DC to AC Converters

ECE 320 Electronics I

Jake Glower - Lecture #17

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

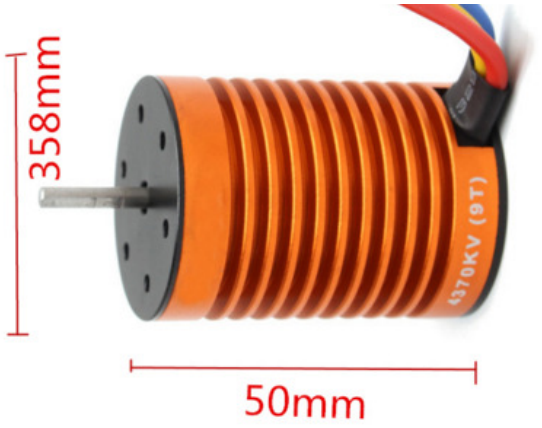
DC to AC Converters

Reasons to convert DC to AC:

- Transformers work at AC but not at DC. If you want to use a transformer to bump up a voltage, you need an AC signal.
- AC motors are smaller and more efficient than DC motors
- BLDC (Brushless DC motors or quad-copter motors) need 3-phase AC

1000W DC Servo Motor
40 lbs, $2400, 18" x 6" dia

820W BLDC Motor
9oz, $35 (including controller)



Uses of BLDC Motors

Brush-type DC motors

- Simple to use. Date back to 1900

Quad-Copters ($35, 850W, 9oz)

- High enough power to weight ratio

Electric Bicycles ($211, 1000W)

- Replace your front wheel to make it electric)

Electric Motorcycles ($7300, 4.2kW, 317lb)

- PCX Electric

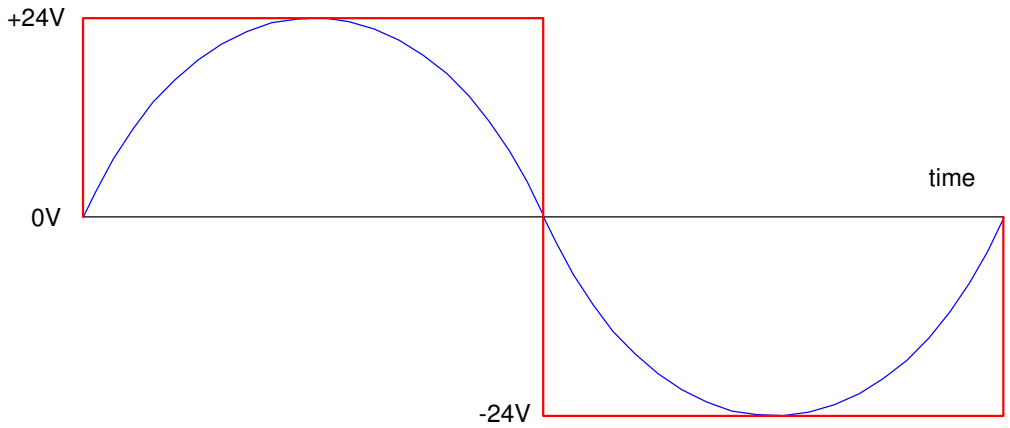
Electric Cars ($31,000, 110kW (147hp), 3,538lb)

