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)

I/O Systems

Communication can happen in a variety of ways:

- Binary parallel signal
- Analog
- Serial signals

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 2^{nd} bit is used
  - Etc.

Serial Experiment…

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
- Bidirectional transmission, but the two halves do not need to be synchronized in time

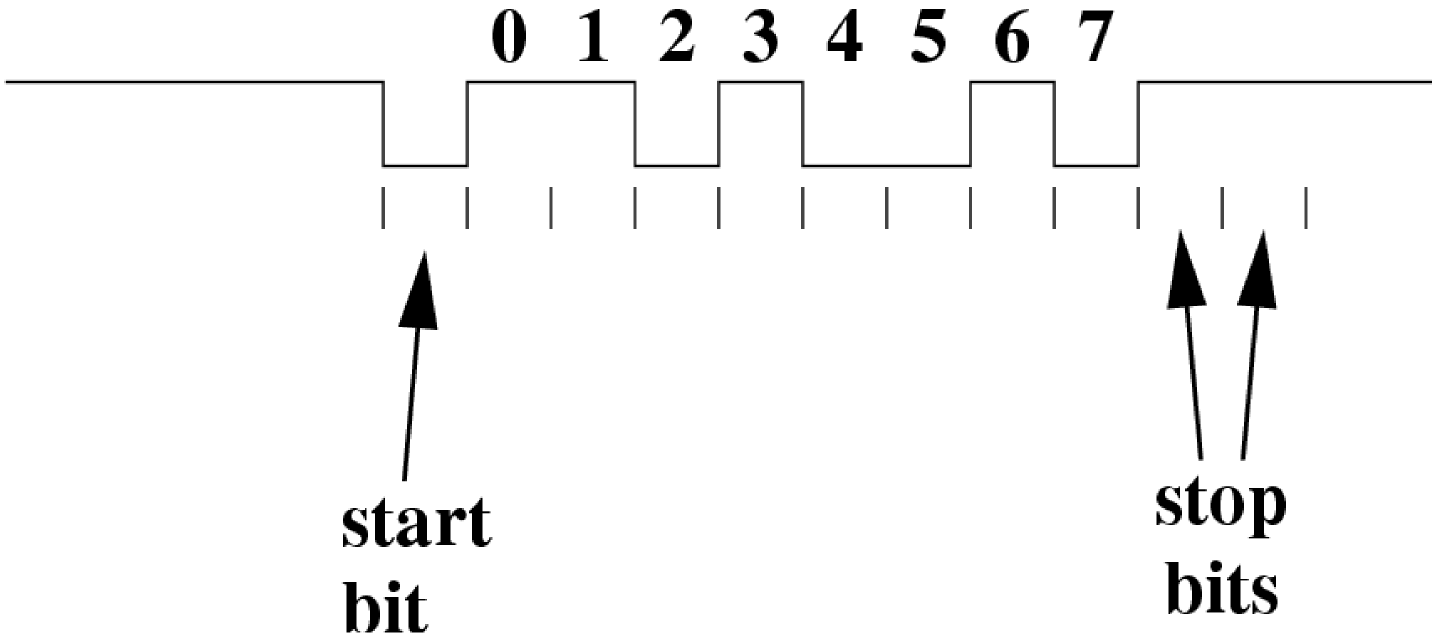
But: we still need some way to agree that data is valid. How?

Asynchronous Serial Communication

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

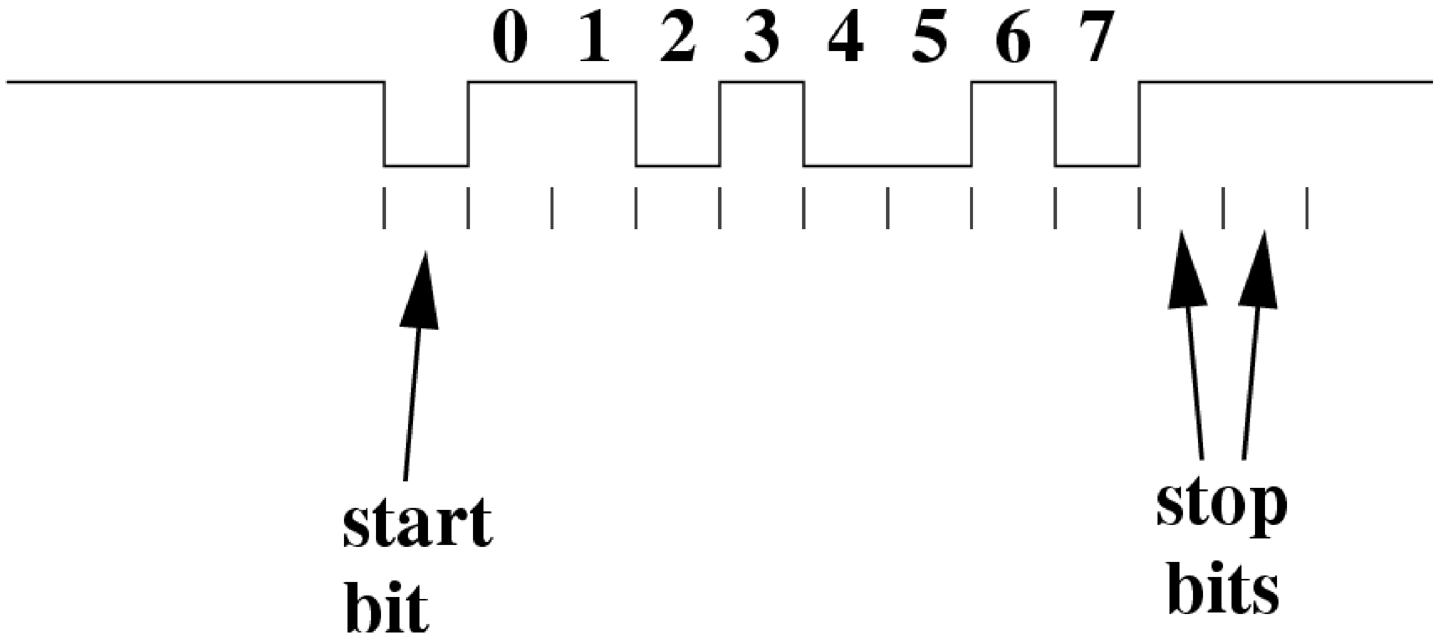
- Must both be operating at essentially the same transmit/receive frequency
- A data byte is prefaced with a bit of information that tells the receiver that bits are coming
- The receiver uses the arrival time of this **start bit** to synchronize its clock

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 Mega2560

Our mega 2560 has FOUR Universal, Asynchronous serial Receiver/Transmitters (UARTs):

- Each handles all of the bit-level manipulation
  - Software only worries about the byte level
- Uses 0V and 5V to encode “lows” and “highs”
  - Must convert if talking to a true RS232C device (+/- 13V)

Mega2560 UART C Interface

Lib C support (standard C):

`char fgetc(fp)`: receive a character

`fputc(’a’, fp)`: put a character out to the port

`fputs(”foobar”, fp)`: put a string out to the port

`fprintf(fp, ”foobar %d %s”, 45, ”baz”)`:
put a formatted string out to the port

Mega2560 UART C Interface

OUlib support:

`fp = serial_init_buffered(1, 38400, 40, 40)`

- Initialize port one for a transmission rate of 38400 bits per second (input and output buffers are both 40 characters long)
- Note: declare fp as a global variable:

```
FILE *fp;
```

`serial_buffered_input_waiting(fp)`

- Is there a character in the buffer?

See the Atmel HOWTO: examples_2560/serial

Reading a Byte from the Serial Port

```
int c;

c=fgetc(fp);
```

Note: fgetc() “blocks” until a byte is available

- Will only return with a value once a character is available to be returned

Processing Serial Input

```
int c;
while(1) {
  if(serial_buffered_input_waiting(fp)) {
     // A character is available for reading
     c = fgetc(fp);
     <do something with the character>
  }
  <do something else while waiting>
}
```

serial_buffered_input_waiting(fp) tells us whether a byte is ready to be read

Mega2560 UART C Interface

Also available:

- `fscanf()`: formatted input

See the LibC documentation or the AVR C textbook

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	~

Buffers

A buffer is an array that temporarily stores data in sequential order

```
fp = serial_init_buffered(1, 38400, 40, 40)
```

- Declares both the input and output buffer sizes to be 40 bytes

Output Buffer

- Any characters that are produced (e.g., with fputc() or fprintf()) are first placed in the output buffer
- Then, the serial hardware removes one byte at a time to send it

Output Buffer

- Advantage: fputc() and fprintf() don't have to wait for the bytes to be transmitted
  - Your program can keep doing the rest of its job
- But: if the buffer fills up, these functions will block until there is space
  - You must choose your buffer size somewhat carefully

Input Buffer

Temporary storage of bytes as they are received

- Your program can read these bytes at its leisure
- With OULIB: if the buffer fills up, then additional bytes will be lost

Last Time: Serial Communication and the ASCII Representation

- Serial Communication: ?
- ASCII: ?
- Output Buffer: ?
- Input Buffer: ?

Last Time: Serial Communication and the ASCII Representation

- Serial Communication: Communicating a byte (or multiple) by sending one bit at a time

- ASCII: translation between binary numbers and glyphs

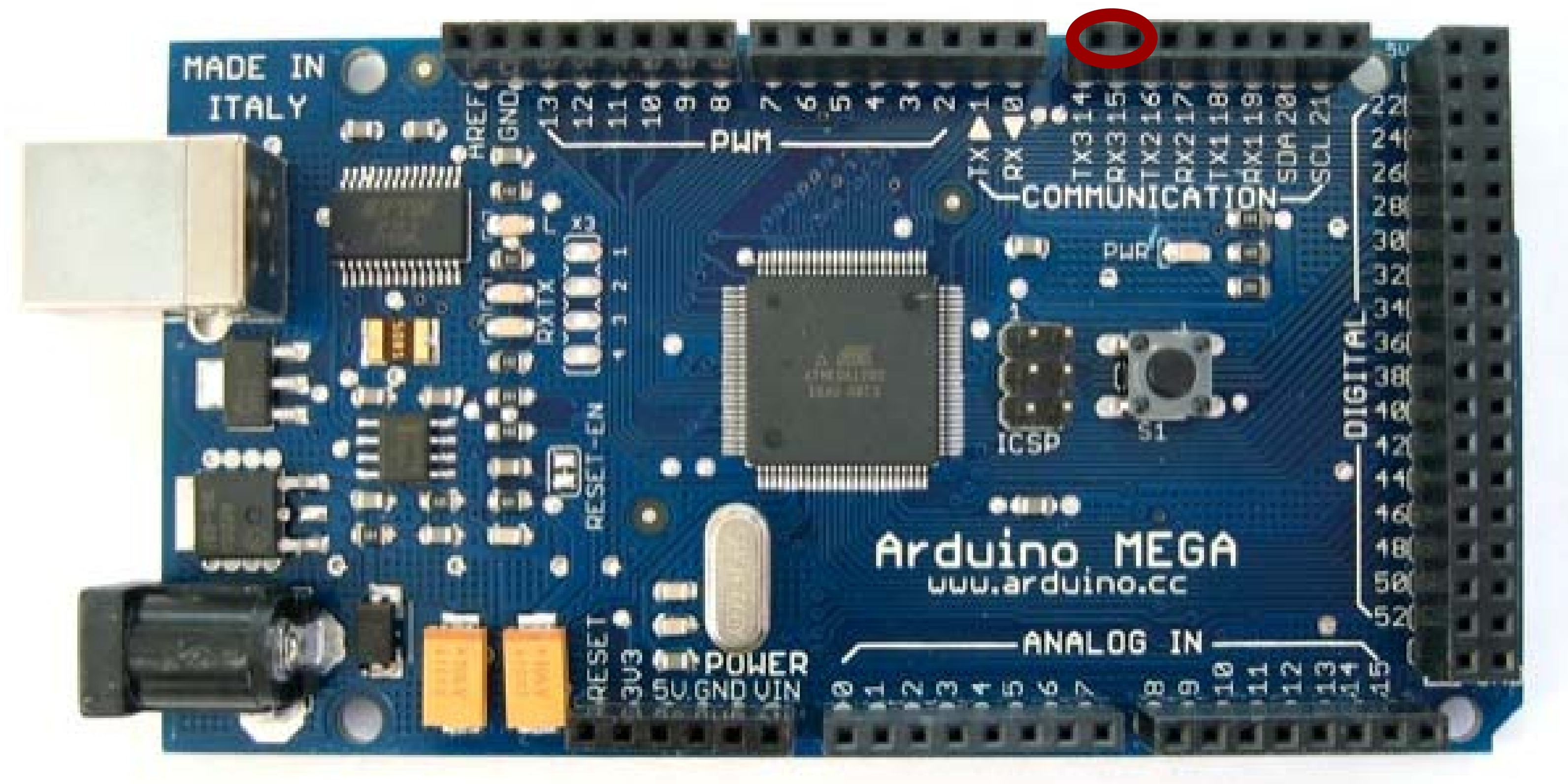
Last Time: Serial Communication and the ASCII Representation

