Spectrum & The Slide Rule!

Featuring: Mitchell Lazarus

Followed by an NSMA PANEL
with Mitchell Lazarus, George Kizer, Joe Sandri

NSMA
National Spectrum Management Association

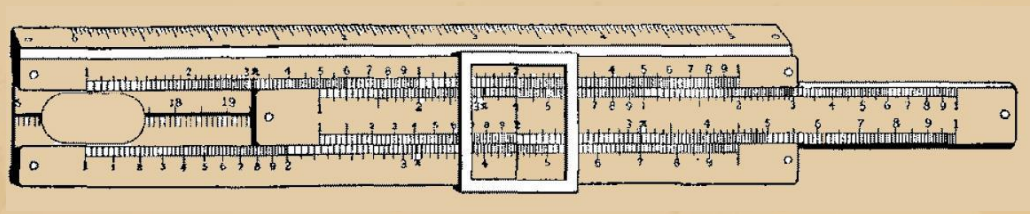
Washington, D. C.
1pm Eastern, Monday, November 30, 2020

Who are we?

- The National Spectrum Management Association (NSMA) is a voluntary international association of microwave radio/wireless and satellite frequency coordinators, licensees, manufacturers and regulators. Established in 1984 at the request of the FCC, the Association provides a forum to develop industry guidelines for efficient use and management of the frequency spectrum by the wireless telecommunications community.
- NSMA provides a linkage between government regulations and industry practice by developing recommendations that streamline and standardize procedures used by the frequency coordination community. We strive to provide an open forum for stakeholders to mold responsible spectrum industry practice and resolve conflicts.

NSMA National Spectrum Management Association

Spectrum and the Slide Rule



Mitchell Lazarus

November 30, 2020

Overview

History

How slide rules work

Comparison with calculators

Sample applications

Conclusion

Commercial break

Resources

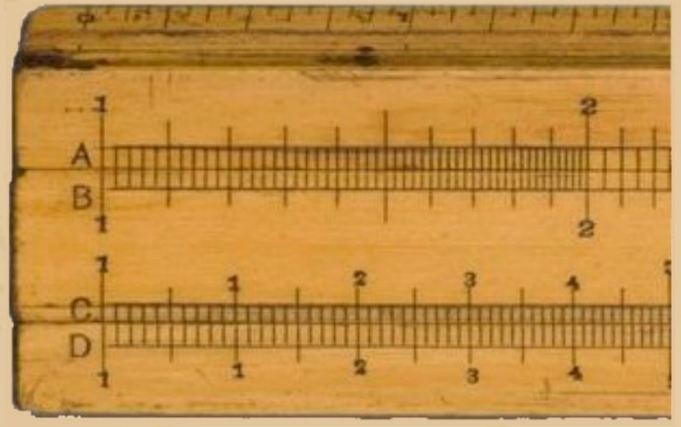
History

400 Years of Slide Rules

- 1614: John Napier discovers logarithms
- 1620: Edmund Gunter uses logarithmic scale and calipers to multiply and divide
- 1622: William Oughtred combines two logarithmic scales for a primitive slide rule
- 1675: Isaac Newton adds a cursor
- 1722: John Warner adds squares, cubes, and their roots
- 1815: Peter Roget adds log-log scales
- 1859: Amedee Mannheim arranges into modern form …

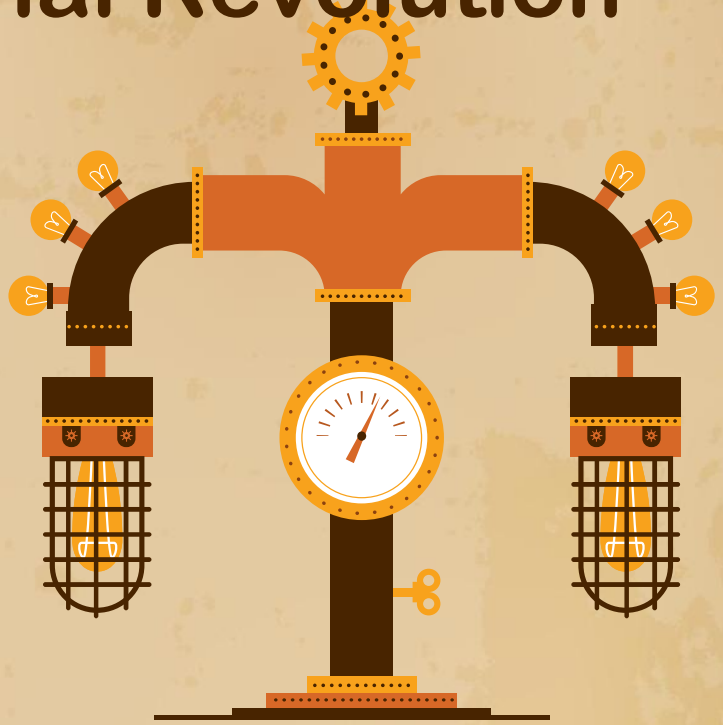
Mannheim Slide Rule (1859)

