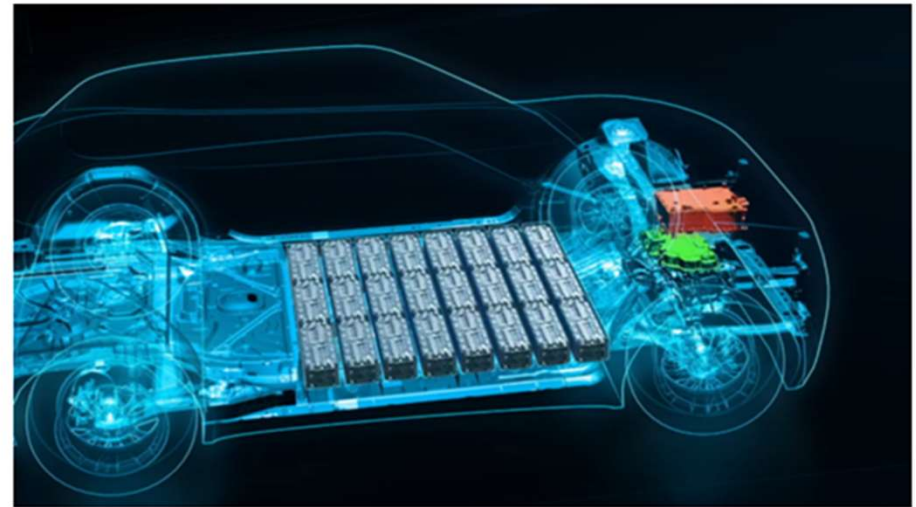
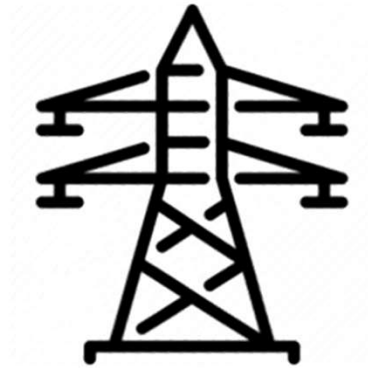


A Novel Philosophy for Designing Asymmetrical Multilevel Circuits to Improve Fidelity and Practicality

Jinshui Zhang¹, Stefan Goetz²

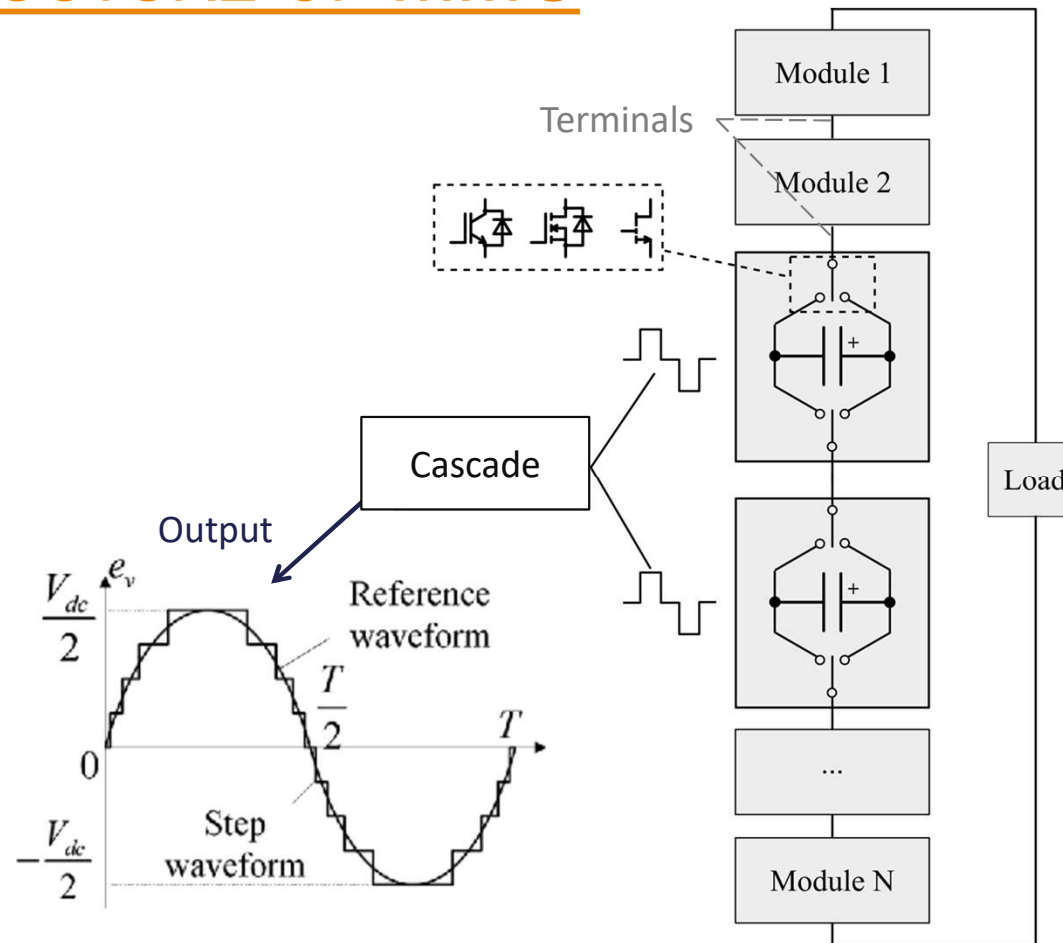
^{1,2} Duke University

MODULAR MULTILEVEL CONVERTER IS EVERYWHERE...



Credit to Stellantis

GENERAL STRUCTURE OF MMC



HOW MANY STATE?

V1

V2

V3

HOW MANY STATE?

V1

$\{+1, -1, 0\}$

V2

$\{+1, -1, 0\}$

V3

$\{+1, -1, 0\}$

HOW MANY STATE?