- Output Buffer: Temporary storage of outgoing characters (bytes!) until the UART can send them

- Input Buffer: Temporary storage of incoming characters until they can be used by the program

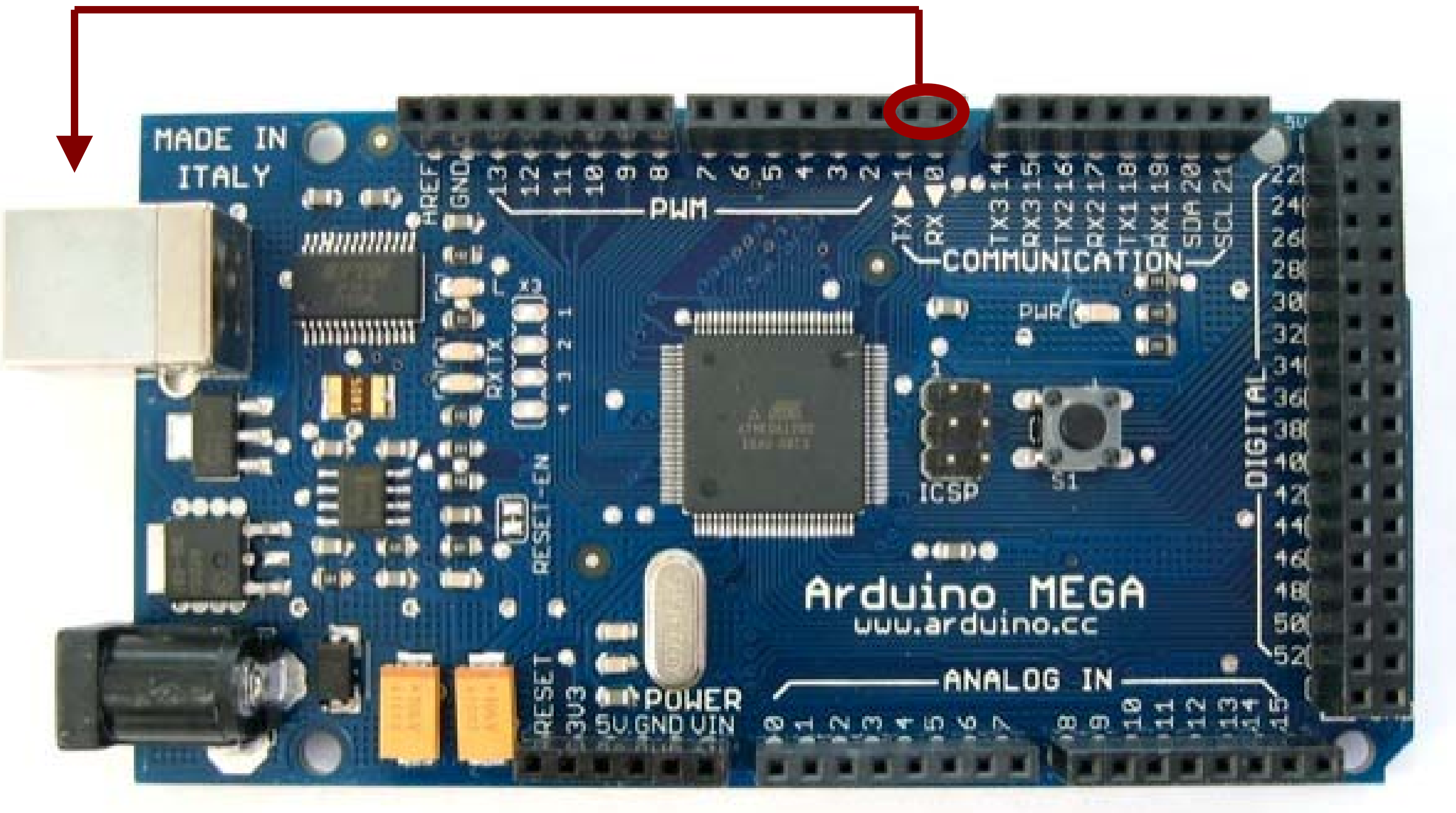
Physical Interface

Four matched pairs of transmit and receive pins (TX? and RX?)



