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TS13401
Neo-Iso™ Solid State Relay Driver
with Sensing and Power Transfer

POWER MANAGEMENT

Features

- Low Quiescent Operating Currents
  15µA in ON state
  2mA in Sensing Mode
- Switch to controller scalable galvanic isolation
- Single control signal for input commands
  Microcontroller-compatible levels
- Switch Characteristics
  Bi-directional blocking in OFF state
  Up to 60V FETs supported
  Up to 10A current during inrush
     and 5A continuous operation
- Operating Modes
  Zero-cross ON / OFF
  Immediate ON / OFF
  Dithering Mode for system power sharing
  Switch state polling
- Sensing Modes for system data acquisition

Summary Specification

- Junction operating temperature -40 °C to 125 °C
- Packaged in a 20 pin QFN (3mm x 3mm)
- Product is lead-free, Halogen Free, RoHS / WEEE compliant

Description

The TS13401 is a galvanically isolated 60V power FET driver with bi-directional blocking. The state of the switch and other product features are controlled by sending commands on the CLK input.
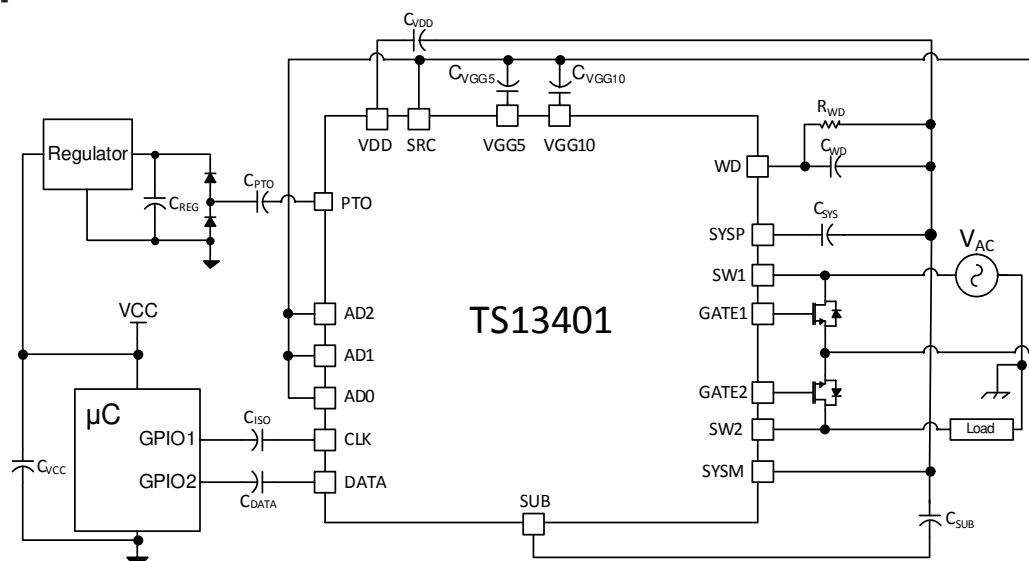
The TS13401 supports several sensing modes where the switch state, load current, supply voltage and device temperature can be sampled. The digitized measurements can be read back from the device on the DATA pin when requested on the CLK pin. In addition, TS13401 supports power transfer from the system's AC supply to the low-voltage controller domain.

The TS13401 includes several protection features. The switch will open in self protection if current exceeds the over-current limit or if the device temperature limit is exceeded. The switch will remain open until a new turn on sequence is given through CLK.

Applications

- Power load/rail switching
- Input supply multiplexing
- Isolated power supplies
- Solid state relays
- HVAC control
- Sprinkler control
- Internet of Things (IoT)

Typical Application

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Pin Description

Pin Symbol	Pin #	Function	Description
SUB	1	IC Substrate Connection	Connect substrate capacitor from SUB to SYSM
SYSP	2	Positive System Voltage	Power is harvested from the SW pins
SYSM	3	Negative System Voltage	Power is harvested from the SW pins
VDD	4	Bias Voltage Output	Connect VDD Capacitor to SYSM
PTO	5	Power Transfer Output	Connect to Power Transfer Capacitor C_{PTO}
CLK	6	Clock Input	Galvanically Isolated Clock Input
DATA	7	Data Output	Galvanically Isolated Data Output
AD2	8	Address Select 2	For logic 0, must be tied to SRC on PCB For logic 1, must be tied to VGG5 on PCB
AD1	9	Address Select 1	For logic 0, must be tied to SRC on PCB For logic 1, must be tied to VGG5 on PCB
N/C	10	No Connect	
AD0	11	Address Select 0	For logic 0, must be tied to SRC on PCB For logic 1, must be tied to VGG5 on PCB
WD	12	Watch Dog	Control input for latching vs non-latching switch
SRC	13	Source	Bulk connection of switch, connect to VGG5, VGG10 capacitors
VGG5	14	Bias Voltage Output	Connect VGG5 Capacitor to SRC
VGG10	15	Bias Voltage Output	Connect VGG10 Capacitor to SRC
SW2	16	Switch Output Node 2	
GATE2	17	Gate 2	Connect to gate of switch between SRC and SW2
SRC	18	Source	Connect to source of external switches
GATE1	19	Gate 1	Connect to gate of switch between SRC and SW1
SW1	20	Switch Output Node 1	
SUB	PAD	Thermal Input	Connect thermally to the FET chip

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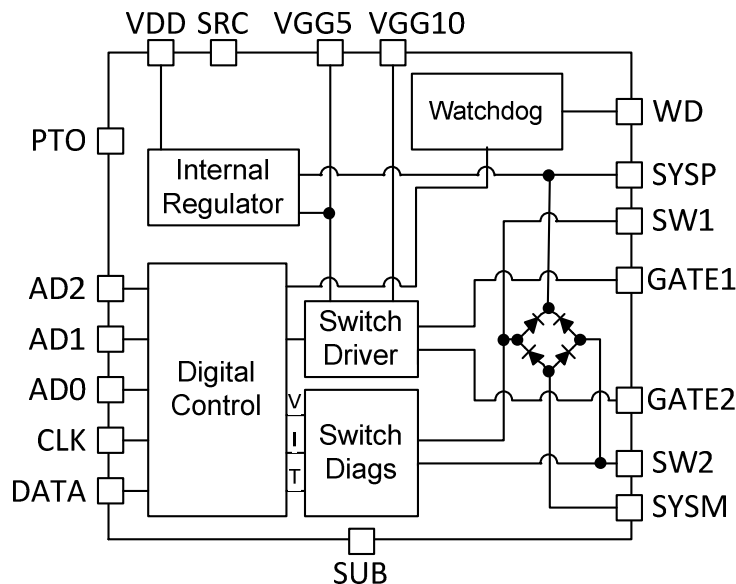
Functional Block Diagram

Figure 1: TS13401 Block Diagram

Absolute Maximum Ratings

Over operating free–air temperature range unless otherwise noted[1, 4]

Parameter	Range	Unit
SW1, SW2 [2]	-1 to 60	V
SYSP, SYSM, PTO [3]	-1 to 60	V
CLK , DATA, VDD, AD2, AD1, AD0, WD [3]	-0.3 to 5.5	V
VGG5 [2]	-0.3 to 5.5	V
GATE1, GATE2, VGG10 [2]	-0.3 to 11	V
SUB [2]	-55 to 0.3	V
Operating Junction Temperature Range, T_J	-40 to 125	°C
Storage Temperature Range, T_{STG}	-65 to 150	°C
Electrostatic Discharge – Human Body Model	±2k	V
Electrostatic Discharge – Charged Device Model	+/-500	V
Peak IR Reflow Temperature (10 to 30 seconds)	260	°C

Notes:
(1) Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute–maximum–rated conditions for extended periods may affect device reliability.
(2) Voltage values are with respect to SRC terminal.
(3) Voltage values are with respect to SYSM terminal.
(4) ESD testing is performed according to the respective JESD22 JEDEC standard.

