

Thermal Signature **of a Resistor**

And Problems Encountered Along the Way

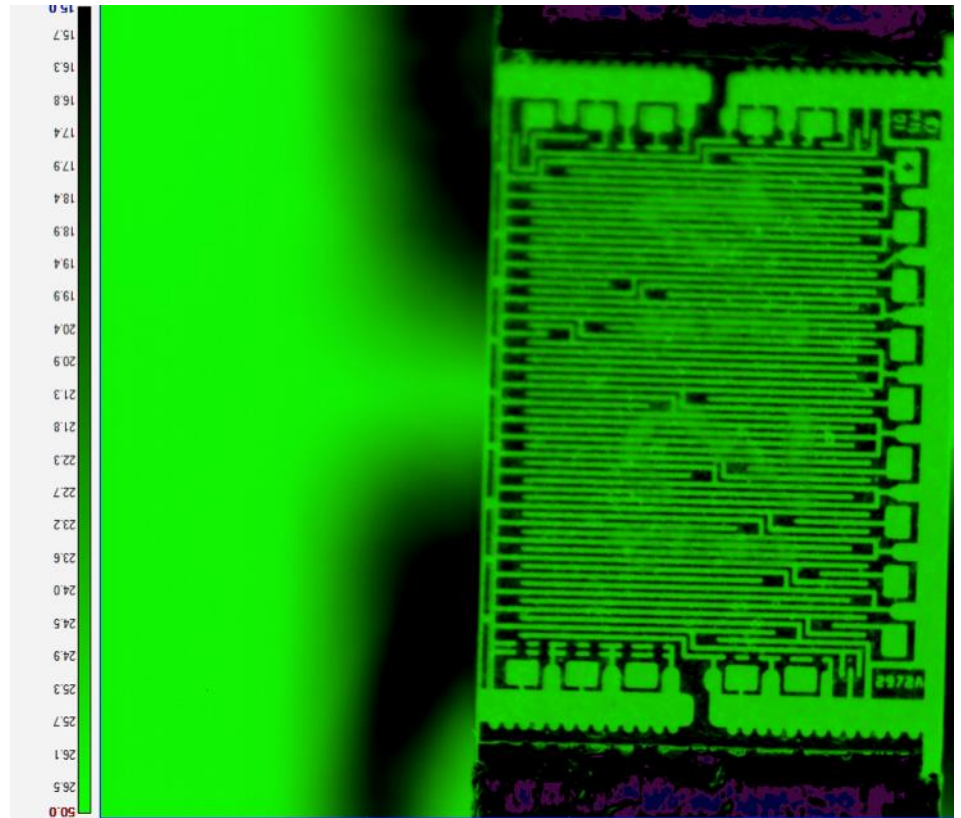
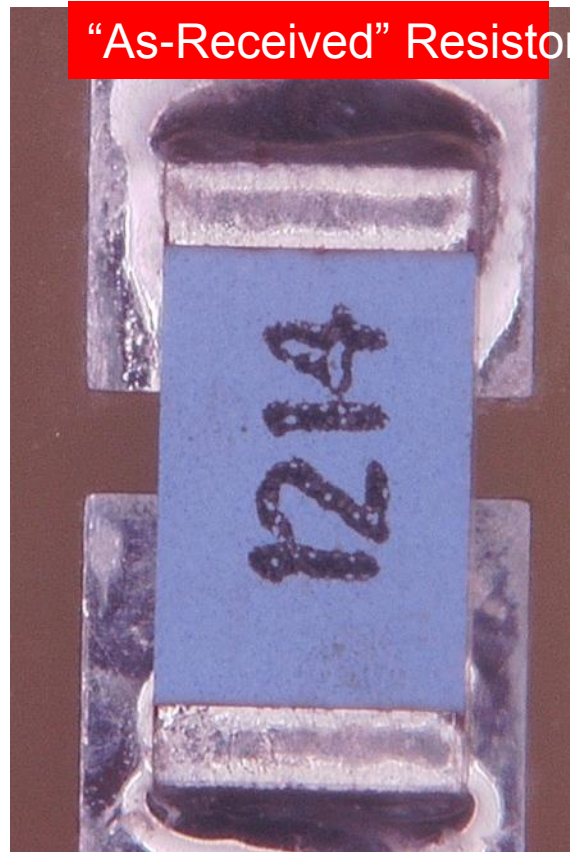
Jack Shue, Jay Brusse, Lyudmyla Panashchenko

FLIR SC8300HD High Resolution Infrared Camera + 4X Lens

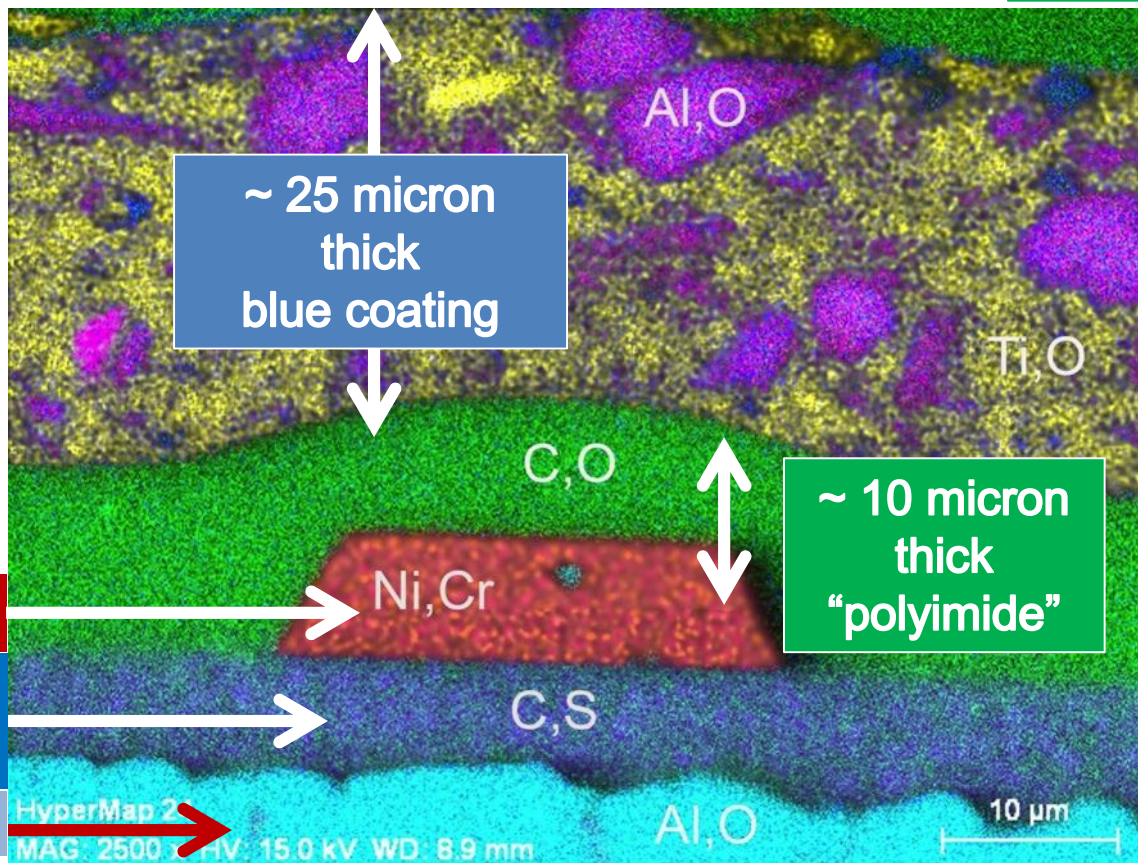
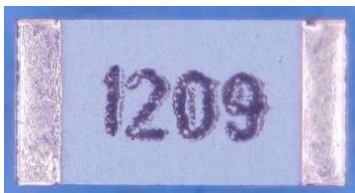
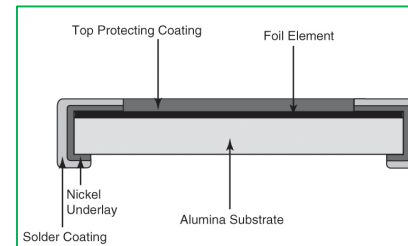


Surprise!!

With This Particular Camera/Lens Configuration
We Could See THROUGH THESE SPECIFIC External Coatings and
Image the Resistor Pattern Even When Device is NOT POWERED



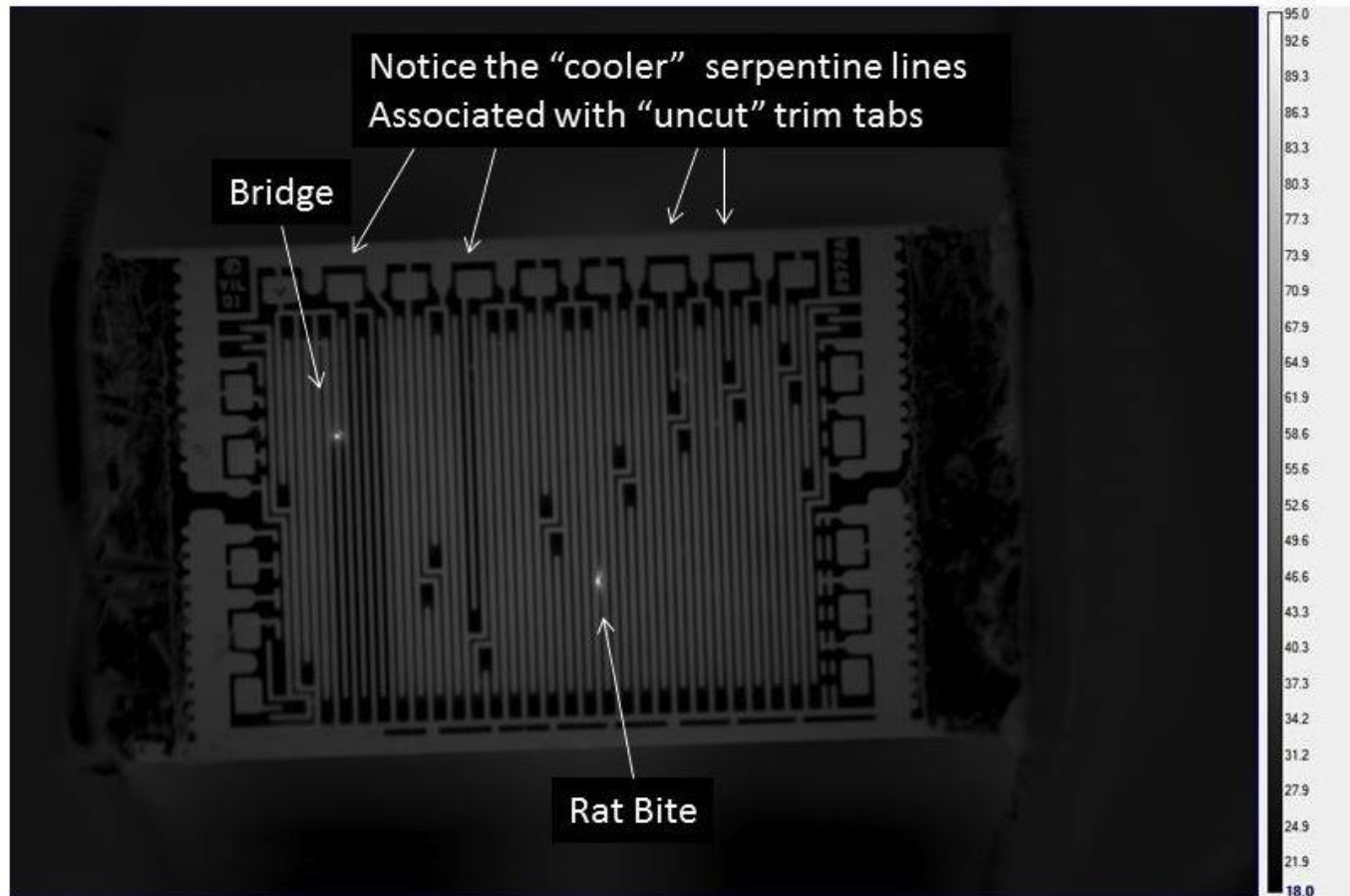
This is what we could “See Through” Cross Section of Resistor



An EDS map of a cross-sectioned resistive element resting on a carbon-sulphur compound on the alumina substrate of the device. The resistive element is coated with a hydrocarbon layer. The protective cover consists of aluminum and titanium oxide particles embedded in a polymer matrix.

IR Camera Investigations of Foil Resistors

Infrared Image of a 2kOhm Size 1206 Foil Resistor Receiving Power



Why We Worry about a Resistor.

- Spacecraft are expensive to build and are usually one of a kind
- We want our spacecraft to last a long time
- **Sometimes...Parts fail!!!**
- Fixing a spacecraft once in orbit is almost always NOT POSSIBLE!
- Because of the above, ideally, we strive to employ effective screening tests to reduce in-flight failure rates by finding weak parts BEFORE they are used.

Why We Worry about a Resistor.

- Experience tells us that the resistor in question has some known failure modes **DESPITE** the use of several different screening tests. These screening tests are **LEAKY** and may allow a few weak parts through!!!

**Can we find a better
screening process
to find weak parts?**

Goal of this Paper

While working on a new screening process for precision foil resistors, there were issues between the IR camera and the test article that all came together in textbook fashion. This paper talks about some of those issues.

In this paper

- What is a foil resistor?
- Unavoidable problems
- Why Thermal Imaging
- The need for a microscope and the problems it represents
- Problems encountered
 - Size and wavelength limitations
 - Moiré patterns
 - Pixel size limitations
 - Emissivity and reflections

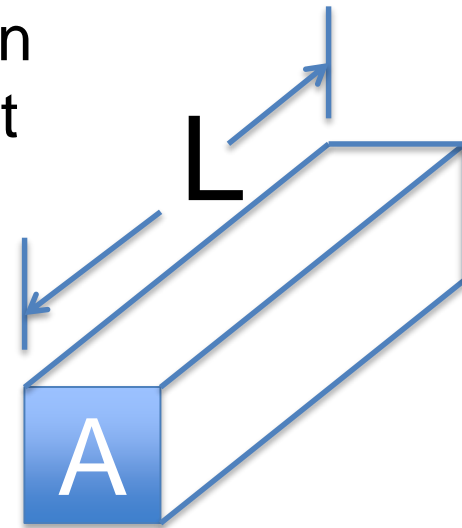
There is nothing new or unusual about these problems but they come together when working on the resistor.

What is Resistance

The electrical resistance of an electrical conductor is the opposition to the passage of an electric current through that conductor.

$$R_{\Omega} = \rho_{\Omega m} \frac{L_m}{A_m^2}$$

Where
R = resistance (ohms)
 ρ = resistivity of the material (ohms · meters)
L = length of the material (meters)
A = cross sectional area of the material (meters²)



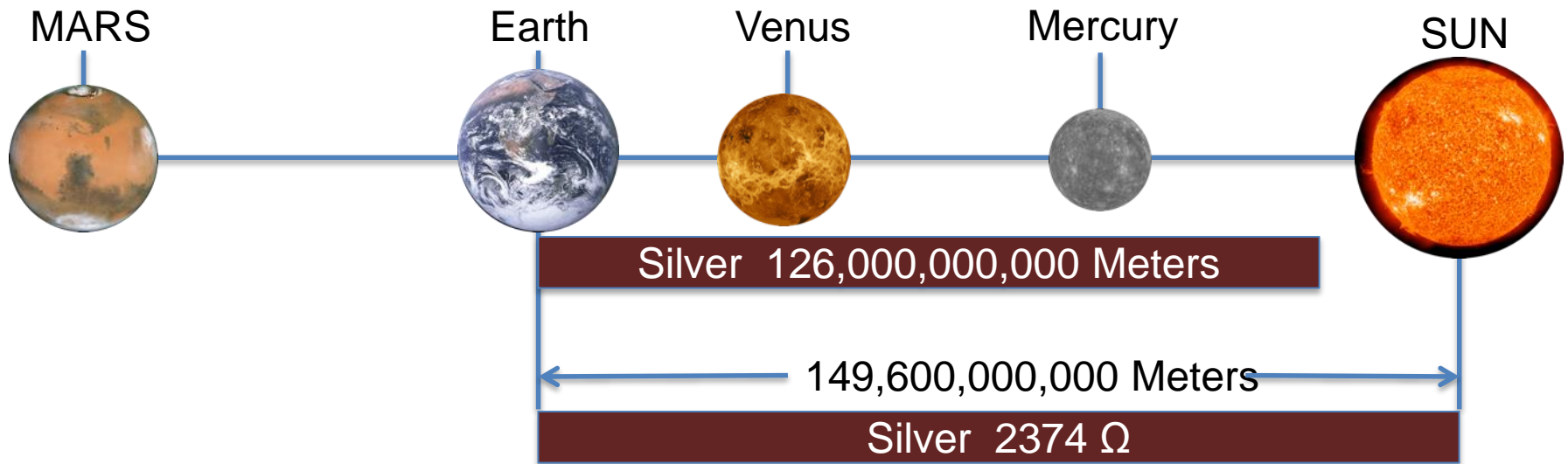
ρ for Copper = 0.000,000,016,78 Ωm = 16.78e-9 Ωm
 ρ for Silver = 0.000,000,015,87 Ωm = 15.87e-9 Ωm

How to Build a 2000 Ω Resistor

Starting with a block of Silver that is
 1 meter wide by 1 meter thick (i.e., 1 m² Cross Sectional Area),
 How LONG would the block have to be to make a 2000Ω Resistor?