V1

$\{+1, -1, 0\}$

V2

$\{+1, -1, 0\}$

V3

$\{+1, -1, 0\}$

3

x

3

x

3

HOW MANY STATE?

V1

{+1, -1, 0}

V2

{+1, -1, 0}

V3

{+1, -1, 0}

3

x

3

x

3

27

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

1

$\{+1, -1, 0\}$

1

$\{+1, -1, 0\}$

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

1

$\{+1, -1, 0\}$

1

$\{+1, -1, 0\}$

$\{-3, -2, -1, 0, 1, 2, 3\}$

HOW MANY LEVELS?



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$

$\{-3, -2, -1, 0, 1, 2, 3\}$

7

HOW MANY LEVELS?



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$

$\{-3, -2, -1, 0, 1, 2, 3\}$

7

$[+1, 0, 0] \leftrightarrow [0, +1, 0] \leftrightarrow [0, 0, +1] \leftrightarrow [-1, +1, +1] \dots$

Lots of redundancy!

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

2

$\{+1, -1, 0\}$

4

$\{+1, -1, 0\}$

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

2

$\{+1, -1, 0\}$

4

$\{+1, -1, 0\}$

$\{-7, -6, \dots, -2, -1, 0, 1, 2, \dots, 6, 7\}$

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

2

$\{+1, -1, 0\}$

4

$\{+1, -1, 0\}$

$\{-7, -6, \dots, -2, -1, 0, 1, 2, \dots, 6, 7\}$

15

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

2

$\{+1, -1, 0\}$

4

$\{+1, -1, 0\}$

$\{-7, -6, \dots, -2, -1, 0, 1, 2, \dots, 6, 7\}$

15

$[+1, 0, 0] \leftrightarrow [-1, +1, 0] \leftrightarrow [-1, -1, +1]$

Still some redundancy, but less!

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

3

$\{+1, -1, 0\}$

9

$\{+1, -1, 0\}$

HOW MANY LEVELS?

1

$\{+1, -1, 0\}$

3

$\{+1, -1, 0\}$

9

$\{+1, -1, 0\}$

$\{-13, \dots, -2, -1, 0, 1, 2, \dots, 12, 13\}$

HOW MANY LEVELS?



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$



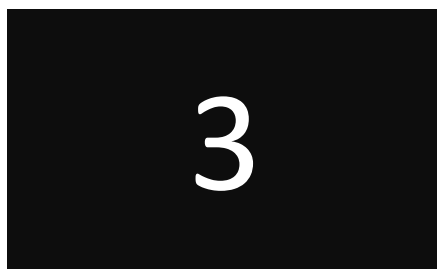
$\{+1, -1, 0\}$

$\{-13, \dots, -2, -1, 0, 1, 2, \dots, 12, 13\}$
27

HOW MANY LEVELS?



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$



$\{+1, -1, 0\}$

$\{-13, \dots, -2, -1, 0, 1, 2, \dots, 12, 13\}$
27

No redundancy, one state is one unique output level!

Any others?

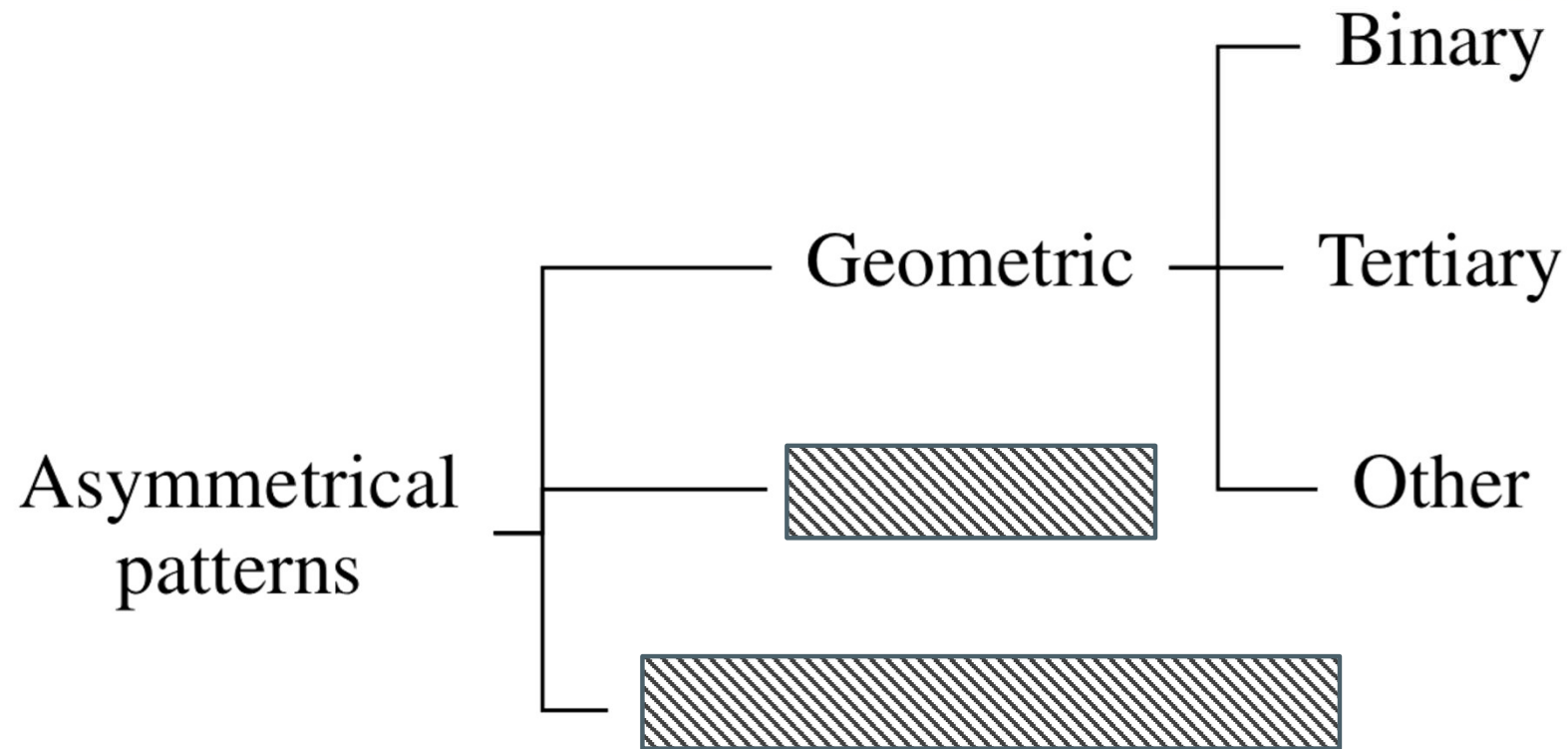
Any others?