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Thermal Characteristics

Symbol	Parameter	Value	Unit
θ_{JC}	Thermal Resistance Junction to Case [1]	50	°C/W
T_{STG}	Storage Temperature Range	-65 to 150	°C
$T_{J\,MAX}$	Maximum Junction Temperature	150	°C
T_J	Operating Junction Temperature Range	-40 to 125	°C

Notes:
(1)   Case Temperature is measured in the center of the case at the bottom of the package adjacent to the circuit board.

Recommended Operating Conditions

Symbol	Parameter	Min	Typ	Max	Unit
V_{SW}	AC Switch Voltage		24	36	V_{RMS}
C_{DATA}	Data Isolation Capacitor		100		pF
C_{ISO}	Clock Isolation Capacitor		220		pF
C_{PTO}	Power Transfer Capacitor		10		nF
C_{VDD}	VDD Capacitor		470		nF
C_{VGG5}	VGG5 Capacitor		470		nF
C_{VGG10}	VGG10 Capacitor		470		nF
C_{SUB}	Sub Capacitor		100		nF
C_{WD}	Watch Dog Timer Capacitor		22		nF
R_{WD}	Watch Dog Timer Resistor	100k	1M		Ω
C_{SYS}	VSYS Capacitor		2		µF
R_{SYSP}	SYSP Resistor		100		Ω
R_{SYSM}	SYSM Resistor		100		Ω
V_{CLK}	Clock Drive Voltage	1.7		5.5	V
T_{CLK}	Clock Period	0.8	1	1.2	µs
T_{BIT}	Bit Period	7	8	10	µs
T_{RESET}	Reset Time	18			µs

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Electrical Characteristics

Electrical Characteristics, T_J = -40°C to 125°C (unless otherwise noted)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
Supply Voltages						
I_{SYSP}	System Supply Current	Latch Mode		15	20	µA
I_{SYSP_CONV}	System Supply Current-Converting	Switch on, sensing enabled, converting			2	mA
V_{DD}	VDD Bias Output Voltage	With respect to SYSM	4.5	5.0	5.5	V
V_{GG5}	VGG5 Bias Output Voltage	With respect to SRC	4.5	5.0	5.5	V
V_{GG10}	VGG10 Bias Output Voltage	With respect to SRC	9	10	11	V
I/O Parameters						
V_{DATAH}	DATA Output High Voltage Drop	$2.5V < V_{DD} < 5.5V$; I_{OH} = -4mA $V_{DATAH} = V_{DD} - V_{DATA}$		0.7	1.3	V
V_{DATAL}	DATA Output Low Voltage	$2.5V < V_{DD} < 5.5V$; I_{OH} = 4mA $V_{DATAL} = V_{DATA} - V_{SYSM}$		0.1	0.2	V
I_{DATAZ}	DATA Output Off-State Leakage	$2.5V < V_{DD} < 5.5V$ $0V < V_{DATA} < V_{DD}$	-1		8	µA
I_{IL}	Input Low-level Leakage Current	AD0, AD1, AD2 Inputs; $V_{INPUT} = V_{SRC}$ CLK Input; $V_{INPUT} = V_{SYSM}$	-1		1	µA
I_{IH}	Input High-level Leakage Current	AD0, AD1, AD2 Inputs; $V_{INPUT} = V_{GG5}$	-1		1	µA
I_{IH_CLK}	CLK Input High-level Leakage Current	CLK Input; $V_{INPUT} = V_{DD}$	-1		15	µA
Current Sense						
$|I_{RANGE}|$	Current Sense Full-Scale Range			0.25		V
$I_{RANGE-TC}$	Current Sense Channel TC			1.5625		$\frac{mV}{°C}$
$|I_{RANGE-IR}|$	Current Sense Full-Scale Range	Inrush Mode		0.5		V
$I_{RANGE-IR-TC}$	Current Sense Channel TC	Inrush Mode		3.125		$\frac{mV}{°C}$
Temperature Sense						
T_{RANGE}	Temperature Sense Full-Scale Range	Note: Accuracy not guaranteed above T_J = 127°C (Not tested in production)	-40		155	°C
T_{CODE}	Temperature Channel Gain	(1)		1		$\frac{°C}{Code}$
Voltage Sense						
$|V_{RANGE}|$	System Voltage Sense Full-Scale Range		60	63.5	67	V
V_{CODE}	Voltage Sense Channel Gain		0.472	0.5	0.528	$\frac{V}{Code}$
Data Converter						
N_{BITS}	ADC Reported Resolution	Reported Resolution via Serial Interface		8		Bits
N_{ERR}	ADC Total Error	Total linearity, zero and full-scale errors. F_{CLK} = 1MHz			1	LSB
t_{CONV}	ADC Conversion Time	F_{CLK} = 1MHz			10	µs
Communication						
T_{HB}	Heartbeat Pulse Width			24		µs
Dither						
T_{DOFF}	Dither Off Period			38		µs
T_{DRTY}	Dither Retry Interval			5.2		ms
V_{DITHER_ON}	Dither On Threshold	$V_{SYSP}-V_{SYSM}$		18.5		V
V_{DITHER_OFF}	Dither Off Threshold	$V_{SYSP}-V_{SYSM}$		19.5		V