ρ for Copper = 0.000,000,016,78 Ωm = 16.78e-9 Ωm
 ρ for Silver = 0.000,000,015,87 Ωm = 15.87e-9 Ωm

$$R_{\Omega} = \rho_{\Omega m} \cdot \frac{L_m}{A_m^2}$$



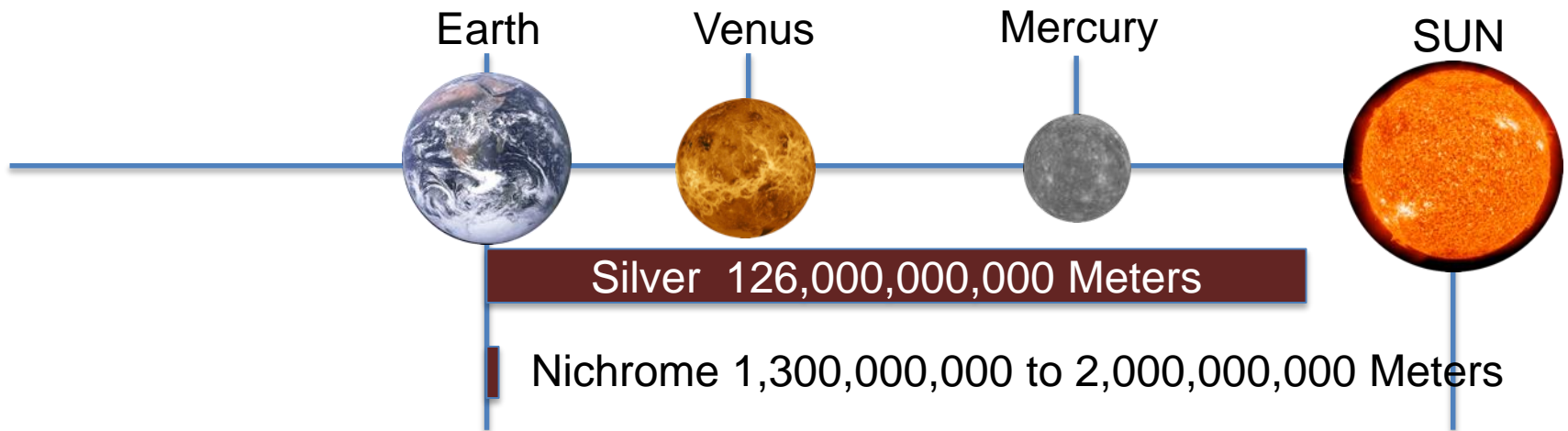
Improvements in the Size – Part I

Choose a Different Material with a different RESISTIVITY!!!

Nichrome (Nickel Chromium Alloy) alloys are commonly used to make resistors.

$$R_{\Omega} = \rho_{\Omega m} \cdot \frac{L_m}{A_m^2}$$

ρ for Nichrome = $1 \text{ e-}6$ to $1.5 \text{ e-}6$



A factor of approximately 100 better!

But that is still 4.3 times the distance from the earth to the moon!

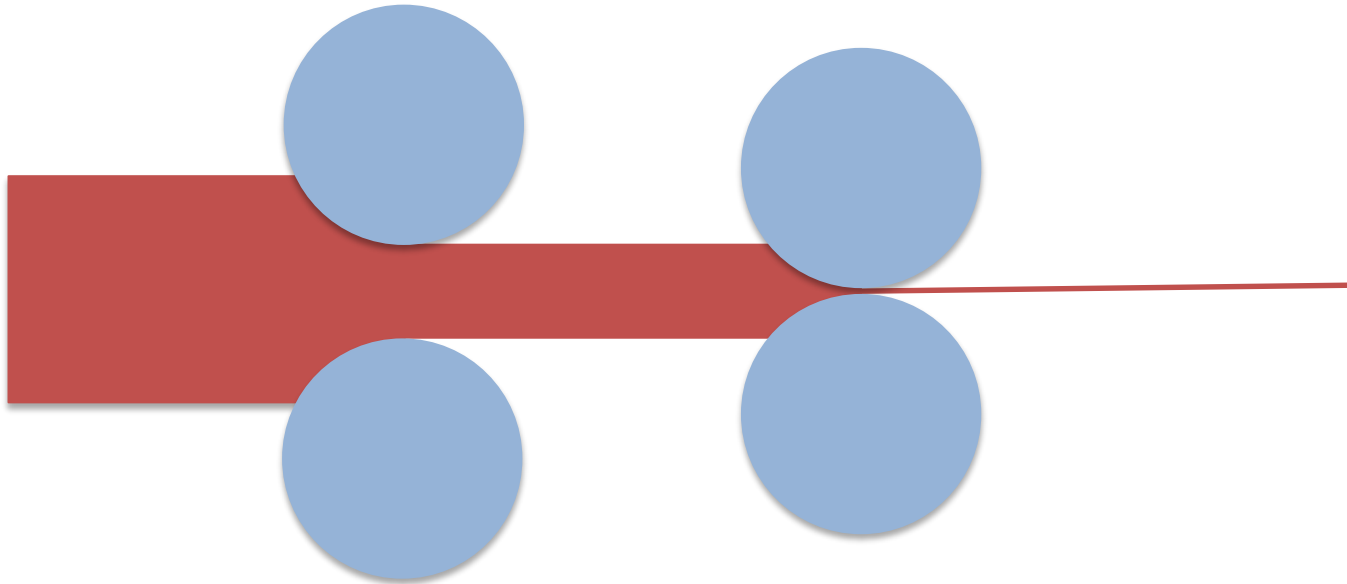


Improvements in the Size – Part II

Reduce the Cross Sectional **AREA** of the Conductor and it will NOT have to be So Long!!!

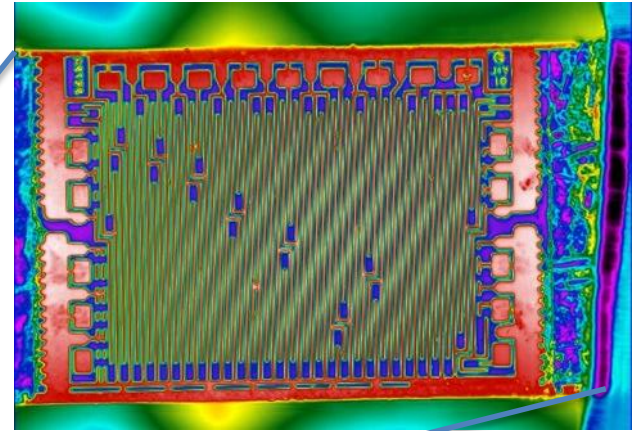
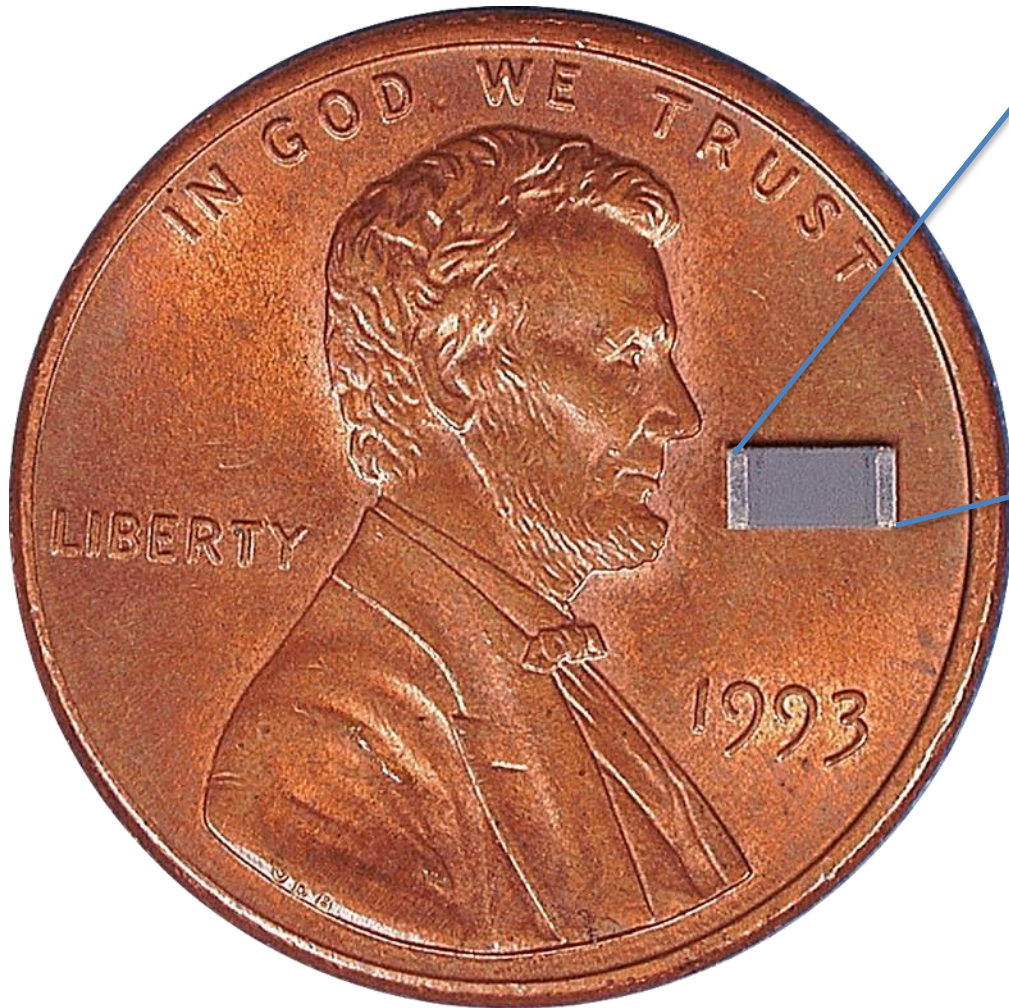
$$R_{\Omega} = \rho_{\Omega m} \cdot \frac{L_m}{A_m^2}$$

For this Resistor Technology the Nichrome can be reduced in width and thickness from 1 meter² down to ~0.000002 meter x 0.000002 meter, which means the length needed for 2000 ohms becomes ~ 1 cm long.



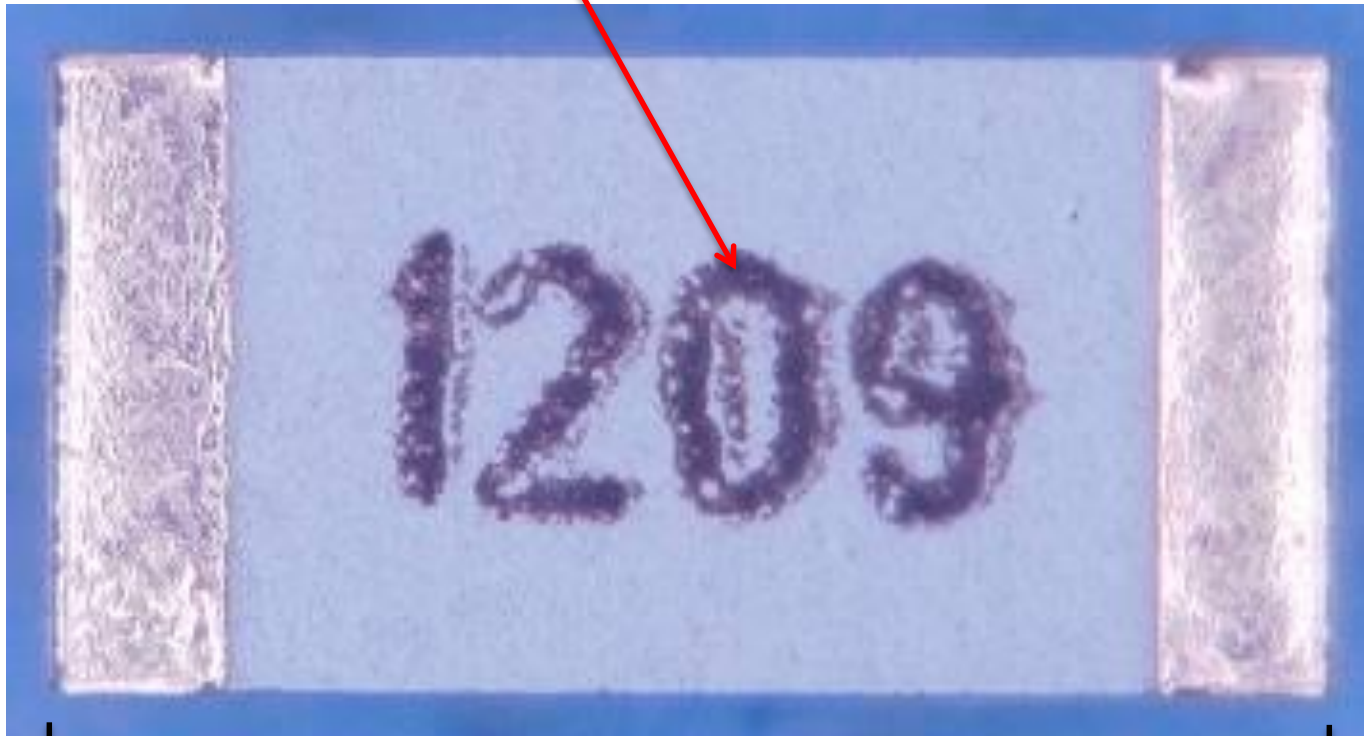
This is a reduction in area of 12 orders of magnitude!
Now THAT'S Much More Practical!

