Serial Communication

Input/Output Systems

Processor needs to communicate with other devices:

- Receive signals from sensors
- Send commands to actuators
- Or both (e.g., disks, audio, video devices, other processors)

An Example: SICK Laser Range Finder

- Laser is scanned horizontally
- Using phase information, can infer the distance to the nearest obstacle
- Resolution: ~.5 degrees, 1 cm
- Can handle full 180 degrees at 20 Hz

Serial Communication

- Communicate a set of bytes using a single signal line
- We do this by sending one bit at a time:
  - The value of the first bit determines the state of a signal line for a specified period of time
  - Then, the value of the 2nd bit is used
  - Etc.

Serial Communication

The sender and receiver must have some way of agreeing on ***when*** a specific bit is being sent

- Some cases: the sender will also send a clock signal (on a separate line)
- Other cases: each side has a clock to tell it when to write/read a bit
  - The sender/receiver must first synchronize their clocks before transfer begins

Asynchronous Serial Communication

- The sender and receiver have their own clocks, which they do not share
- This reduces the number of signal lines

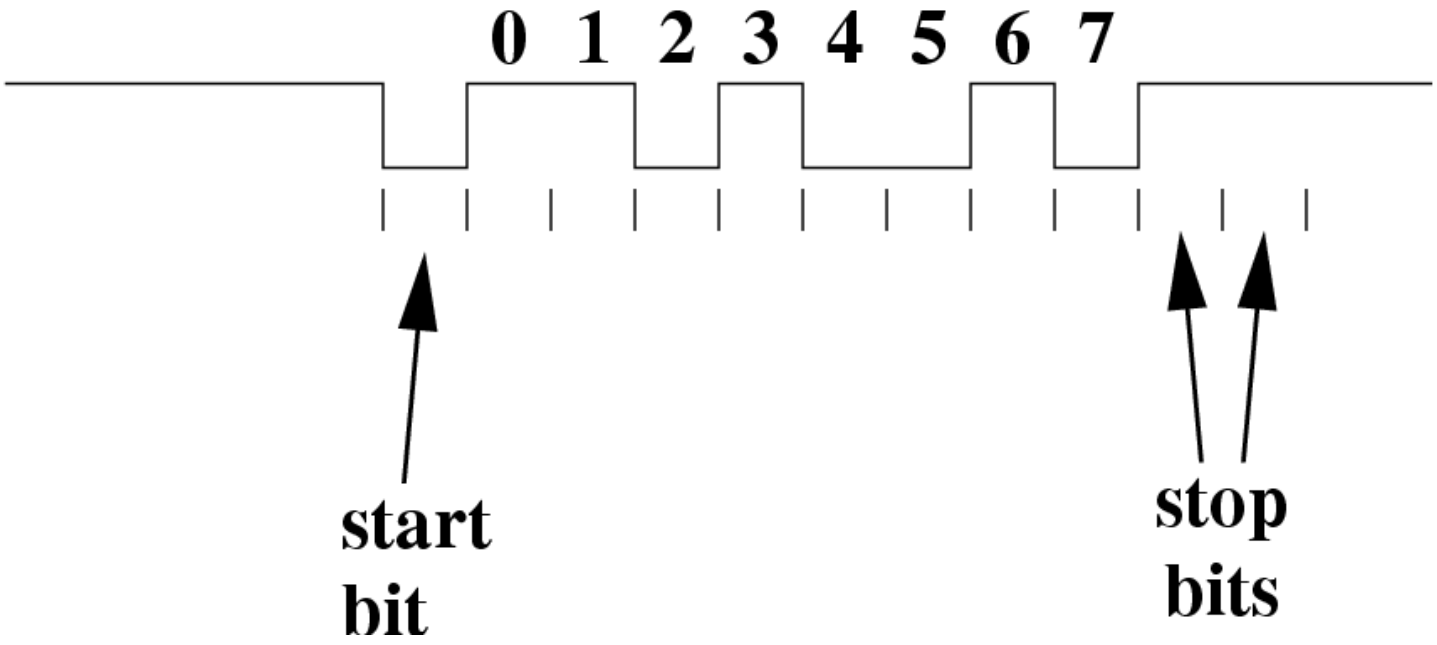
But: we still need some way to agree that data is valid. How?

Asynchronous Serial Communication

How can the two sides agree that the data is valid?

