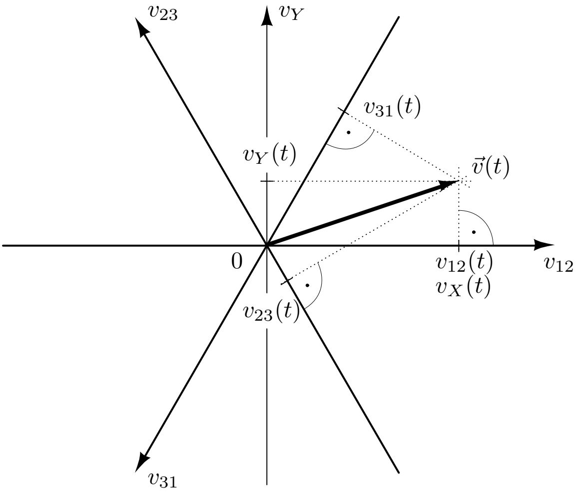
A Simple Circuit to Visualize Space Vectors by an Oscilloscope

Predrag Pejović

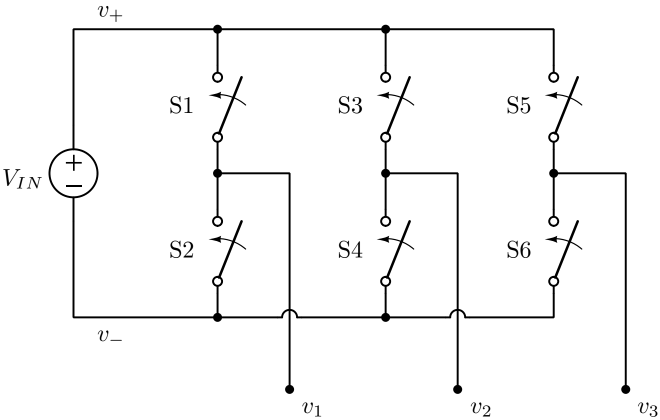
Introduction

- sometimes it is nice to visualize space vectors ...
- three phase voltage system ...
- the only requirement $v_{12} + v_{23} + v_{31} = 0$
- let us define $\vec{v} = (v_X,\, v_Y)$
- $v_{12} = \vec{v} \cdot (1,\, 0) = v_X$
- $v_{23} = \vec{v} \cdot \left(-\frac{1}{2},\, \frac{\sqrt{3}}{2}\right) = -\frac{1}{2}\, v_X + \frac{\sqrt{3}}{2}\, v_Y$
- $v_{31} = \vec{v} \cdot \left(-\frac{1}{2},\, -\frac{\sqrt{3}}{2}\right) = -\frac{1}{2}\, v_X - \frac{\sqrt{3}}{2}\, v_Y$
- these are line voltages from $(v_X,\, v_Y)$
- the transform is invertable

Space Vectors



Three-Phase Voltage Source Inverter

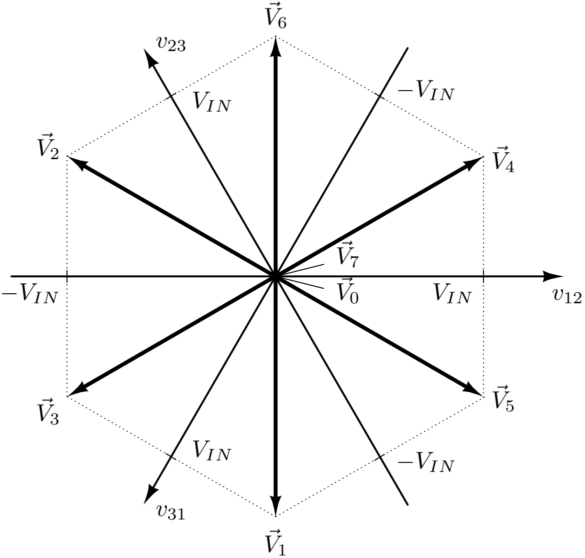


The Inverter, States and Line Voltages

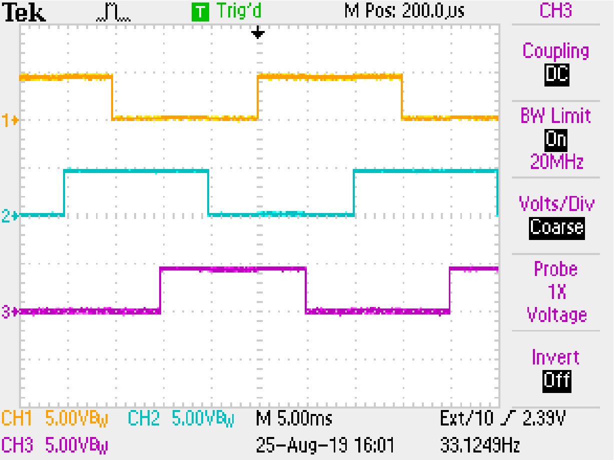
Three-Phase Voltage Source Inverter, Switch State Variations and Line Voltages

