

## 12-Bit, 500MSPS A/D Converter

### General Description

The KAD5512P-50 is a low-power, high-performance, 12-bit, 500MSPS analog-to-digital converter designed with Kenet's proprietary *FemtoCharge*<sup>®</sup> technology on a standard CMOS process. The KAD5512P-50 is part of a pin-compatible portfolio of 10, 12 and 14-bit A/Ds with sample rates ranging from 125MSPS to 500MSPS.

The device utilizes two time-interleaved 12-bit, 250MSPS A/D cores to achieve the ultimate sample rate of 500MSPS. A single 500MHz conversion clock is presented to the converter, and all interleave clocking is managed internally.

A serial peripheral interface (SPI) port allows for extensive configurability, as well as fine control of matching characteristics (gain, offset, skew) between the two converter cores. These adjustments allow the user to minimize spurs associated with the interleaving process.

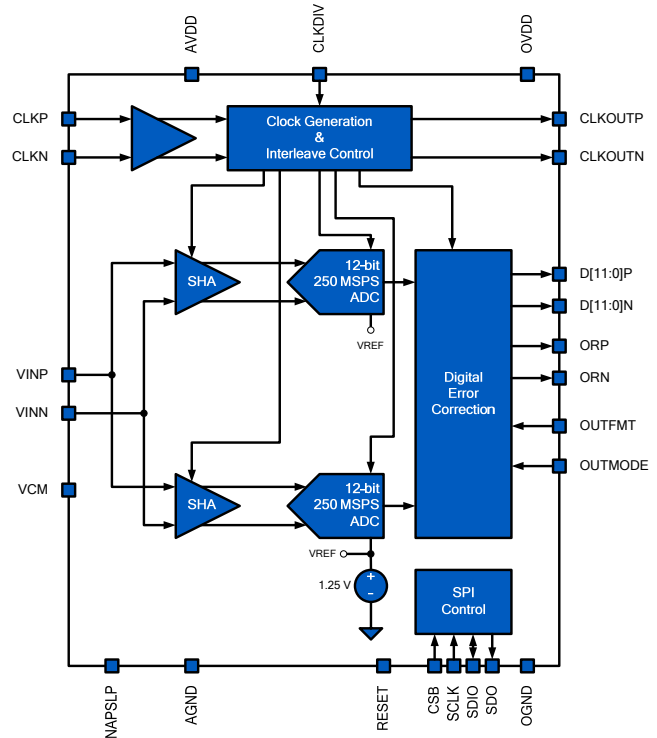
Digital output data is presented in selectable LVDS or CMOS formats. The KAD5512P-50 is available in a 72-contact QFN package with an exposed paddle. Performance is specified over the full industrial temperature range (-40 to +85°C).

### Features

- Programmable gain, offset and skew control
- 1.3 GHz analog input bandwidth
- 52fs Clock Jitter
- Over-range indicator
- Selectable Clock Divider: ÷1 or ÷2
- Clock Phase Selection
- Nap and Sleep modes
- Two's complement, Gray code or Binary data format
- DDR LVDS-compatible or LVCMOS outputs
- Programmable Built-in Test Patterns
- 1.8V Analog and Digital Supplies

### Applications

- Radar and Satellite Antenna Array Processing
- Broadband Communications
- High-Performance Data Acquisition



### Key Specifications

- SNR = 64.3dBFS for  $f_{IN} = 250\text{MHz}$  (-1dBFS)
- SFDR = 80dBc for  $f_{IN} = 250\text{MHz}$  (-1dBFS)
- Power consumption = 400mW

### Pin-Compatible Family

Model	Resolution	Speed (MSPS)
KAD5514P-25	14	250
KAD5514P-21	14	210
KAD5514P-17	14	170
KAD5514P-12	14	125
KAD5512P-50	12	500
KAD5512P-25, KAD5512HP-25	12	250
KAD5512P-21, KAD5512HP-21	12	210
KAD5512P-17, KAD5512HP-17	12	170
KAD5512P-12, KAD5512HP-12	12	125
KAD5510P-50	10	500

# KAD5512P-50

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# KAD5512P-50

## Electrical Specifications

All specifications apply under the following conditions unless otherwise noted: AVDD = 1.8V, OVDD = 1.8V, TA = -40°C to +85°C, AIN = -1dBFS, fsAMPLE = 500MSPS.

## DC Specifications

			KAD5512P-50			
Parameter	Symbol	Conditions	Min	Typ	Max	Units
<b>Analog Input</b>						
Full-Scale Analog Input Range	VFS	Differential	1.38	1.45	1.59	VPP
Input Resistance	RIN	Differential	500			Ω
Input Capacitance	CIN	Differential	4			pF
Full Scale Range Temp. Drift	AVTC	Full Temp	90			ppm/°C
Input Offset Voltage	VOs		±1.5			mV
Gain Error	EG		±0.6			%
Common-Mode Output Voltage	VCM		0.535			V
<b>Power Requirements</b>						
1.8V Analog Supply Voltage	AVDD		1.7	1.8	1.9	V
1.8V Digital Supply Voltage	OVDD		1.7	1.8	1.9	V
1.8V Analog Supply Current	IAVDD		157			mA
1.8V Digital Supply Current	IOVDD		65			mA
Power Supply Rejection Ratio	PSRR		-53			dBFS
<b>Power Dissipation</b>						
Normal Mode	PD		400			mW
Nap Mode	PD		40			mW
Sleep Mode	PD		10			mW

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## AC Specifications

			KAD5512P-50			
Parameter	Symbol	Conditions	Min	Typ	Max	Units
Differential Nonlinearity	DNL	$f_{IN} = 10\text{MHz}$	-1.0	$\pm 0.5$	1.25	LSB
Integral Nonlinearity	INL	$f_{IN} = 10\text{MHz}$	-2.5	$\pm 0.5$	2.5	LSB
Minimum Conversion Rate	$f_s$ MIN				TBD	MSPS
Maximum Conversion Rate	$f_s$ MAX		500			MSPS
Signal-to-Noise Ratio	SNR	$f_{IN} = 10\text{MHz}$		64.3		dBFS
		$f_{IN} = 70\text{MHz}$		64.3		dBFS
		$f_{IN} = 140\text{MHz}$	TBD	64.2		dBFS
		$f_{IN} = 230\text{MHz}$		64.0		dBFS
		$f_{IN} = 400\text{MHz}$		63.2		dBFS
		$f_{IN} = 974\text{MHz}$		58.0		dBFS
Signal-to-Noise and Distortion <sup>1</sup>	SINAD	$f_{IN} = 10\text{MHz}$		63.1		dBFS
		$f_{IN} = 70\text{MHz}$		63.1		dBFS
		$f_{IN} = 140\text{MHz}$	TBD	63.0		dBFS
		$f_{IN} = 230\text{MHz}$		62.8		dBFS
		$f_{IN} = 400\text{MHz}$		61.3		dBFS
		$f_{IN} = 974\text{MHz}$		51.9		dBFS
Effective Number of Bits <sup>1</sup>	ENOB	$f_{IN} = 10\text{MHz}$		10.2		Bits
		$f_{IN} = 70\text{MHz}$		10.2		Bits
		$f_{IN} = 140\text{MHz}$	TBD	10.2		Bits
		$f_{IN} = 230\text{MHz}$		10.1		Bits
		$f_{IN} = 400\text{MHz}$		9.9		Bits
		$f_{IN} = 974\text{MHz}$		8.3		Bits
Spurious-Free Dynamic Range <sup>1</sup>	SFDR	$f_{IN} = 10\text{MHz}$		81		dBc
		$f_{IN} = 70\text{MHz}$		81		dBc
		$f_{IN} = 140\text{MHz}$	TBD	79		dBc
		$f_{IN} = 230\text{MHz}$		79		dBc
		$f_{IN} = 400\text{MHz}$		70		dBc
		$f_{IN} = 974\text{MHz}$		55		dBc
Intermodulation Distortion	IMD	$f_{IN} = 10\text{MHz}$		TBD		dBc
		$f_{IN} = 70\text{MHz}$		-90.5	TBD	dBc
		$f_{IN} = 170\text{MHz}$		-86.0		dBc
Two-Tone SFDR	2TSFDR	$f_{IN} = 10\text{MHz}$		TBD		dBc
		$f_{IN} = 124\text{MHz}$	TBD	TBD		dBc
		$f_{IN} = 170\text{MHz}$		TBD		dBc
Word Error Rate				$10^{-12}$		
Full Power Bandwidth	FPBW			1.3		GHz

1. SFDR, SINAD and ENOB specifications apply after gain error and timing skew between ADC cores have been minimized through external calibration.

# KAD5512P-50

## Digital Specifications

Parameter	Symbol	Conditions	Min	Typ	Max	Units
<b>Inputs</b>						
Input Current High (RESETN)	$I_{IH}$	$V_{IN} = 1.8V$	0	1	10	$\mu A$
Input Current Low (RESETN)	$I_{IL}$	$V_{IN} = 0V$	25	50	75	$\mu A$
Input Current High (OUTMODE, NAP/SLP, CLKDIV, OUTFMT)	$I_{IH}$		TBD	25	TBD	$\mu A$
Input Current Low (OUTMODE, NAP/SLP, CLKDIV, OUTFMT)	$I_{IL}$		TBD	25	TBD	$\mu A$
Input Capacitance	$C_{DI}$			3		pF
<b>LVDS Outputs</b>						
Differential Output Voltage	$V_T$			210		mV
Output Offset Voltage	$V_{OS}$			TBD		mV
Output Rise Time	$t_R$			500		ps
Output Fall Time	$t_F$			500		ps
<b>CMOS Outputs</b>						
Voltage Output High	$V_{OH}$			OVDD-0.1		V
Voltage Output Low	$V_{OL}$			0.1		V
Output Rise Time	$t_R$			TBD		ns
Output Fall Time	$t_F$			TBD		ns

## Timing Diagrams

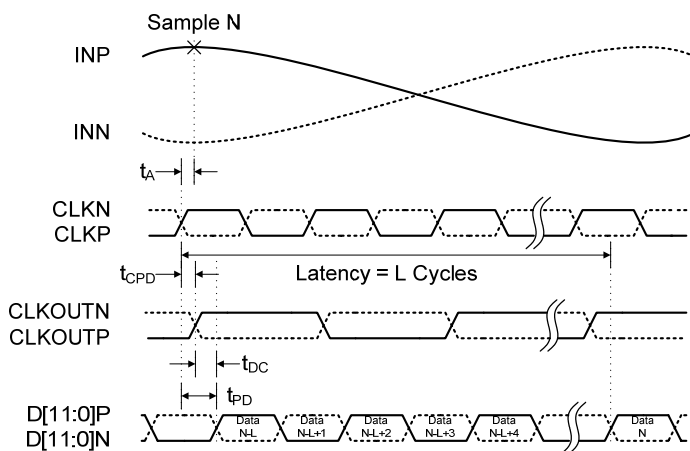


Figure 1. LVDS Timing Diagram

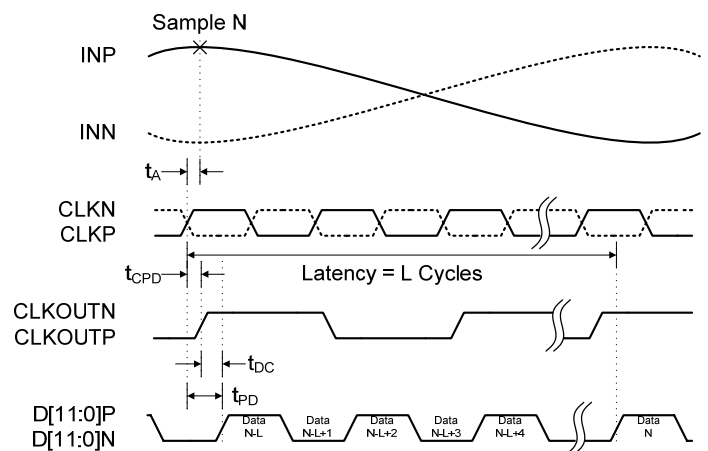


Figure 2. CMOS Timing Diagram

# KAD5512P-50

## Switching Specifications

Parameter	Symbol	Min	Typ	Max	Units
<b>ADC</b>					
Aperture Delay	$t_A$		375		ps
RMS Aperture Jitter	$j_A$		52		fs
Input Clock to Output Clock Propagation Delay	$t_{CPD}$	TBD	TBD	TBD	ps
Input Clock to Data Propagation Delay	$t_{PD}$	TBD	TBD	TBD	ps
Output Clock to Data Propagation Delay	$t_{DC}$	TBD	TBD	TBD	ps
Latency (Pipeline Delay)	L		15		cycles
Over Voltage Recovery	$t_{OVR}$		1		cycles

## Absolute Maximum Ratings<sup>1</sup>

Parameter	Min	Max	Unit
AVDD to AVSS	-0.4	2.1	V
OVDD to OVSS	-0.4	2.1	V
AVSS to OVSS	-0.3	0.3	V
Analog Inputs to AVSS	-0.4	AVDD + 0.3	V
Clock Inputs to AVSS	-0.4	AVDD + 0.3	V
Logic Input to AVSS	-0.4	OVDD + 0.3	V
Logic Inputs to OVSS	-0.4	OVDD + 0.3	V
Operating Temperature	-40	85	°C
Storage Temperature	-65	150	°C
Junction Temperature		150	°C

1. Exposing the device to levels in excess of the maximum ratings may cause permanent damage. Exposure to maximum conditions for extended periods may affect device reliability.