Resistor to Scale



Resistor Part of Interest

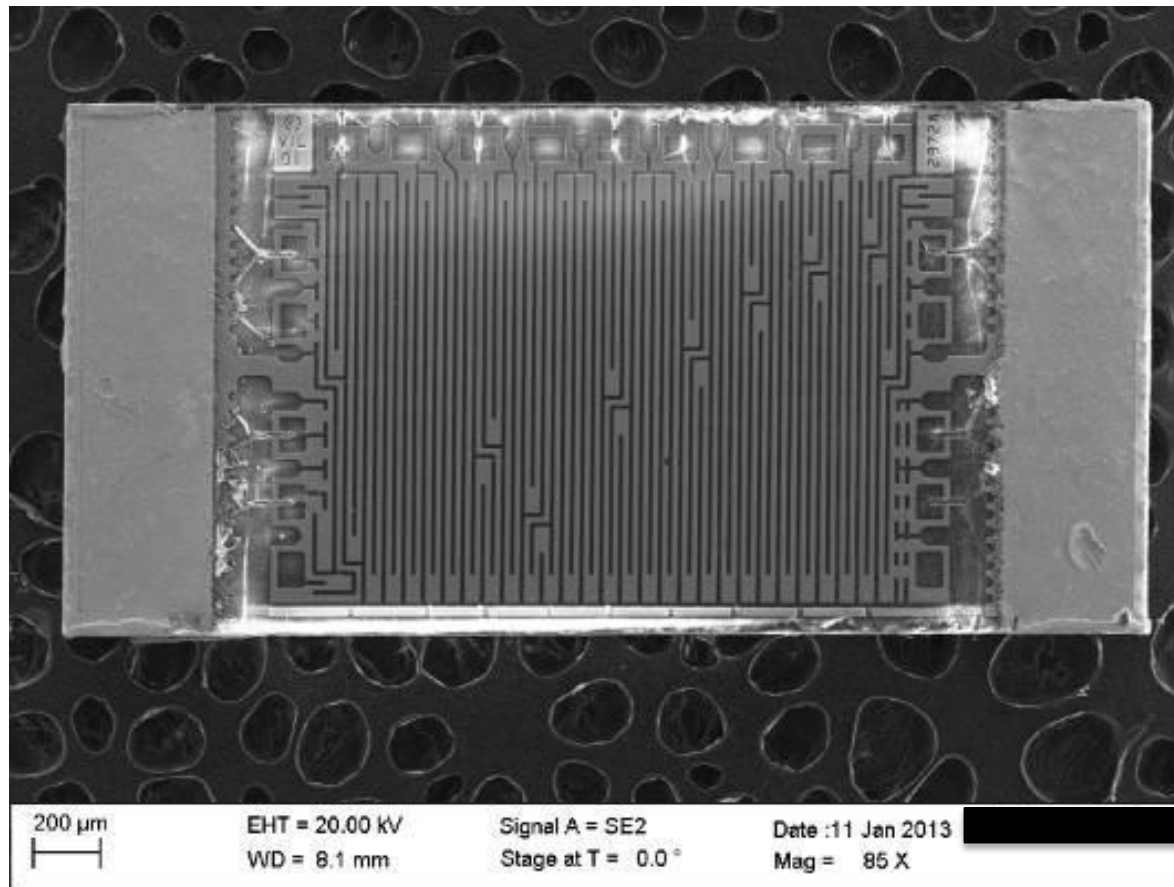
Date Code: 9th week of 2012



0.060 Inches
0.0015 meters

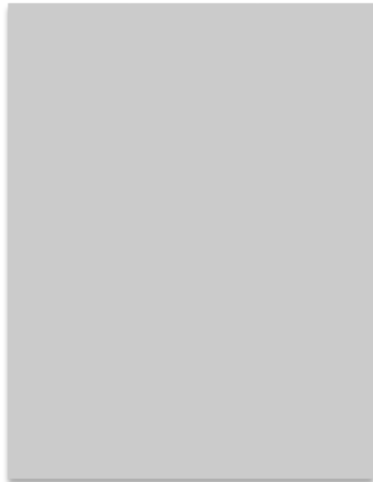
0.120 inches
.00305 meters

Scanning Electron Microscope (SEM) Image of Resistor Without Blue Coat



What Happens to Thin Metals

Household Aluminum Foil
0.000,016 meters thick

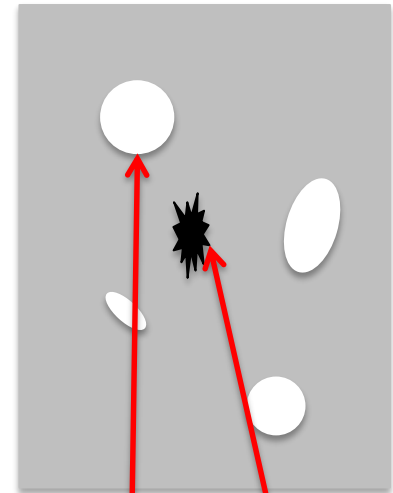


**Porous
aluminum**



**Metal
foam**

A foil 0.000,001 meters thick



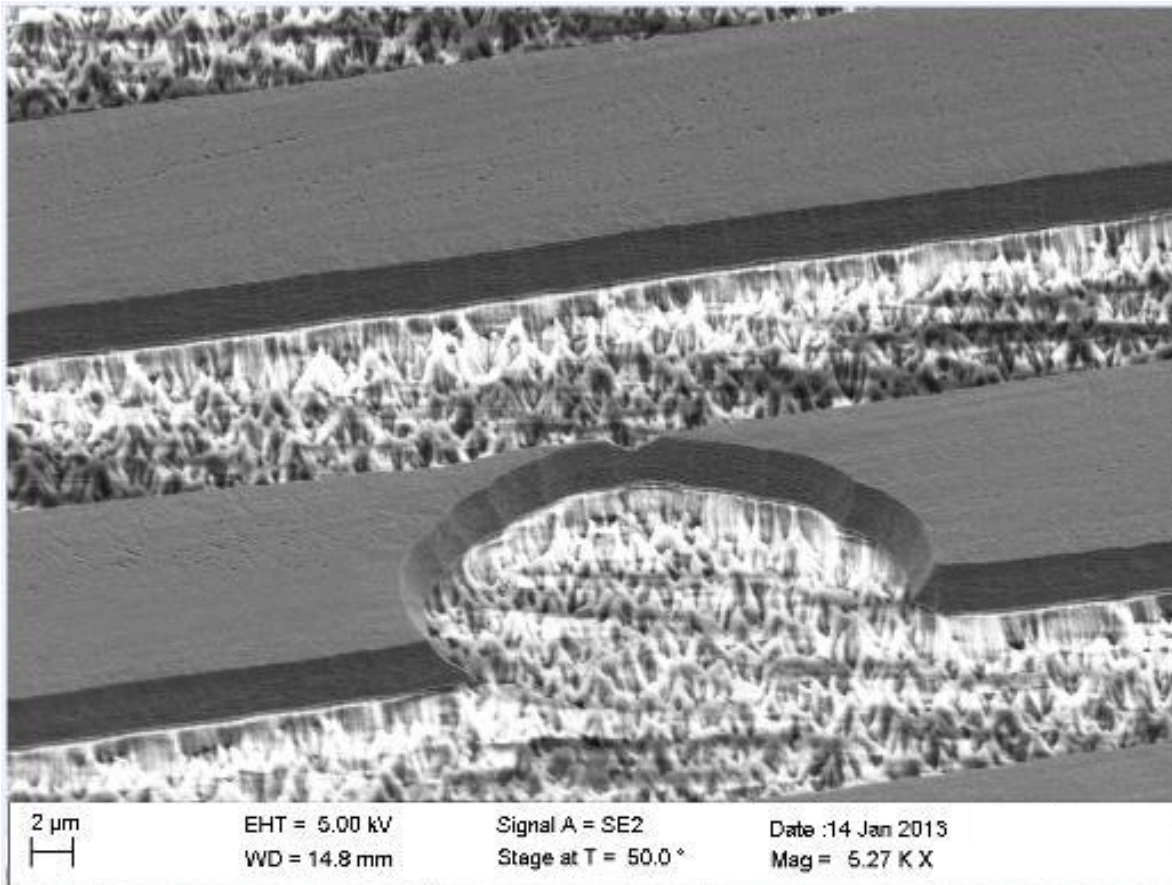
Holes

Particles

http://b2bimg.bridgat.com/files/Porous_aluminum_An_Alternative_to_Sintered_Metals.jpg

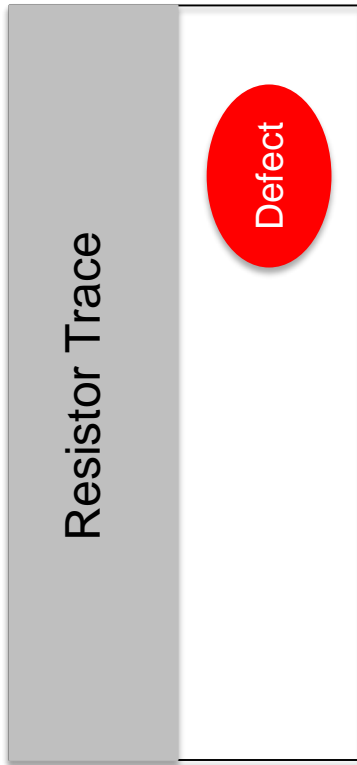
Metallurgists describe this as a metal becoming **porous**

Nichrome Foil Resistor with a “RAT BITE” (May Be Caused by Working with a “Porous” Foil)

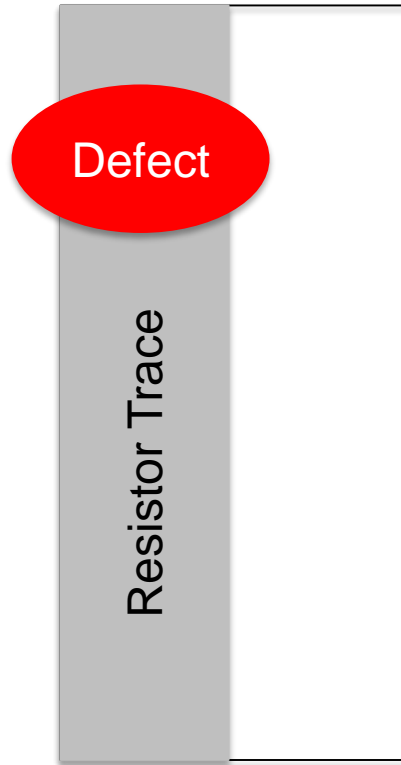


What do “Defects” do to Resistance?

No Effect

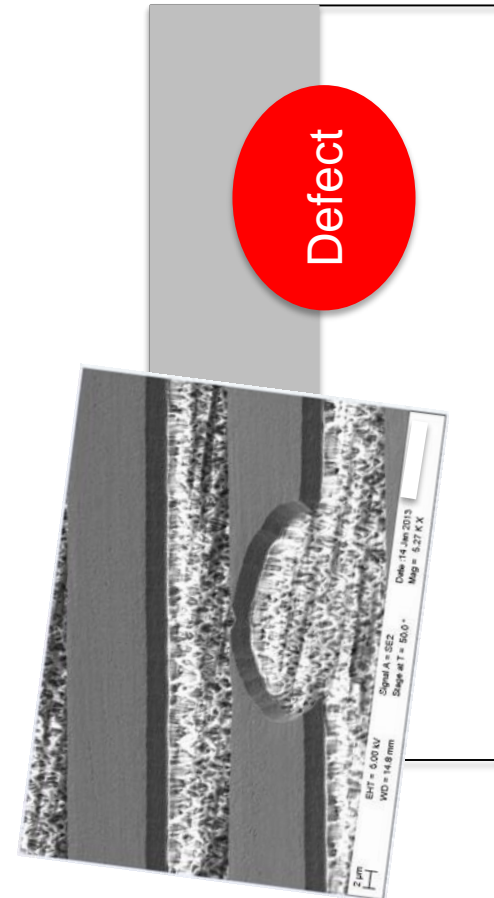


Open Circuit
No Resistor



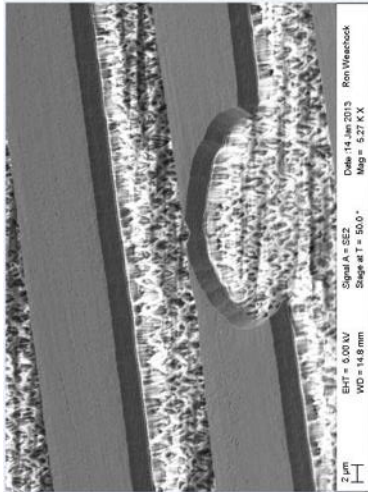
?

See next slide



Change in Resistance

A rat bite at one location where 90% of a trace is missing before it can be electrically detected (Maybe*).



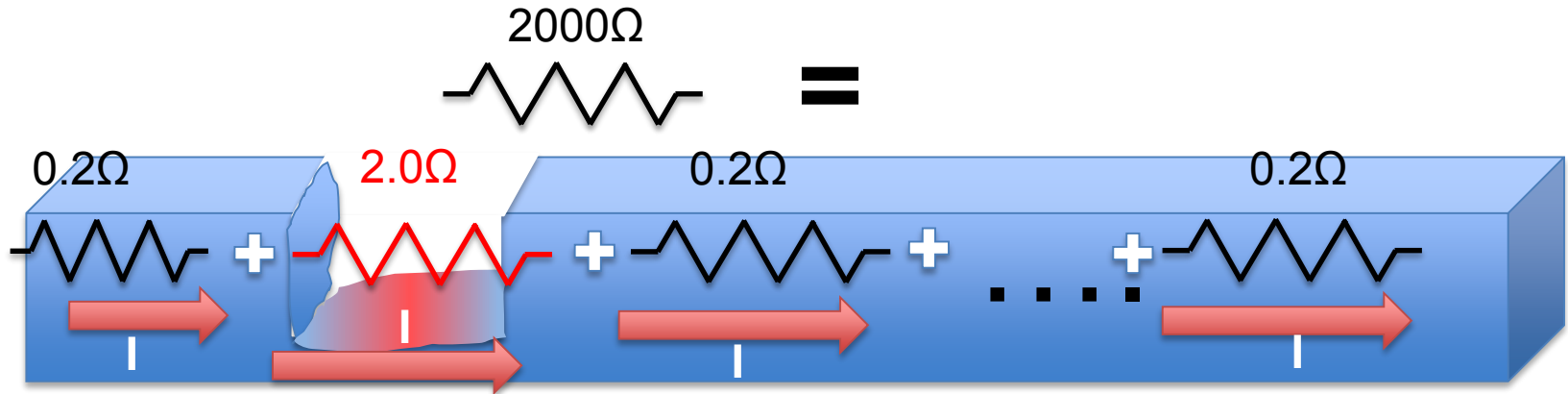
* In the case of a “Trimmed Part” the change in resistance is accounted for and the change becomes part of the final value.

A “Rat Bite” Has a Higher Resistance Due to the Smaller Cross Sectional Area

Example:

For a given Length (L) segment of resistor a 90% reduction in the Cross Sectional Area, Produces a 10x INCREASE in the resistance of the normal segment

The Same Electrical Current (I) in Amperes Flows Through ALL Segments of this Resistor



But the POWER Dissipated in the “RAT BITE” is Higher Because its Resistance is Larger

$$P = I^2 * R$$

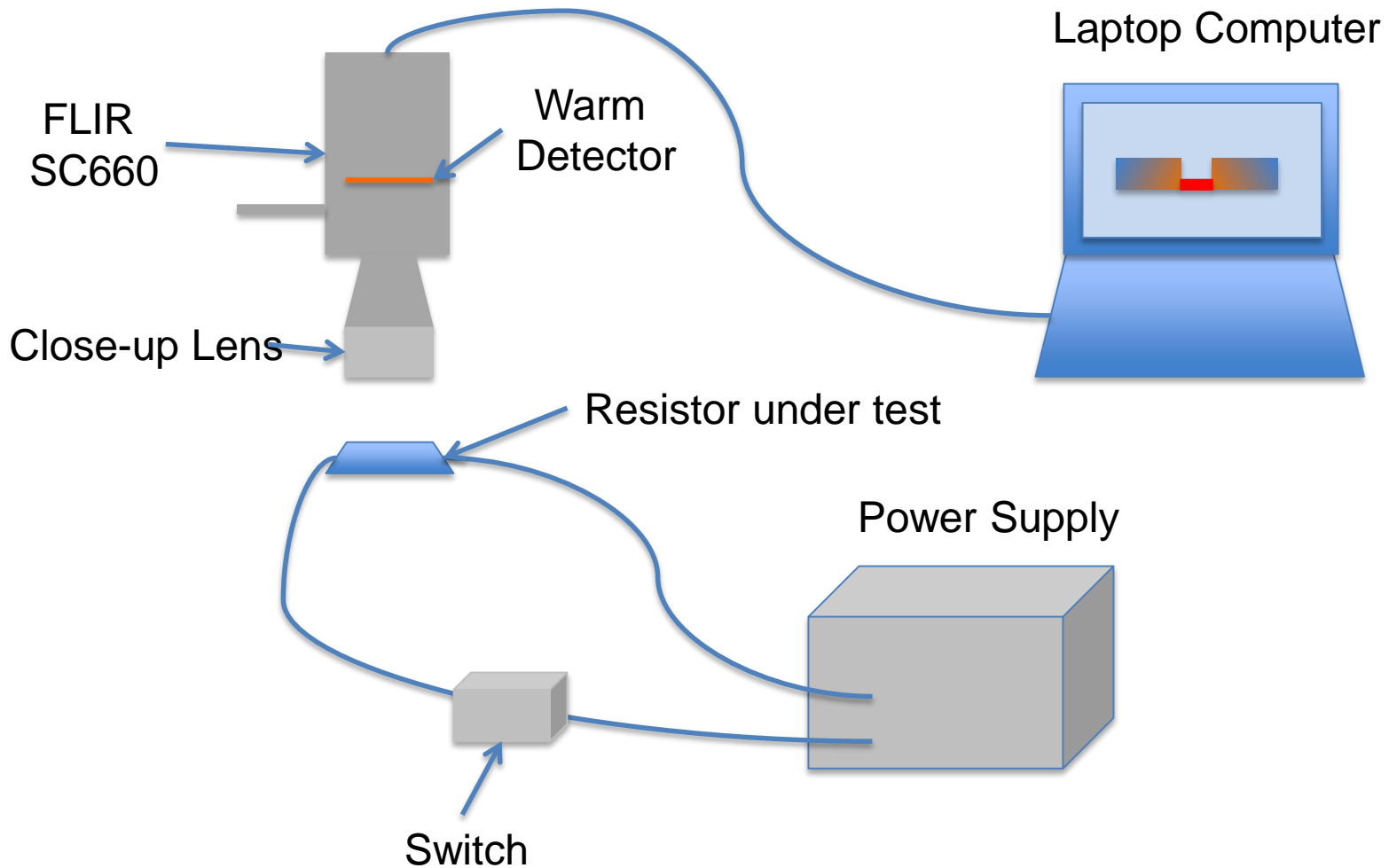
“Rat Bites” Get Hot Because

they

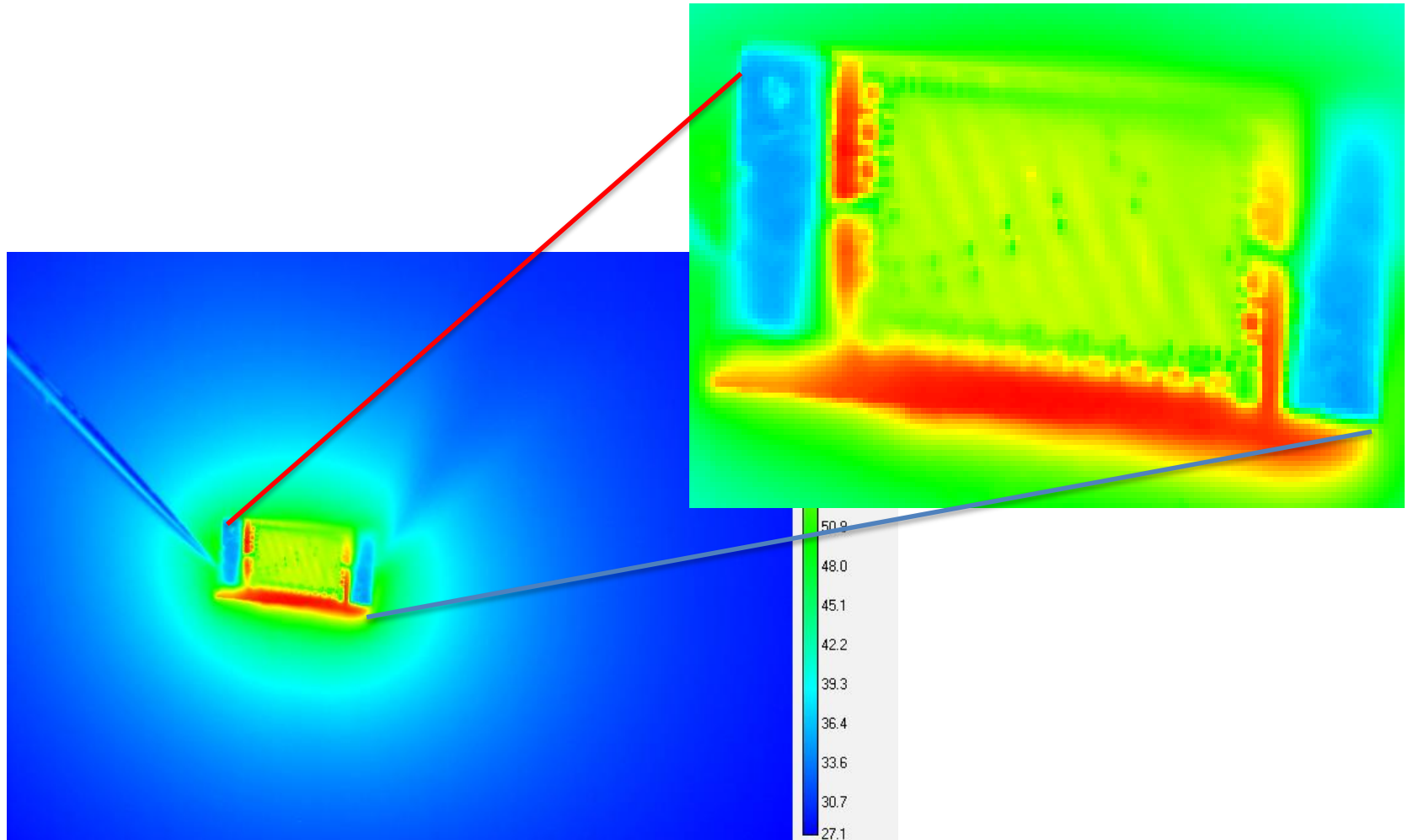
Dissipate MORE Power than Other Parts
of the Resistor

How hot does it get, how fast
does it get hot and could it
induce a failure?

