Physics 124: Lecture 8

Odds and Ends

Binary/Hex/ASCII

Memory & Pointers in C

Decibels & dB Scales

Coherent Detection

Adapted from Tom Murphy's lectures

Binary, Hexadecimal Numbers

- Computers store information in binary
  - 1 or 0, corresponding to V_{CC} and 0 volts, typically
  - the CC subscript originates from "collector" of transistor
- Become familiar with binary counting sequence

binary	decimal	hexadecimal
0000 0000	0	0x00
0000 0001	1	0x01
0000 0010	2	0x02
0000 0011	2+1 = 3	0x03
0000 0100	4	0x04
0000 0101	4+1 = 5	0x05
etc.		
1111 1100	128+64+32+16+8+4 = 252	0xfc
1111 1101	128+64+32+16+8+4+1 = 253	0xfd
1111 1110	128+64+32+16+8+4+2 = 254	0xfe
1111 1111	128+64+32+16+8+4+2+1 = 255	0xff

Binary to Hex: easy!

- Note separation of previous 8-bit (one-byte) numbers into two 4-bit pieces (nibbles)
  - makes expression in hex (base-16; 4-bits) natural

binary	hexadecimal	decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A (lower case fine)	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

ASCII Table in Hex

first hex digit (columns); second hex digit (rows)

	0	1	2	3	4	5	6	7
0	NUL ^@ null (\0)	DLE ^P	SP space	0	@	P	`	p
1	SOH ^A start of hdr	DC1 ^Q	!	1	A	Q	a	q
2	STX ^B start text	DC2 ^R	"	2	B	R	b	r
3	ETX ^C end text	DC3 ^S	#	3	C	S	c	s
4	EOT ^D end trans	DC4 ^T	$	4	D	T	d	t
5	ENQ ^E	NAK ^U	%	5	E	U	e	u
6	ACK ^F acknowledge	SYN ^V	&	6	F	V	f	v
7	BEL ^G bell	ETB ^W	'	7	G	W	g	w
8	BS ^H backspace	CAN ^X	(	8	H	X	h	x
9	HT ^I horiz. tab (\t)	EM ^Y	)	9	I	Y	i	y
A	LF ^J linefeed (\r)	SUB ^Z	*	:	J	Z	j	z
B	VT ^K vertical tab	ESC escape	+	;	K	[	k	{
C	FF ^L form feed	FS	,	<	L	\	l	|
D	CR ^M carriage ret (\n)	GS	-	=	M	]	m	}
E	SO ^N	RS	.	>	N	^	n	~
F	SI ^O	US	/	?	O	_	o	DEL

ASCII in Hex

- Note the patterns and conveniences in the ASCII table
  - 0 thru 9 is hex 0x30 to 0x39 (just add 0x30)
  - A-Z parallels a-z; just add 0x20
    - starts at 0x41 and 0x61, so H is 8th letter, is 0x48, etc.
  - the first 32 characters are control characters, often represented as Ctrl-C, denoted ^C, for instance
    - associated control characters mirror 0x40 to 0x5F
    - put common control characters in red; useful to know in some primitive environments

Two's Complement

- Unsigned are direct binary representation
- Signed integers usually follow "two's complement"

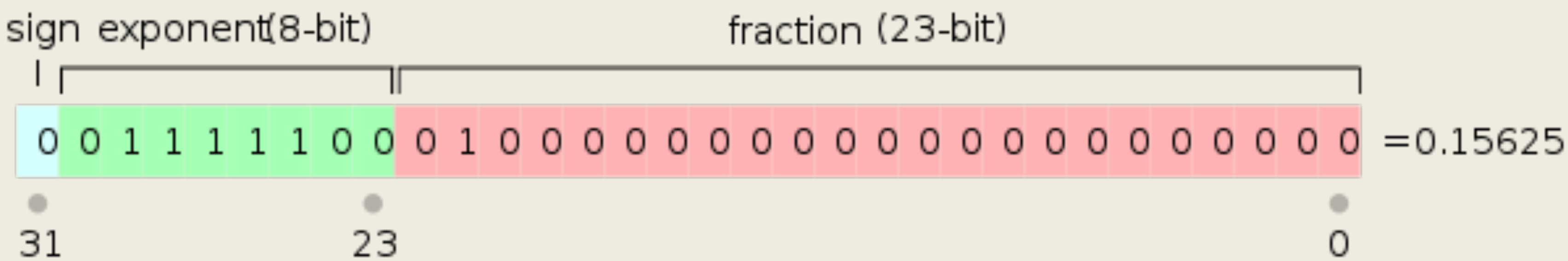
binary	hex	unsigned	2's complement
0000 0000	0x00	0	0
0000 0001	0x01	1	1
0000 0010	0x02	2	2
0111 1111	0x7F	127	127
1000 0000	0x80	128	-128
1000 0001	0x81	129	-127
1111 1110	0xFE	254	-2
1111 1111	0xFF	255	-1

– rule: to get neg. number, flip all bits and add one
  - example: -2: 0000 0010 → 1111 1101 + 1 = 1111 1110
  - Also called "bias", $2^8 = 256$ for single precision, 2^{16} for double precision

– adding pos. & neg. → 0000 0000 (ignore overflow bit)

Floating Point Numbers

- Most standard is IEEE format
  - ~~http://en.wikipedia.org/wiki/IEEE_754-1985~~
  - https://en.wikipedia.org/wiki/IEEE_floating_point#IEEE_754-2008



$$\mathbf{0.15625_{10}} = \mathbf{0.00101_2} = 2^{-3} + 2^{-5} = +\mathbf{1.01}_2 \times 2^{-3}$$