- Adopted by French military
  - standardized; mass produced
  - similar to entry-level slide rules 100 years later



Role of the Industrial Revolution

- Science-based analysis replaced trial and error
- Designs required extensive calculation
  - drove need for better slide rules
  - precise mass production gave better slide rules



Designed Using Slide Rules

Examples (~ 1800-1975):

- steam technology (railroads, ships, factories, mines)
- electrical power (generation, distribution. motors, etc.)
- radio & TV transmitters and receivers
- Empire State Building, Golden Gate Bridge, Hoover Dam, more
- telephone system
- “Little Boy” (Hiroshima) atomic bomb
- early satellite / microwave equipment
- Mercury / Gemini / Apollo rockets and spacecraft
  - carried on lunar missions
- early computers, calculators

Flew on Apollo 11

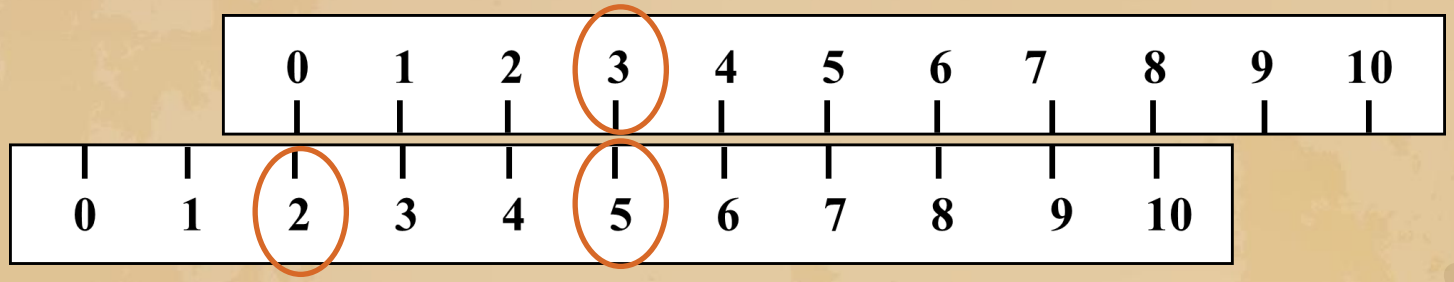
First short Q&A Break

How slide rules work

Add with Two Rulers

2 + 3 = 5

(b) set cursor at 3

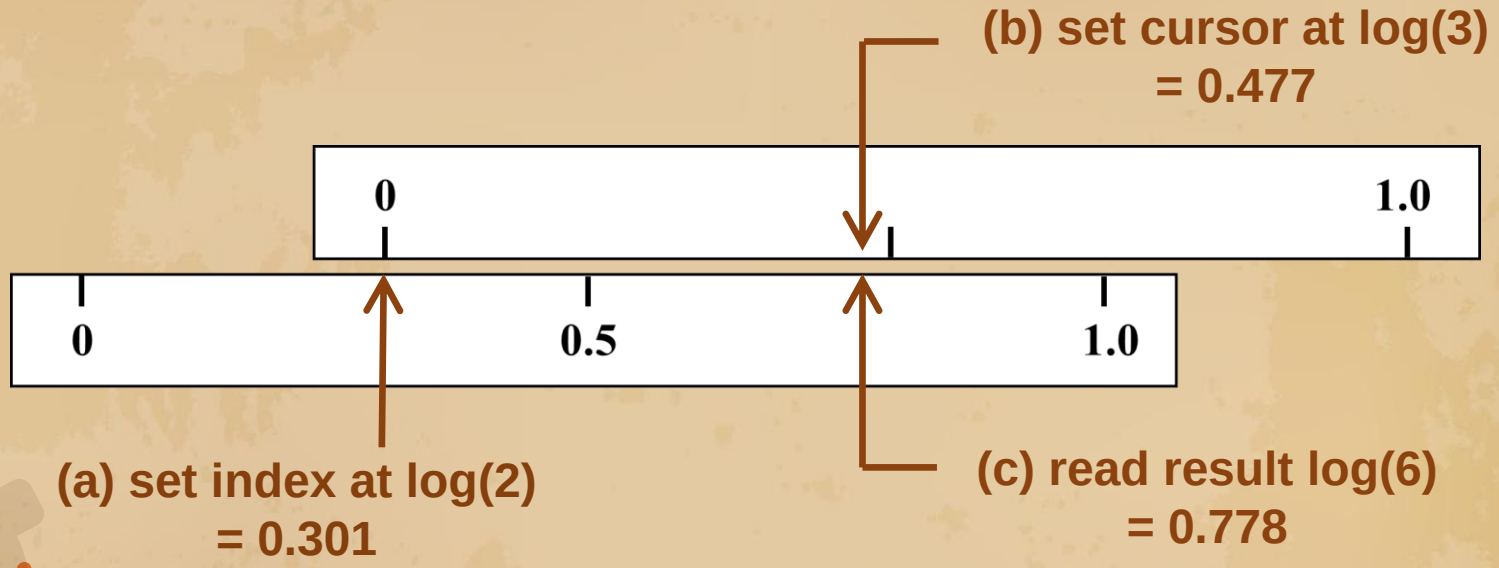


(a) set index at 2

(c) read result 5

Multiply with Two Rulers

2 x 3 = 6
log(2) + log(3) = log(6)

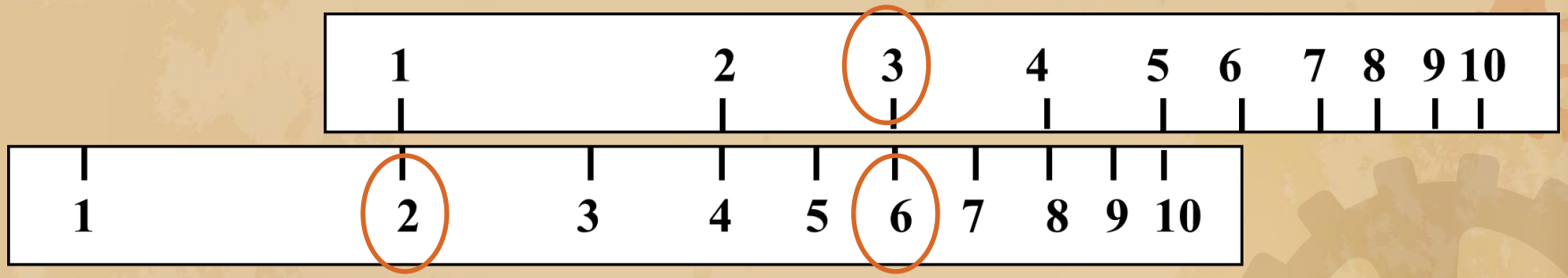


Relabel the Rulers

- Label with numbers at corresponding log values
  - now easy to set slide and read result