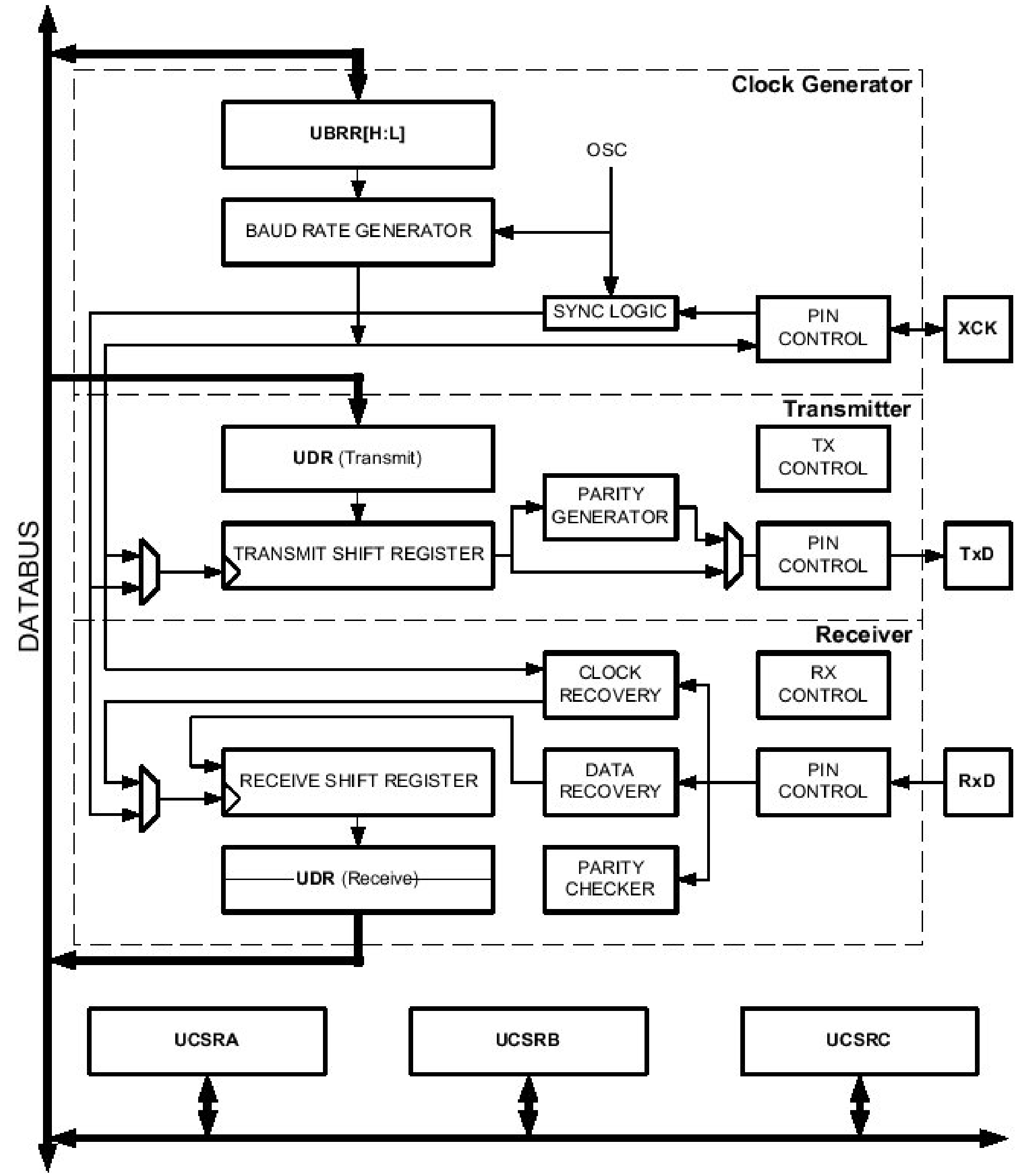
Physical Interface

Port 0 is also connected to the USB port



See “hyperterm” on downloads page

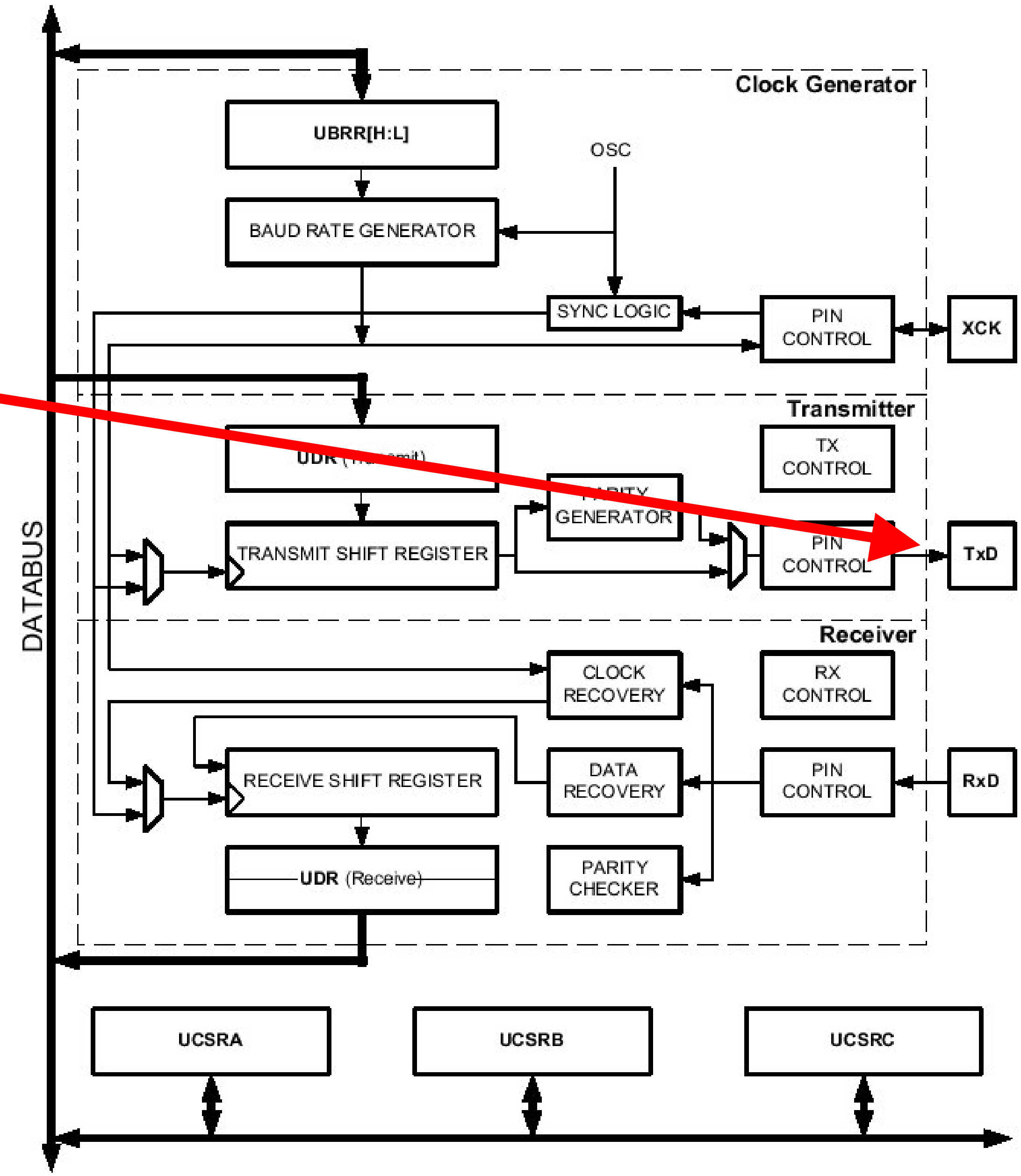
Mega8 UART



Clock Generator
UBRR[H:L]
OSC
BAUD RATE GENERATOR
SYNC LOGIC
PIN CONTROL
XCK
Transmitter
TX CONTROL
UDR (Transmit)
PARITY GENERATOR
TRANSMIT SHIFT REGISTER
PIN CONTROL
TxD
DATABUS
Receiver
CLOCK RECOVERY
RX CONTROL
RECEIVE SHIFT REGISTER
DATA RECOVERY
PIN CONTROL
RxD
UDR (Receive)
PARITY CHECKER
UCSRA
UCSRB
UCSRC

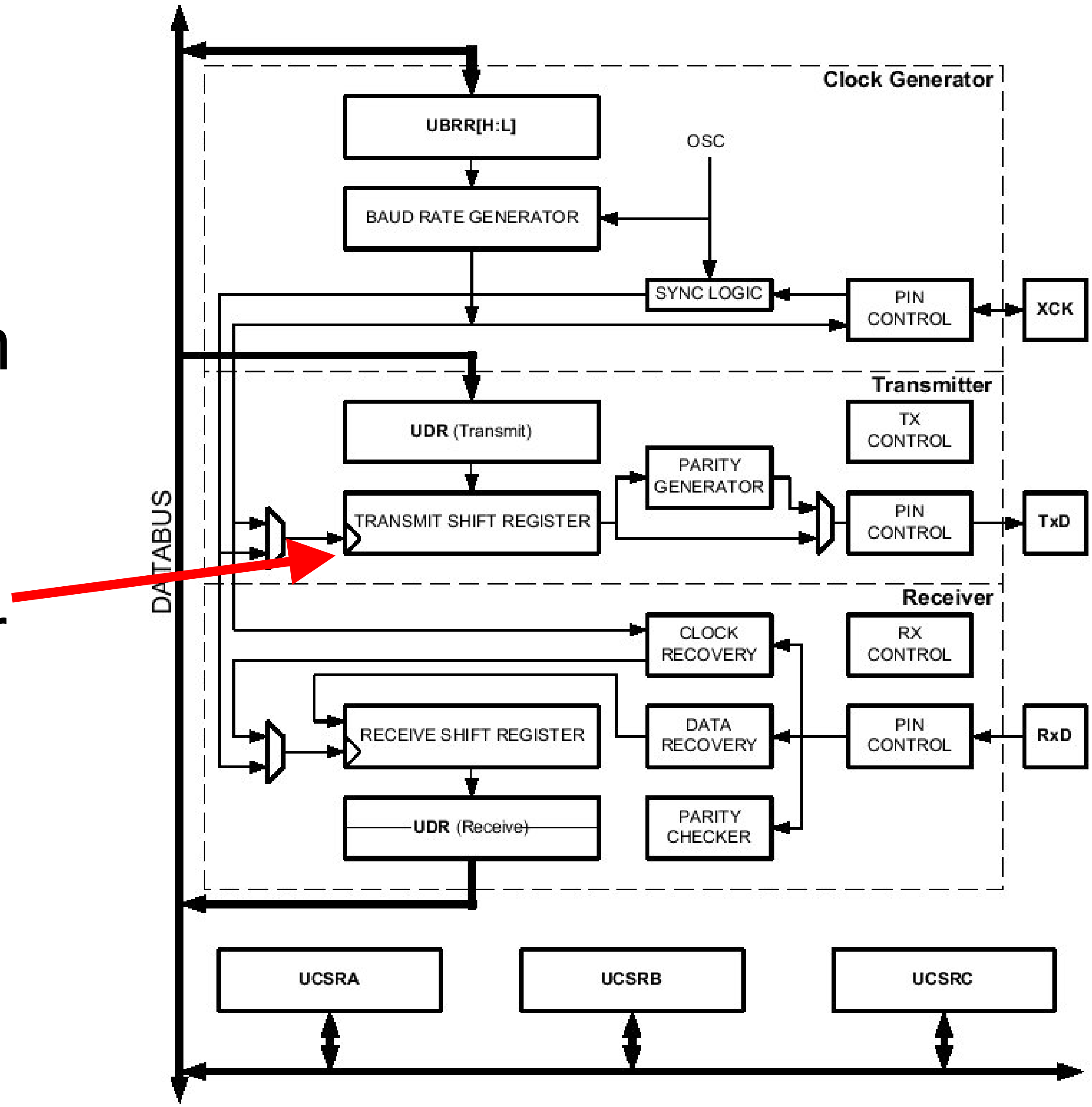
Mega8 UART

- Transmit pin (PD1)



Mega8 UART

- Transmit pin (PD1)
- Transmit shift register



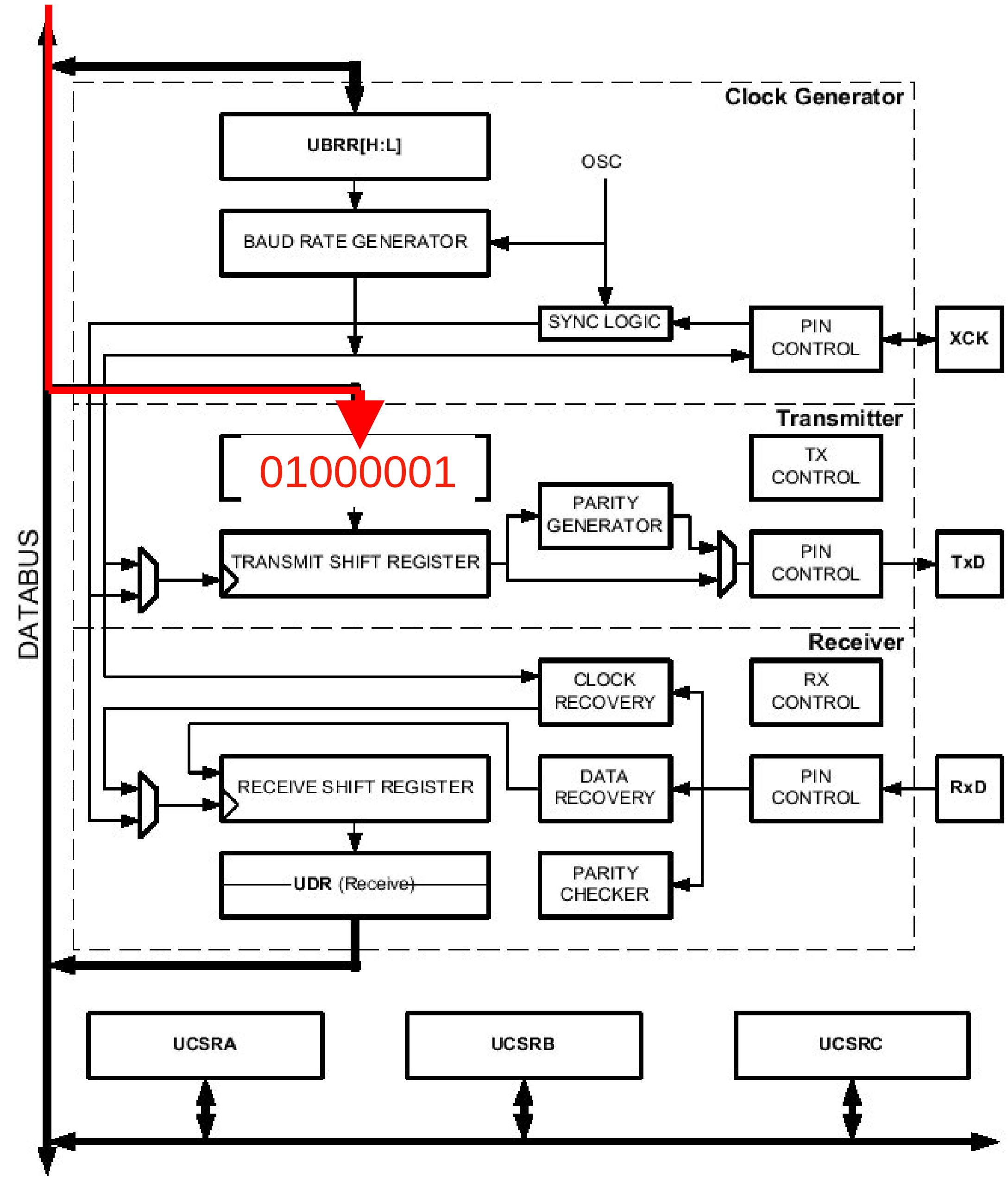
Writing a Byte to the Serial Port

```
putchar('A');
```

(assuming trivial input/output buffers for this illustration)