- Three parts: sign, mantissa, exponent
  - sign: 0 is positive, 1 is negative ; mantissa, 1 is implied
  - exponent: bias by 127, i.e., 127-3-124 = 0b01111100
  - single-precision (float) has 32 bits (1, 8, 23, resp.)
    - 7 digits, $10^{\pm 38}$: log(10)/log(2) = 3.32, so $2^{23} \approx 10^7$; ±127/3.32 ≈ 38
  - double precision (double) has 64 bits (1, 11, 52, resp.)
    - 16 digits, $10^{\pm 308}$
- The actual convention is not critical for us to understand, as much as:
  - limitations to finite representation
  - space allocation in memory: just 32 or 64 bits of 1's & 0's

Arrays & Storage in C

- We can hold more than just one value in a variable
  - but the program needs to know how many places to save in memory
- Examples:

```
int i[8], j[8]={0}, k[]={9,8,6,5,4,3,2,1,0};
double x[10], y[10000]={0.0}, z[2]={1.0,3.0};
char name[20], state[]="California";
```

  - we can either say how many elements to allow and leave them unset; say how many elements and initialize all elements to zero; leave out the number of elements and specify explicitly; specify number of elements and contents
  - character arrays are strings
  - strings must end in `'\0'` to signal the end
  - must allow room: `char name[4]="Bob"`
    - fourth element is `'\0'` by default

Indexing Arrays

```
int i,j[8]={0},k[]={2,4,6,8,1,3,5,7};
double x[8]={0.0},y[2]={1.0,3.0},z[8];
char name[20],state[]="California";

for (i=0; i<8; i++)
{
  z[i] = 0.0;
  printf(”j[%d] = %d, k[%d] = %d\n",i,j[i],i,k[i]);
}
name[0]='T';
name[1]='o';
name[2]='m';
name[3] = '\0';
printf("%s starts with %c and lives in %s\n",name,name[0],state);
```

- Index array integers, starting with zero
- Sometimes initialize in loop (`z[ ]` above)
- String assignment awkward outside of declaration line
  - `#include <string.h>` provides “useful” string routines
    - done automatically in Arduino, but also String type makes many things easier

Memory Allocation in Arrays

- `state[]="California";` →

each block is 8-bit `char`

C	a	l	i	f	o	r	n	i	a	\0

- `name[11]="Bob";` →

B	o	b	\0							

  – empty spaces at the end could contain any random garbage

- `int i[] = {9,8,7,6,5,4,3,2};` →

9	8	7	6	5	4	3	2

each block is 16 or 32-bit `int`

  – indexing `i[8]` is out of bounds, and will either cause a segmentation fault (if writing), or return garbage (if reading)

Multi-Dimensional Arrays

```
int i,j,arr[2][4];

for (i=0; i<2; i++){
  for (j=0; j<4; j++){
    arr[i][j] = 4+j-2*i;
  }
}
```

i \ j	0	1	2	3
0	4	5	6	7
1	2	3	4	5

in memory space:

4	5	6	7	2	3	4	5

- C is a row-major language: the first index describes which row (not column), and arranged in memory row-by-row
  - memory is, after all, arranged one-dimensionally
- Have the option of treating a 2-D array as 1-D
  - `arr[5] = arr[1][1] = 3`
- Can have arrays of 2, 3, 4, … dimensions

Arrays and functions

- How to pass arrays into and out of functions?
- An array in C is actually handled as a "pointer"
  - a pointer is a direction to a place in memory
- A pointer to a variable's address is given by the & symbol
  - you may remember this from `scanf` functions
- For an array, the name is *already* an address
  - because it's a block of memory, the name by itself doesn't contain a unique value
  - instead, the name returns the address of the first element
  - if we have `int arr[i][j];`
    - `arr` and `&arr[0]` and `&arr[0][0]` mean the same thing: the address of the first element
- By passing an address to a function, it can manipulate the contents of memory directly, without having to pass bulky objects back and forth explicitly

Example: 3x3 matrix multiplication

```
void mm3x3(double a[], double b[], double c[])

// Takes two (3x3 matrix) pointers, a, b, stored in 1-d arrays nine
// elements long (row major, such that elements 0,1,2 go across a
// row, and 0,3,6 go down a column), and multiplies a*b = c.
// Dimensionality and encoding of the arguments are assumed.
{

  double *cptr;    // define a pointer variable to double
  int i,j;

  cptr = c;        // without *, it's address; point to addr. for c

  for (i=0; i<3; i++){
    for (j=0; j<3; j++){
      *cptr++ = a[3*i]*b[j] + a[3*i+1]*b[j+3] + a[3*i+2]*b[j+6];
      // calc value to stick in current cptr location, then
      // increment the value for cptr to point to next element
      // * gets at contents
    }
  }
}
```

mm3x3, expanded

- The function is basically doing the following:

```
*cptr++ = a[0]*b[0] + a[1]*b[3] + a[2]*b[6];
*cptr++ = a[0]*b[1] + a[1]*b[4] + a[2]*b[7];
*cptr++ = a[0]*b[2] + a[1]*b[5] + a[2]*b[8];

*cptr++ = a[3]*b[0] + a[4]*b[3] + a[5]*b[6];
*cptr++ = a[3]*b[1] + a[4]*b[4] + a[5]*b[7];
*cptr++ = a[3]*b[2] + a[4]*b[5] + a[5]*b[8];

*cptr++ = a[6]*b[0] + a[7]*b[3] + a[8]*b[6];
*cptr++ = a[6]*b[1] + a[7]*b[4] + a[8]*b[7];
*cptr++ = a[6]*b[2] + a[7]*b[5] + a[8]*b[8];
```

