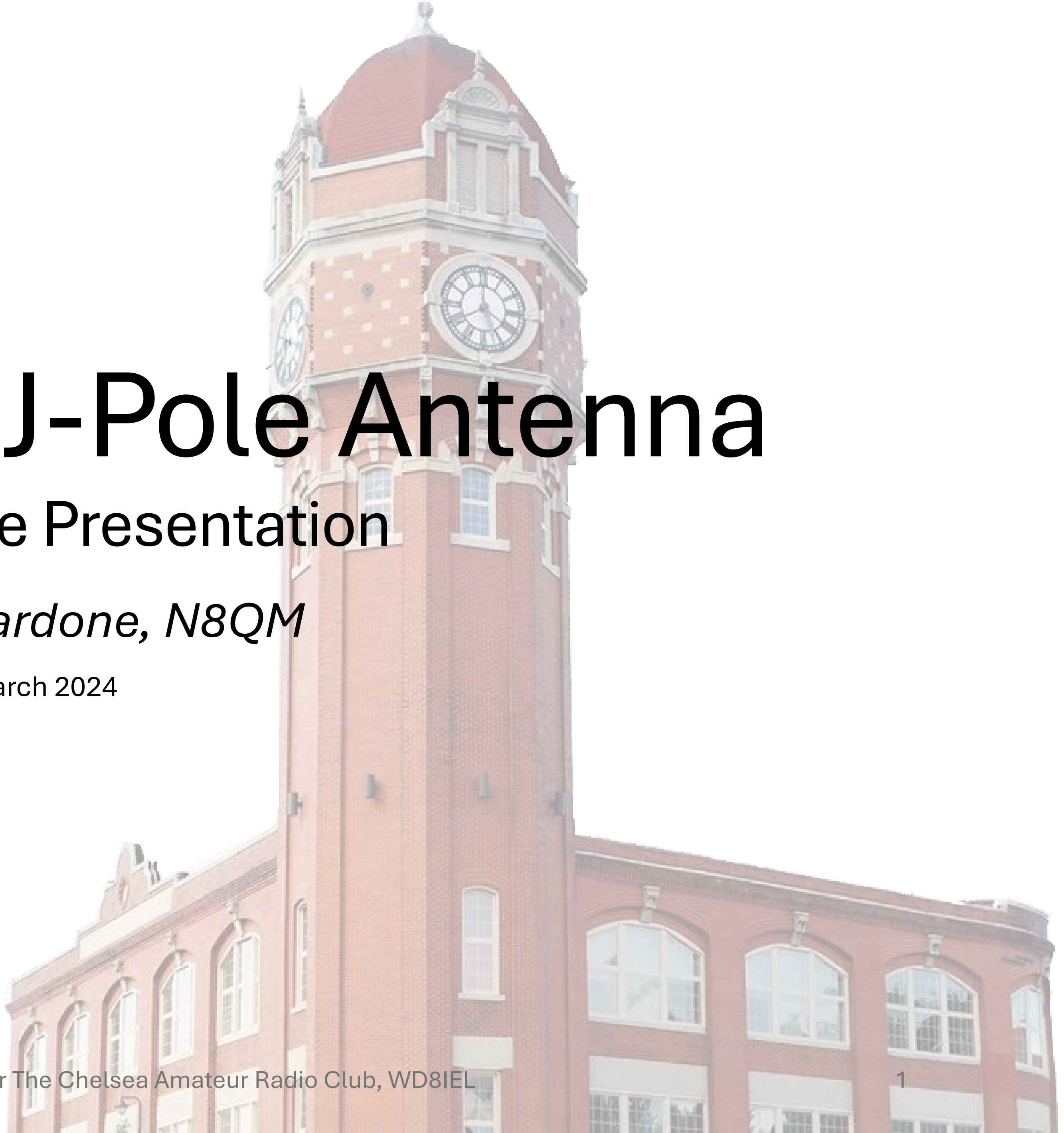


Modeling the J-Pole Antenna

A Deep Dive Presentation

Wesley Cardone, N8QM

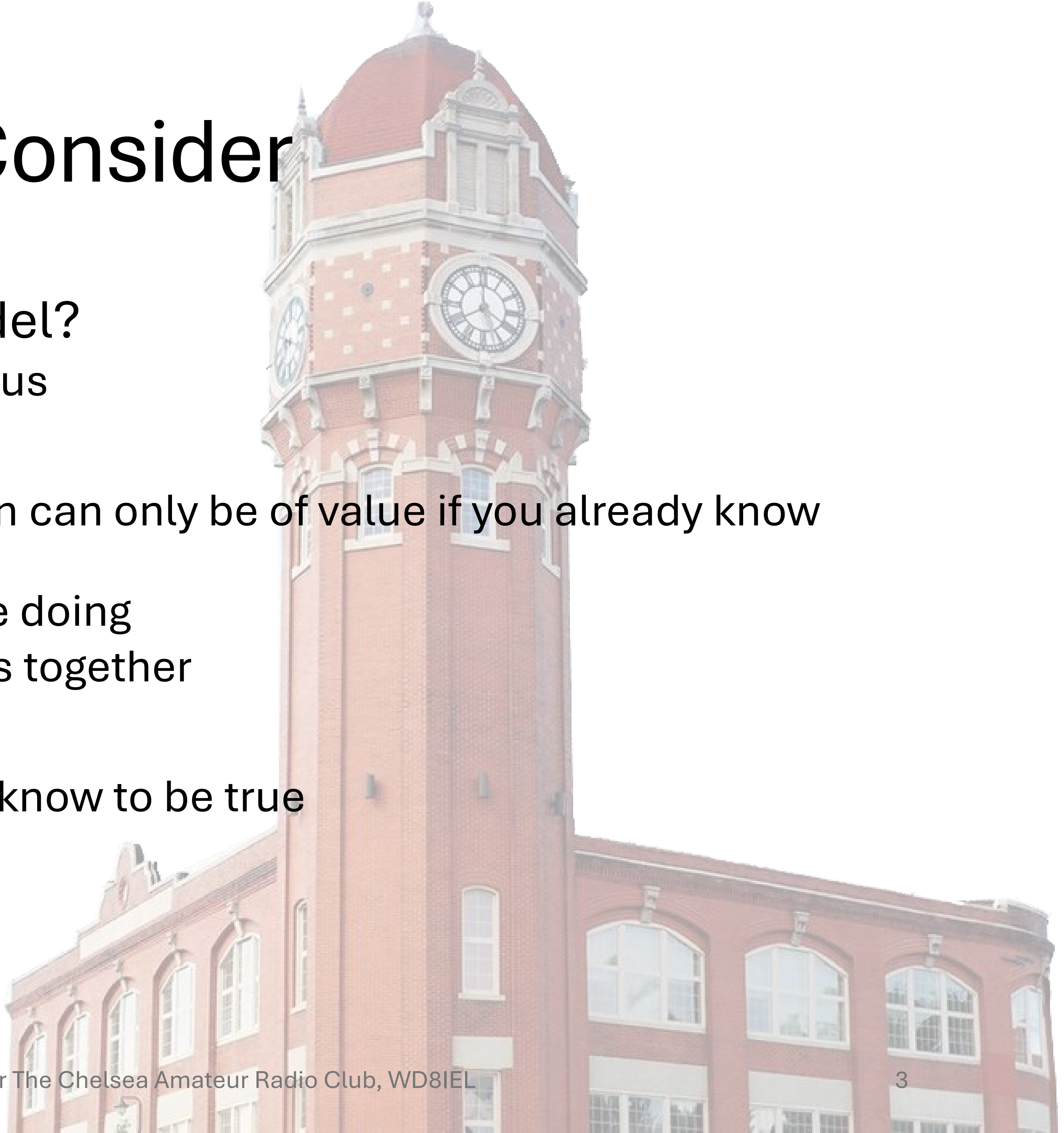
March 2024

Proposed:

- A J-Pole antenna will be modeled for computer simulation using the NEC antenna simulation engine developed by the Lawrence-Livermore Laboratory in the 1970s.
- We will be using the
  - EZNEC and
    - This application is particularly useful for presentations and beginners of antenna modeling.
  - 4NEC2 implementations of the NEC engine.
    - This application is more useful for the skilled NEC user owing to its symbology facilitation.
- Recommend that the viewer have reviewed the earlier “qualitative” presentation.
  - The basics of modeling the J-Pole for simulation.
- This will be a deep-dive into the actual modeling.
  - An Excel spreadsheet will be presented.
  - “Deep Dive” is not intended to mean “for rocket scientists only.”
  - Nothing beyond what is expected of amateur extra class licensees will be presented.

Questions You Must Consider

- What is a computer antenna model?
  - An architecture of wires with stimulus
- What knowledge to you need?
  - Success in modeling and simulation can only be of value if you already know most of the answers.
  - You understand what the pieces are doing
  - Might not understand their workings together
- Why Model Antennas?
  - Apply changes to what you already know to be true
- What are must-haves
  - Objectives
  - What answers are sought?

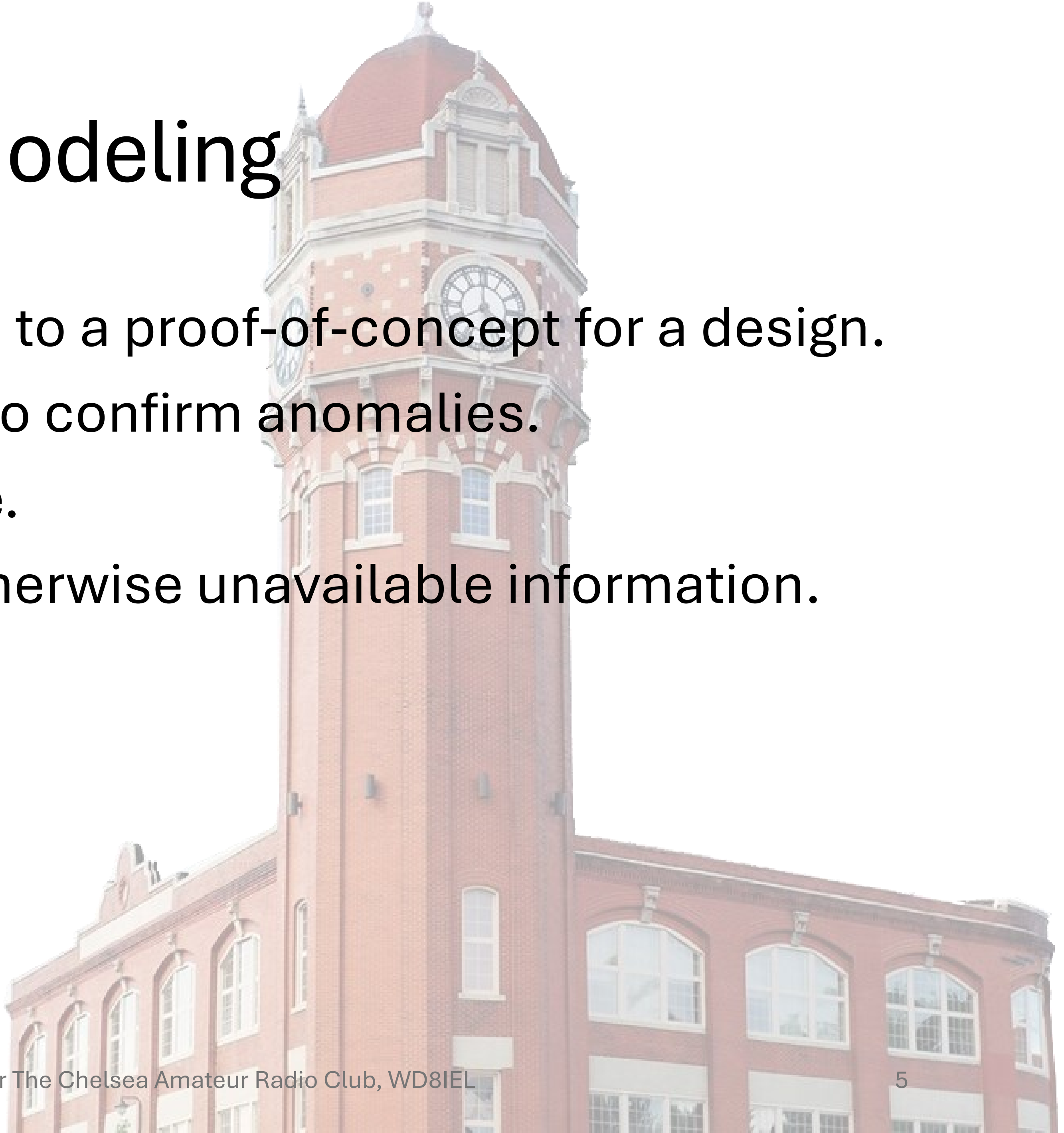


Why Model the J-Pole Antenna?

- The workings of the J-Pole are fully understood.
- Value-Add
  - Little operational value can be gained by simulating a J-Pole antenna.
- Ideal subject matter for learning NEC modeling
  - We know what the J-Pole is supposed to be doing
  - Does our model reflect that?
    - If yes---you are learning.
    - If no—what have you missed.

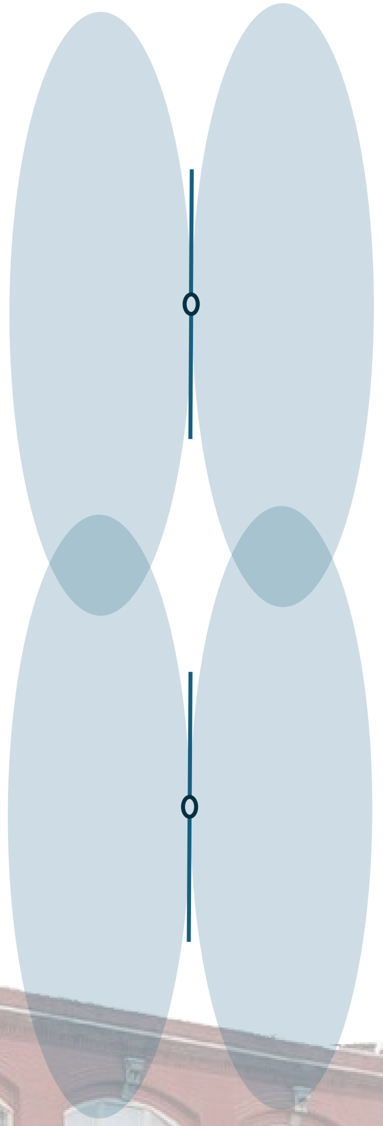
Benefits of Antenna Modeling

- Can serve as a second witness to a proof-of-concept for a design.
- Can model without parasitics to confirm anomalies.
- Useful in idea or concept value.
- Can provide information for otherwise unavailable information.