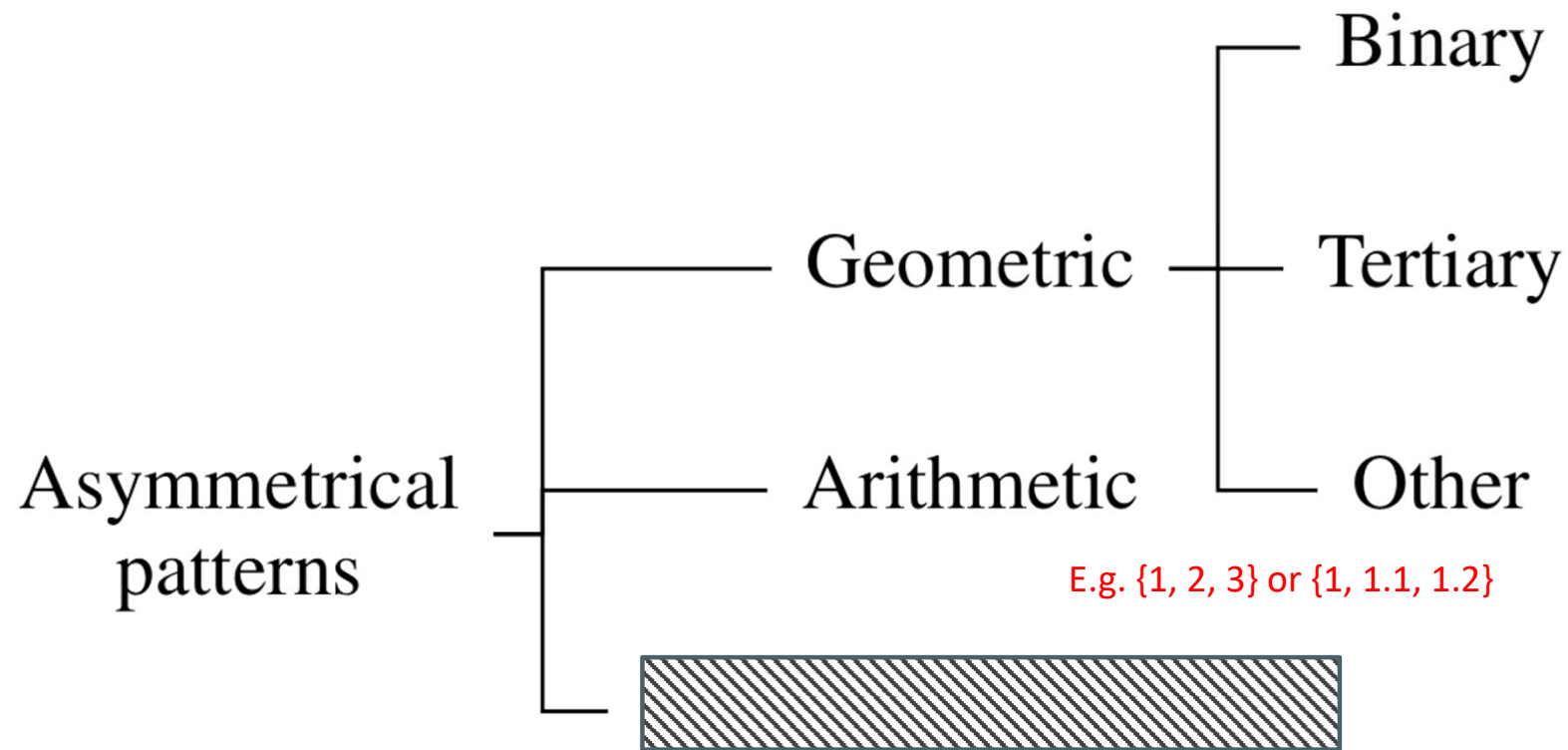
1, 4, 16, ...? Works, but not as well.

Any others?

1, 4, 16, ...? Works, but not as well.

Are there any other numbers other than 1, 2, 3?