Original Test Setup

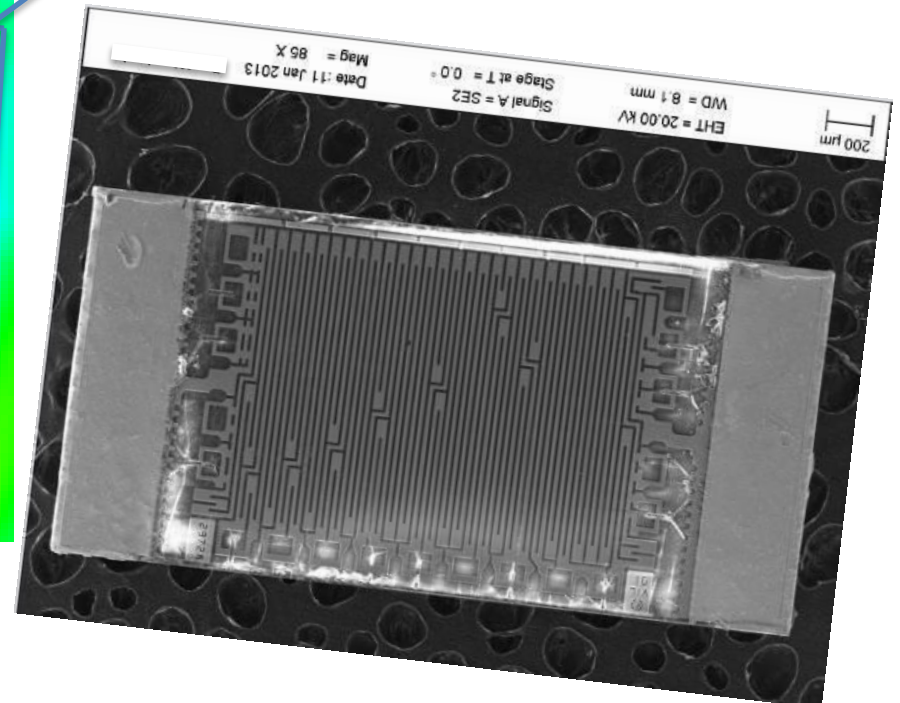
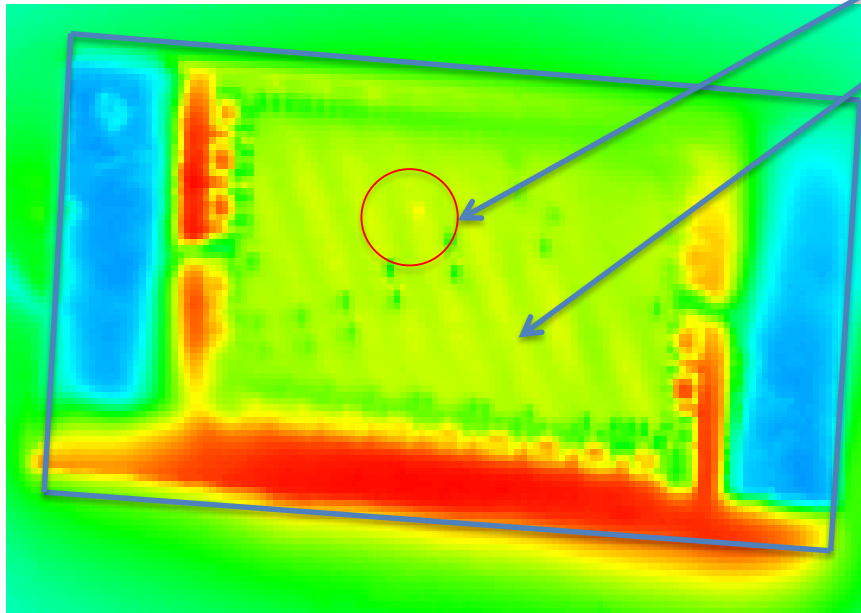


First Test Run



Items of Interest

Hot Spot
Stripes

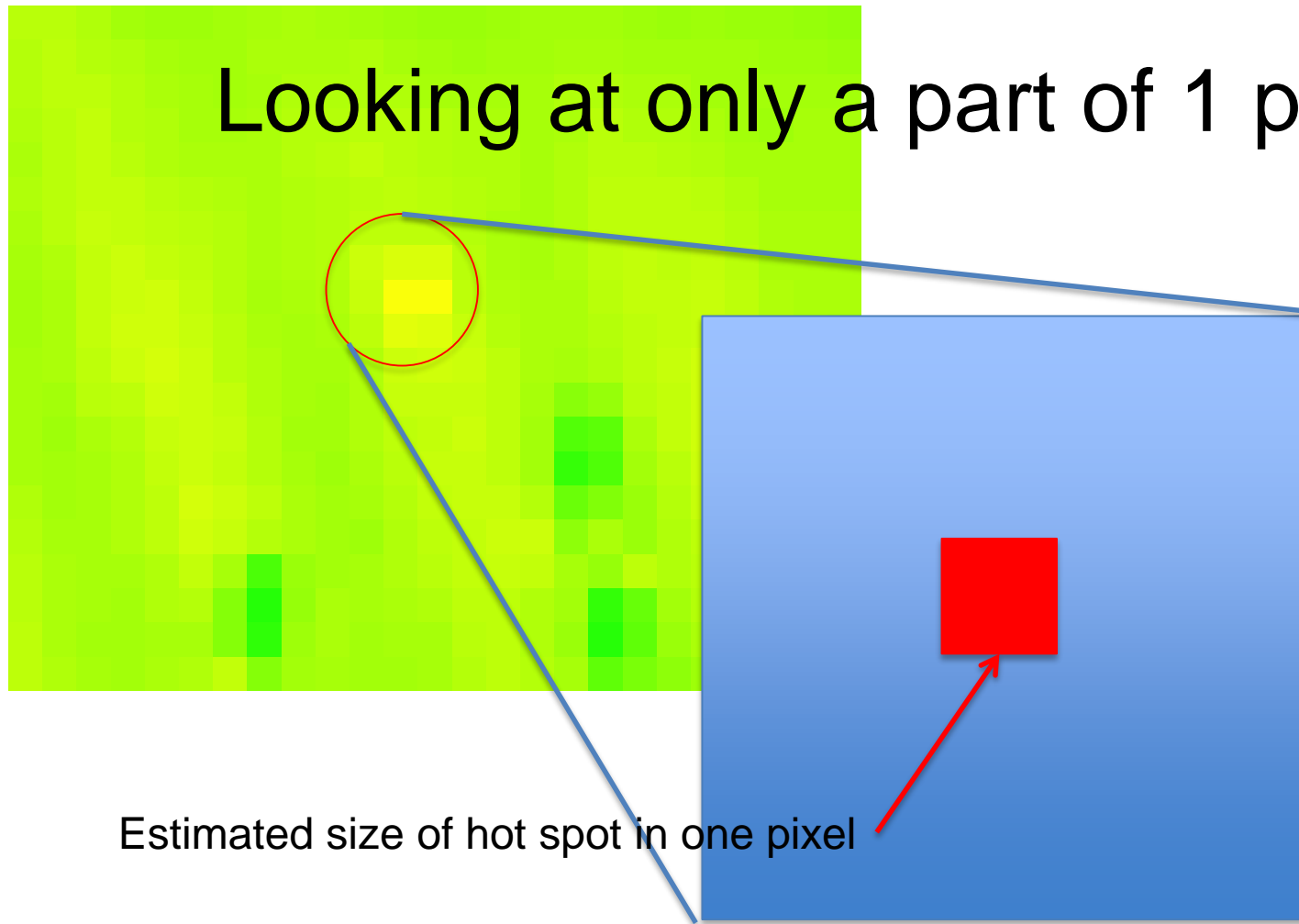


Accomplishments of First Run

- Overall we could see the resistor was getting hot.
- Temperature rise at one spot was MAYBE 2C had expected a 60C rise.
- Expected to see 2 hot spots and saw maybe only 1.
- Saw “diagonal” stripes that were unexpected.

Disappointed, but What Went Right?

Looking at only a part of 1 pixel!



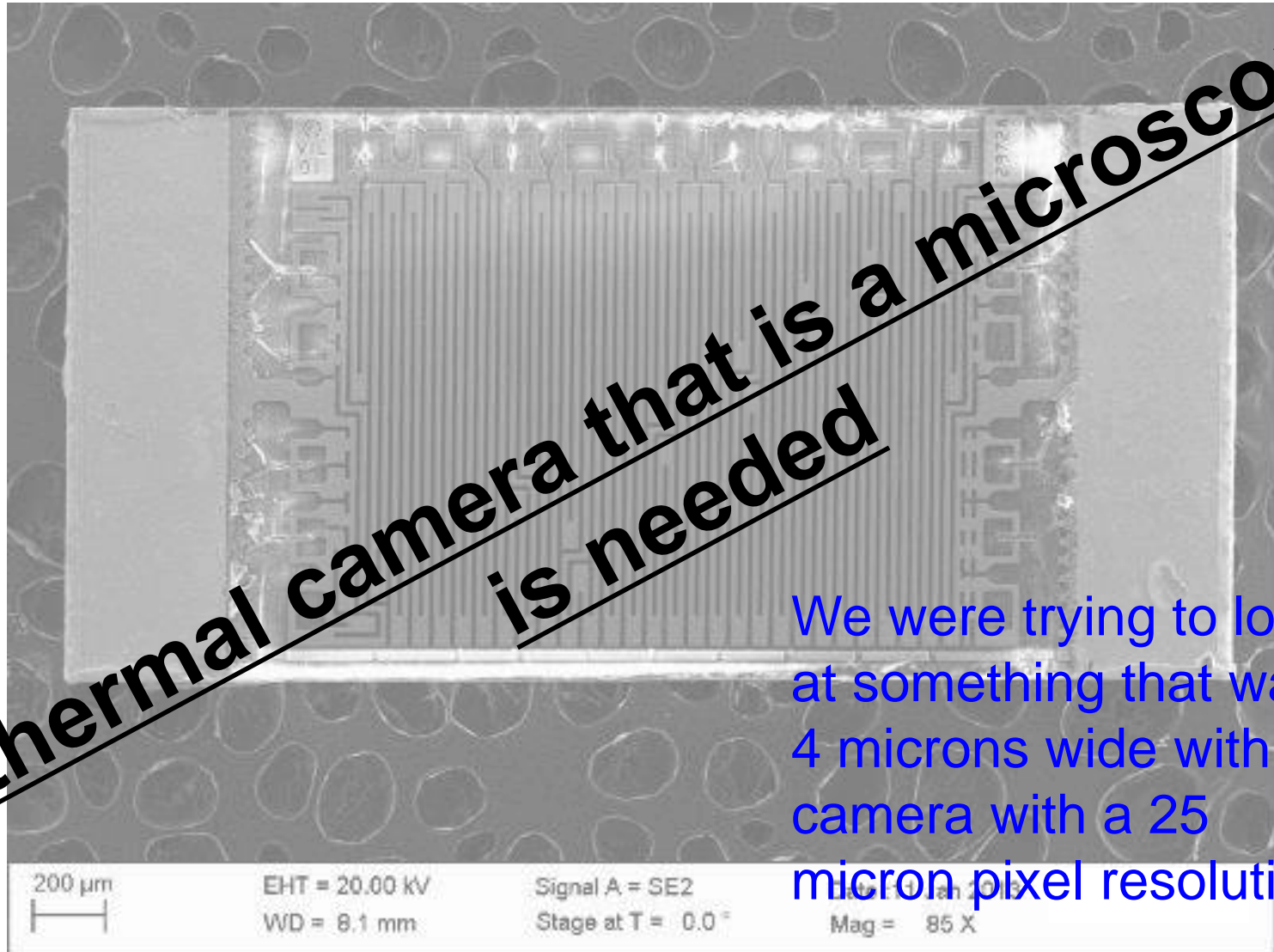
Disappointed, but What Went Right?

- Overall we could see the resistor was getting hot.
- With a quick calculation the expected temperature of the one pixel was about right.
 - This is hand waving at its finest
- Expected to see 2 hot spots and saw maybe only 1.
 - To be expected as the second hot spot was **physically even smaller than the one we saw**
- Saw **diagonal** stripes that were unexpected.
 - More on this later

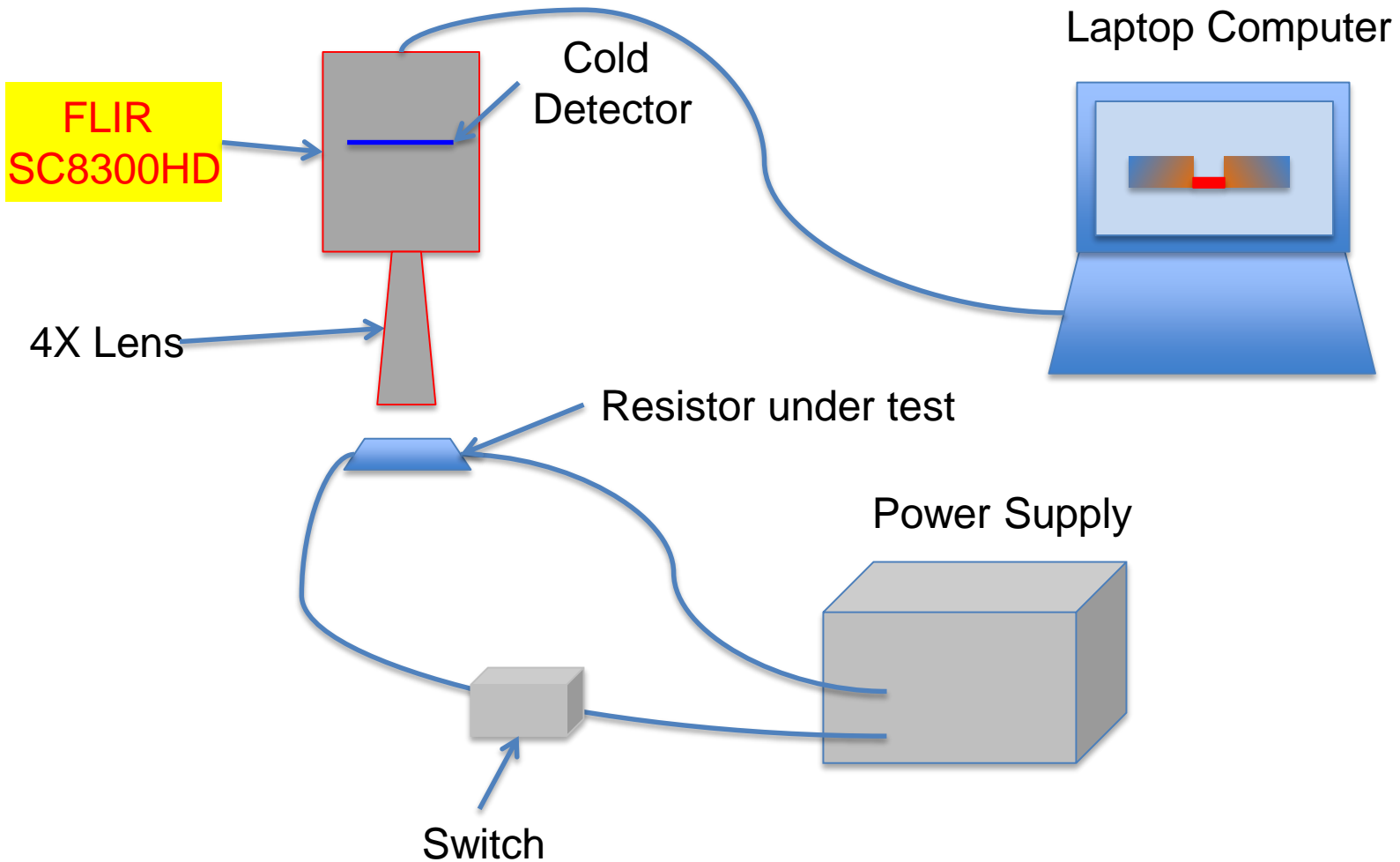
A Conclusion

A thermal camera that is a microscope is needed

We were trying to look at something that was 4 microns wide with a camera with a 25 micron pixel resolution.