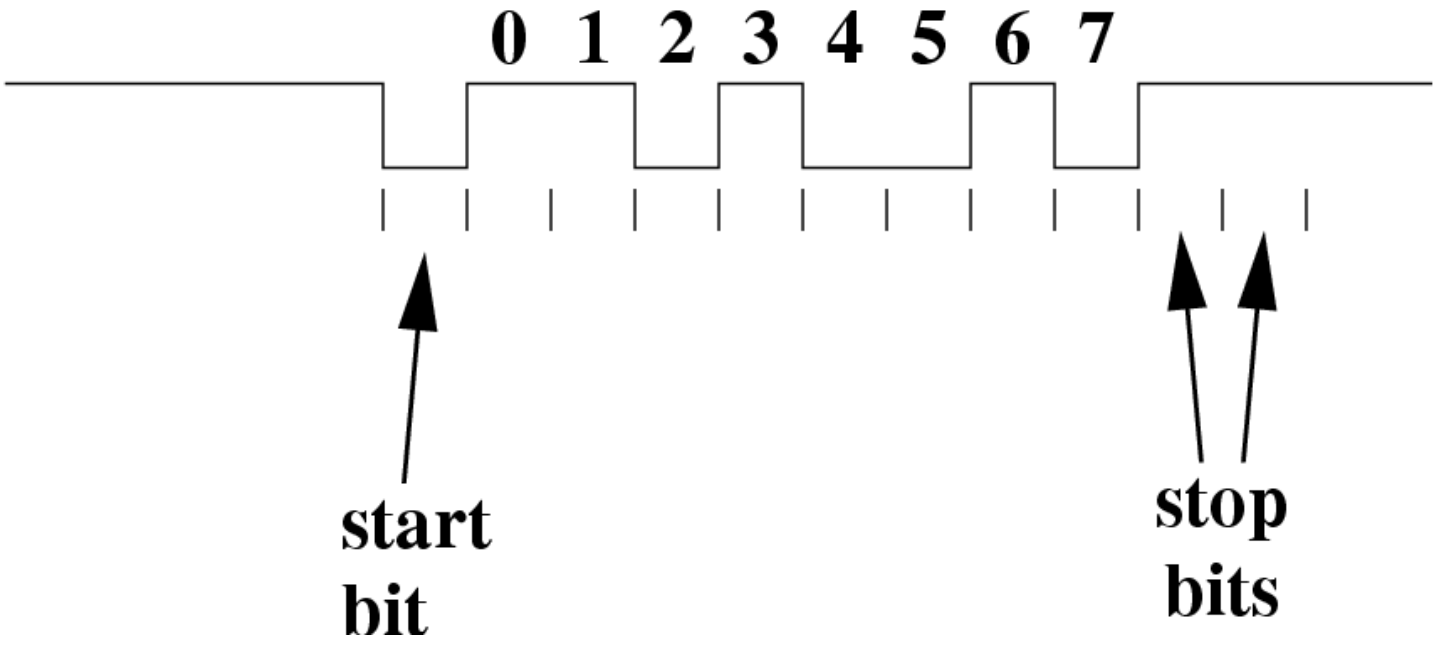
- Must both be operating at essentially the same transmit/receive frequency
- A data byte is prefaced with a bit of information that tells the receiver that bits are coming
- The receiver uses the arrival time of this **start bit** to synchronize its clock

A Typical Data Frame



The start bit indicates that a byte is coming

A Typical Data Frame



The stop bits allow the receiver to immediately check whether this is a valid frame

- If not, the byte is thrown away

Data Frame Handling

Most of the time, we do not deal with the data frame level. Instead, we rely on:

- Hardware solutions: Universal Asynchronous Receiver Transmitter (UART)
  - Very common in computing devices
- Software solutions in libraries