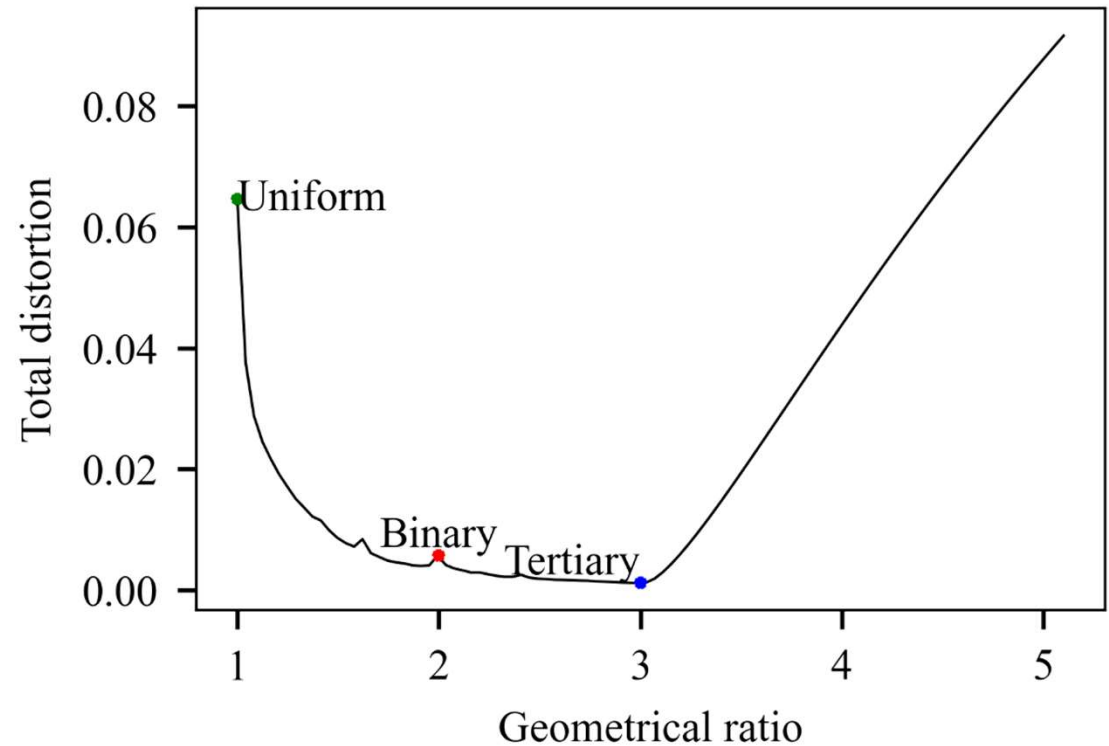




RESULTS WITH SINUSOIDAL SIGNALS

Trial info

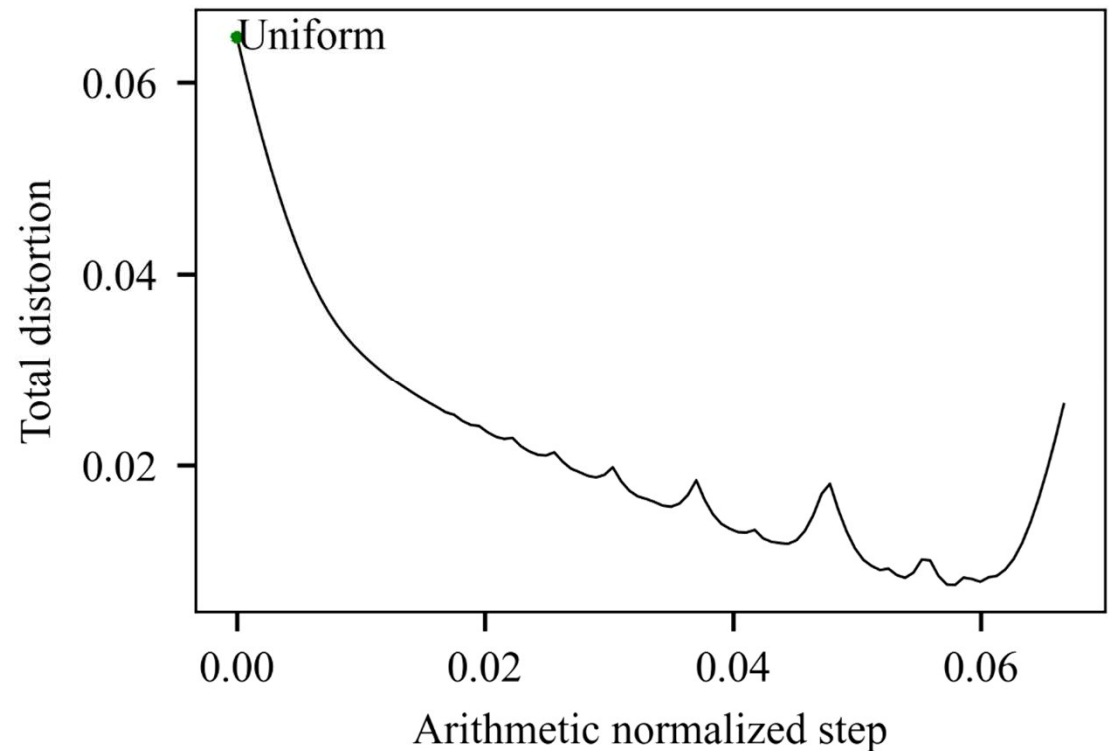
- Reference signal: full amplitude sinusoidal
- Variable: geometrical ratio of module voltages
- Modulation method: nearest level modulation
- Output estimator: total distortion