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Symbol	Parameter	Condition	Min	Typ	Max	Unit
Output Switch						
I_{SWX}	SW1/2 Leakage	$V_{SYS} = 42V$; $V_{SWX} = 0$, 42V; $V_{SYSM} = 0V$	-3		3	µA
$IOUT_{OC-00}$	Output Over Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 00, Measured as V_{SWX}		220		mV
$IOUT_{OC-01}$	Output Over Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 01, Measured as V_{SWX}		350		mV
$IOUT_{OC-10}$	Output Over Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 10, Measured as V_{SWX}		460		mV
$IOUT_{OC-11}$	Output Over Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 11, Measured as V_{SWX}		580		mV
$IOUT_{IR-00}$	Output Inrush Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 00, Measured as V_{SWX}		930		mV
$IOUT_{IR-01}$	Output Inrush Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 01, Measured as V_{SWX}		1050		mV
$IOUT_{IR-10}$	Output Inrush Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 10, Measured as V_{SWX}		1150		mV
$IOUT_{IR-11}$	Output Inrush Current Shutdown SWx Threshold	T_J=25°C, OC_SET = 11, Measured as V_{SWX}		1260		mV
OC_{FILT}	Output Over Current Deglitch		2.75	4	7	µs
OC_{IR_FILT}	Output Inrush Current Deglitch		1	2	3	µs
N_{IR_CYCLES}	Inrush Duration			4		Cycles
$T_{BLANK-OC}$	Current Limit Blanking Time		19	25	39	µs
$V_{TURN-OFF}$	Switch Voltage for Zero Cross Turn-Off	$T_J = 25$°C	-37.5		37.5	mV
V_{OFF-TH}	Zero Cross Turn-Off Voltage Threshold	$T_J = 25$°C; Switch will turn off if absolute value of voltage is below this threshold after Zero Cross Off command	12.5	25	37.5	mV
V_{CLAMP}	V_{SWX} Clamp Voltage	Measured as V_{SW1}-V_{SW2}, V_{SW2}-V_{SW1} $I_{SW} = 10mA$	58		65	V
Watch Dog						
WD_{TO}	Turn-Off Threshold	Switch shuts off if WD drops below this voltage	500	700	900	mV
WD_{RC}	WD Recharge Voltage	WD recharges to this voltage when command is received	V_{GG5}-1.1	V_{GG5}-0.9	V_{GG5}-0.5	V
Over Temperature						
T_{WARN}	Over Temperature Warning	[1]	90		120	°C
T_{SD}	Over Temperature Shutdown	[1]	120		150	°C
T_{HYST}	Over Temperature Hysteresis	[1]		20		°C
T_{DIFF}	Temperature Difference Between Warning and Shutdown Thresholds	[1]		30		°C
Power Transfer						
F_{PTO}	Power Transfer Output Frequency	V_{SYSP}-V_{SYSM} = 24V	50	80	110	kHz
R_{HS_PTO}	Power Transfer High Side Driver Resistance	V_{SYSP}-V_{SYSM} = 24V	30	55	80	Ω
R_{LS_PTO}	Power Transfer Low Side Driver Resistance	V_{SYSP}-V_{SYSM} = 24V	20	35	50	Ω

Notes:

(1) Not tested in production

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Detailed Description

Communication Protocol

The TS13401 device supports a proprietary single-wire interface that is compact and allows support of systems where galvanic isolation is required with a minimum number of external components.

Bit Signaling

The MCU can generate three signals on the CLK pin: Reset, Zero, and One. The Zero and One signals are digital bits and form a command word. Each command word is preceded by a Reset signal.

Reset Signal (R)
The Reset signal is a zero logic level that is kept low for longer than T_{RESET}.

Zero Signal (0)
The Zero signal is two pulses during a bit period T_{BIT}.

One Signal (1)
The One signal is four pulses during a bit period T_{BIT}.
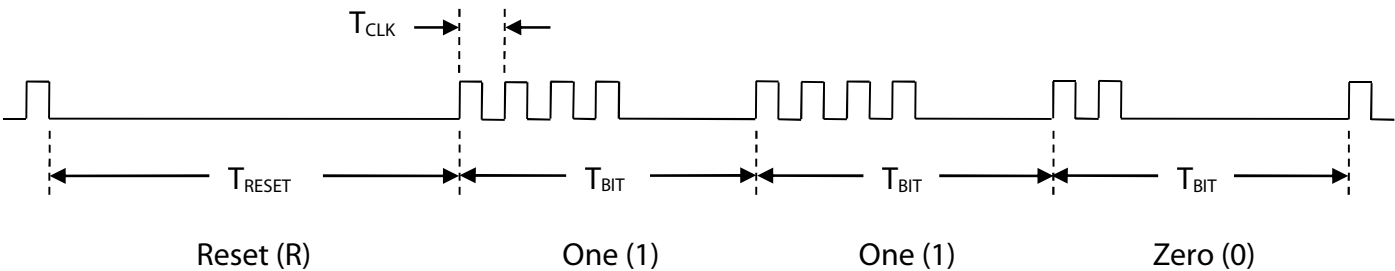
Figure 2: Communication Protocol

CLK:	ANY	R	P2	P1	P0	A2	A1	A0	C3	C2	C1	C0	1	1	…	1	1	ANY
Switch State:	Old State																	New State
DATA:	High Impedance											0	S7	…	S0	0	High Impedance

Page: P2, P1, P0 — Address: A2, A1, A0 — Command: C3, C2, C1, C0 — Status: S7 … S0

Figure 3: Communication Sequence

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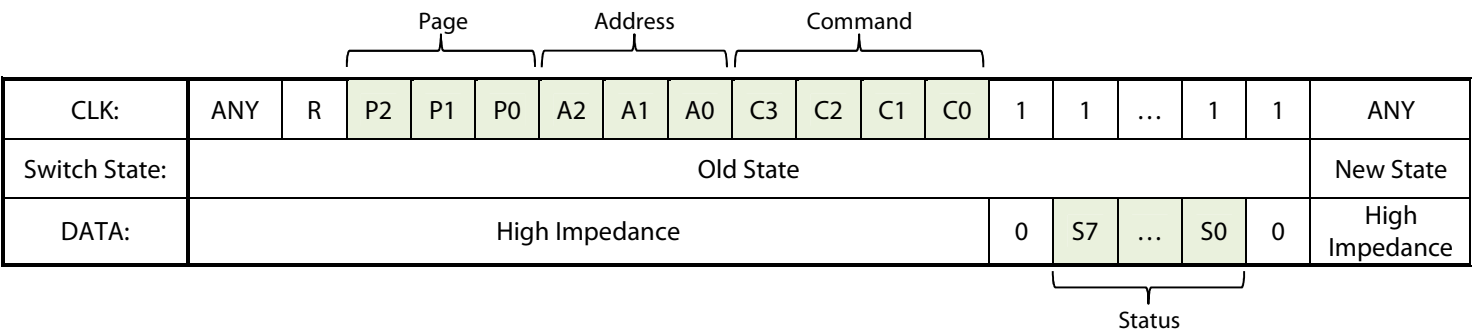
Page Selection

The three bits (P2 P1 P0) in Figure 3 select the page of commands to be used for the current communication sequence. There are two possible selections; 110 for the Command Page and 111 for the Configuration Page (see Table 1). The commands available on each page are listed in Tables 2 and 3.

Table 1: Valid Pages

P2	P1	P0	Page
0	0	0	Reserved
0	0	1	Reserved
0	1	0	Reserved
0	1	1	Reserved
1	0	0	Reserved
1	0	1	Reserved
1	1	0	Command Page
1	1	1	Configuration Page

Device Addressing

Figure 2 shows the beginning of a command sequence. This pattern appears at the CLK input and starts with a low period for duration of T_{RESET} or greater, followed by the preamble (P2 P1 P0). The following three bits designate the address of the device being selected. These three bits (A2 A1 A0) correspond to the device with AD2, AD1, and AD0 pins connected as in the Address Configuration Table shown in Figure 8. See the Multi-channel Application Section for more information.