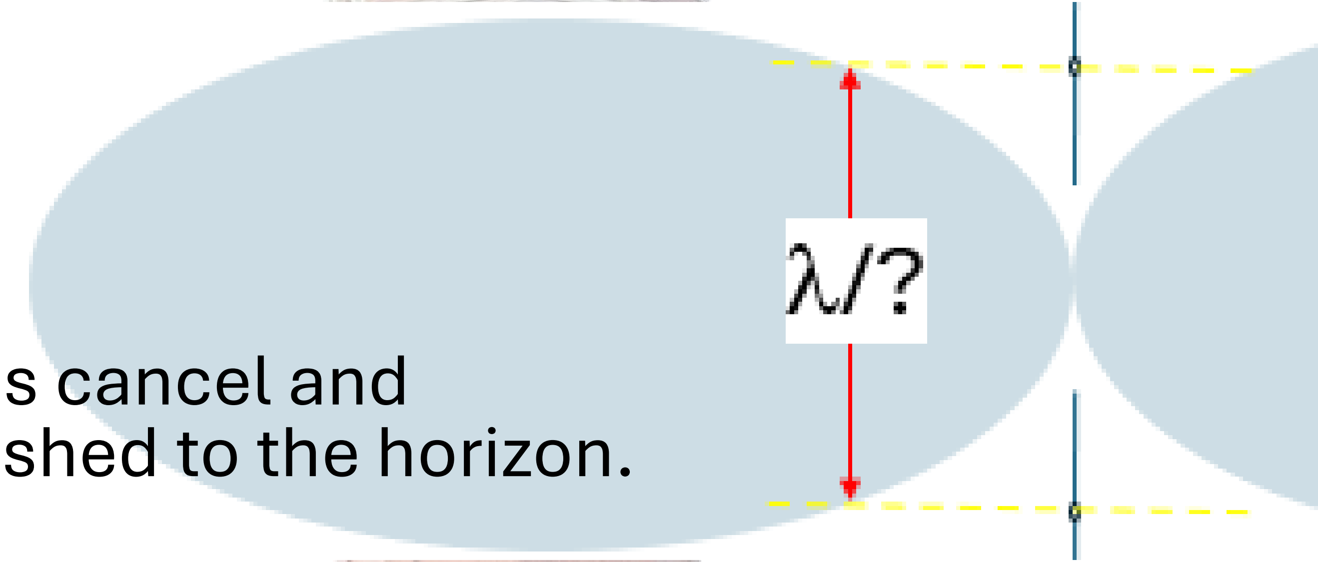
Example of Usefulness

- Devise a scheme whereby a pair of center-fed dipoles, stacked vertically, generate an omnidirectional flattened pattern.
- The doughnut pattern is to be squashed so as to send less energy to the moon and more to the horizon.
- What distance needs to exist between the centers of the antennas?



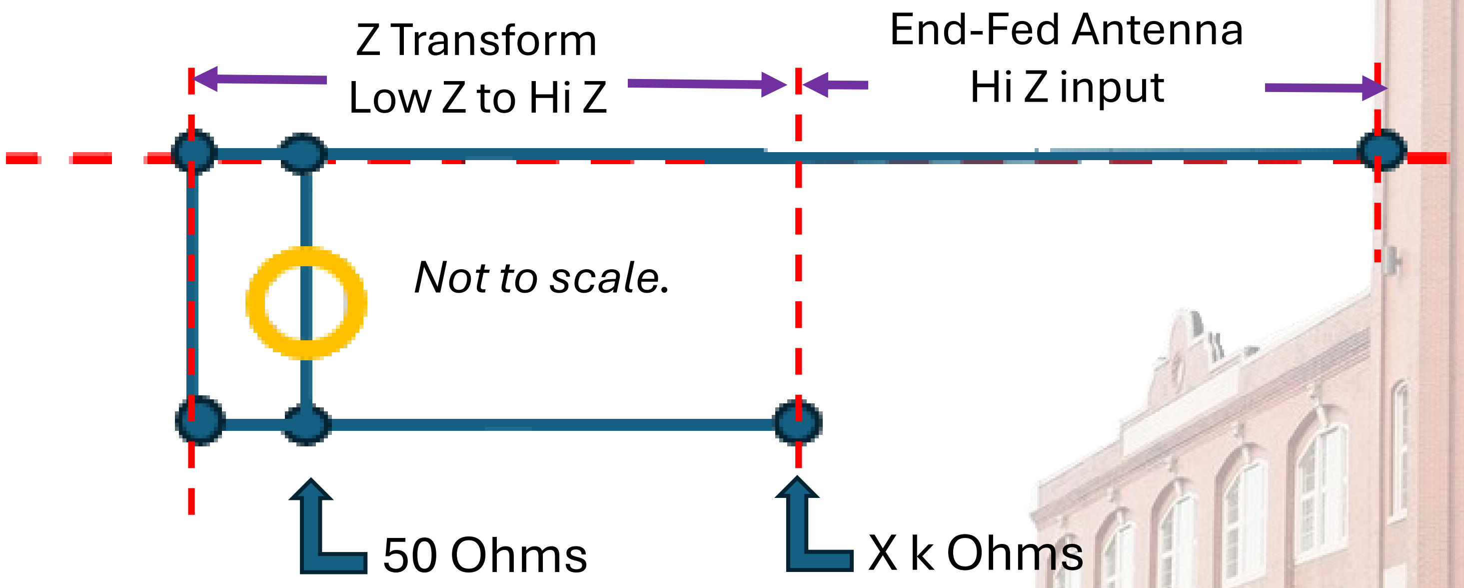
Example of Usefulness

- There exists a
  - Phase difference and
  - Feed-point separation distance
- Such that the doughnut patterns cancel and add that the net pattern is squashed to the horizon.
- Questions
  - What phase difference and
  - What feed-point distance
  - Is required for a squashed pattern?
- Without a witness we cannot be certain that the simulation answer is correct but it is useful information nevertheless.

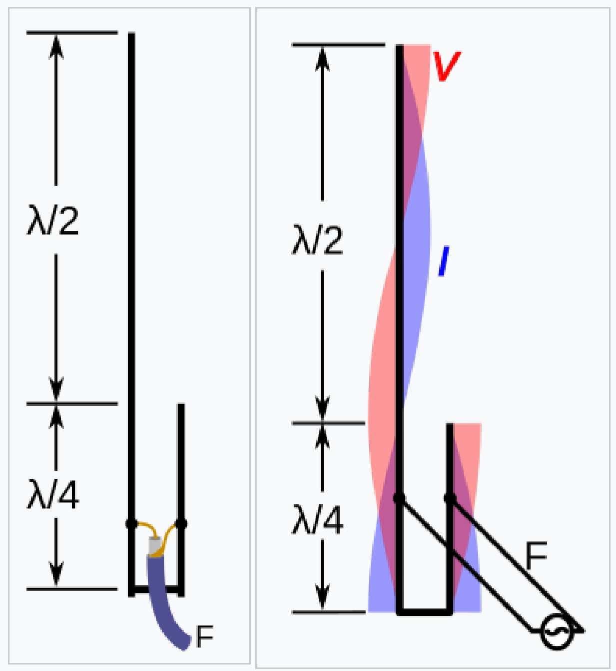


The J-Pole Components

- The actual antenna
- A Z-transformer
  - Unfold revealing center-fed dipole
  - Z at the center is 50 Ohms
  - Z at the ends is several thousand—High Z



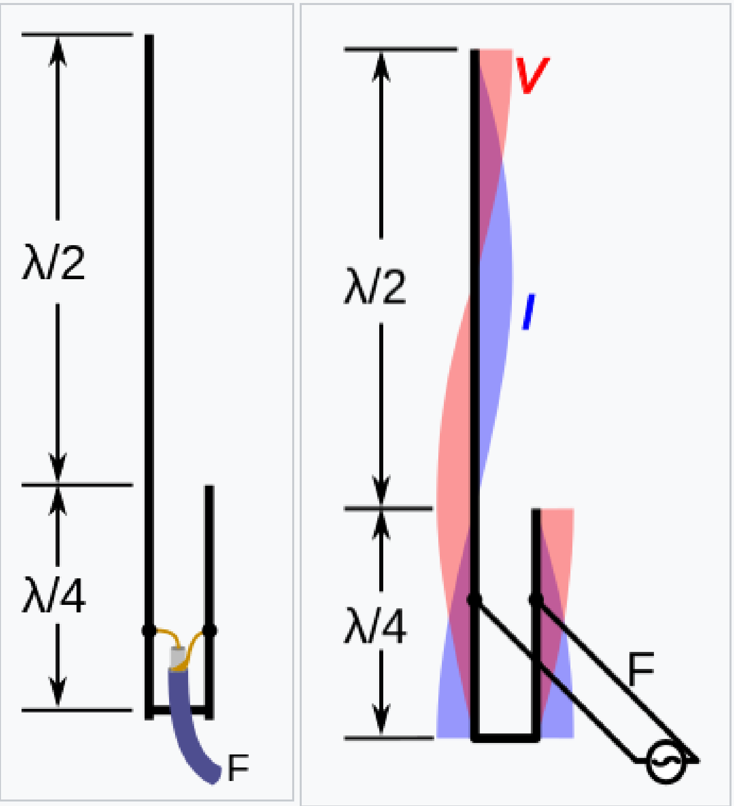
J-pole antenna - Wikipedia



J-pole antenna fed by coaxial cable *(left)* and parallel line *(right)*. The right diagram shows the standing waves of voltage (***V***, *red bands*) and current (***I***, *blue bands*) on the elements.

J-Pole Impedance Transformations

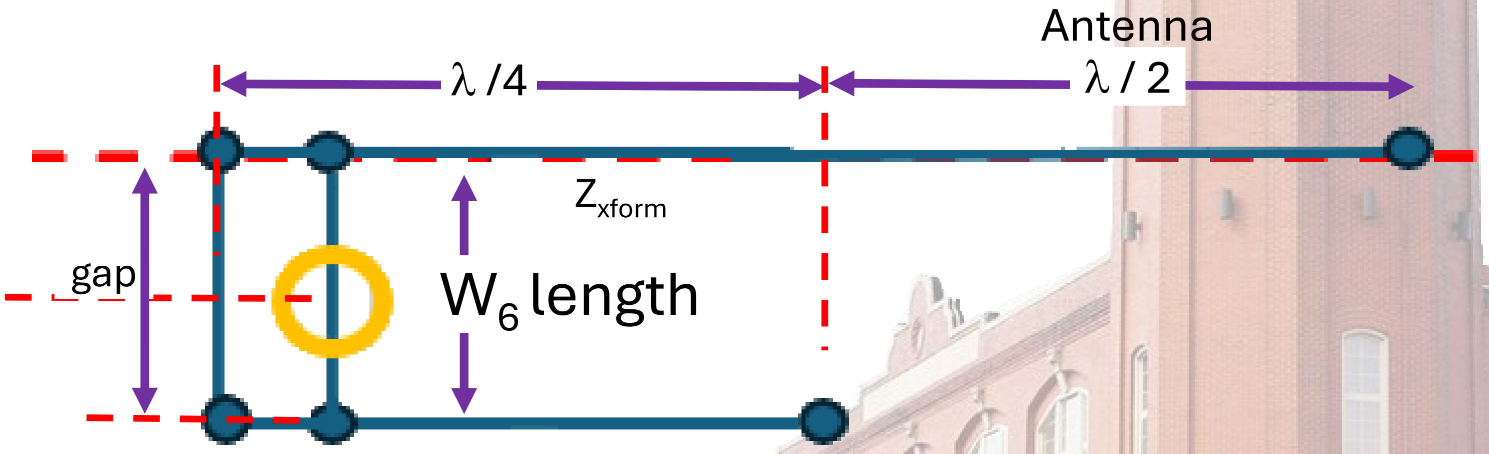
- The actual antenna is $\lambda/2$
  - Is end-fed
  - Therefore, is a high-Z input (typically 3 to 10 kΩ
- Z_{xform}
  - low-Z input
  - High-Z output
- End-Fed antennas have a Hi-Z input Z.

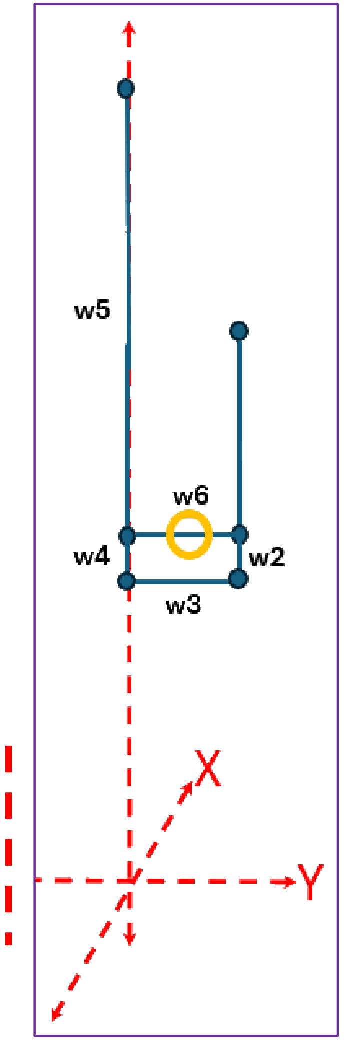


J-pole antenna fed by coaxial cable *(left)* and parallel line *(right)*. The right diagram shows the standing waves of voltage (***V***, *red bands*) and current (***I***, *blue bands*) on the elements.

J-Pole Component Lengths

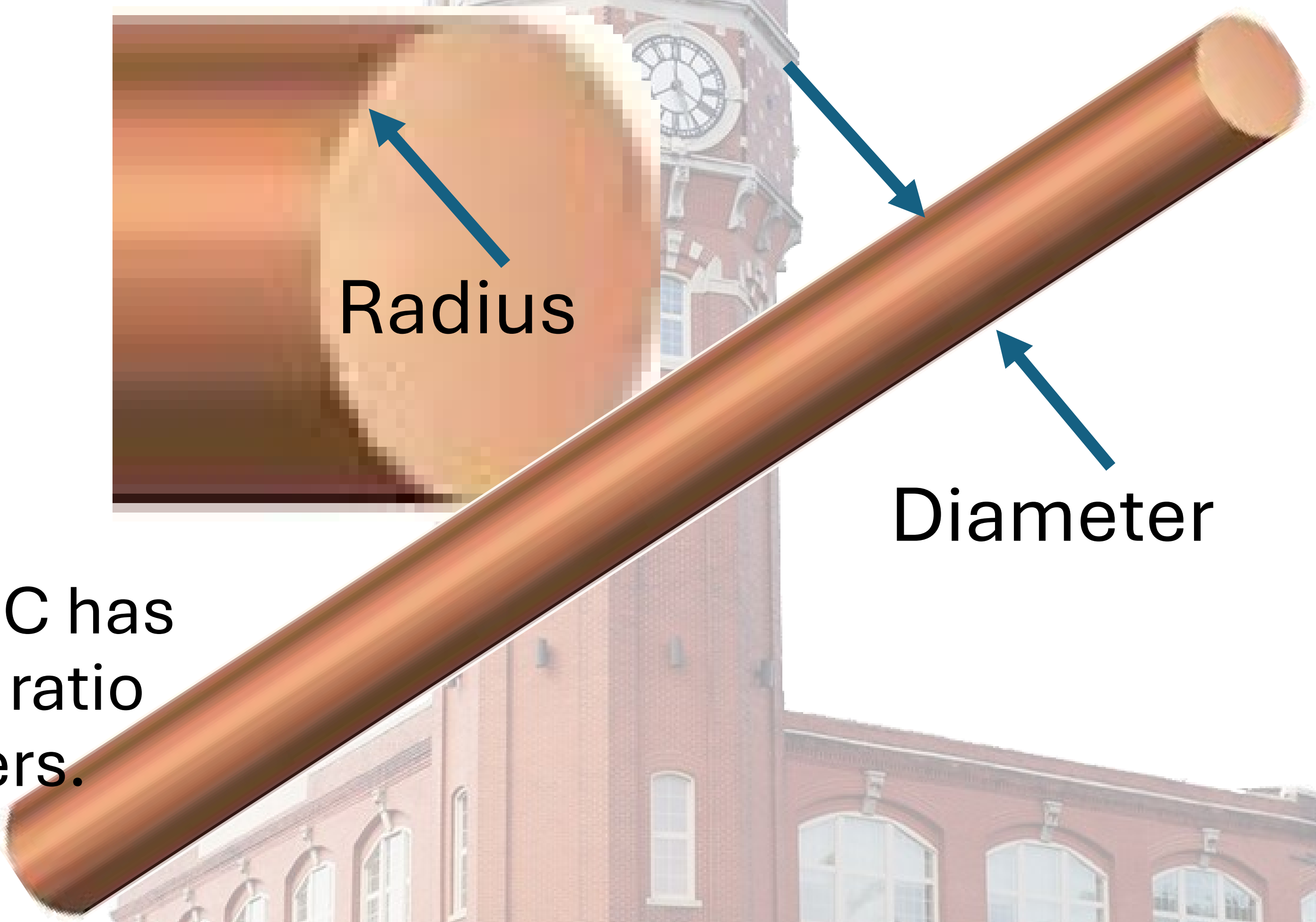
- The actual antenna is λ/2
- Z_{xform} length
  - Is λ/4
  - Unfold and xformer becomes a half-wave dipole, center fed.