One (Old) Standard: RS232-C

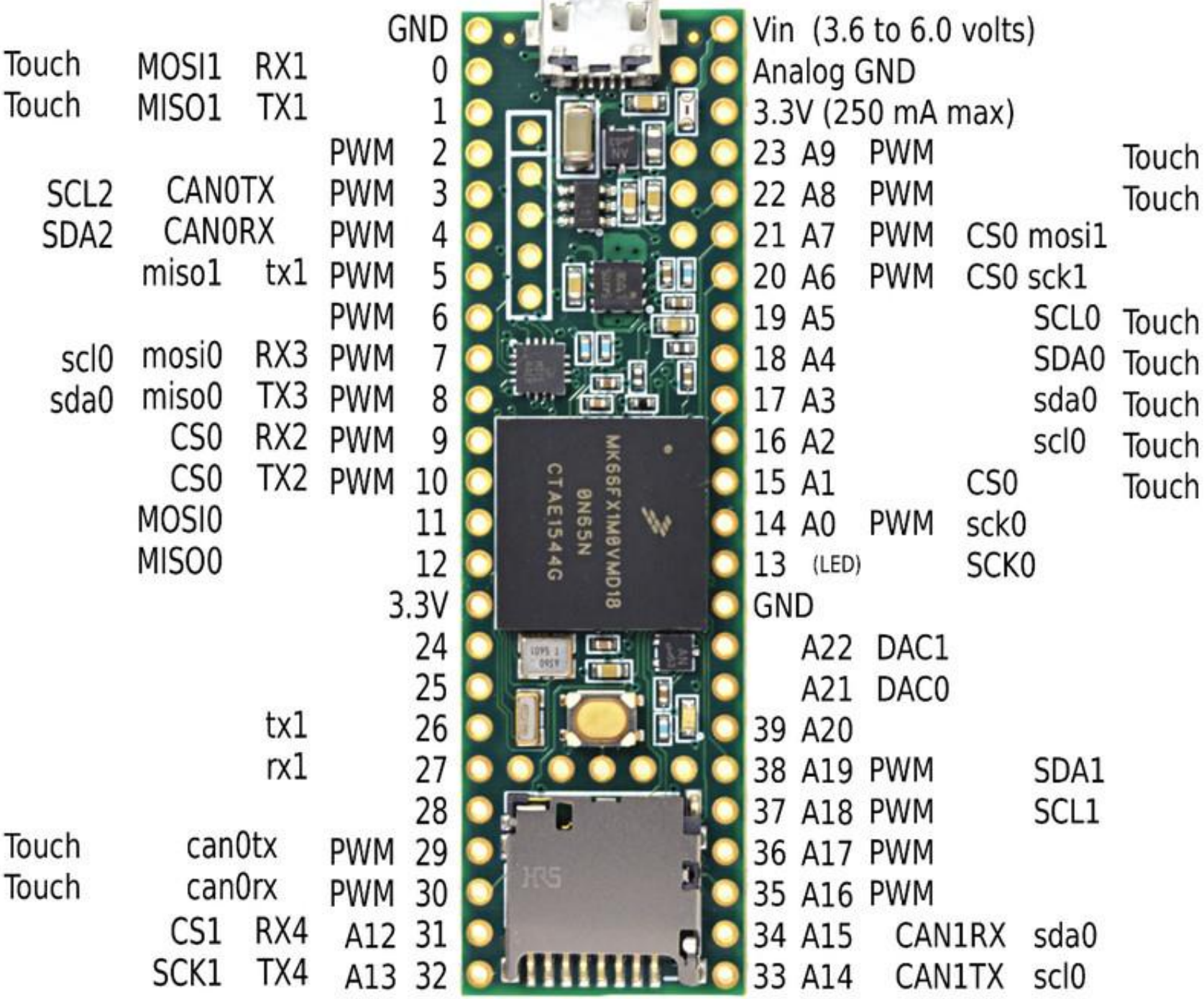
Defines a logic encoding standard:

- “High” is encoded with a voltage of -5 to -15 (-12 to -13V is typical)
- “Low” is encoded with a voltage of 5 to 15 (12 to 13V is typical)

RS232 on the Teensy 3.5

Our Teensy has 7 Universal, Asynchronous serial Receiver/Transmitters (UARTs):

- #0: USB; #1 … 6: RX/TX pins
- Each handles all of the bit-level manipulation
  - Software only worries about the byte level
- 1 … 6 use 0V and 3.3V to encode “lows” and “highs”
  - Must convert if talking to a true RS232C device (+/- 13V)


GND
Touch MOSI1 RX1 0
Touch MISO1 TX1 1
PWM 2
SCL2 CAN0TX PWM 3
SDA2 CAN0RX PWM 4
miso1 tx1 PWM 5
PWM 6
scl0 mosi0 RX3 PWM 7
sda0 miso0 TX3 PWM 8
CS0 RX2 PWM 9
CS0 TX2 PWM 10
MOSI0 11
MISO0 12
3.3V
24
25
tx1 26
rx1 27
28
Touch can0tx PWM 29
Touch can0rx PWM 30
CS1 RX4 A12 31
SCK1 TX4 A13 32
Vin (3.6 to 6.0 volts)
Analog GND
3.3V (250 mA max)
23 A9 PWM Touch
22 A8 PWM Touch
21 A7 PWM CS0 mosi1
20 A6 PWM CS0 sck1
19 A5 SCL0 Touch
18 A4 SDA0 Touch
17 A3 sda0 Touch
16 A2 scl0 Touch
15 A1 CS0 Touch
14 A0 PWM sck0
13 (LED) SCK0
GND
A22 DAC1
A21 DAC0
39 A20
38 A19 PWM SDA1
37 A18 PWM SCL1
36 A17 PWM
35 A16 PWM
34 A15 CAN1RX sda0
33 A14 CAN1TX scl0
MK66FX1M0VMD18
0N65N
CTAE1544G