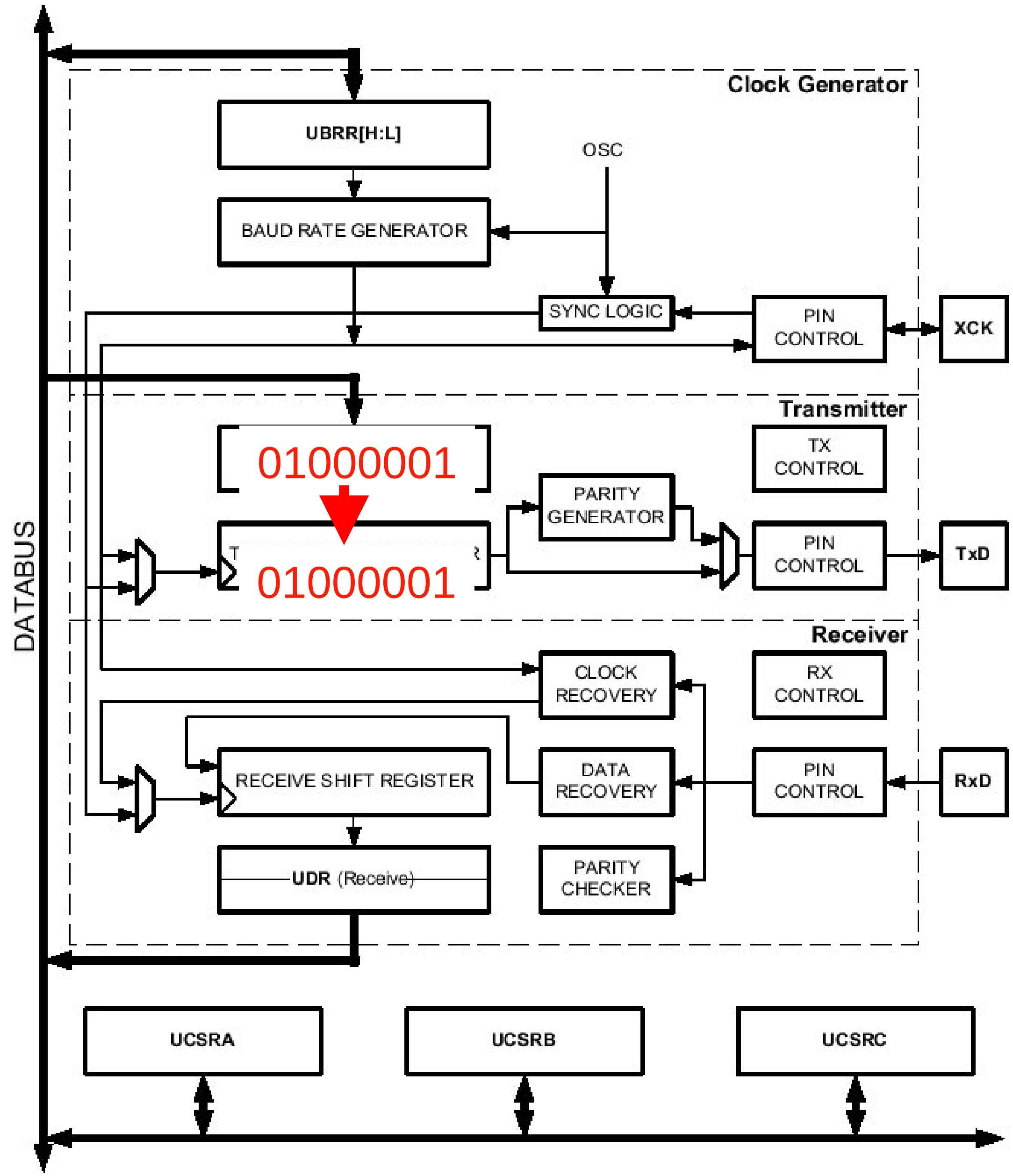
Transmit

```
putchar('A');
```



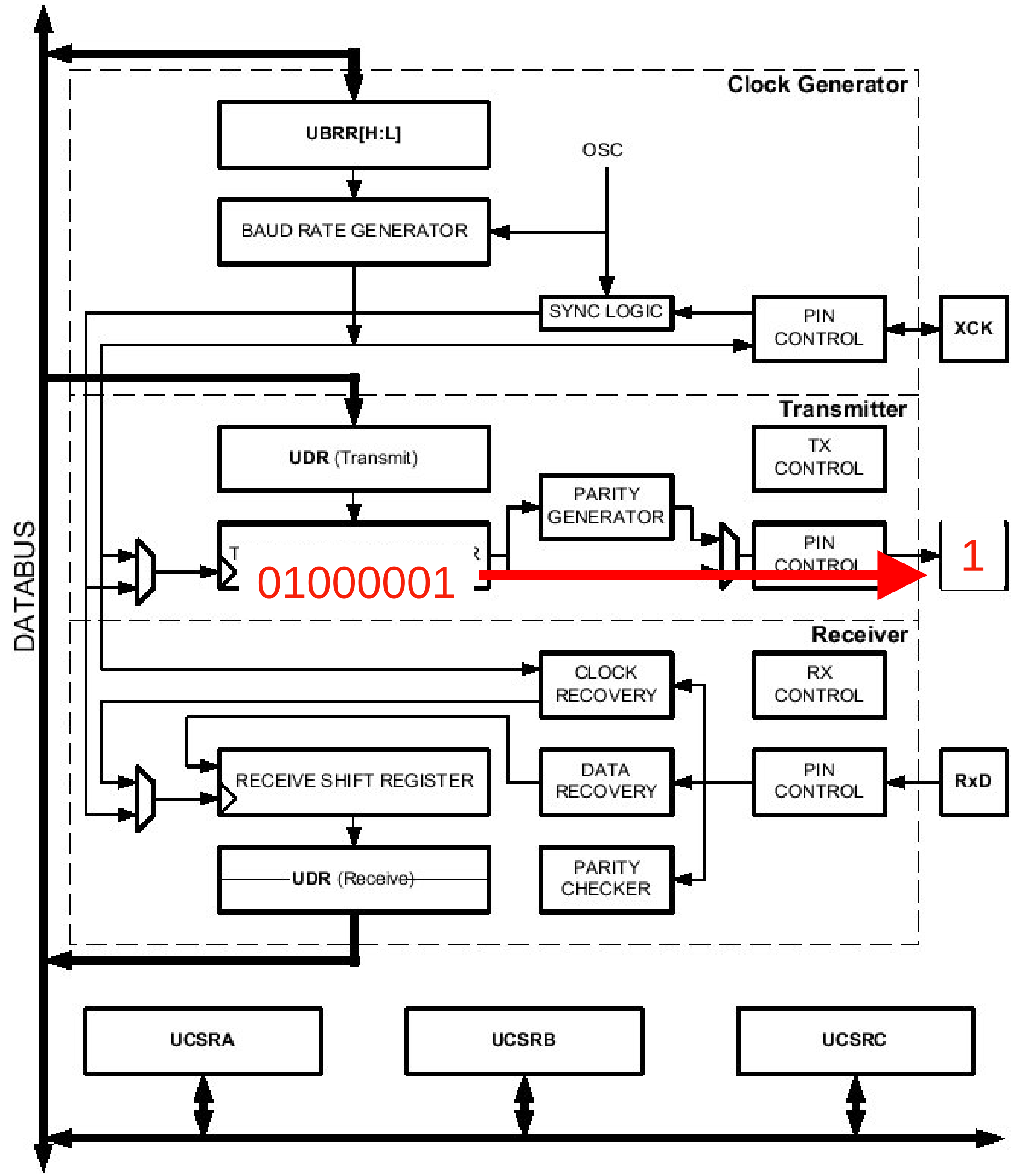
Transmit

When UART is ready, the buffer contents are copied to the shift register



Transmit

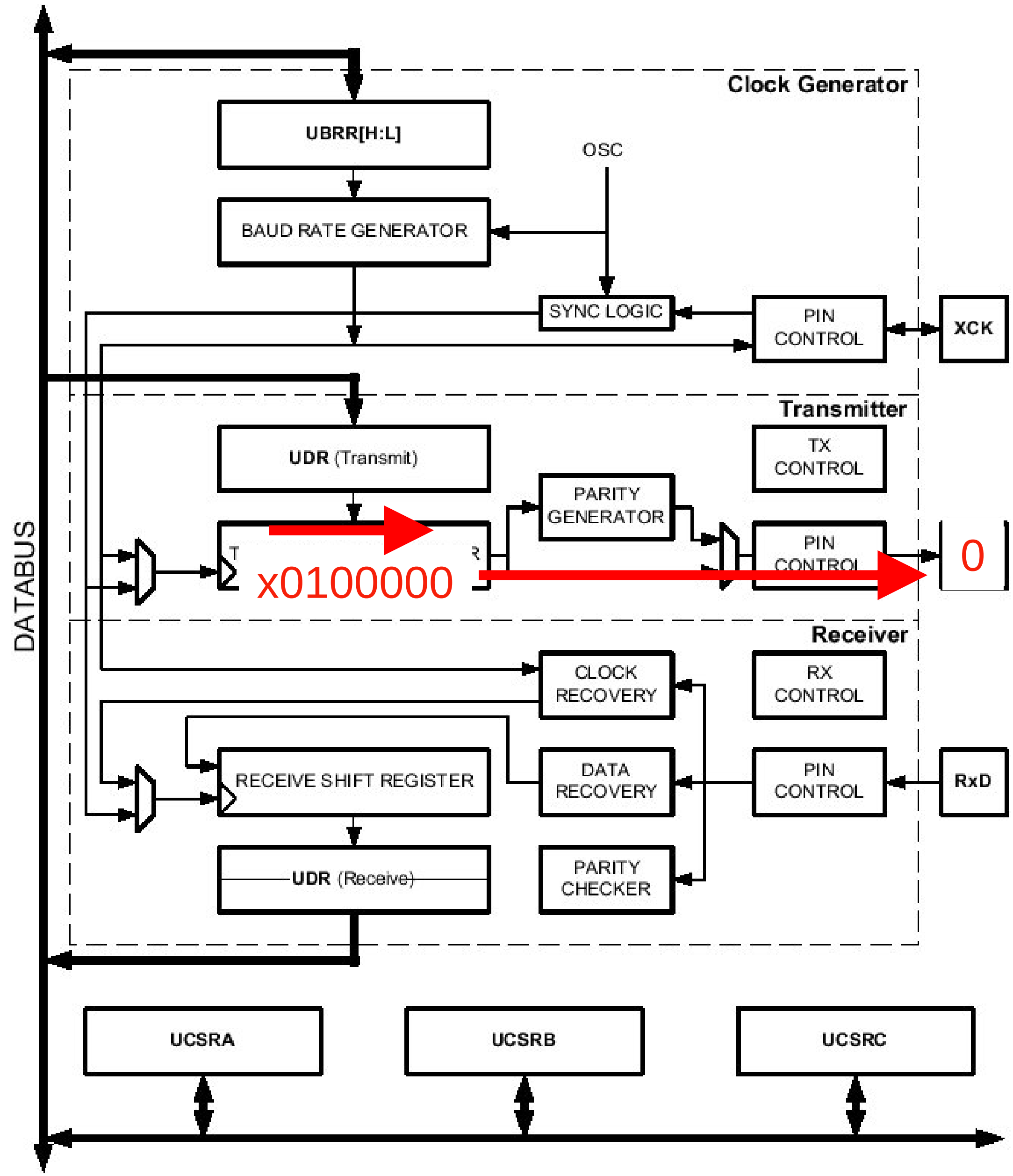
The least significant bit (LSB) of the shift register determines the state of the pin