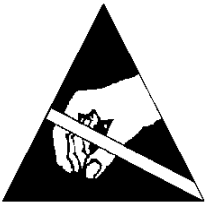
# KAD5512P-50

## Thermal Impedance

Parameter	Symbol	Typ	Unit
Junction to Paddle <sup>2</sup>	$\Phi_{JP}$	30	°C/W
Junction to Case <sup>2</sup>	$\Phi_{JC}$	TBD	°C/W
Junction to Ambient <sup>2</sup>	$\Phi_{JA}$	TBD	°C/W

2. Paddle soldered to ground plane.

## ESD



Electrostatic charge accumulates on humans, tools and equipment and may discharge through any metallic package contacts (pins, balls, exposed paddle, etc.) of an integrated circuit. Industry-standard protection techniques have been utilized in the design of this product. However, reasonable care must be taken in the storage and handling of ESD sensitive products. Contact Kenet for the specific ESD sensitivity rating of this product.

# KAD5512P-50

## Pin Descriptions

Pin #	LVDS [LVCMOS] Name	LVDS [LVCMOS] Function
1, 6, 12, 19, 24, 71	AVDD	1.8V Analog Supply
2-5, 13, 14, 17, 18, 28-31	DNC	Do Not Connect
7, 8, 11, 72	AVSS	Analog Ground
9, 10	VINN, VINP	Analog Input Negative, Positive
15	VCM	Common Mode Output
16	CLKDIV	Clock Divider Control
20, 21	CLKP, CLKN	Clock Input True, Complement
22	OUTMODE	Output Mode (LVDS, LVCMOS)
23	NAPSLP	Power Control (Nap, Sleep modes)
25	RESETN	Power On Reset (Active Low)
26, 45, 55, 65	OVSS	Output Ground
27, 36, 56	OVDD	1.8V Output Supply
32, 33	D0N, D0P [NC, D0]	LVDS Bit 0 (LSB) Output Complement, True [NC, LVCMOS Bit 0]
34, 35	D1N, D1P [NC, D1]	LVDS Bit 1 Output Complement, True [NC, LVCMOS Bit 1]
37, 38	D2N, D2P [NC, D2]	LVDS Bit 2 Output Complement, True [NC, LVCMOS Bit 2]
39, 40	D3N, D3P [NC, D3]	LVDS Bit 3 Output Complement, True [NC, LVCMOS Bit 3]
41, 42	D4N, D4P [NC, D4]	LVDS Bit 4 Output Complement, True [NC, LVCMOS Bit 4]
43, 44	D5N, D5P [NC, D5]	LVDS Bit 5 Output Complement, True [NC, LVCMOS Bit 5]
46	RLVDS	LVDS Bias Resistor (connect to OVSS with a 10k $\Omega$ , 1% resistor)
47, 48	CLKOUTN, CLKOUTP [NC, CLKOUT]	LVDS Clock Output Complement, True [NC, LVCMOS CLKOUT]
49, 50	D6N, D6P [NC, D6]	LVDS Bit 6 Output Complement, True [NC, LVCMOS Bit 6]
51, 52	D7N, D7P [NC, D7]	LVDS Bit 7 Output Complement, True [NC, LVCMOS Bit 7]
53, 54	D8N, D8P [NC, D8]	LVDS Bit 8 Output Complement, True [NC, LVCMOS Bit 8]
57, 58	D9N, D9P [NC, D9]	LVDS Bit 9 Output Complement, True [NC, LVCMOS Bit 9]
59, 60	D10N, D10P [NC, D10]	LVDS Bit 10 Output Complement, True [NC, LVCMOS Bit 10]
61, 62	D11N, D11P [NC, D11]	LVDS Bit 11 (MSB) Output Complement, True [NC, LVCMOS Bit 11]
63, 64	ORN, ORP [NC, OR]	LVDS Over Range Complement, True [NC, LVCMOS Over Range]
66	SDO	SPI Serial Data Output ( <b>4.7k<math>\Omega</math> pull-up to OVDD is required</b> )
67	CSB	SPI Chip Select (active low)
68	SCLK	SPI Clock
69	SDIO	SPI Serial Data Input/Output
70	OUTFMT	Output Data Format (Two's Comp., Gray Code, Offset Binary)
Exposed Paddle	AVSS	Analog Ground

LVCMOS Output Mode Functionality is shown in brackets (NC = No Connection)



# KAD5512P-50

## Pin Configuration

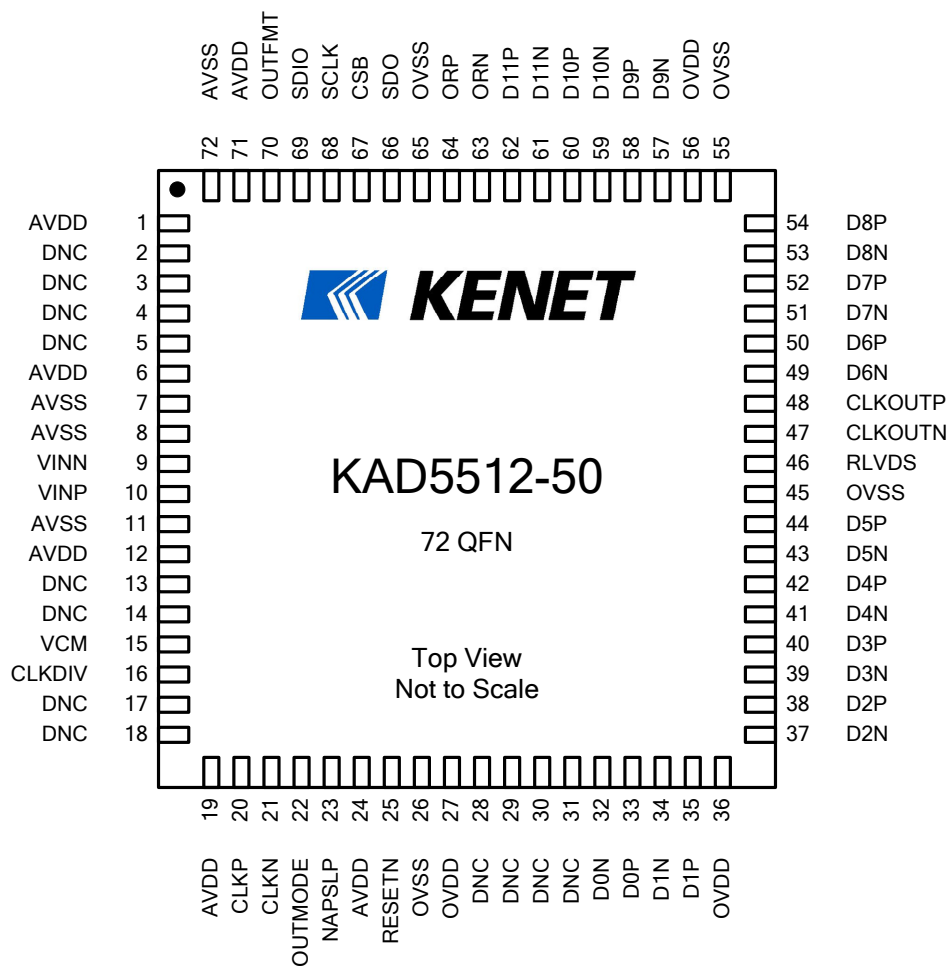


Figure 3. Pin Configuration

# KAD5512P-50

## Typical Performance Curves

All specifications apply under the following conditions unless otherwise noted: AVDD = 1.8V, OVDD = 1.8V, TA = +25°C, AIN = -1dBFS, fSAMPLE = 500MSPS.

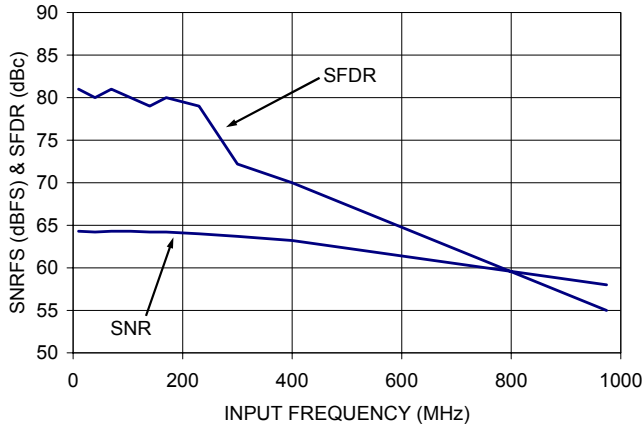


Figure 4. SNR & SFDR vs.  $f_{IN}$

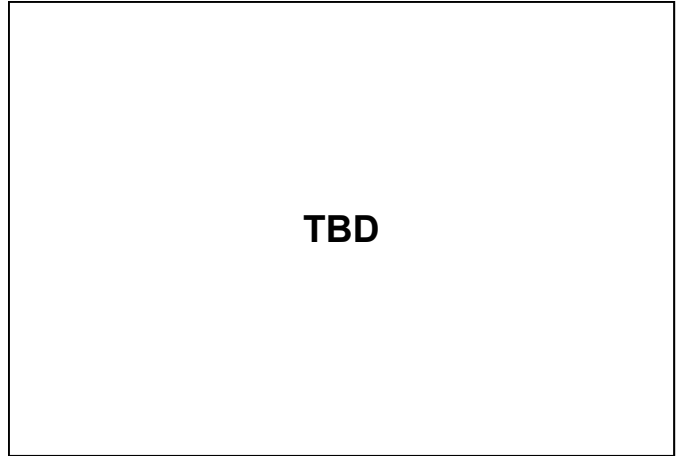


Figure 5. HD2 & HD3 vs.  $f_{IN}$

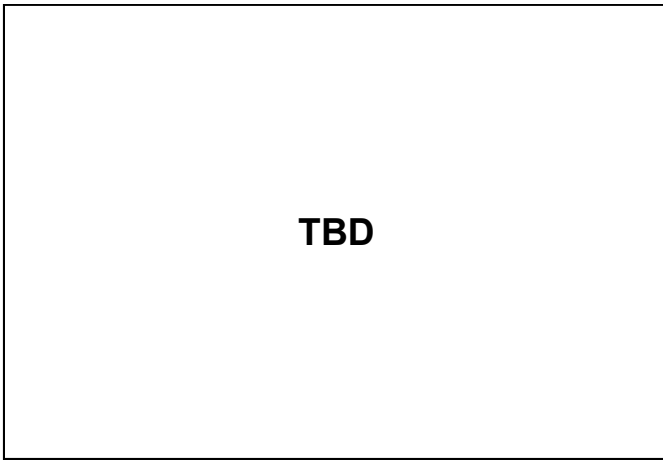


Figure 6. SNR & SFDR vs.  $A_{IN}$

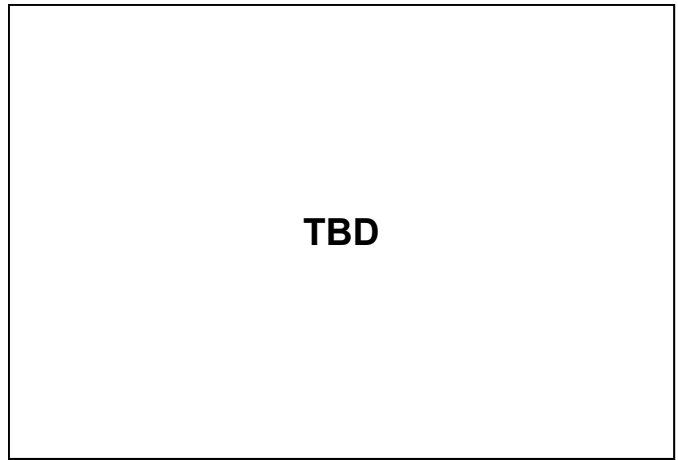


Figure 7. HD2 & HD3 vs.  $A_{IN}$

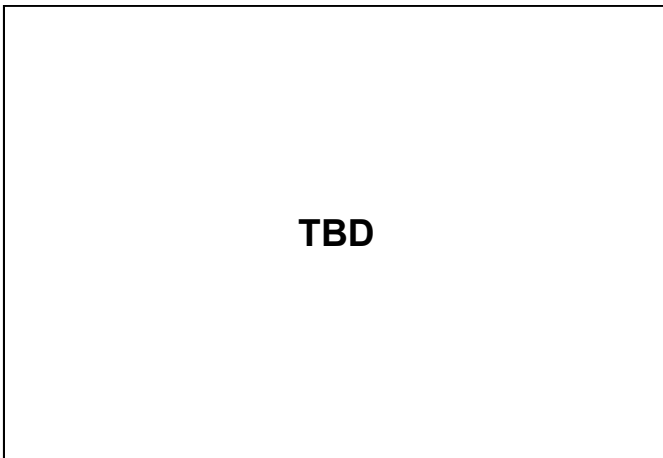


Figure 8. SNR & SFDR vs.  $f_{SAMPLE}$

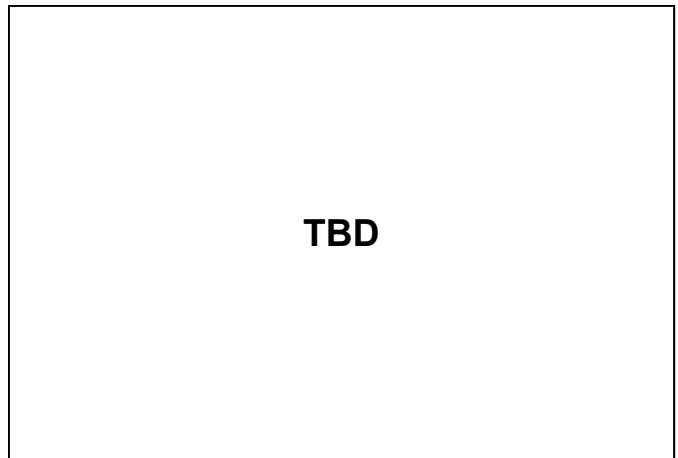


Figure 9. HD2 & HD3 vs.  $f_{SAMPLE}$

Note: SFDR, SINAD and ENOB specifications apply after gain error and timing skew between ADC cores have been minimized through external calibration.