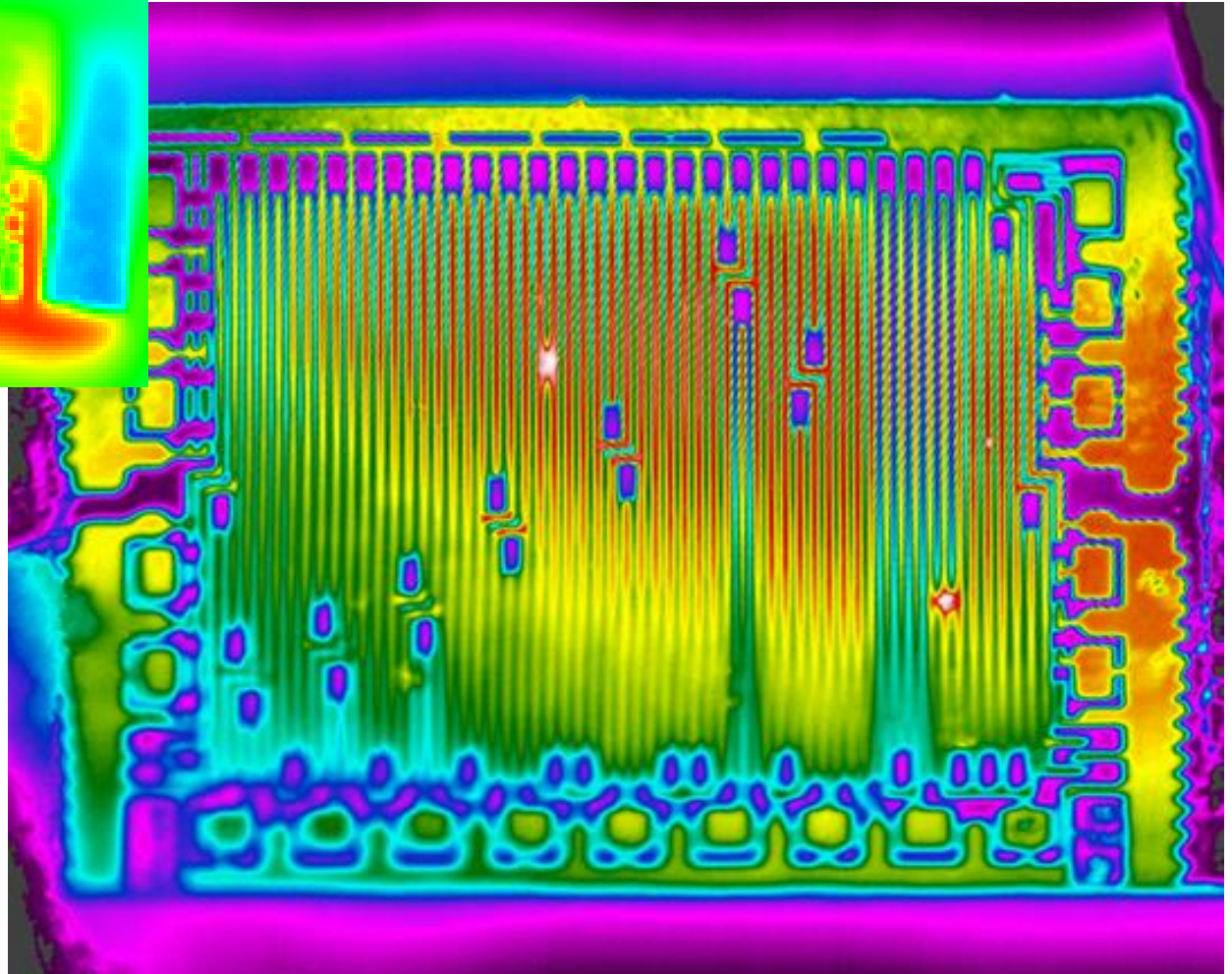
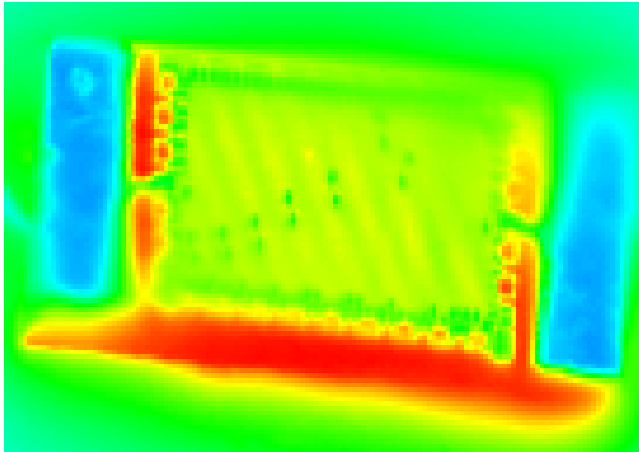


New Test Setup



First Light

Was

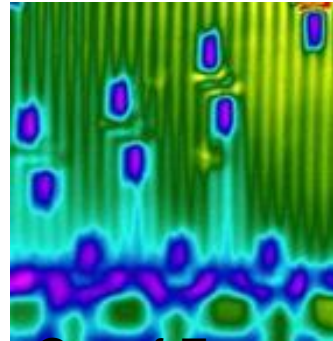


IS

Items of Interest from First Light

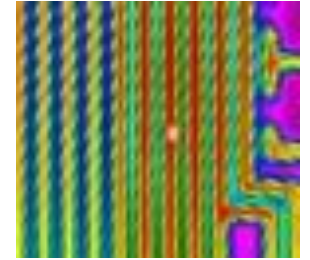


Moiré Patterns



Out of Focus

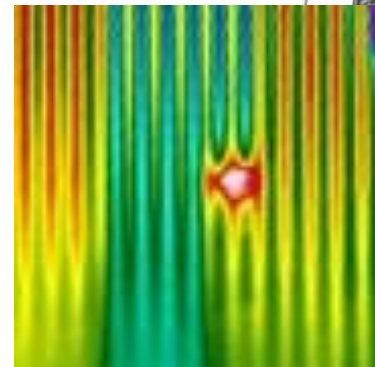
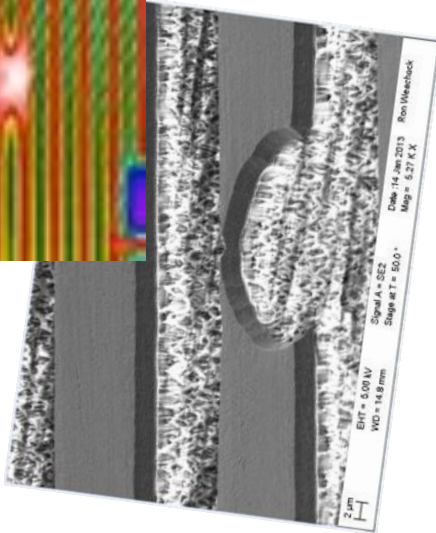
Dust



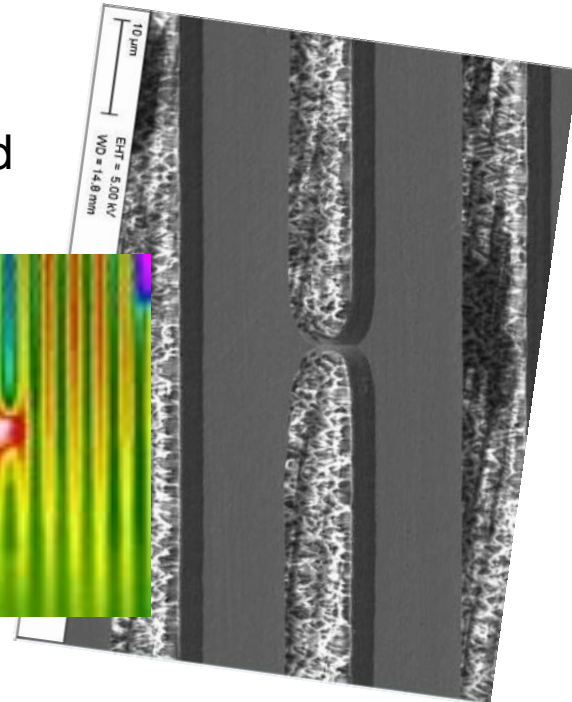
Due to Time Constraints
Very Shallow Depth of Field



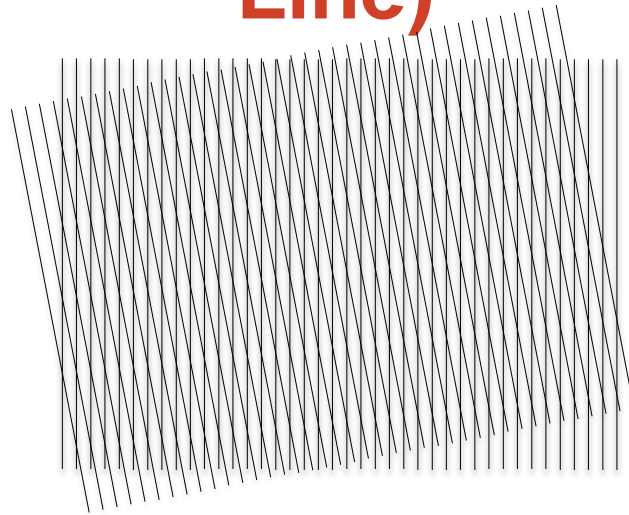
The Rat Bite



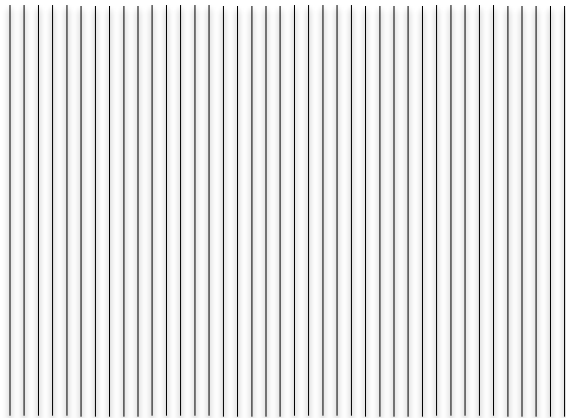
Bridge Short



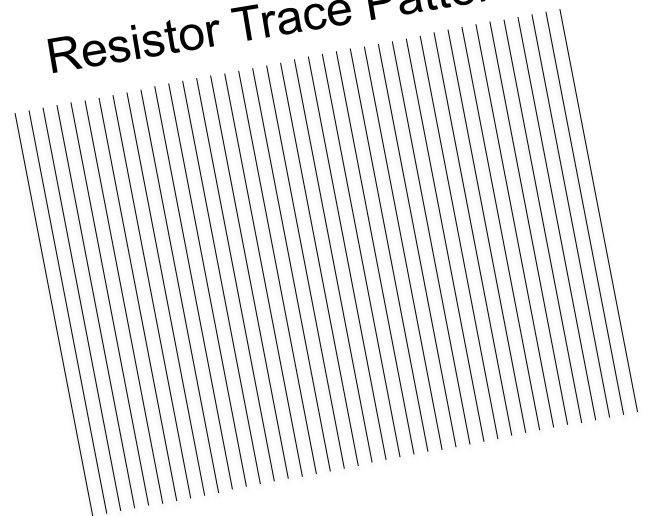
Moiré Pattern (11° Angle Fine Line)



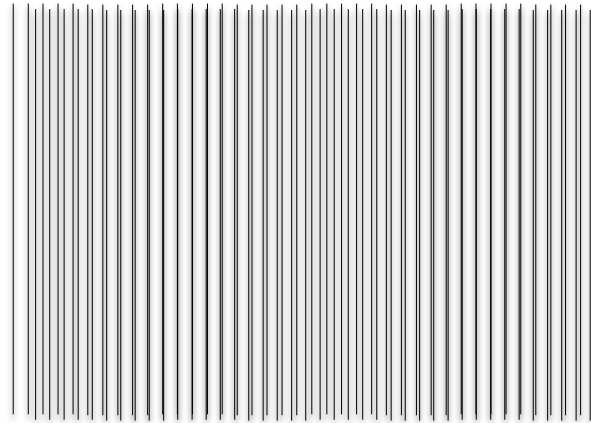
Camera Pixel Pattern



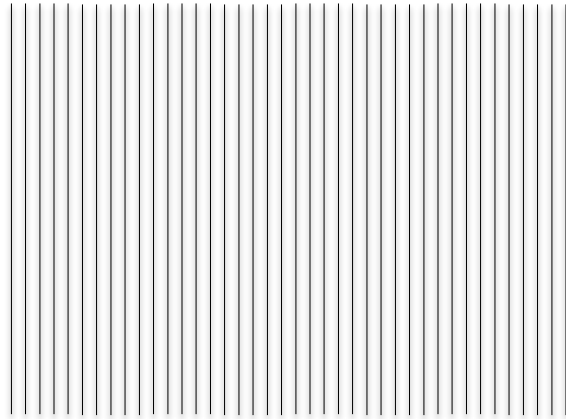
Resistor Trace Pattern



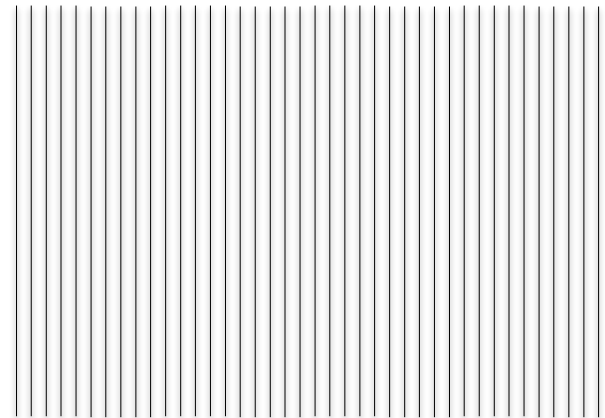
Moiré Pattern (Parallel Fine Line)



