern sehr gut an und es erfreute uns zusätzlich, dass viele Besucher eine große Sinnhaftigkeit in unserem Projekt als gegeben sahen. Die App bereitete den Standbesuchern bei Anwendung keinerlei Probleme in der Handhabung, da sie recht übersichtlich und selbsterklärend gestaltet ist. Zusätzlich kamen unsere selbstgebackenen Raspberry Pies so gut an, dass wir lauter glücklich und zufriedene Standbesucher weiter auf die Jahresausstellung ziehen lassen konnten.

Auch wenn dieses Projekt mehr Zeit und Nerven als das Lernen für eine Klausur am Ende des Semesters bedeutet hat, nehmen wir viel mehr daraus mit, als es bei einer Klausur der Fall wäre. Es gab düstere Momente der Verzweiflung aber auch Momente der Freude und des Stolzes am Ende, als alles (fast) so lief, wie es sollte.

Wir hatten viel Freude an der Projektarbeit.

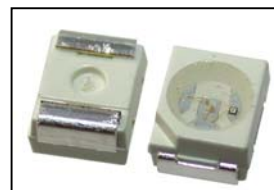
6 Literaturverzeichnis

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[Zugriff am 13 Juli 2016].
- Microchip Technology Inc., 2008. Datenblatt MCP3008, USA: Microchip Technology Inc.

6 Anhang



GUVA-S12SD



TECHNICAL DATA

UV-B Sensor

Features

- Gallium Nitride Based Material
- Schottky-type Photodiode
- Photovoltaic Mode Operation
- Good Visible Blindness
- High Responsivity & Low Dark Current

Applications

- UV Index Monitoring
- UV-A Lamp Monitoring

Absolute Maximum Ratings

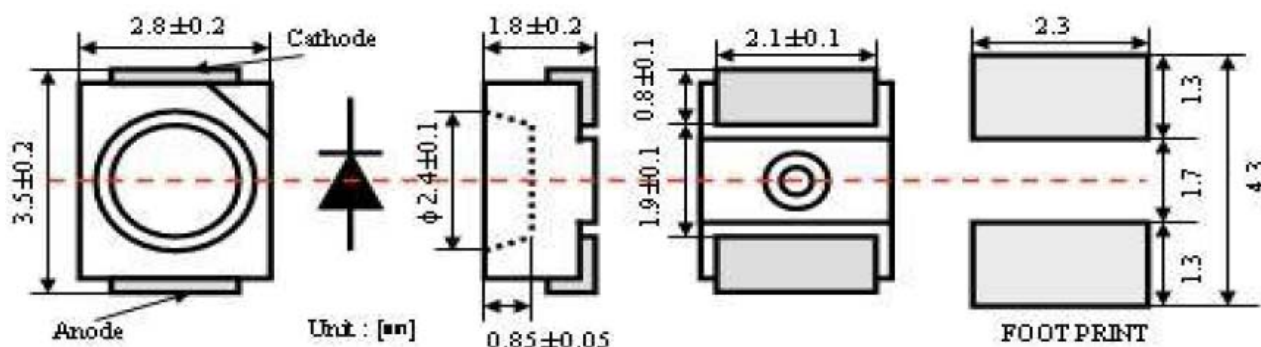
Item	Symbol	Value	Unit
Forward Current	I_F	1	mA
Reverse Voltage	V_R	5	V
Operating Temperature	T_{op}	-30 ... +85	°C
Storage Temperature	T_{st}	-40 ... +90	°C
Soldering Temperature *	T_{sol}	260	°C

* must be completed within 10 seconds

Characteristics (25°C)

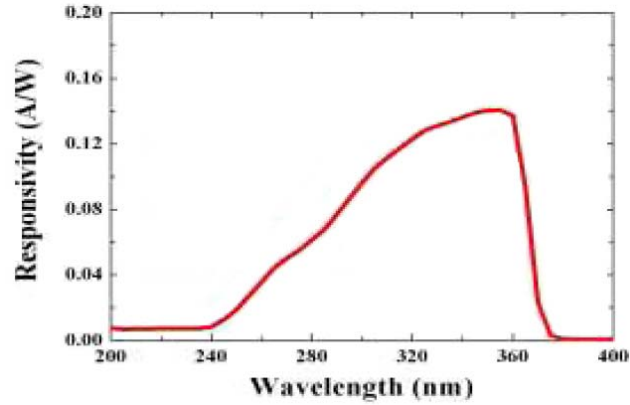
Item	Symbol	Test Conditions	Min.	Typ.	Max.	Unit
Dark Current	I_D	$V_R = 0.1 \text{ V}$	-	-	1	nA
Photo Current	I_{PD}	UVA Lamp, 1 mW/cm ²	-	113	-	nA
		1 UVI	-	26	-	nA
Temperature Coefficient	I_{TC}	UVA Lamp	-	0.08	-	% / °C
Responsivity	R	$\lambda = 300 \text{ nm}, V_R = 0 \text{ V}$	-	0.14	-	A/W
Spectral Detection Range	λ	10% of R	240	-	370	nm

Package Dimension

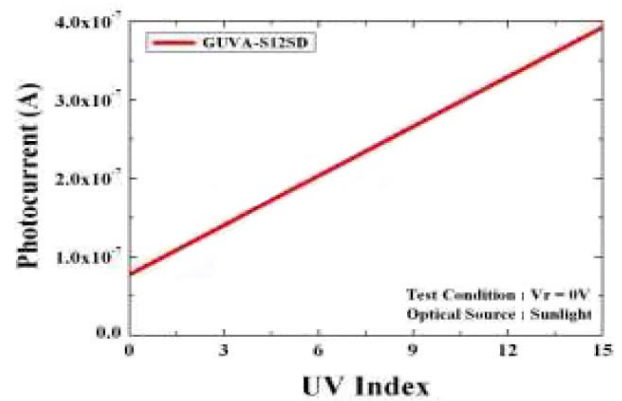
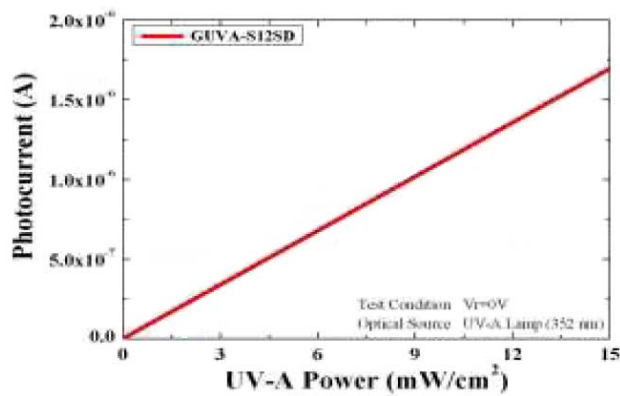




Responsivity Curve



Photocurrent along UV Power



2.7V 4-Channel/8-Channel 10-Bit A/D Converters with SPI Serial Interface

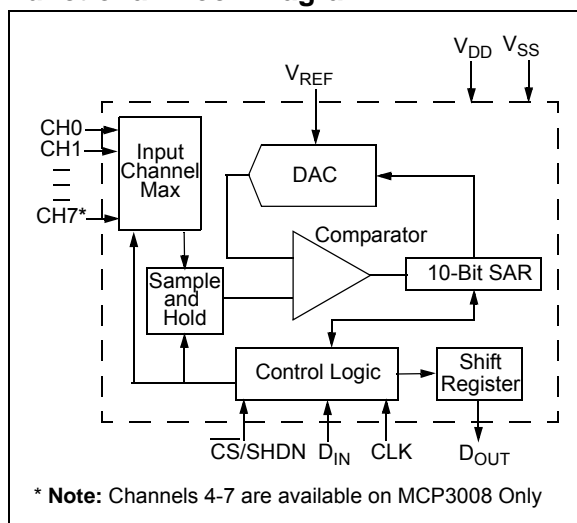
Features

- 10-bit resolution
- ± 1 LSB max DNL
- ± 1 LSB max INL
- 4 (MCP3004) or 8 (MCP3008) input channels
- Analog inputs programmable as single-ended or pseudo-differential pairs
- On-chip sample and hold
- SPI serial interface (modes 0,0 and 1,1)
- Single supply operation: 2.7V - 5.5V
- 200 kps max. sampling rate at $V_{DD} = 5V$
- 75 kps max. sampling rate at $V_{DD} = 2.7V$
- Low power CMOS technology
- 5 nA typical standby current, 2 μA max.
- 500 μA max. active current at 5V
- Industrial temp range: $-40^{\circ}C$ to $+85^{\circ}C$
- Available in PDIP, SOIC and TSSOP packages

Applications

- Sensor Interface
- Process Control
- Data Acquisition
- Battery Operated Systems

Functional Block Diagram

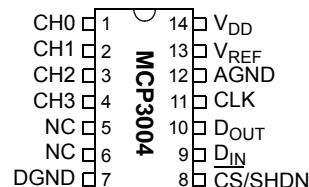


Description

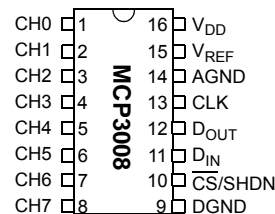
The Microchip Technology Inc. MCP3004/3008 devices are successive approximation 10-bit Analog-to-Digital (A/D) converters with on-board sample and hold circuitry. The MCP3004 is programmable to provide two pseudo-differential input pairs or four single-ended inputs. The MCP3008 is programmable to provide four pseudo-differential input pairs or eight single-ended inputs. Differential Nonlinearity (DNL) and Integral Nonlinearity (INL) are specified at ± 1 LSB. Communication with the devices is accomplished using a simple serial interface compatible with the SPI protocol. The devices are capable of conversion rates of up to 200 kps. The MCP3004/3008 devices operate over a broad voltage range (2.7V - 5.5V). Low-current design permits operation with typical standby currents of only 5 nA and typical active currents of 320 μA . The MCP3004 is offered in 14-pin PDIP, 150 mil SOIC and TSSOP packages, while the MCP3008 is offered in 16-pin PDIP and SOIC packages.

Package Types

PDIP, SOIC, TSSOP



PDIP, SOIC



MCP3004/3008

NOTES:

1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V_{DD}	7.0V
All Inputs and Outputs w.r.t. V_{SS}	- 0.6V to $V_{DD} + 0.6V$
Storage Temperature	-65°C to +150°C
Ambient temperature with power applied	-65°C to +150°C
Soldering temperature of leads (10 seconds)	+300°C
ESD Protection On All Pins (HBM)	≥ 4 kV

† **Notice:** Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL SPECIFICATIONS

Electrical Characteristics: Unless otherwise noted, all parameters apply at $V_{DD} = 5V$, $V_{REF} = 5V$, $T_A = -40^{\circ}C$ to $+85^{\circ}C$, $f_{SAMPLE} = 200$ ksp/s and $f_{CLK} = 18 \cdot f_{SAMPLE}$. Unless otherwise noted, typical values apply for $V_{DD} = 5V$, $T_A = +25^{\circ}C$.

Parameter	Sym	Min	Typ	Max	Units	Conditions
Conversion Rate						
Conversion Time	t_{CONV}	—	—	10	clock cycles	
Analog Input Sample Time	t_{SAMPLE}	1.5			clock cycles	
Throughput Rate	f_{SAMPLE}	—	—	200 75	ksp/s ksp/s	$V_{DD} = V_{REF} = 5V$ $V_{DD} = V_{REF} = 2.7V$
DC Accuracy						
Resolution		10			bits	
Integral Nonlinearity	INL	—	±0.5	±1	LSB	
Differential Nonlinearity	DNL	—	±0.25	±1	LSB	No missing codes over temperature
Offset Error		—	—	±1.5	LSB	
Gain Error		—	—	±1.0	LSB	
Dynamic Performance						
Total Harmonic Distortion		—	-76		dB	$V_{IN} = 0.1V$ to $4.9V@1$ kHz
Signal-to-Noise and Distortion (SINAD)		—	61		dB	$V_{IN} = 0.1V$ to $4.9V@1$ kHz
Spurious Free Dynamic Range		—	78		dB	$V_{IN} = 0.1V$ to $4.9V@1$ kHz
Reference Input						
Voltage Range		0.25	—	V_{DD}	V	Note 2
Current Drain		—	100 0.001	150 3	μA μA	$\overline{CS} = V_{DD} = 5V$
Analog Inputs						
Input Voltage Range for CH0 or CH1 in Single-Ended Mode		V_{SS}	—	V_{REF}	V	
Input Voltage Range for IN+ in pseudo-differential mode		IN-	—	$V_{REF}+IN-$		
Input Voltage Range for IN- in pseudo-differential mode		$V_{SS}-100$	—	$V_{SS}+100$	mV	

Note 1: This parameter is established by characterization and not 100% tested.

2: See graphs that relate linearity performance to V_{REF} levels.

3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for more information.