## Typical Performance Curves

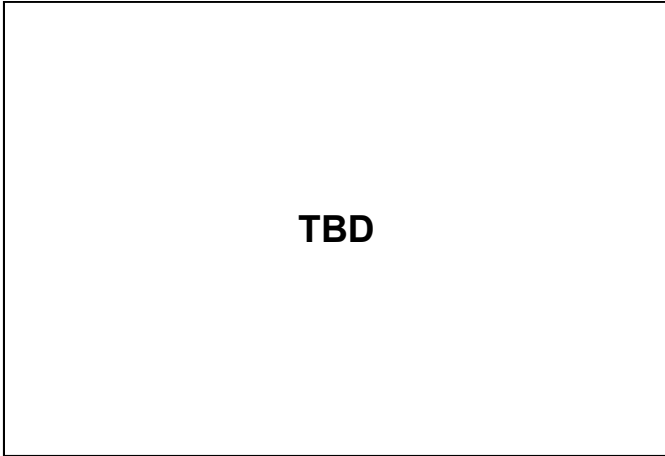


Figure 10. Power vs.  $f_{\text{SAMPLE}}$



Figure 11. Differential Nonlinearity

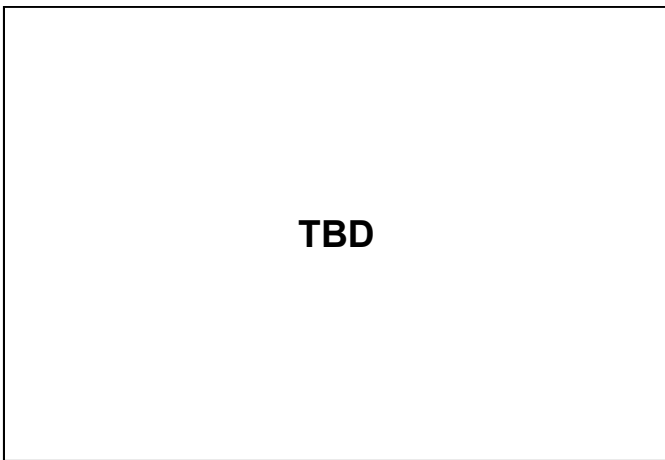


Figure 12. Integral Nonlinearity

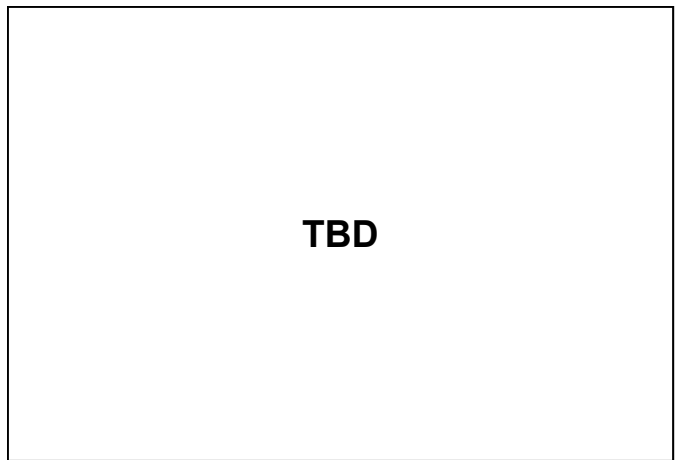


Figure 13. SNR & SFDR vs. VCM

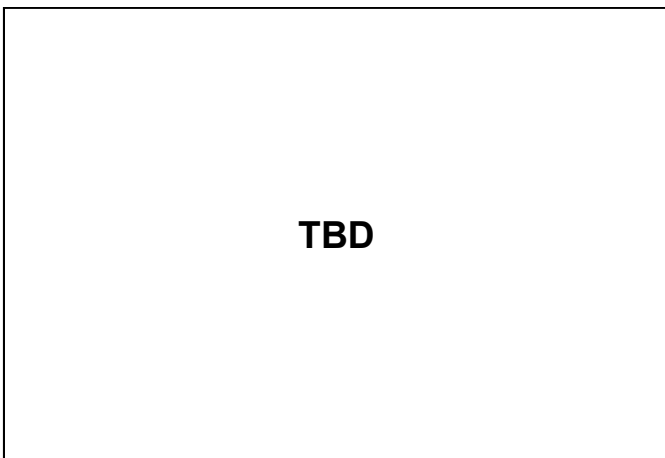


Figure 14. Noise Histogram

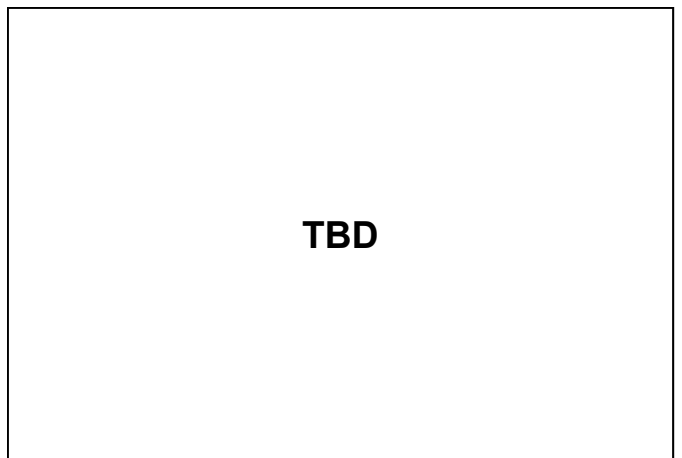


Figure 15. Single Tone Spectrum @ 10 MHz

## Typical Performance Curves

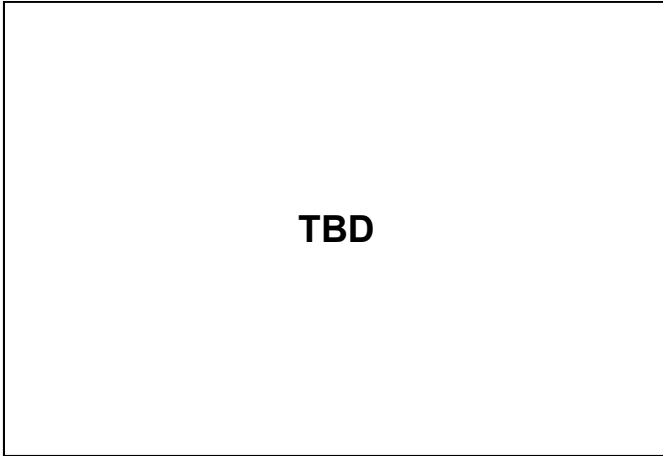


Figure 16. Single Tone Spectrum @ 70 MHz

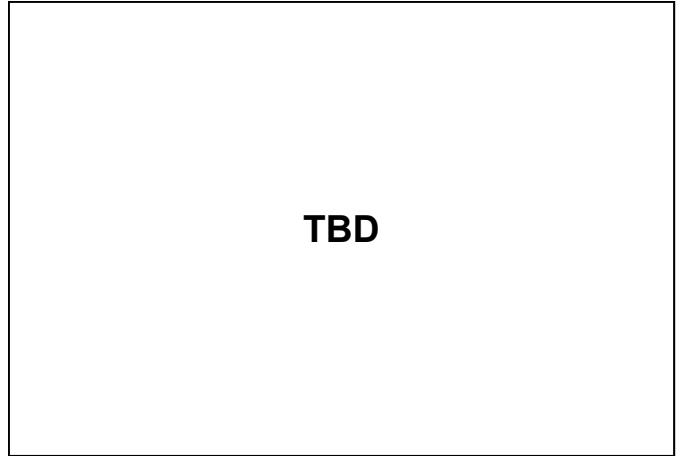


Figure 17. Single Tone Spectrum @ 140 MHz

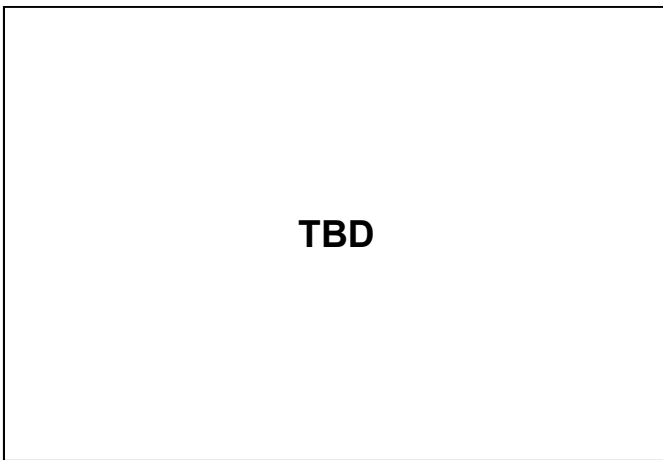


Figure 18. Single Tone Spectrum @ 240 MHz

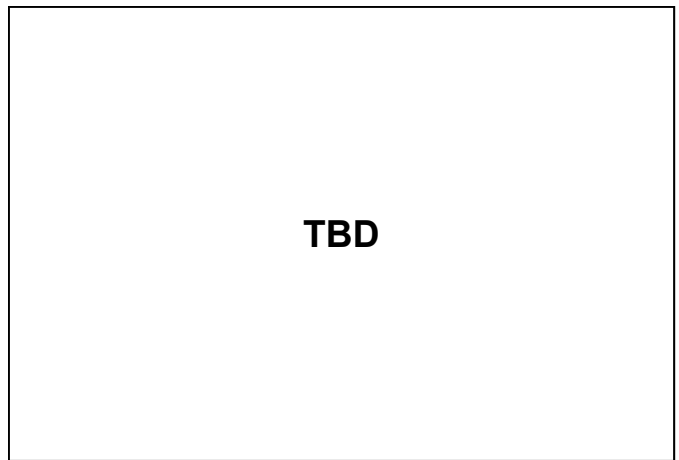


Figure 19. Single Tone Spectrum @ 500 MHz

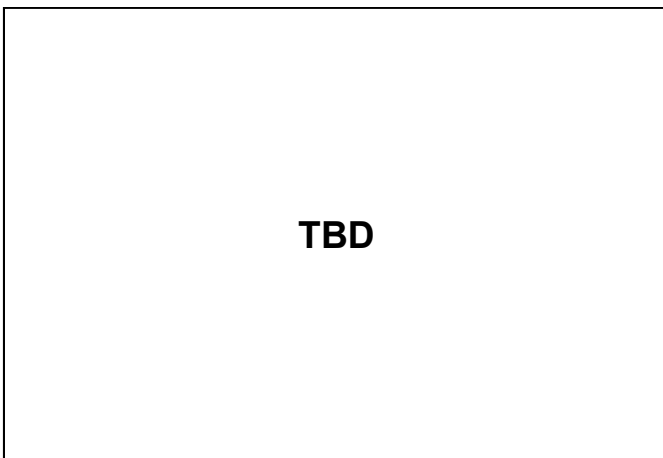


Figure 20. Two-Tone Spectrum @ 10 MHz

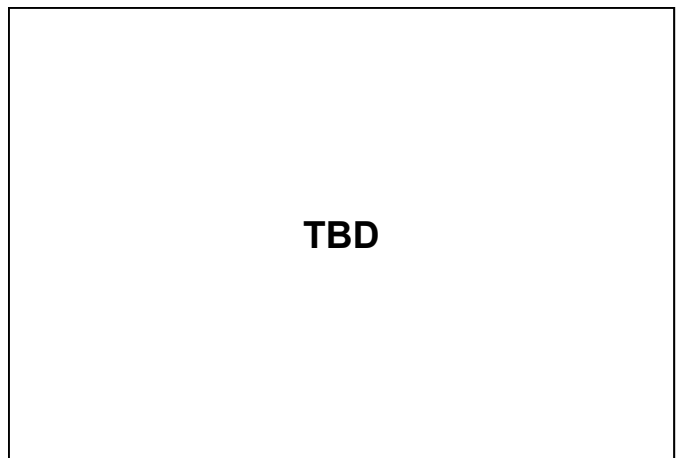


Figure 21. Two-Tone Spectrum @ 70 MHz

## Typical Performance Curves

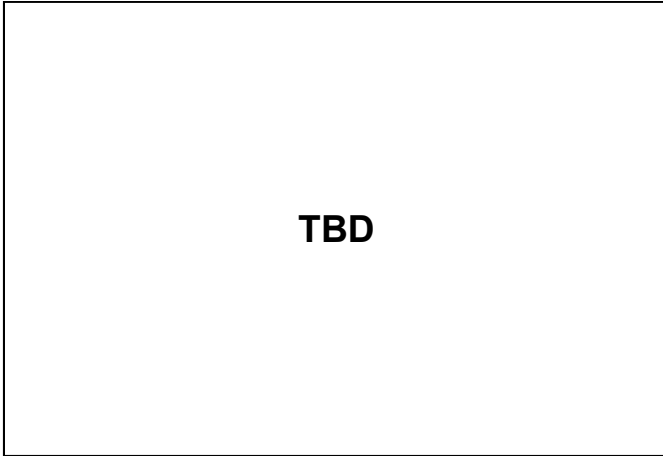


Figure 22. Two-Tone Spectrum @ 140 MHz

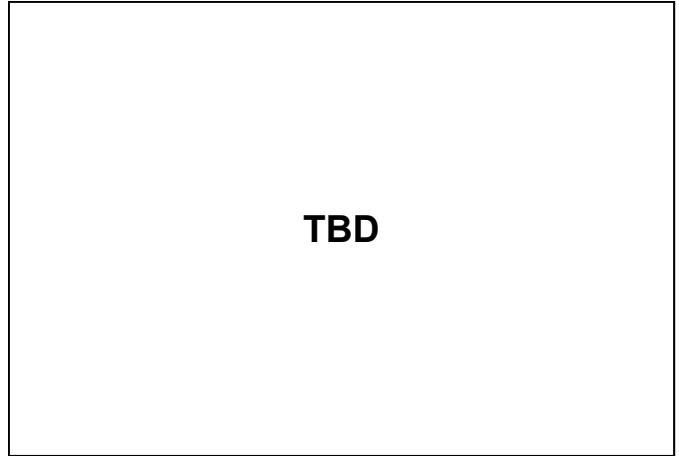


Figure 23. Two-Tone Spectrum @ 240 MHz

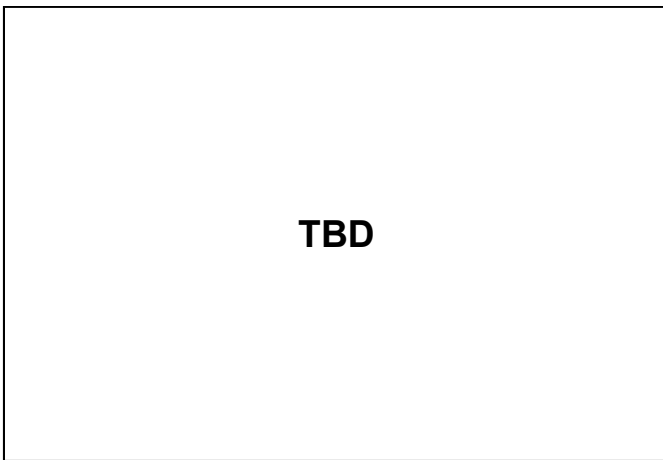


Figure 24. Two-Tone Spectrum @ 500 MHz

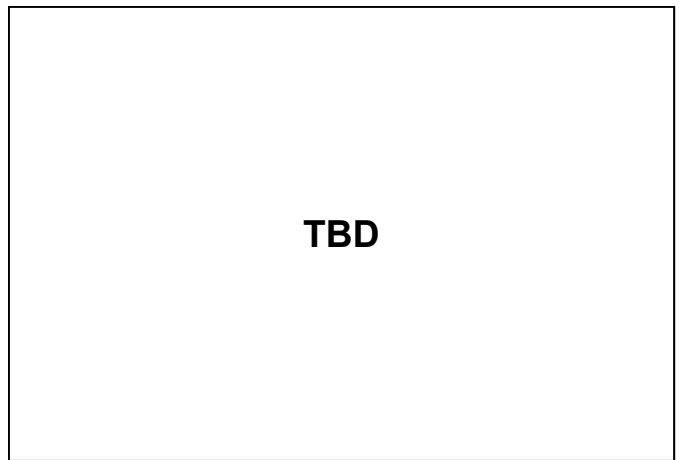


Figure 25. SNR & SFDR vs. Temperature

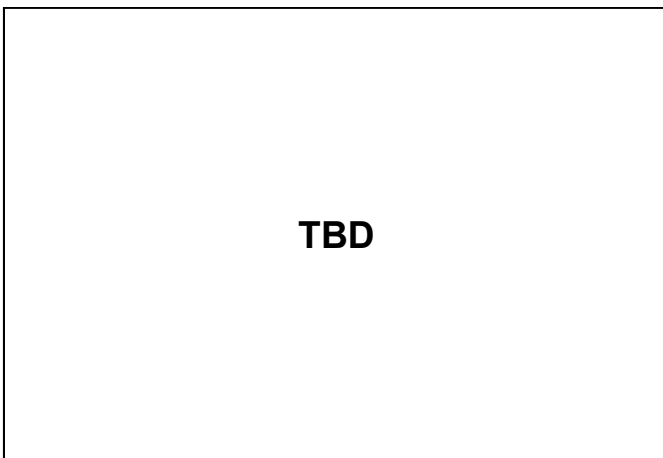


Figure 26. SNR & SFDR vs. Power Supply Voltage

# KAD5512P-50

## Functional Description

The KAD5512P-50 is based upon a 12-bit, 250MSPS A/D converter core that utilizes a pipelined successive approximation architecture (Figure 27). The input voltage is captured by a Sample-Hold Amplifier (SHA) and converted to a unit of charge. Proprietary charge domain techniques are used to successively compare the input to a series of reference charges. Decisions made during the successive approximation operations determine the digital code for each input value. The converter pipeline requires twelve samples to produce a result. Digital error correction is also applied, resulting in a total latency of fifteen clock cycles. This is evident to the user as a latency between the start of a conversion and the data being available on the digital outputs.

The device contains two A/D converter cores with carefully matched transfer characteristics. The cores are clocked on opposite clock edges, resulting in a doubling of the sample rate. The gain, offset and skew errors between the two cores are adjustable via the SPI port to minimize spurs associated with the interleaving process.

At start-up, each core performs a self-calibration to minimize gain and offset errors. The reset pin (RESETN) is initially set high at power-up and will remain in that state until the calibration is complete. The clock fre-