RESULTS WITH SINUSOIDAL SIGNALS

Trial info

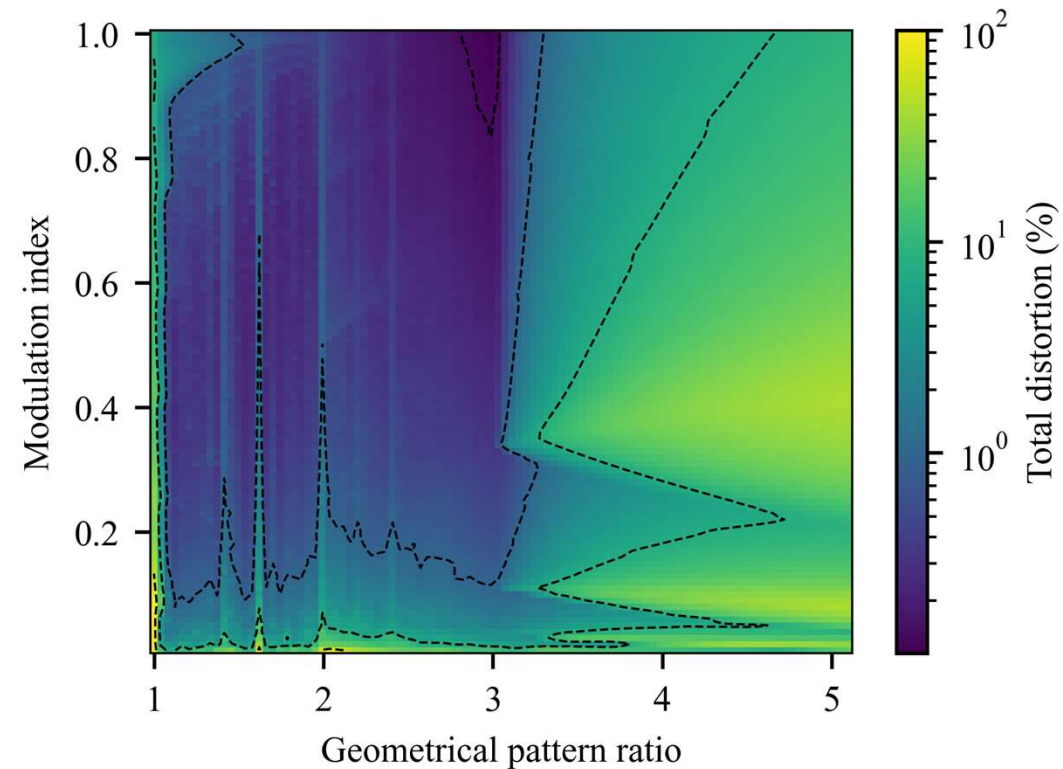
- Reference signal: full amplitude sinusoidal
- Variable: arithmetic step * of module voltages
- Modulation method: nearest level modulation
- Output estimator: total distortion



RESULTS WITH SINUSOIDAL SIGNALS

Trial info

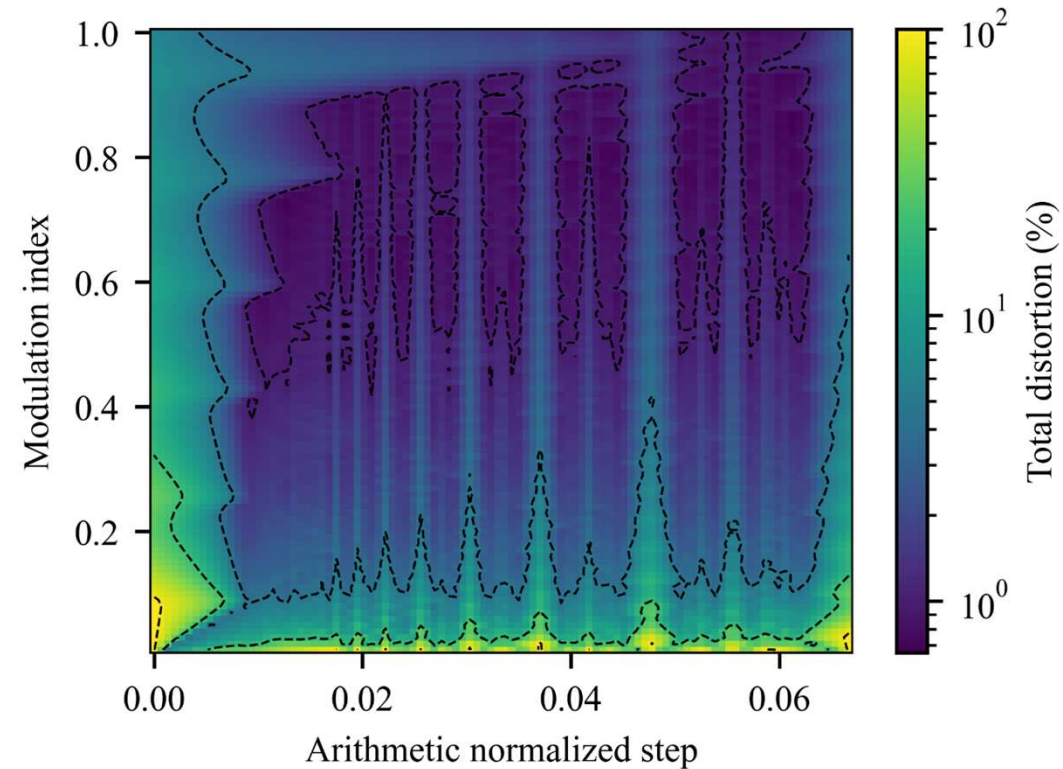
- Reference signal: sinusoidal signal
- Variable:
 - Amplitude of reference signal
 - Geometrical ratio of module voltages
- Modulation method: nearest level modulation
- Output estimator: total distortion