MCP3004/3008

ELECTRICAL SPECIFICATIONS (CONTINUED)

Electrical Characteristics: Unless otherwise noted, all parameters apply at $V_{DD} = 5V$, $V_{REF} = 5V$, $T_A = -40^{\circ}C$ to $+85^{\circ}C$, $f_{SAMPLE} = 200$ kps and $f_{CLK} = 18 \cdot f_{SAMPLE}$. Unless otherwise noted, typical values apply for $V_{DD} = 5V$, $T_A = +25^{\circ}C$.						
Parameter	Sym	Min	Typ	Max	Units	Conditions
Leakage Current		—	0.001	± 1	μA	
Switch Resistance		—	1000	—	Ω	See Figure 4-1
Sample Capacitor		—	20	—	pF	See Figure 4-1
Digital Input/Output						
Data Coding Format		Straight Binary				
High Level Input Voltage	V_{IH}	$0.7 V_{DD}$	—	—	V	
Low Level Input Voltage	V_{IL}	—	—	$0.3 V_{DD}$	V	
High Level Output Voltage	V_{OH}	4.1	—	—	V	$I_{OH} = -1$ mA, $V_{DD} = 4.5V$
Low Level Output Voltage	V_{OL}	—	—	0.4	V	$I_{OL} = 1$ mA, $V_{DD} = 4.5V$
Input Leakage Current	I_{LI}	-10	—	10	μA	$V_{IN} = V_{SS}$ or V_{DD}
Output Leakage Current	I_{LO}	-10	—	10	μA	$V_{OUT} = V_{SS}$ or V_{DD}
Pin Capacitance (All Inputs/Outputs)	C_{IN} , C_{OUT}	—	—	10	pF	$V_{DD} = 5.0V$ (Note 1) $T_A = 25^{\circ}C$, $f = 1$ MHz
Timing Parameters						
Clock Frequency	f_{CLK}	—	—	3.6 1.35	MHz MHz	$V_{DD} = 5V$ (Note 3) $V_{DD} = 2.7V$ (Note 3)
Clock High Time	t_{HI}	125	—	—	ns	
Clock Low Time	t_{LO}	125	—	—	ns	
CS Fall To First Rising CLK Edge	t_{SUCS}	100	—	—	ns	
CS Fall To Falling CLK Edge	t_{CSD}	—	—	0	ns	
Data Input Setup Time	t_{SU}	50	—	—	ns	
Data Input Hold Time	t_{HD}	50	—	—	ns	
CLK Fall To Output Data Valid	t_{DO}	—	—	125 200	ns ns	$V_{DD} = 5V$, See Figure 1-2 $V_{DD} = 2.7V$, See Figure 1-2
CLK Fall To Output Enable	t_{EN}	—	—	125 200	ns ns	$V_{DD} = 5V$, See Figure 1-2 $V_{DD} = 2.7V$, See Figure 1-2
CS Rise To Output Disable	t_{DIS}	—	—	100	ns	See Test Circuits, Figure 1-2
CS Disable Time	t_{CSH}	270	—	—	ns	
D_{OUT} Rise Time	t_R	—	—	100	ns	See Test Circuits, Figure 1-2 (Note 1)
D_{OUT} Fall Time	t_F	—	—	100	ns	See Test Circuits, Figure 1-2 (Note 1)

Note 1: This parameter is established by characterization and not 100% tested.

2: See graphs that relate linearity performance to V_{REF} levels.

3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for more information.

ELECTRICAL SPECIFICATIONS (CONTINUED)

Electrical Characteristics: Unless otherwise noted, all parameters apply at $V_{DD} = 5V$, $V_{REF} = 5V$, $T_A = -40^{\circ}C$ to $+85^{\circ}C$, $f_{SAMPLE} = 200$ kps and $f_{CLK} = 18 \cdot f_{SAMPLE}$. Unless otherwise noted, typical values apply for $V_{DD} = 5V$, $T_A = +25^{\circ}C$.

Parameter	Sym	Min	Typ	Max	Units	Conditions
Power Requirements						
Operating Voltage	V_{DD}	2.7	—	5.5	V	
Operating Current	I_{DD}	—	425 225	550	μA	$V_{DD} = V_{REF} = 5V$, D_{OUT} unloaded $V_{DD} = V_{REF} = 2.7V$, D_{OUT} unloaded
Standby Current	I_{DSS}	—	0.005	2	μA	$\overline{CS} = V_{DD} = 5.0V$

- Note 1:** This parameter is established by characterization and not 100% tested.
2: See graphs that relate linearity performance to V_{REF} levels.
3: Because the sample cap will eventually lose charge, effective clock rates below 10 kHz can affect linearity performance, especially at elevated temperatures. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for more information.

TEMPERATURE CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated, $V_{DD} = +2.7V$ to $+5.5V$, $V_{SS} = GND$.

Parameters	Sym	Min	Typ	Max	Units	Conditions
Temperature Ranges						
Specified Temperature Range	T_A	-40	—	+85	$^{\circ}C$	
Operating Temperature Range	T_A	-40	—	+85	$^{\circ}C$	
Storage Temperature Range	T_A	-65	—	+150	$^{\circ}C$	
Thermal Package Resistances						
Thermal Resistance, 14L-PDIP	θ_{JA}	—	70	—	$^{\circ}C/W$	
Thermal Resistance, 14L-SOIC	θ_{JA}	—	108	—	$^{\circ}C/W$	
Thermal Resistance, 14L-TSSOP	θ_{JA}	—	100	—	$^{\circ}C/W$	
Thermal Resistance, 16L-PDIP	θ_{JA}	—	70	—	$^{\circ}C/W$	
Thermal Resistance, 16L-SOIC	θ_{JA}	—	90	—	$^{\circ}C/W$	

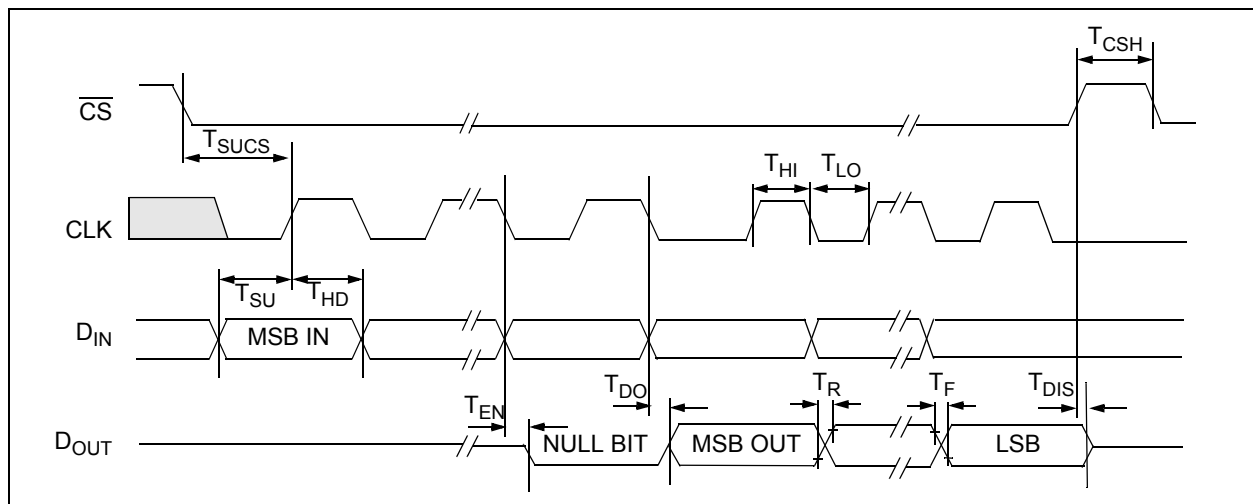


FIGURE 1-1: Serial Interface Timing.

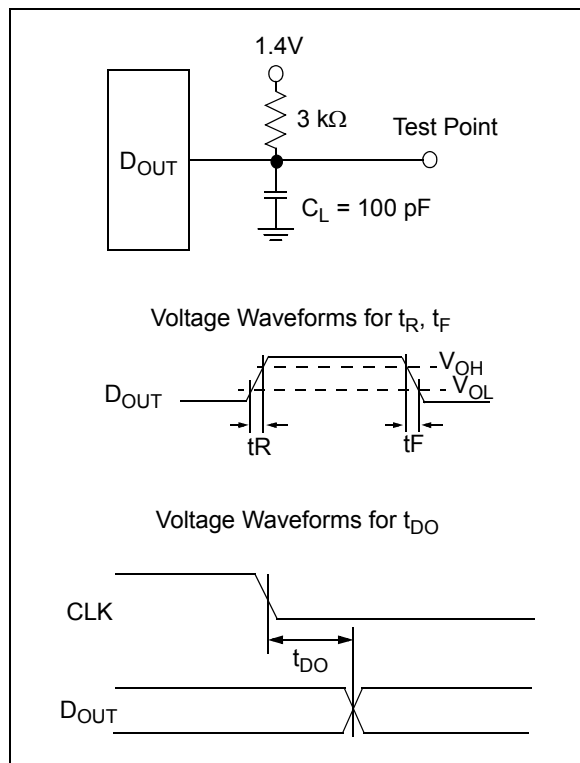


FIGURE 1-2: Load Circuit for t_R , t_F , t_{DO} .

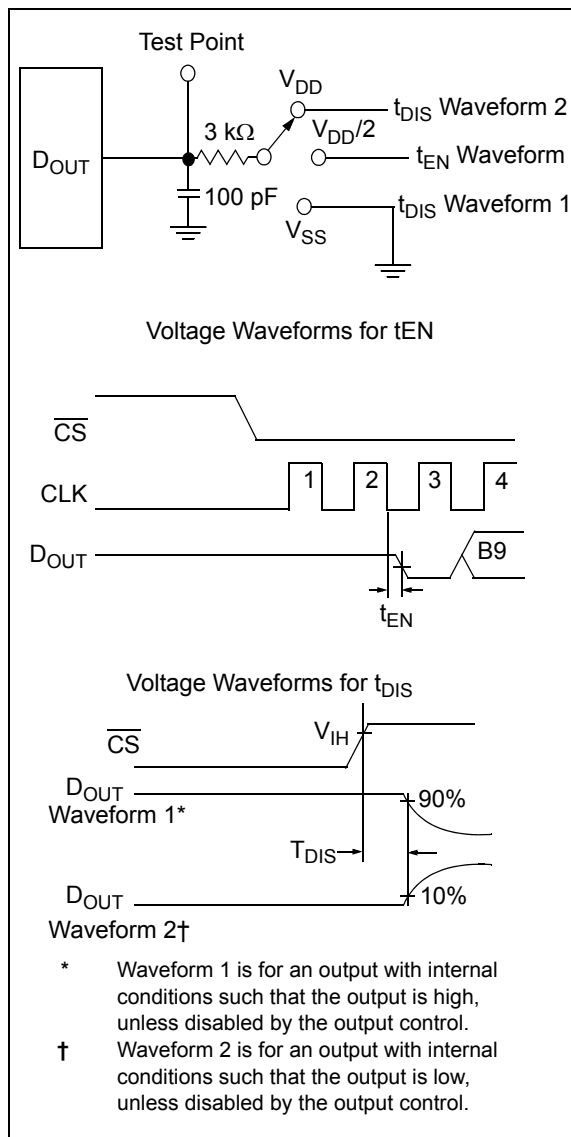


FIGURE 1-3: Load circuit for t_{DIS} and t_{EN} .

2.0 TYPICAL PERFORMANCE CHARACTERISTICS

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 * f_{SAMPLE}$, $T_A = +25^{\circ}C$.

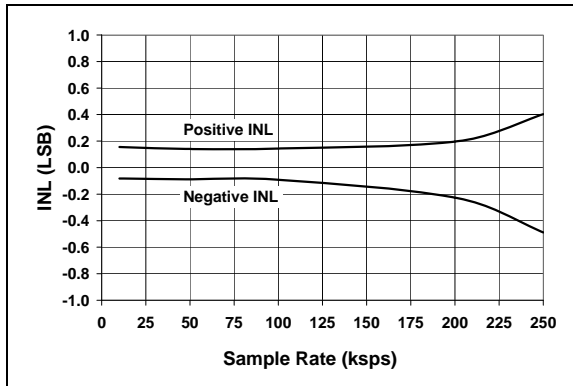


FIGURE 2-1: Integral Nonlinearity (INL) vs. Sample Rate.

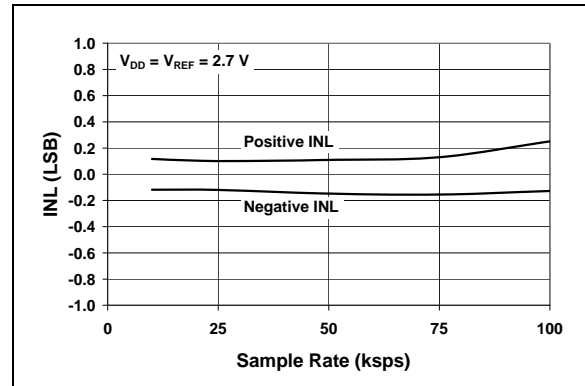


FIGURE 2-4: Integral Nonlinearity (INL) vs. Sample Rate ($V_{DD} = 2.7V$).

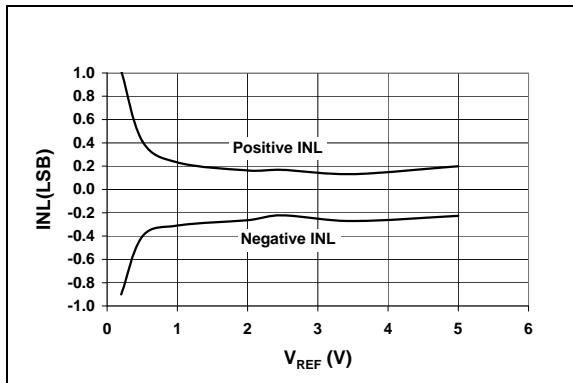


FIGURE 2-2: Integral Nonlinearity (INL) vs. V_{REF}

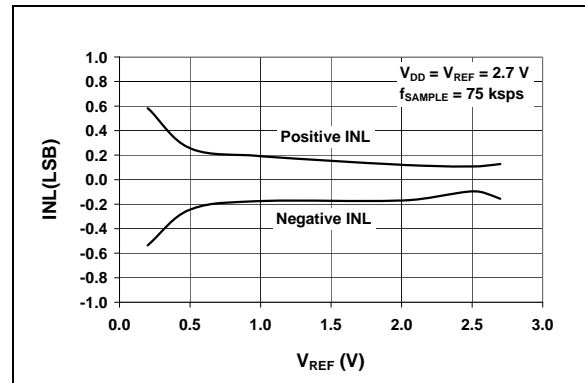


FIGURE 2-5: Integral Nonlinearity (INL) vs. V_{REF} ($V_{DD} = 2.7V$).

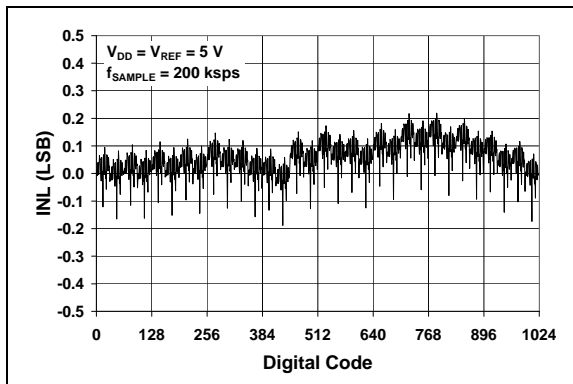


FIGURE 2-3: Integral Nonlinearity (INL) vs. Code (Representative Part).