quency should remain fixed during this time, and no SPI communications should be attempted. Recalibration can be initiated via the SPI port at any time after the initial self-calibration.

## Power-On Calibration

At start-up, the core performs a self-calibration to minimize gain and offset errors. An internal power-on-reset (POR) circuit detects the supply voltage ramps and initiates the calibration when the analog and digital supply voltages are above a threshold. The following conditions must be adhered to for the power-on calibration to execute successfully:

- A frequency-stable conversion clock must be applied to the CLKP/CLKN pins
- DNC pins (especially 3, 4 and 18) must not be pulled up or down
- SDO (pin 66) must be high
- RESETN (pin 25) must begin low
- SPI communications must not be attempted

A user-initiated reset can subsequently be invoked in the event that the above conditions cannot be met at power-up.

The SDO pin requires an external 4.7kΩ pull-up to OVDD. If the SDO pin is pulled low externally during power-up, calibration will not be executed properly.

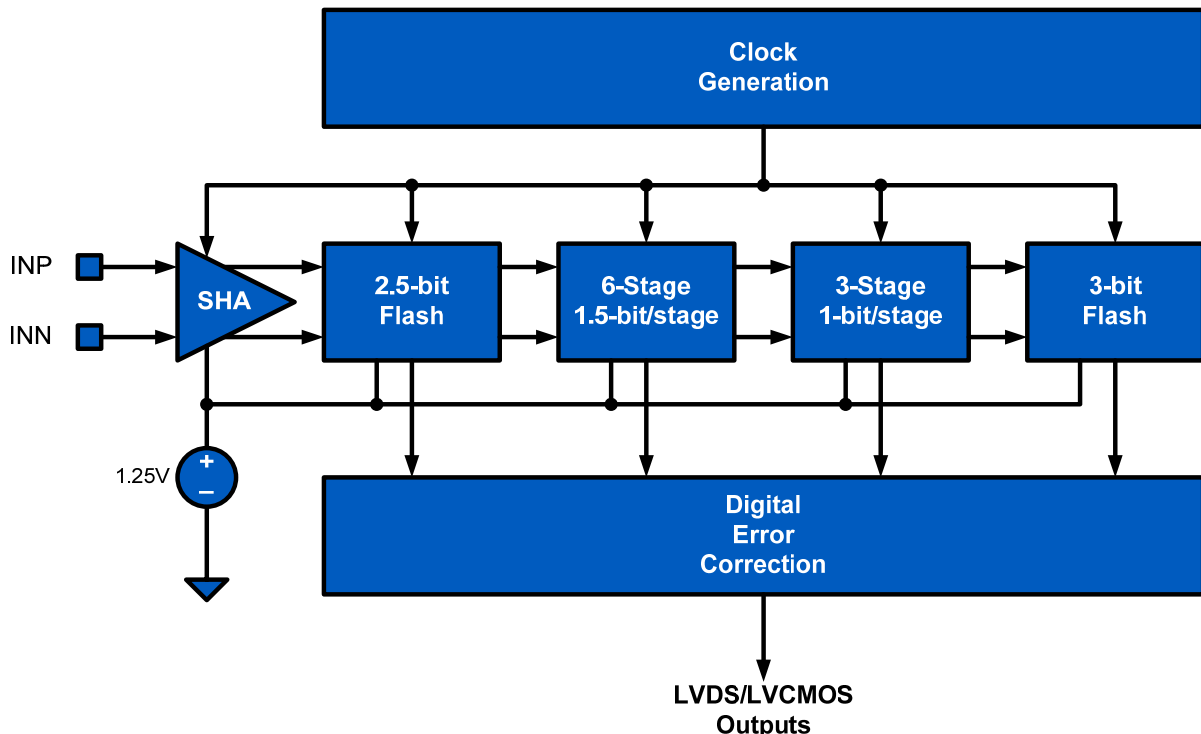


Figure 27. ADC Core Block Diagram

# KAD5512P-50

After the power supply has stabilized the internal POR releases RESETN and an internal pull-up pulls it high, which starts the calibration sequence. The RESETN pin should be connected to an open-drain driver with a drive strength of less than 0.5mA.

The calibration sequence is initiated on the rising edge of RESETN, as shown in Figure 28. The over-range output (OR) is set high once RESETN is pulled low, and remains in that state until calibration is complete. The OR output returns to normal operation at that time, so it's important that the analog input be within the converter's full-scale range in order to observe the transition. If the input is in an over-range condition the OR pin will stay high and it will not be possible to detect the end of the calibration cycle.

While RESETN is low, the output clock (CLKOUTP/CLKOUTN) stops toggling and is set low. Normal operation of the output clock resumes at the next input clock edge (CLKP/CLKN) after RESETN is deasserted. At 500MSPS the nominal calibration time is TBDms.

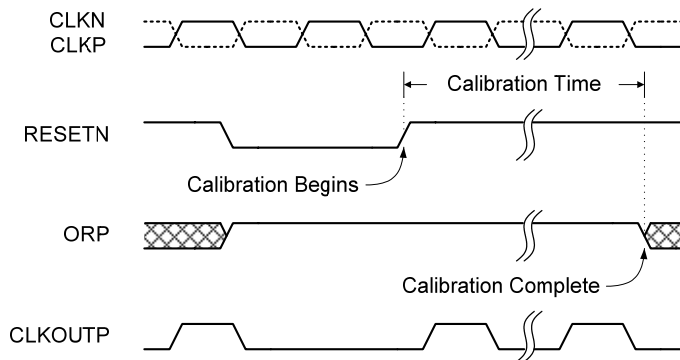


Figure 28. Calibration Timing

## User Initiated Reset

Recalibration of the ADC can be initiated at any time by driving the RESETN pin low for a minimum of one clock cycle. An open-drain driver with a drive strength of less than 0.5mA is recommended. As is the case during power-on reset, the SDO, RESETN and DNC pins must be in the proper state for the calibration to successfully execute.