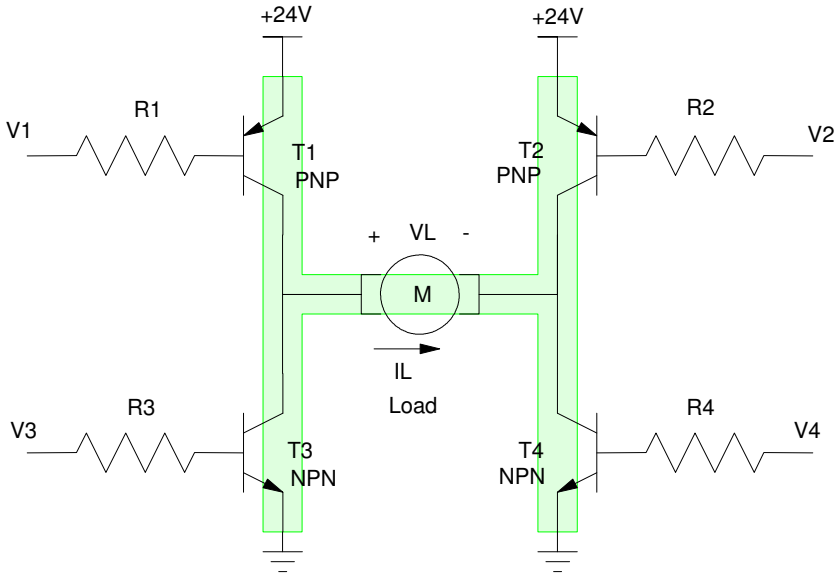
- Nissan Leaf

Single-Phase DC to AC Converter

Option 1: H-Bridge

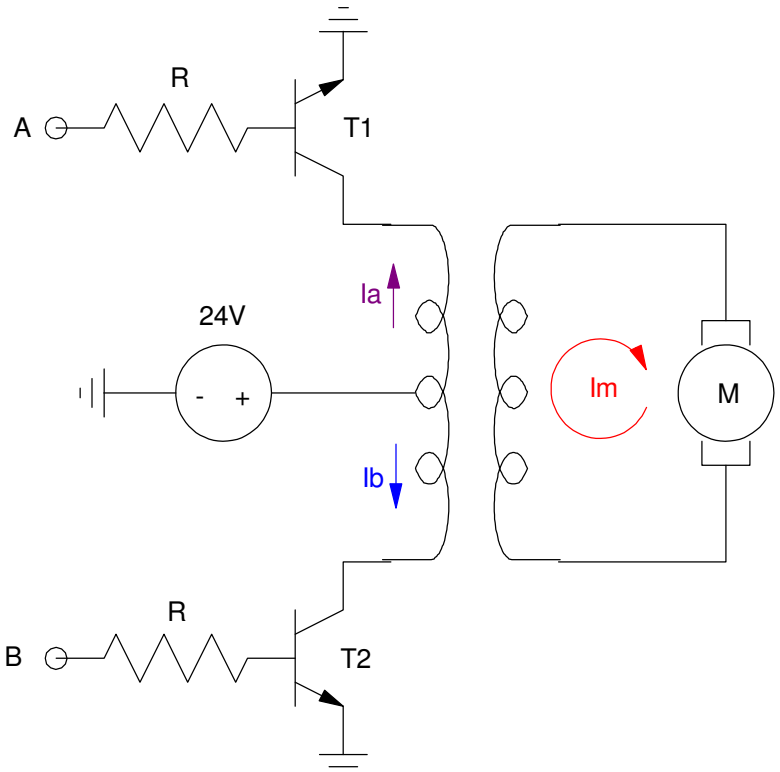
State	T1	T2	T3	T4
VL = +24V	ON	OFF	OFF	ON
VL = -24V	OFF	ON	ON	OFF
VL = 0V	OFF	OFF	OFF	OFF