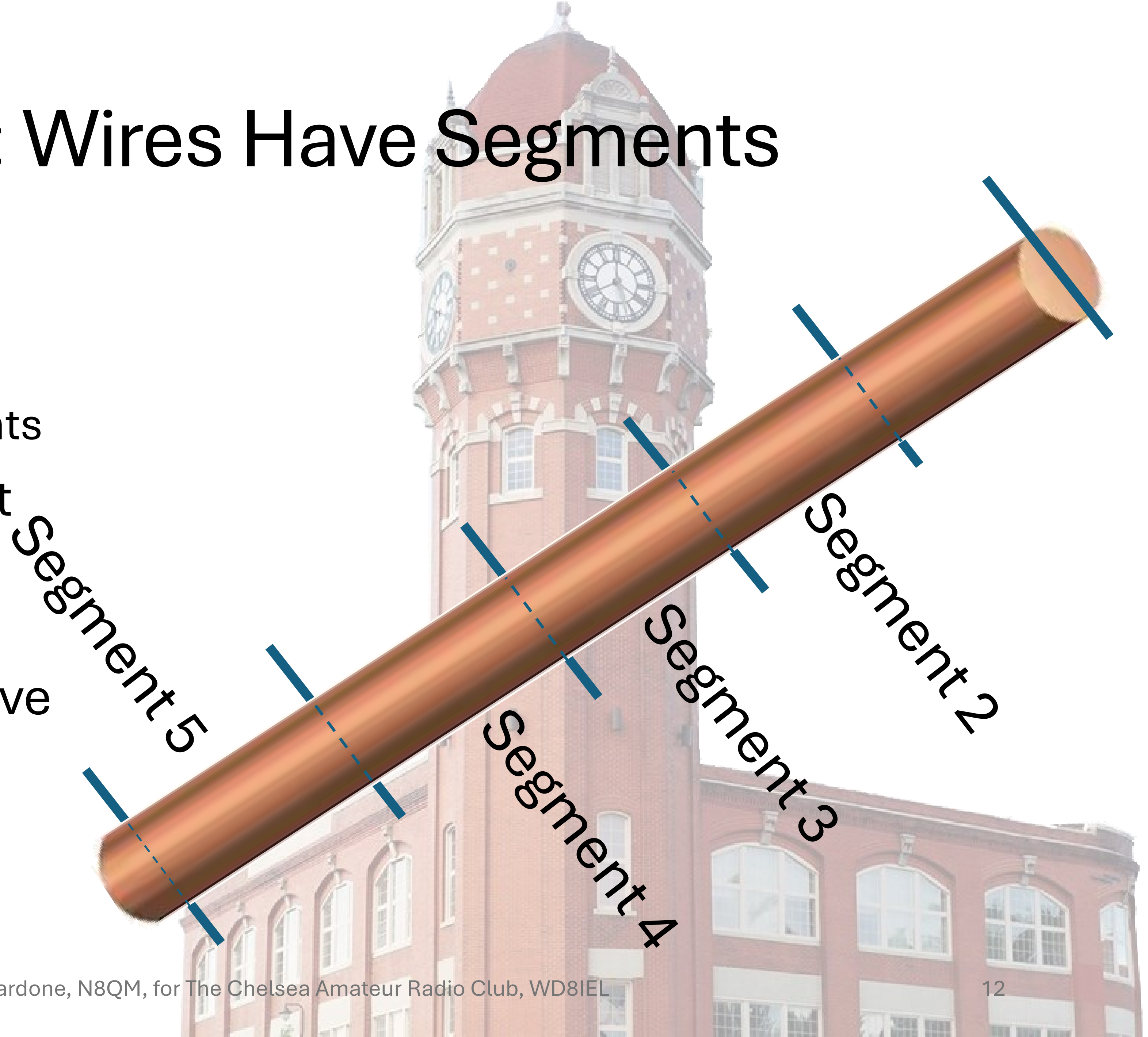
Antenna is Defined as a Set of Wires

- Wires define the antenna
- These have specifications
  - Diameter
  - Composition (molecular structure)
  - Length
- The numerical engine of NEC has requirements regarding the ratio of lengths and wire diameters.



Critical Concept: Wires Have Segments

- An antenna wire
  - may have any length.
  - Is composed of segments
- The length of a segment
  - Has a minimum
  - Has a maximum
- A very long wire may have many segments.
- Each segment has a min/max limitation.

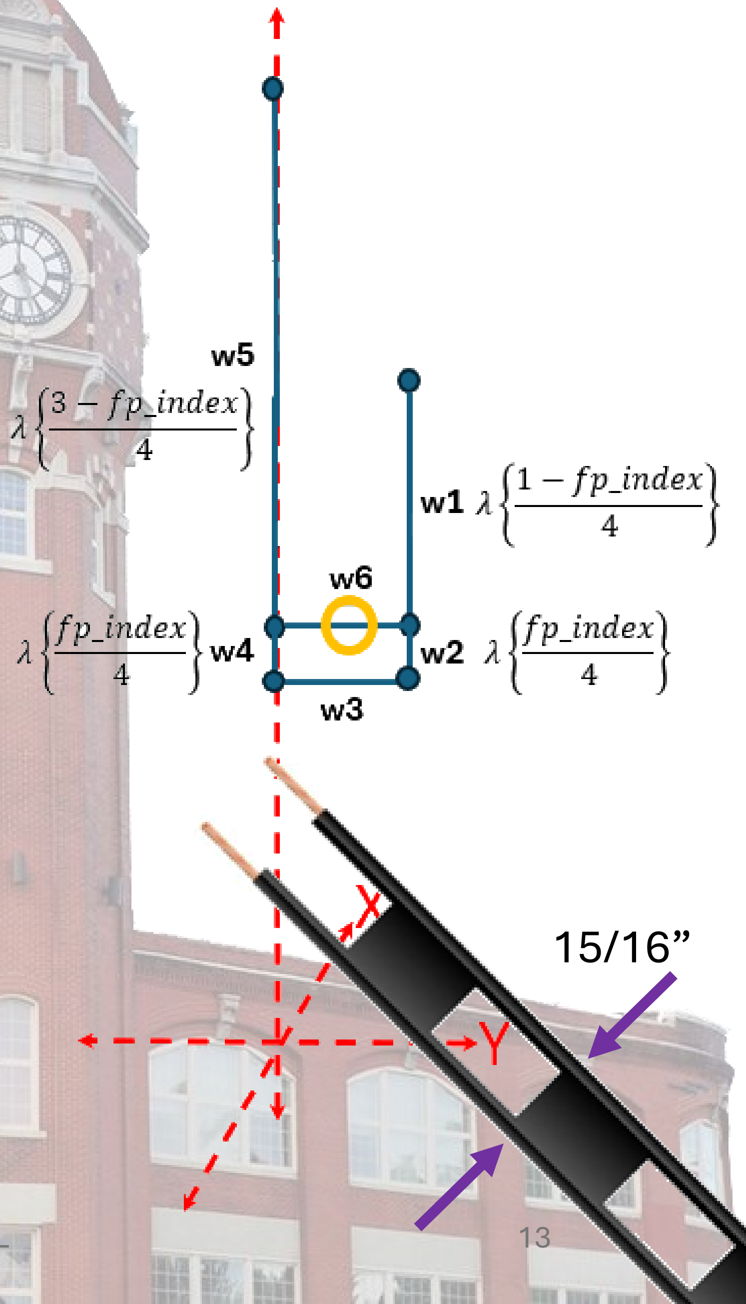


Define the Antenna Specifications

- Resonant frequency: 146 MHz
- Velocity factor: 1.0

  Note: For purposes of the NEC modeling software, we will ignore velocity factor. But that is only for now and for simplification purposes because of the nature of the NEC software.
- J-Pole Composition: Ladder Line
- Use AWG #12 Wire
  - Diameter = 0.002052 meters
- Wire lengths shown at right ➔
- Will solve for the segments per wire in f[illegible]g slides.

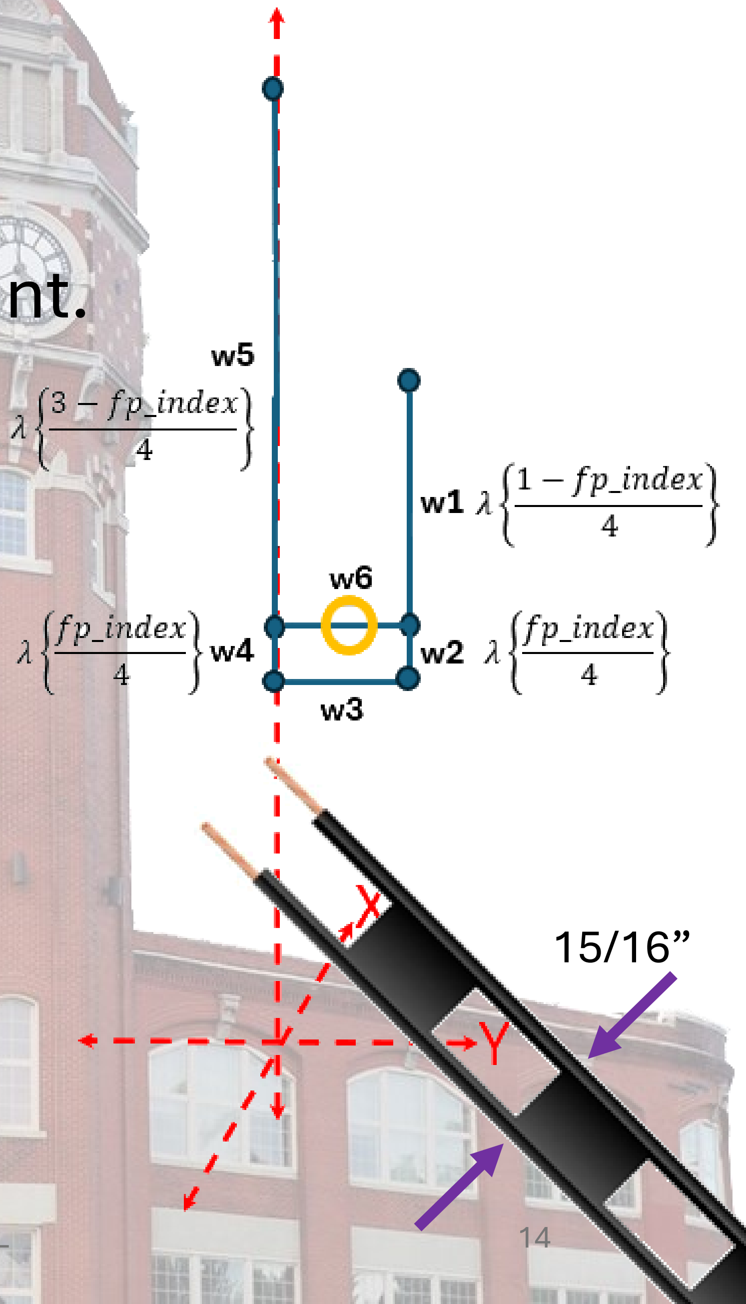
w#	End-to-End Needed (m)
w1	0.475769838
w2	0.025667163
w3	0.0238125
w4	0.025667163
w5	1.514362588
w6	0.0238125



Purpose of *fp_index* Variable

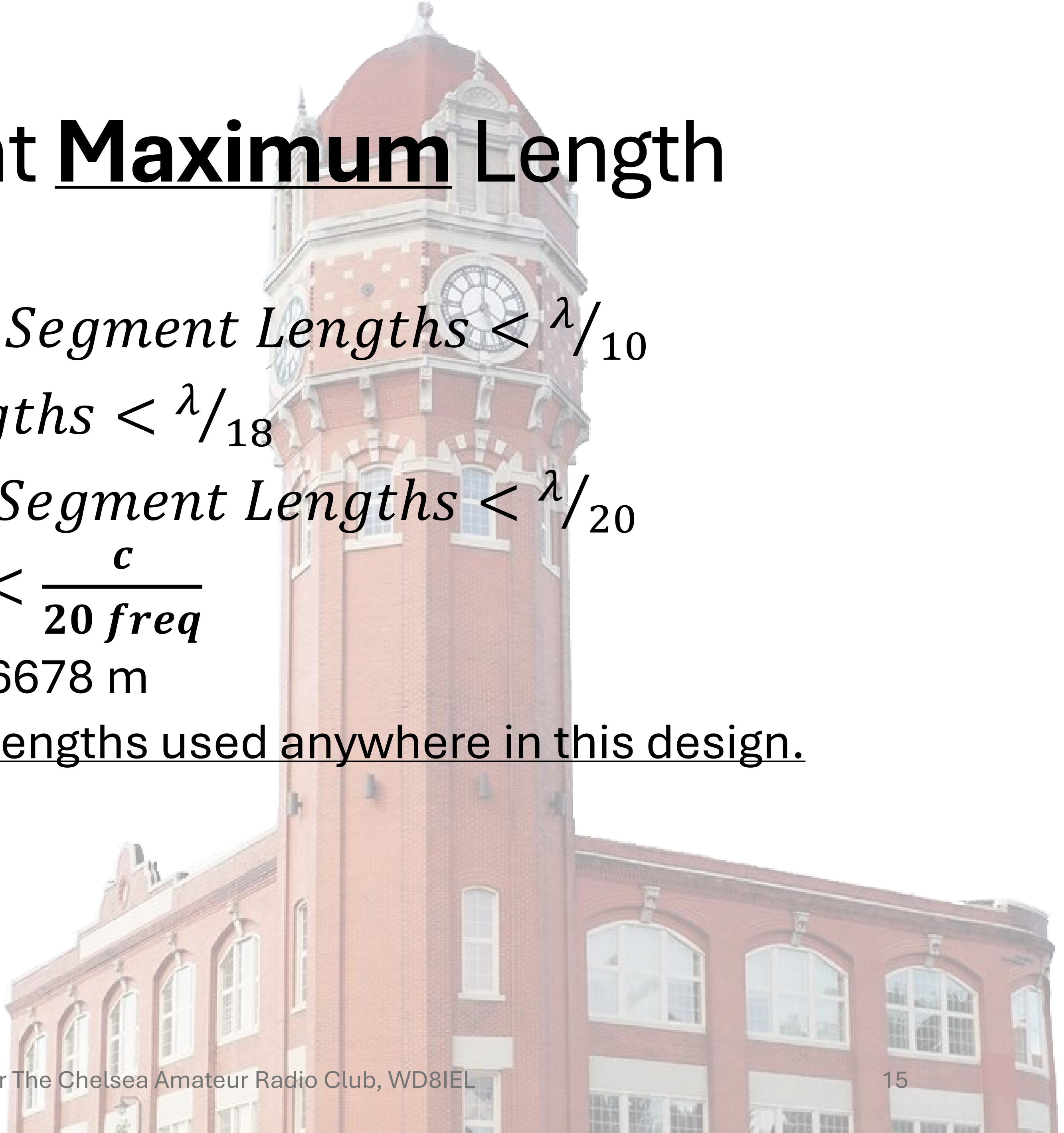
- A crap-shoot knowing where to place the feed point.
- The feed point defined here as a function of *fp_index*.
- Is the equivalent of sliding the feed point up and down trombone style.
- Facilitates ease of iteration for a solution.