## Analog Input

Each ADC core contains a fully differential input (AINP/AINN, BINP/BINN) to the sample and hold amplifier (SHA). The ideal full-scale input voltage is 1.45V, centered at the VCM voltage of 0.535V as shown in Figure 29.

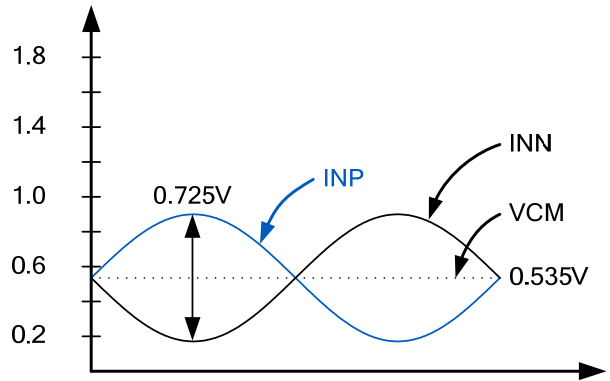


Figure 29. Analog Input Range

Best performance is obtained when the analog inputs are driven differentially. The common mode output voltage, VCM, should be used to properly bias the inputs as shown in Figures 30 through 32. An RF transformer will give the best noise and distortion performance for wideband and/or high intermediate frequency (IF) inputs. Two different transformer input schemes are shown in Figures 30 and 31.

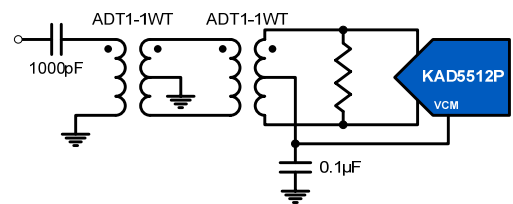


Figure 30. Transformer Input for General Purpose Applications

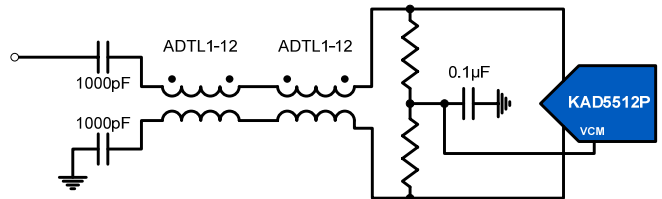


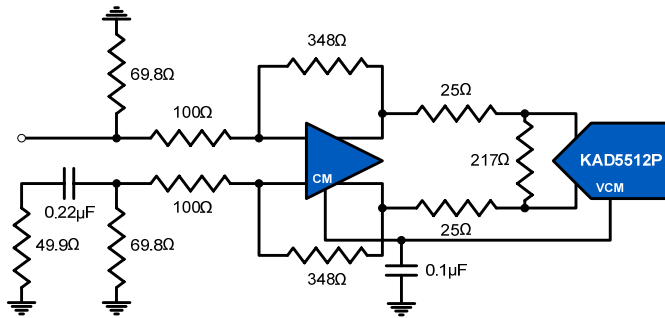
Figure 31. Transmission-line Transformer Input for High IF Applications

A back-to-back transformer scheme is used to improve common mode rejection, which keeps the common mode level of the input matched to VCM. The value of the shunt resistor should be determined based on the desired load impedance. The differential input resistance of the KAD5512P is 500Ω.

The SHA design uses a switched capacitor input stage, which creates charge kick-back when the sampling capacitance is reconnected to the input voltage. This kick-back creates a disturbance at the input which must settle before the next sampling point. Lower source impedance will result in faster

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settling and improved performance. Therefore a 1:1 transformer and low shunt resistance are recommended for optimal performance.



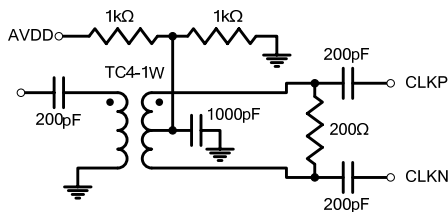
**Figure 32. Differential Amplifier Input**

A differential amplifier, as shown in Figure 32, can be used in applications that require dc-coupling. In this configuration the amplifier will typically dominate the achievable SNR and distortion performance.

## Clock Input

The clock input circuit is a differential pair (see Figure 47). Driving these inputs with a high level (up to 1.8V<sub>PP</sub> on each input) sine or square wave will provide the lowest jitter performance. A transformer with 4:1 impedance ratio will provide increased drive levels.

The recommended drive circuit is shown in Figure 33. The clock can be driven single-ended, but this will reduce the edge rate and may impact SNR performance. The clock inputs are internally self-biased to AVDD/2 to facilitate ac coupling.



**Figure 33. Recommended Clock drive**

A selectable 2X divider is provided in series with the clock input. The divider can be used in the 2X mode with a sample clock equal to twice the desired sample rate. This will result in a clock input with 50% duty cycle and will maximize the converter's performance.

CLKDIV Pin	Divide Ratio
AVSS	2
Float	1
AVDD	Not Allowed

**Table 1. CLKDIV Pin Settings**

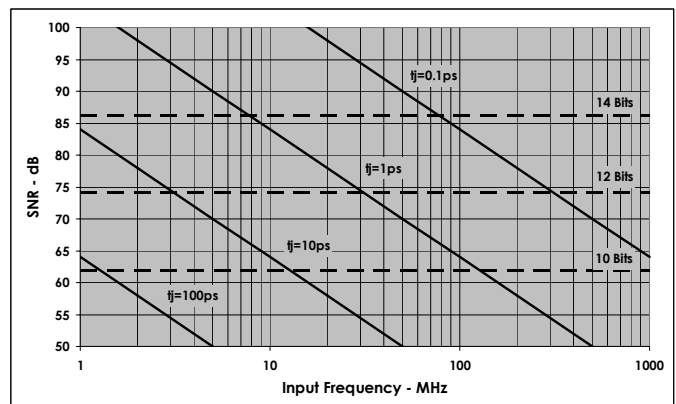
The clock divider can also be controlled through the SPI port, which overrides the CLKDIV pin setting. Details on this are contained in the **Serial Peripheral Interface** section.

## Jitter

In a sampled data system, clock jitter directly impacts the achievable SNR performance. The theoretical relationship between clock jitter ( $t_J$ ) and SNR is shown in Equation 1 and is illustrated in Figure 34.

$$SNR = 20 \log_{10} \left( \frac{1}{2\pi f_{IN} t_J} \right)$$

**Equation 1.**



**Figure 34. SNR vs. Clock Jitter**

This relationship shows the SNR that would be achieved if clock jitter were the only non-ideal factor. In reality, achievable SNR is limited by internal factors such as linearity, aperture jitter and thermal noise. Internal aperture jitter is the uncertainty in the sampling instant shown in Figure 1. The internal aperture jitter combines with the input clock jitter in a root-sum-square fashion, since they are not statistically correlated, and this determines the total jitter in the system. The total jitter, combined with other noise sources, then determines the achievable SNR.



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## Voltage Reference

A temperature compensated voltage reference provides the reference charges used in the successive approximation operations. The full-scale range of each A/D is proportional to the reference voltage. The nominal value of the voltage reference is 1.25V.

## Digital Outputs

Output data is available as a parallel bus in LVDS-compatible or CMOS modes. In either case, the data is presented in double data rate (DDR) format. Figures 1 and 2 show the timing relationships for LVDS and CMOS modes, respectively.

Additionally, the drive current for LVDS mode can be set to a nominal 3 mA or a power-saving 2 mA. The lower current setting can be used in designs where the receiver is in close physical proximity to the ADC. The applicability of this setting is dependent upon the PCB layout, therefore the user should experiment to determine if performance degradation is observed.

The output mode and LVDS drive current are selected via the OUTMODE pin as shown in Table 2.

OUTMODE Pin	Mode
AVSS	LVC MOS
Float	LVDS, 3 mA
AVDD	LVDS, 2 mA

Table 2. OUTMODE Pin Settings

The output mode can also be controlled through the SPI port, which overrides the OUTMODE pin setting. Details on this are contained in the **Serial Peripheral Interface** section.

An external resistor creates the bias for the LVDS drivers. A 10kΩ, 1% resistor must be connected from the RLVD pin to OVSS.

## Power Dissipation

The power dissipated by the KAD5512P is primarily dependent on the sample rate, but is also related to the input signal in CMOS output mode. There is a static bias in the analog supply, while the remaining power dissipation is linearly related to the sample rate. The output supply dissipation is approximately constant in LVDS mode, but linearly related to the clock frequency in CMOS mode. Figures 35 and 36 illustrate these relationships.

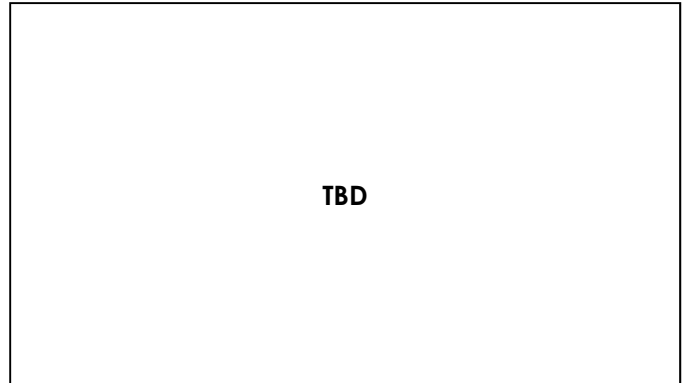


Figure 35. Power vs. Sample Rate, LVDS Mode

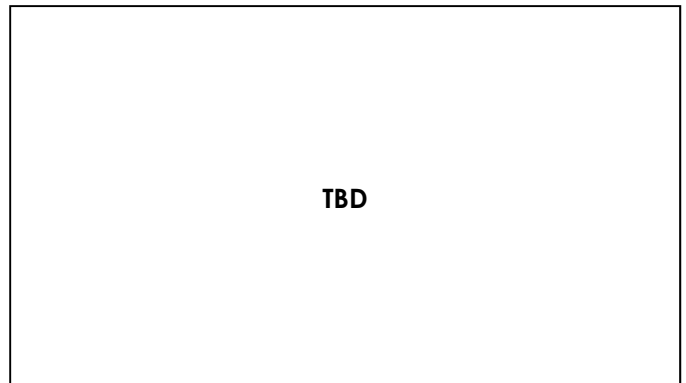


Figure 36. Power vs. Sample Rate, CMOS Mode

## Nap/Sleep

Portions of the device may be shut down to save power during times when operation of the ADC is not required. Two power saving modes are available: nap, and sleep. Nap mode reduces power dissipation to 40mW and recovers to normal operation in approximately 1μs. Sleep mode reduces power dissipation to 10mW but requires 1ms to recover. The clock should remain running and at a fixed frequency during Nap or Sleep. Recovery time from Nap mode will increase if the clock is stopped, since the internal DLL can take up to 52μs to regain lock at 500MSPS.

By default after the device is powered on, the operational state is controlled by the NAPSLP pin as shown in Table 3.

NAPSLP Pin	Mode
AVSS	Normal
Float	Sleep
AVDD	Nap

Table 3. NAPSLP Pin Settings

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The power down mode can also be controlled through the SPI port, which overrides the NAPSLP pin setting. Details on this are contained in the **Serial Peripheral Interface** section. This is an indexed function when controlled from the SPI, but a global function when driven from the pin.

## Data Format

Output data can be presented in three formats: two's complement, Gray code and offset binary. The data format is selected via the OUTFMT pin as shown in Table 4.

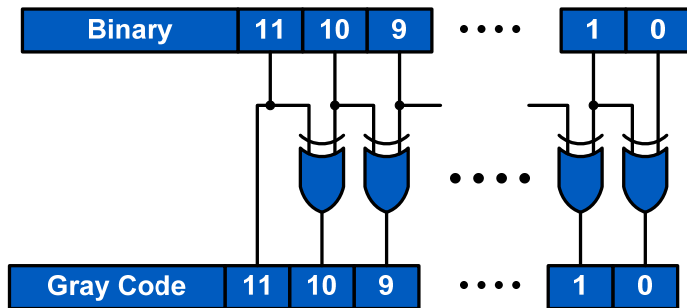
OUTFMT Pin	Mode
AVSS	Offset Binary
Float	Two's Complement
AVDD	Gray Code

**Table 4. OUTFMT Pin Settings**

The data format can also be controlled through the SPI port, which overrides the OUTFMT pin setting. Details on this are contained in the **Serial Peripheral Interface** section.