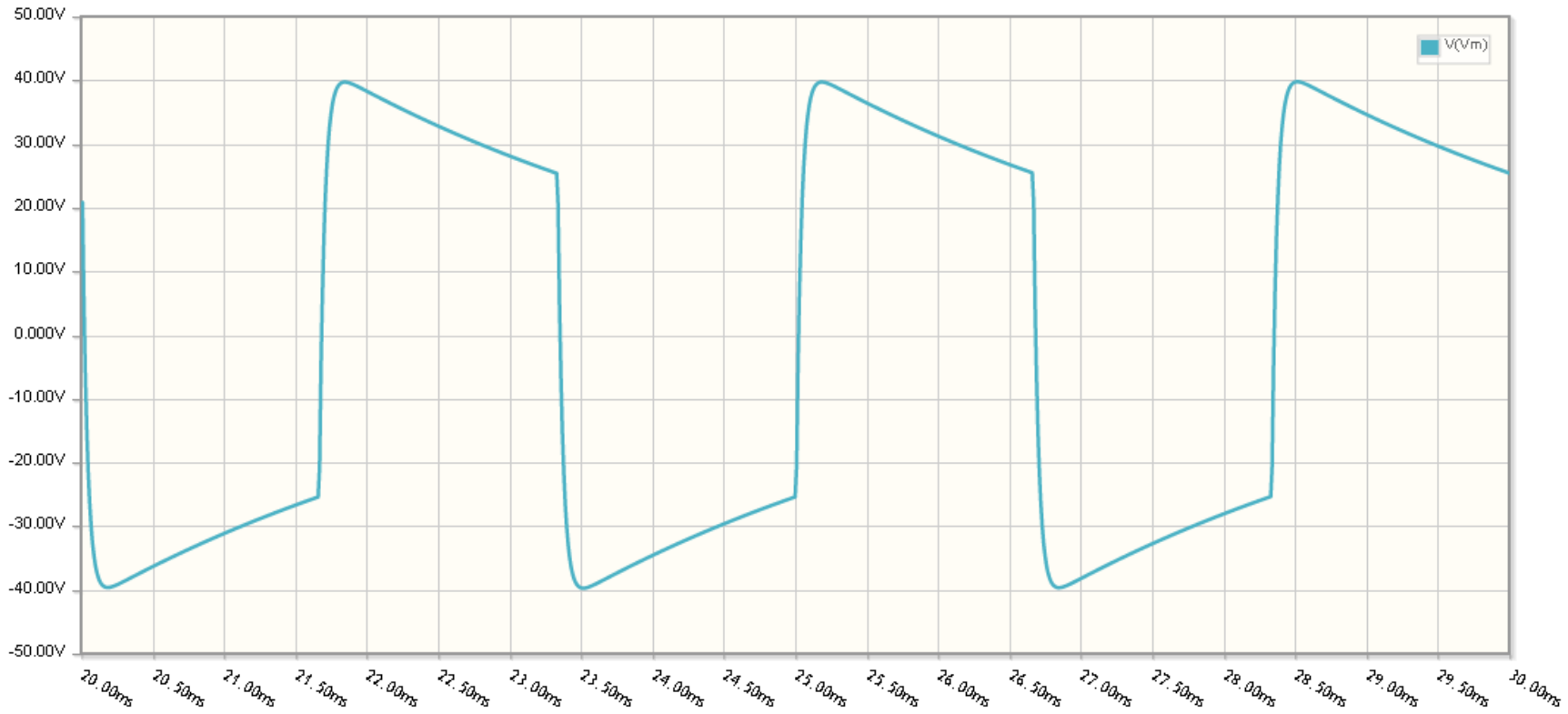
Option 2: Center Tap Transformer

- When A = 5V, transistor T1 turns on and current flows up (Ia). This induces clockwise current to the motor (Im > 0).
- When B = 5V, transistor T2 turns on and current flows down (Ib). This induces counterclockwise current to the motor (Im < 0).



CircuitLab Simulation:

- 24VDC converted to 40Vp AC



AC voltage to the motor when T1 and T2 are alternately turned on at 300Hz

Efficiency of DC to AC Converters

- 60Hz term drives the motor
- Higher harmonics produce heat (wasted)

Efficiency of the DC to AC converter is

- Energy at 60Hz (1st harmonic) vs.
- Total energy

To determine the efficiency, use Fourier Transforms

Fourier Transform of a 50% Duty Cycle Square Wave

Assume f(t) is a square wave

$$x(t) = \begin{cases} +24V & t < \pi \\ -24V & t > \pi \end{cases}$$

Harmonics are:

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t = [0.001:0.001:1]' * 2 * pi;
x = 24*(t <= pi) - 24*(t > pi);