Switch Commands

The (C3 C2 C1 C0) field sent using the CLK pin determines the command sent to the switch. Two pages are available; one is for issuing commands, and the other is for configuring the device. The Command page defines possible actions that control the various functions. The Configuration page sets the parameters that affect those functions. Table 2 shows valid commands:

Table 2: Command Page--Valid Command Sequences

C3	C2	C1	C0	Command
0	0	0	0	No Operation
0	0	0	1	OFF, Immediate
0	0	1	0	OFF, Zero Crossing
0	0	1	1	ON, Immediate
0	1	0	0	ON, Zero Crossing
0	1	0	1	ON, Immediate, with Dithering
0	1	1	0	ON, Zero Crossing, with Dithering
0	1	1	1	Heartbeat
1	0	0	0	Set Power Transfer Mode
1	0	0	1	Cancel Power Transfer Mode
1	0	1	0	Set Inrush Mode
1	0	1	1	Cancel Inrush Mode
1	1	0	0	Start a load current measurement
1	1	0	1	Start a system voltage measurement
1	1	1	0	Start a switch temperature measurement
1	1	1	1	Poll State (No Operation)

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Table 3 defines the possible configuration sequences. These sequences are intended to be used in the system primarily during initial setup (usually on system power-up). These commands are "sticky", that is to say, once one is written, that corresponding configuration remains in effect until such a time as power is removed, thereby re-setting the part. Upon reset, the configuration will return to its default state. The default configuration settings are shown in the table.

Table 3: Configuration Page--Valid Configuration Sequences

C3	C2	C1	C0	Configuration
0	0	0	0	Reserved
0	0	0	1	Set Over-Current Shutdown Set to 00
0	0	1	0	Set Over-Current Shutdown Set to 01
0	0	1	1	Set Over-Current Shutdown Set to 10
0	1	0	0	Set Over-Current Shutdown Set to 11 (default)
0	1	0	1	Reserved
0	1	1	0	Reserved
0	1	1	1	Reserved
1	0	0	0	Reserved
1	0	0	1	Reserved
1	0	1	0	Reserved
1	0	1	1	Reserved
1	1	0	0	Reserved
1	1	0	1	Reserved
1	1	1	0	Reserved
1	1	1	1	Poll State (No Operation)

Each device monitors the CLK line regardless of the address; however only the device with the (AD2 AD1 AD0) pins configured to match the (A2 A1 A0) field sent via the CLK pin will respond to the Command bits (C3 C2 C1 C0). If two or more devices on the CLK bus have address pins wired alike, those devices will all respond to the same command. However, doing this may lead to DATA bus conflicts when the device Status Values are reported.

The command is executed after the status values are shifted out to avoid interference on the status values caused by transients in the system.

ON Commands

Four modes of closing the switch are available:
1. ON, Immediate: When this command sequence is sent, the switch will be closed after the status values are shifted out. The system must comprehend the time it takes to complete the sequence in order to place the switch in the closed state at the desired time.
2. ON, Zero Crossing: When this command sequence is sent, the switch will close on the first occurrence of a polarity change in the voltage across the switch (V_{SW1}-V_{SW2} changes sign to indicate a voltage zero-crossing) after the switch receives the command and the status values are shifted out. This should not be used for DC applications.
3. ON, Immediate with Dithering: This command closes the switch as in ON, Immediate, above, but puts the device into Dither mode as well. Dithering opens the switch after an interval of T_{DRTY} for a period of time, T_{DOFF} when the system voltage drops below V_{DON}. This allows the C_{SYS} capacitor to be re-charged. See the Dither Functionality Section for more details.
4. ON, Zero Crossing with Dithering: This command closes the switch as in ON, Zero Crossing, but enables the Dither mode as described above.

OFF Commands

Two modes of opening the switch are available:
1. OFF, Immediate: When the OFF, Immediate sequence is sent, the switch will transition to the open state after the status values are shifted out.
2. OFF, Zero Crossing: When the OFF, Zero-Crossing sequence is received, the switch will open on the first occurrence of the load-current dropping within I_{TURN_OFF} after the status values are shifted out.

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Poll Command

A Poll State command may be sent to the device when no change of operation is desired, but the state of the Status Values is needed by the microcontroller. In non-latched operation, this command will also serve to recharge the Watchdog Timer. See the Latching Configuration Section for details.

Sensing Modes

The device has the ability to make system parametric measurements related to the load being actuated. The parameters that can be measured are:

1. **Load Current**
   The load current can be measured by writing the command sequence shown in the commands table to initiate a load current measurement. Note that the load current can only be measured when the switch is in the "ON" state. The switch must be commanded to the "ON" state using any of the supported command sequences before sending a load current measurement command.
   Normal Measurement
   For a given code value (CODE) from a load current measurement, the current through the external switch (I_{SW}) with total resistance equal to R_{FET} is:

$$I_{SW} = \frac{-I_{RANGE} + CODE \times \left(\frac{2 \times I_{RANGE}}{255}\right)}{R_{FET}}$$

   Inrush Measurement
   For a given code value (CODE) from a load current measurement with Inrush Mode enabled, the current through the external switch (I_{SW}) with total resistance equal to R_{FET} is:

$$I_{SW} = \frac{-I_{RANGE-IR} + CODE \times \left(\frac{2 \times I_{RANGE-IR}}{255}\right)}{R_{FET}}$$

2. **System Voltage**
   The system voltage can be measured by writing the command sequence shown in the commands table to initiate a system voltage measurement. This measures the voltage between one switch terminal tied to the supply and the other tied to the load, and depends on the load being terminated to ground in order to make the measurement. It is also important to note that this measurement can only be made when the switch is in the "OFF" state. The switch must be placed into that state by any of the supported command sequences or by an over-current event before sending a system voltage measurement command.

   For a given code value (CODE) from a system voltage measurement, the voltage across SW1 and SW2 (V_{SW}) is:

$$V_{SW} = -|V_{RANGE}| + CODE \times \left(\frac{2 \times |V_{RANGE}|}{255}\right)$$

3. **Switch Temperature**
   The switch temperature may be measured by writing the command sequence shown in the commands table to initiate a switch temperature measurement. There are no constraints on the switch state to be able to make a temperature measurement.

   For a given code value (CODE) from a temperature ADC measurement, the temperature of the device (T_J) is:

$$T_J = T_{ROOM} + (CODE - 128) \times T_{CODE}$$

$$T_{ROOM} = 25°C$$

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When any of the above sensing modes are commanded, the information returned on the DATA pin will be amended with the system measurement results. This will consist of eight bits of data following the Status Values and a "0" bit. The sequence will be as follows:

For Continuous Sample Mode, drive 9 "1" bits
(D7-D0, 0) for each additional conversion desired

CLK:	R	Page	Addr	Sensing Command	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	ANY
					↑ Sample Param. Conv. Complete ↑								↓ Output Data ↓										
DATA:	High-Z				0	S7	S6	S5	S4	S3	S2	S1	S0	0	D7	D6	D5	D4	D3	D2	D1	D0	0	High-Z

Figure 4: Sensing Communication Protocol

The switch depends on the CLK to make its data conversion, so it is required that the CLK continue to be driven until the output data is received.