w#	End-to-End Needed (m)
w1	0.475769838
w2	0.025667163
w3	0.0238125
w4	0.025667163
w5	1.514362588
w6	0.0238125



Rule #1: Wire Segment **Maximum** Length

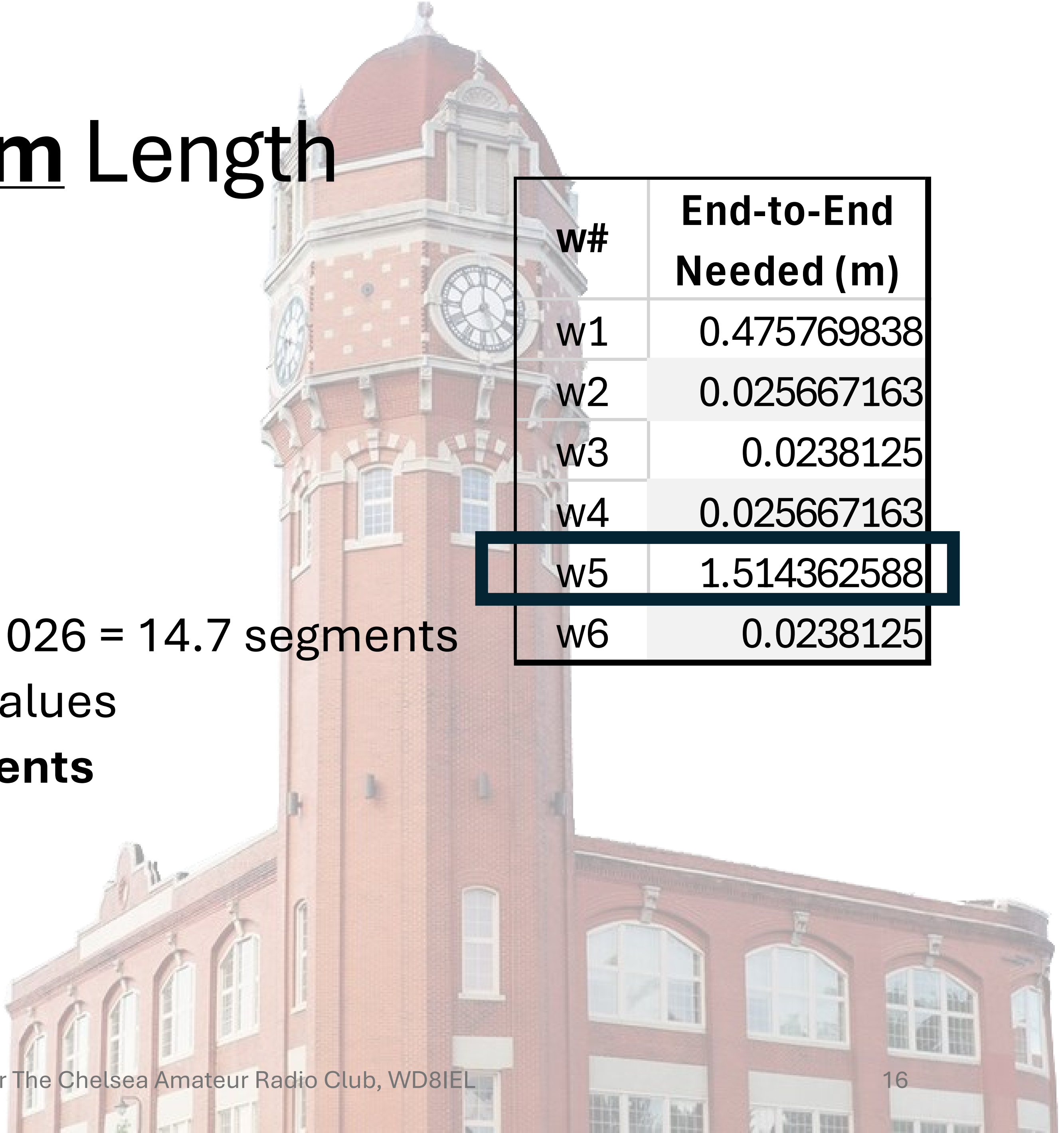
- The official rule: NEC requires: $Segment\ Lengths < {}^{\lambda}/_{10}$
- EZNEC requires $Segment\ Lengths < {}^{\lambda}/_{18}$
- All things considered, lets use $Segment\ Lengths < {}^{\lambda}/_{20}$
  - For convenience: $\boldsymbol{SegLen < \frac{c}{20\,freq}}$
  - λ / 20 = 2.053356 m / 20 = 0.1026678 m
  - This applies to all wire segment lengths used anywhere in this design.



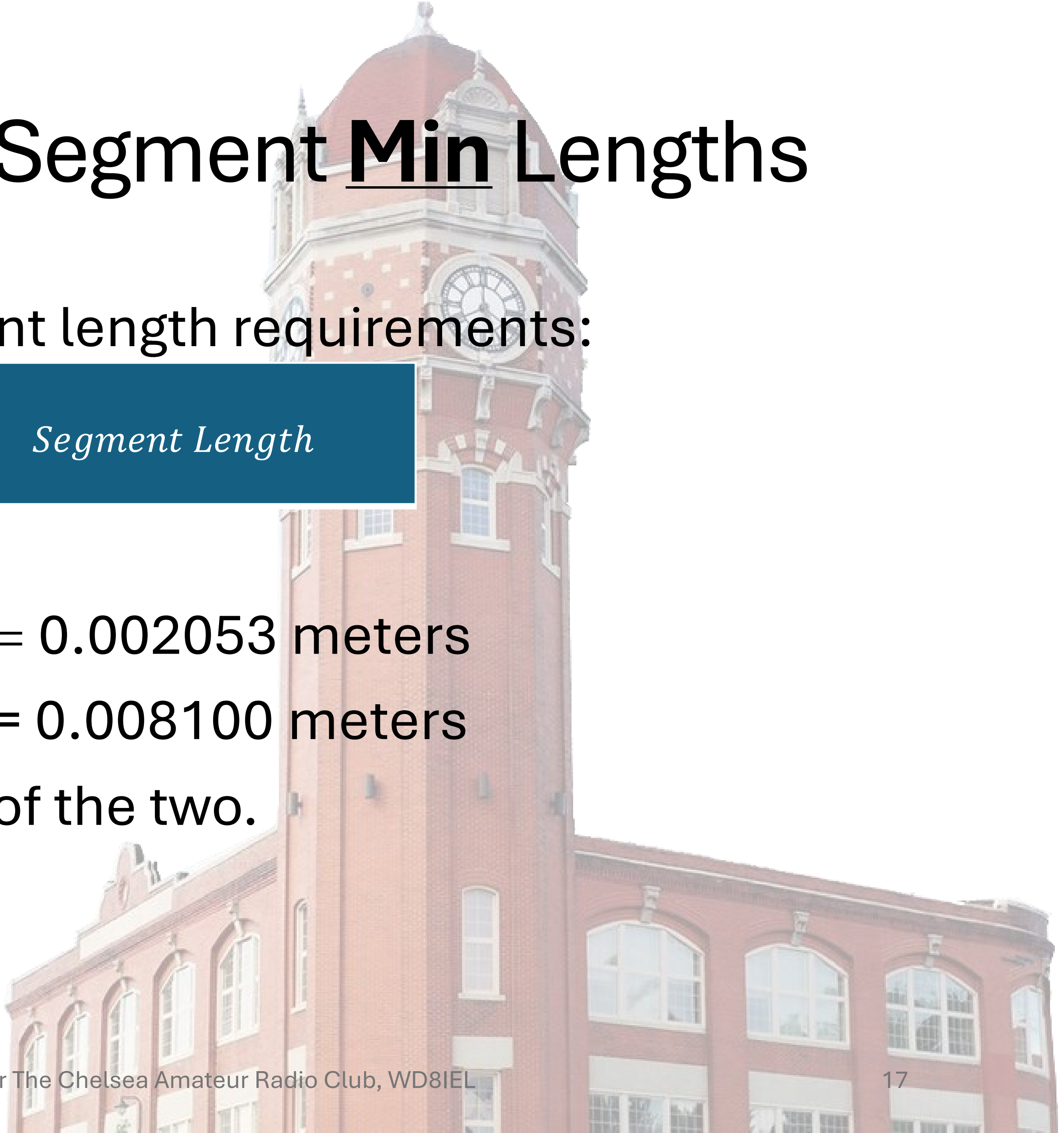
Test W_5 for a <u>**Maximum**</u> Length

- W_5 length is 1.5144 meters
- Truth test:
  - is 1.51 m < 0.1026 m ➔ FALSE
- What must be done
  - W_5 must have **AT LEAST** 1.51/0.1026 = 14.7 segments
  - Segments only come in integer values
  - **W_5 must have at least 15 segments**

w#	End-to-End Needed (m)
w1	0.475769838
w2	0.025667163
w3	0.0238125
w4	0.025667163
w5	1.514362588
w6	0.0238125



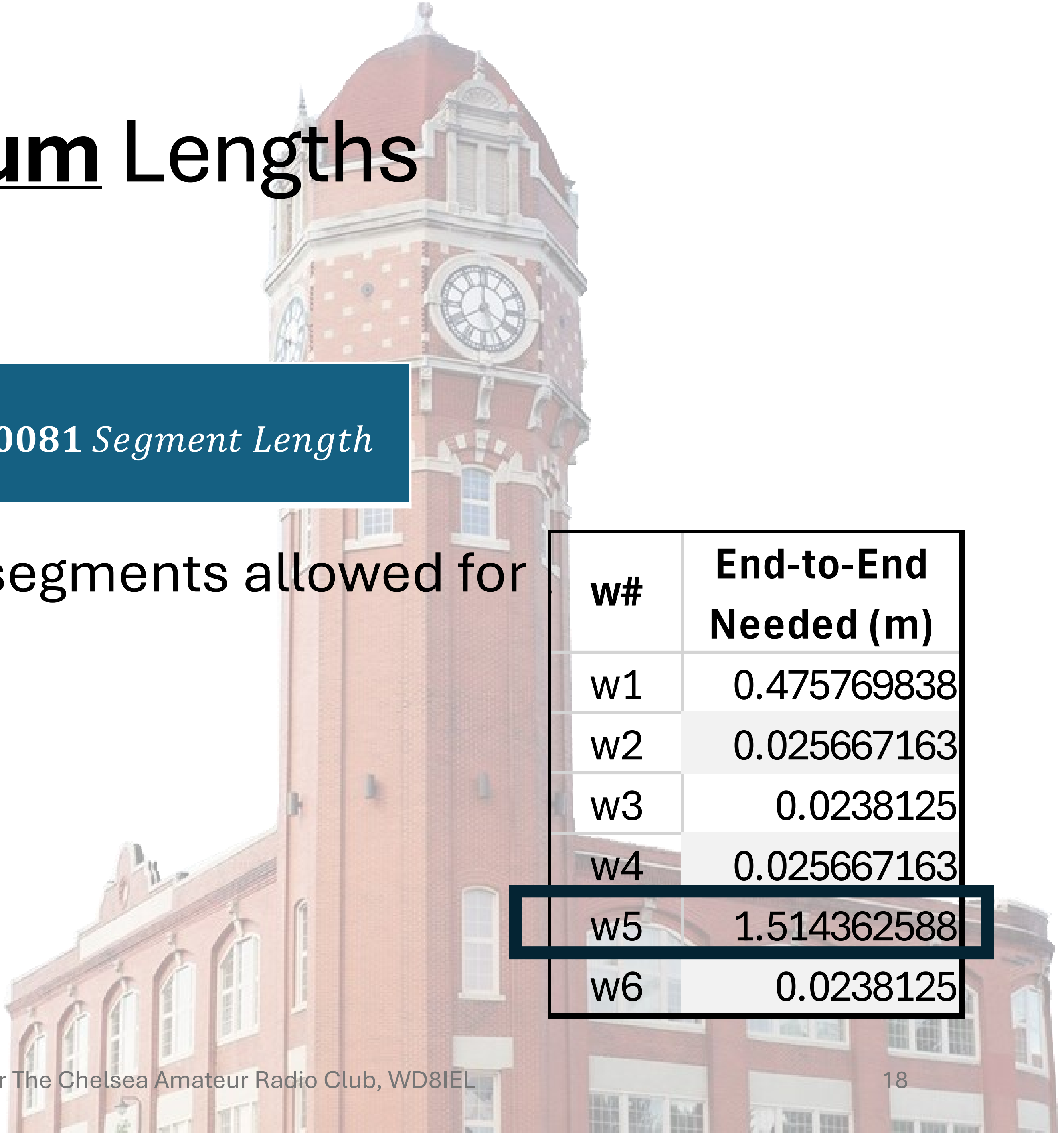
Rule #2 a and b: Wire Segment **Min** Lengths



- NEC has two MINIMUM segment length requirements:
  - $\lambda/_{1,000}$
  - $4\,Wire\ Diamete$

  $< \quad Segment\ Length$
- λ remains 2.053356 meters
- Min len #1: $\lambda/1{,}000$ = 0.002053 meters
- Min len #2: 4*Dia of #12 wire = 0.008100 meters
- Segment lengths > the greater of the two.