state	S1	S3	S5	v_{12}	v_{23}	v_{31}
0	0	0	0	0	0	0
1	0	0	1	0	$-V_{IN}$	V_{IN}
2	0	1	0	$-V_{IN}$	V_{IN}	0
3	0	1	1	$-V_{IN}$	0	V_{IN}
4	1	0	0	V_{IN}	0	$-V_{IN}$
5	1	0	1	V_{IN}	$-V_{IN}$	0
6	1	1	0	0	V_{IN}	$-V_{IN}$
7	1	1	1	0	0	0

The Inverter, Achievable Space Vectors

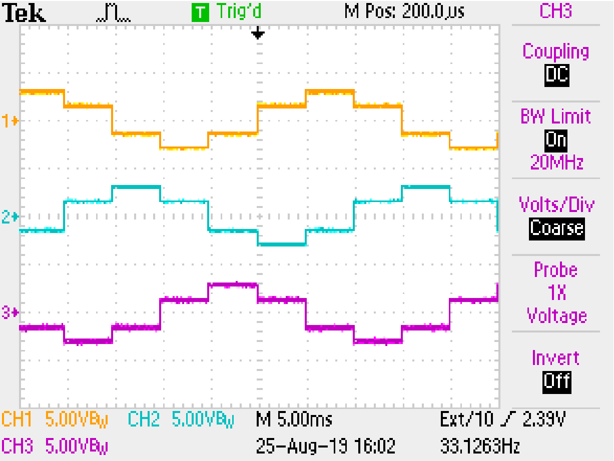


The Inverter, Phase Voltages Referred to v_-



Phase voltages v_1 (yellow), v_2 (cyan), and v_3 (magenta), referred to v_-.

The Inverter, Phase Voltages Referred to v_N

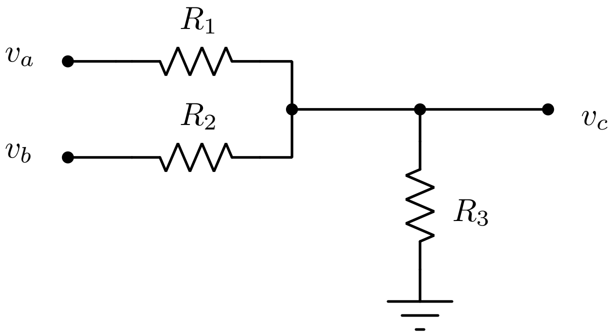


Phase voltages v_1 (yellow), v_2 (cyan), and v_3 (magenta), referred to the neutral point voltage v_N.

Some Math ...

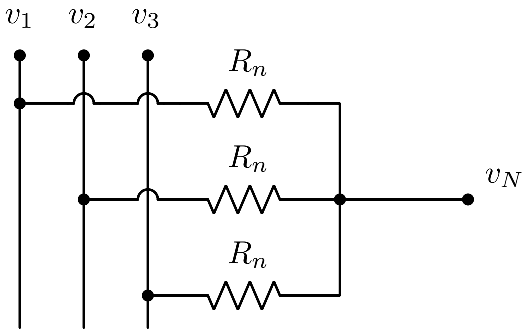
- $v_N = \frac{1}{3}\left(v_1 + v_2 + v_3\right)$
- lets refer v_1, v_2, and v_3 to v_N
- then $v_1 + v_2 + v_3 = 0$
- finally:
  1. $v_X = 2\,v_1 + v_3$
  2. $v_Y = \sqrt{3}\left(v_1 + v_2\right)$
- just scale with k small enough and voila!

Linear Combination of Voltages . . .