  – which you could confirm is the proper set of operations for multiplying out 3×3 matrices

Notes on mm3x3

- The function is constructed to deal with 1-d instead of 2-d arrays
  - 9 elements instead of 3×3
  - it could have been done either way
- There is a pointer, `*cptr` being used
  - by specifying `cptr` as a double pointer, and assigning its address (just `cptr`) to `c`, we can stock the memory by using "pointer math"
  - `cptr` is the address; `*cptr` is the value at that address
  - just like `&x_val` is an address, while `x_val` contains the value
  - `cptr++` bumps the address *by the amount appropriate to that particular data type* *(double prec. here)*, called "pointer math"
  - `*cptr++ = value;` assigns value to `*cptr`, then advances the `cptr` count

Using mm3x3

```c
#include <stdio.h>

void mm3x3(double a[], double b[], double c[]);

int main()
{
  double a[]={1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0};
  double b[]={1.0, 2.0, 3.0, 4.0, 5.0, 4.0, 3.0, 2.0, 1.0};
  double c[9];

  mm3x3(a,b,c);

  printf("c = %f  %f  %f\n",c[0],c[1],c[2]);
  printf("    %f  %f  %f\n",c[3],c[4],c[5]);
  printf("    %f  %f  %f\n",c[6],c[7],c[8]);

  return 0;
}
```

- passing just the names (addresses) of the arrays
  - filling out `a` and `b`, but just making space for `c`
  - note function declaration before main

Another way to skin the cat

```
double a[3][3]={{1.0, 2.0, 3.0},
                {4.0, 5.0, 6.0},
                {7.0, 8.0, 9.0}};
double b[3][3]={{1.0, 2.0, 3.0},
                {4.0, 5.0, 4.0},
                {3.0, 2.0, 1.0}};
double c[3][3];

mm3x3(a,b,c);
```

- Here, we define the arrays as 2-d, knowing that in memory they will still be 1-d
  - we will get compiler warnings, but the thing will still *work*
  - not a recommended approach, just presented here for educational purposes
  - Note that we could replace `a` with `&a[0][0]` in the function call, and the same for the others, and get no compiler errors

Decibels

- Sound is measured in decibels, or dB
  - as are many radio-frequency (RF) applications
- Logarithmic scale
  - common feature is that every 10 dB is a factor of 10 in power/intensity
  - other handy metrics
    - 3 dB is 2×
    - 7 dB is 5×
    - obviously piling 2× and 5× is 10×, which is 10 dB = 3 dB + 7 dB
  - decibels thus combine like logarithms: addition represents multiplicative factors

Sound Intensity

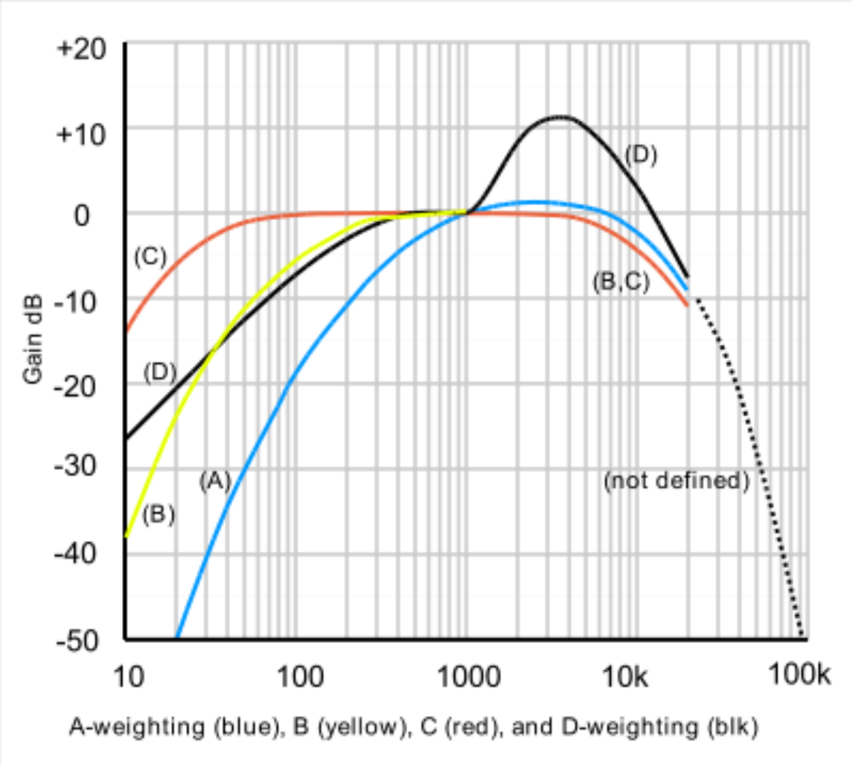
- Sound requires energy (pushing atoms/molecules through a distance), and therefore a power
- Sound is characterized in decibels (dB), according to:
  - sound level = $10\times\log(I/I_0)$ = $\underline{20}\times\log(P/P_0)$ dB
  - $I_0 = 10^{-12}$ W/m^2 is the threshold power intensity (0 dB)
  - $P_0 = 2\times10^{-5}$ N/m^2 is the threshold pressure (0 dB)
    - atmospheric pressure is about 10^5 N/m^2
    - <u>20</u> out front accounts for intensity going like P^2
- Examples:
  - 60 dB (conversation) means $\log(I/I_0) = 6$, so $I = 10^{-6}$ W/m^2
    - and $\log(P/P_0) = 3$, so $P = 2\times10^{-2}$ N/m^2 = 0.0000002 atmosphere!!
  - 120 dB (pain threshold) means $\log(I/I_0) = 12$, so $I = 1$ W/m^2
    - and $\log(P/P_0) = 6$, so $P = 20$ N/m^2 = 0.0002 atmosphere
  - 10 dB (barely detectable) means $\log(I/I_0) = 1$, so $I = 10^{-11}$ W/m^2
    - and $\log(P/P_0) = 0.5$, so $P \approx 6\times10^{-5}$ N/m^2