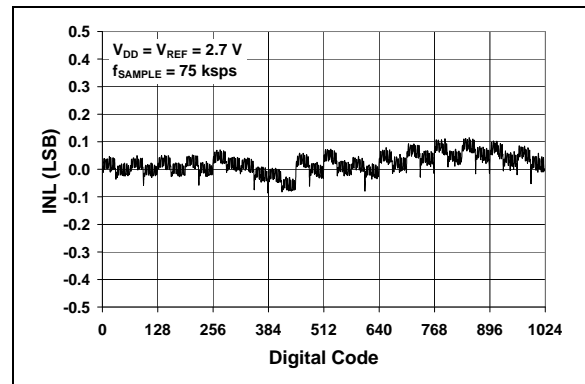


FIGURE 2-6: Integral Nonlinearity (INL) vs. Code (Representative Part, $V_{DD} = 2.7V$).

MCP3004/3008

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 \cdot f_{SAMPLE}$, $T_A = +25^\circ C$.

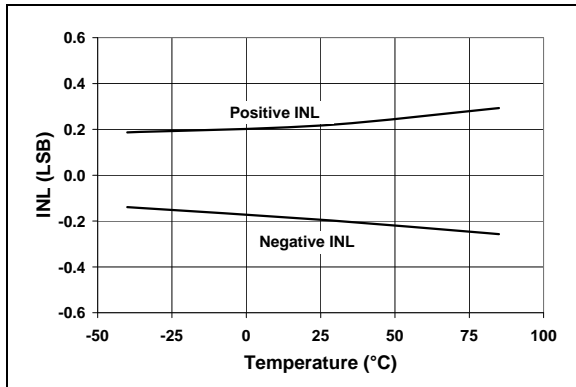


FIGURE 2-7: Integral Nonlinearity (INL) vs. Temperature.

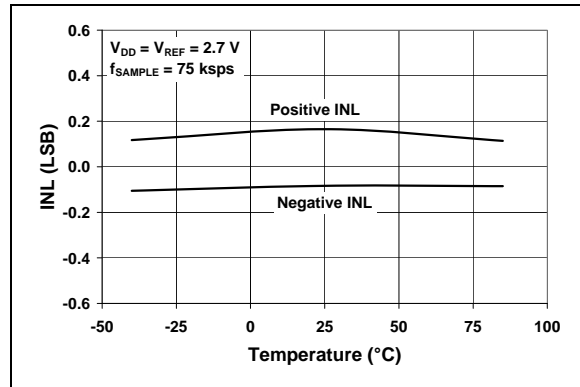


FIGURE 2-10: Integral Nonlinearity (INL) vs. Temperature ($V_{DD} = 2.7V$).

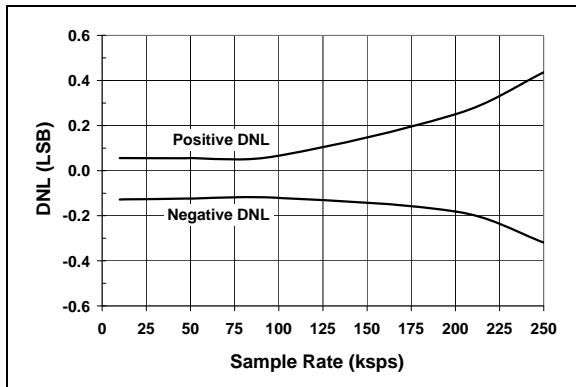


FIGURE 2-8: Differential Nonlinearity (DNL) vs. Sample Rate.

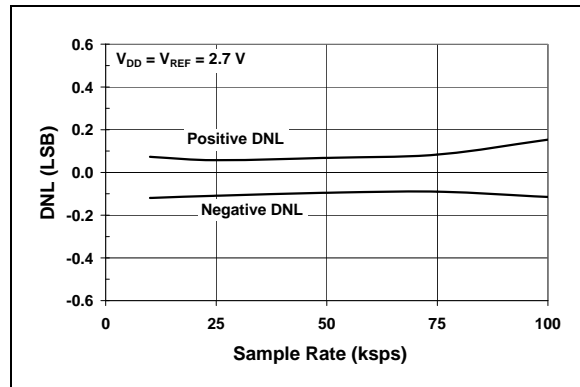


FIGURE 2-11: Differential Nonlinearity (DNL) vs. Sample Rate ($V_{DD} = 2.7V$).

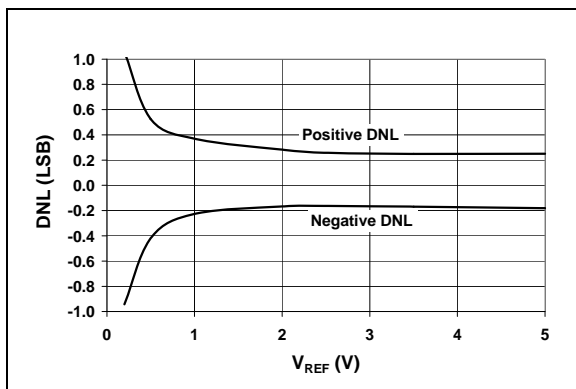


FIGURE 2-9: Differential Nonlinearity (DNL) vs. V_{REF}

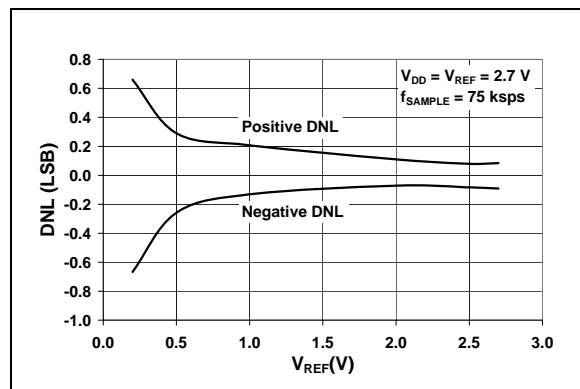


FIGURE 2-12: Differential Nonlinearity (DNL) vs. V_{REF} ($V_{DD} = 2.7V$).

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 \cdot f_{SAMPLE}$, $T_A = +25^\circ C$.

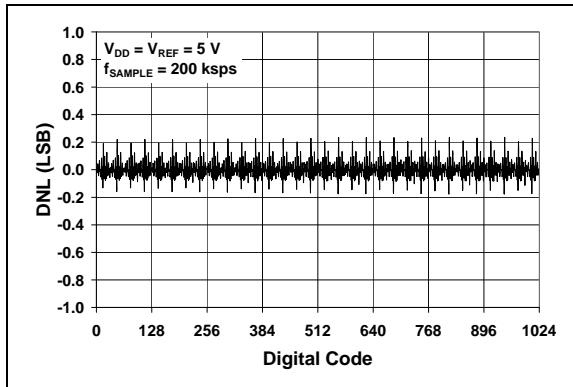


FIGURE 2-13: Differential Nonlinearity (DNL) vs. Code (Representative Part).

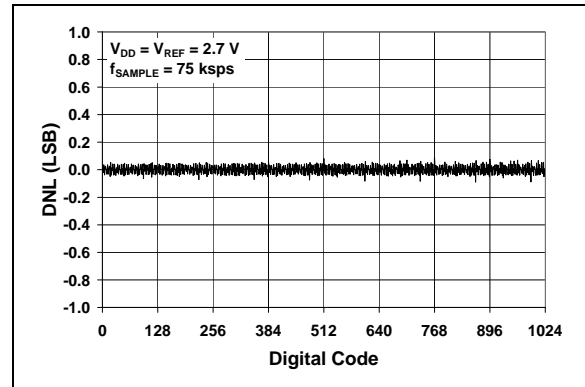


FIGURE 2-16: Differential Nonlinearity (DNL) vs. Code (Representative Part, $V_{DD} = 2.7V$).

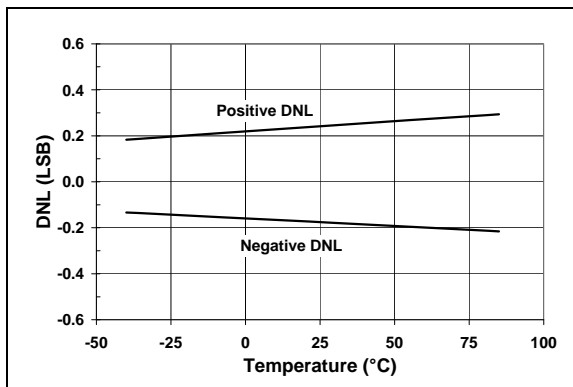


FIGURE 2-14: Differential Nonlinearity (DNL) vs. Temperature.

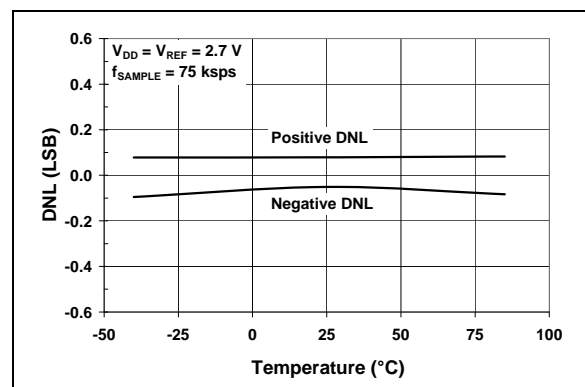


FIGURE 2-17: Differential Nonlinearity (DNL) vs. Temperature ($V_{DD} = 2.7V$).

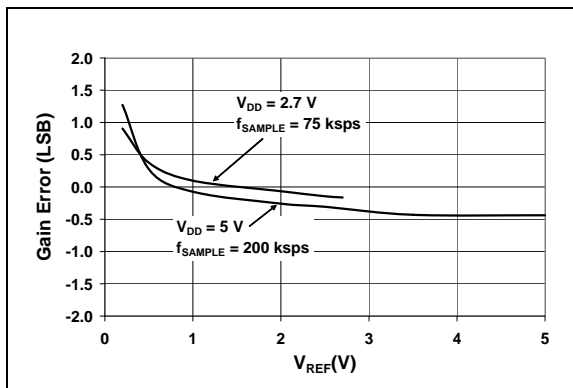


FIGURE 2-15: Gain Error vs. V_{REF}

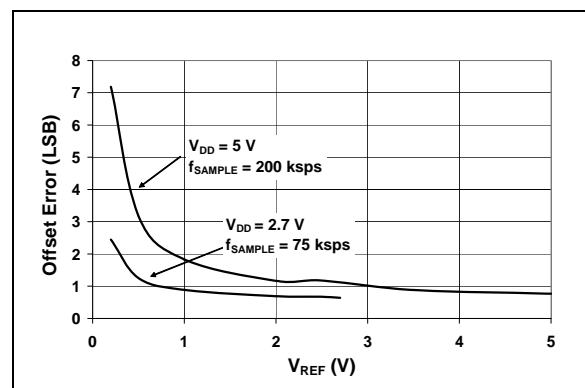


FIGURE 2-18: Offset Error vs. V_{REF}

MCP3004/3008

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 \cdot f_{SAMPLE}$, $T_A = +25^\circ C$.

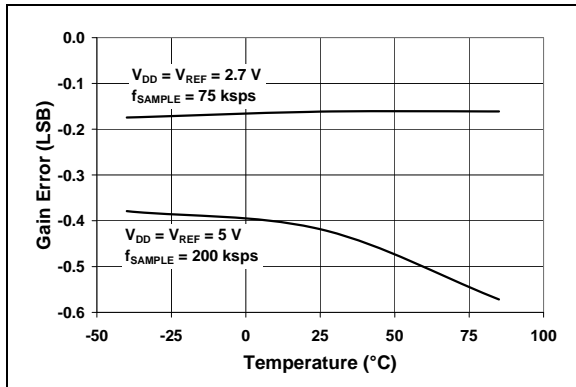


FIGURE 2-19: Gain Error vs. Temperature.

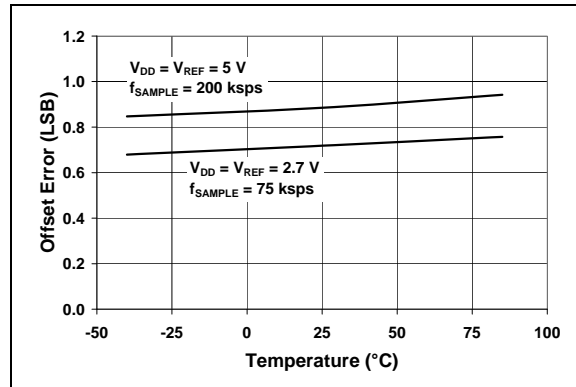


FIGURE 2-22: Offset Error vs. Temperature.

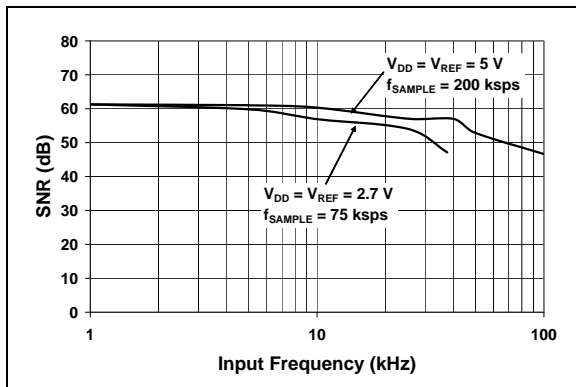


FIGURE 2-20: Signal-to-Noise (SNR) vs. Input Frequency.

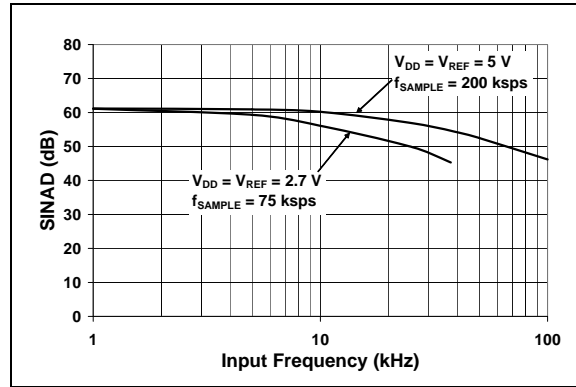


FIGURE 2-23: Signal-to-Noise and Distortion (SINAD) vs. Input Frequency.