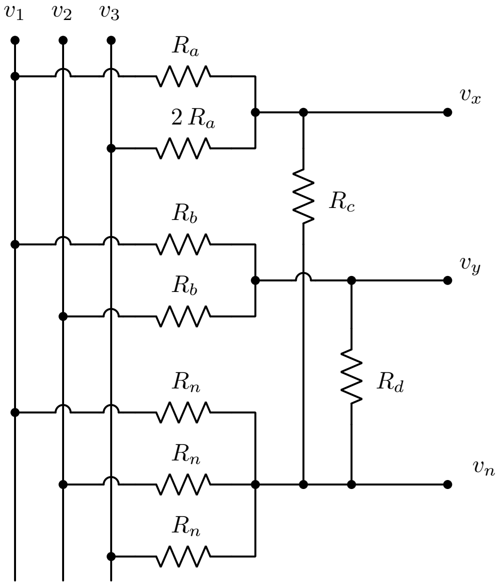
The circuit used to provide linear combination of two voltages.

Neutral Point ...



The circuit used to set the neutral point voltage.

Complete Circuit Diagram

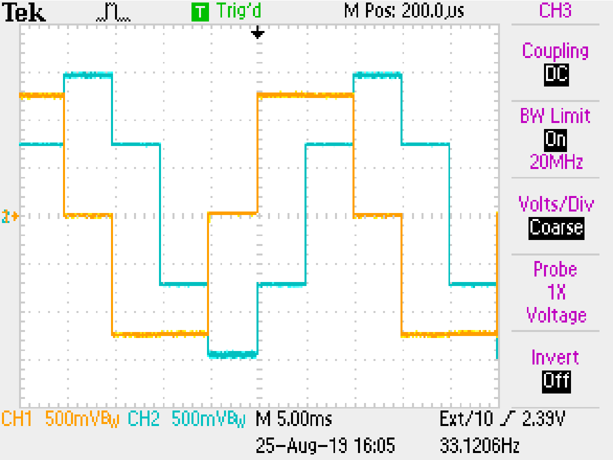


The circuit for analog computation of the space vector components.

Some Math in the Paper . . .

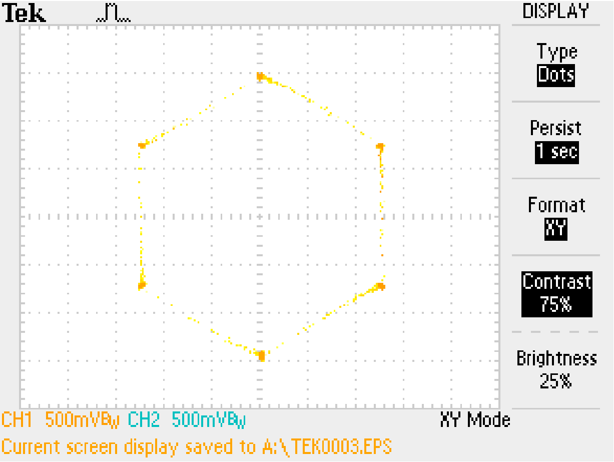
- resistors?
  1. choose R_a and R_b
  2. $R_c = \frac{2\,k}{1-3\,k}\,R_a$
  3. $R_d = \frac{\sqrt{3}\,k}{1-2\,\sqrt{3}\,k}\,R_b$
- the limit for $0 \leq k \leq \frac{1}{2\,\sqrt{3}} \approx 0.28868$
- choose R_n such that $R_a,\ R_b \gg \frac{1}{3\,\sqrt{3}\,k}\,R_n$
- maybe redo choice for R_a and R_b, increase to save power
- approximation!
- and some more math and a program to verify the design . . .
- . . . just read in the paper, can't fit here

Experimental Results: Arduino Board



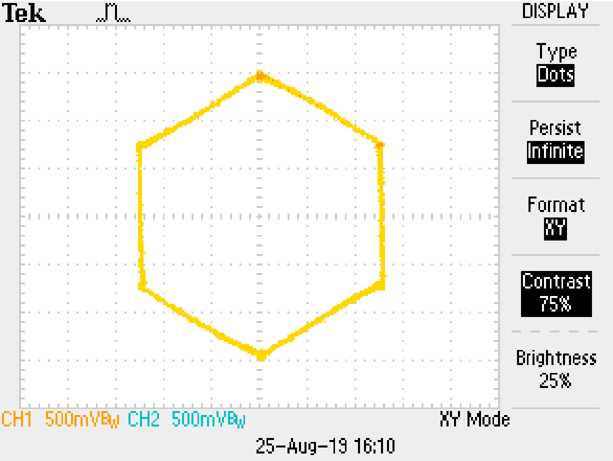
Space vector components $v_x(t)$ and $v_y(t)$.