Sound hitting your eardrum

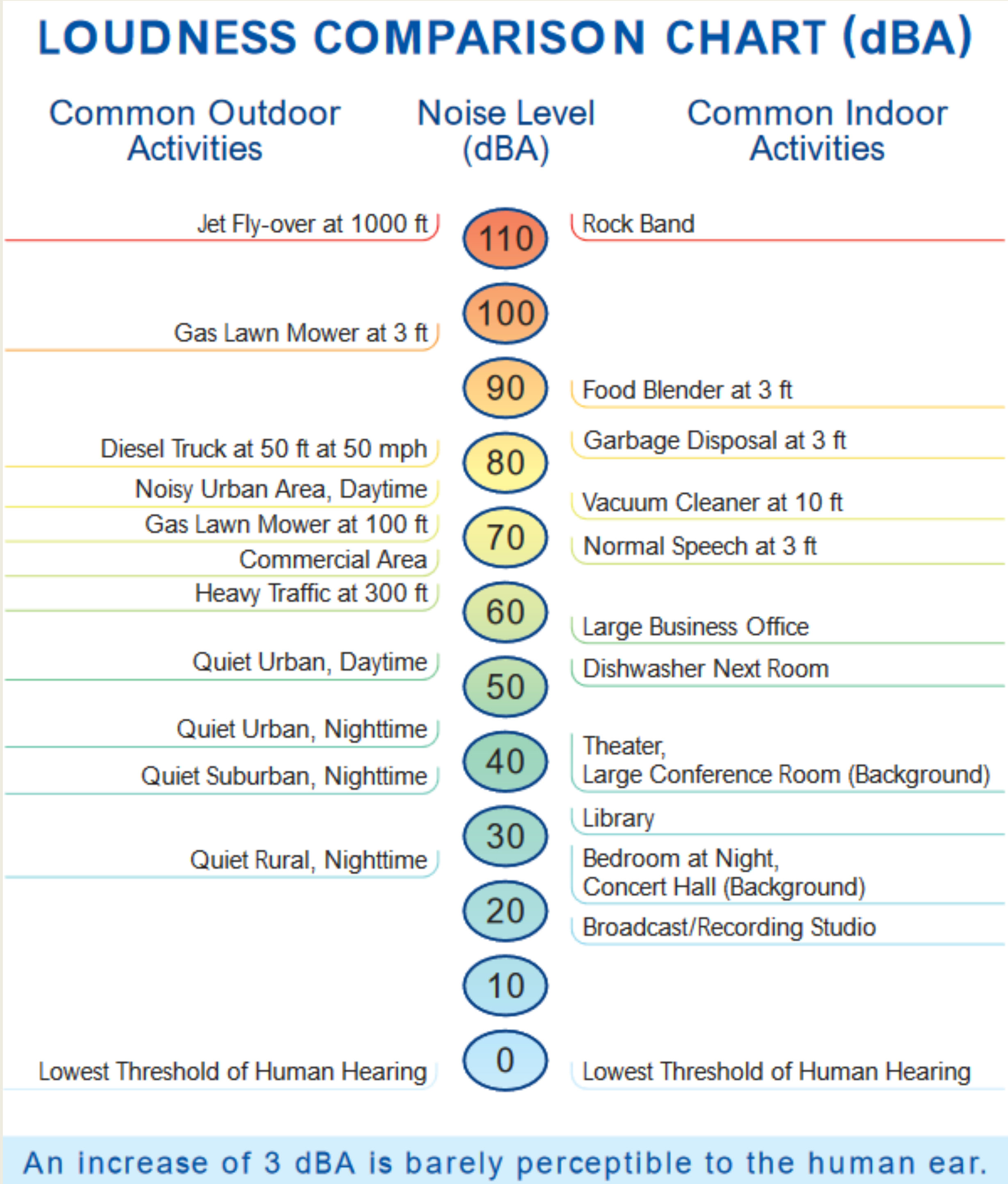
- Pressure variations displace membrane (eardrum, microphone) which can be used to measure sound
  - my speaking voice is moving your eardrum by a mere 1.5×10^{-4} mm = 150 nm = 1/4 wavelength of visible light!
  - threshold of hearing detects 5×10^{-8} mm motion, one-half the diameter of a single atom!!!
  - pain threshold corresponds to 0.05 mm displacement
- Ear ignores changes slower than 20 Hz
  - so though pressure changes even as you climb stairs, it is too slow to perceive as sound
- Eardrum can't be wiggled faster than about 20 kHz
  - just like trying to wiggle resonant system too fast produces no significant motion