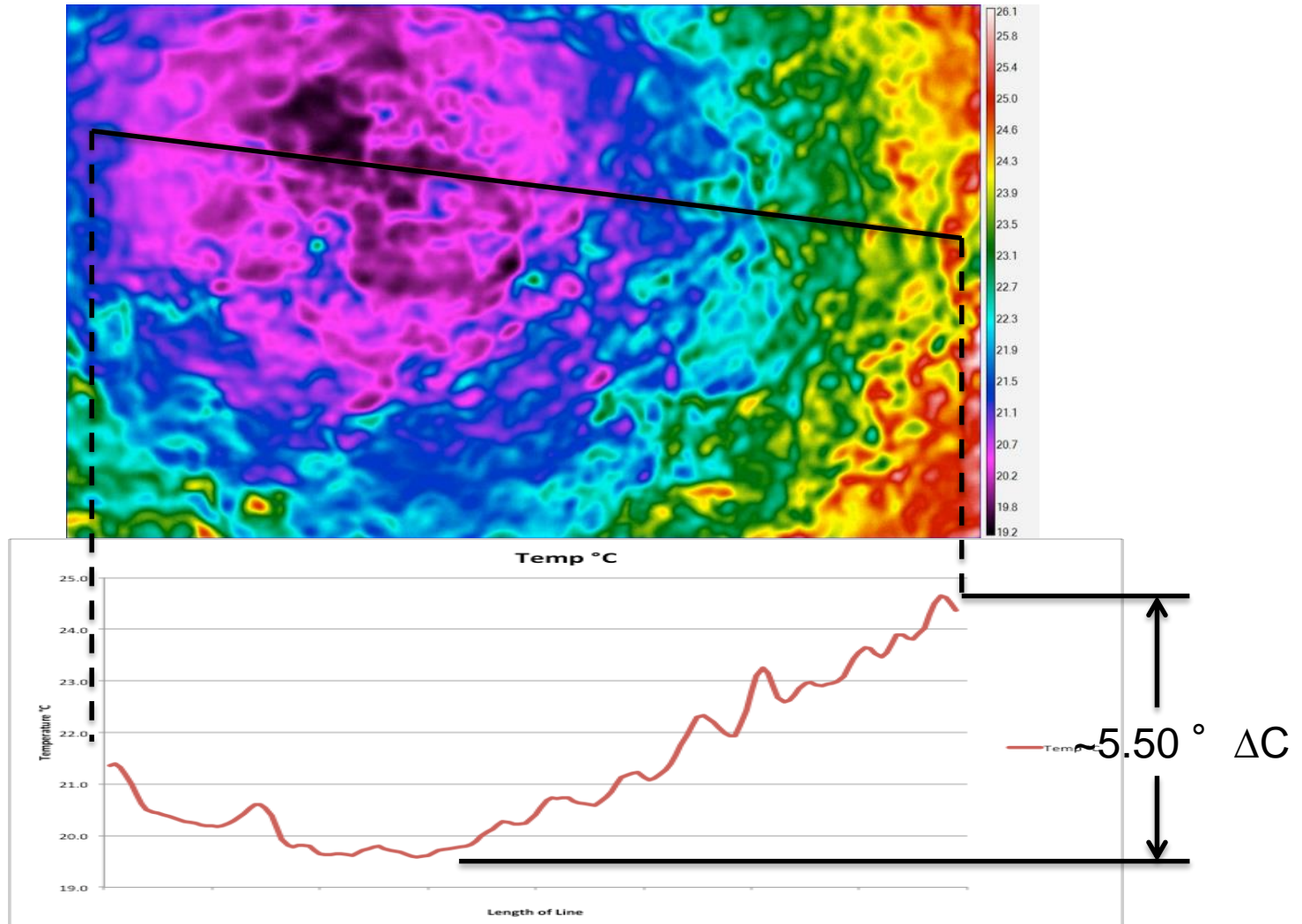
Camera Pixel Pattern



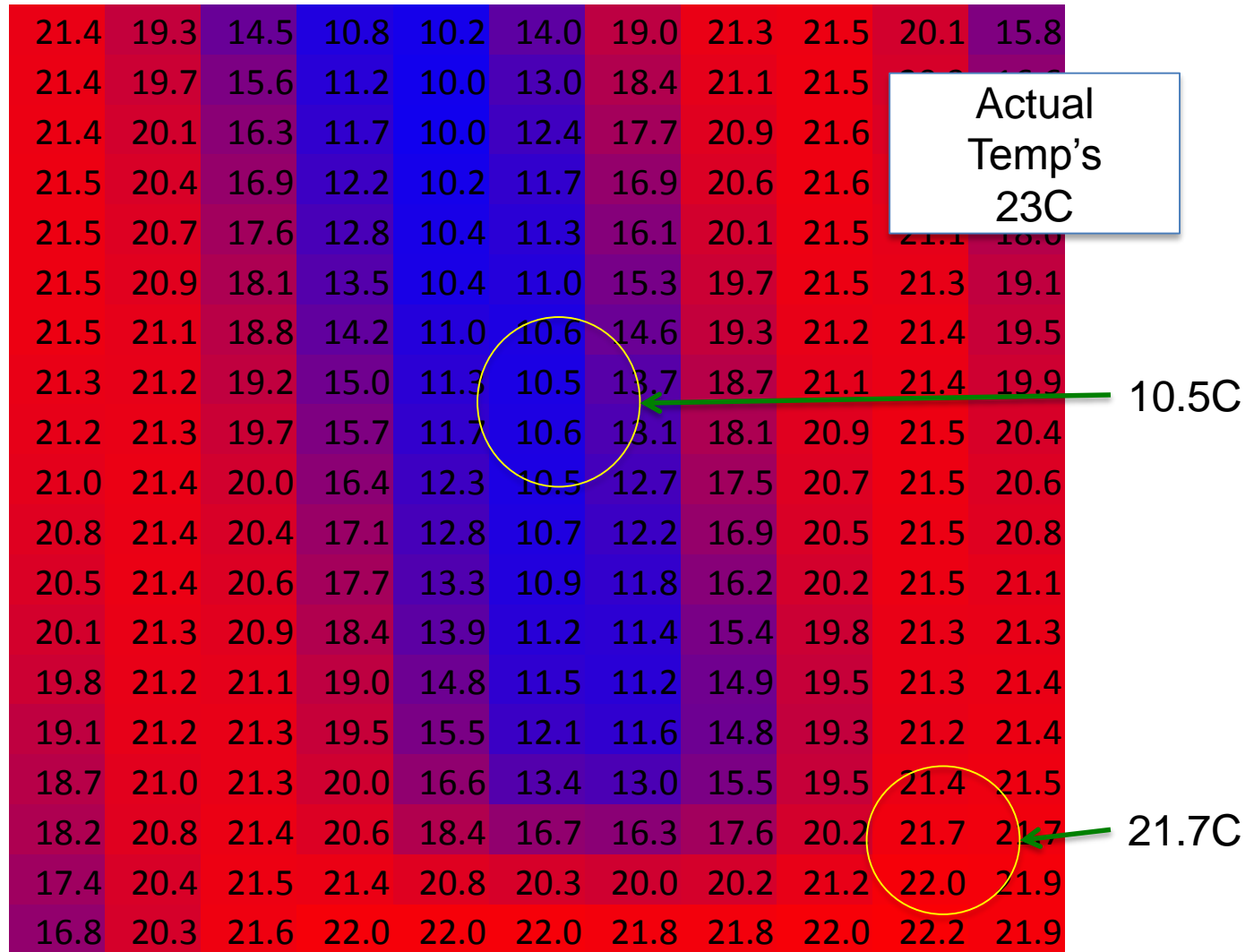
Resistor Trace Pattern



Narcissus Effect on Emissivity Measurement



Room Temp with One Emissivity



Emissivity Map

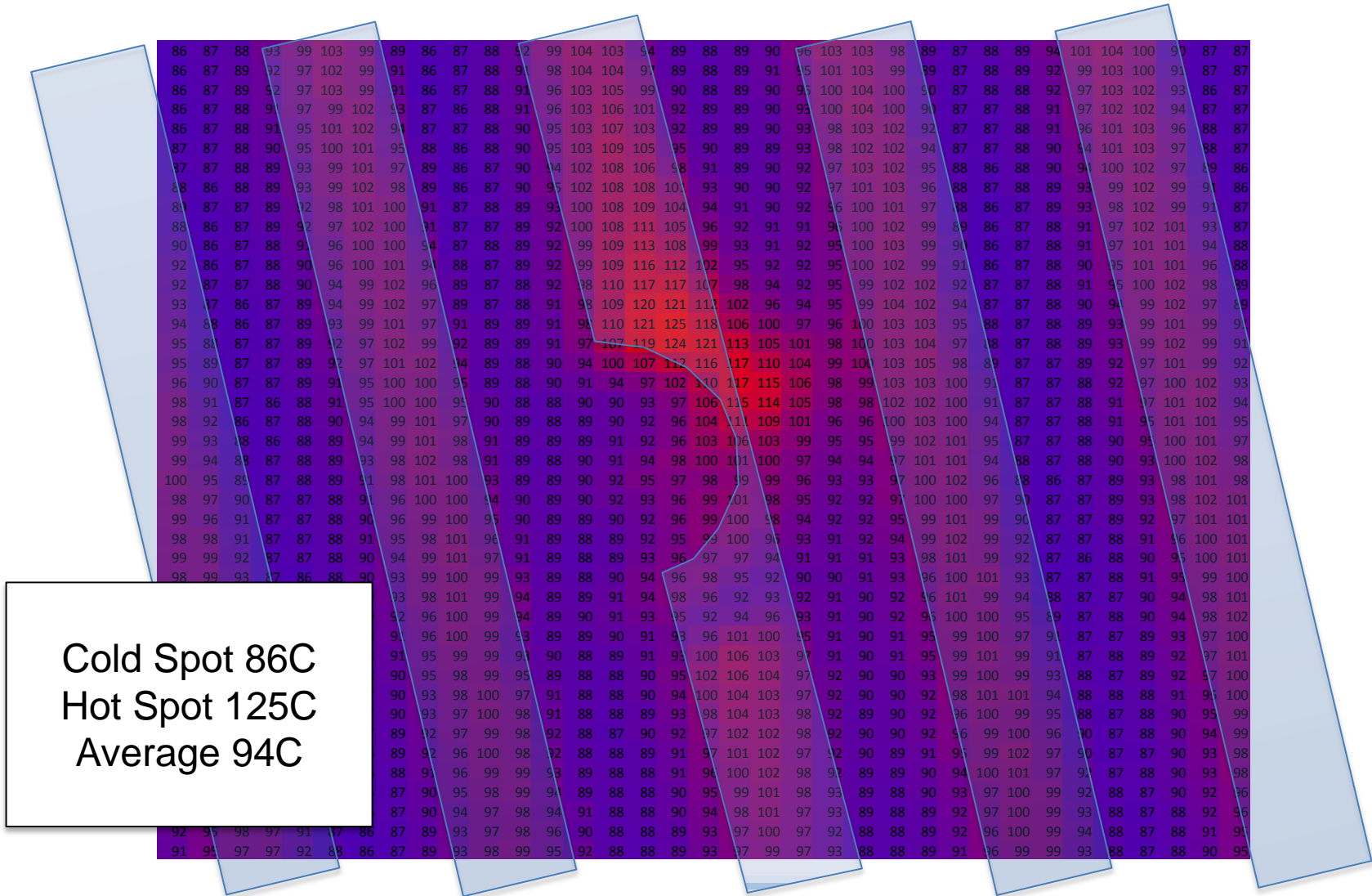
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86	87	82	71	54	42	49	70	84	87	83	67	46	37	43	64	82	87	85	72	51	38	39	56	77	86	86	78	58	41	37	49	73	85	87	82	65
86	87	84	69	49	39	45	66	82	87	84	69	48	38	41	61	80	87	86	75	55	39	38	52	74	85	87	80	61	43	37	46	69	84	88	83	68
85	87	83	67	47	38	43	63	80	87	84	72	51	38	39	57	78	86	86	78	57	41	37	48	71	84	87	82	65	45	37	43	66	82	87	84	71
84	87	83	69	48	38	40	58	78	86	85	75	54	40	38	53	75	86	87	79	60	42	36	45	68	83	87	83	68	48	38	41	61	81	87	85	73
83	87	84	71	50	38	39	55	76	86	86	77	57	41	37	50	73	85	87	81	64	44	38	43	64	82	87	84	71	50	39	40	58	79	86	86	76
81	87	85	74	53	39	38	52	74	85	87	79	61	43	37	47	70	84	87	82	66	46	37	41	61	80	86	85	73	53	39	39	54	76	86	87	79
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Rat Bite at One Emissivity

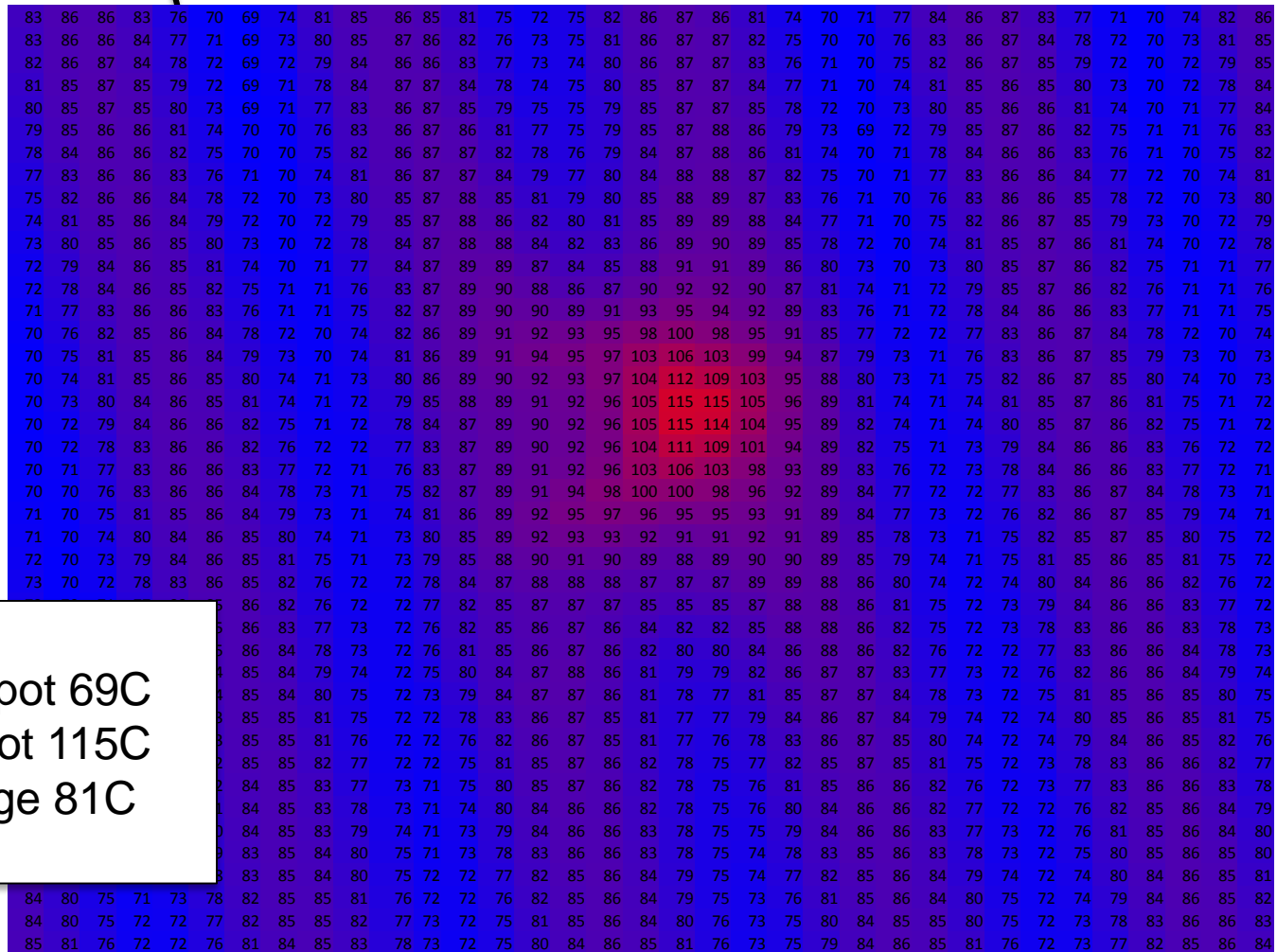
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Cold Spot 69C
 Hot Spot 115C
 Average 81C

Hot Spot Adjusted Emissivity



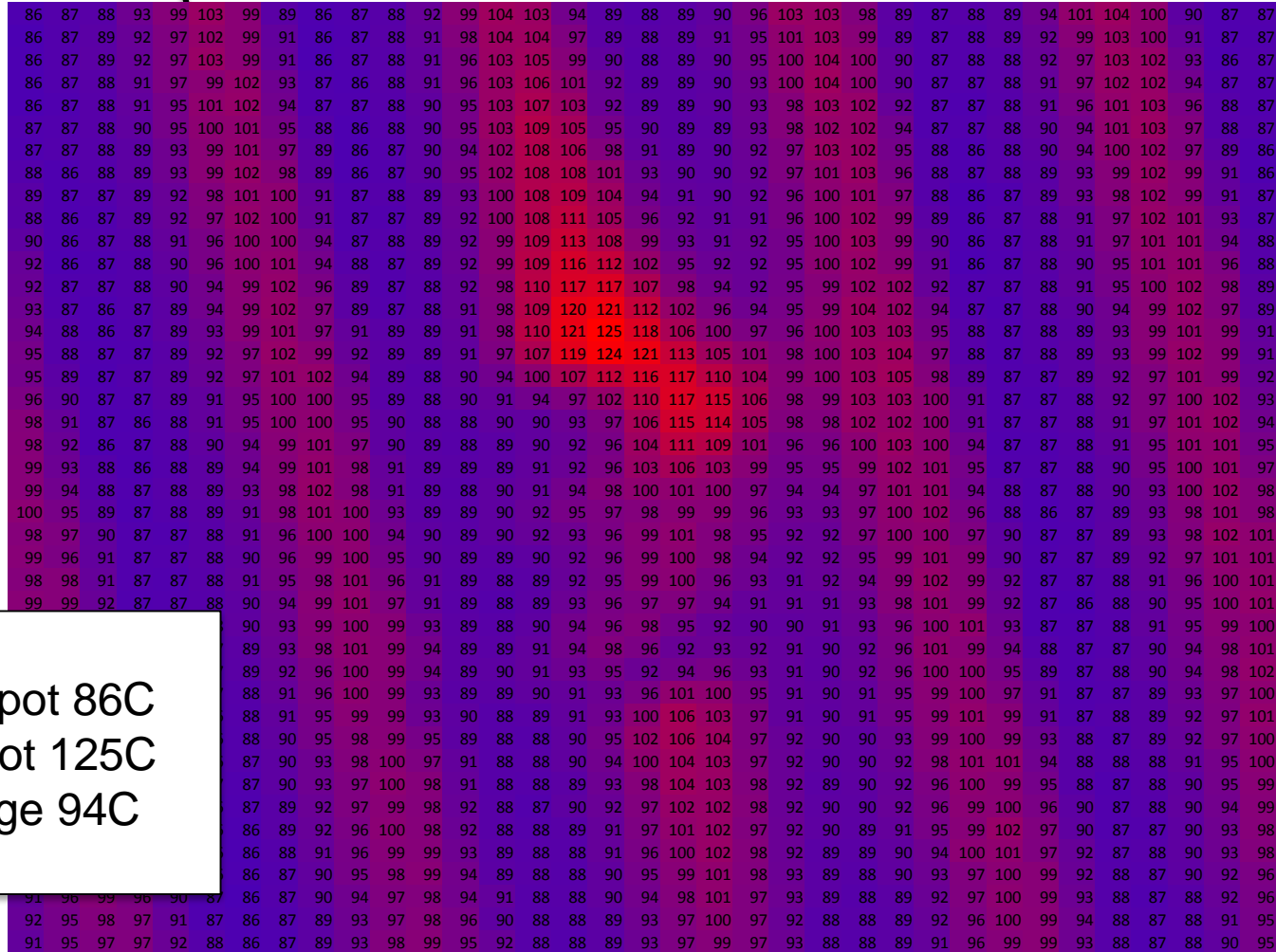
Rat Bite at One Emmissivity



Cold Spot 69C
Hot Spot 115C
Average 81C

Reference Line

Hot Spot Adjusted Emissivity



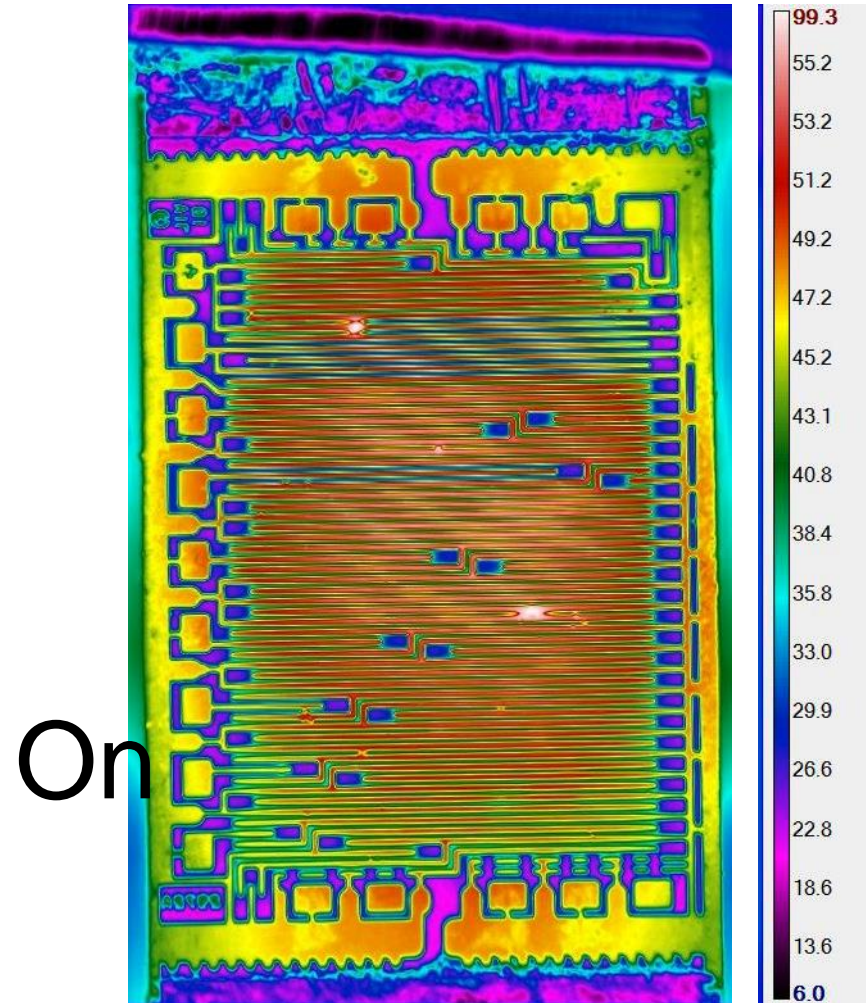
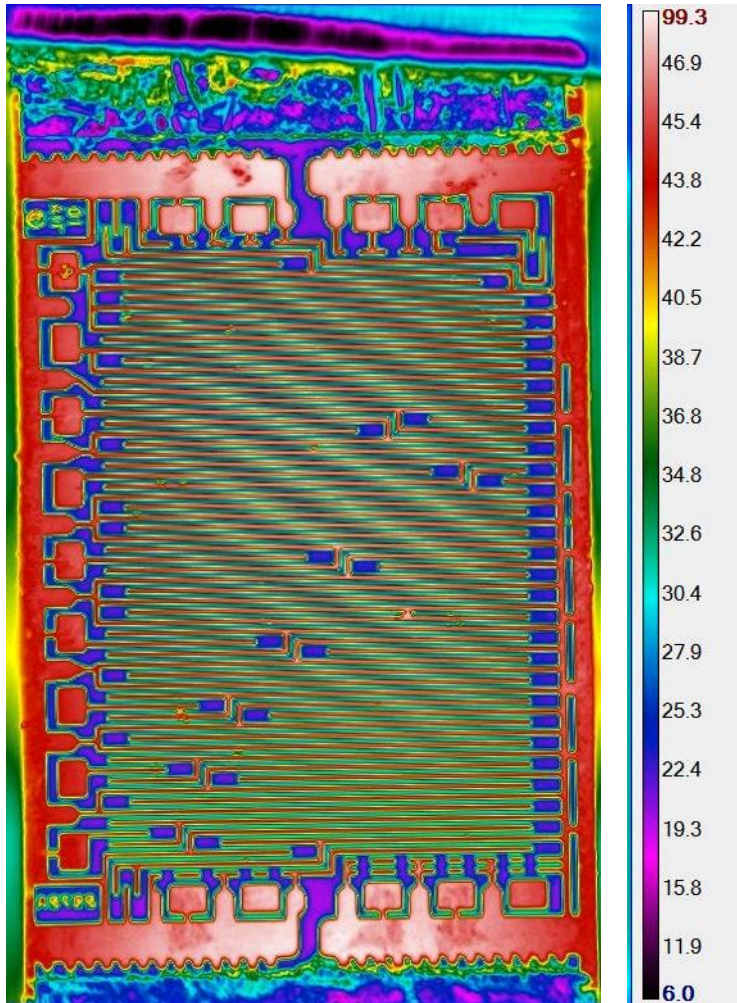
Reference Line

Lesson Learned

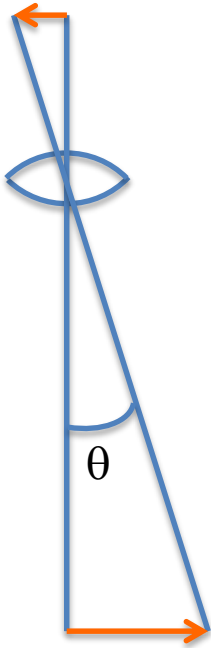
Because of the **very small** size of the part the trace internal to the resistor heats up quickly and cools off quickly.