Experimental Results



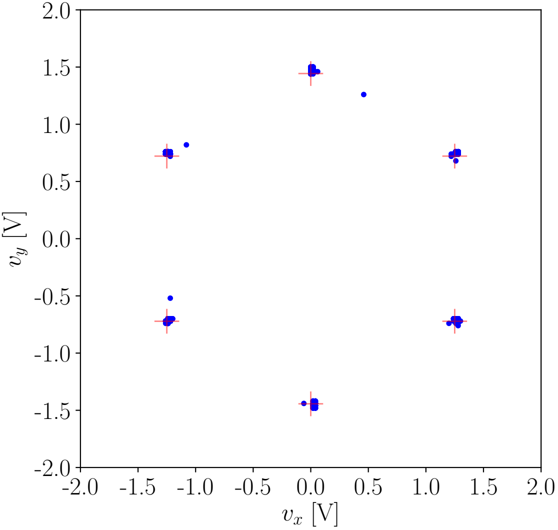
Space vector trajectory, persistence 1 s.

Experimental Results



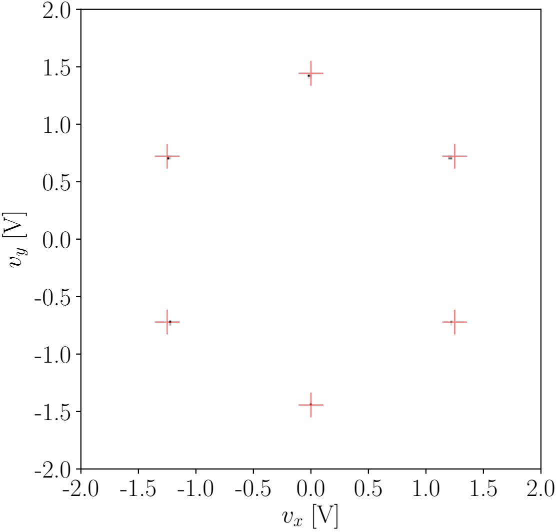
Space vector trajectory, infinite persistence.

Experimental Results



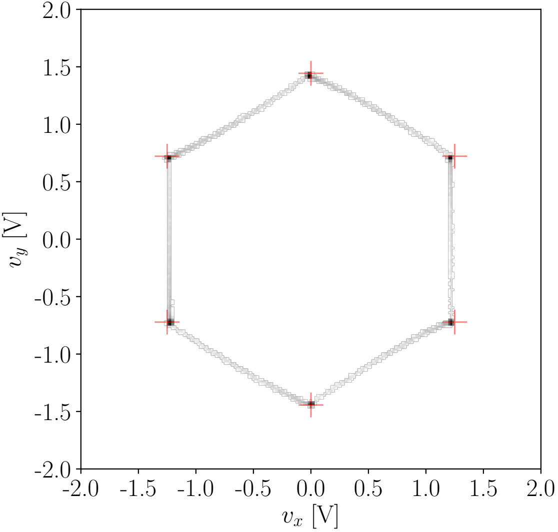
Recorded space vector positions, one screen, 2500 data points.

Experimental Results



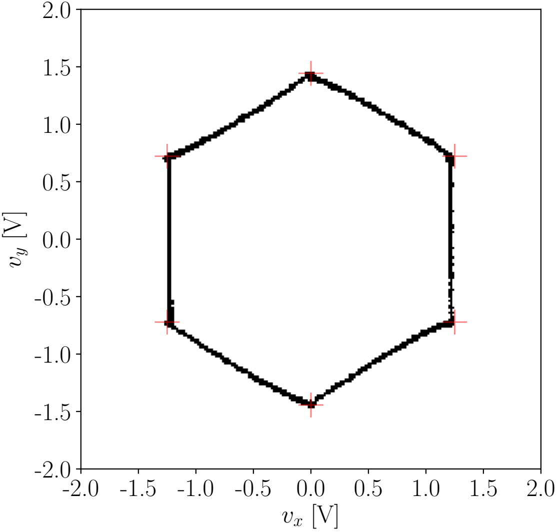
Observed space vectors, 25 million data points, intensity proportional to the number of space vector occurrences.

Experimental Results



Observed space vectors, 25 million data points, intensity proportional to the logarithm of the number of occurrences.

Experimental Results



Observed space vectors, 25 million data points, black dot corresponds to at least one occurrence of the space vector.

Conclusions

- a circuit to visualize space vectors
- analog computation, just nine resistors
- two voltage probes needed (differential!)
- after you get the data, how to present?
- transitions are short!
- collect lots of data, mimic persistence ...
    1. intensity proportional to the number of occurrences
    2. intensity proportional to the logarithm of the # of occurrences
    3. dot if a space vector appeared there
- choose the presentation mode according to your needs
- enjoy!