Wire Segment **Minimum** Lengths



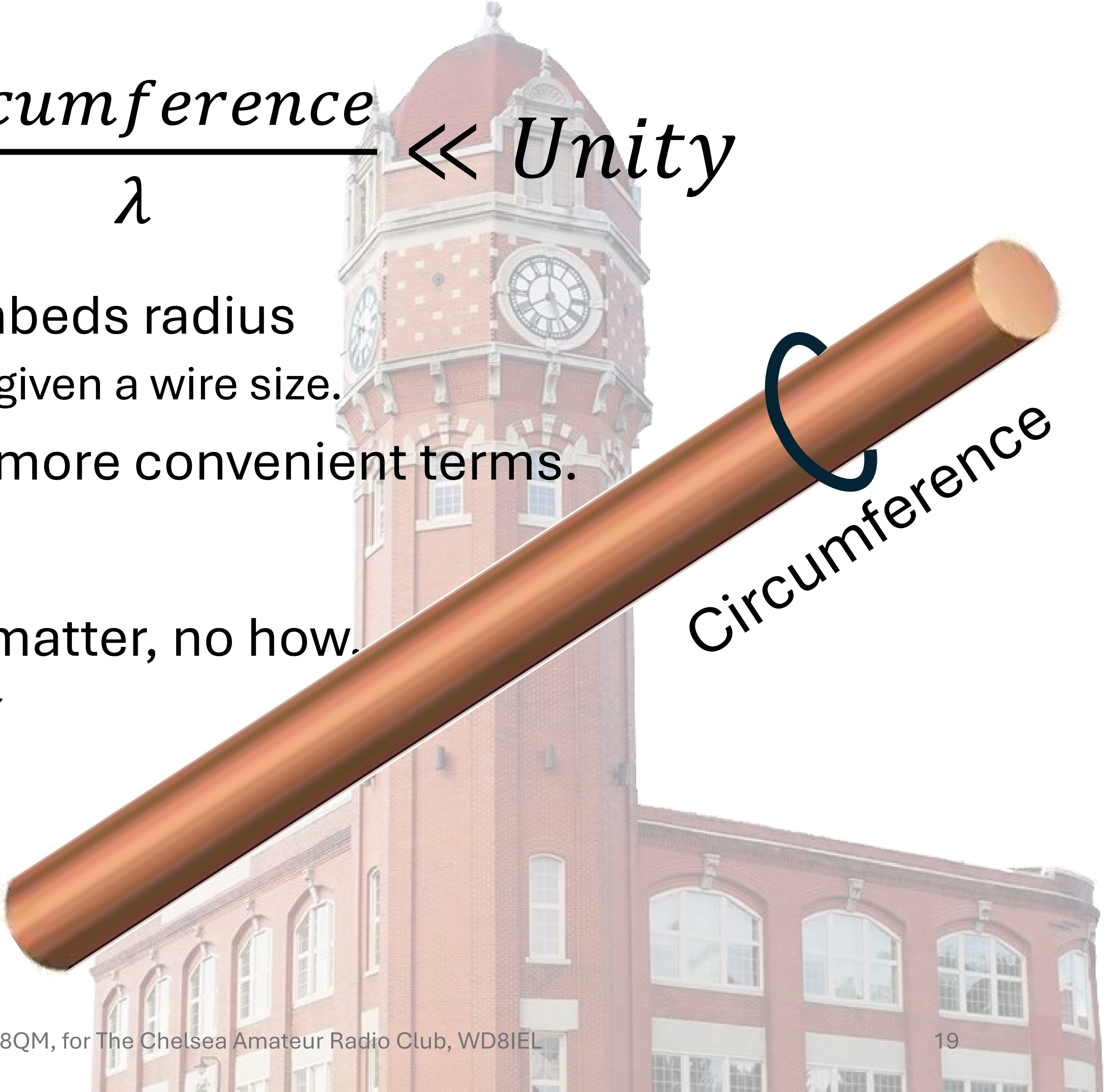
$\lambda/_{1,000} = \mathbf{0.002053m}$	$< \ \mathbf{0.0081}\ Segment\ Length$
$4\ Wire\ Dia = 0.0081m$	

- What is the largest number of segments allowed for wire W_5?
- 1.514m/0.0081m = 186
- Resulting requirement for W_5:
  - 15 <= W_5 # Segments <= 186

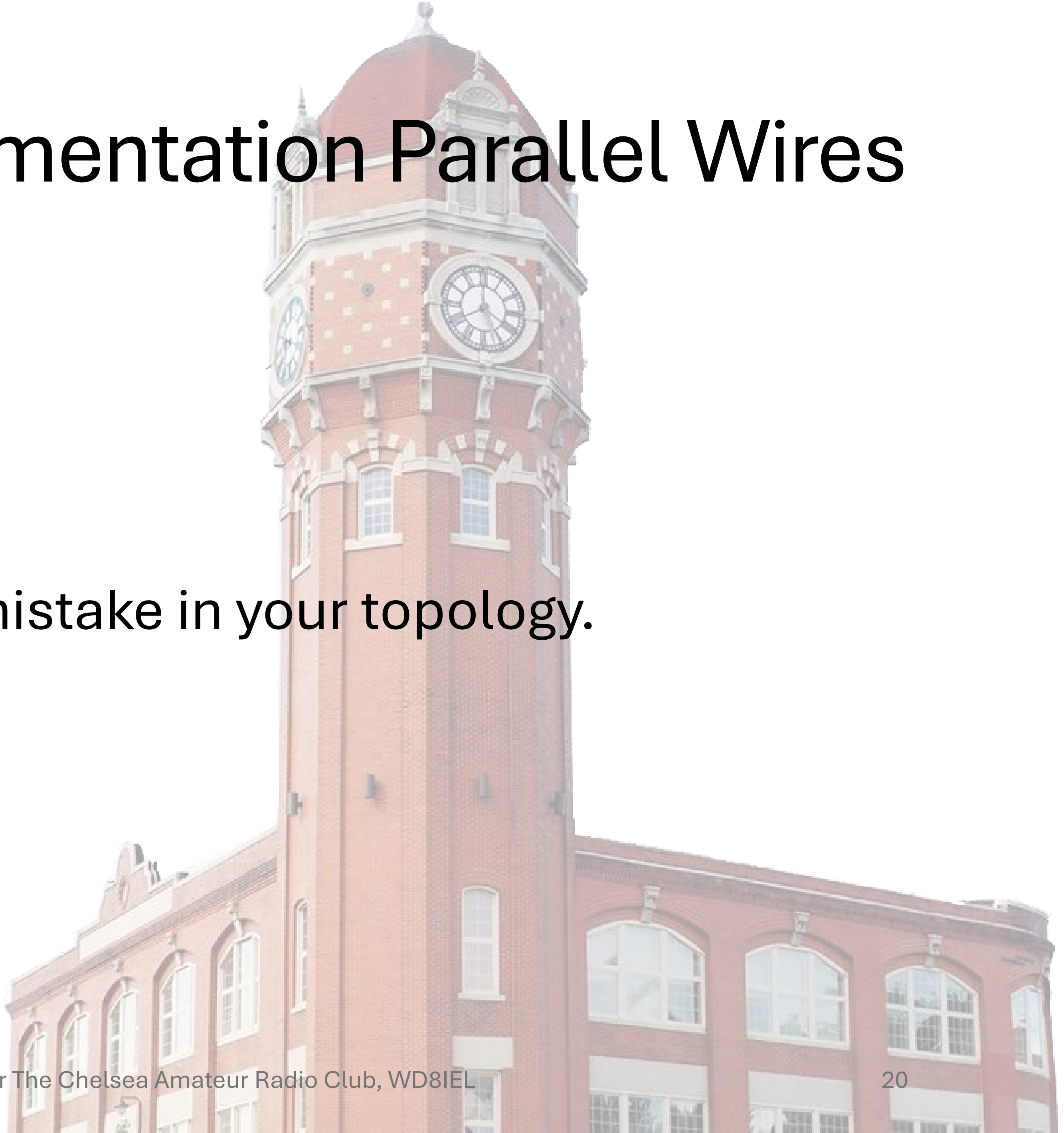
w#	End-to-End Needed (m)
w1	0.475769838
w2	0.025667163
w3	0.0238125
w4	0.025667163
w5	1.514362588
w6	0.0238125

Rule #3: Circ ➔ $\frac{circumference}{\lambda} \ll Unity$

- Because circumference embeds radius
  - Max f_o NEC may be used for given a wire size.
- This can be re-defined into more convenient terms.
  - $f_{o\,max(GHz)} \ll {}^{\frac{3e8m}{s}vf}\big/_{\pi\,Diam}$
- But how much less? Don't matter, no how.
  - #1 AWG wire: $fo < 0.82\ GHz$
  - #30 AWG wire: $fo < 75\ GHz$



Rule #4: Unequal Segmentation Parallel Wires

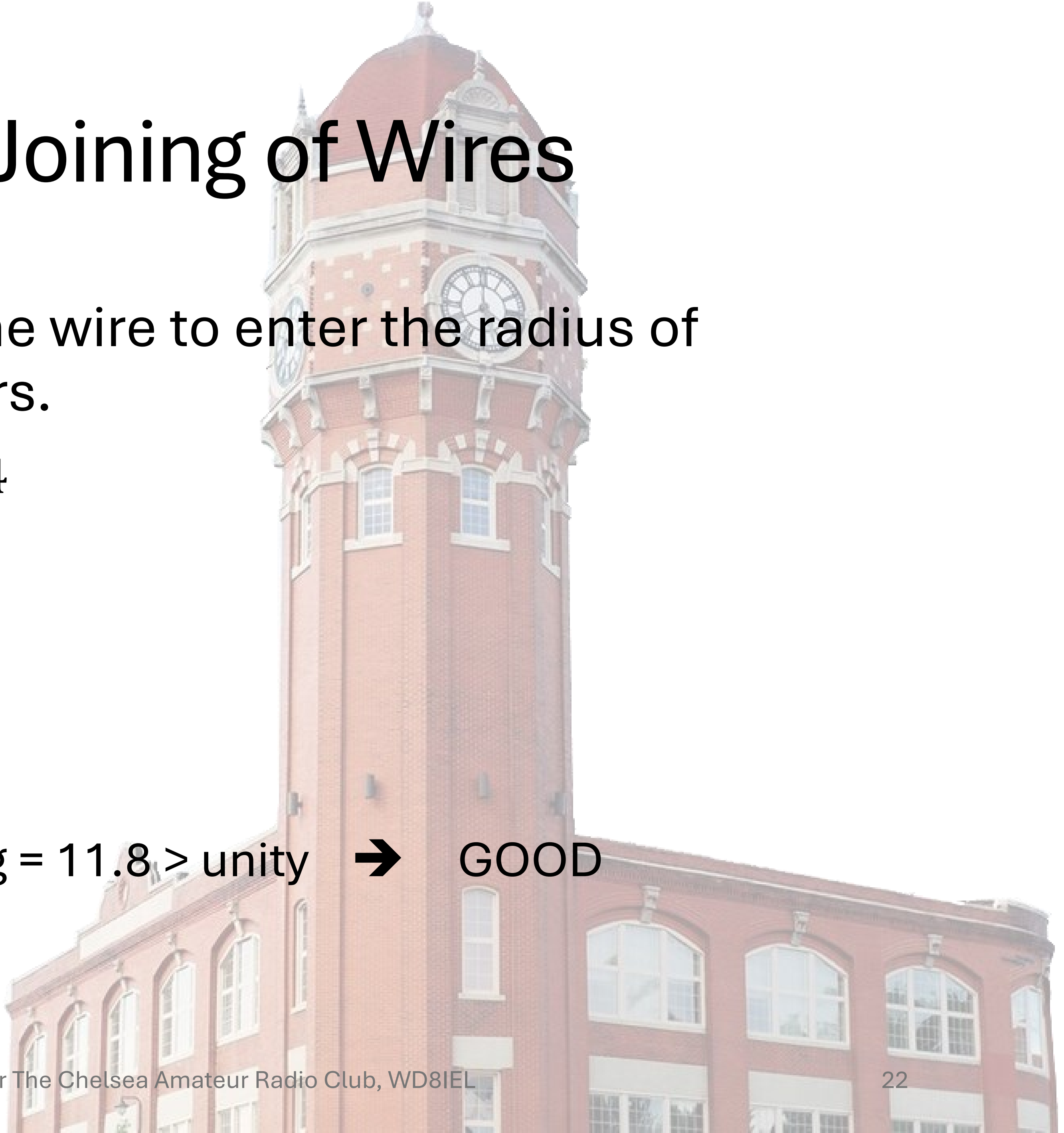


- Unequal Segmentation for
  - Parallel wires
  - Within $\lambda/20$ of each other
  - Having an overlap of $\lambda/10$.
- If you get this error, look for a mistake in your topology.

Relational Segment Lengths

- A segment length must not differ by more than 5x the segment length of another wire.

Special Case: Angled Joining of Wires

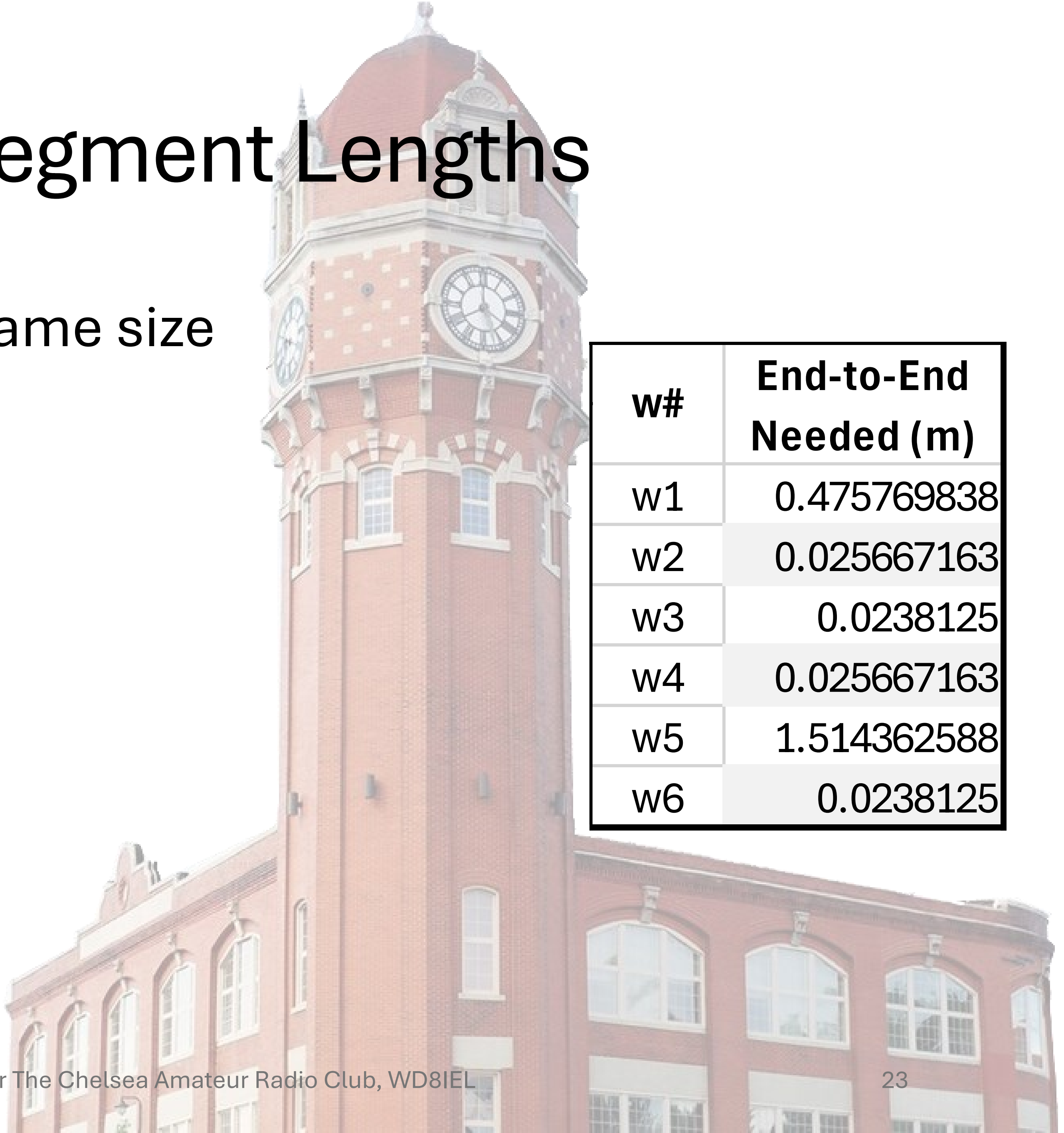


- Must not allow the center of one wire to enter the radius of another wire—these are corners.
  - Satisfied with: $\frac{Segment\ Length}{Wire\ Diameter} > 4$
- Re-written for convenience:
  - $\frac{Segment\ Length}{4\ Wire\ Diameter} > unity$
- For w1
  - Will be using 5 segments
  - 0.4873m/ (4 * 0.002052m) / 5seg = 11.8 > unity ➔ GOOD