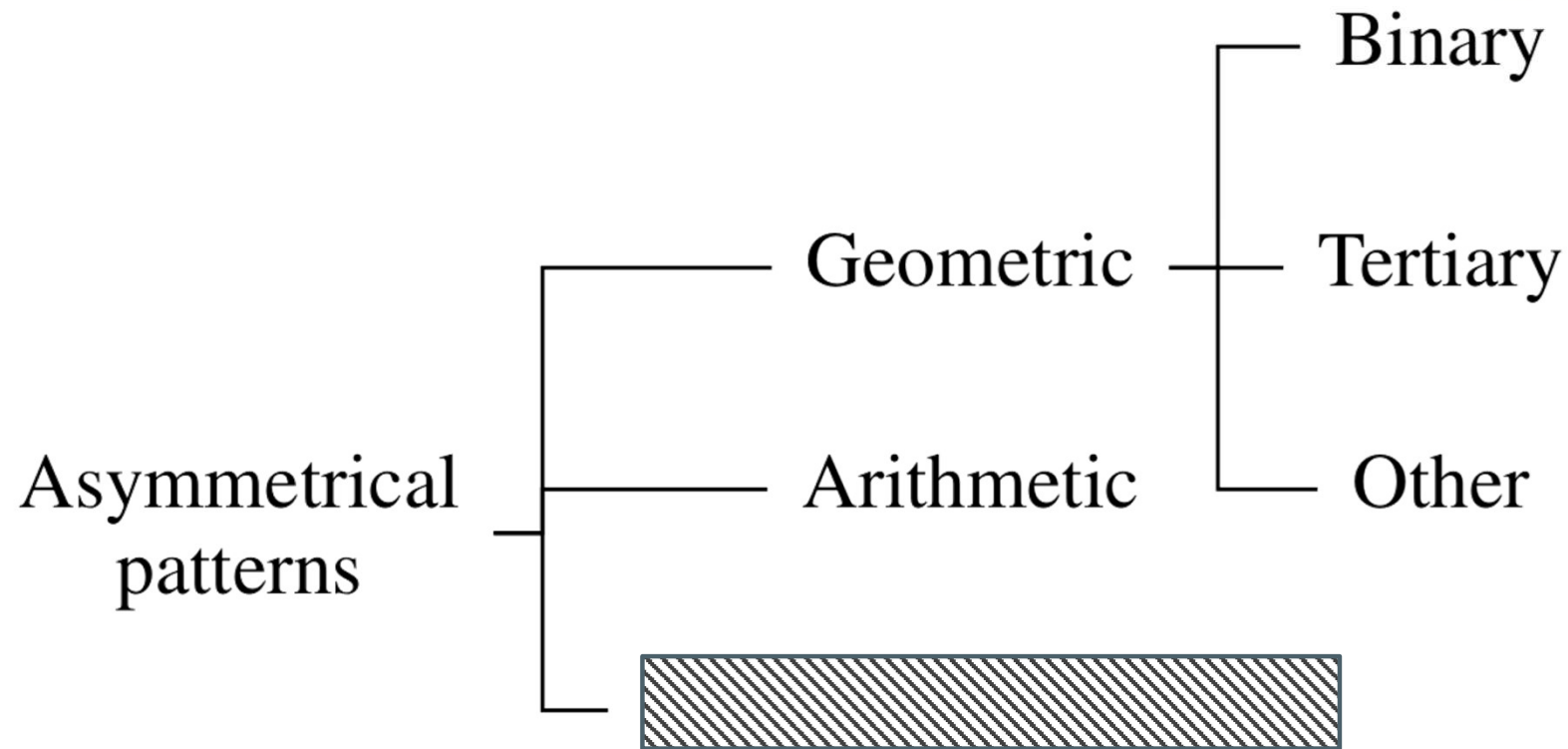
RESULTS WITH SINUSOIDAL SIGNALS

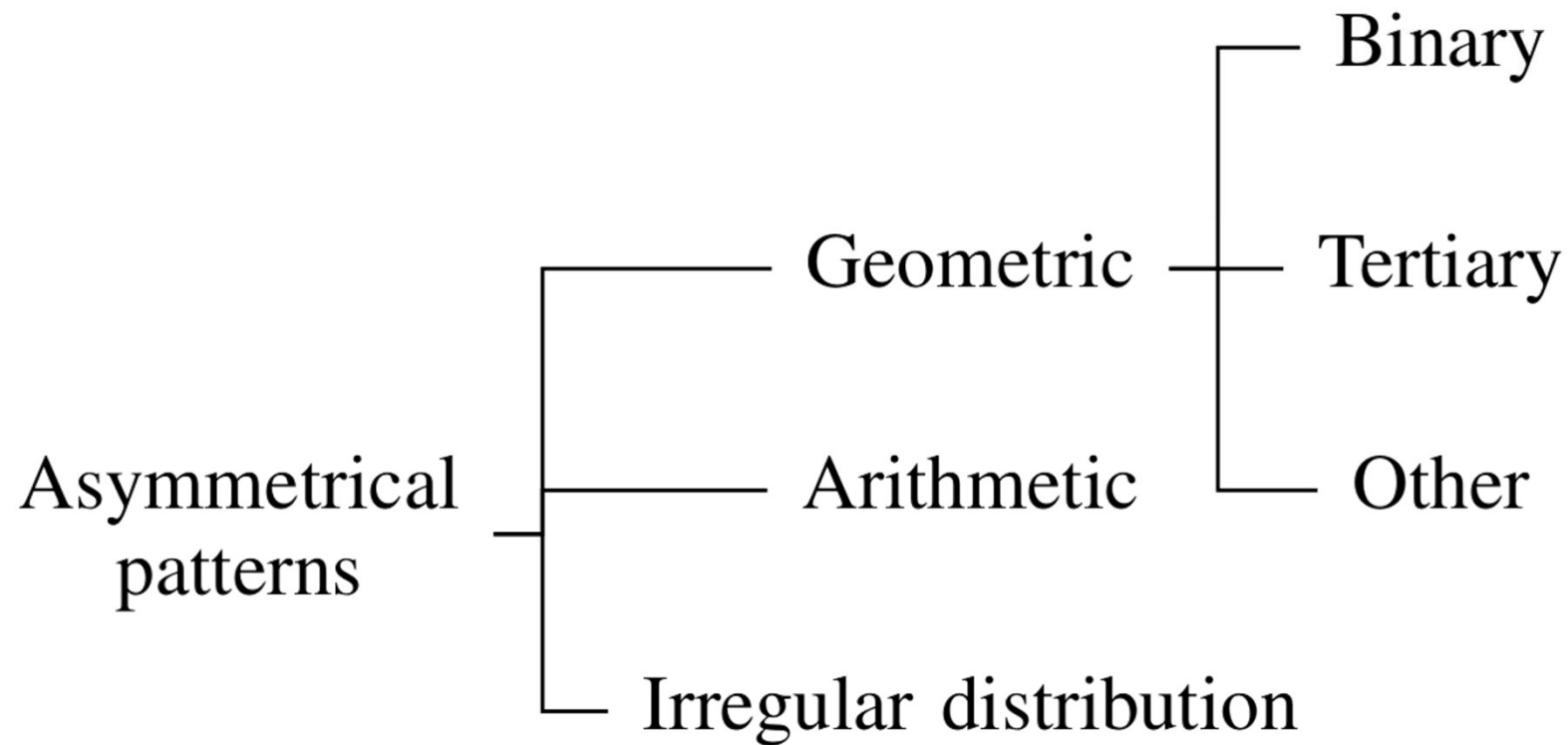
Trial info

- Reference signal: sinusoidal signal
- Variable:
 - Amplitude of reference signal
 - arithmetic step * of module voltages
- Modulation method: nearest level modulation
- Output estimator: total distortion