$2 \times 3 = 6$

(b) set cursor at 3



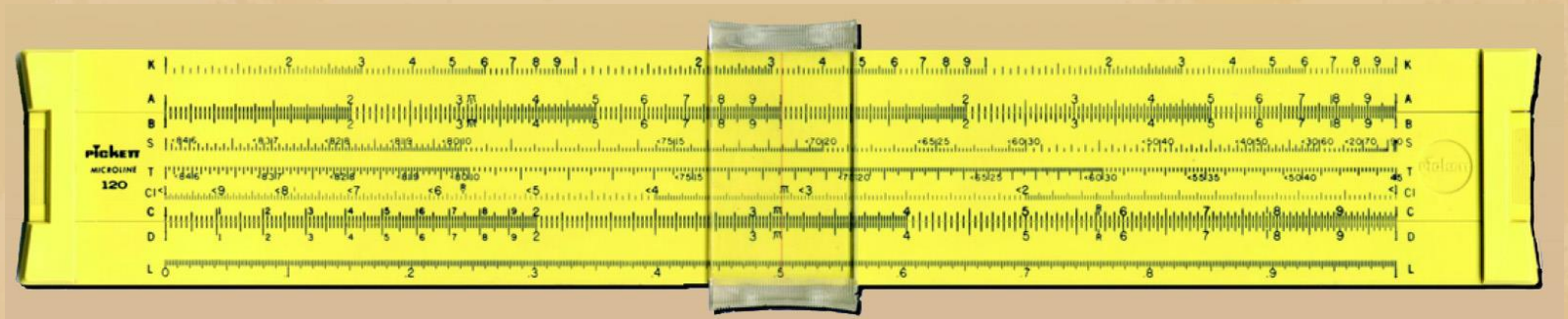
(a) set index at 2

(c) read result 6

General-Purpose Slide Rules – 1

- Basic models (1 side, 6-9 scales)
  - multiply & divide
  - square & square root
  - cube & cube root
  - radians / degrees
  - sin, cos, tan
  - log and exponent (base 10)

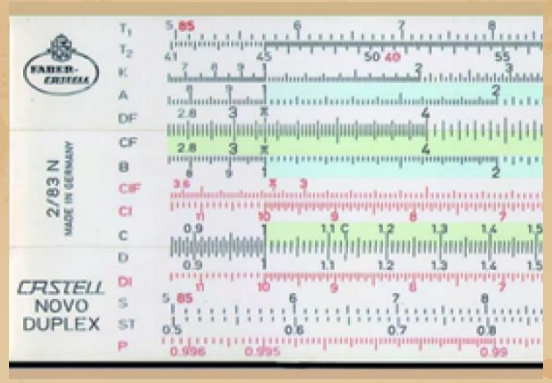
  } not on all models

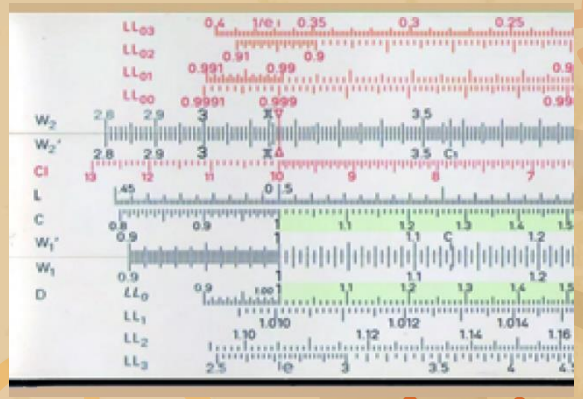


General-Purpose Slide Rules – 2

- Advanced models (2 sides, ~35 scales)
  - all functions on previous slide plus …
  - fast operations on π
  - log and exponent (base *e*)
  - polar-Cartesian conversion
  - any number to any power
  - any root of any number
  - log of any number to any base
  - hyperbolic trig functions
  - Pythagorean
  - … plus specialized scales