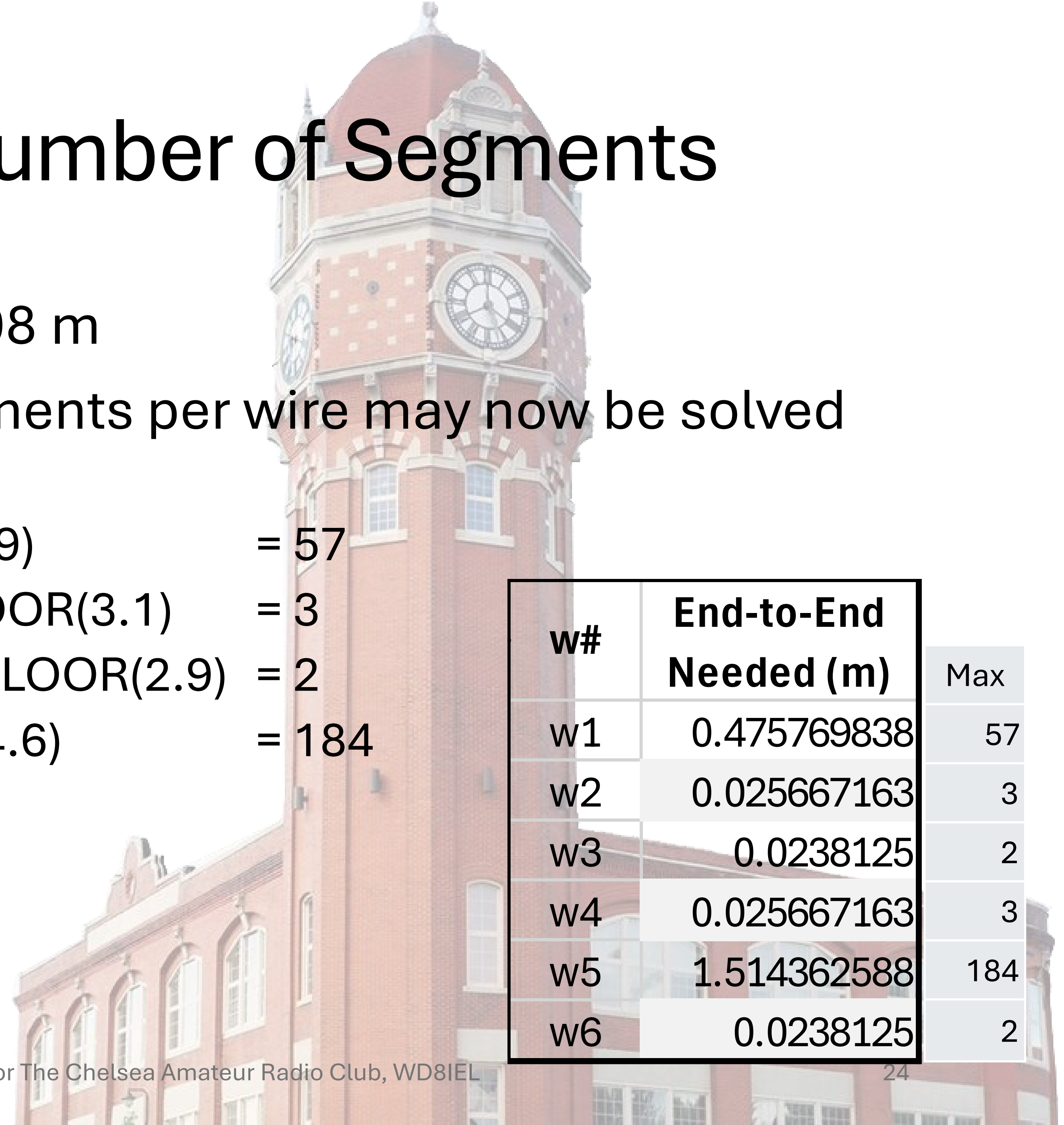
Test Wire Maximum Segment Lengths

- Because all the wires are the same size
  - Max #1: λ/20 = 0.10267 m
  - Max #2: 4 * dia
    - #12 AWG ➔ Dia = 0.002052 m
    - 4 * Dia = 0.008208m
  - Net Max is the lesser of the two
    - Max Seg Len = 0.008208 m
- Applicability
  - Because λ has one value
  - and there is one wire size
    - Max Seg Len = 0.008208 m

w#	End-to-End Needed (m)
w1	0.475769838
w2	0.025667163
w3	0.0238125
w4	0.025667163
w5	1.514362588
w6	0.0238125



Solve for Maximum Number of Segments



- MIN Segment length = 0.008208 m
- The MAXIMUM number of segments per wire may now be solved for.
  - W_1 = 0.475/0.0082 = FLOOR(57.9) = 57
  - $W_2 = W_4$ = 0.02567/0.0082 = FLOOR(3.1) = 3
  - $W_3 = W_6$ = 0.0238125/0.0082 = FLOOR(2.9) = 2
  - W_5 = 1.514/0.0082 = FLOOR(184.6) = 184

w#	End-to-End Needed (m)	Max
w1	0.475769838	57
w2	0.025667163	3
w3	0.0238125	2
w4	0.025667163	3
w5	1.514362588	184
w6	0.0238125	2

Solve for Minimum Number of Segments

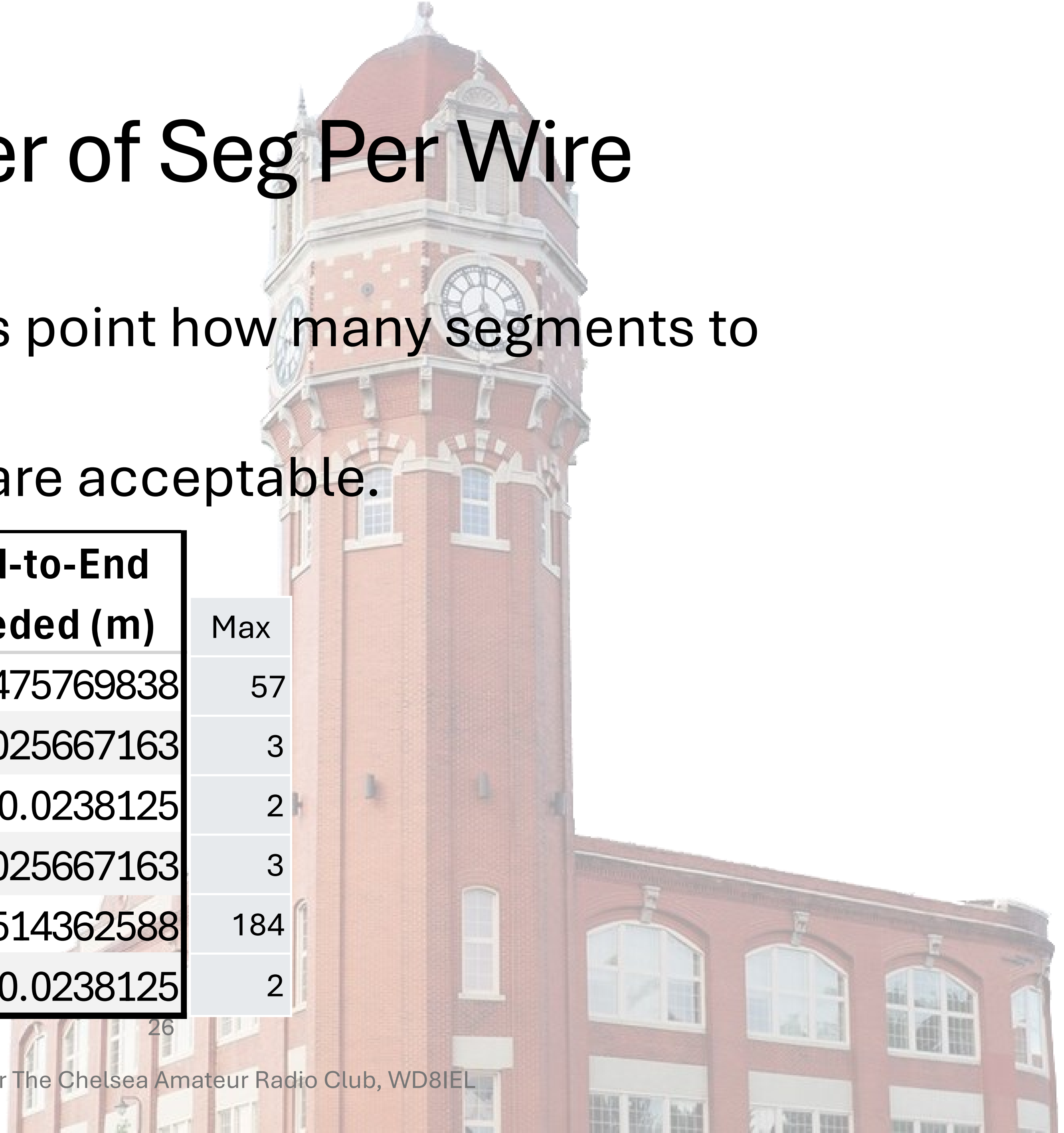
- Max Segment length = 0.10266865 m
- The MINIMUM number of segments per wire may now be solved for.
    - W_1 = 0.475/0.103 = CEILING(4.6) = 5
    - W_2 = W_4 = 0.02567/0.103 = CEILING(0.249) = 3
    - W_3 = W_6 = 0.0238125/0.103 = CEILING(0.23) = 1
    - W_5 = 1.514/0.103 = CEILING(14.7) = 15

Min	w#	End-to-End Needed (m)	Max
5	w1	0.475769838	57
1	w2	0.025667163	3
1	w3	0.0238125	2
1	w4	0.025667163	3
15	w5	1.514362588	184
1	w6	0.0238125	2

Arbitrarily Pick Number of Seg Per Wire

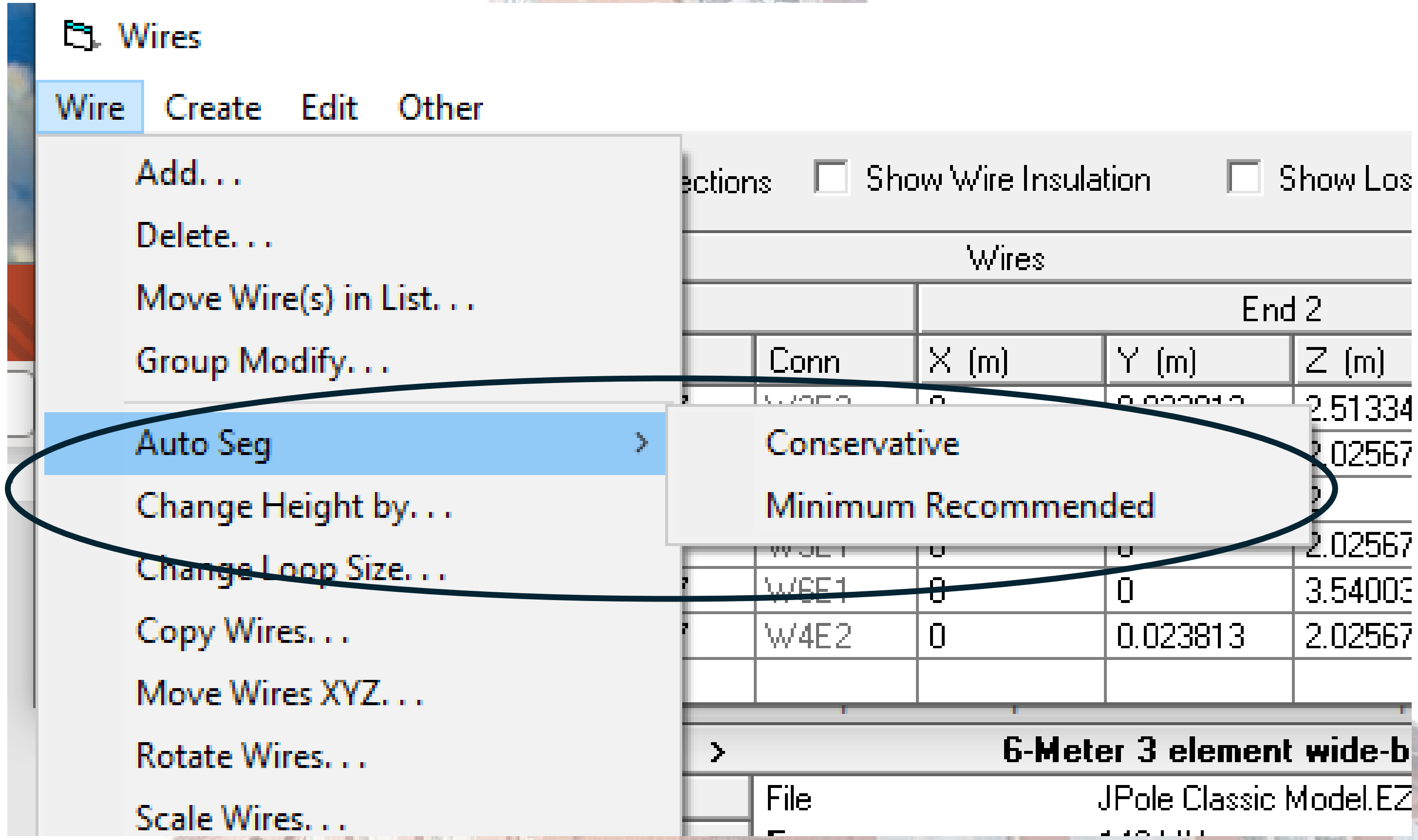
- It is an arbitrary decision at this point how many segments to specify per wire.
- Any values within those limits are acceptable.

Number Used	Min	w#	End-to-End Needed (m)	Max
11	5	w1	0.475769838	57
2	1	w2	0.025667163	3
1	1	w3	0.0238125	2
1	1	w4	0.025667163	3
22	15	w5	1.514362588	184
1	1	w6	0.0238125	2



EZNEC Offers Auto Segment

- A very handy feature to have available.