Thermal cycling is quick, and testing with many cycles is beneficial

Pulse Test

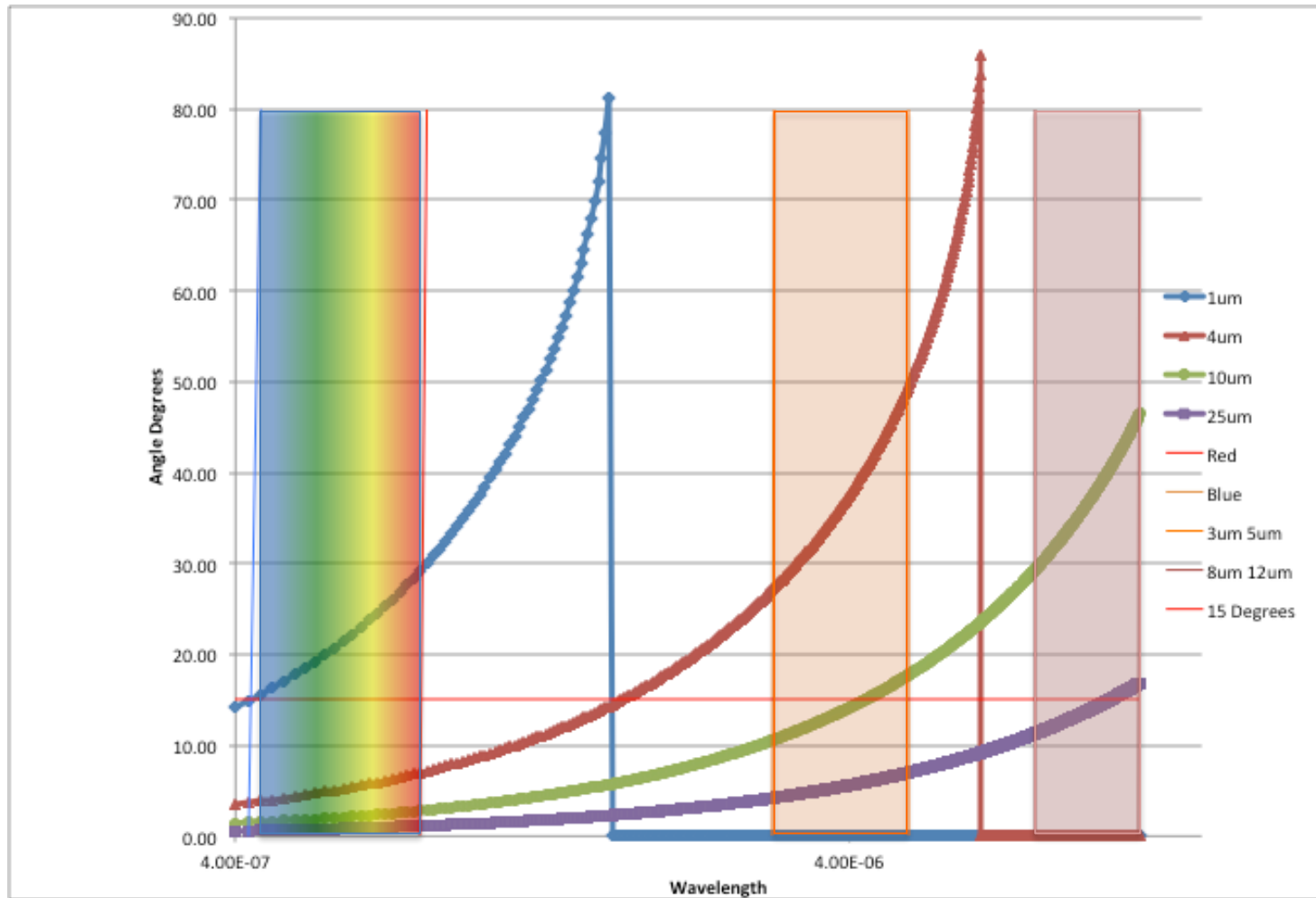


Resolution (r)

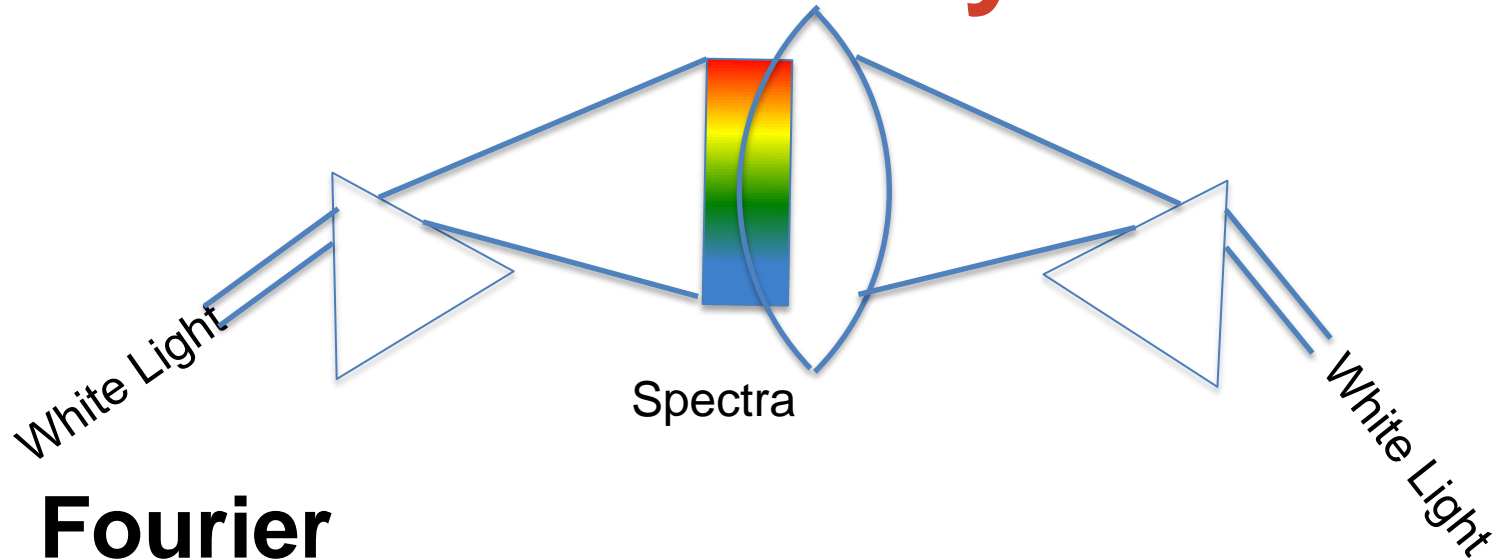


$$r = \frac{1.22\lambda}{2n \sin \theta}$$

Wavelength vs Angle

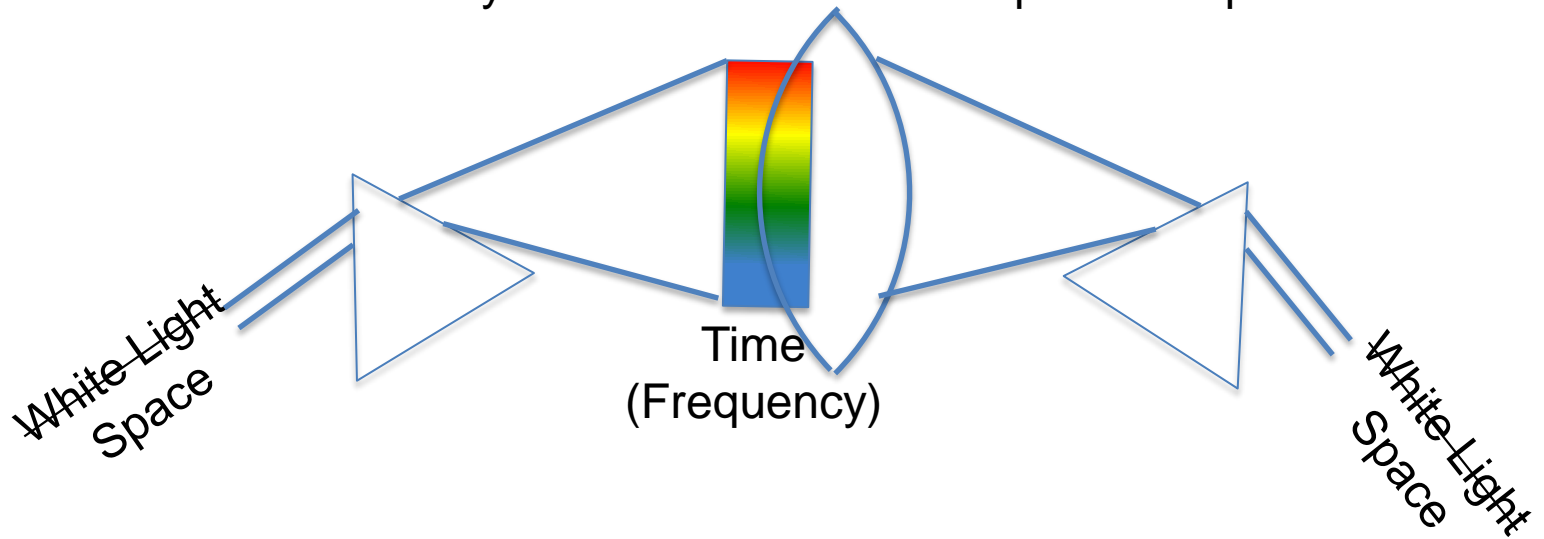


Newtonian Physics

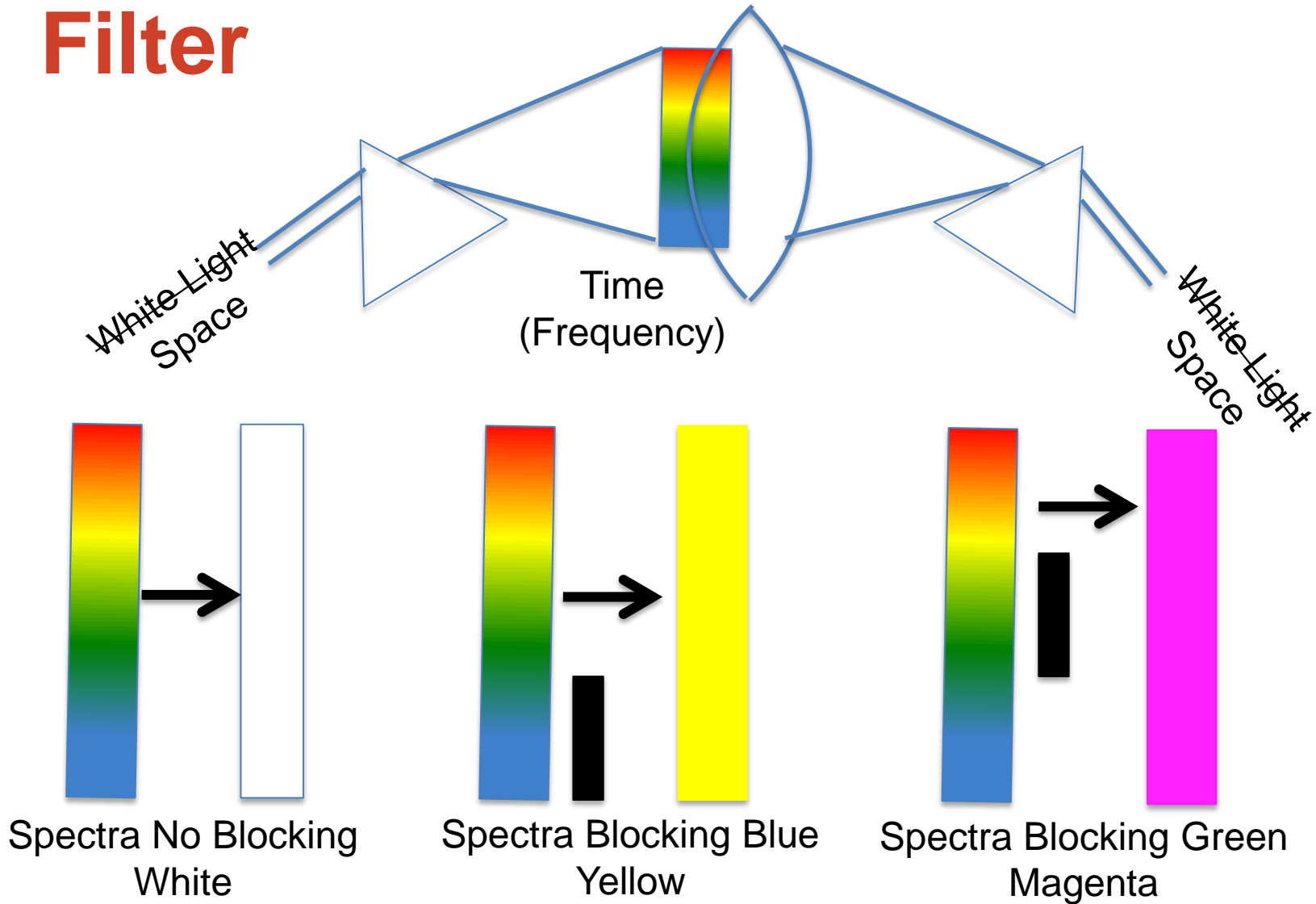


Fourier

Looks at the analysis between Time and Space of a periodic function

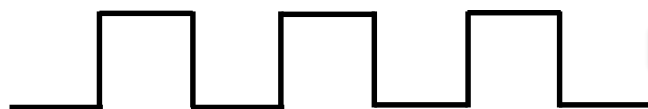
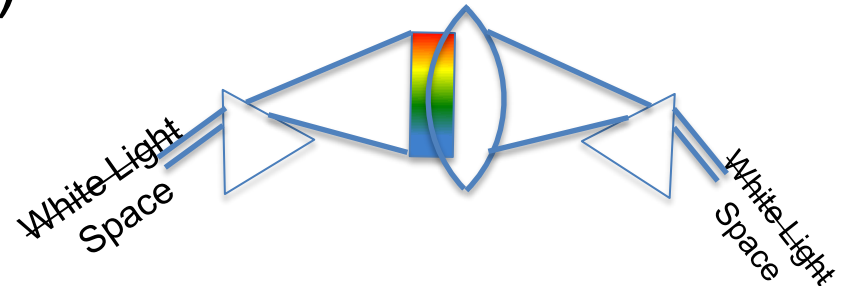


Use of Fourier Transform as a Filter

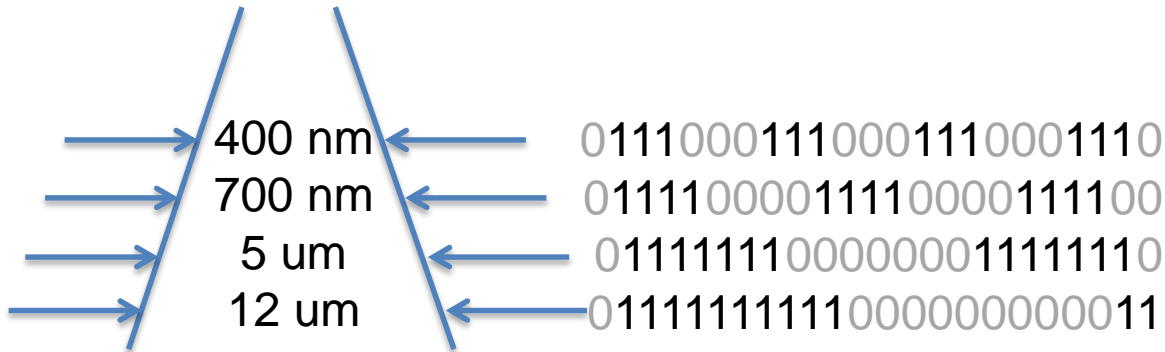


Resolution of Periodic Signal (Lines)

Line Width (space)