The requested measurement is sampled during the "0" bit at the beginning of the status bit stream. The converted signal is complete at the end of the "0" bit following the status bit stream, with the transfer of the converted data commencing afterward. For temporally-accurate measurements to be made, the microcontroller must comprehend the delay between the start of the Reset / Preamble / Address / Command sequence and the sampling period. The timing of the sample will be entirely dependent on the CLK timing presented to the device.

Continuous Sample Mode

The device supports a continuous sample mode whereby a continuous series of samples is provided without having to send another command. By continuing to send a series of "1" bits on the CLK pin, the microcontroller will be provided a continuous series of converted samples of the selected type, 8 bits long, and separated by a "0" transmission. By utilizing this feature, the microcontroller may sample waveforms and use the data for numerical analysis to gain insight into the health of the load, the quality of the supply voltage, compute power factor, frequency, distortion, etc. Samples following the first conversion will be taken at the end of the D3 bit transmission of the prior sampled data.

Status Values

The (S7…S0) field received using the DATA pin provides the status of the switch before the command has been executed. Each of the status bits is generated by the switch in the following way:
- For zero: the DATA pin is pulsed for first 2 clock pulses matching the protocol (the pulses corresponding to the Zero signal).
- For one: the DATA pin duplicates the signal available at the CLK pin (the pulses corresponding to the One signal).

The following status values are defined:

Table 4: Status Bits

S7	Power Transfer Mode Enabled
S6	Inrush Mode Enabled
S5	Dithering Enabled
S4	Over Temperature Warning
S3	Over-Temperature Shutdown
S2	Inrush Over-Current Shutdown
S1	Over-Current Shutdown
S0	Switch State

Data Values

The DATA (D7, D6…D0) field is used to provide the acquired value of the system parameter requested by the Command Sequence if there is data to be returned by that command. The data will be transmitted with the MSB first.

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Latching Configuration

The device can be configured for latching or non-latching functionality via external interconnect. When the WD pin is tied to VGG5, the switch state is latched after each command (CMD) sequence. When the WD pin is tied to an RC circuit, the device is configured for non-latching behavior. If a CMD sequence is not transmitted before the RC decays to WD_{TO}, the switch will be turned off. A CMD sequence received by the device before the WD pin voltage decays to WD_{TO} will cause the WD pin to recharge to WD_{RC}, and the switch will remain closed. In order to recharge, the CMD address must be for the corresponding device address configuration. Typical waveforms for non-latching behavior are shown below.

CLK	ANY	R	P2	P1	P0	A2	A1	A0	C3	C2	C1	C0	1	1	...	1	1	ANY
Switch State	Old State																	New State
DATA	High Impedance											0	S7	...	S0	0	High Impedance
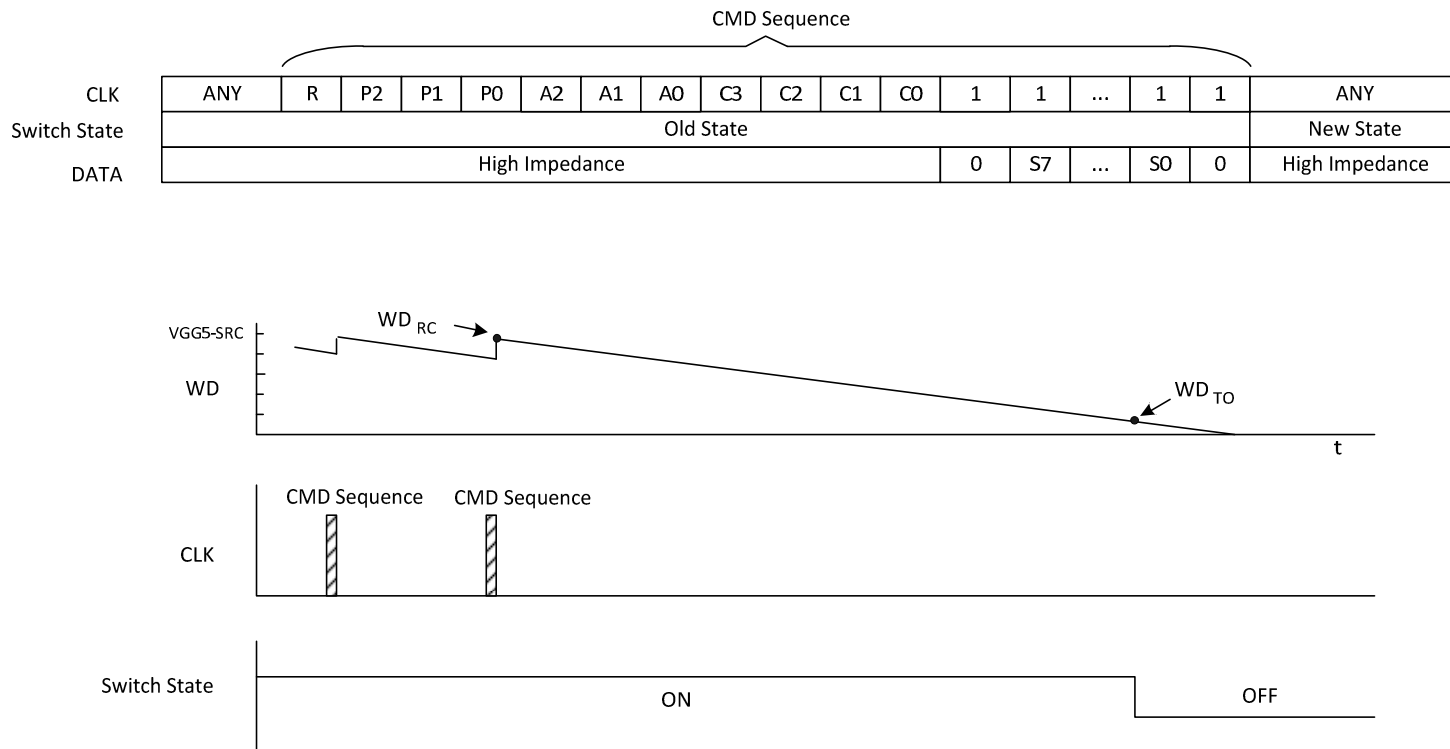
Figure 5: Latching Functionality

The time between the last CMD sequence and the switch opening (in a non-latching configuration) can be computed by the following equation:

$$t_{OFF} = -R_{WD} C_{WD} \ln\left(\frac{WD_{TO}}{WD_{RC}}\right)$$

Where:

t_{OFF} is the time from the last CMD sequence until the switch opens
R_{WD} is the WD pin resistor
C_{WD} is the WD pin capacitor
WD_{TO} is the WD pin turn-off voltage threshold
WD_{RC} is the WD pin re-charge voltage

It should be noted that the WD capacitor, C_{WD}, is recommended to be 22nF. The reason for this is that charge proportional to C_{WD} is drawn from the C_{SYS} capacitor in every re-charge cycle, thereby elevating the average current, and forcing the device to switch off more frequently in order to re-charge C_{SYS} (see Figure 8, below). C_{WD} can be made smaller, but this will necessitate a larger value of R_{WD} to be used to define a given t_{OFF} time. R_{WD} has its practical limits due to leakage within the components attached to the WD pin and possible leakage on the circuit board due to contamination. The system designer should consider all these issues when selecting R_{WD} and C_{WD}. Device 2 in Figure 8 shows R_{WD} and C_{WD} being used to create a non-latching channel. Device 1 is shown in latching mode.