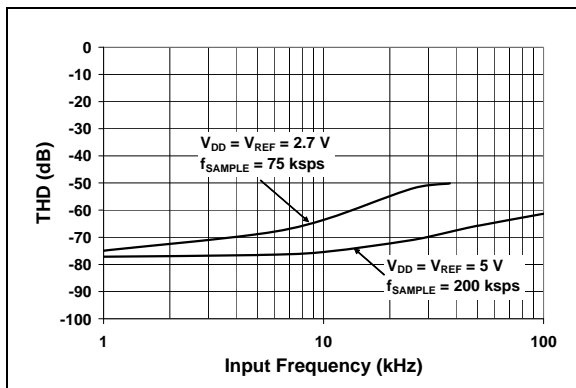


FIGURE 2-21: Total Harmonic Distortion (THD) vs. Input Frequency.

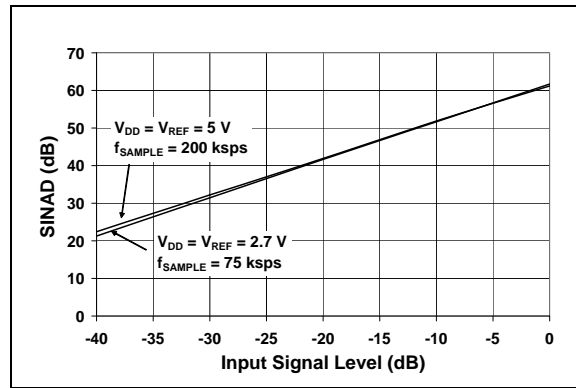


FIGURE 2-24: Signal-to-Noise and Distortion (SINAD) vs. Input Signal Level.

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 \cdot f_{SAMPLE}$, $T_A = +25^\circ C$.

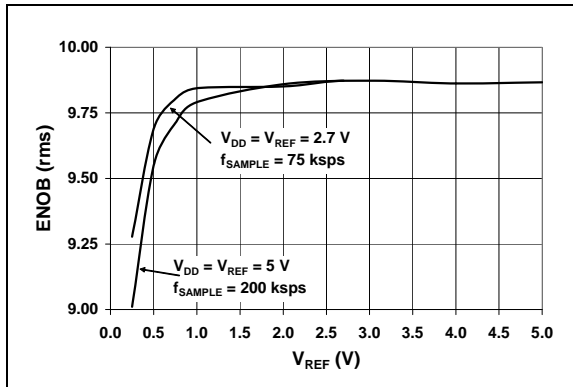


FIGURE 2-25: Effective Number of Bits (ENOB) vs. V_{REF}

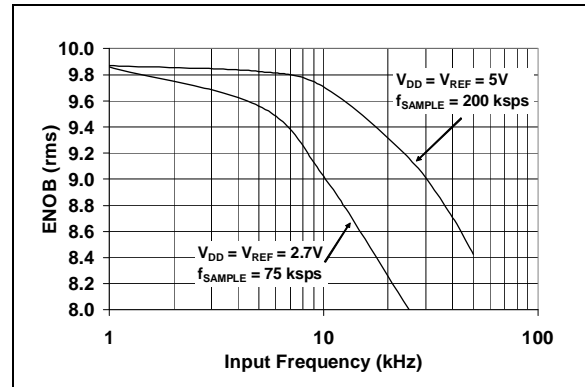


FIGURE 2-28: Effective Number of Bits (ENOB) vs. Input Frequency.

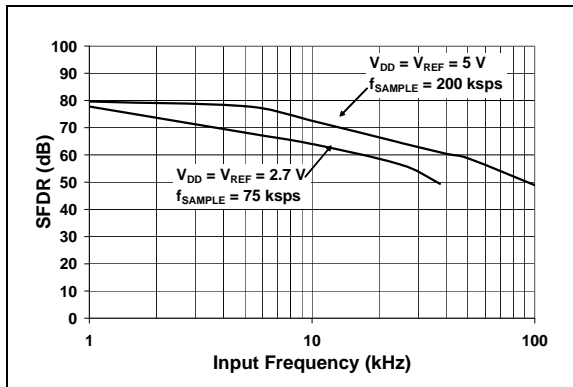


FIGURE 2-26: Spurious Free Dynamic Range (SFDR) vs. Input Frequency.

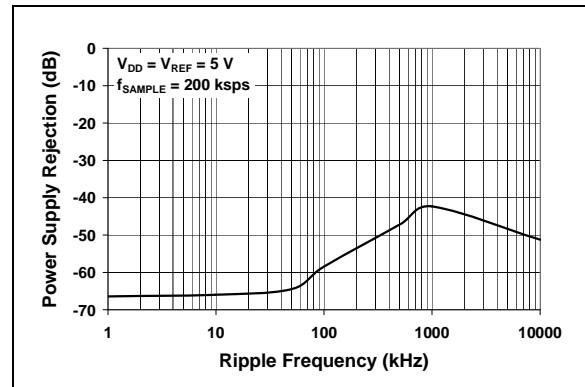


FIGURE 2-29: Power Supply Rejection (PSR) vs. Ripple Frequency.

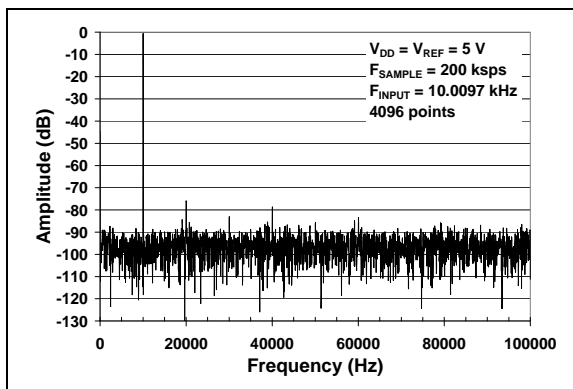


FIGURE 2-27: Frequency Spectrum of 10 kHz Input (Representative Part).

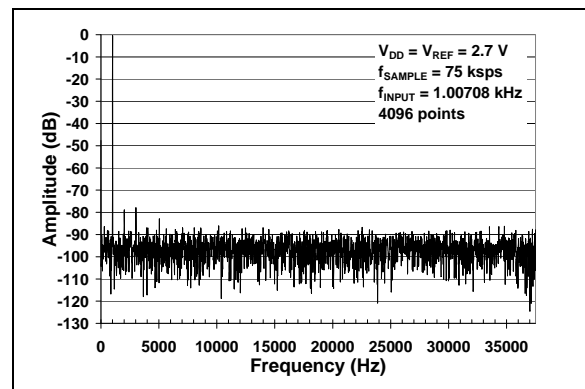


FIGURE 2-30: Frequency Spectrum of 1 kHz Input (Representative Part, $V_{DD} = 2.7V$).

MCP3004/3008

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 \cdot f_{SAMPLE}$, $T_A = +25^\circ C$.

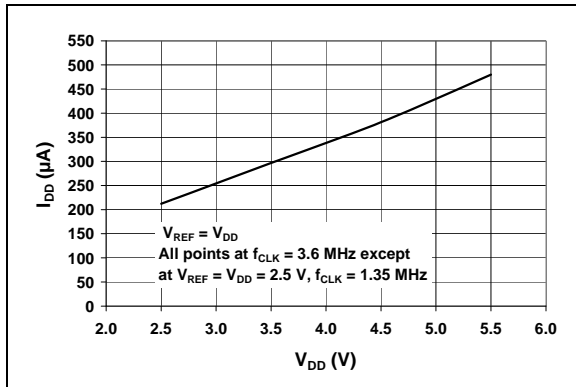


FIGURE 2-31: I_{DD} vs. V_{DD} .

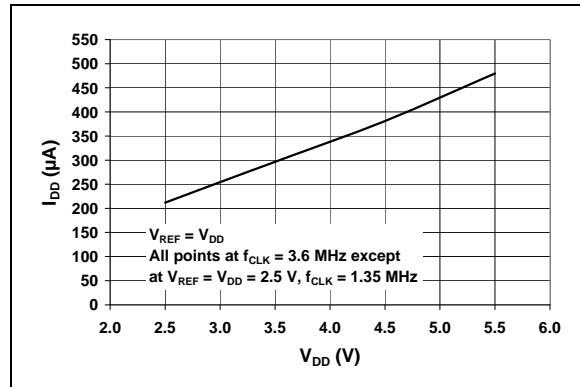


FIGURE 2-34: I_{REF} vs. V_{DD} .

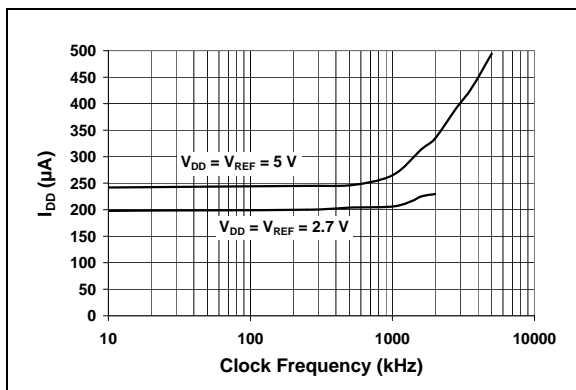


FIGURE 2-32: I_{DD} vs. Clock Frequency.

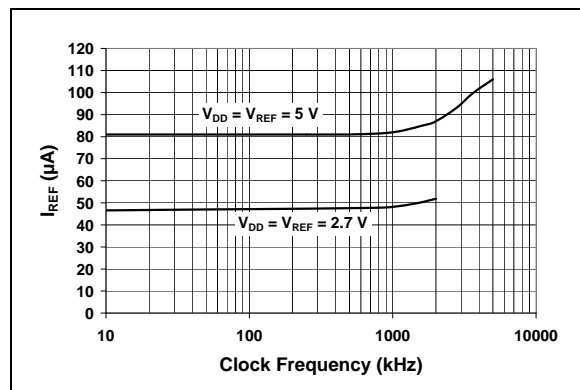


FIGURE 2-35: I_{REF} vs. Clock Frequency.

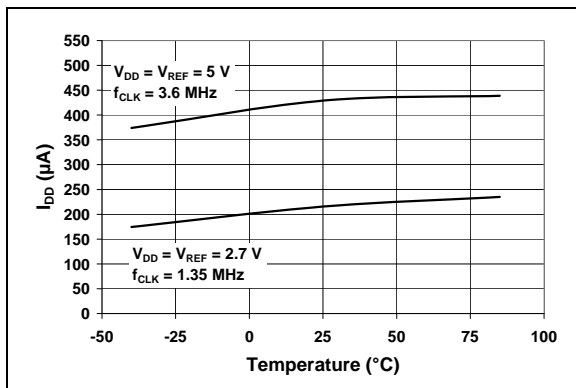


FIGURE 2-33: I_{DD} vs. Temperature.

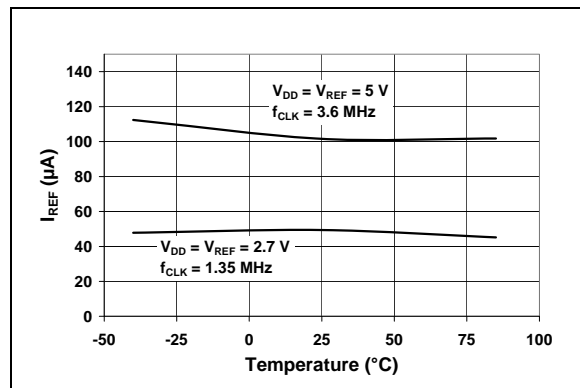


FIGURE 2-36: I_{REF} vs. Temperature.

Note: Unless otherwise indicated, $V_{DD} = V_{REF} = 5V$, $f_{CLK} = 18 * f_{SAMPLE}$, $T_A = +25^{\circ}C$.

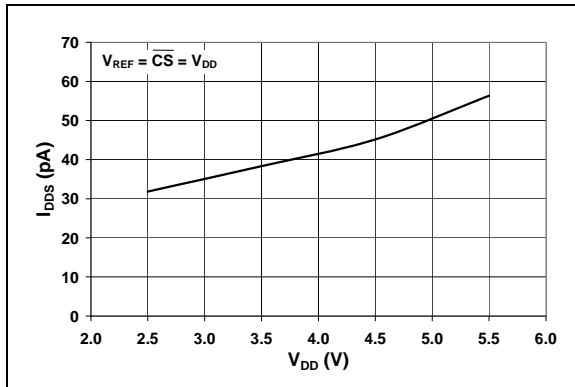


FIGURE 2-37: I_{DDS} vs. V_{DD} .

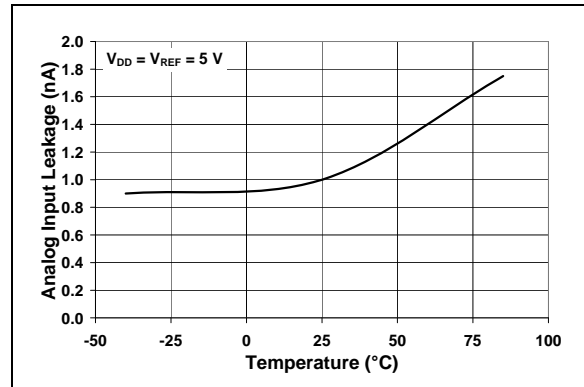


FIGURE 2-39: Analog Input Leakage Current vs. Temperature.

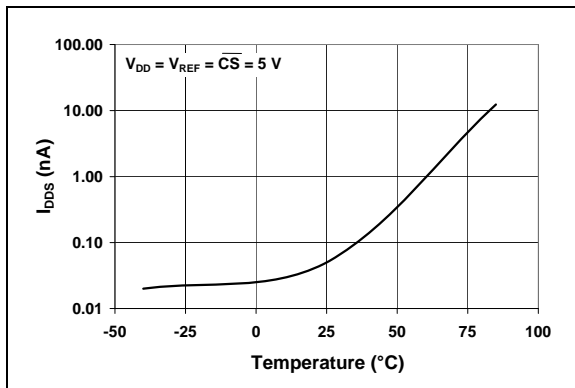


FIGURE 2-38: I_{DDS} vs. Temperature.