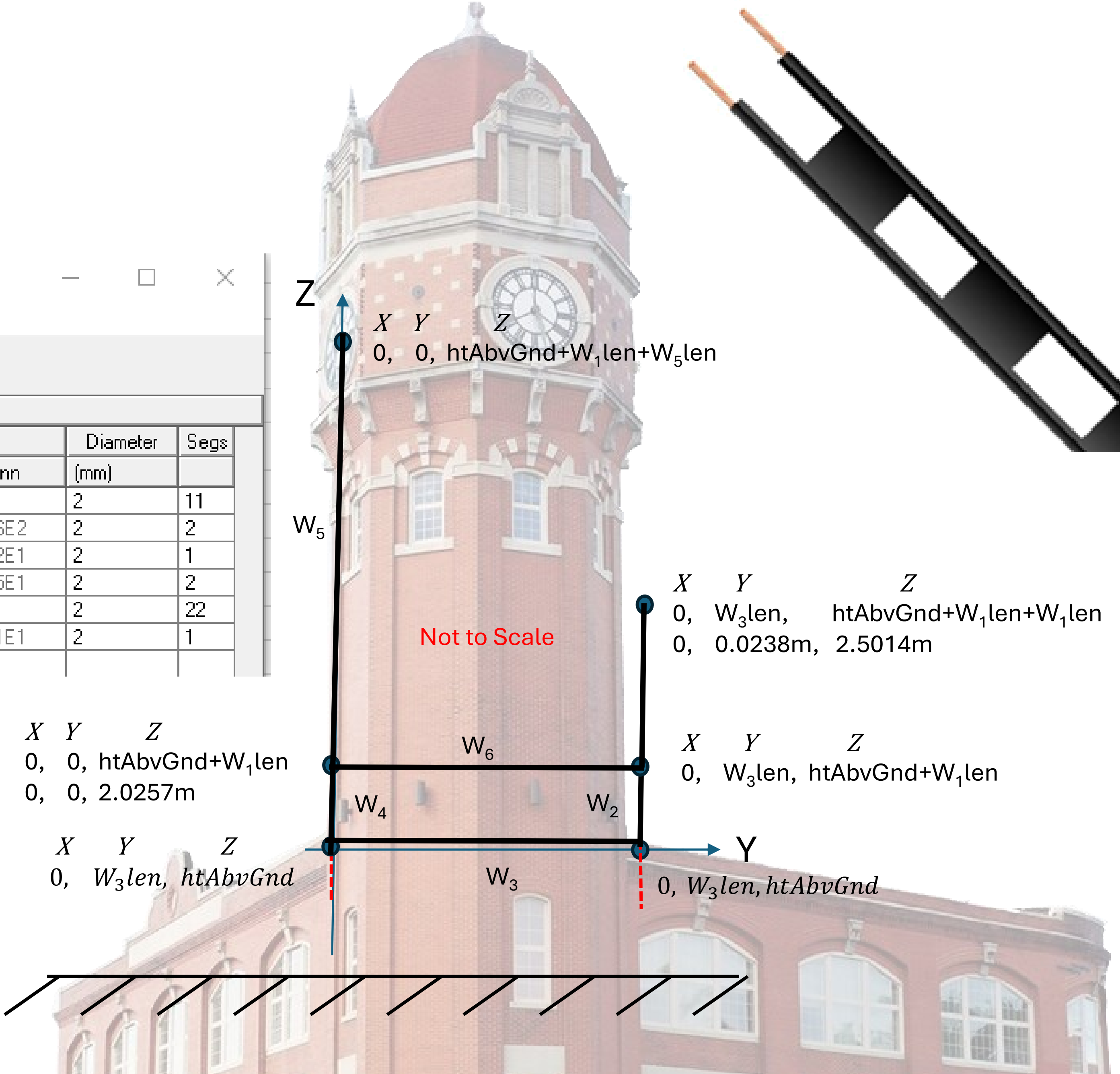
NEC Wire Table

Wires

Wire Create Edit Other

☐ Coord Entry Mode ☐ Preserve Connections ☐ Show Wire Insulation

Wires										
No.	End 1				End 2				Diameter	Segs
	X (m)	Y (m)	Z (m)	Conn	X (m)	Y (m)	Z (m)	Conn	(mm)	
1	0	0.023813	2.02567	W2E2	0	0.023813	2.50144		2	11
2	0	0.023813	2	W3E2	0	0.023813	2.02567	W6E2	2	2
3	0	0	2	W4E1	0	0.023813	2	W2E1	2	1
4	0	0	2	W3E1	0	0	2.02567	W5E1	2	2
5	0	0	2.02567	W6E1	0	0	3.52812		2	22
6	0	0	2.02567	W4E2	0	0.023813	2.02567	W1E1	2	1
*										

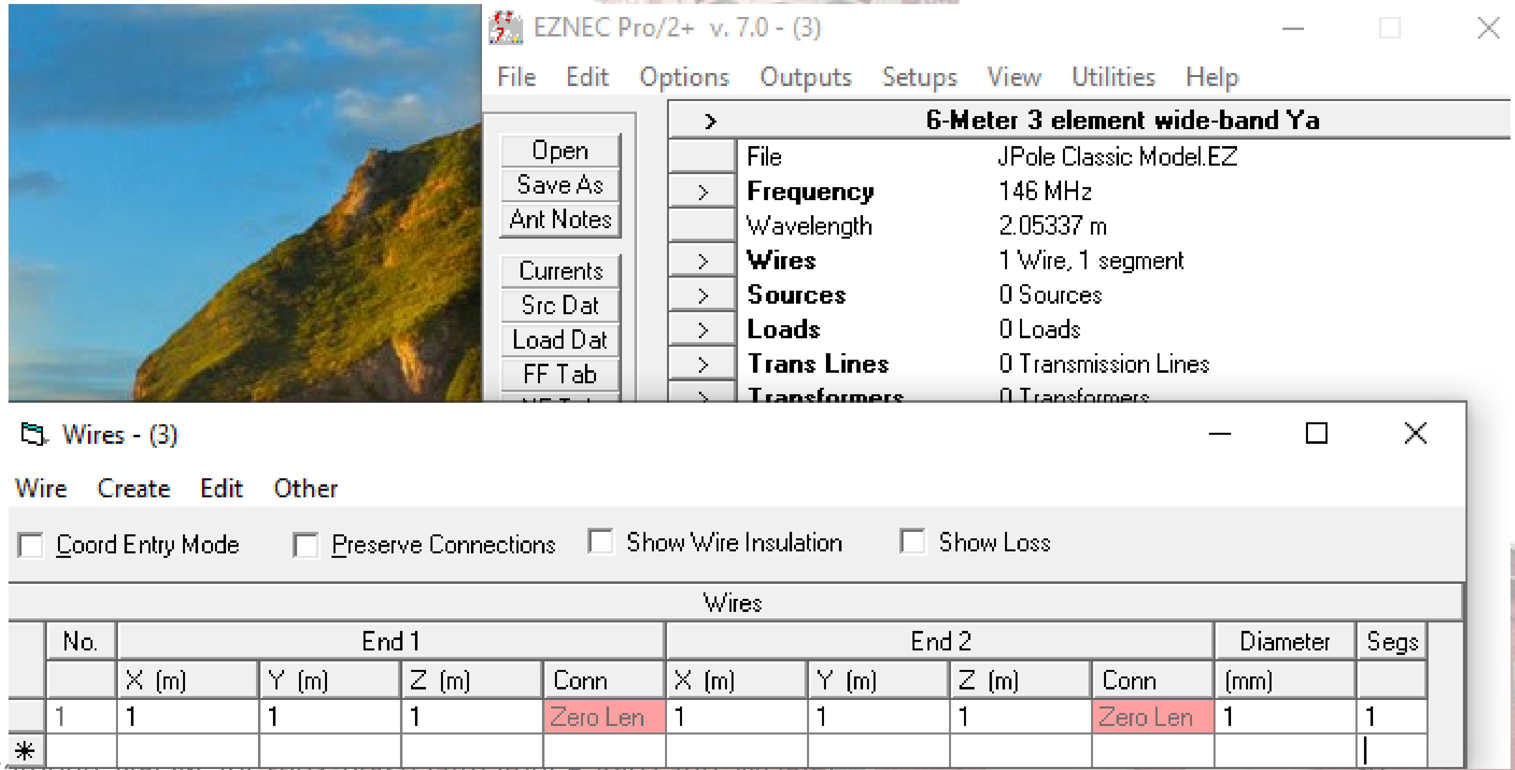


- A table defines the topology of the antenna.

Wes' Excel Spreadsheet

Steps to Input to EZNEC

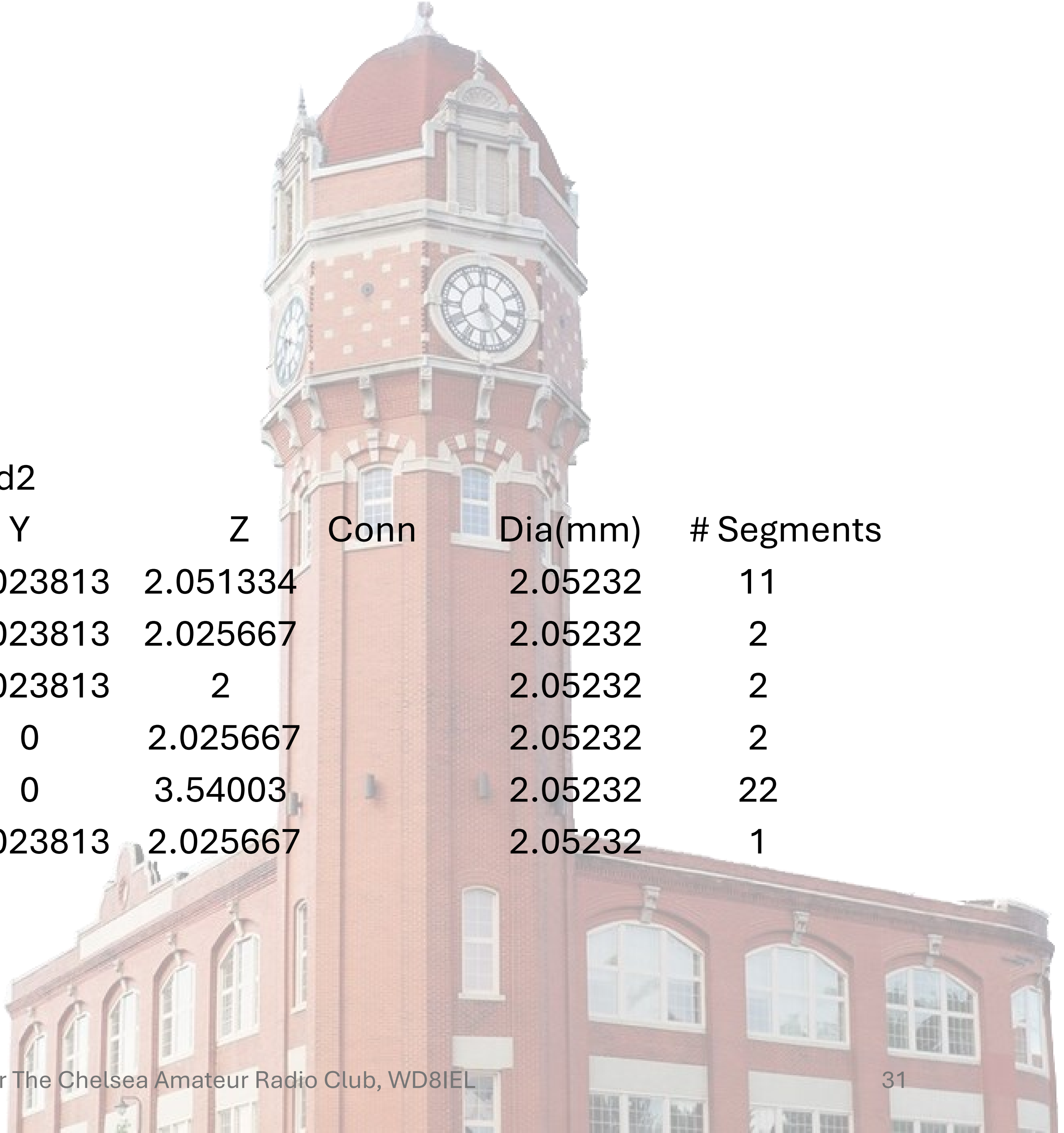
- Define the resonant frequency of the antenna.
- Define the ground options
- Define the wire list



Defining the Wire List

- Type in the wire list
- The format is:

End 1				End2					
X	Y	Z	Conn	X	Y	Z	Conn	Dia(mm)	# Segments
0	0.023813	2.02567		0	0.023813	2.051334		2.05232	11
0	0.023813	2		0	0.023813	2.025667		2.05232	2
0	0	2		0	0.023813	2		2.05232	2
0	0	2		0	0	2.025667		2.05232	2
0	0	2.02567		0	0	3.54003		2.05232	22
0	0	2.02567		0	0.023813	2.025667		2.05232	1



Defining the Source List

- Type in the wire list
- The format is:
  - Specified Pos. End2
  - No Wire # % From E1 % From E1 Seg (V, A) Phase Type
  - 6 50 50 1 1 0 1

Sources - (3)

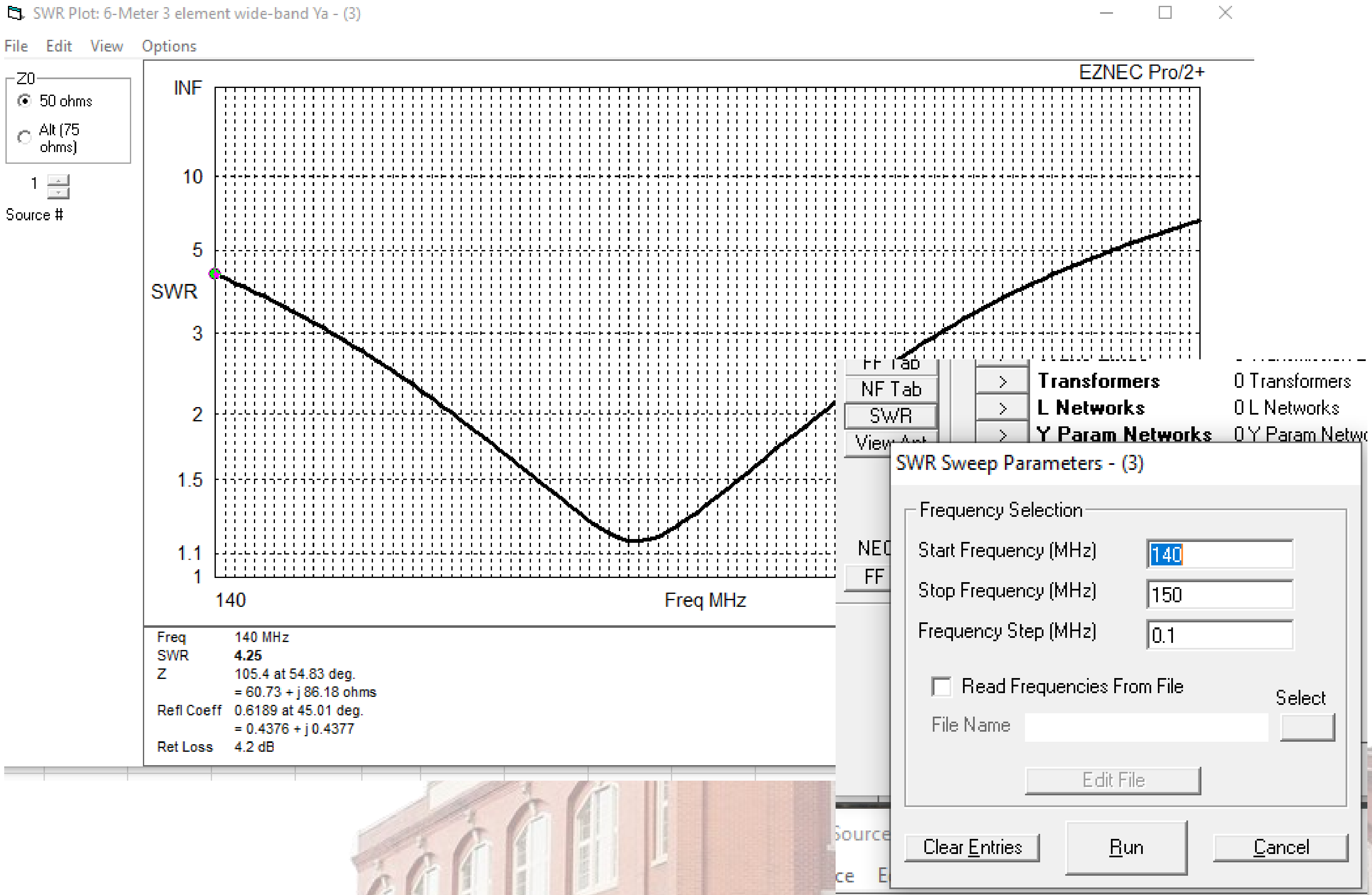
Source Edit Other

Sources

	No.	Specified Pos.		Actual Pos.		Amplitude	Phase	Type
		Wire #	% From E1	% From E1	Seg	(V, A)	(deg.)	
▶	1	6	50	50	1	1	0	I
*								