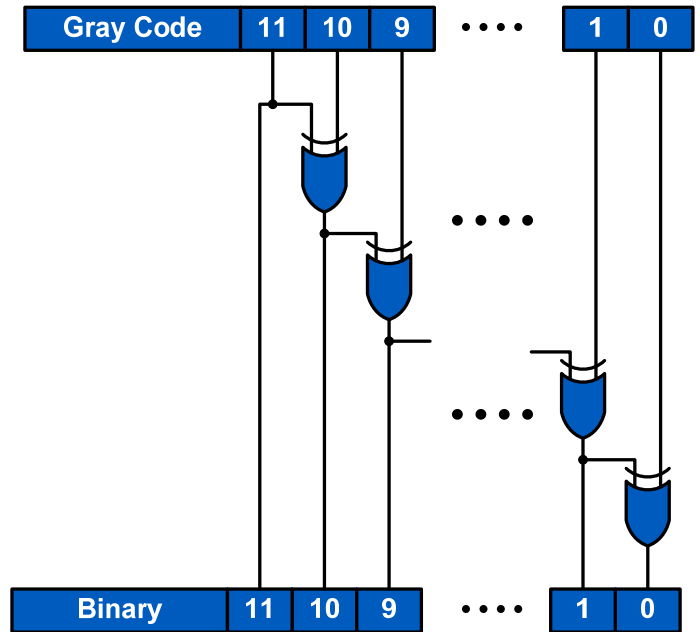
Offset binary coding maps the most negative input voltage to code 0x000 (all zeros) and the most positive input to 0xFF (all ones). Two's complement coding simply complements the MSB of the offset binary representation.

When calculating Gray code the MSB is unchanged. The remaining bits are computed as the XOR of the current bit position and the next most significant bit. Figure 37 shows this operation.



**Figure 37. Binary to Gray Code Conversion**

Converting back to offset binary from gray code must be done recursively, using the result of each bit for the next lower bit as shown in Figure 38.



**Figure 38. Gray Code to Binary Conversion**

Mapping of the input voltage to the various data formats is shown in Table 5.

Input Voltage	Offset Binary	Two's Complement	Gray Code
-Full Scale	000000000000	100000000000	000000000000
-Full Scale + 1LSB	000000000001	100000000001	000000000001
Mid-Scale	100000000000	000000000000	110000000000
+Full Scale - 1LSB	111111111110	011111111110	100000000001
+Full Scale	111111111111	011111111111	100000000000

**Table 5. Input Voltage to Output Code Mapping**

## Serial Peripheral Interface

A serial peripheral interface (SPI) bus is used to facilitate configuration of the device and to optimize performance. The SPI bus consists of chip select (CSB), serial clock (SCLK) and serial data input/output (SDIO). The maximum SCLK rate is equal to the ADC sample rate ( $f_{\text{SAMPLE}}$ ) divided by 16 for write operations and  $f_{\text{SAMPLE}}$  divided by 66 for reads. At  $f_{\text{SAMPLE}} = 250\text{MHz}$ , maximum SCLK is 15.63MHz for writing and 3.79MHz for write operations. There is no minimum SCLK rate.

The following sections describe various registers that are used to configure the SPI or adjust performance

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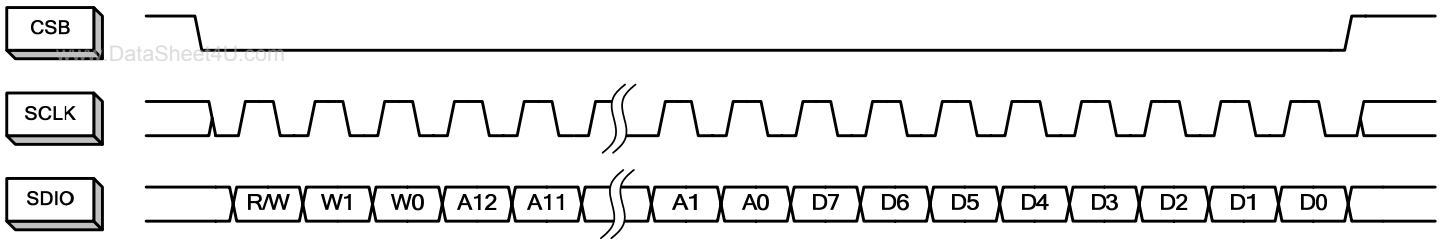


Figure 39. MSB-First Addressing

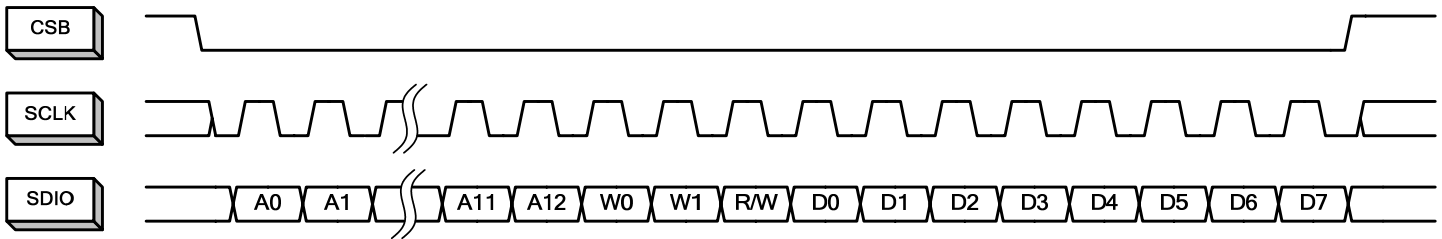


Figure 40. LSB-First Addressing

or functional parameters. Many registers in the available address space (0x00 to 0xFF) are not defined in this document. Additionally, within a defined register there may be certain bits or bit combinations that are reserved. Undefined registers and undefined values within defined registers are reserved and should not be selected. Setting any reserved register or value may produce indeterminate results.

## SPI Physical Interface

The SPI port operates in a half or full duplex master/slave configuration, with the KAD5512P-50 functioning as a slave. Multiple slave devices can interface to a single master. The chip-select bar (CSB) pin determines when a slave device is being addressed. Multiple slave devices can be written to concurrently, but only one slave device can be read from at a given time. If multiple slave devices are selected for reading at the same time, the results will be indeterminate.

The serial clock pin (SCLK) provides synchronization for the data transfer. By default, all data is presented on the serial data input/output (SDIO) pin. The state of the SDIO pin is set automatically in the communication protocol (described below). A dedicated serial data output pin (SDO) can be activated by setting 0x00[7] high to allow operation in full duplex mode.

The communication protocol begins with an instruction/address phase. The first rising SCLK edge following a high to low transition on CSB determines the

beginning of the two-byte instruction/address command. Data can be presented in MSB-first order or LSB-first order. The default is MSB-first, but this can be changed by setting 0x00[6] high. Figures 39 and 40 show the appropriate bit ordering for the MSB-first and LSB-first modes, respectively. In MSB-first mode the address is incremented for multi-byte transfers, while in LSB-first mode it's decremented.

In the default mode the MSB is R/W, which determines if the data is to be read (active high) or written. The next two bits, W1 and W0, determine the number of data bytes to be read or written (see Table 6). The lower 13 bits contain the first address for the data transfer. This relationship is illustrated in Figure 41, and timing values are given in the **Switching Specifications** section.

After the instruction/address bytes have been read, the appropriate number of data bytes are written to or read from the ADC (based on the R/W bit status). The data transfer will continue as long as CSB remains low and SCLK is active. Stalling of the CSB pin is allowed at any byte boundary (instruction/address or data) if the number of bytes being transferred is three or less. For transfers of four bytes or more, CSB is allowed stall in the middle of the instruction/address bytes or before the first data byte. If CSB transitions to a high state after that point the state machine will reset and terminate the data transfer.

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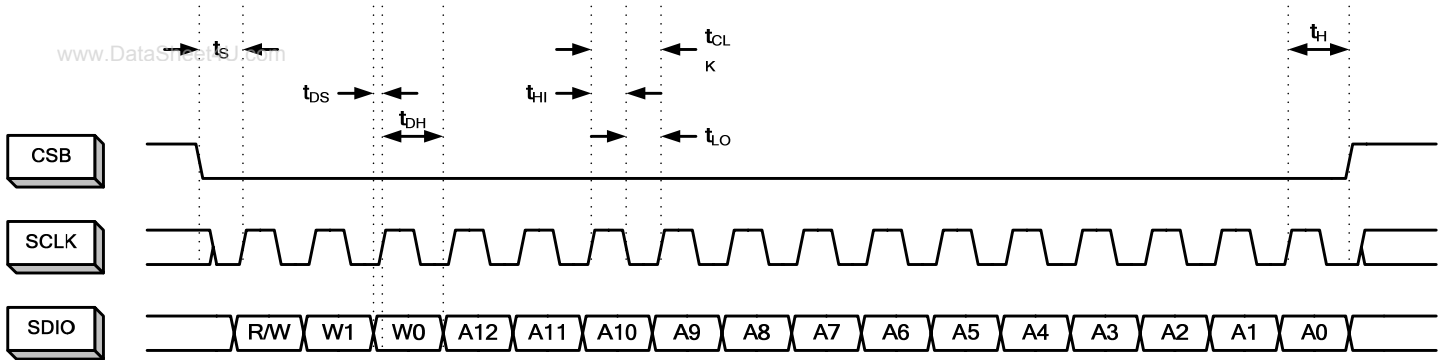


Figure 41. Instruction/Address Phase

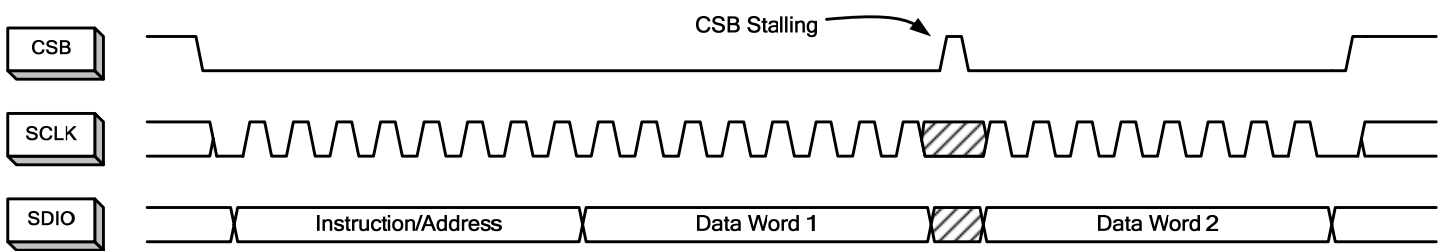


Figure 42. 2-Byte Transfer

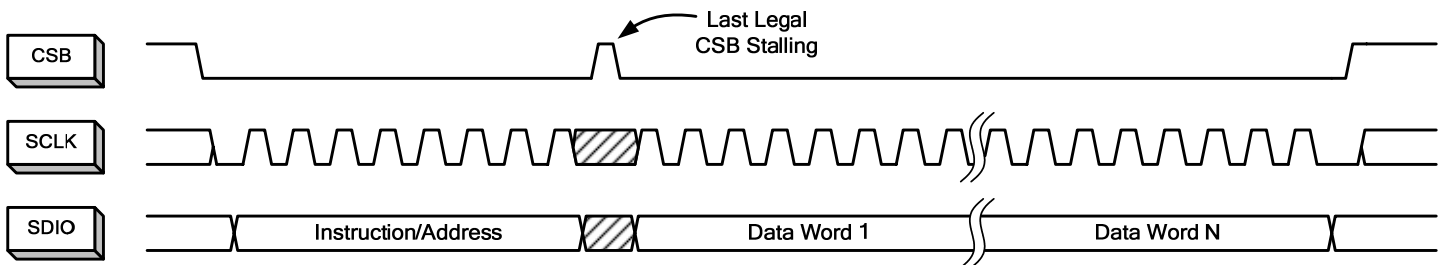


Figure 43. N-Byte Transfer

[W1:W0]	Bytes Transferred
00	1
01	2
10	3
11	4 or more

Table 6. Byte Transfer Selection

Figures 42 and 43 illustrate the timing relationships for 2-byte and N-byte transfers, respectively. The operation for a 3-byte transfer can be inferred from these diagrams.

## SPI Configuration

### Address 0x00: chip\_port\_config

Bit ordering and SPI reset are controlled by this register. Bit order can be selected as MSB to LSB (MSB first) or LSB to MSB (LSB first) to accommodate various microcontrollers.

Bit 7 SDO Active

Bit 6 LSB First

Setting this bit high configures the SPI to interpret serial data as arriving in LSB to MSB order.

Bit 5 Soft Reset

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Setting this bit high resets all SPI registers to default values.

Bit 4 Reserved

This bit should always be set high.

Bits 3:0 These bits should always mirror bits 4:7 to avoid ambiguity in bit ordering.