Transmit

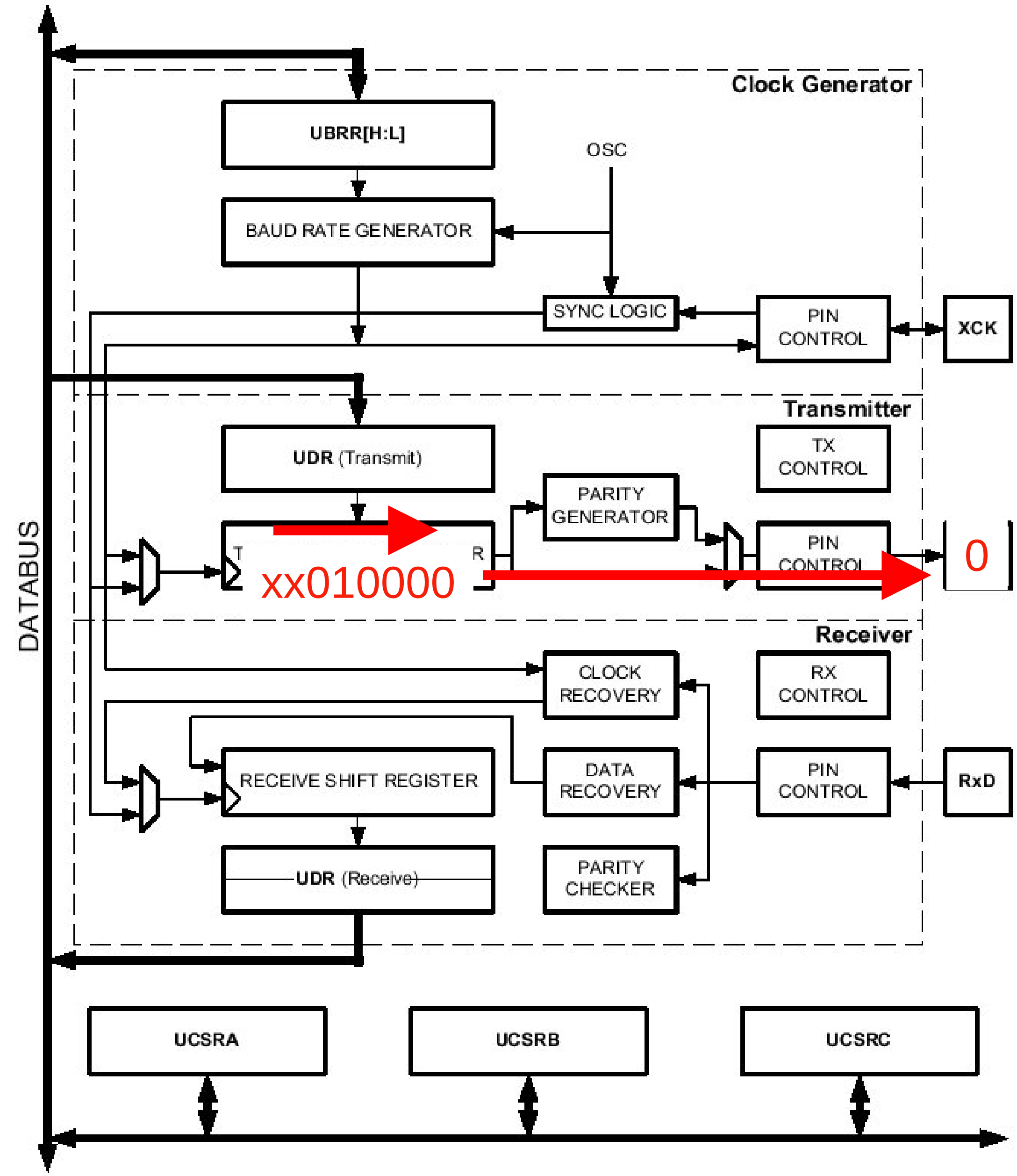
After a delay, the UART shifts the values to the right