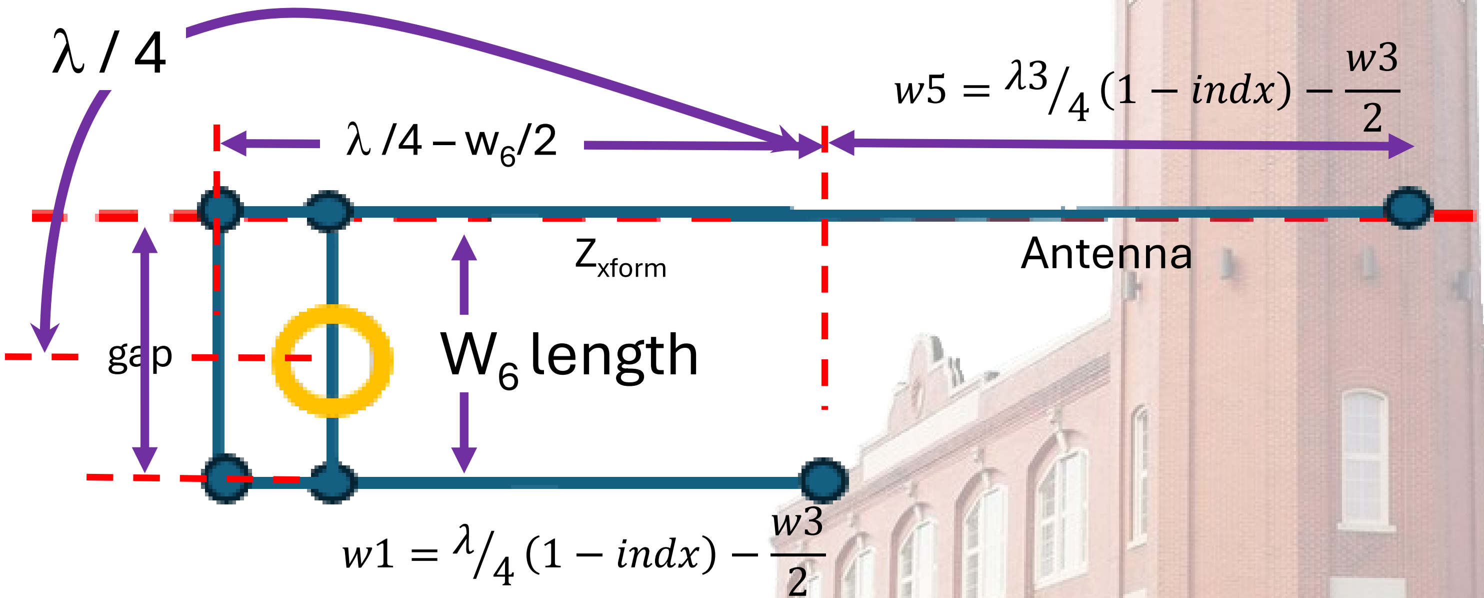
Plot the SWR

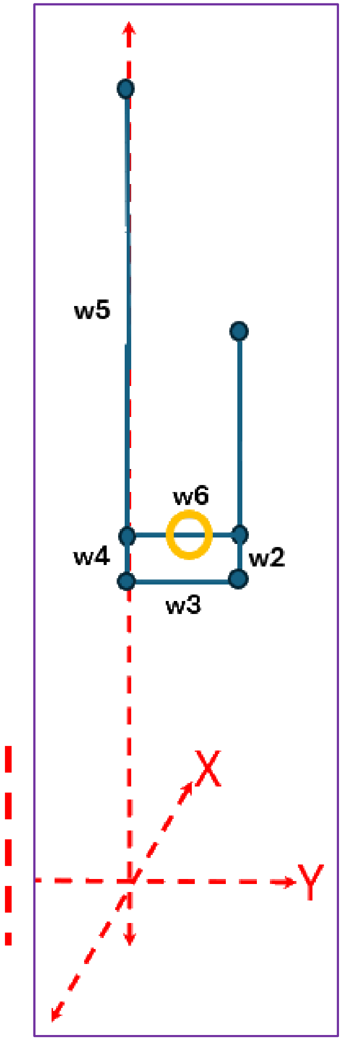
- Not very impressive.
- Resonates at 144 MHz
- Consider the gap.



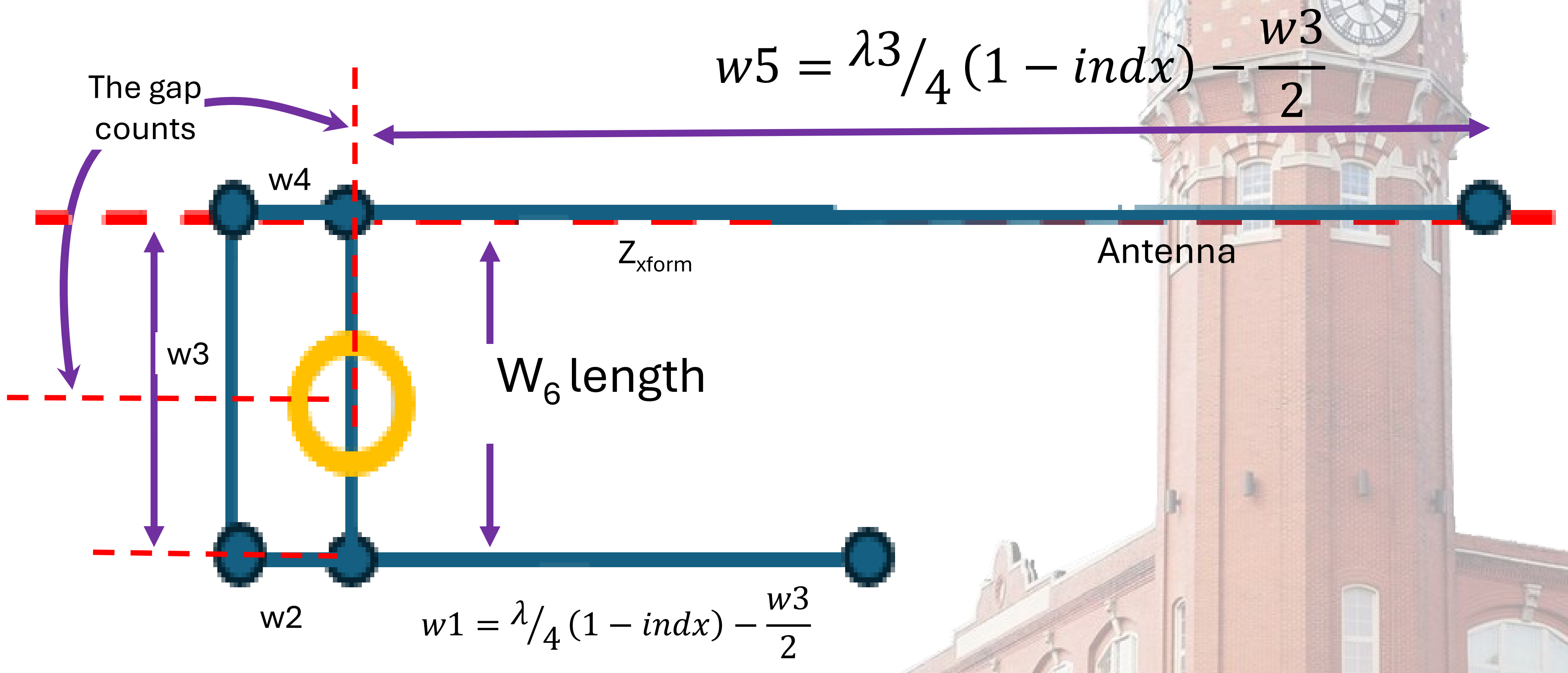
J-Pole Component Lengths

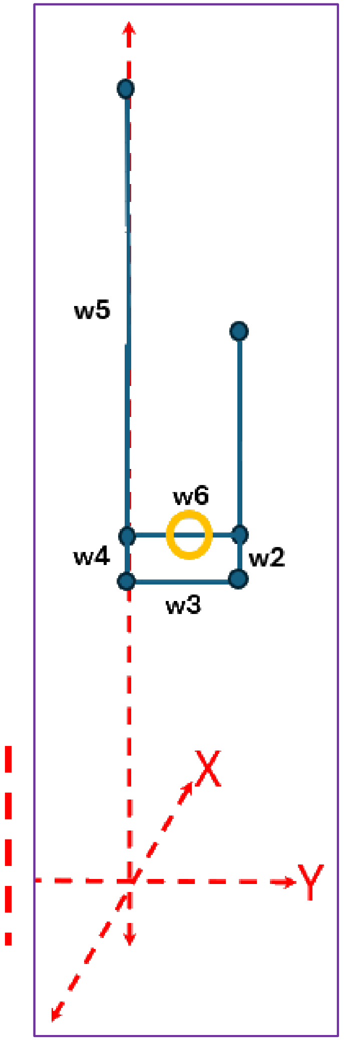
- The actual antenna is $\lambda/2$
- Z_{xform} length
  - Is $\lambda/4$ but not where you would think.
  - Includes the gap





Wes’ Stuff Closer Up





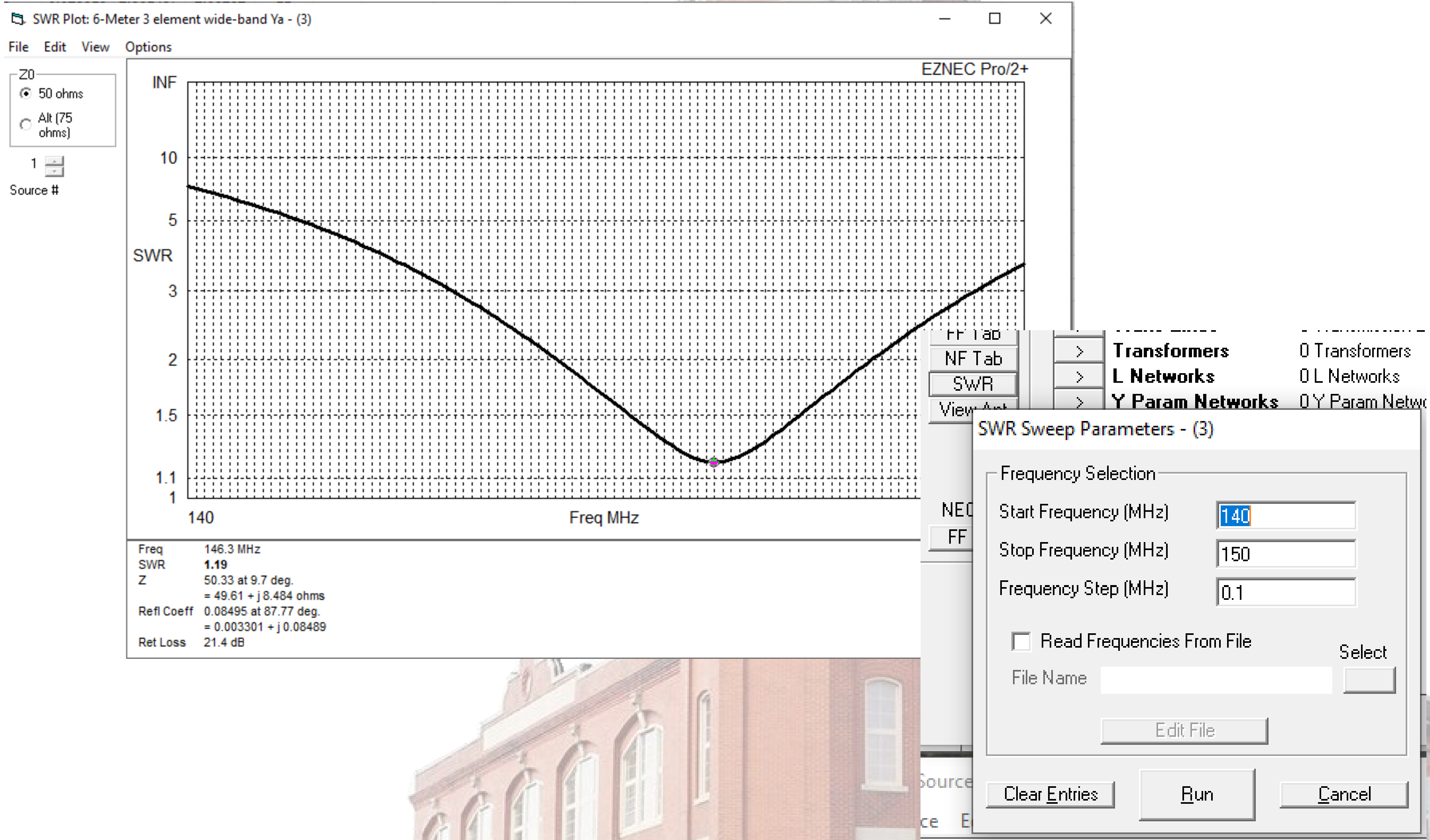
Defining the Wire List

- Make two changes to account for the "missing" gap

End 1				End2					
X	Y	Z	Conn	X	Y	Z	Conn	Dia(mm)	# Segments
0	0.023813	2.02567		0	0.023813	2.0501437		2.05232	11
0	0.023813	2		0	0.023813	2.025667		2.05232	2
0	0	2		0	0.023813	2		2.05232	2
0	0	2		0	0	2.025667		2.05232	2
0	0	2.02567		0	0	3.528124		2.05232	22
0	0	2.02567		0	0.023813	2.025667		2.05232	1

Plot the Revised SWR

- impressive.
- Resonates at 146.3 MHz



What About our Feed Point Entry Point?

- We guessed at a value of 0.05
- It was a good guess but can still be optimized.
- I’ve tried
  - 0.04 which returns an SWR of 1.5.
  - 0.07 which was but resonating at 148 MHz.
- But don’t forget that we have been using a velocity factor of unity.