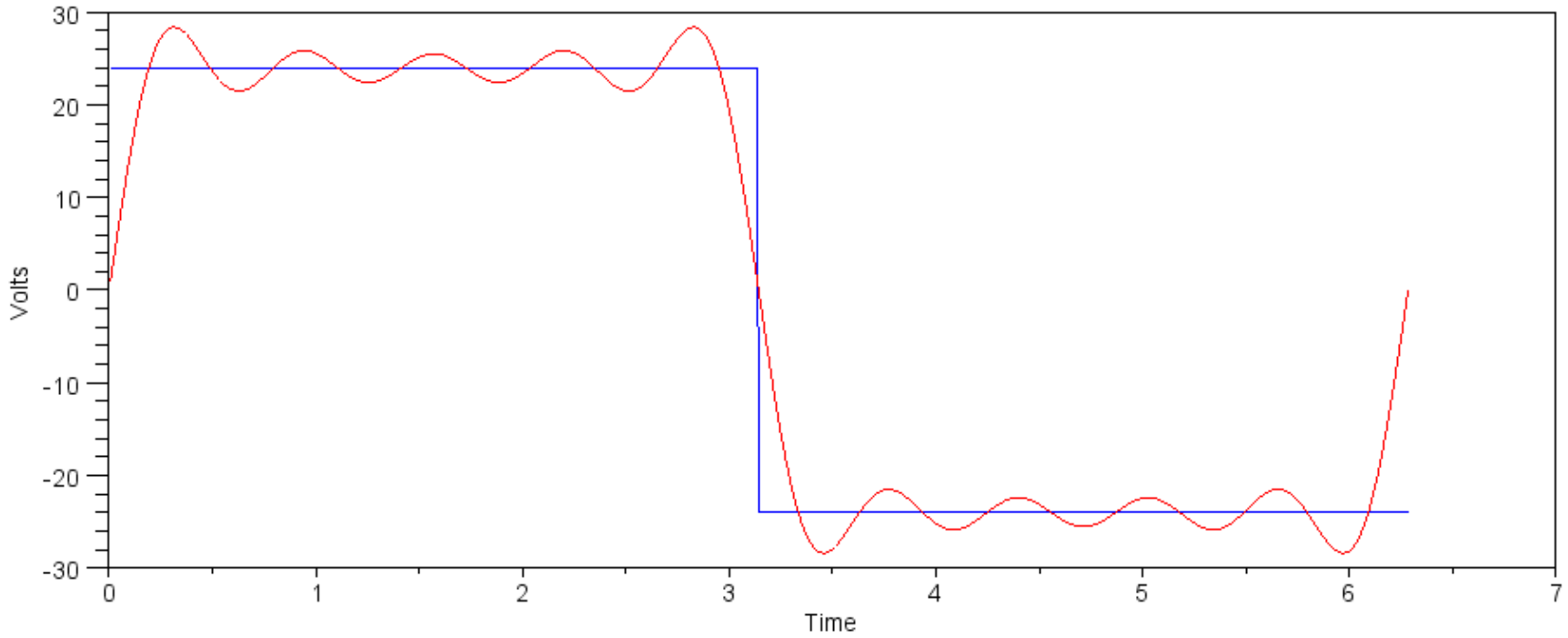

X1 = 2 * mean(x .* exp(-j*t))
X1 =  -0.0960 -30.5576i

X3 = 2 * mean(x .* exp(-3*j*t))
X3 =  -0.0960 -10.1856i


X5 = 2 * mean(x .* exp(-5*j*t))
X5 =  -0.0960 - 6.1110i
```

Harmonics (cont'd)

n	1	2	3	4	5	6	7	8	9
Xn	-j30.55	0	-j10.18	0	-j6.11	0	-j4.36	0	-j3.39

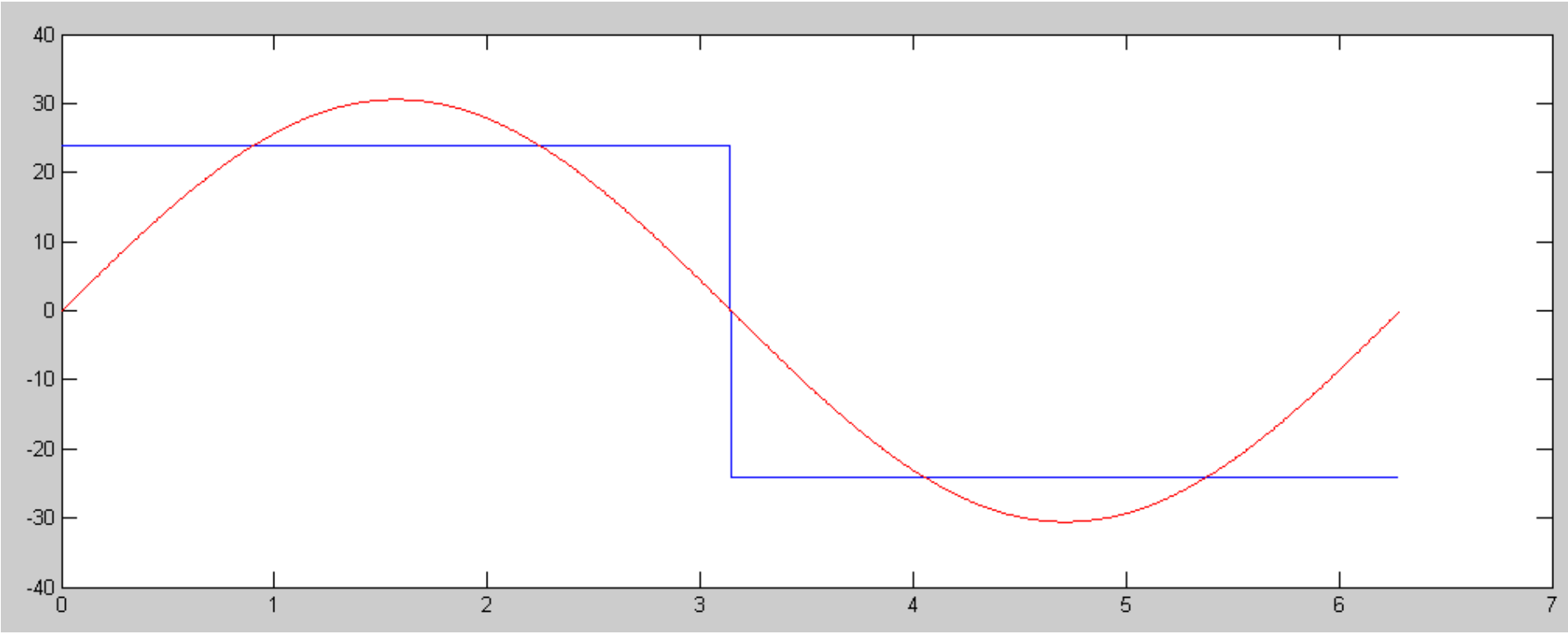


Energy in Each Harmonic

n	Xn	Power (Watts)	% Total
1	-j30.5576	466.8896	81.06
2	0	0.0000	0
3	-j10.1856	51.8780	9.01
4	0	0.0000	0
5	-j6.1110	18.6771	3.24
6	0	0.0000	0
7	-j4.3647	9.5299	1.65
8	0	0.0000	0