Serial Initialization

Options include:

- Serial.begin(9600);
- SerialX.begin(9600);
  - Where X = 1 … 6

Generating Serial Output

```
int val = 42;
float f = 6.282;

Serial.println(“foo:”);
Serial.println(val);
Serial.printf(“foo: %d (%f)\n”, val, f);
```

Reading Serial Input

- Serial.read() will return the next character in the buffer
- If the buffer is empty, then this function will ***block*** until a character is available to be read
- This can be very dangerous in a real-time domain

Checking for Characters

What we would like to do is to ask ahead of time as to whether a character is ready to be read …

Checking for Characters

What we would like to do is to ask ahead of time as to whether a character is ready to be read …

```
loop(){
     if(Serial.available()) {
          char c = Serial.read();
          <do something with the read char>
     }
     <do something else while waiting>
}
```

Character Representation

- A “char” is just an 8-bit number
- This allows us to perform meaningful mathematical operations on the characters

Character Representation: ASCII

Binary	Dec	Hex	Glyph
010 0000	32	20	SP
010 0001	33	21	!
010 0010	34	22	"
010 0011	35	23	#
010 0100	36	24	$
010 0101	37	25	%
010 0110	38	26	&
010 0111	39	27	'
010 1000	40	28	(
010 1001	41	29	)
010 1010	42	2A	*
010 1011	43	2B	+
010 1100	44	2C	,
010 1101	45	2D	-
010 1110	46	2E	.
010 1111	47	2F	/
011 0000	48	30	0
011 0001	49	31	1
011 0010	50	32	2
011 0011	51	33	3
011 0100	52	34	4
011 0101	53	35	5
011 0110	54	36	6
011 0111	55	37	7
011 1000	56	38	8
011 1001	57	39	9
011 1010	58	3A	:
011 1011	59	3B	;
011 1100	60	3C	<
011 1101	61	3D	=
011 1110	62	3E	>
011 1111	63	3F	?

Binary	Dec	Hex	Glyph
100 0000	64	40	@
100 0001	65	41	A
100 0010	66	42	B
100 0011	67	43	C
100 0100	68	44	D
100 0101	69	45	E
100 0110	70	46	F
100 0111	71	47	G
100 1000	72	48	H
100 1001	73	49	I
100 1010	74	4A	J
100 1011	75	4B	K
100 1100	76	4C	L
100 1101	77	4D	M
100 1110	78	4E	N
100 1111	79	4F	O
101 0000	80	50	P
101 0001	81	51	Q
101 0010	82	52	R
101 0011	83	53	S
101 0100	84	54	T
101 0101	85	55	U
101 0110	86	56	V
101 0111	87	57	W
101 1000	88	58	X
101 1001	89	59	Y
101 1010	90	5A	Z
101 1011	91	5B	[
101 1100	92	5C	\
101 1101	93	5D	]
101 1110	94	5E	^
101 1111	95	5F	_

Binary	Dec	Hex	Glyph
110 0000	96	60	`
110 0001	97	61	a
110 0010	98	62	b
110 0011	99	63	c
110 0100	100	64	d
110 0101	101	65	e
110 0110	102	66	f
110 0111	103	67	g
110 1000	104	68	h
110 1001	105	69	i
110 1010	106	6A	j
110 1011	107	6B	k
110 1100	108	6C	l
110 1101	109	6D	m
110 1110	110	6E	n
110 1111	111	6F	o
111 0000	112	70	p
111 0001	113	71	q
111 0010	114	72	r
111 0011	115	73	s
111 0100	116	74	t
111 0101	117	75	u
111 0110	118	76	v
111 0111	119	77	w
111 1000	120	78	x
111 1001	121	79	y
111 1010	122	7A	z
111 1011	123	7B	{
111 1100	124	7C	|
111 1101	125	7D	}
111 1110	126	7E	~

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Time Systen

Serial Challenge

- Suppose that we know that we will be receiving a sequence of 3 decimal digits from the serial port
- How do we translate these digits into an integer representation?

```
int32_t read_number()
{
    int val = 0;
    char c = Serial.read();
    val += (c - '0') * 100;
    c = Serial.read();
    val += (c - '0') * 10;
    c = Serial.read();
    val += (c - '0');
    return val;
}
```

Serial Challenge II

- Suppose that we know that we will be receiving a sequence of k decimal digits from the serial port
- How do we translate these digits into an integer representation?