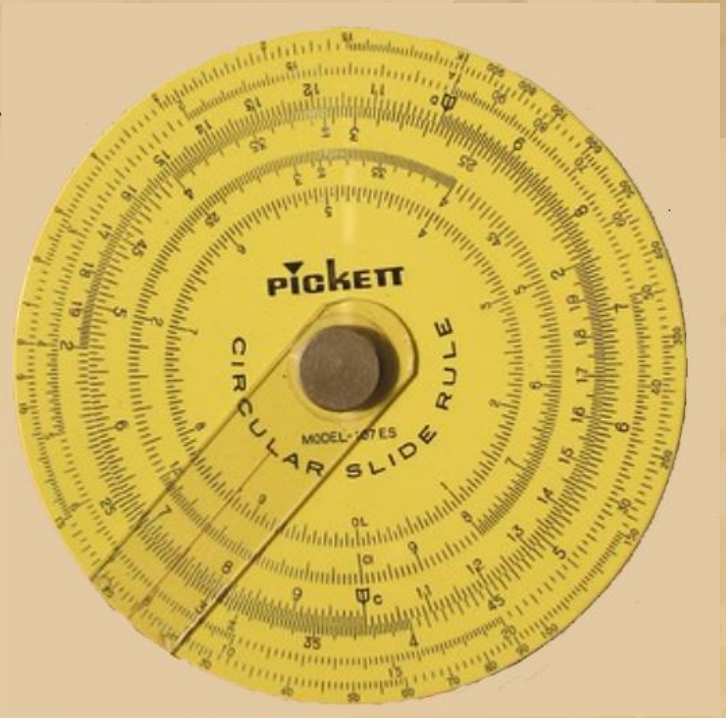
  } not on all models





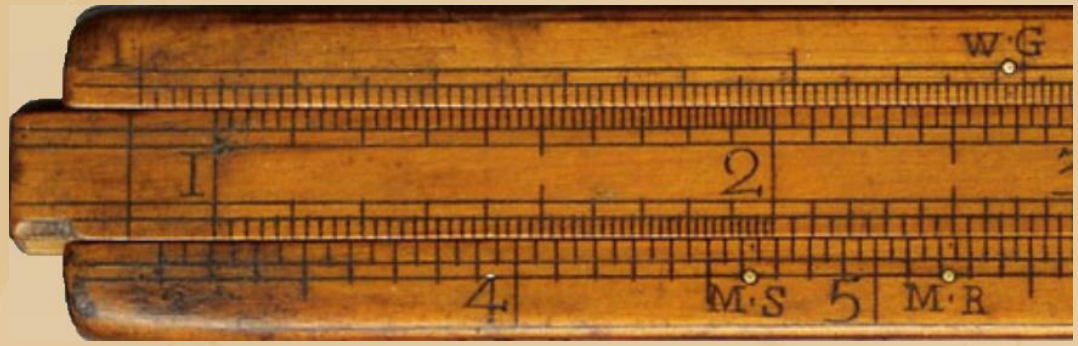
Circular Slide Rules

- Less popular than linear slide rules
  - pro: fits in smaller pocket
  - con: short inner scales give poor precision



Special-Purpose Slide Rules – 1

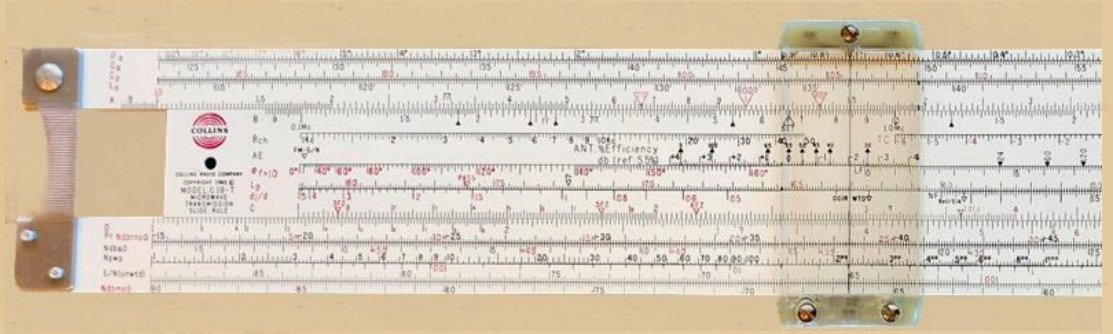
- Early:
  - 1677: measuring and calculating length, area, volume of timber
    - used by merchants and builders for 200 years
  - 1683: assessing barrel volume and alcohol content
    - used for by tax collectors for 200 years



18th century rule for taxing alcohol

Special-Purpose Slide Rules – 2

- Modern
  - made for branches of engineering, skilled trades, general business
  - either general-purpose slide rule with added scales, or dedicated device.