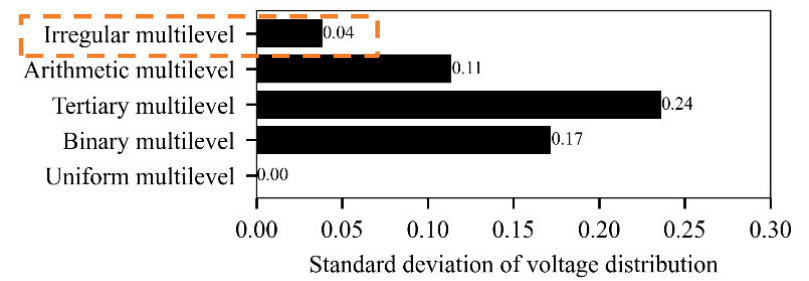
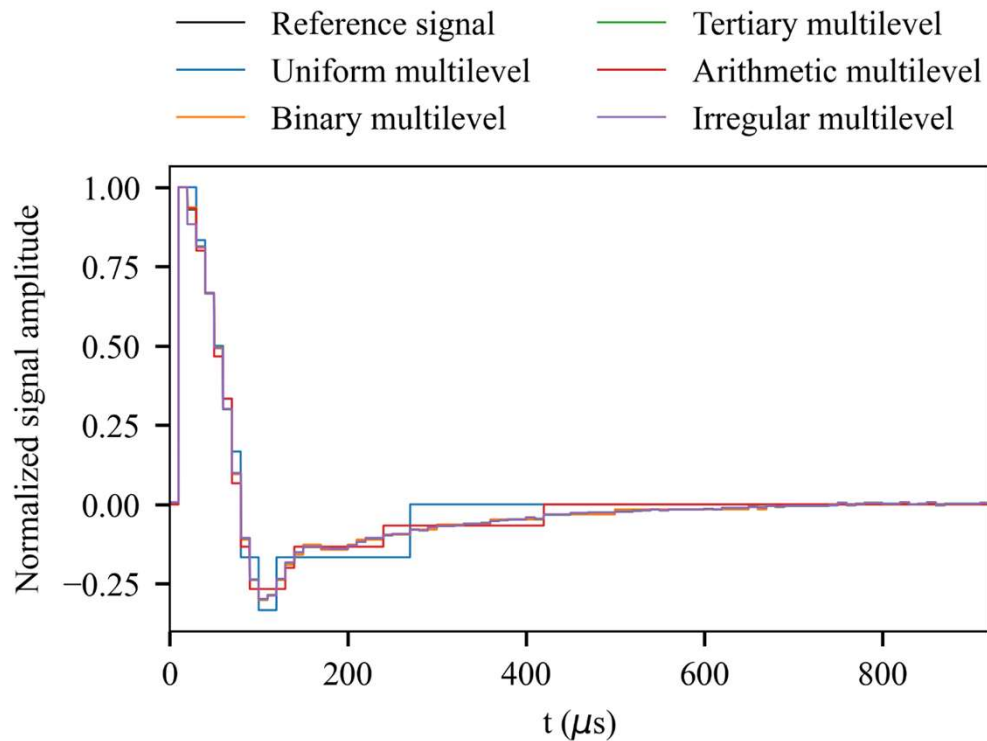


Any others?