x = value doesn't matter



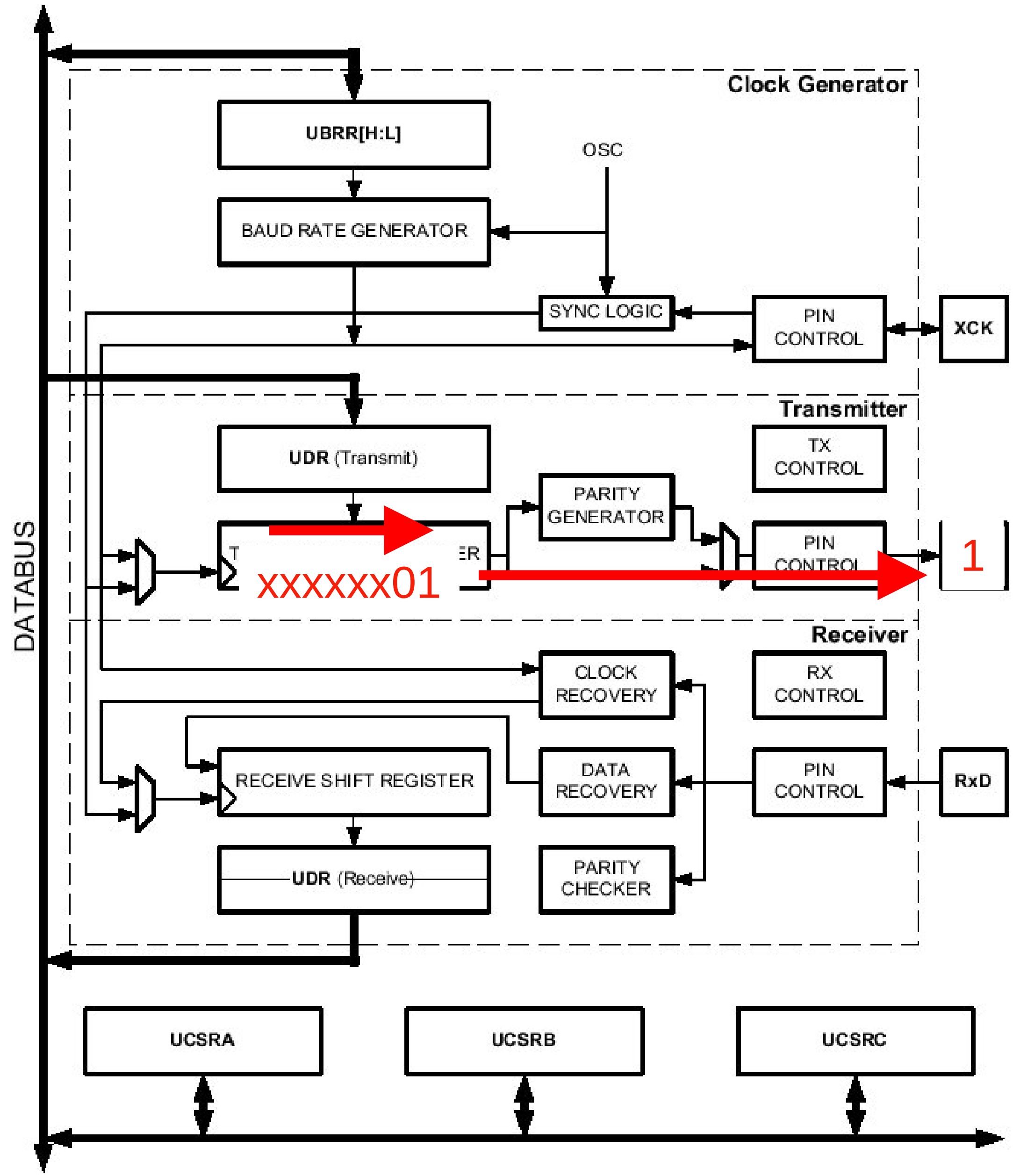
Transmit

Next shift



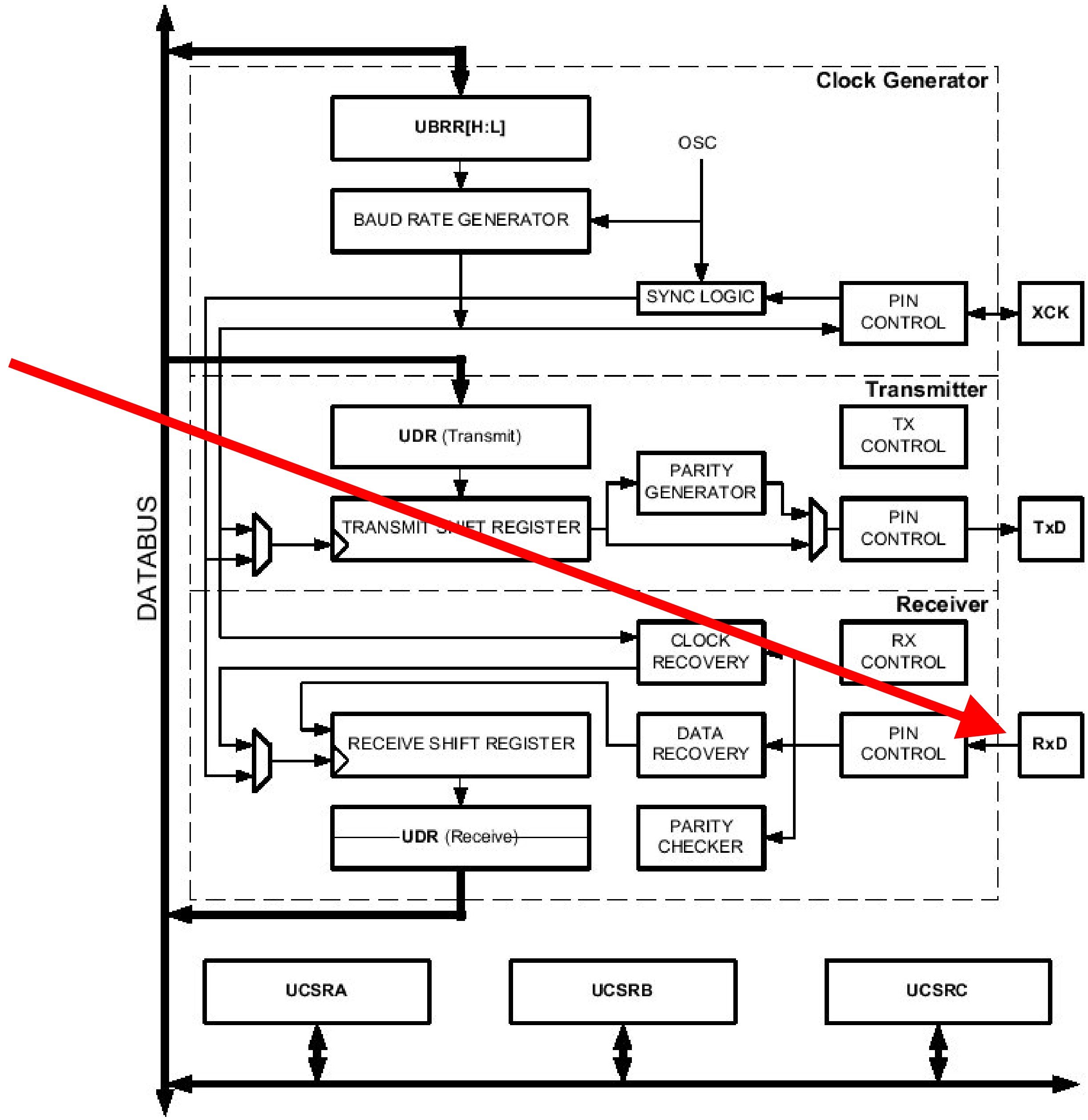
Transmit

Several shifts later…



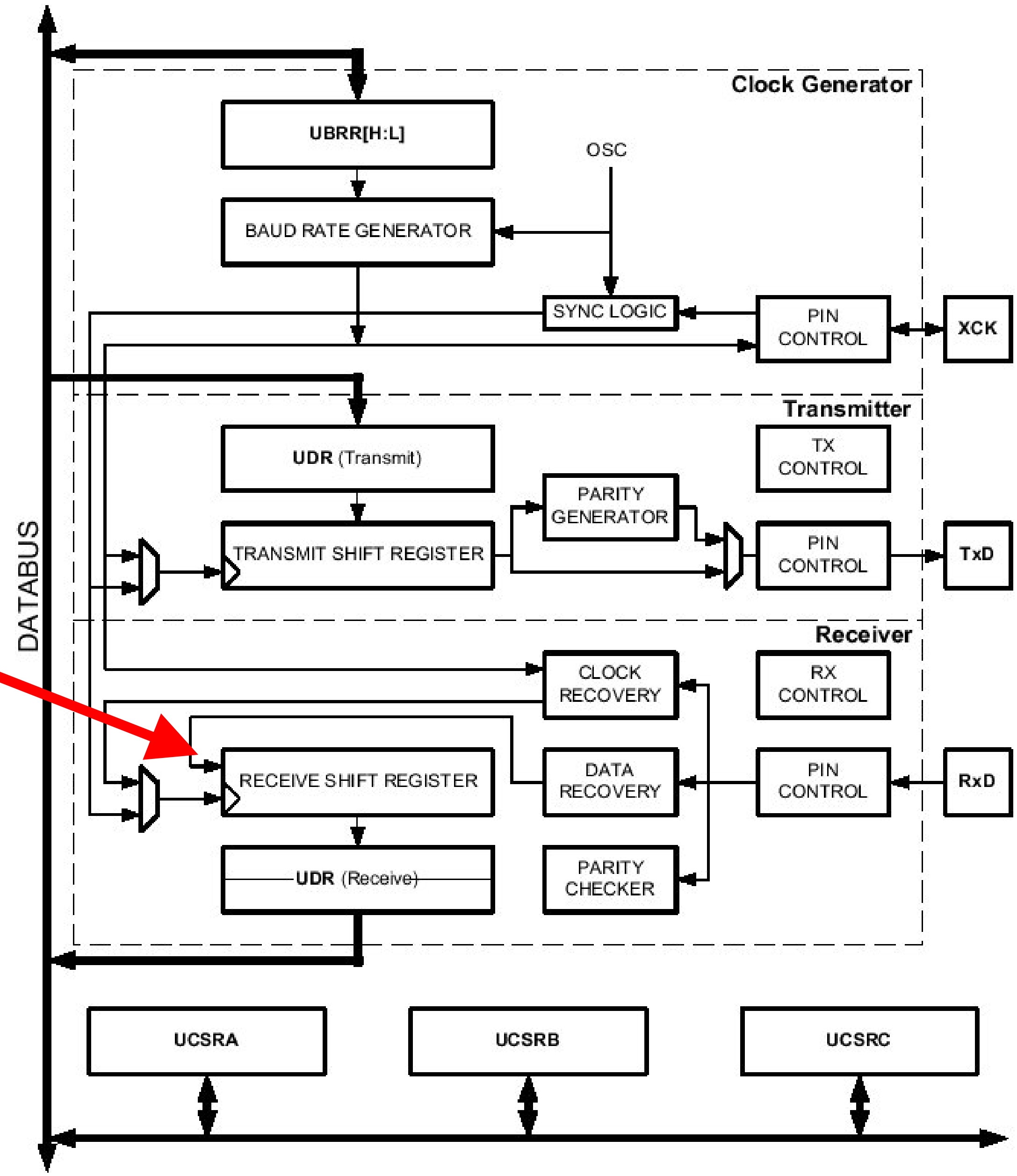
Receive

- Receive pin (PD0)