A-weighting: account for relative loudness

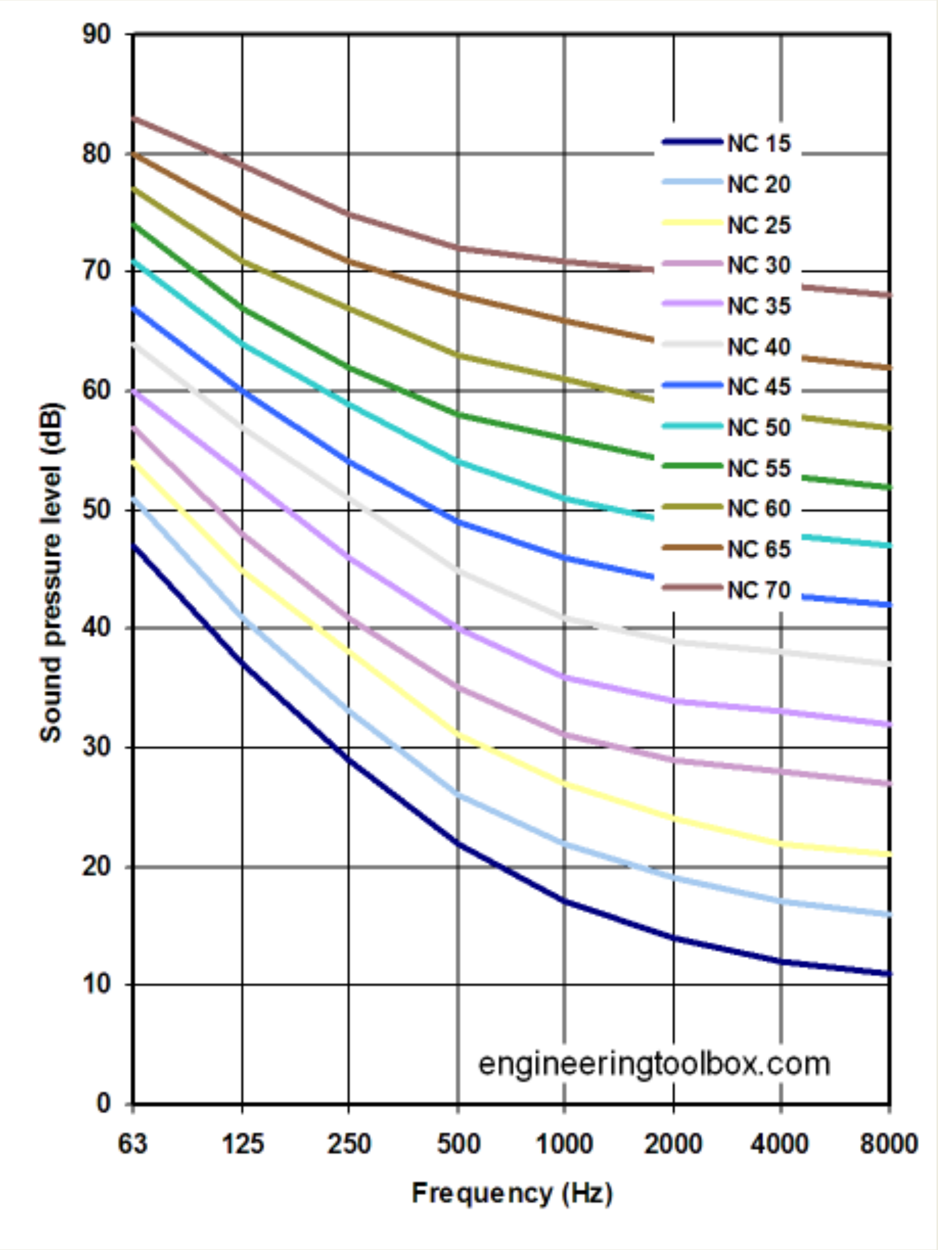
- Related to measurement of sound pressure level
- Defined in standard IEC 61672:2003, for environmental and industrial noise
- Accounts for low sensitivity of human ear at low frequencies, reduces importance of low freq. in human impact assessments



Other weightings available: B, C, D


LOUDNESS COMPARISON CHART (dBA)
Common Outdoor Activities
Noise Level (dBA)
Common Indoor Activities
Jet Fly-over at 1000 ft
110
Rock Band
100
Gas Lawn Mower at 3 ft
90
Food Blender at 3 ft
Diesel Truck at 50 ft at 50 mph
80
Garbage Disposal at 3 ft
Noisy Urban Area, Daytime
Gas Lawn Mower at 100 ft
Vacuum Cleaner at 10 ft
70
Normal Speech at 3 ft
Commercial Area
Heavy Traffic at 300 ft
60
Large Business Office
Quiet Urban, Daytime
50
Dishwasher Next Room
Quiet Urban, Nighttime
40
Theater,
Large Conference Room (Background)
Quiet Suburban, Nighttime
30
Library
Quiet Rural, Nighttime
Bedroom at Night,
Concert Hall (Background)
20
Broadcast/Recording Studio
10
0
Lowest Threshold of Human Hearing
Lowest Threshold of Human Hearing
An increase of 3 dBA is barely perceptible to the human ear.