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Heartbeat Functionality

When the switch is off and the heartbeat command sequence has been transmitted, the DATA pin provides a pulse synchronous with the zero crossings of the AC waveform. A single pulse or "Heartbeat" for each crossing will be present with a pulse width of T_{HB} as shown in the figure below. This is useful for monitoring load presence and for evaluating the phase of the AC waveform. To cancel the heartbeat command, send any other valid command. If a heartbeat command is sent while the switch is on no data will be sent back, the switch state will remain the same, and the heartbeat command will not be enacted.
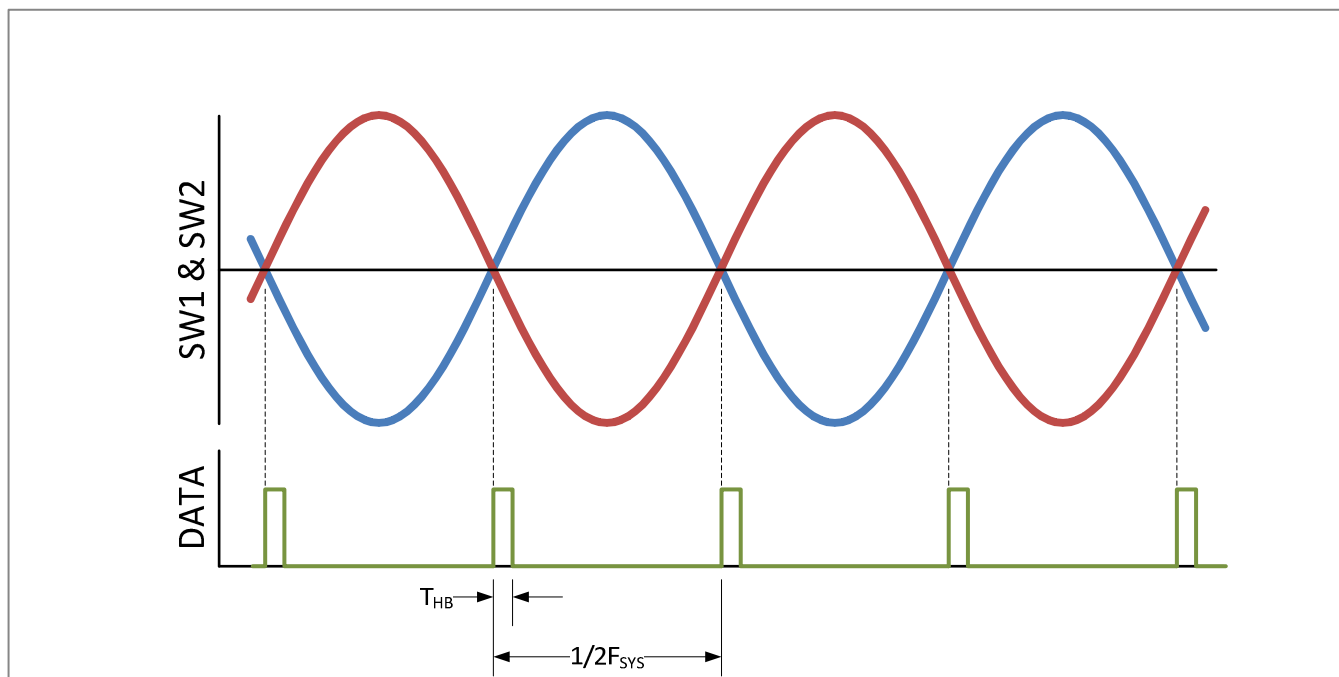
Figure 6: Heartbeat Functionality

Power Transfer

When the set power transfer mode command is sent to the device, the PTO pin will be driven from SYSP to SYSM at frequency F_{PTO}. The PTO pin will continue to drive a pulse train until the cancel power transfer mode command is sent. This feature can be used to drive a charge pump to harvest power from the SW pins. See Figure 8 for a typical configuration.

Over Temperature

In the event of the device reaches temperatures exceeding T_{WARN} or T_{SD}, status bits 4 or 3 respectively will be set and visible on the DATA pin (see Table 4). There is also hysteresis T_{HYST} built into each trip point. When T_{WARN} is reached, functionality of the device will remain the same and this status is just for user information. When T_{SD} is reached, the device will drive the switch off and ignore turn on commands until the temperature goes below T_{SD}-T_{HYST}. Since the switch is external, it is important to thermally couple the PAD to the switch through the PCB layout.

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Inrush Support

A system may present loads to the switch which result in high inrush currents when initially energized, but rapidly decrease to a lower level. If the inrush level is higher than the switch over-current shutdown, it may be impossible to activate the load. This device supports an inrush mode to allow the activation of loads with inrush currents on the order of twice their normal operating current for a short period of time. During the inrush period, the switch over-current shutdown is elevated, allowing current to build in the load, ensuring actuation. After the inrush event, the over-current threshold can be reduced to a lower level to allow protection against faults. Figure 7 below illustrates the time-variant peak load current and how the inrush over-current shutdown threshold can be used to energize a load successfully when the higher inrush current would otherwise have tripped the lower steady-state over-current threshold. As long as the load current stays within the safe shaded area, the switch will remain closed.
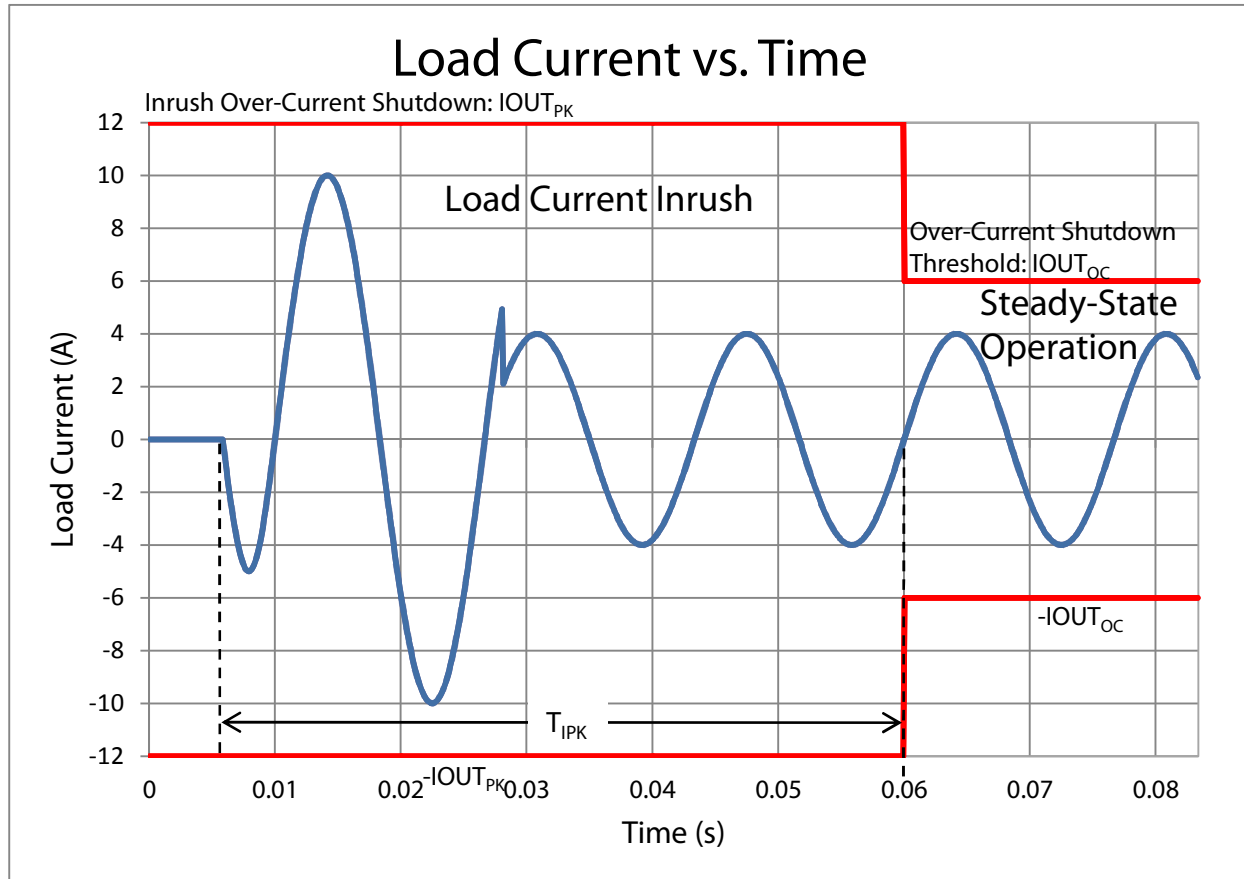