50% Duty Cycle DC to AC Converter (81% efficient):

- 81% of the energy is in the 1st harmonic
- A 50% duty cycle DC to AC converter is 81% efficient (max)

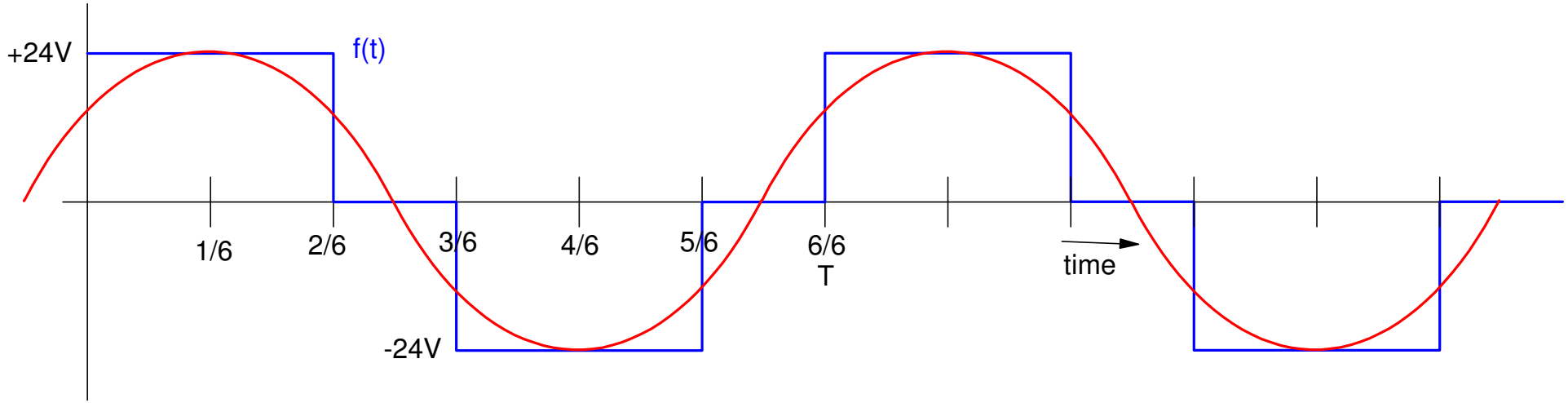


Square Wave (blue) and its 1st Harmonic (red)

Improved DC to AC Converter (91% efficient)

Slight variation in driving the H-bridge increases the efficiency

- +24V for 1/3rd of the time,
- -24V for 1/3rd of the time, and
- 0V for 1/6th of the time when you go -24V as well as when you go to +24V:



Energy in Each Harmonic

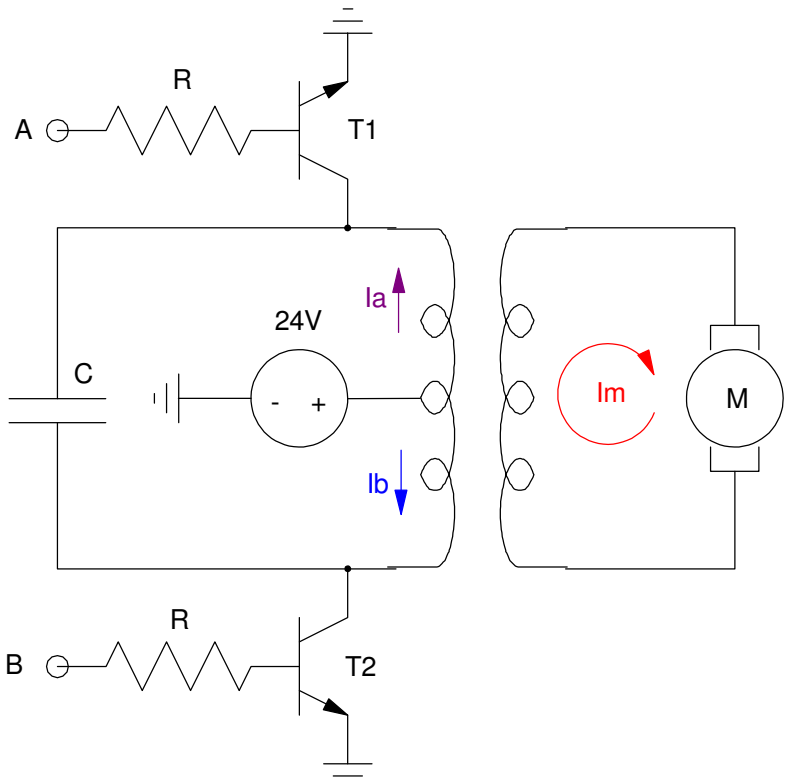