Sound scales not for humans
Noise Criterion (NC)



dB Scales

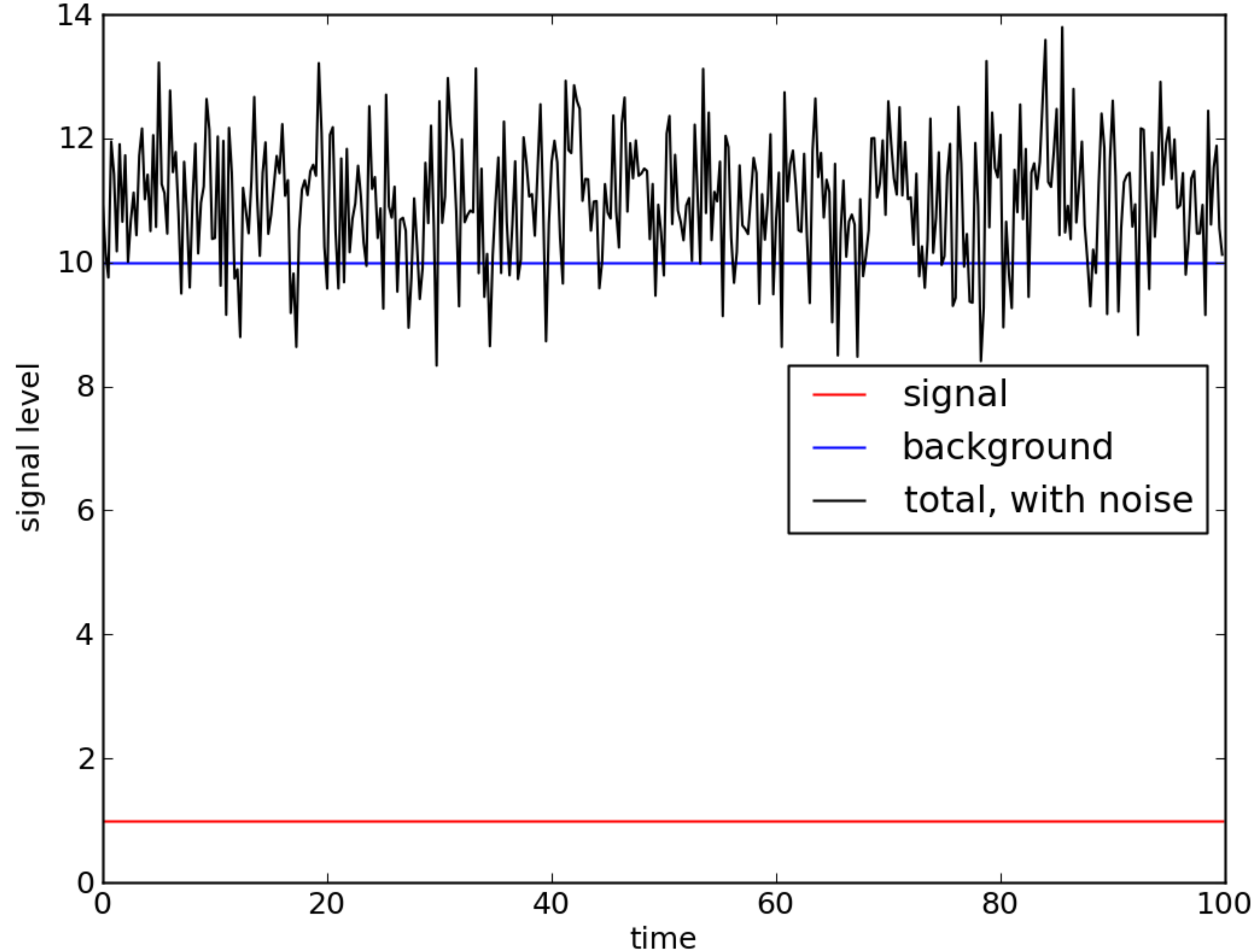
- In the radio-frequency (RF) world, dB is used several ways
  - dB is a relative scale: a ratio: often characterizing a gain or loss
    - +3 dB means a factor of two more
    - −17 dB means a factor of 50 loss, or 2% throughput
  - dBm is an absolute scale, in milliwatts: 10×log(P/1 mW)
    - 0 dBm is 1 mW, a 30 dBm signal is 1 W
    - 36 dBm is 4 W (note 6 dB is two 3 dB, each a factor of 2 → 4×)
    - −27 dBm is 2 μW
  - dBc is signal strength relative to the carrier
    - often characterizes distortion from sinusoid
    - −85 dBc means any distortions are almost nine orders-of-magnitude weaker than the main sinusoidal "carrier"
- Voltage is the equivalent of sound pressure, an amplitude:

$$10\times\log\frac{Power_2}{Power_1} = 20\times\log\frac{Voltage_2}{Voltage_1}\ \text{dB}$$