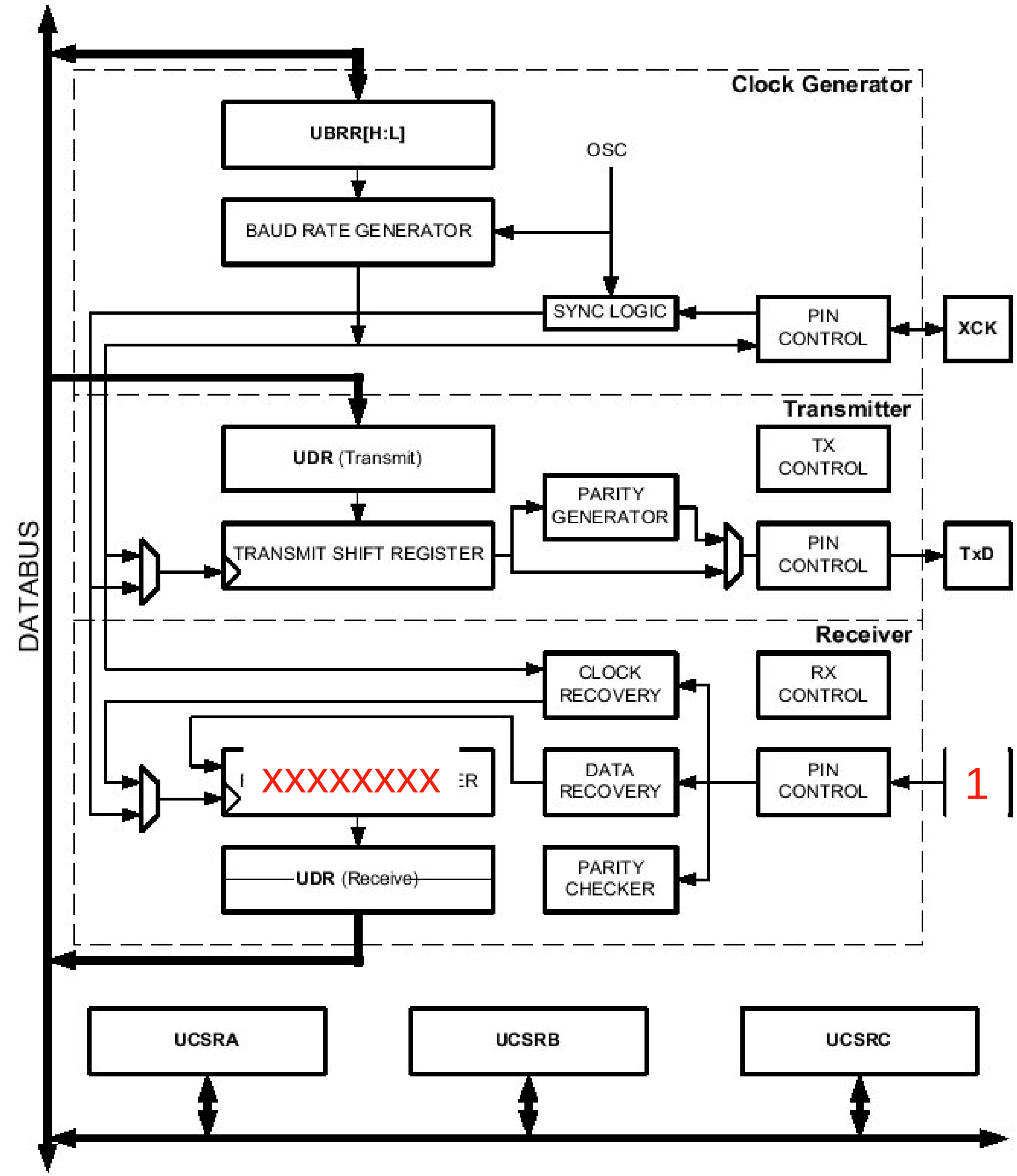
Receive

- Receive pin (PD0)
- Receive shift register



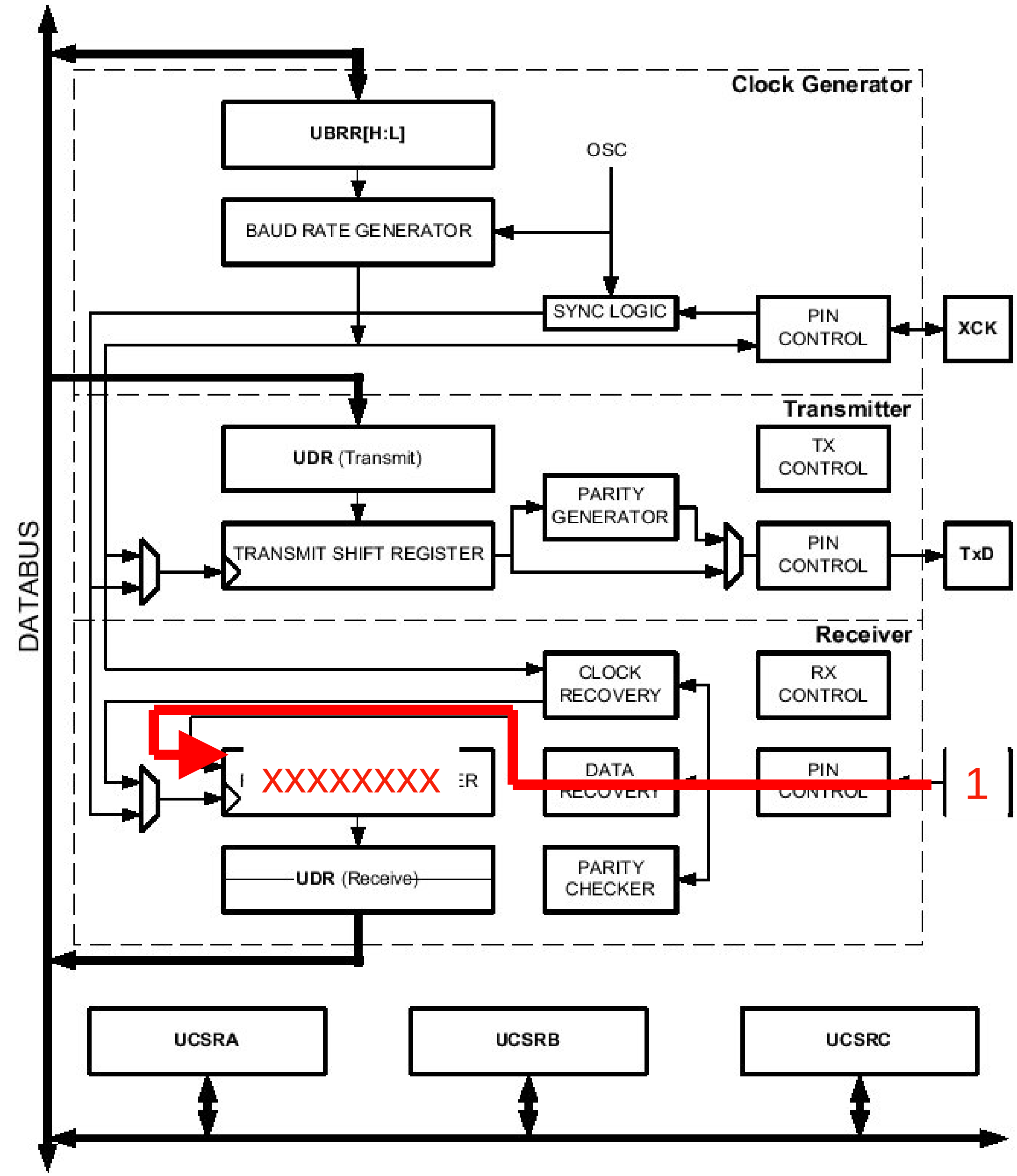
Receive

- "1" on the pin
- Shift register initially in an unknown state



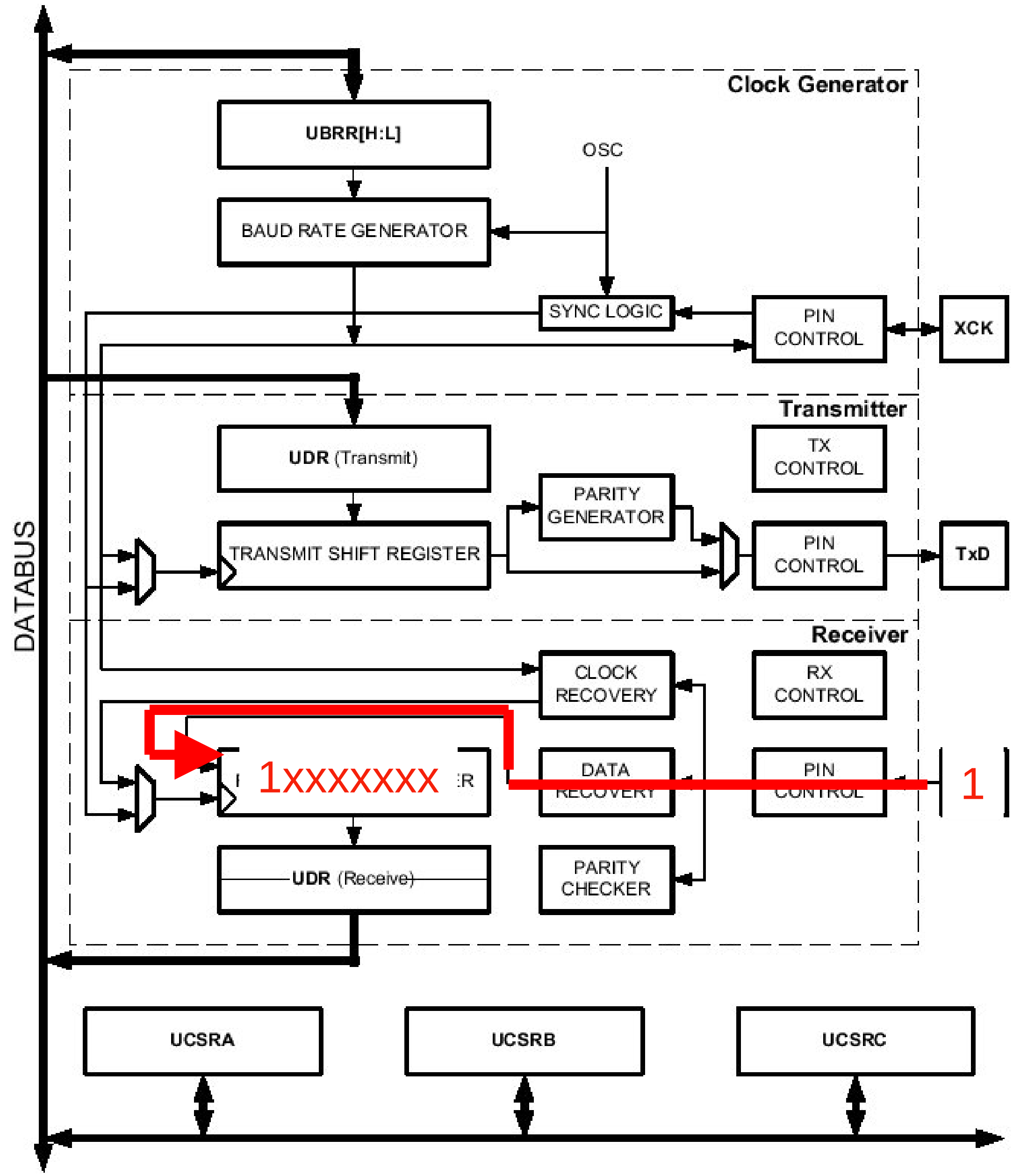
Receive

"1" is presented to the shift register



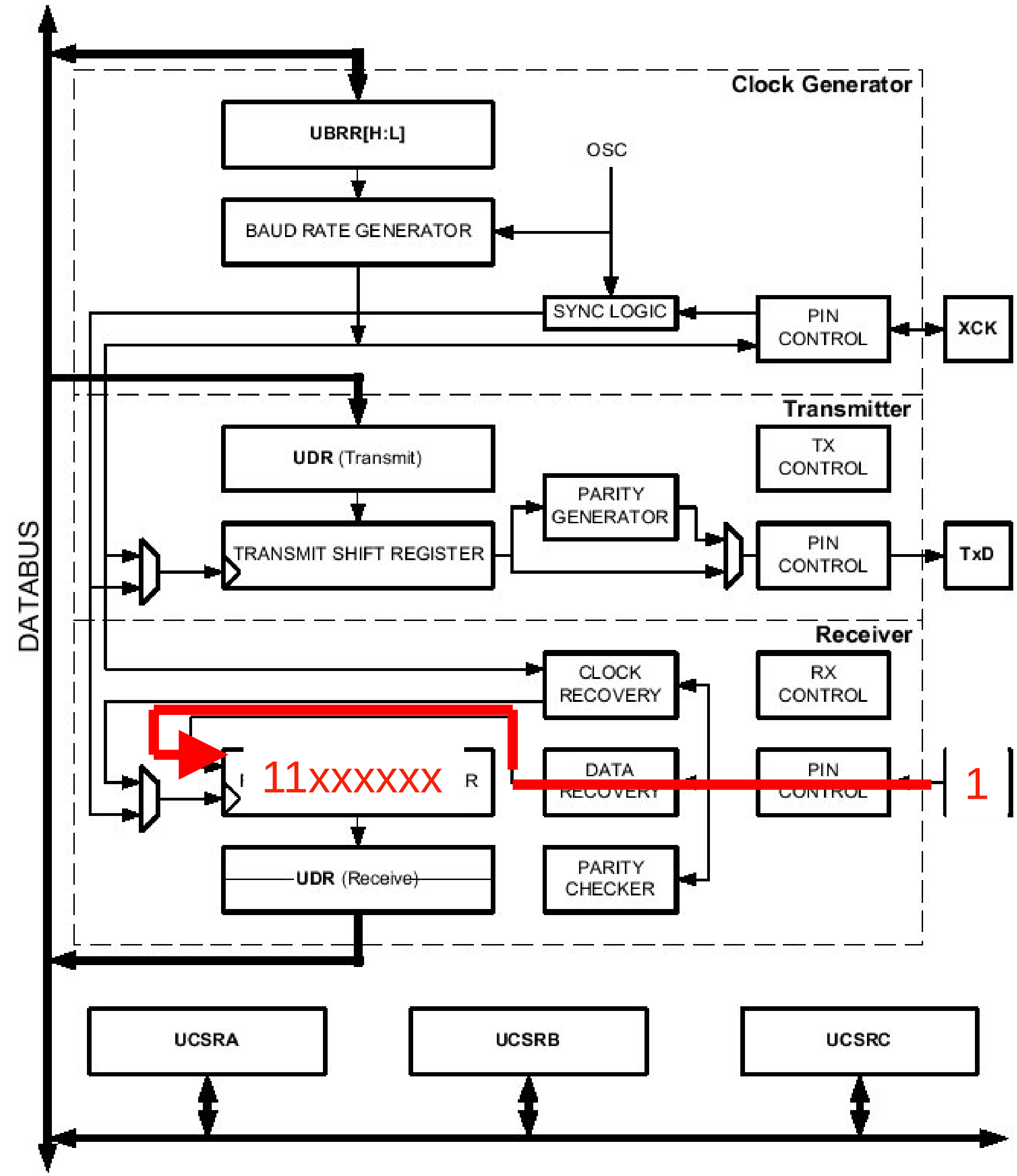
Receive

"1" is shifted into the most significant bit (msb) of the shift register



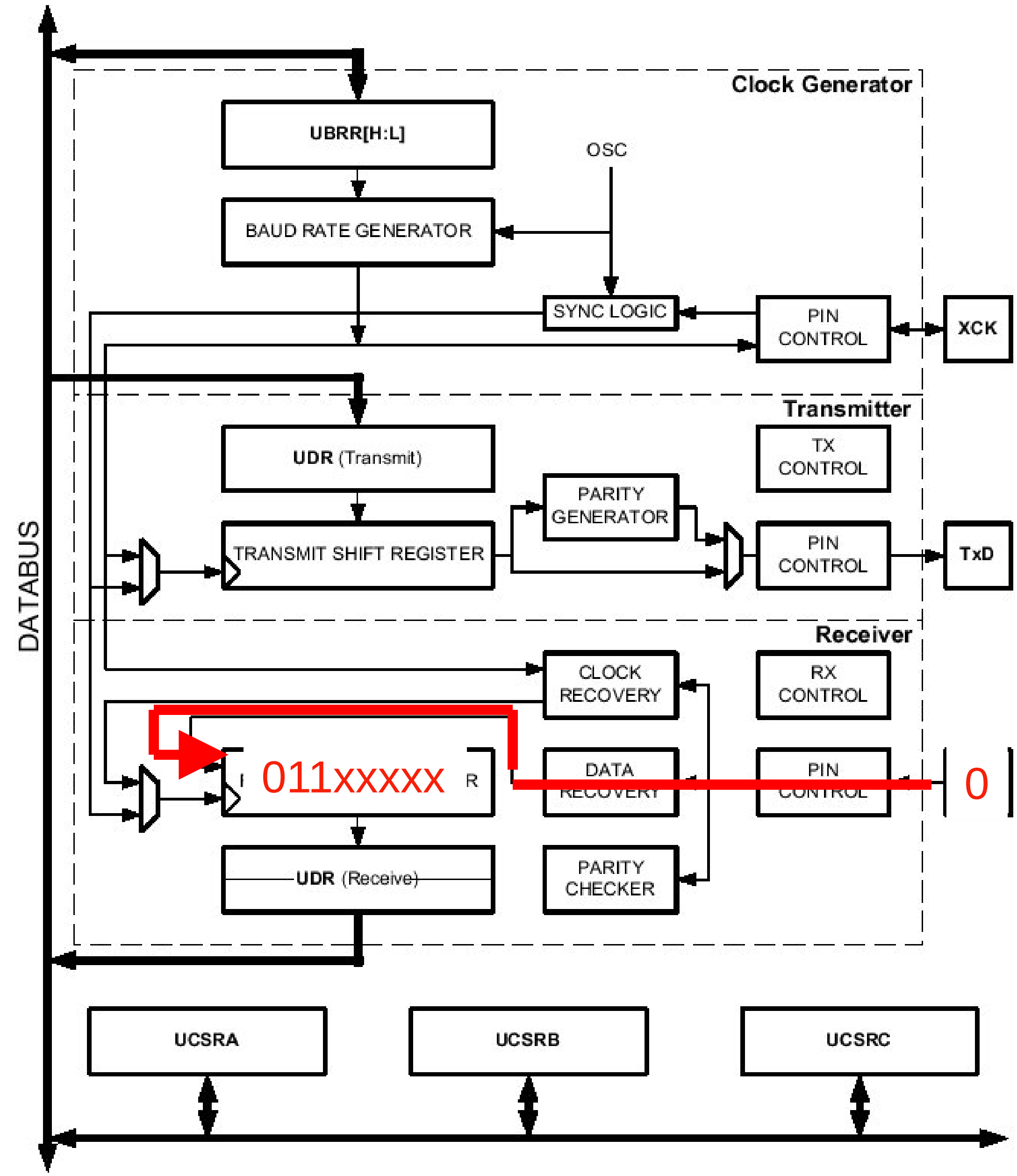
Receive

Next bit is shifted in



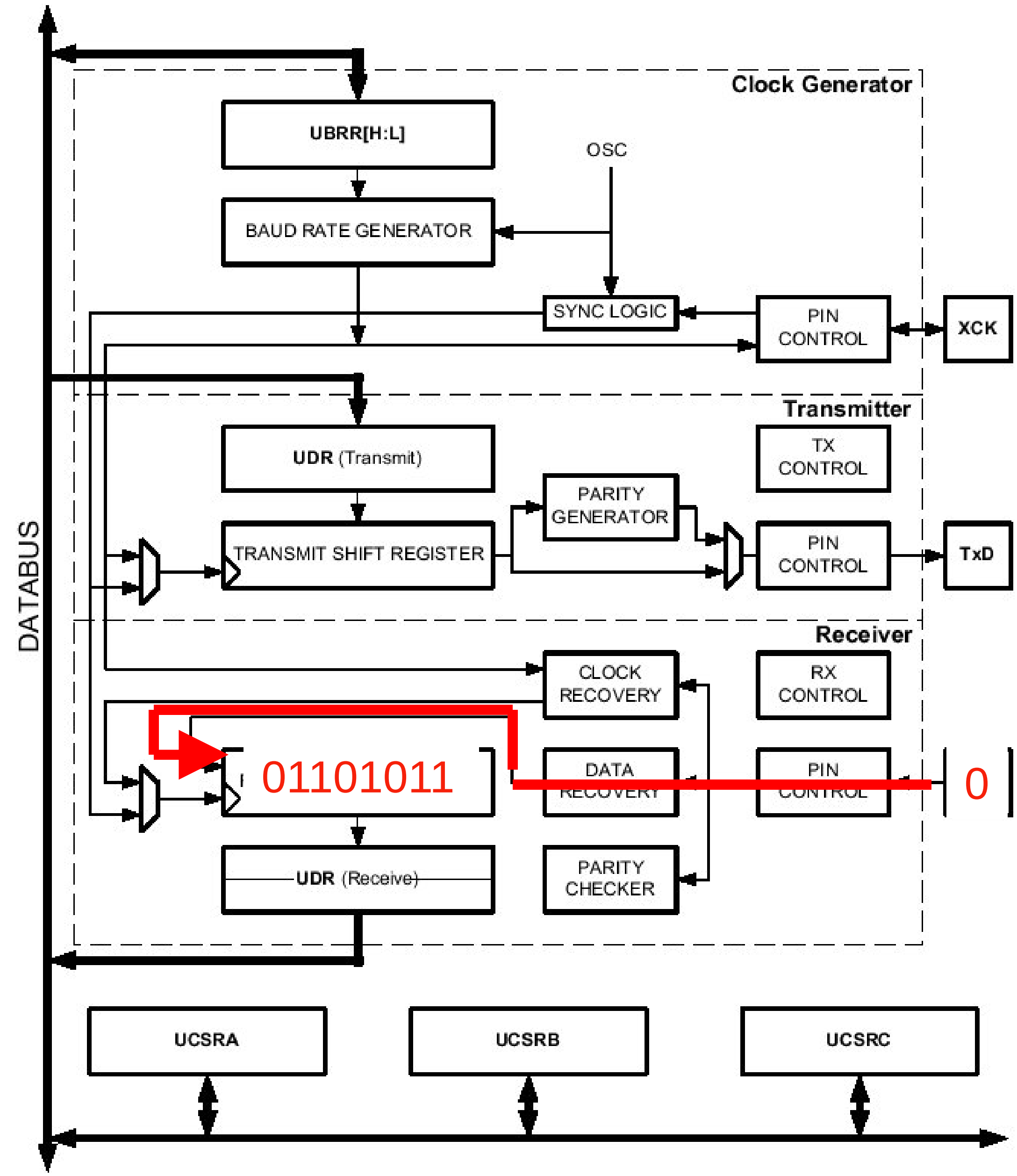