- 6-segment DC to AC converter is 91.11% efficient

n	Xn	Power (Watts)	% Total
1	13.2107 -22.9092i	349.6774	91.11
2	0	0	0
3	0	0	0
4	0	0	0
5	-2.6518 - 4.5650i	13.9358	3.63
6	0	0	0
7	1.8805 - 3.2843i	7.1615	1.87
8	0	0	0

Variation 3: 98.79% Efficient

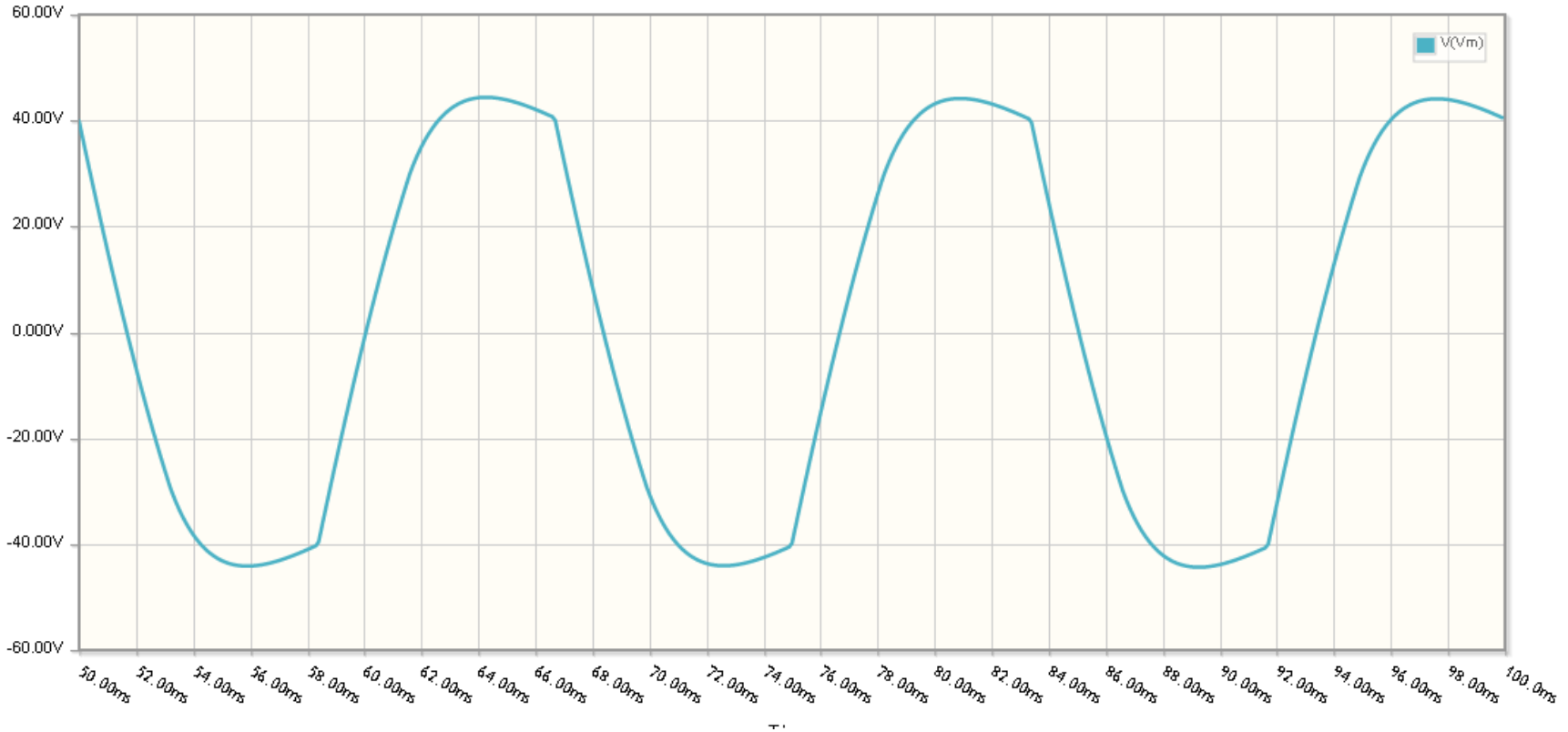
Add a capacitor across the primary side of the transformer

- The capacitor helps to remove the delta functions in voltage as Ia switches to Ib
- It also adds filtering - removing some of the high-frequency terms on the primary side