- Can assume that the digits will fit within a uint16_t

Character Representation: ASCII

Binary	Dec	Hex	Glyph
010 0000	32	20	SP
010 0001	33	21	!
010 0010	34	22	"
010 0011	35	23	#
010 0100	36	24	$
010 0101	37	25	%
010 0110	38	26	&
010 0111	39	27	'
010 1000	40	28	(
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010 1010	42	2A	*
010 1011	43	2B	+
010 1100	44	2C	,
010 1101	45	2D	-
010 1110	46	2E	.
010 1111	47	2F	/
011 0000	48	30	0
011 0001	49	31	1
011 0010	50	32	2
011 0011	51	33	3
011 0100	52	34	4
011 0101	53	35	5
011 0110	54	36	6
011 0111	55	37	7
011 1000	56	38	8
011 1001	57	39	9
011 1010	58	3A	:
011 1011	59	3B	;
011 1100	60	3C	<
011 1101	61	3D	=
011 1110	62	3E	>
011 1111	63	3F	?

Binary	Dec	Hex	Glyph
100 0000	64	40	@
100 0001	65	41	A
100 0010	66	42	B
100 0011	67	43	C
100 0100	68	44	D
100 0101	69	45	E
100 0110	70	46	F
100 0111	71	47	G
100 1000	72	48	H
100 1001	73	49	I
100 1010	74	4A	J
100 1011	75	4B	K
100 1100	76	4C	L
100 1101	77	4D	M
100 1110	78	4E	N
100 1111	79	4F	O
101 0000	80	50	P
101 0001	81	51	Q
101 0010	82	52	R
101 0011	83	53	S
101 0100	84	54	T
101 0101	85	55	U
101 0110	86	56	V
101 0111	87	57	W
101 1000	88	58	X
101 1001	89	59	Y
101 1010	90	5A	Z
101 1011	91	5B	[
101 1100	92	5C	\
101 1101	93	5D	]
101 1110	94	5E	^
101 1111	95	5F	_

Binary	Dec	Hex	Glyph
110 0000	96	60	`
110 0001	97	61	a
110 0010	98	62	b
110 0011	99	63	c
110 0100	100	64	d
110 0101	101	65	e
110 0110	102	66	f
110 0111	103	67	g
110 1000	104	68	h
110 1001	105	69	i
110 1010	106	6A	j
110 1011	107	6B	k
110 1100	108	6C	l
110 1101	109	6D	m
110 1110	110	6E	n
110 1111	111	6F	o
111 0000	112	70	p
111 0001	113	71	q
111 0010	114	72	r
111 0011	115	73	s
111 0100	116	74	t
111 0101	117	75	u
111 0110	118	76	v
111 0111	119	77	w
111 1000	120	78	x
111 1001	121	79	y
111 1010	122	7A	z
111 1011	123	7B	{
111 1100	124	7C	|
111 1101	125	7D	}
111 1110	126	7E	~

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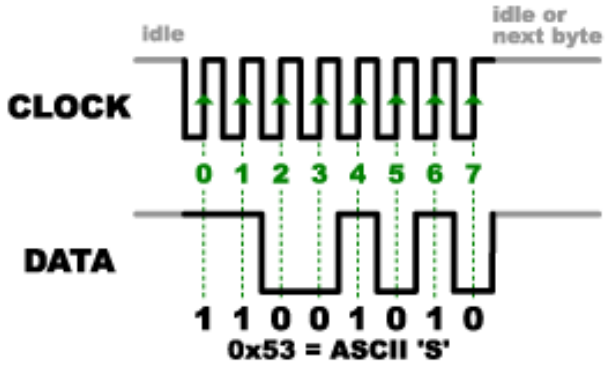
Time Systen

```
int32_t read_number()
{
    int32_t val = 0;
    char c = Serial.read();
    while(c >= '0' && c <= '9') {
        val = (c - '0') + val * 10;
        c = Serial.read();
    }
    return val;
}
```

Synchronous Serial Communication

Synchronous Serial Communication

- A clock signal is also provided
- This allows for very fast communication
- Main/secondary model of communication: one side (the main processor) is in control of when/what are communicated



learn.sparkfun.com/tutorials/serial-peripheral-interface-spi/all

Serial Peripheral Interface (SPI)

Signal lines:

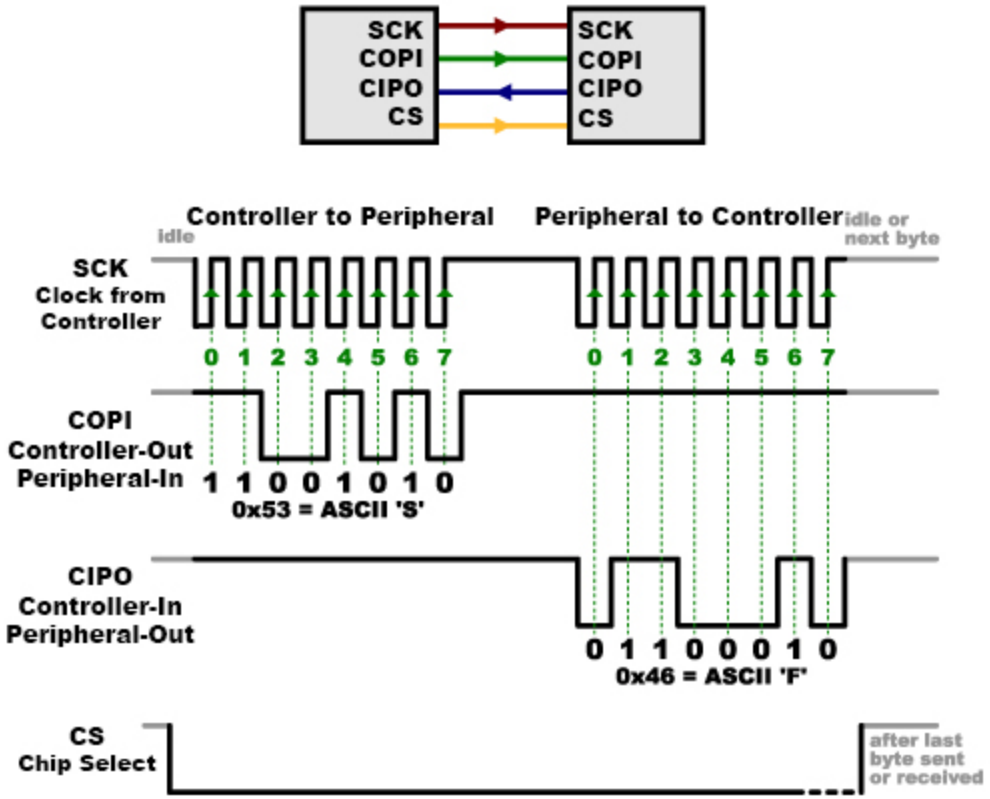
- SCK: serial clock
- MOSI: main-out-secondary-in: communication of data from main to secondary
- MISO: main-in-secondary-out: secondary to main
- CS: chip select: main brings this line low before data are exchanged. This is generally unique for each device

Serial Peripheral Interface (SPI)

- Secondary can only transmit/receive data when CS is low
- Data exchange can happen simultaneously
- Only one main in the circuit
- Secondaries can be daisy-chained into a single circuit
- Teensy has hardware support for this