Radio propagation
Photo: George Kizer

Aircraft operations (still in daily use)

Second short Q&A Break

Comparison with Calculators

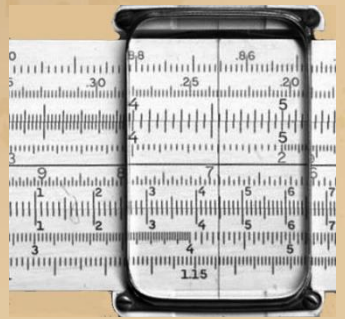
Slide Rule *vs.* Calculator

	Slide Rule	Calculator
Speed	(comparable)	
Signigicant Figures	~3 *	8-12
Decimal Placement	manual	automatic
Learning Curve	long	short
Error *vs.* Mistake	2 x 3 = 5.99	2 x 3 = 782

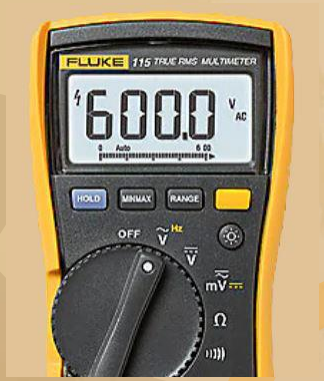
* adequate for most engineering purposes

Learning Curve: Analog *vs.* Digital

Then



Reading analog meter scales similar to using slide rule



Now

All-digital environment impedes slide rule skills

Sample applications

Slide Rules and dB Scale – 1

$$P_{dBW} = 10 \times \log_{10}(P_{watts})$$

- dB scale converts × to + and / to –
  - same principle as slide rule
  - slide rules easily convert to and from dB values

Link Budget (equivalent forms)		
watts × and /		dBm + and –
1.50 W	Xmit power	31.8 dBm
× 16	Xmit ant. gain	+ 12.0 db
/ 20,000	Free-space loss	– 43.0 dB
/ 40	Building loss	–16.0 dB
× 7	Receive ant. gain	+ 8.45 dB
0.21 mW	Receive power	– 6.75 dBm

Sample Applications – 1

- Inverse-square law:

$$P_2 = \left(\frac{r_1}{r_2}\right)^2 P_1$$

- frequency-wavelength conversions
  - *e.g.,* for quarter-wave, half-wave antennas

$$wavelength = \frac{2.998 \times 10^8}{f}$$

Sample Applications – 2

- Polar-Cartesian conversions, *e.g.*, impedance:

$$|Z| = \sqrt{R^2 + \frac{1}{(2\pi f C)^2}}$$

$$|Z| = \sqrt{R^2 + (2\pi f L)^2}$$

$$\theta = \tan^{-1}\left(\frac{1}{2\pi f \mathrm{RC}}\right)$$

$$\theta = \tan^{-1}\left(\frac{2\pi f \mathrm{L}}{\mathrm{R}}\right)$$

Sample Applications – 3

- Fast method for repetitive calculations:
  - unit conversions

$$D_{km} = 1.609 \times D_{miles}$$

  - coverage area

$$A = \pi R^2$$

  - finding harmonics

$$f_N = N \times f_0$$

  - power density

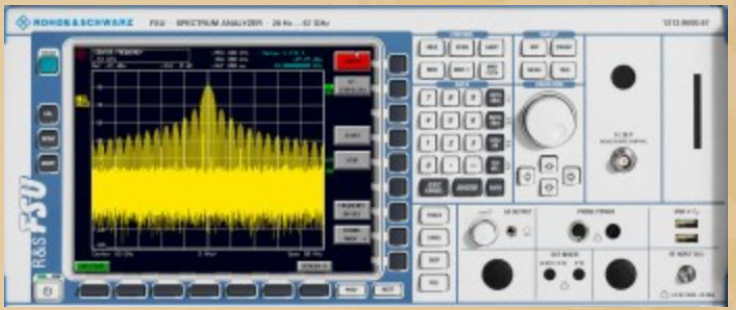
$$S = P / 4\pi R^2$$

Sample Applications – 4

- Converting FCC emissions limits
  - E volts/meter at D meters $$P_{EIRP} = \frac{4\pi E^2 D^2}{120\pi} = \frac{E^2 D^2}{30}$$
    - & extrapolation factors for other measurement distances
  - peak envelope power limits (FCC Part 97)
    - & peak / average limits
  - milliwatts / square cm

$$P_{EIRP} = 4\pi S D^2$$

  - watts to dBm

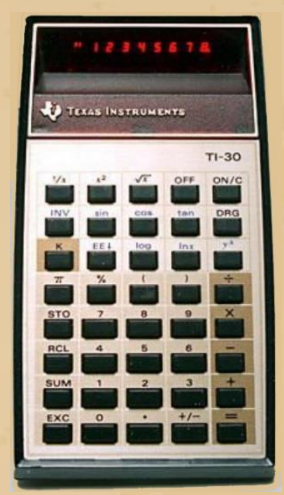


Conclusion

- Slide rules gave way to scientific calculators
  - HP-35 cost $395 in 1972
    - ($2,460 in 2020 dollars)
    - (top end slide rule ~ $30-50)
  - prices came down fast
    - TI-30 cost $25 in 1976
  - IBM PC with Lotus 1-2-3 (1983) added more power
- Slide rules still have dedicated users and niche applications.