## Address 0x02: burst\_end

If a series of sequential registers are to be set, burst mode can improve throughput by eliminating redundant addressing. In 3-wire SPI mode the burst is ended by pulling the CSB pin high. If the device is operated in 2-wire mode the CSB pin is not available. In that case, setting the burst\_end address determines the end of the transfer. During a write operation, the user must be cautious to transmit the correct number of bytes based on the starting and ending addresses.

Bits 7:0 Burst End Address

This register value determines the ending address of the burst data.

## DUT Information

### Address 0x08: chip\_id

### Address 0x09: chip\_version

The generic die identifier and a revision number, respectively, can be read from these two registers.

## Indexed DUT Configuration/Control

### Address 0x10: device\_index\_A

Bits 1:0 ADC01, ADC00

Determines which ADC is addressed. Valid states for this register are 0x01 or 0x10. The two ADC cores cannot be adjusted concurrently.

A common SPI map, which can accommodate single-channel or multi-channel devices, is used for all Kenet ADC products. Certain configuration commands (identified as Indexed in the SPI map) can be executed on a per-converter basis. This register determines which converter is being addressed for an Indexed command. It is important to note that only a single converter can be addressed at a time.

This register defaults to 00h, indicating that no ADC is addressed.

### Address 0x20: offset\_coarse

### Address 0x21: offset\_fine

The input offset of the ADC core can be adjusted in fine and coarse steps. Both adjustments are made

via an 8-bit word as detailed in Table 7. The data format is twos complement.

The default value of each register will be the result of the self-calibration after initial power-up. If a register is to be incremented or decremented, the user should first read the register value then write the incremented or decremented value back to the same register.

Parameter	0x20[7:0] Coarse Offset	0x21[7:0] Fine Offset
Steps	256	256
-Full Scale (0x80)	-24.0mV	-1.7mV
Mid-Scale (0x00)	0.0mV	0.0mV
+Full Scale (0x7F)	+23.8mV	+1.7mV
Nominal Step Size	187.5 $\mu$ V	13.3 $\mu$ V

Table 7. Offset Adjustments

### Address 0x22: gain\_coarse

### Address 0x23: gain\_medium

### Address 0x24: gain\_fine

Gain of the ADC core can be adjusted in coarse, medium and fine steps. Coarse gain is a 4-bit adjustment while medium and fine are 8-bit. The data format is twos complement for all three registers.

The default value of each register will be the result of the self-calibration after initial power-up. If a register is to be incremented or decremented, the user should first read the register value then write the incremented or decremented value back to the same register.

Parameter	0x22[3:0] Coarse Gain
Steps	16
-Full Scale (0x08)	-11.2%
Mid-Scale (0x00)	0.0%
+Full Scale (0x07)	+9.8%
Nominal Step Size	1.4%

Table 8. Coarse Gain Adjustment

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Parameter	0x23[7:0] Medium Gain	0x24[7:0] Fine Gain
Steps	256	256
-Full Scale (0x80)	-10.56%	-1.06%
Mid-Scale (0x00)	0.0%	0.0%
+Full Scale (0x7F)	+10.48%	+1.05%
Nominal Step Size	0.0825%	0.00825%

**Table 9. Medium and Fine Gain Adjustments**

## Address 0x25: modes

Two distinct reduced power modes can be selected. By default, the tri-level NAPSLP pin can select normal operation, nap or sleep modes (refer to **Nap/Sleep** section). This functionality can be overridden and controlled through the SPI. This is an indexed function when controlled from the SPI, but a global function when driven from the pin. This register is not changed by a Soft Reset.

Value	0x25[2:0] Power Down Mode
000	Pin Control
001	Normal Operation
010	Nap Mode
100	Sleep Mode

**Table 10. Power Down Control**

## Global DUT Configuration/Control

### Address 0x70: skew\_diff

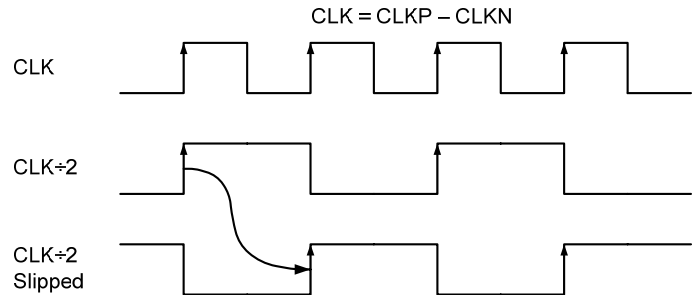
The value in the skew\_diff register adjusts the timing skew between the two ADCs cores. The nominal range and resolution of this adjustment are given in Table 11. The default value of this register after power-up is 00h.

Parameter	0x70[7:0] Differential Skew
Steps	256
-Full Scale (0x08)	-6.5ps
Mid-Scale (0x00)	0.0ps
+Full Scale (0x07)	+6.5ps
Nominal Step Size	51fs

**Table 11. Differential Skew Adjustment**

### Address 0x71: phase\_slip

When using a clock divider, it's not possible to determine the synchronization of the incoming and divided clock phases. This is particularly important when multiple ADCs are used in a time-interleaved system. The phase slip feature allows the rising edge of the divided clock to be advanced by one input clock cycle, as shown in Figure 44.



**Figure 44. Phase Slip**

### Address 0x72: clock\_divide

The KAD5512P has a selectable clock divider that can be set to divide by four, two or one (no division). By default, the tri-level CLKDIV pin selects the divisor (refer to **Clock Input** section). This functionality can be overridden and controlled through the SPI, as shown in Table 12. This register is not changed by a Soft Reset.

Value	0x72[2:0] Clock Divider
000	Pin Control
001	Divide by 1
010	Divide by 2
100	Divide by 4

**Table 12. Clock Divider Selection**

### Address 0x73: output\_mode\_A

The output\_mode\_A register controls the physical output format of the data, as well as the logical coding. The KAD5512P can present output data in two physical formats: LVDS or LVCMOS. Additionally, the drive strength in LVDS mode can be set high (3mA) or low (2mA). By default, the tri-level OUTMODE pin selects the mode and drive level (refer to **Digital Outputs** section). This functionality can be overridden and controlled through the SPI, as shown in Table 13.

Data can be coded in three possible formats: two's complement, Gray code or offset binary. By default, the tri-level OUTFMT pin selects the data format (refer to **Data Format** section). This functionality can be

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overridden and controlled through the SPI, as shown in Table 14.

This register is not changed by a Soft Reset.

Value	0x93[7:5] Output Mode
000	Pin Control
001	LVDS 2mA
010	LVDS 3mA
100	LVC MOS

Table 13. Output Mode Control

Value	0x93[2:0] Output Format
000	Pin Control
001	Two's Complement
010	Gray Code
100	Offset Binary

Table 14. Output Format Control

Address 0x74: output\_mode\_B

Address 0x75: config\_status

Bit 6 DLL Range

This bit sets the DLL operating range to fast (TBD2MSPS to 250MSPS) or slow (40 to TBD1MSPS).

The output\_mode\_B and config\_status registers are used in conjunction to enable DDR mode and select the frequency range of the DLL clock generator. The method of setting these options is different from the other registers.

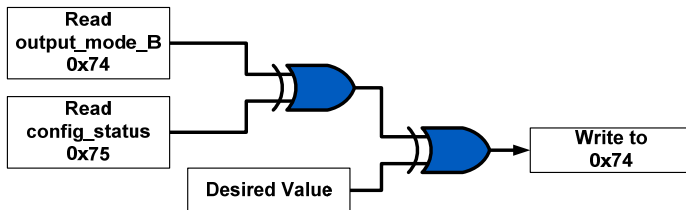


Figure 45. Setting output\_mode\_B register

The procedure for setting output\_mode\_B is shown in Figure 45. Read the contents of output\_mode\_B and config\_status and XOR them. Then XOR this result with the desired value for output\_mode\_B and write that XOR result to the register.

## DUT Test

The KAD2512 can produce preset or user defined patterns on the digital outputs to facilitate in-situ test-

ing. A static word can be placed on the output bus, or two different words can alternate. In the alternate mode, the values defined as Word 1 and Word 2 (as shown in Table 15) are set on the output bus on alternating clock phases.

Address 0xC0: test\_io

Bits 7:6 User Test Mode

These bits set the test mode to static (0x00) or alternate (0x01) mode. Other values are reserved.

The four LSBs in this register (Output Test Mode) determine the test pattern in combination with registers 0xC2 through 0xC5. Refer to Table 16.

Value	0xC0[3:0] Output Test Mode	Word 1	Word 2
0000	Off		
0001	Midscale	0x8000	N/A
0010	Positive Full-Scale	0xFFFF	N/A
0011	Negative Full-Scale	0x0000	N/A
0100	Checkerboard	0xAAAA	0x5555
0101	Reserved	N/A	N/A
0110	Reserved	N/A	N/A
0111	One/Zero	0xFFFF	0x0000
1000	User Pattern	user_patt1	user_patt2

Table 15. Output Test Modes

Address 0xC2: user\_patt1\_lsb

Address 0xC3: user\_patt1\_msb

These registers define the lower and upper eight bits, respectively, of the first user-defined test word.

Address 0xC2: user\_patt2\_lsb

Address 0xC3: user\_patt2\_msb

These registers define the lower and upper eight bits, respectively, of the second user-defined test word.

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## SPI Memory Map

	Addr (Hex)	Parameter Name	Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)	Def. Value (Hex)	Indexed/Global		
SPI Config	00	port_config	SDO Active	LSB First	Soft Reset	Reserved			Mirror (bit5)	Mirror (bit6)	Mirror (bit7)	00h	G	
	01	reserved	Reserved											
	02	burst_end	Burst end address [7:0]									00h	G	
	03-07	reserved	Reserved											
DUT Info	08	chip_id	Chip ID #									Read only	G	
	09	chip_version	Chip Version #									Read only	G	
Indexed DUT Config/Control	10	device_index_A	Reserved						ADC01	ADC00	00h			I
	11-1F	reserved	Reserved											
	20	offset_coarse	Coarse Offset									cal. value	I	
	21	offset_fine	Fine Offset									cal. value	I	
	22	gain_coarse	Reserved				Coarse Gain					cal. value	I	
	23	gain_medium	Medium Gain									cal. value	I	
	24	gain_fine	Fine Gain									cal. value	I	
	25	modes								<b>Power Down Mode [2:0]</b> 000=Pin Control 001=Normal Operation 010=Nap 100=Sleep other codes=reserved			00h NOT affected by Soft Reset	I
	26-5F	reserved	Reserved											
	60-6F	reserved	Reserved											
Global DUT Config/Control	70	skew_diff	Differential Skew									7Fh	G	
	71	phase_slip	Reserved							Next Clock Edge		00h	G	
	72	clock_divide						<b>Clock Divide [2:0]</b> 000=Pin Control 001=divide by 1 010=divide by 2 100=divide by 4 other codes=reserved				00h NOT affected by Soft Reset	G	
	73	output_mode_A	<b>Output Mode [2:0]</b> 000=Pin Control 001=LVDS 2mA 010=LVDS 3mA 100=LVC MOS other codes=reserved				<b>Output Format [2:0]</b> 000=Pin Control 001=Twos Complement 010=Gray Code 100=Offset Binary other codes=reserved				00h NOT affected by Soft Reset	G		
	74	output_mode_B		<b>DLL Range</b> 0=fast 1=slow								00h NOT affected by Soft Reset	G	
	75	config_status		XOR Result								Read Only	G	
76-BF	reserved	Reserved												
DUT Test	C0	test_io	<b>User Test Mode [2:0]</b> 00=Single 01=Alternate 10=Single Once 11=Alternate Once		Reset PN Long Gen	Reset PN Short Gen	<b>Output Test Mode [3:0]</b> 0=Off 1=Midscale Short 2=+FS Short 3=-FS Short 4=Checker Board 5=reserved 6=reserved				7=One/Zero Word Toggle 8=User Input 9-15=reserved	00h	G	
	C1	Reserved	Reserved											
	C2	user_patt1_lsb	B7	B6	B5	B4	B3	B2	B1	B0	00h		G	
	C3	user_patt1_msb	B15	B14	B13	B12	B11	B10	B9	B8	00h		G	
	C4	user_patt2_lsb	B7	B6	B5	B4	B3	B2	B1	B0	00h		G	
	C5	user_patt2_msb	B15	B14	B13	B12	B11	B10	B9	B8	00h		G	
	C6-FF	reserved	Reserved											