MCP3004/3008

NOTES:

3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in [Table 3-1](#). Additional descriptions of the device pins follows.

TABLE 3-1: PIN FUNCTION TABLE

MCP3004	MCP3008	Symbol	Description
PDIP, SOIC, TSSOP	PDIP, SOIC		
1	1	CH0	Analog Input
2	2	CH1	Analog Input
3	3	CH2	Analog Input
4	4	CH3	Analog Input
–	5	CH4	Analog Input
–	6	CH5	Analog Input
–	7	CH6	Analog Input
–	8	CH7	Analog Input
7	9	DGND	Digital Ground
8	10	$\overline{\text{CS}}/\text{SHDN}$	Chip Select/Shutdown Input
9	11	D _{IN}	Serial Data In
10	12	D _{OUT}	Serial Data Out
11	13	CLK	Serial Clock
12	14	AGND	Analog Ground
13	15	V _{REF}	Reference Voltage Input
14	16	V _{DD}	+2.7V to 5.5V Power Supply
5,6	–	NC	No Connection

3.1 Digital Ground (DGND)

Digital ground connection to internal digital circuitry.

3.2 Analog Ground (AGND)

Analog ground connection to internal analog circuitry.

3.3 Analog inputs (CH0 - CH7)

Analog inputs for channels 0 - 7, respectively, for the multiplexed inputs. Each pair of channels can be programmed to be used as two independent channels in single-ended mode or as a single pseudo-differential input where one channel is IN+ and one channel is IN-. See **Section 4.1 “Analog Inputs”**, “Analog Inputs”, and **Section 5.0 “Serial Communication”**, “Serial Communication”, for information on programming the channel configuration.

3.4 Serial Clock (CLK)

The SPI clock pin is used to initiate a conversion and clock out each bit of the conversion as it takes place. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for constraints on clock speed.

3.5 Serial Data Input (D_{IN})

The SPI port serial data input pin is used to load channel configuration data into the device.

3.6 Serial Data Output (D_{OUT})

The SPI serial data output pin is used to shift out the results of the A/D conversion. Data will always change on the falling edge of each clock as the conversion takes place.

3.7 Chip Select/Shutdown ($\overline{\text{CS}}/\text{SHDN}$)

The $\overline{\text{CS}}/\text{SHDN}$ pin is used to initiate communication with the device when pulled low. When pulled high, it will end a conversion and put the device in low-power standby. The $\overline{\text{CS}}/\text{SHDN}$ pin must be pulled high between conversions.

MCP3004/3008

NOTES:

4.0 DEVICE OPERATION

The MCP3004/3008 A/D converters employ a conventional SAR architecture. With this architecture, a sample is acquired on an internal sample/hold capacitor for 1.5 clock cycles starting on the first rising edge of the serial clock once \overline{CS} has been pulled low. Following this sample time, the device uses the collected charge on the internal sample and hold capacitor to produce a serial 10-bit digital output code. Conversion rates of 100 ksp/s are possible on the MCP3004/3008. See **Section 6.2 “Maintaining Minimum Clock Speed”**, “Maintaining Minimum Clock Speed”, for information on minimum clock rates. Communication with the device is accomplished using a 4-wire SPI-compatible interface.

4.1 Analog Inputs

The MCP3004/3008 devices offer the choice of using the analog input channels configured as single-ended inputs or pseudo-differential pairs. The MCP3004 can be configured to provide two pseudo-differential input pairs or four single-ended inputs. The MCP3008 can be configured to provide four pseudo-differential input pairs or eight single-ended inputs. Configuration is done as part of the serial command before each conversion begins. When used in the pseudo-differential mode, each channel pair (i.e., CH0 and CH1, CH2 and CH3 etc.) are programmed as the IN+ and IN- inputs as part of the command string transmitted to the device. The IN+ input can range from IN- to ($V_{REF} + IN-$). The IN- input is limited to ± 100 mV from the V_{SS} rail. The IN- input can be used to cancel small signal common-mode noise, which is present on both the IN+ and IN- inputs.

When operating in the pseudo-differential mode, if the voltage level of IN+ is equal to or less than IN-, the resultant code will be 000h. If the voltage at IN+ is equal to or greater than $\{[V_{REF} + (IN-)] - 1 \text{ LSB}\}$, then the output code will be 3FFh. If the voltage level at IN- is more than 1 LSB below V_{SS} , the voltage level at the IN+ input will have to go below V_{SS} to see the 000h output code. Conversely, if IN- is more than 1 LSB above V_{SS} , the 3FFh code will not be seen unless the IN+ input level goes above V_{REF} level.

For the A/D converter to meet specification, the charge holding capacitor (C_{SAMPLE}) must be given enough time to acquire a 10-bit accurate voltage level during the 1.5 clock cycle sampling period. The analog input model is shown in [Figure 4-1](#).

This diagram illustrates that the source impedance (R_S) adds to the internal sampling switch (R_{SS}) impedance, directly affecting the time that is required to charge the capacitor (C_{SAMPLE}). Consequently, larger source impedances increase the offset, gain and integral linearity errors of the conversion (see [Figure 4-2](#)).

4.2 Reference Input

For each device in the family, the reference input (V_{REF}) determines the analog input voltage range. As the reference input is reduced, the LSB size is reduced accordingly.

EQUATION 4-1: LSB SIZE CALCULATION

$$LSB \text{ Size} = \frac{V_{REF}}{1024}$$

The theoretical digital output code produced by the A/D converter is a function of the analog input signal and the reference input, as shown below.

EQUATION 4-2: DIGITAL OUTPUT CODE CALCULATION

$$Digital \text{ Output Code} = \frac{1024 \times V_{IN}}{V_{REF}}$$

Where:

$$\begin{aligned} V_{IN} &= \text{analog input voltage} \\ V_{REF} &= \text{analog input voltage} \end{aligned}$$

When using an external voltage reference device, the system designer should always refer to the manufacturer's recommendations for circuit layout. Any instability in the operation of the reference device will have a direct effect on the operation of the A/D converter.

MCP3004/3008

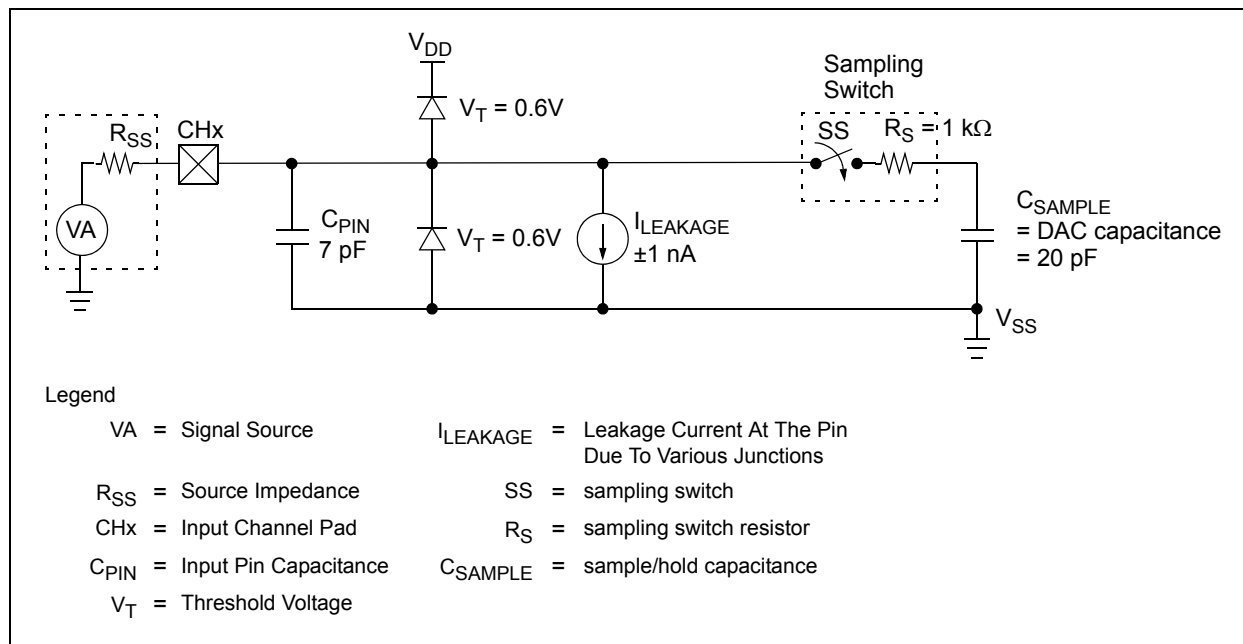


FIGURE 4-1: Analog Input Model.

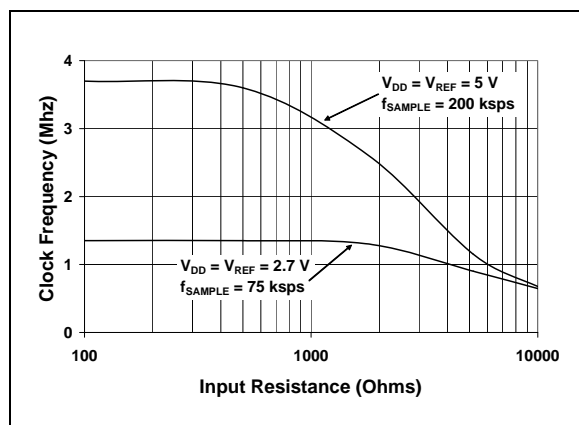


FIGURE 4-2: Maximum Clock Frequency vs. Input resistance (R_S) to maintain less than a 0.1 LSB deviation in INL from nominal conditions.

5.0 SERIAL COMMUNICATION

Communication with the MCP3004/3008 devices is accomplished using a standard SPI-compatible serial interface. Initiating communication with either device is done by bringing the \overline{CS} line low (see Figure 5-1). If the device was powered up with the \overline{CS} pin low, it must be brought high and back low to initiate communication. The first clock received with \overline{CS} low and D_{IN} high will constitute a start bit. The SGL/DIFF bit follows the start bit and will determine if the conversion will be done using single-ended or differential input mode. The next three bits (D0, D1 and D2) are used to select the input channel configuration. Table 5-1 and Table 5-2 show the configuration bits for the MCP3004 and MCP3008, respectively. The device will begin to sample the analog input on the fourth rising edge of the clock after the start bit has been received. The sample period will end on the falling edge of the fifth clock following the start bit.

Once the D0 bit is input, one more clock is required to complete the sample and hold period (D_{IN} is a “don’t care” for this clock). On the falling edge of the next clock, the device will output a low null bit. The next 10 clocks will output the result of the conversion with MSB first, as shown in Figure 5-1. Data is always output from the device on the falling edge of the clock. If all 10 data bits have been transmitted and the device continues to receive clocks while the \overline{CS} is held low, the device will output the conversion result LSB first, as is shown in Figure 5-2. If more clocks are provided to the device while \overline{CS} is still low (after the LSB first data has been transmitted), the device will clock out zeros indefinitely.

If necessary, it is possible to bring \overline{CS} low and clock in leading zeros on the D_{IN} line before the start bit. This is often done when dealing with microcontroller-based SPI ports that must send 8 bits at a time. Refer to Section 6.1 “Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports”, “Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports”, for more details on using the MCP3004/3008 devices with hardware SPI ports.

TABLE 5-1: CONFIGURE BITS FOR THE MCP3004

Control Bit Selections				Input Configuration	Channel Selection
Single/Diff	D2*	D1	D0		
1	X	0	0	single-ended	CH0
1	X	0	1	single-ended	CH1
1	X	1	0	single-ended	CH2
1	X	1	1	single-ended	CH3
0	X	0	0	differential	CH0 = IN+ CH1 = IN-
0	X	0	1	differential	CH0 = IN- CH1 = IN+
0	X	1	0	differential	CH2 = IN+ CH3 = IN-
0	X	1	1	differential	CH2 = IN- CH3 = IN+

* D2 is “don’t care” for MCP3004

TABLE 5-2: CONFIGURE BITS FOR THE MCP3008

Control Bit Selections				Input Configuration	Channel Selection
Single/Diff	D2	D1	D0		
1	0	0	0	single-ended	CH0
1	0	0	1	single-ended	CH1
1	0	1	0	single-ended	CH2
1	0	1	1	single-ended	CH3
1	1	0	0	single-ended	CH4
1	1	0	1	single-ended	CH5
1	1	1	0	single-ended	CH6
1	1	1	1	single-ended	CH7
0	0	0	0	differential	CH0 = IN+ CH1 = IN-
0	0	0	1	differential	CH0 = IN- CH1 = IN+
0	0	1	0	differential	CH2 = IN+ CH3 = IN-
0	0	1	1	differential	CH2 = IN- CH3 = IN+
0	1	0	0	differential	CH4 = IN+ CH5 = IN-
0	1	0	1	differential	CH4 = IN- CH5 = IN+
0	1	1	0	differential	CH6 = IN+ CH7 = IN-
0	1	1	1	differential	CH6 = IN- CH7 = IN+

MCP3004/3008

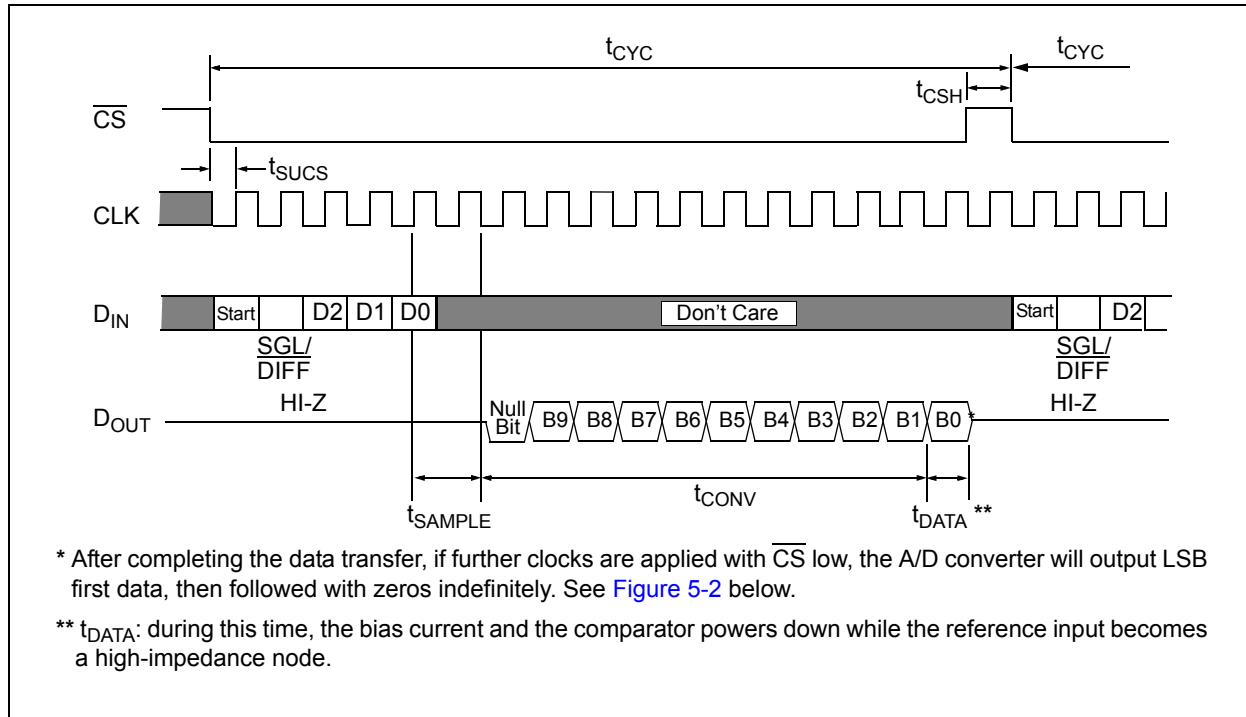


FIGURE 5-1: Communication with the MCP3004 or MCP3008.