Receive

And the next bit…



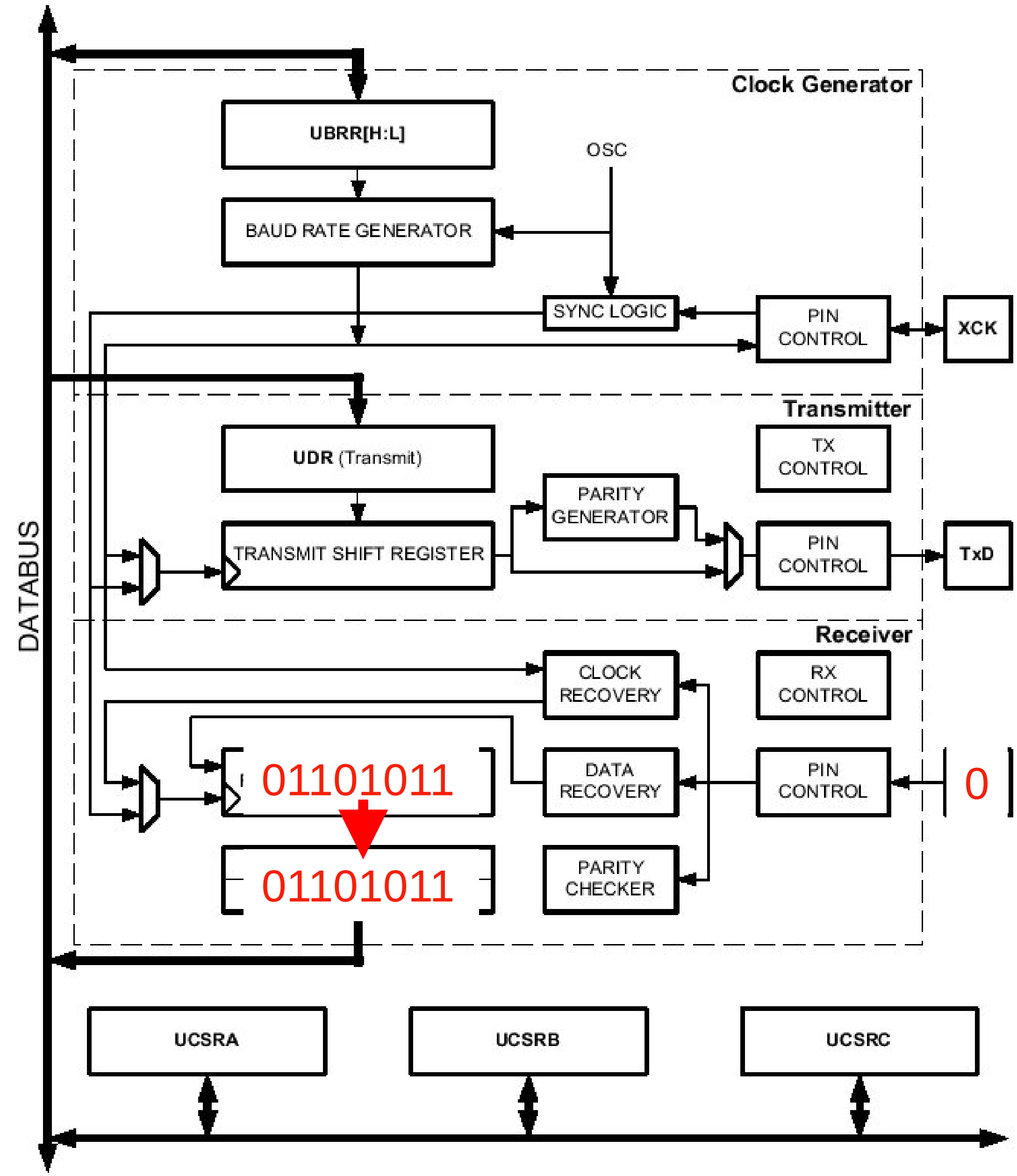
Receive

And the 8th bit



Receive

Completed byte is stored in the UART buffer



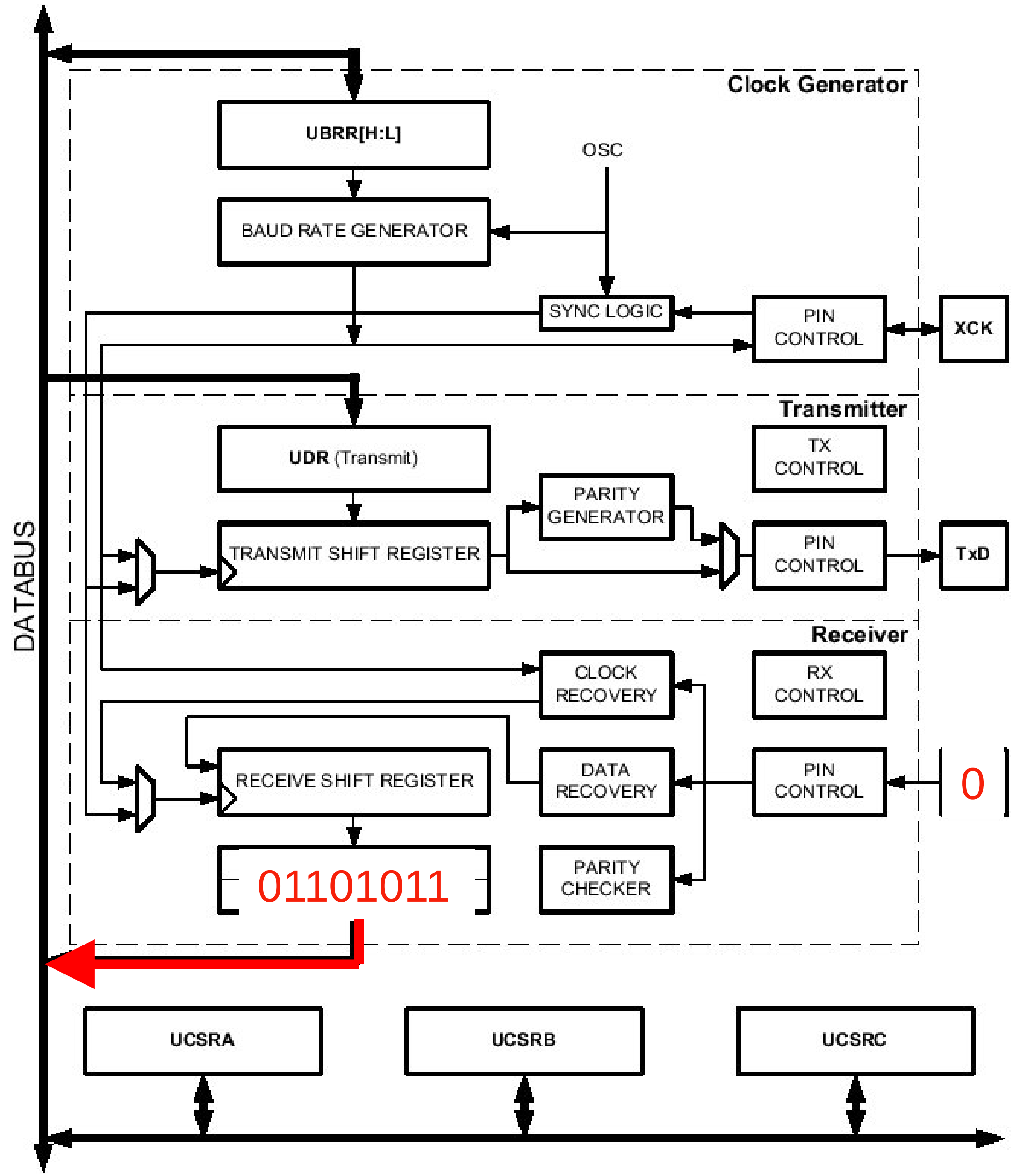
Reading a Byte from the Serial Port

```
int c;

c=getchar();
```

Receive

getchar() retrieves this byte from the buffer



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?

- Bonus: what if we don't know how many digits are coming? (we read digits until a non-digit is read)

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	~