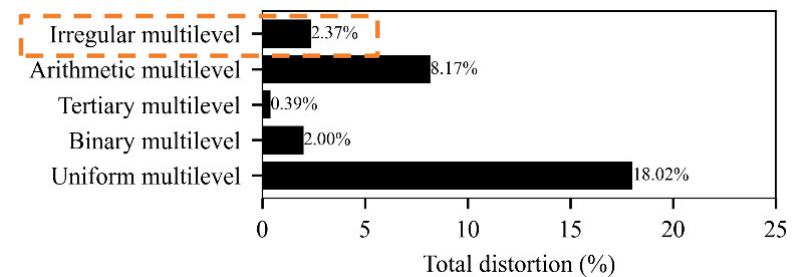
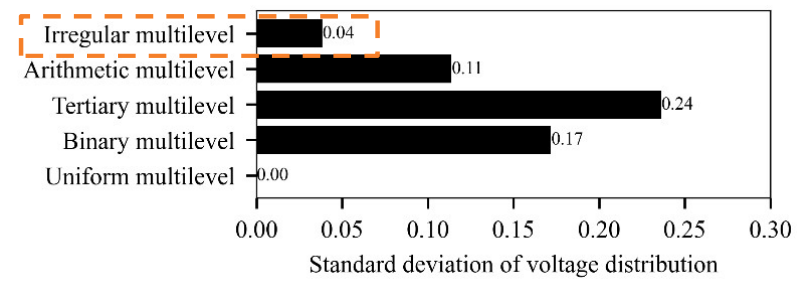
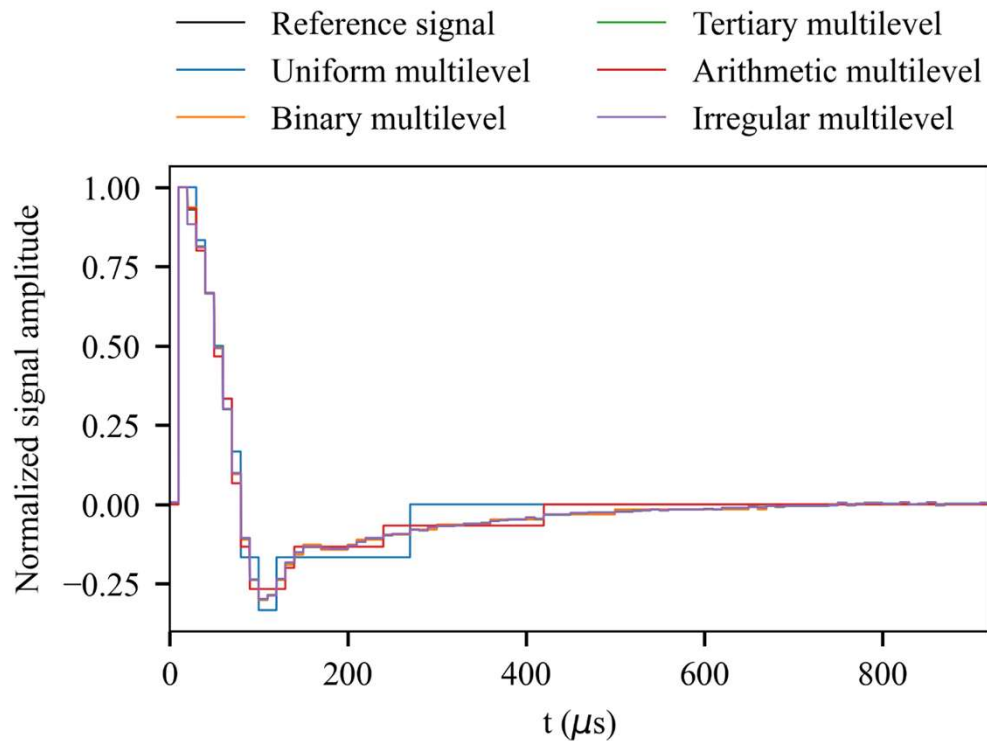




EXAMPLE IN MEDICAL APPLICATION

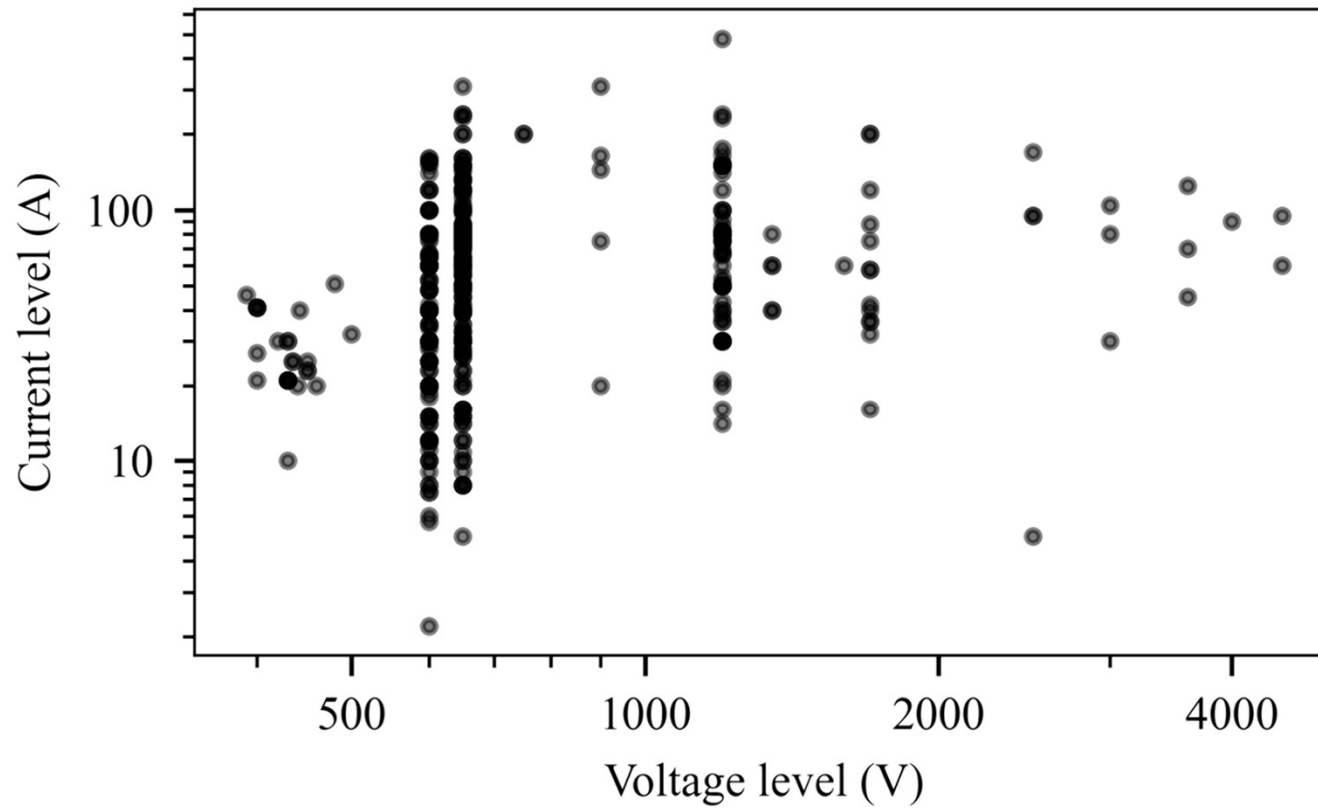


EXAMPLE IN MEDICAL APPLICATION



Why do we need this,
since binary and tertiary configurations are
already good?

TRANSISTOR PRODUCTS MARKET



CONCLUSION

- Asymmetry is a key to higher quality of MMC
- There is no single optimal asymmetrical pattern
- Whatever works for you is what's best for you

Thank you!