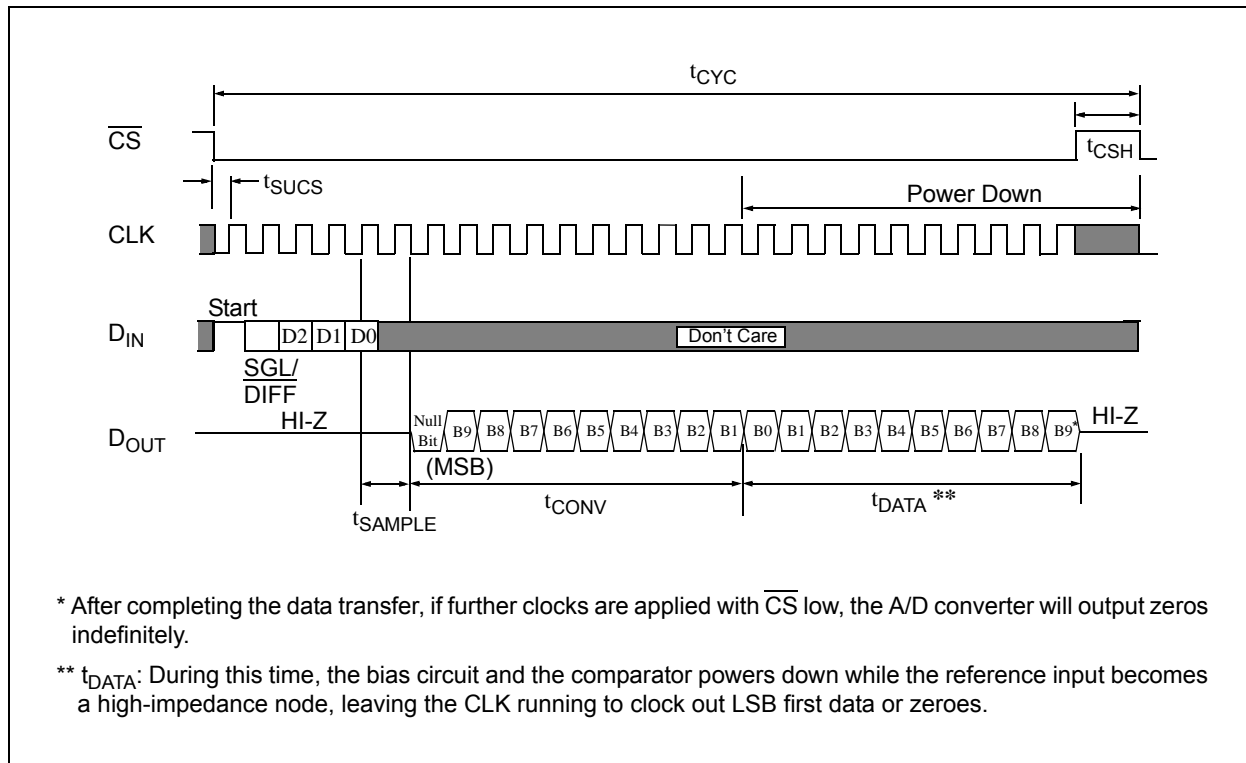


FIGURE 5-2: Communication with MCP3004 or MCP3008 in LSB First Format.

6.0 APPLICATIONS INFORMATION

6.1 Using the MCP3004/3008 with Microcontroller (MCU) SPI Ports

With most microcontroller SPI ports, it is required to send groups of eight bits. It is also required that the microcontroller SPI port be configured to clock out data on the falling edge of clock and latch data in on the rising edge. Because communication with the MCP3004/3008 devices may not need multiples of eight clocks, it will be necessary to provide more clocks than are required. This is usually done by sending 'leading zeros' before the start bit. As an example, [Figure 6-1](#) and [Figure 6-2](#) shows how the MCP3004/3008 can be interfaced to a MCU with a hardware SPI port. [Figure 6-1](#) depicts the operation shown in SPI Mode 0,0, which requires that the SCLK from the MCU idles in the 'low' state, while [Figure 6-2](#) shows the similar case of SPI Mode 1,1, where the clock idles in the 'high' state.

As is shown in [Figure 6-1](#), the first byte transmitted to the A/D converter contains seven leading zeros before the start bit. Arranging the leading zeros this way induces the 10 data bits to fall in positions easily manipulated by the MCU. The MSB is clocked out of the A/D converter on the falling edge of clock number 14. Once the second eight clocks have been sent to the device, the MCU receive buffer will contain five unknown bits (the output is at high-impedance for the first two clocks), the null bit and the highest order 2 bits of the conversion. Once the third byte has been sent to the device, the receive register will contain the lowest order eight bits of the conversion results. Employing this method ensures simpler manipulation of the converted data.

[Figure 6-2](#) shows the same thing in SPI Mode 1,1, which requires that the clock idles in the high state. As with mode 0,0, the A/D converter outputs data on the falling edge of the clock and the MCU latches data from the A/D converter in on the rising edge of the clock.

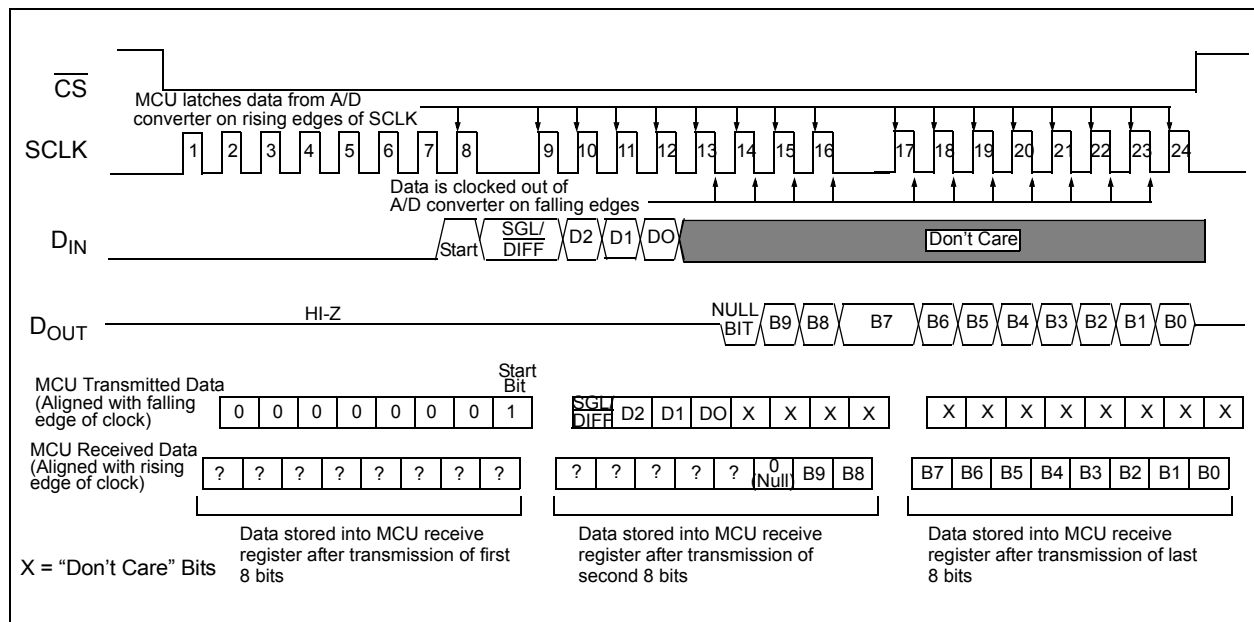


FIGURE 6-1: SPI Communication with the MCP3004/3008 using 8-bit segments (Mode 0,0: SCLK idles low).

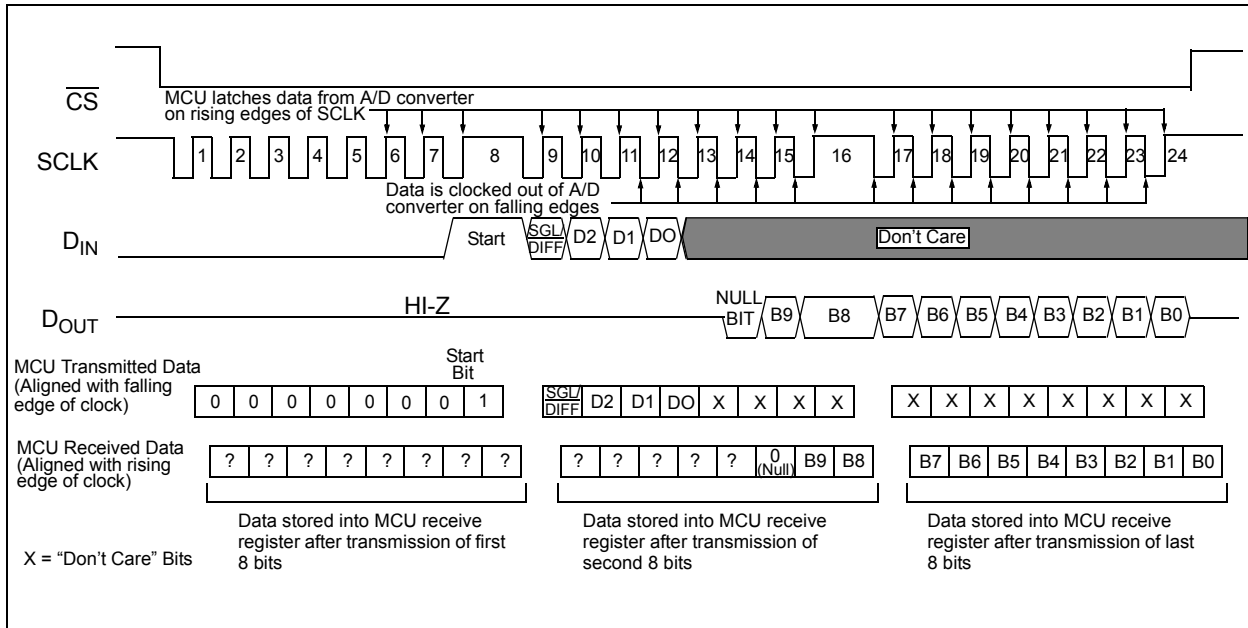


FIGURE 6-2: SPI Communication with the MCP3004/3008 using 8-bit segments (Mode 1,1: SCLK idles high).

6.2 Maintaining Minimum Clock Speed

When the MCP3004/3008 initiates the sample period, charge is stored on the sample capacitor. When the sample period is complete, the device converts one bit for each clock that is received. It is important for the user to note that a slow clock rate will allow charge to bleed off the sample capacitor while the conversion is taking place. At 85°C (worst case condition), the part will maintain proper charge on the sample capacitor for at least 1.2 ms after the sample period has ended. This means that the time between the end of the sample period and the time that all 10 data bits have been clocked out must not exceed 1.2 ms (effective clock frequency of 10 kHz). Failure to meet this criterion may introduce linearity errors into the conversion outside the rated specifications. It should be noted that during the entire conversion cycle, the A/D converter does not require a constant clock speed or duty cycle, as long as all timing specifications are met.

6.3 Buffering/Filtering the Analog Inputs

If the signal source for the A/D converter is not a low-impedance source, it will have to be buffered or inaccurate conversion results may occur (see Figure 4-2). It is also recommended that a filter be used to eliminate any signals that may be aliased back in to the conversion results, as is illustrated in Figure 6-3, where an op amp is used to drive, filter and gain the analog input of the MCP3004/3008. This amplifier provides a low-impedance source for the converter input, plus a low-pass filter, which eliminates unwanted high-frequency noise.

Low-pass (anti-aliasing) filters can be designed using Microchip's free interactive FilterLab® software. FilterLab will calculate capacitor and resistors values, as well as determine the number of poles that are required for the application. For more information on filtering signals, see AN699, "Anti-Aliasing Analog Filters for Data Acquisition Systems".