Resulting voltage vs. time

- CircuitLab Simulation
- C = 200uF (by trial and error)



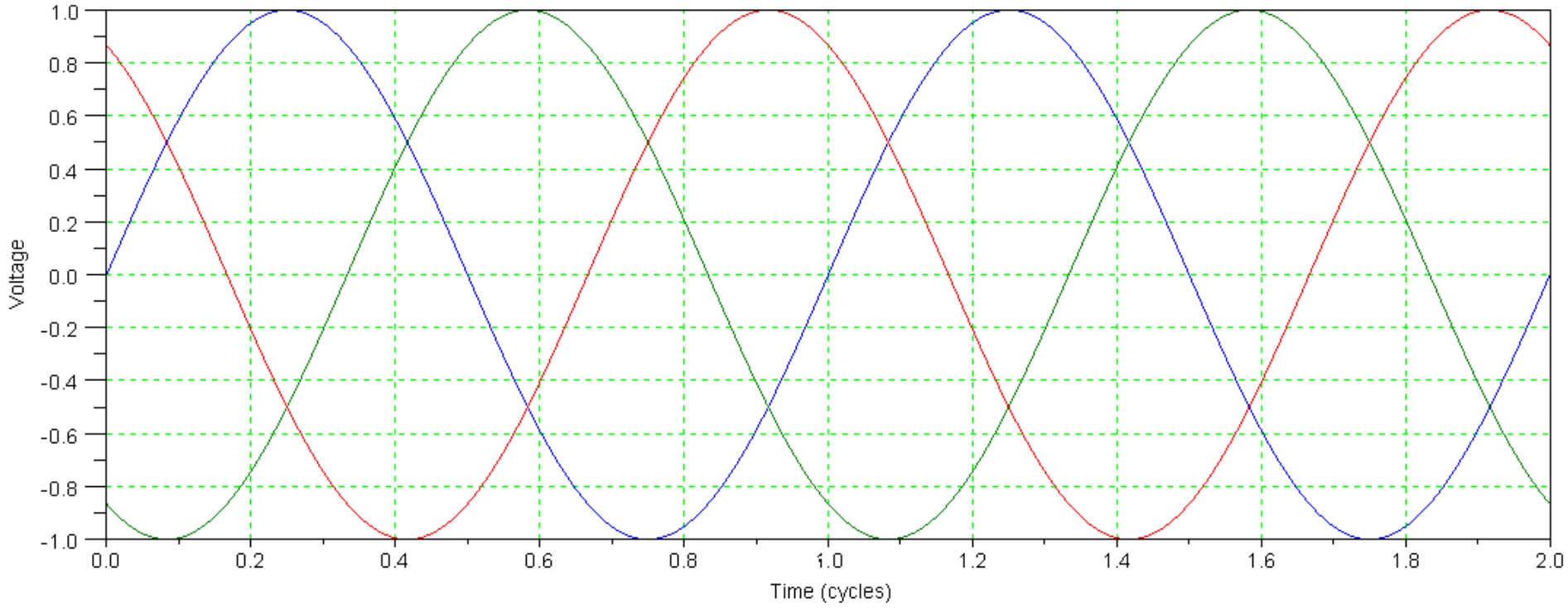
Vm: PartSim simulation of DC to AC coverter running at 60hz with C = 200uF

1st Harmonic contains 98.79% of the total energy

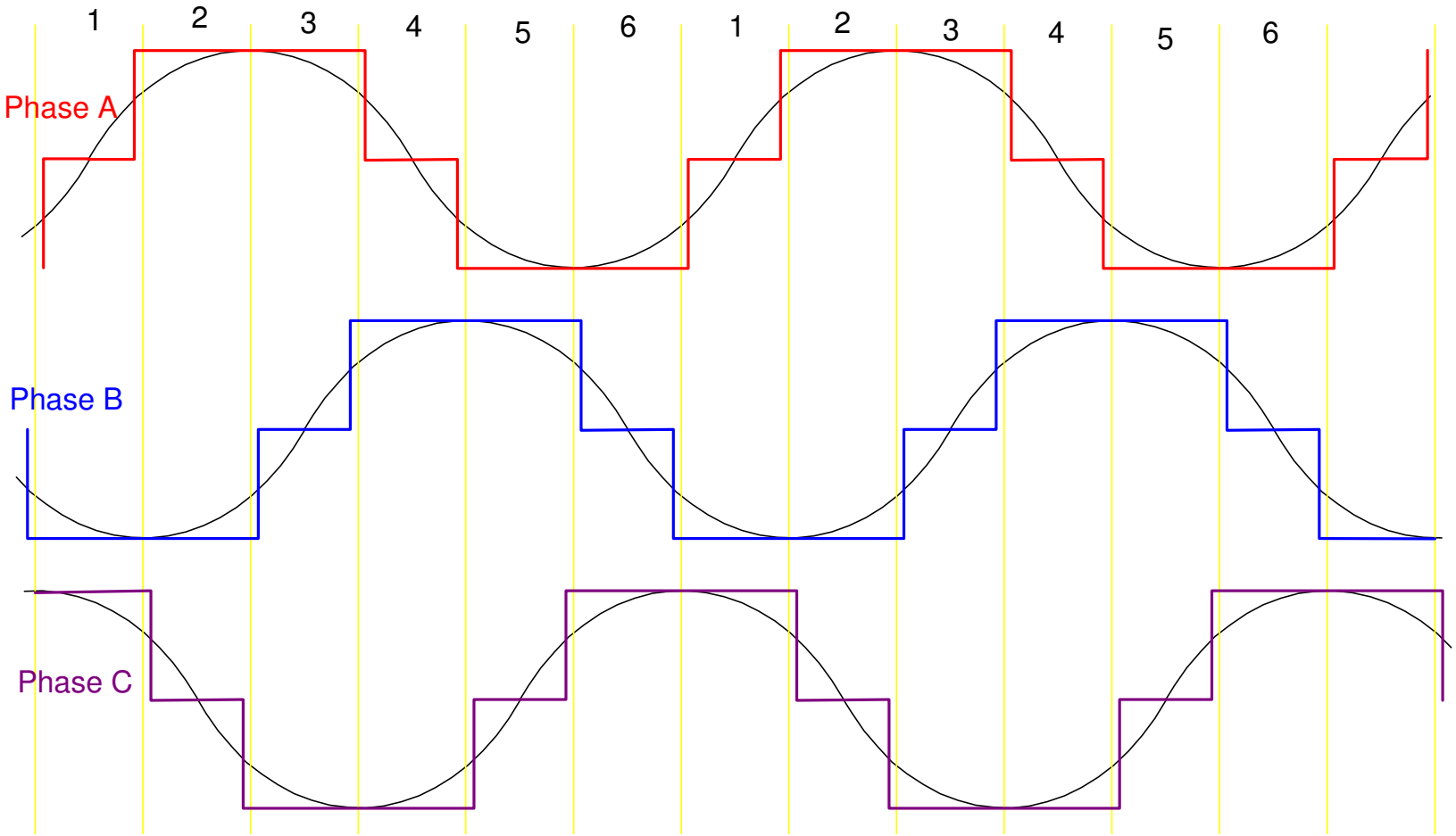
n	Xn	Power (Watts)	% Total
1	-30.2949 -35.1378i	1,076.2	98.79%
2	0	0	0
3	-4.6643 + 1.6672i	12.27	1.13%
4	0	0	0
5	-1.1407 + 0.5278i	0.79	0.07%
6	0	0	0
7	-0.5034 + 0.2105i	0.15	0.01%
8	0	0	0

3-Phase DC to AC Conversion: BLDC Motor Controller

- "Brushless DC"
- Actually a 3-phase AC synchronous motor
- Needs 3-phase AC



The corresponding digital signals for phase A, B, and C are then as follows:



Summary

DC to AC converters are the heart of driving 3-phase AC motors

- Quad-copter motors (BLDC)
- 3-Phase AC Synchronous Motors (electric vehicles)

An H-bridge can convert DC to AC at 91% efficiency

- 91% of the energy is in the 1st harmonic

Two transistors and a transformer can produce higher efficiencies

This is some of what is covered in

- ECE 437: Power Electronics
- ECE 438: Electric Drives