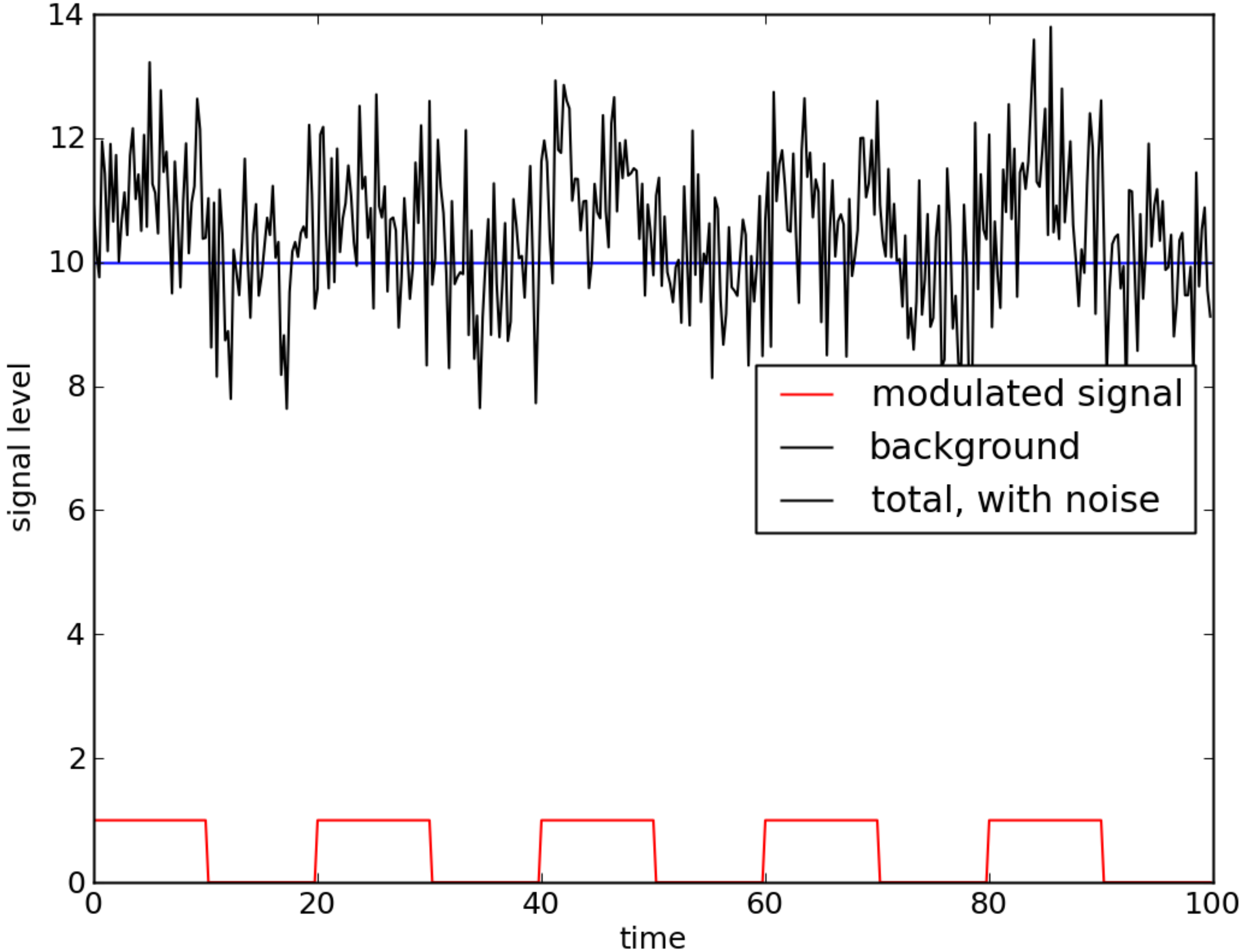
Coherent Detection

- Sometimes fighting to discern signal against background noise
  - photogate in bright setting, for instance
- One approach is *coherent detection*
  - modulate signal at known phase, in ON/OFF pattern at 50% duty cycle
  - accumulate (add) in-phase parts, while subtracting out-of-phase parts
  - have integrator perform accumulation, or try in software
    - but if background is noisy in addition to high, integration better
  - basically background subtraction
  - gain more the greater the number of cycles integrated