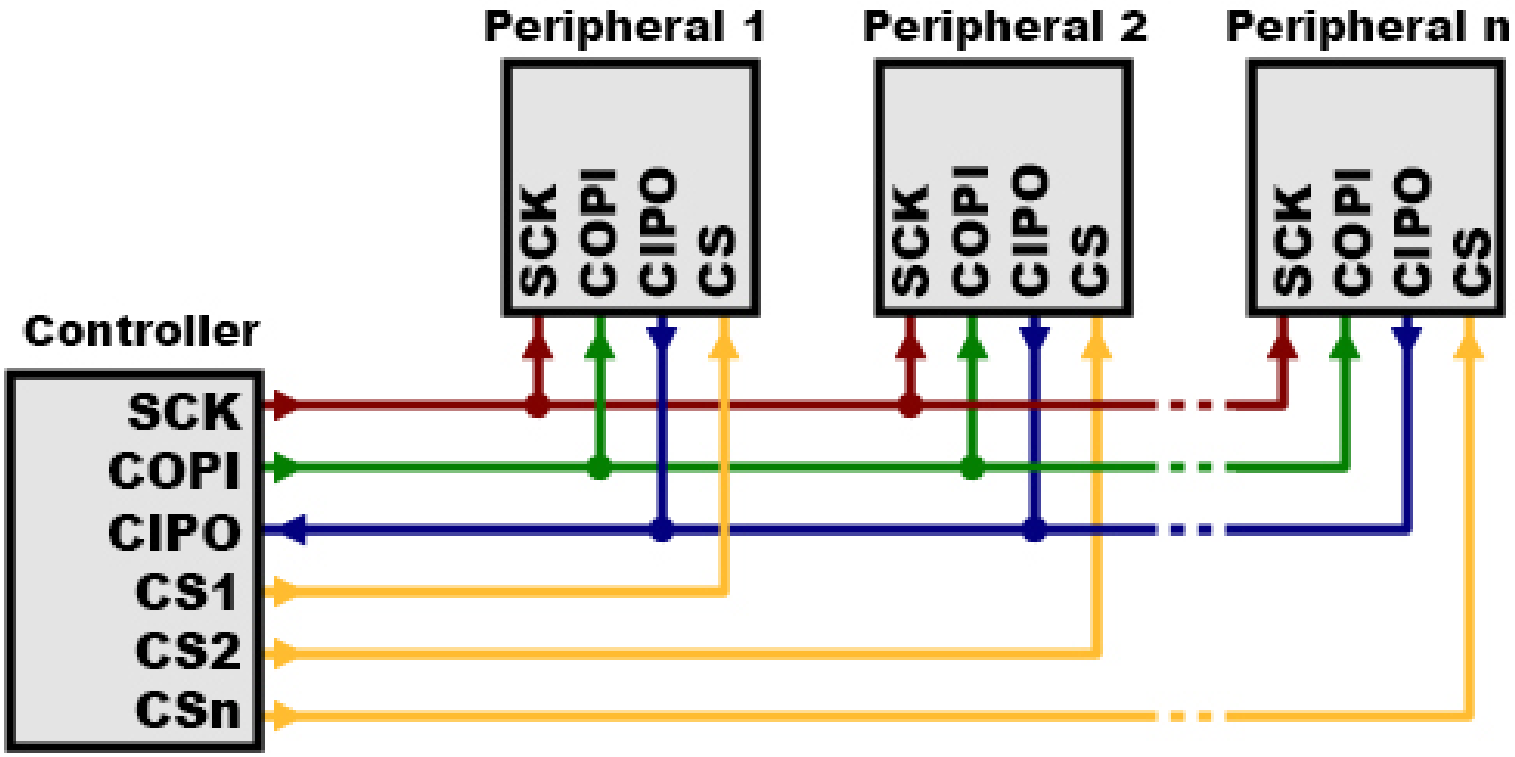
Serial Peripheral Interface (SPI)

- C = main
- P = secondary
- COPI = MOSI
- CIPO = MISO



Serial Peripheral Interface (SPI)

Multiple secondaries: one chip select for each



			GND				Vin (3.6 to 6.0 volts)						
Touch	MOSI1	RX1		0			Analog GND						
Touch	MISO1	TX1		1			3.3V (250 mA max)						
			PWM	2			23	A9	PWM				Touch
SCL2	CAN0TX		PWM	3			22	A8	PWM				Touch
SDA2	CAN0RX		PWM	4			21	A7	PWM	CS0	mosi1		
	miso1	tx1	PWM	5			20	A6	PWM	CS0	sck1		
			PWM	6			19	A5				SCL0	Touch
scl0	mosi0	RX3	PWM	7			18	A4				SDA0	Touch
sda0	miso0	TX3	PWM	8			17	A3				sda0	Touch
	CS0	RX2	PWM	9			16	A2				scl0	Touch
	CS0	TX2	PWM	10			15	A1			CS0		Touch
	MOSI0			11			14	A0	PWM		sck0		
	MISO0			12			13	(LED)			SCK0		
				3.3V			GND						
				24				A22	DAC1				
				25				A21	DAC0				
		tx1		26			39	A20					
		rx1		27			38	A19	PWM			SDA1	
				28			37	A18	PWM			SCL1	
Touch	can0tx		PWM	29			36	A17	PWM				
Touch	can0rx		PWM	30			35	A16	PWM				
	CS1	RX4	A12	31			34	A15		CAN1RX		sda0	
	SCK1	TX4	A13	32			33	A14		CAN1TX		scl0	

Inter Integrated Circuit (I2C)

Signals:

- SCL: clock signal
- SDA: data signal

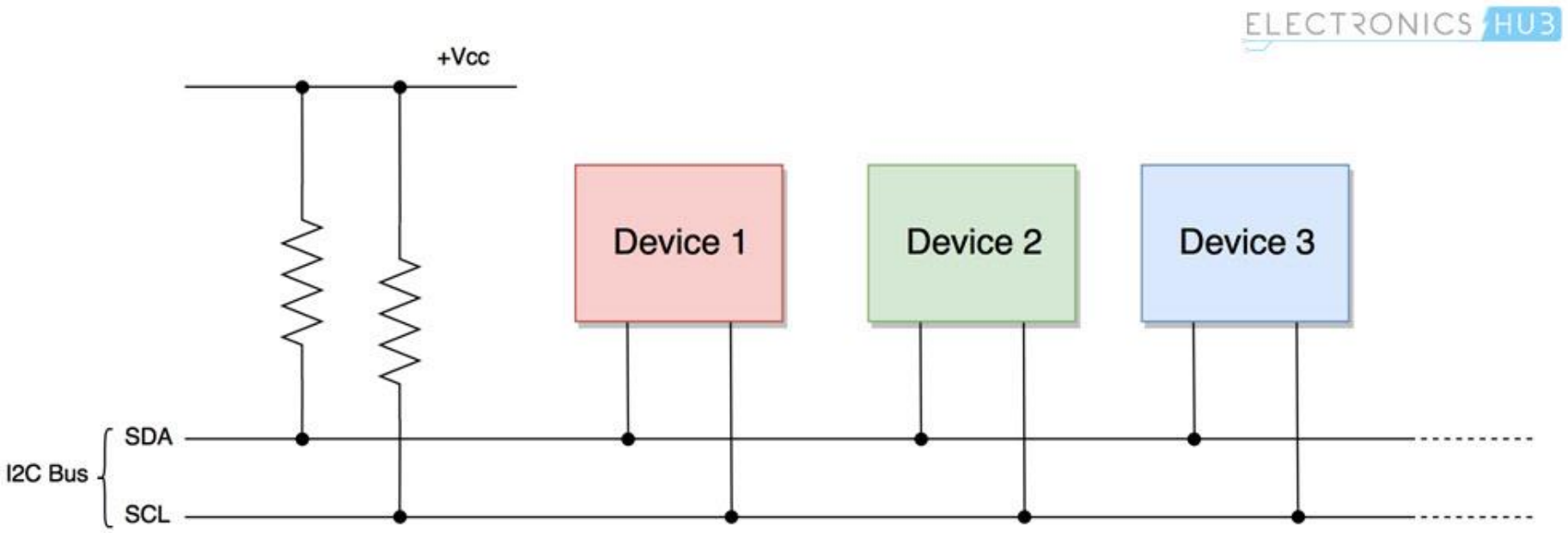
Secondaries have unique addresses (ID numbers) that are used by the main to initiate the conversation

Inter Integrated Circuit (I2C)

- Both the main and the secondary write to the data bus:
  - First the main writes data
  - Followed by the secondary writing data
- Multiple mains can exist
- The main always provides the clock signal
- Support for I2C in hardware on the Teensy

Inter Integrated Circuit (I2C)

A device can act as either a main or a secondary (but is typically only one)



			GND				Vin (3.6 to 6.0 volts)						
Touch	MOSI1	RX1		0			Analog GND						
Touch	MISO1	TX1		1			3.3V (250 mA max)						
			PWM	2			23	A9	PWM				Touch
SCL2	CAN0TX		PWM	3			22	A8	PWM				Touch
SDA2	CAN0RX		PWM	4			21	A7	PWM	CS0	mosi1		
	miso1	tx1	PWM	5			20	A6	PWM	CS0	sck1		
			PWM	6			19	A5				SCL0	Touch
scl0	mosi0	RX3	PWM	7			18	A4				SDA0	Touch
sda0	miso0	TX3	PWM	8			17	A3				sda0	Touch
	CS0	RX2	PWM	9			16	A2				scl0	Touch
	CS0	TX2	PWM	10			15	A1			CS0		Touch
	MOSI0			11			14	A0	PWM		sck0		
	MISO0			12			13	(LED)			SCK0		
				3.3V			GND						
				24				A22	DAC1				
				25				A21	DAC0				
		tx1		26			39	A20					
		rx1		27			38	A19	PWM			SDA1	
				28			37	A18	PWM			SCL1	
Touch	can0tx		PWM	29			36	A17	PWM				
Touch	can0rx		PWM	30			35	A16	PWM				
	CS1	RX4	A12	31			34	A15		CAN1RX		sda0	
	SCK1	TX4	A13	32			33	A14		CAN1TX		scl0	

Controller Area Network

- Communication across devices that are separated by some distance (10s of meters)
- Can function in electrically noisy environments
- Slow communication speeds (compared to I2C and SPI)
- Main/secondary model, but secondariesare not explicitly addressed. Instead, message types are addressed