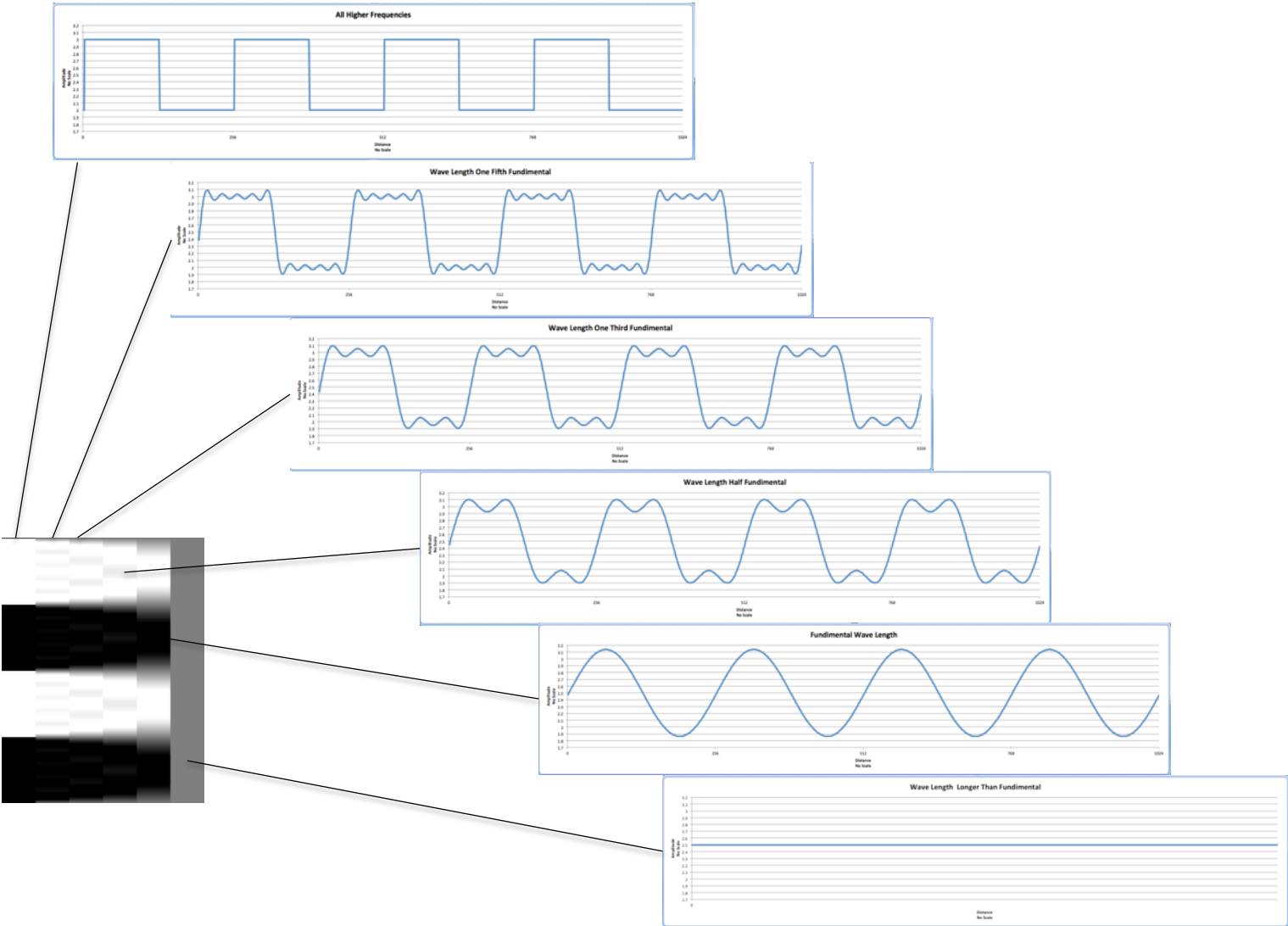


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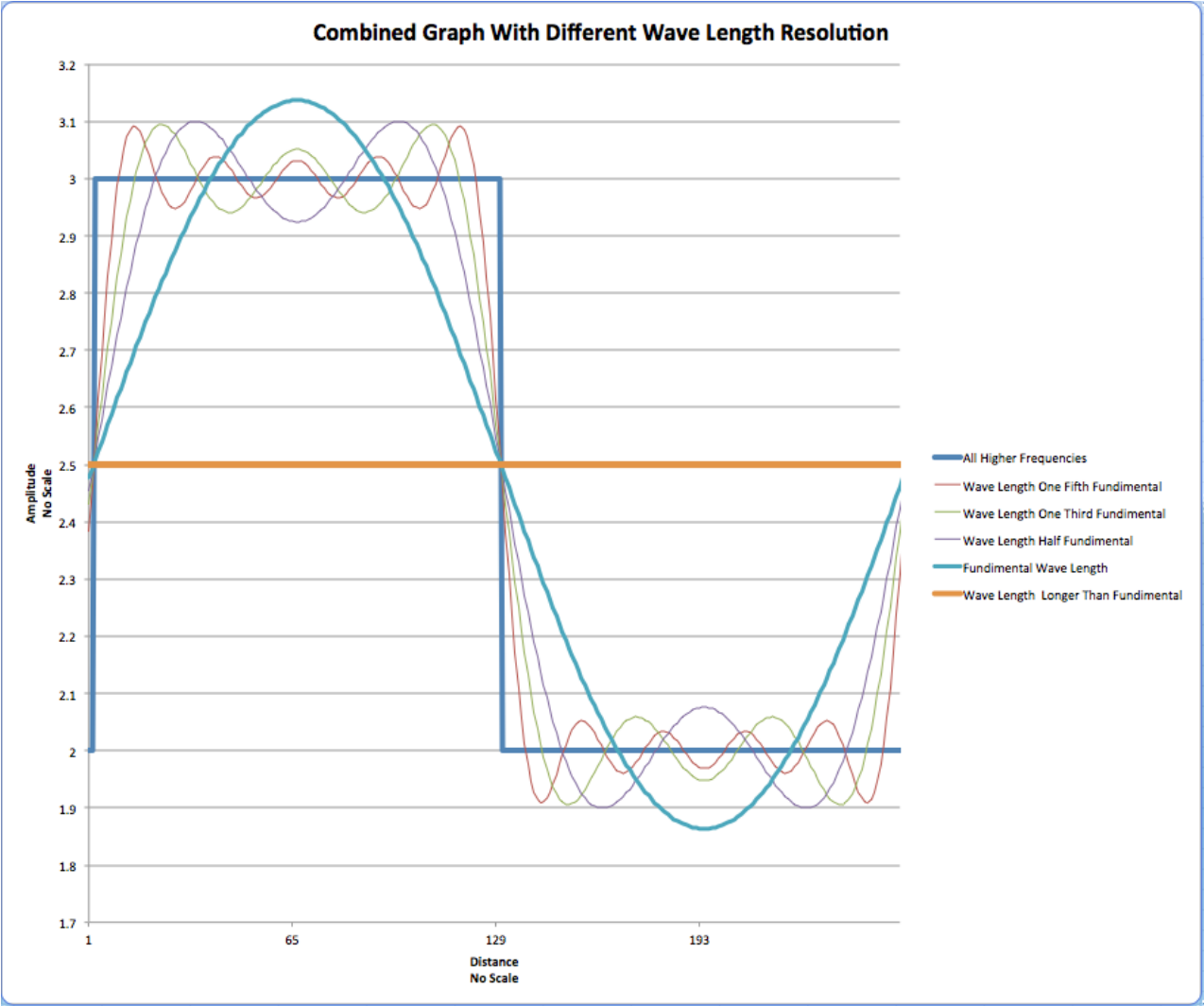


Not to scale

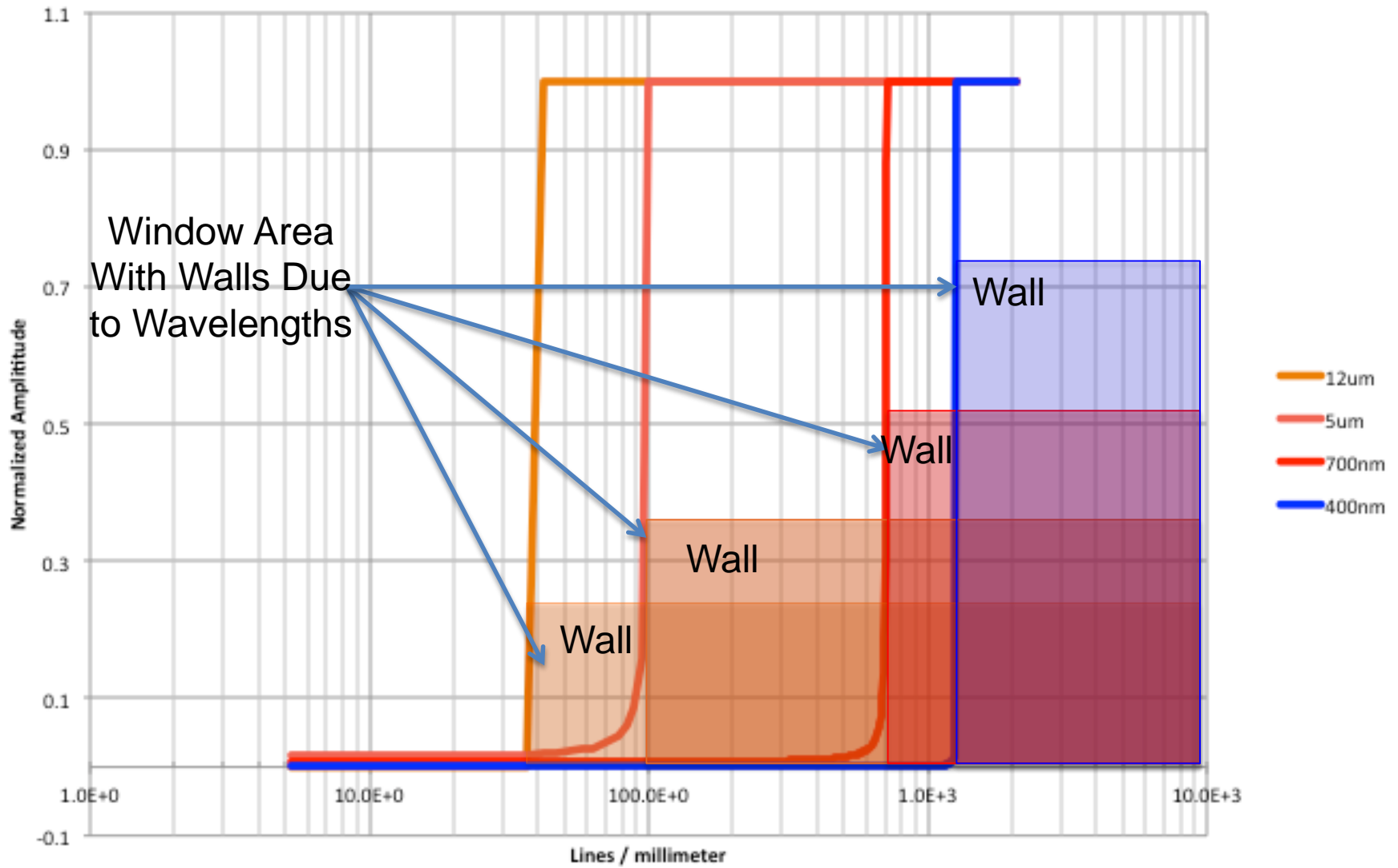
Fourier Remove of Frequencies



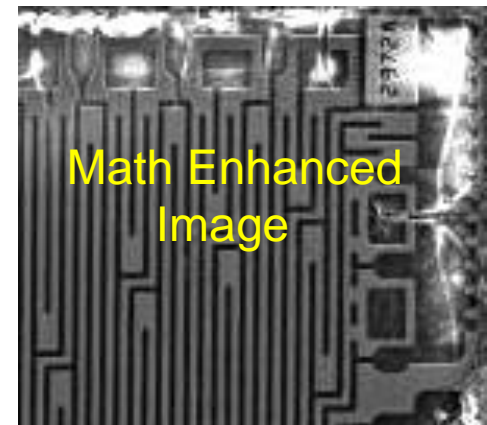
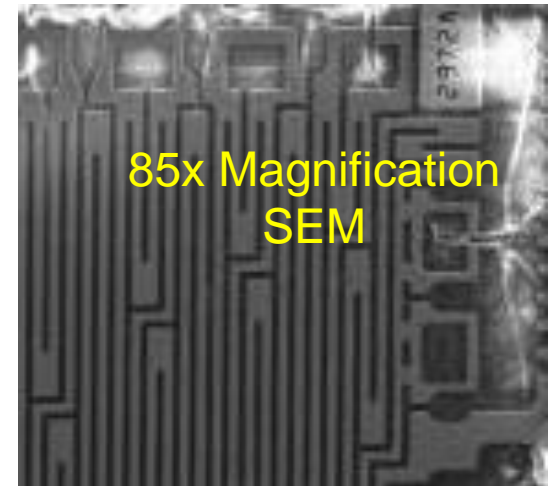
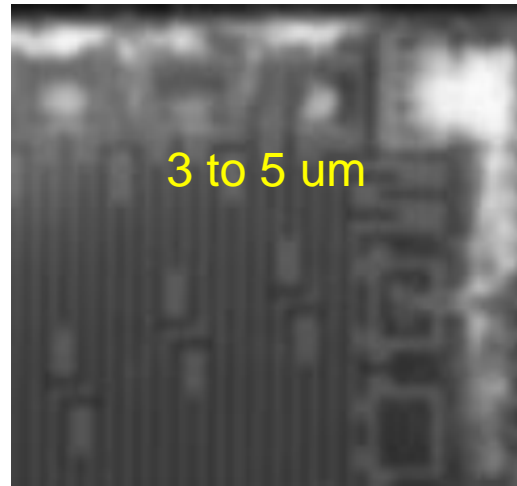
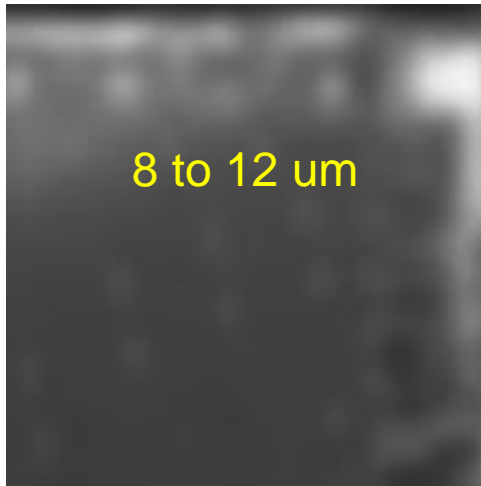
Fourier Remove of Frequencies



Window Due to Wavelength

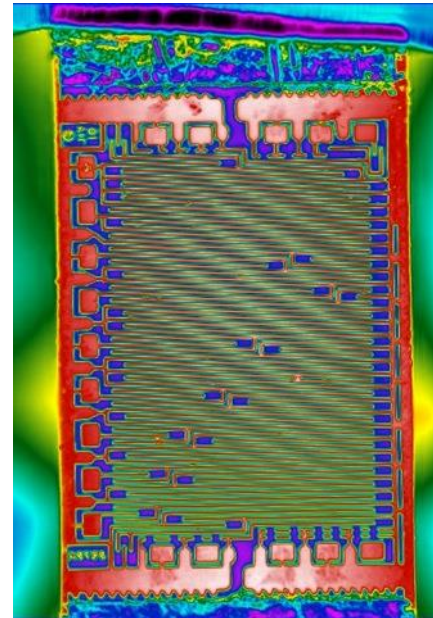


Simulation of Resolution of different Wavelengths



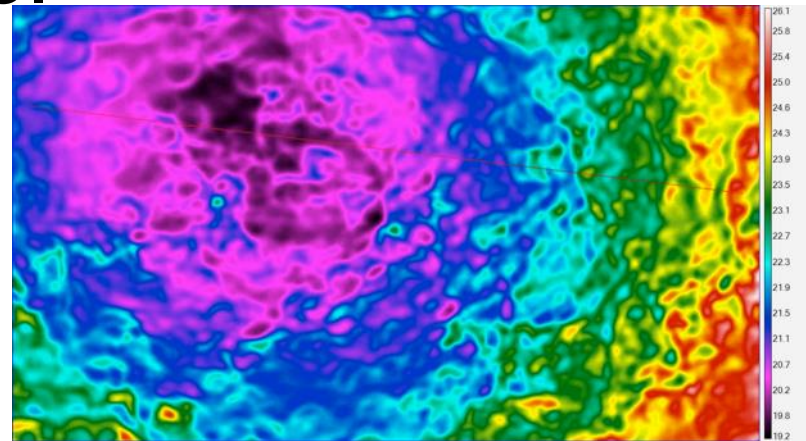
Conclusions

- Defects do cause hot spots
- There are test setup issues with using a Thermal Microscope.
 - Moiré Patterns



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 - Narcissus effects



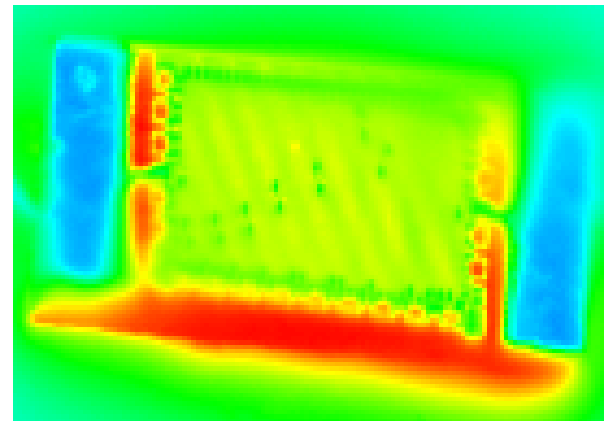
Conclusions


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 - Emissivity



Conclusions

- Defects do cause hot spots
- There are test setup issues with using a Thermal Microscope.
 - Moiré Patterns
 - Narcissus effects
 - Emissivity
 - Limits on Resolution in the IR



The image features a vibrant, multi-colored background with a complex, grid-like pattern. The colors transition from purple and blue at the edges to yellow and green in the center, with red and orange accents. The pattern consists of numerous small, interconnected shapes and lines, giving it the appearance of a circuit board or a highly detailed data visualization. Overlaid on this background is the text "Thank You" in a large, white, sans-serif font, centered horizontally and vertically.

Thank You