Figure 7: Inrush Waveform

Note that T_{IPK} is internally limited to a maximum of $N_{IR\_CYCLES} = 4$ cycles (8 current zero-crossings). Therefore T_{IPK} is defined as:

$$\frac{8}{2 * F_{SYS}} \leq T_{IPK} \leq \frac{9}{2 * F_{SYS}}$$

If it is desired to limit this period to something less, the normal over-current shutdown threshold may be restored by writing the command sequence to cancel inrush mode. If the device is used in a DC application, note that T_{IPK} will be infinite, so it is critical that the system controller adjusts this time as required so that the system is not sustained in the load current inrush state indefinitely. It is recommended that the inrush period be only as long as is required by the load in the system.

Dither Functionality

Dithering is provided as a mode of operation for applications where a single device per system is used. It enables powering the TS13401 from the AC waveform. The device monitors system voltage and if it is below V_{DITHER_ON}, the switch is shut off for approximately T_{DOFF}. This causes energy stored in the inductor to be transferred into the C_{SYS} capacitor. When the device is in Dither mode, this event occurs at T_{DRTY} intervals until the system voltage reaches V_{DITHER_OFF}.

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Multi-channel Application

In a multi-channel application, dithering is unnecessary when the switch for at least one channel is open and providing power to the other channels. As long as the device address pins are wired uniquely for each channel, a single pair of GPIO pins on the microcontroller can control each device by matching the address in the CMD sequence with the hardwired address. If all devices must be on simultaneously, one device can be configured for dithering mode to maintain system supply.

The SYSP net should be tied to the SYSM net through the C_{SYS} capacitor as shown in Figure 8 below. For a single transformer system, only one is necessary. If additional transformers are used in a given system, then the SYSP and SYSM pins for those TS13401 devices will need an additional C_{SYS} capacitor for each additional transformer.

Current limit resistors are needed for each SYSP pin and each SYSM pin as shown below (R_{SYSP} and R_{SYSM} respectively). These are typically 100Ω, ¼ W.

As shown below, a pair of GPIO pins can manage the command and control for up to 8 loads as long as each part has a unique address. The address pins are set using hard wired connections according to the Address Configuration Table shown in Figure 8.

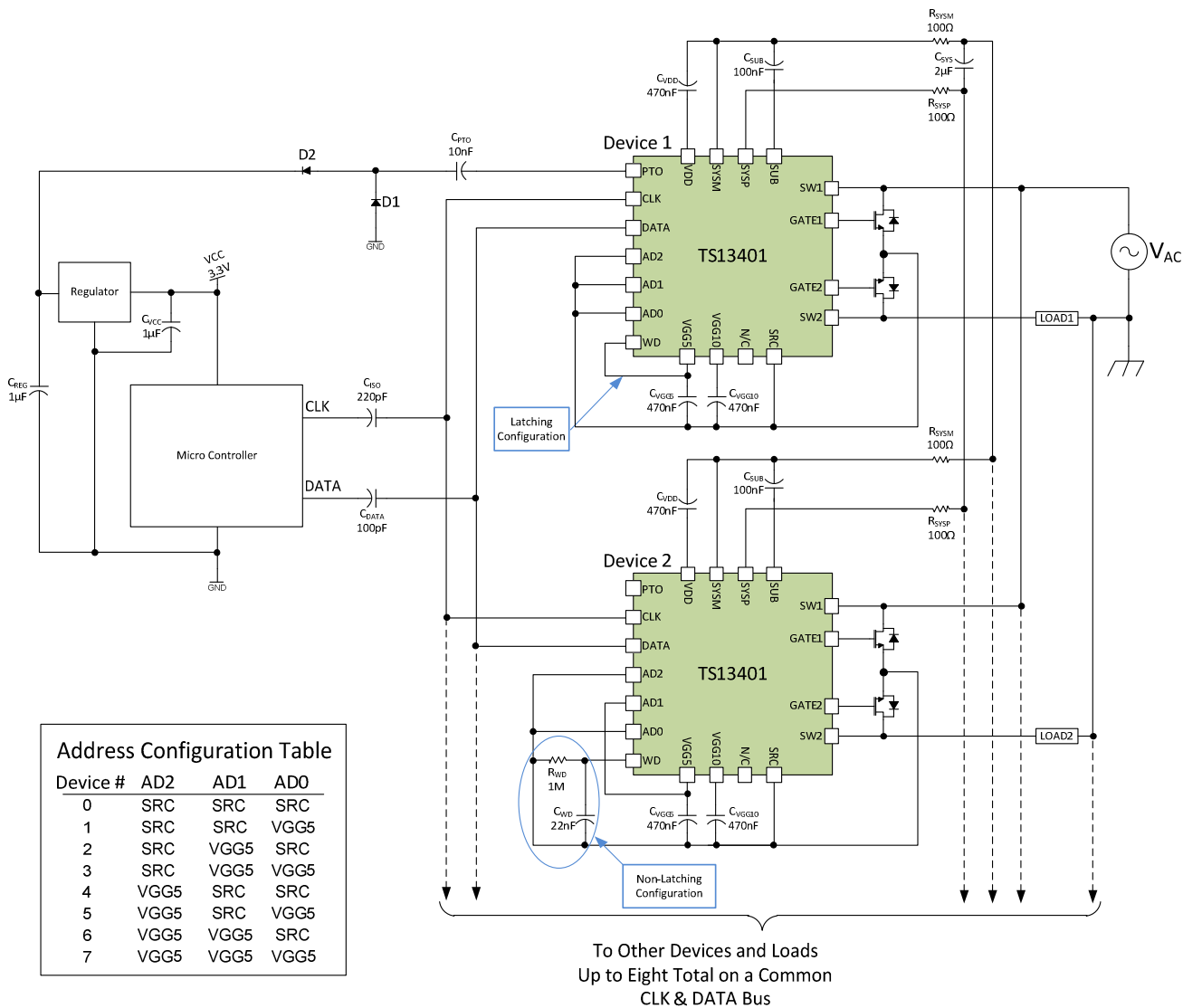Also note that some devices can be wired in non-latching mode and others in latching mode.