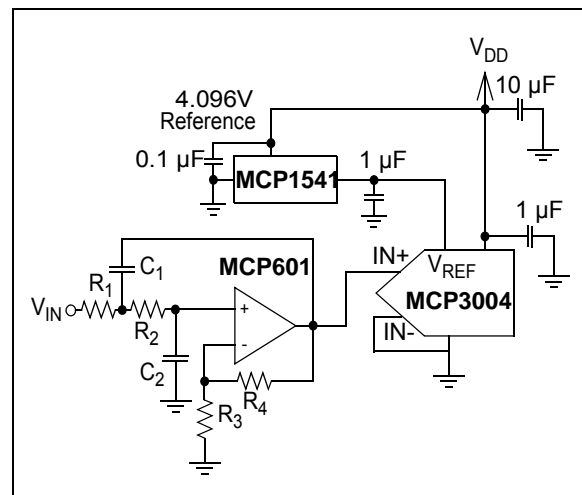


FIGURE 6-3: The MCP601 Operational Amplifier is used to implement a second order anti-aliasing filter for the signal being converted by the MCP3004.

6.4 Layout Considerations

When laying out a printed circuit board for use with analog components, care should be taken to reduce noise wherever possible. A bypass capacitor should always be used with this device and should be placed as close as possible to the device pin. A bypass capacitor value of 1 μF is recommended.

Digital and analog traces should be separated as much as possible on the board, with no traces running underneath the device or bypass capacitor. Extra precautions should be taken to keep traces with high-frequency signals (such as clock lines) as far as possible from analog traces.

Use of an analog ground plane is recommended in order to keep the ground potential the same for all devices on the board. Providing V_{DD} connections to devices in a "star" configuration can also reduce noise by eliminating return current paths and associated errors (see Figure 6-4). For more information on layout tips when using A/D converters, refer to AN688, "Layout Tips for 12-Bit A/D Converter Applications".

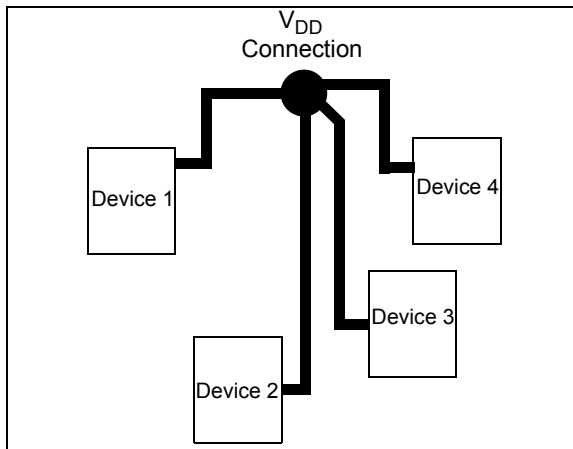


FIGURE 6-4: V_{DD} traces arranged in a 'Star' configuration in order to reduce errors caused by current return paths.

6.5 Utilizing the Digital and Analog Ground Pins

The MCP3004/3008 devices provide both digital and analog ground connections to provide additional means of noise reduction. As is shown in Figure 6-5, the analog and digital circuitry is separated internal to the device. This reduces noise from the digital portion of the device being coupled into the analog portion of the device. The two grounds are connected internally through the substrate which has a resistance of 5 - 10 Ω .

If no ground plane is utilized, both grounds must be connected to V_{SS} on the board. If a ground plane is available, both digital and analog ground pins should be connected to the analog ground plane. If both an analog and a digital ground plane are available, both the digital and the analog ground pins should be connected to the analog ground plane. Following these steps will reduce the amount of digital noise from the rest of the board being coupled into the A/D converter.

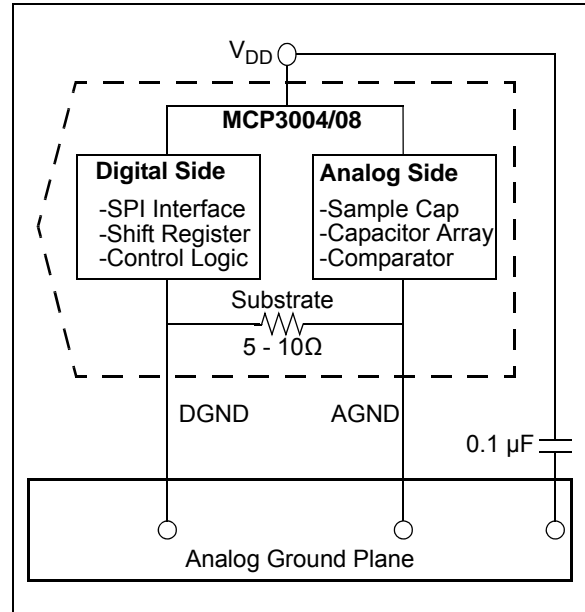


FIGURE 6-5: Separation of Analog and Digital Ground Pins.

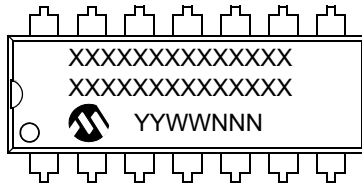
MCP3004/3008

NOTES:

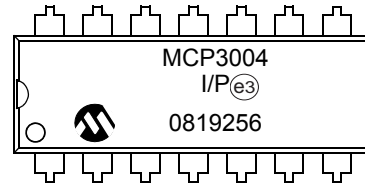
7.0 PACKAGING INFORMATION

7.1 Package Marking Information

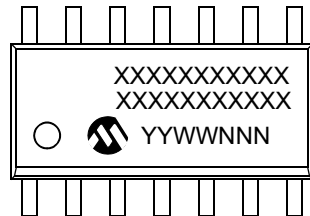
14-Lead PDIP (300 mil)



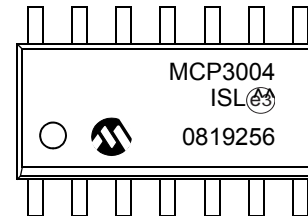
Example:



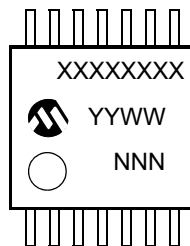
14-Lead SOIC (150 mil)



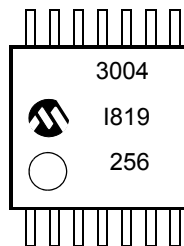
Example:



14-Lead TSSOP (4.4mm) *



Example:



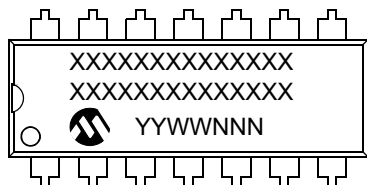
Legend:	XX...X	Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
	e3	Pb-free JEDEC designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator (e3) can be found on the outer packaging for this package.

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

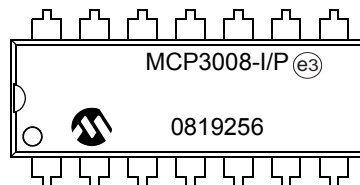
MCP3004/3008

Package Marking Information (Continued)

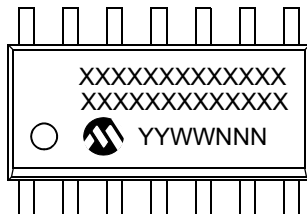
16-Lead PDIP (300 mil) (**MCP3008**)



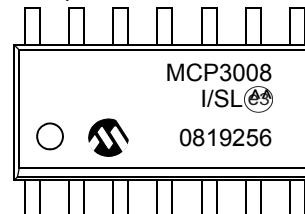
Example:



16-Lead SOIC (150 mil) (**MCP3008**)

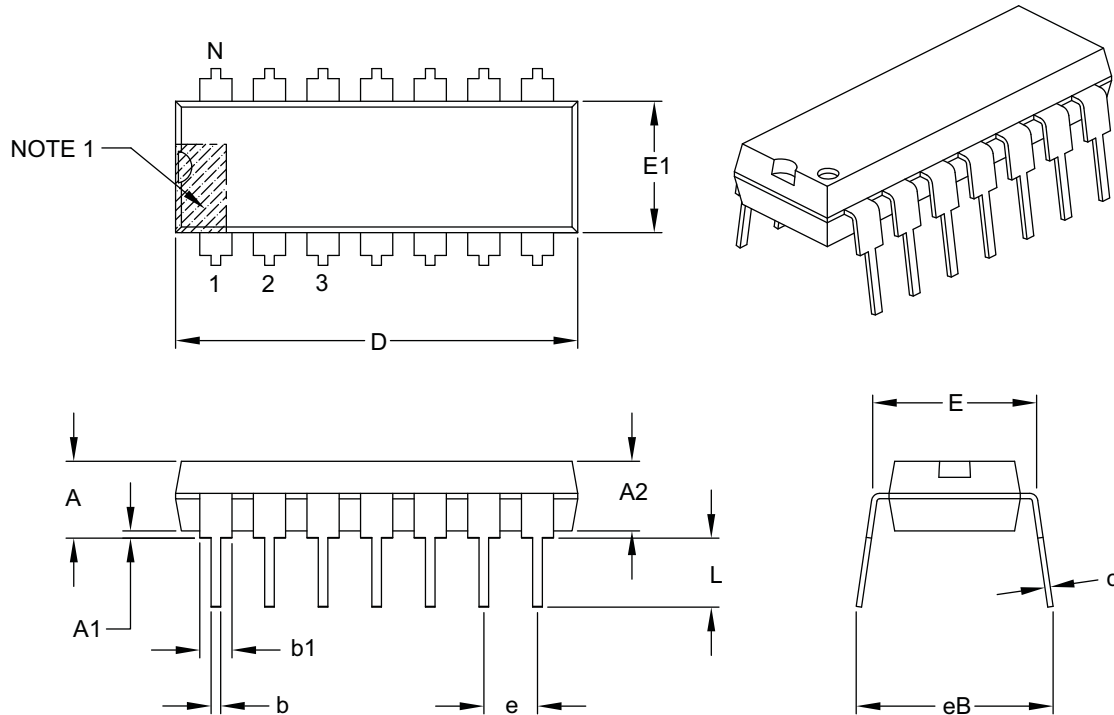


Example:



14-Lead Plastic Dual In-Line (P) – 300 mil Body [PDIP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packages>



Dimension Limits	Units	INCHES		
		MIN	NOM	MAX
Number of Pins	N	14		
Pitch	e	.100 BSC		
Top to Seating Plane	A	–	–	.210
Molded Package Thickness	A2	.115	.130	.195
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.290	.310	.325
Molded Package Width	E1	.240	.250	.280
Overall Length	D	.735	.750	.775
Tip to Seating Plane	L	.115	.130	.150
Lead Thickness	c	.008	.010	.015
Upper Lead Width	b1	.045	.060	.070
Lower Lead Width	b	.014	.018	.022
Overall Row Spacing §	eB	–	–	.430

Notes:

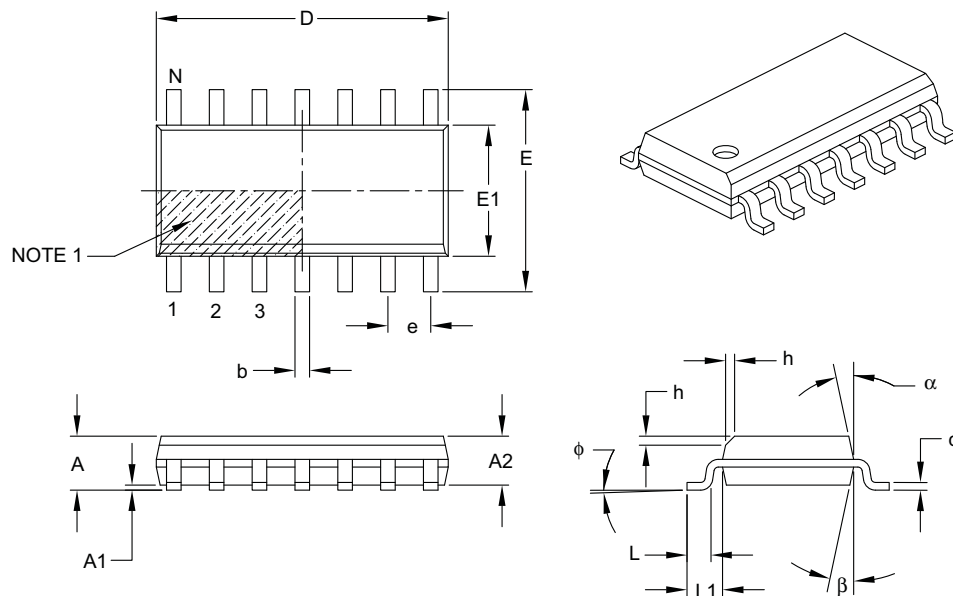
- Pin 1 visual index feature may vary, but must be located with the hatched area.
- § Significant Characteristic.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" per side.
- Dimensioning and tolerancing per ASME Y14.5M.
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-005B

MCP3004/3008

14-Lead Plastic Small Outline (SL) – Narrow, 3.90 mm Body [SOIC]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Dimension Limits	Units	MILLIMETERS		
		MIN	NOM	MAX
Number of Pins	N	14		
Pitch	e	1.27 BSC		
Overall Height	A	–	–	1.75
Molded Package Thickness	A2	1.25	–	–
Standoff §	A1	0.10	–	0.25
Overall Width	E	6.00 BSC		
Molded Package Width	E1	3.90 BSC		
Overall Length	D	8.65 BSC		
Chamfer (optional)	h	0.25	–	0.50
Foot Length	L	0.40	–	1.27
Footprint	L1	1.04 REF		
Foot Angle	φ	0°	–	8°
Lead Thickness	c	0.17	–	0.25
Lead Width	b	0.31	–	0.51
Mold Draft Angle Top	α	5°	–	15°
Mold Draft Angle Bottom	β	5°	–	15°

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- § Significant Characteristic.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
- Dimensioning and tolerancing per ASME Y14.5M.