Table 16. SPI Memory Map



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## Equivalent Circuits

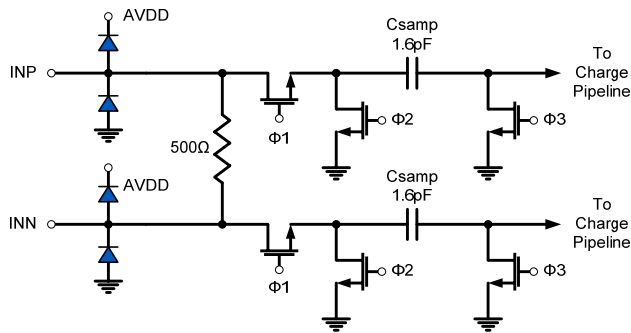


Figure 46. Analog Inputs

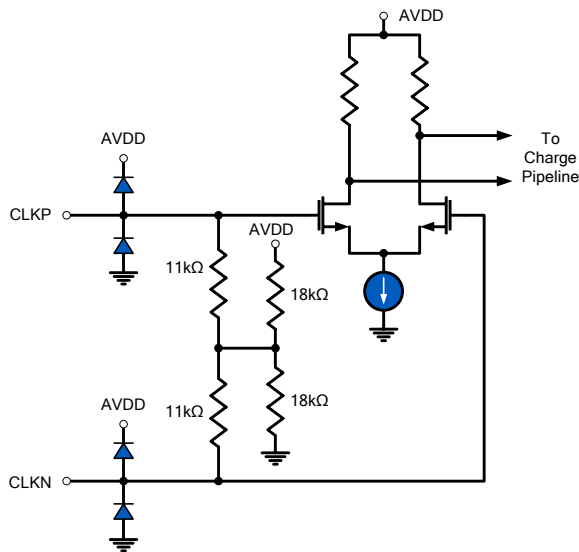


Figure 47. Clock Inputs

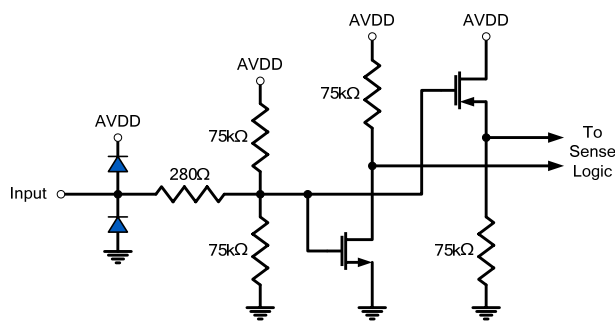


Figure 48. Tri-Level Digital Inputs

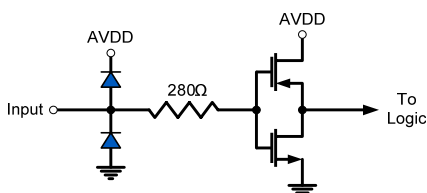


Figure 49. Digital Inputs

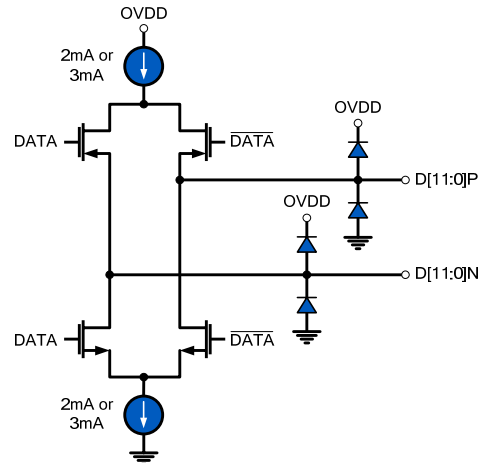


Figure 50. LVDS Outputs

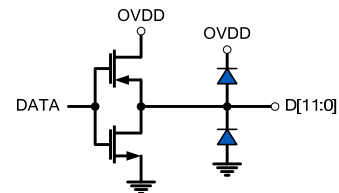


Figure 51. CMOS Outputs

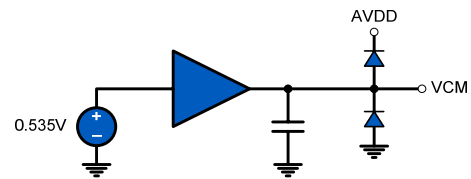


Figure 52. VCM\_OUT Output

## Layout Considerations

### Split Ground and Power Planes

Data converters operating at high sampling frequencies require extra care in PC board layout. Many complex board designs benefit from isolating the analog and digital sections. Analog supply and ground planes should be laid out under signal and clock inputs. Locate the digital planes under outputs and logic pins. Grounds should be joined under the chip.

### Clock Input Considerations

Use matched transmission lines to the transformer inputs for the analog input and clock signals. Locate transformers and terminations as close to the chip as possible.

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## Exposed Paddle

The exposed paddle must be electrically connected to analog ground (AVSS) and should be connected to a large copper plane using numerous vias for optimal thermal performance.

## Bypass and Filtering

Bulk capacitors should have low equivalent series resistance. Tantalum is a good choice. For best performance, keep ceramic bypass capacitors very close to device pins. Longer traces will increase inductance, resulting in diminished dynamic performance and accuracy. Make sure that connections to ground are direct and low impedance. Avoid forming ground loops.

## LVDS Outputs

Output traces and connections must be designed for 50Ω (100Ω differential) characteristic impedance. Keep traces direct and minimize bends where possible. Avoid crossing ground and power plane breaks with signal traces.

## LVC MOS Outputs

Output traces and connections must be designed for 50Ω characteristic impedance.

## Unused Inputs

Standard logic inputs (RESETN, CSB, SCLK, SDIO, SDO) which will not be operated do not require connection to ensure optimal ADC performance. These inputs can be left floating if they are not used. Tri-level inputs (NAPSLP, OUTMODE, OUTFMT, CLKDIV) accept a floating input as a valid state, and therefore should be biased according to the desired functionality.

## Definitions

**Analog Input Bandwidth** is the analog input frequency at which the spectral output power at the fundamental frequency (as determined by FFT analysis) is reduced by 3dB from its full-scale low-frequency value. This is also referred to as Full Power Bandwidth.

**Aperture Delay or Sampling Delay** is the time required after the rise of the clock input for the sampling switch to open, at which time the signal is held for conversion.

**Aperture Jitter** is the RMS variation in aperture delay for a set of samples.

**Clock Duty Cycle** is the ratio of the time the clock wave is at logic high to the total time of one clock period.

**Differential Non-Linearity (DNL)** is the deviation of any code width from an ideal 1 LSB step.

**Effective Number of Bits (ENOB)** is an alternate method of specifying Signal to Noise-and-Distortion Ratio (SINAD). In dB, it is calculated as:  $ENOB = (SINAD - 1.76) / 6.02$

**Gain Error** is the ratio of the difference between the voltages that cause the lowest and highest code transitions to the full-scale voltage (less 2 LSB). It is typically expressed in percent.

**Integral Non-Linearity (INL)** is the deviation of each individual code from a line drawn from negative full-scale (1/2 LSB below the first code transition) through positive full-scale (1/2 LSB above the last code transition). The deviation of any given code from this line is measured from the center of that code.

**Least Significant Bit (LSB)** is the bit that has the smallest value or weight in a digital word. Its value in terms of input voltage is  $V_{FS} / (2^N - 1)$  where N is the resolution in bits.

**Missing Codes** are output codes that are skipped and will never appear at the ADC output. These codes cannot be reached with any input value.

**Most Significant Bit (MSB)** is the bit that has the largest value or weight.

**Pipeline Delay** is the number of clock cycles between the initiation of a conversion and the appearance at the output pins of the data.

**Power Supply Rejection Ratio (PSRR)** is the ratio of a change in input voltage necessary to correct a change in output code that results from a change in power supply voltage.

**Signal to Noise-and-Distortion (SINAD)** is the ratio of the RMS signal amplitude to the RMS value of the sum of all other spectral components below one half the clock frequency, including harmonics but excluding DC.

**Signal-to-Noise Ratio** (without Harmonics) is the ratio of the RMS signal amplitude to the sum of all other spectral components below one-half the sampling frequency, excluding harmonics and DC.

SNR and SINAD are either given in units of dBc (dB to carrier) when the absolute power of the fundamental is used as the reference, or dBFS (dB to full scale) when the converter's full-scale input power is used as the reference.

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**Spurious-Free-Dynamic Range (SFDR)** is the ratio of the RMS signal amplitude to the RMS value of the peak spurious spectral component. The peak spurious spectral component may or may not be a harmonic.

**Two-Tone SFDR** is the ratio of the RMS value of the lowest power input tone to the RMS value of the peak spurious component, which may or may not be an IMD product.

## Outline Dimensions

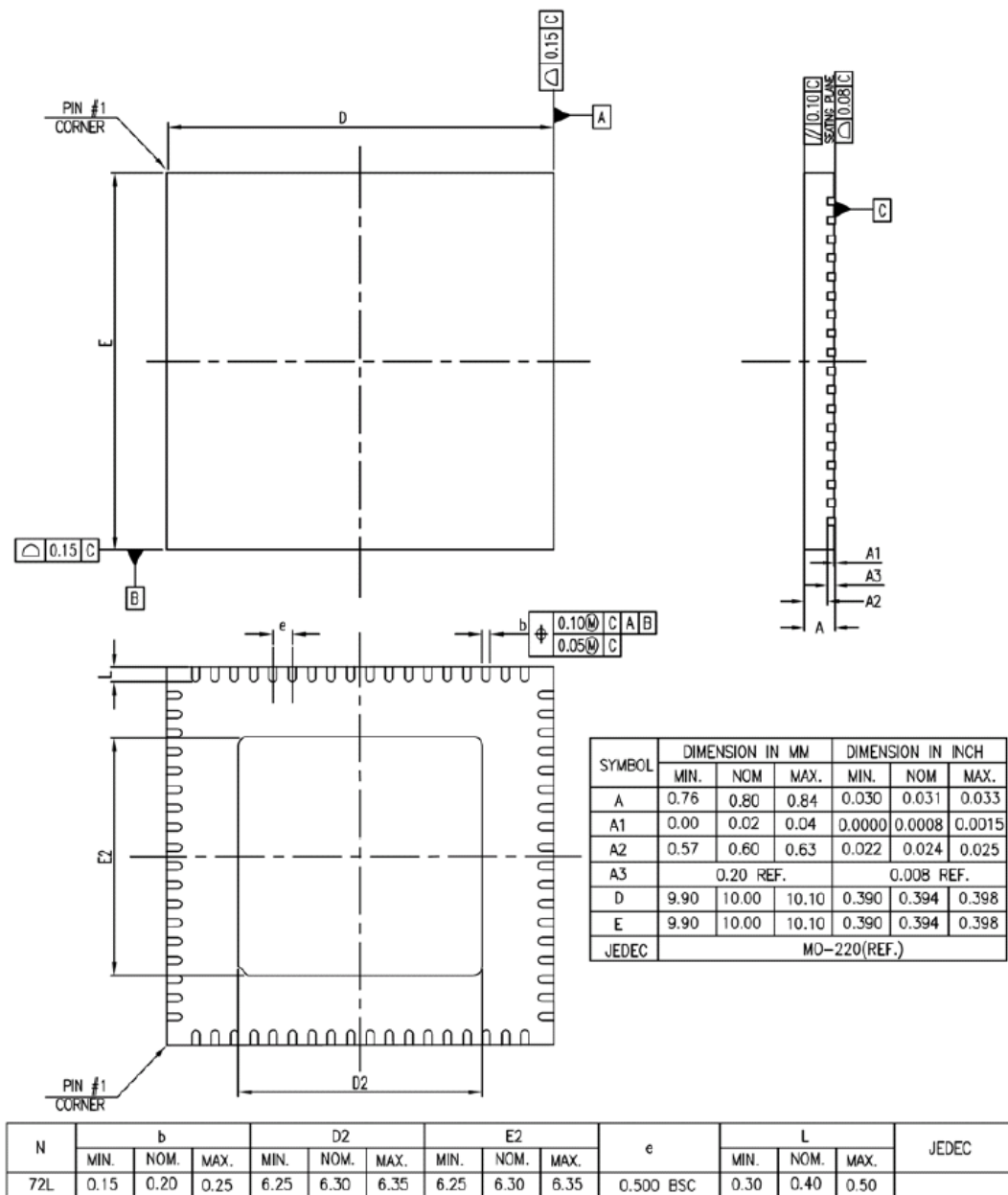


Figure 53. 72QFN Dimensions

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## Ordering Guide



The KAD5512P-50 is compliant with EU directive 2002/95/EC regarding the Restriction of Hazardous Substances (RoHS). Contact Kenet for a materials declaration for this product.

Model	Speed	Package	Temp. Range
KAD5512P-50Q72	500MSPS	72-QFN	-40°C to +85°C

## Revision History

14-May-07:	Rev 0.1	Updated to new format
21-Jun-07:	Rev 0.2	Errata Updated
13-Aug-07:	Rev 0.3	Content/specification updates
07-Dec-07:	Rev 0.4	Content/specification updates
21-Feb-08:	Rev 0.5	Updated specifications, added functional descriptions
19-Mar-08	Rev 0.5.1	Corrected minor typos

## Preliminary Datasheet

This datasheet contains preliminary technical data, which is subject to change without notice. Contact Kenet prior to initiating design activity using this product.