Address Configuration Table			
Device #	AD2	AD1	AD0
0	SRC	SRC	SRC
1	SRC	SRC	VGG5
2	SRC	VGG5	SRC
3	SRC	VGG5	VGG5
4	VGG5	SRC	SRC
5	VGG5	SRC	VGG5
6	VGG5	VGG5	SRC
7	VGG5	VGG5	VGG5

To Other Devices and Loads
Up to Eight Total on a Common
CLK & DATA Bus

Figure 8: System Block Diagram

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Package Information

Product Marking
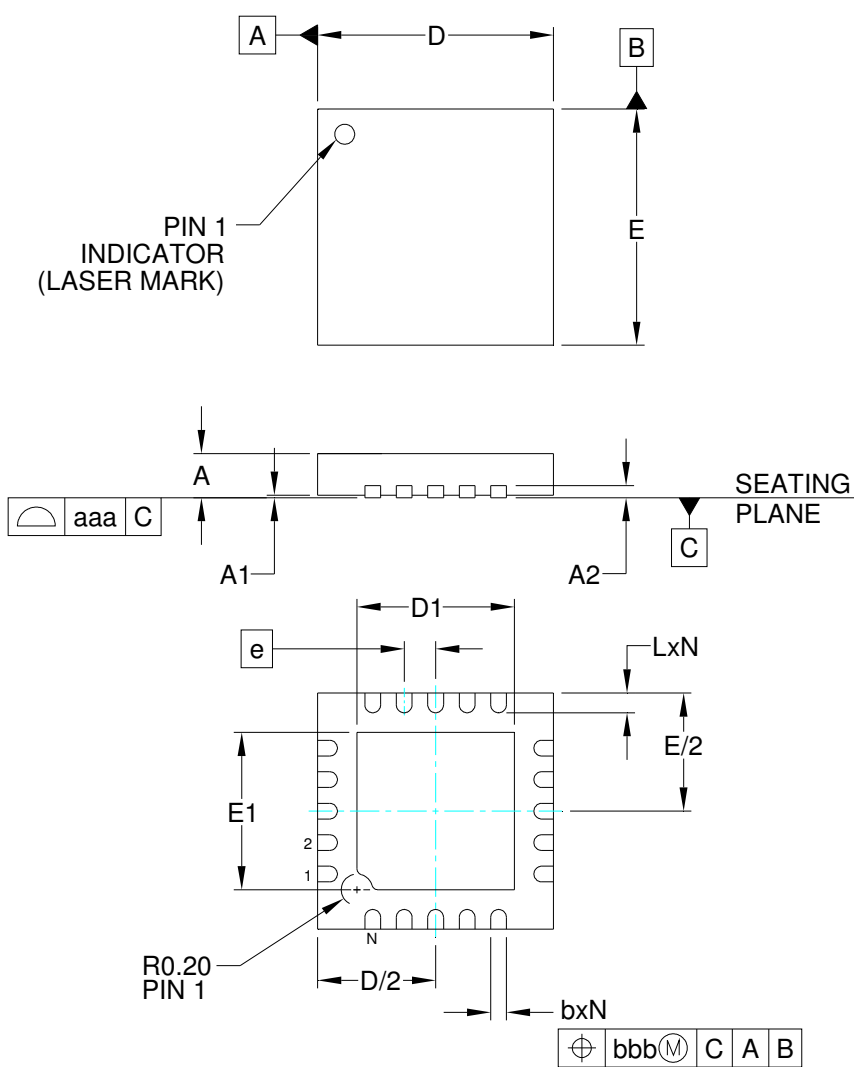
```
  ○
 13401
 yyww
 xxxxx
```

Marking for the 3 x 3mm MLPQ-UT 20 Lead package:

nnnnn= Part Number (Example: 13401)
yyww = Date Code (Example: 1652)
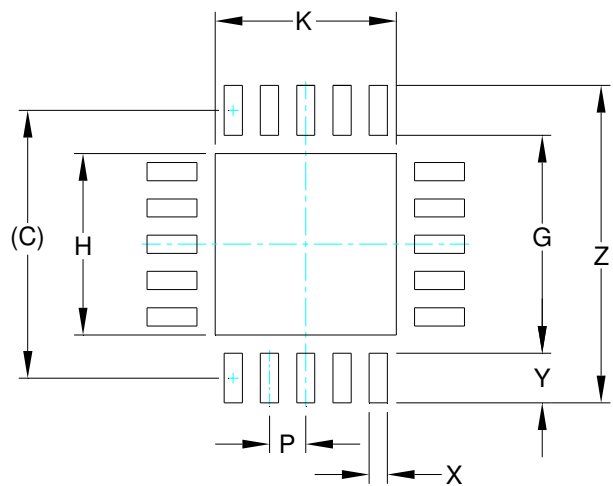xxxxx = Semtech Lot No. (Example: E9010)

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Package Outline Drawing

DIMENSIONS			
DIM	MILLIMETERS		
	MIN	NOM	MAX
A	0.51	0.55	0.60
A1	0.00	0.02	0.05
A2	(0.153)		
b	0.15	0.20	0.25
D	2.90	3.00	3.10
D1	1.90	2.00	2.10
E	2.90	3.00	3.10
E1	1.90	2.00	2.10
e	0.40 BSC		
L	0.15	0.25	0.35
N	20		
aaa	0.08		
bbb	0.10		

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).

2. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

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Board Land Pattern

DIMENSIONS	
DIM	MILLIMETERS
C	(2.95)
G	2.40
H	2.00
K	2.00
P	0.40
X	0.20
Y	0.55
Z	3.50

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).

2. THIS LAND PATTERN IS FOR REFERENCE PURPOSES ONLY.
   CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR
   COMPANY'S MANUFACTURING GUIDELINES ARE MET.

Ordering Information

Device	Package
TS13401ULTRT	MLPQ-20 3.0 x 3.0 Tape & Reel (3000 parts/reel)
TS13401EVB	Evaluation Board

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