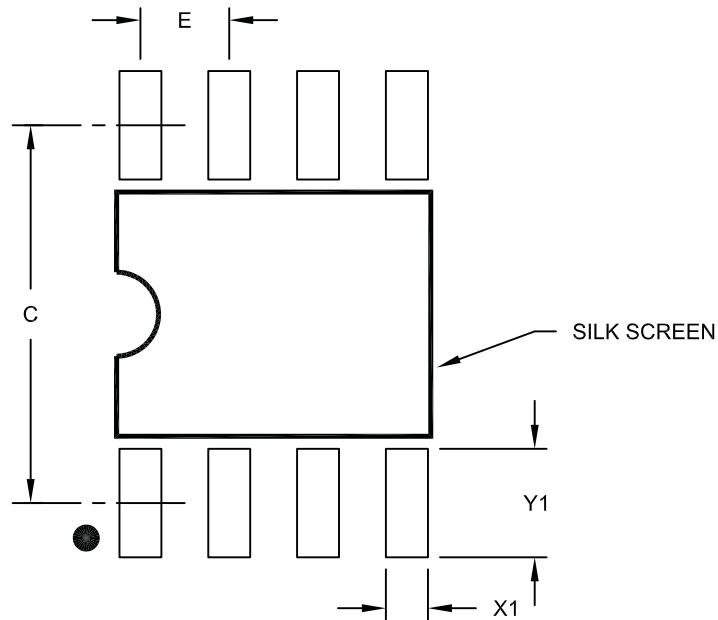
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-065B

8-Lead Plastic Small Outline (SN) – Narrow, 3.90 mm Body [SOIC]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E	1.27 BSC		
Contact Pad Spacing	C		5.40	
Contact Pad Width (X8)	X1			0.60
Contact Pad Length (X8)	Y1			1.55

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

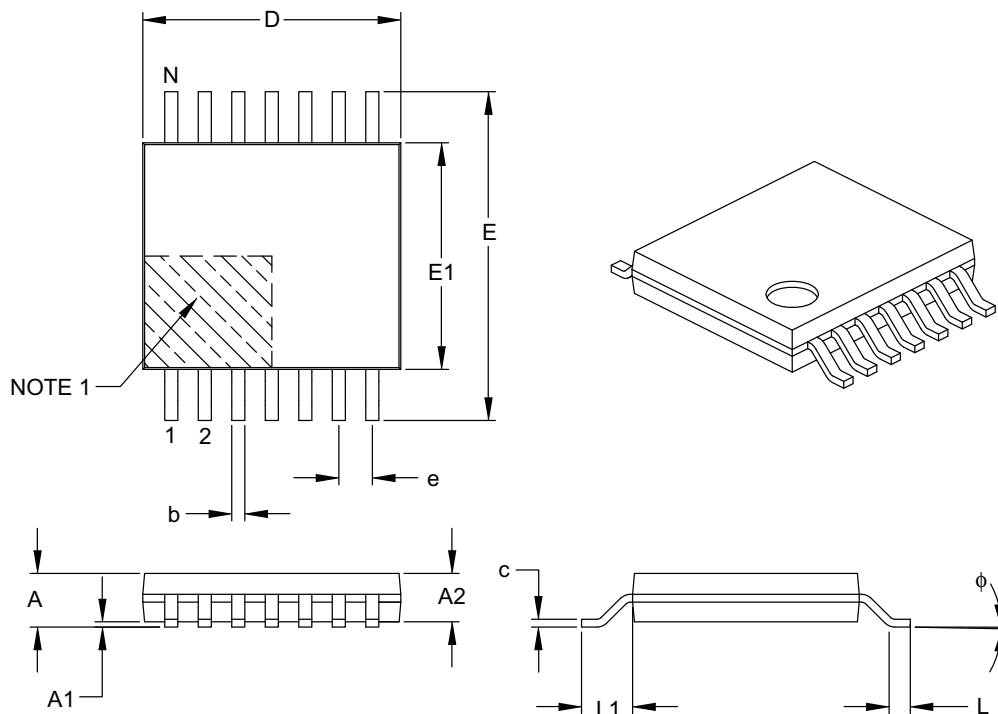
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2057A

MCP3004/3008

14-Lead Plastic Thin Shrink Small Outline (ST) – 4.4 mm Body [TSSOP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Dimension Limits	Units	MILLIMETERS		
		MIN	NOM	MAX
Number of Pins	N	14		
Pitch	e	0.65 BSC		
Overall Height	A	–	–	1.20
Molded Package Thickness	A2	0.80	1.00	1.05
Standoff	A1	0.05	–	0.15
Overall Width	E	6.40 BSC		
Molded Package Width	E1	4.30	4.40	4.50
Molded Package Length	D	4.90	5.00	5.10
Foot Length	L	0.45	0.60	0.75
Footprint	L1	1.00 REF		
Foot Angle	φ	0°	–	8°
Lead Thickness	c	0.09	–	0.20
Lead Width	b	0.19	–	0.30

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
- Dimensioning and tolerancing per ASME Y14.5M.

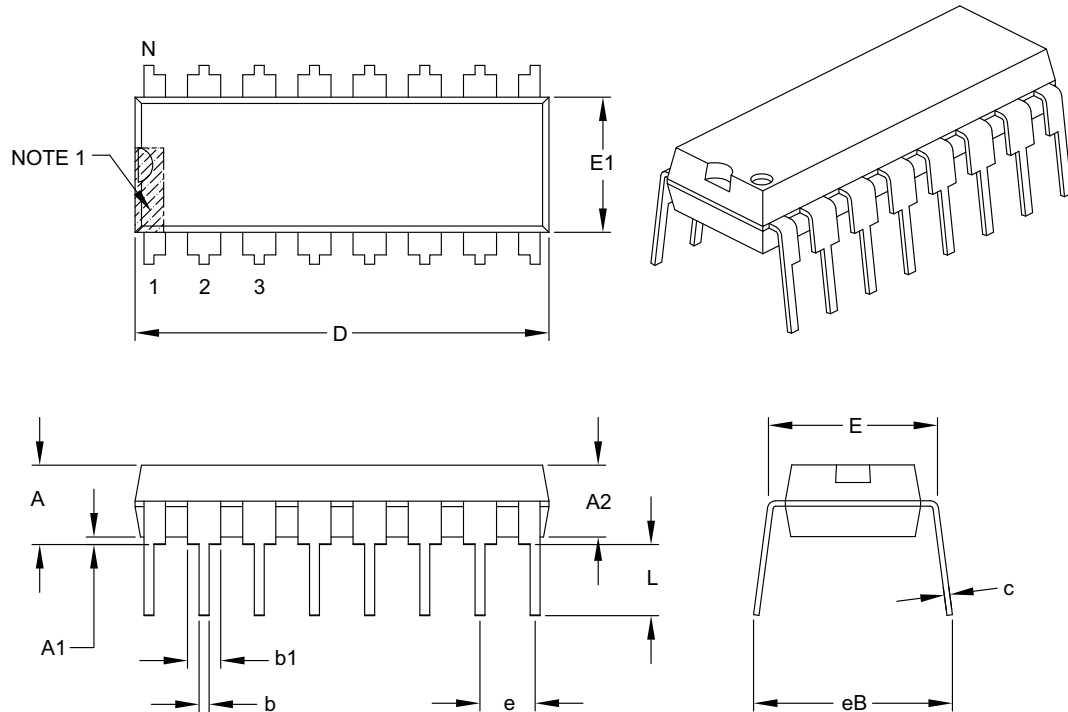
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-087B

16-Lead Plastic Dual In-Line (P) – 300 mil Body [PDIP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packages>



Units		INCHES		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N	16		
Pitch	e	.100 BSC		
Top to Seating Plane	A	–	–	.210
Molded Package Thickness	A2	.115	.130	.195
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.290	.310	.325
Molded Package Width	E1	.240	.250	.280
Overall Length	D	.735	.755	.775
Tip to Seating Plane	L	.115	.130	.150
Lead Thickness	c	.008	.010	.015
Upper Lead Width	b1	.045	.060	.070
Lower Lead Width	b	.014	.018	.022
Overall Row Spacing §	eB	–	–	.430

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- § Significant Characteristic.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" per side.
- Dimensioning and tolerancing per ASME Y14.5M.

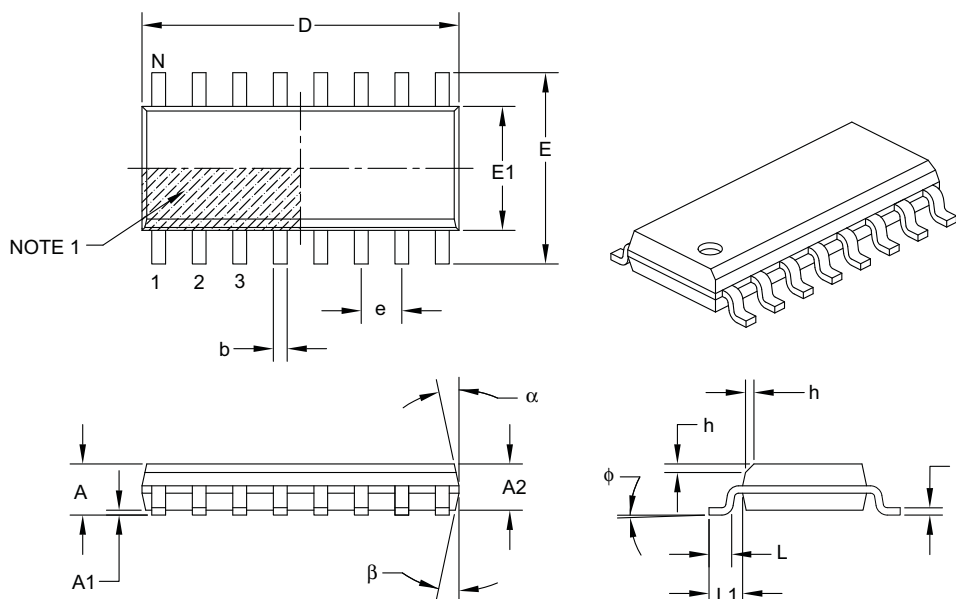
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-017B

MCP3004/3008

16-Lead Plastic Small Outline (SL) – Narrow, 3.90 mm Body [SOIC]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Dimension Limits	Units	MILLIMETERS		
		MIN	NOM	MAX
Number of Pins	N	16		
Pitch	e	1.27 BSC		
Overall Height	A	–	–	1.75
Molded Package Thickness	A2	1.25	–	–
Standoff §	A1	0.10	–	0.25
Overall Width	E	6.00 BSC		
Molded Package Width	E1	3.90 BSC		
Overall Length	D	9.90 BSC		
Chamfer (optional)	h	0.25	–	0.50
Foot Length	L	0.40	–	1.27
Footprint	L1	1.04 REF		
Foot Angle	ϕ	0°	–	8°
Lead Thickness	c	0.17	–	0.25
Lead Width	b	0.31	–	0.51
Mold Draft Angle Top	α	5°	–	15°
Mold Draft Angle Bottom	β	5°	–	15°

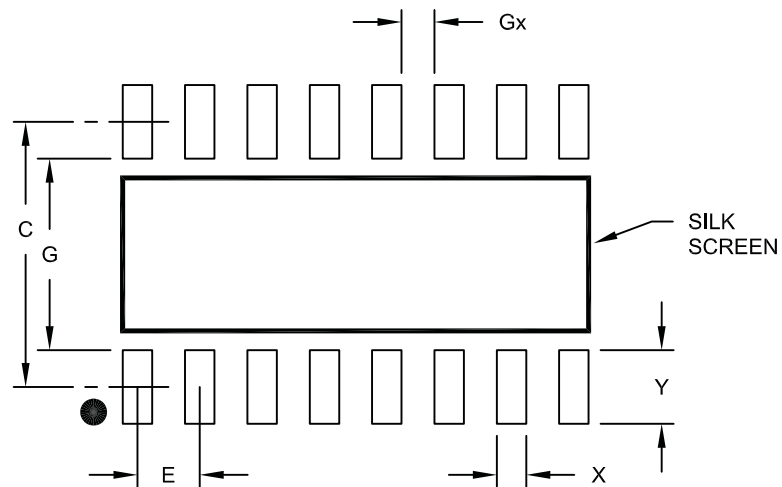
Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- § Significant Characteristic.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15 mm per side.
- Dimensioning and tolerancing per ASME Y14.5M.
BSC: Basic Dimension. Theoretically exact value shown without tolerances.
REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-108B

16-Lead Plastic Small Outline (SL) - Narrow, 3.90 mm Body [SOIC]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E	1.27 BSC		
Contact Pad Spacing	C		5.40	
Contact Pad Width	X			0.60
Contact Pad Length	Y			1.50
Distance Between Pads	Gx	0.67		
Distance Between Pads	G	3.90		

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2108A

MCP3004/3008

NOTES:

APPENDIX A: REVISION HISTORY

Revision D (December 2008)

The following is the list of modifications:

1. Updates to **Section 7.0 “Packaging Information”**.

Revision C (January 2007)

The following is the list of modifications:

1. Updates to the packaging diagrams.

Revision B (May 2002)

The following is the list of modifications:

1. Undocumented changes.

Revision A (February 2000)

- Initial release of this document.

MCP3004/3008

NOTES:

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

<u>PART NO.</u>		<u>X</u>	<u>/XX</u>
Device		Temperature Range	Package
Device	MCP3004:	4-Channel 10-Bit Serial A/D Converter	
	MCP3004T:	4-Channel 10-Bit Serial A/D Converter (Tape and Reel)	
	MCP3008:	8-Channel 10-Bit Serial A/D Converter	
	MCP3008T:	8-Channel 10-Bit Serial A/D Converter (Tape and Reel)	
Temperature Range		I	= -40°C to +85°C (Industrial)
Package	P	= Plastic DIP (300 mil Body), 14-lead, 16-lead	
	SL	= Plastic SOIC (150 mil Body), 14-lead, 16-lead	
	ST	= Plastic TSSOP (4.4mm), 14-lead	

Examples:

a) MCP3004-I/P: Industrial Temperature, PDIP package.

b) MCP3004-I/SL: Industrial Temperature, SOIC package.

c) MCP3004-I/ST: Industrial Temperature, TSSOP package.

d) MCP3004T-I/ST: Industrial Temperature, TSSOP package, Tape and Reel.

a) MCP3008-I/P: Industrial Temperature, PDIP package.

b) MCP3008-I/SL: Industrial Temperature, SOIC package.

MCP3004/3008

NOTES:

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Corporate Office

2355 West Chandler Blvd.
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Tel: 480-792-7200
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Technical Support:
<http://support.microchip.com>
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www.microchip.com

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Asia Pacific Office

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Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
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Fax: 852-2401-3431

Australia - Sydney

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