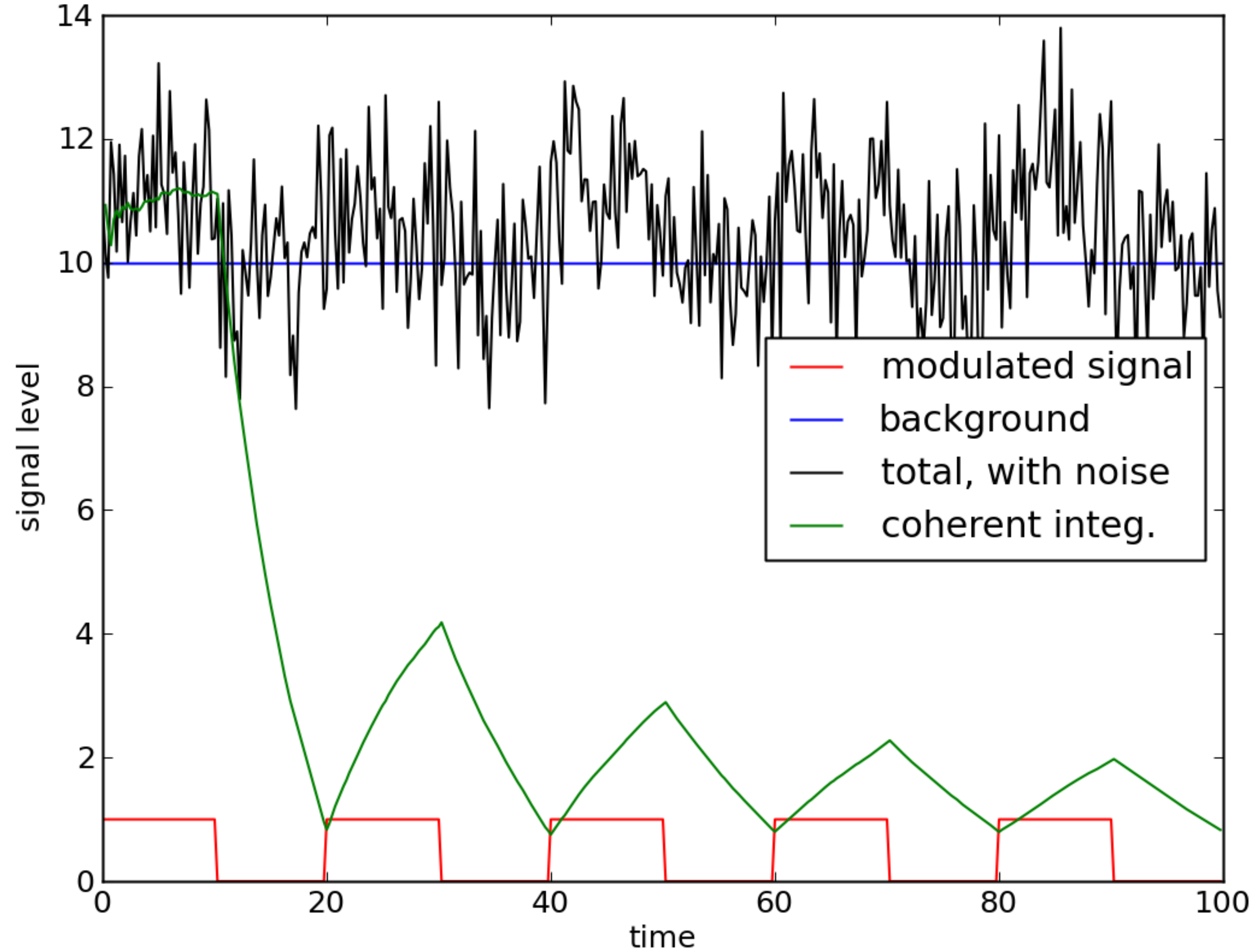
Raw Signal, Background, and Noise



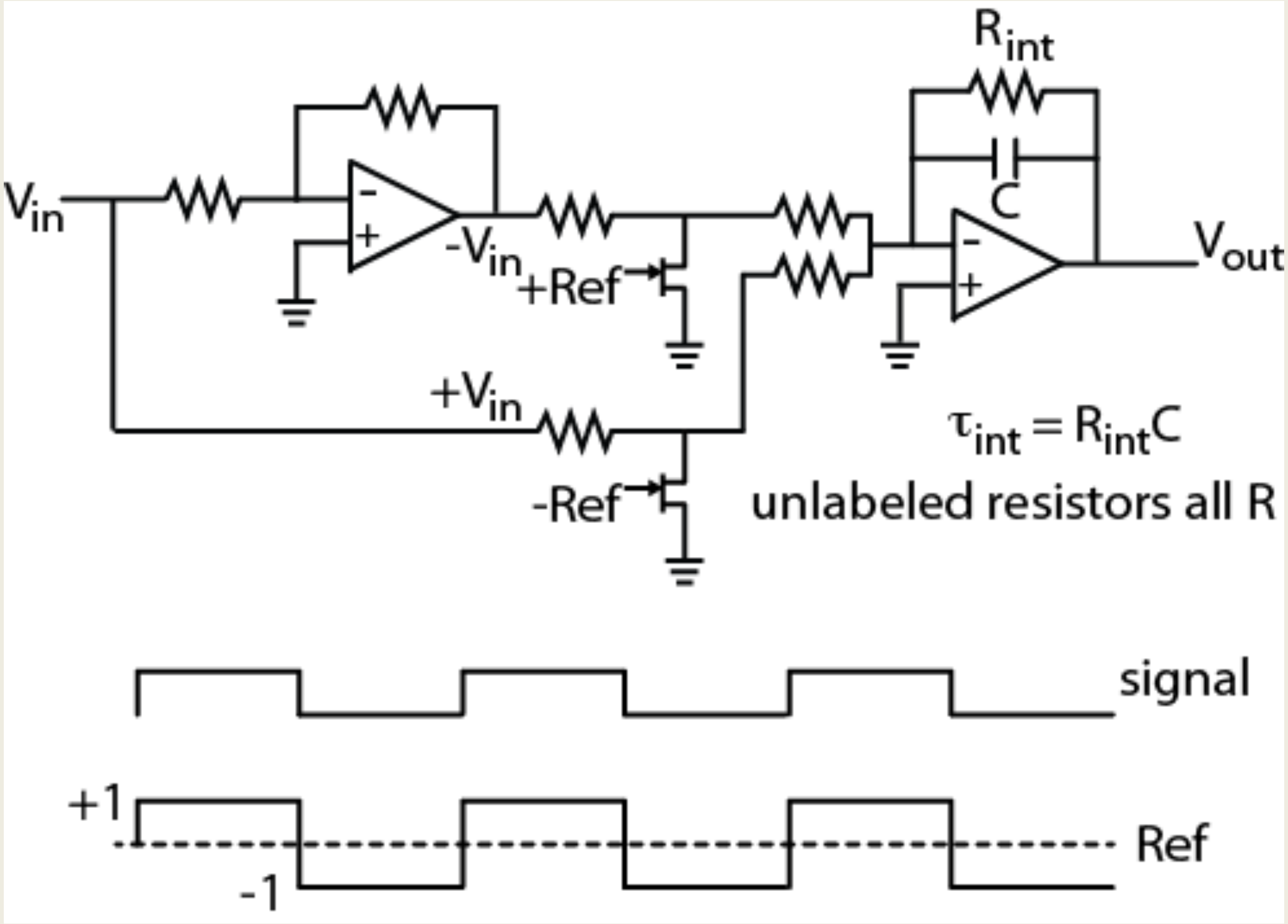
Modulated Signal; still hard to discern



Integration, subtracting “OFF” portions



Expressed in Electronics



first op-amp just inverting; second sums two inputs, only one on at a time
has effect of adding parts when Ref = +1, subtracting where Ref = -1
clears "memory" on timescale of $\tau_{int} = R_{int}C$
could also conceive of performing math in software

Lock-in detection

https://www.zhinst.com/applications/principles-of-lock-in-detection

Announcements

- Project Proposals due in two weeks Friday, Nov. 3
- Lab 3 due next week Mon/Tue (10/23,10/24)
- Lab 4 due in 2+ weeks Tue/Wed (11/6, 11/7)
- Midterm Wed. 11/8