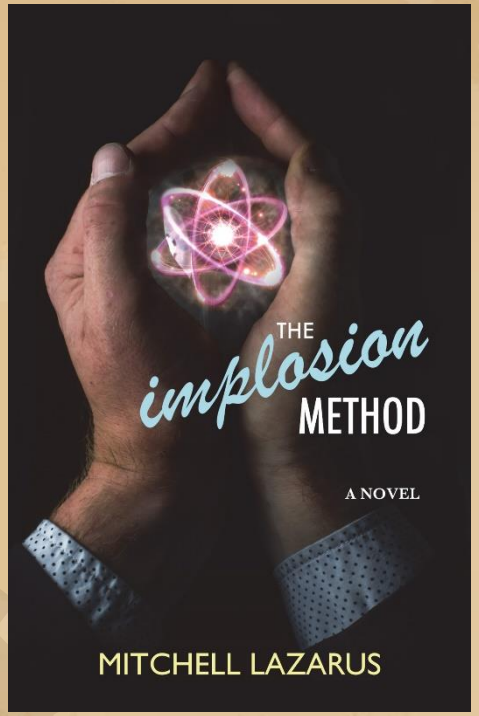
HP-35
(1972 $395)

TI-30
(1976 $25)



Commercial break

The Slide Rule in Fiction



> "Victory [in World War II] would turn on advances in radio, aircraft, RADAR … <u>The decisive weapon would not be the rifle, but the slide rule</u>."

- Novel about the Manhattan Project
  - physics before computers
  - scientifically accurate
  - many references to slide rules
- *5-star reviews by two spectrum experts*
- Search Amazon:
  "Lazarus Implosion Method"

Resources

- To purchase new-in-box and used slide rules:

  sphere.bc.ca/test/sliderule.html (reputable dealer)
  ebay.com (use caution)
  etsy.com/market/slide_rule (inexpensive; use caution)

- The Oughtred Society (slide rule users and collectors
  - oughtred.org (good information; private sales)
  - reference manual:

    http://www.oughtred.org/books/OSSlideRuleReferenceManualrevA.pdf

Thank you!

Questions?
Comments?

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Credits:
Template: Slidesgo
Icons: Flaricon
Images: Freepik
Illustrations: Stories
Help: George Kizer

PANEL

with Mitchell Lazarus & George Kizer:
Moderated by Joe Sandri

FORMAT:

5-minutes with George,
1-minute with Joe &
Panel Discussion and Q&A

George Kizer:

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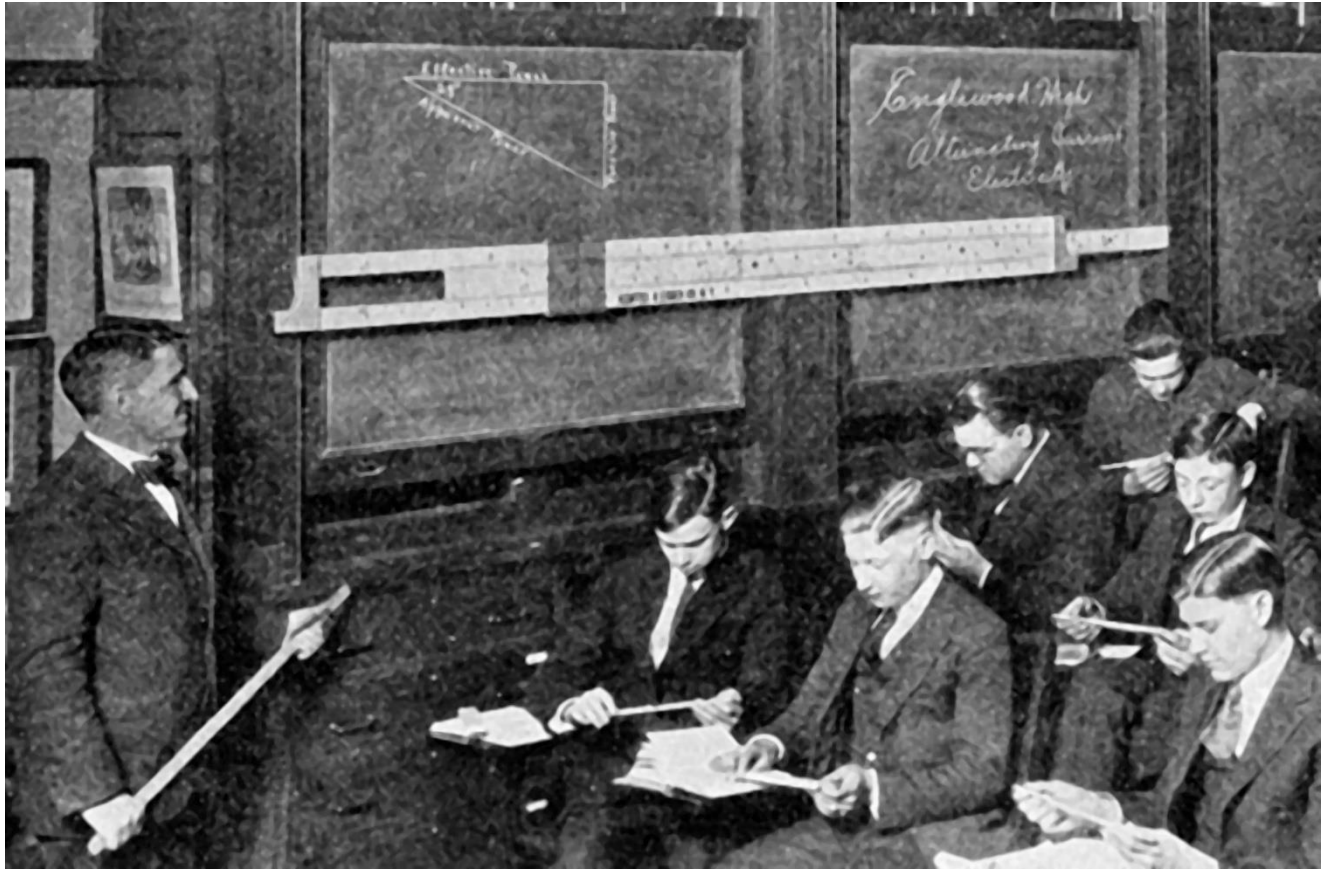
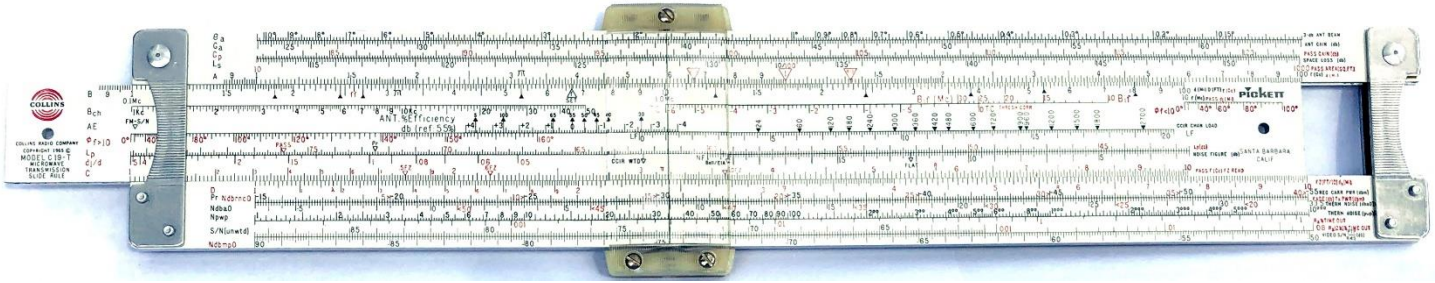
Until the late 1970's, the slide rule was the primary device for engineering calculations



Most were of a relatively standardized Mannheim design

However, a few had specialized designs

An example was the Collins Radio microwave slide rule



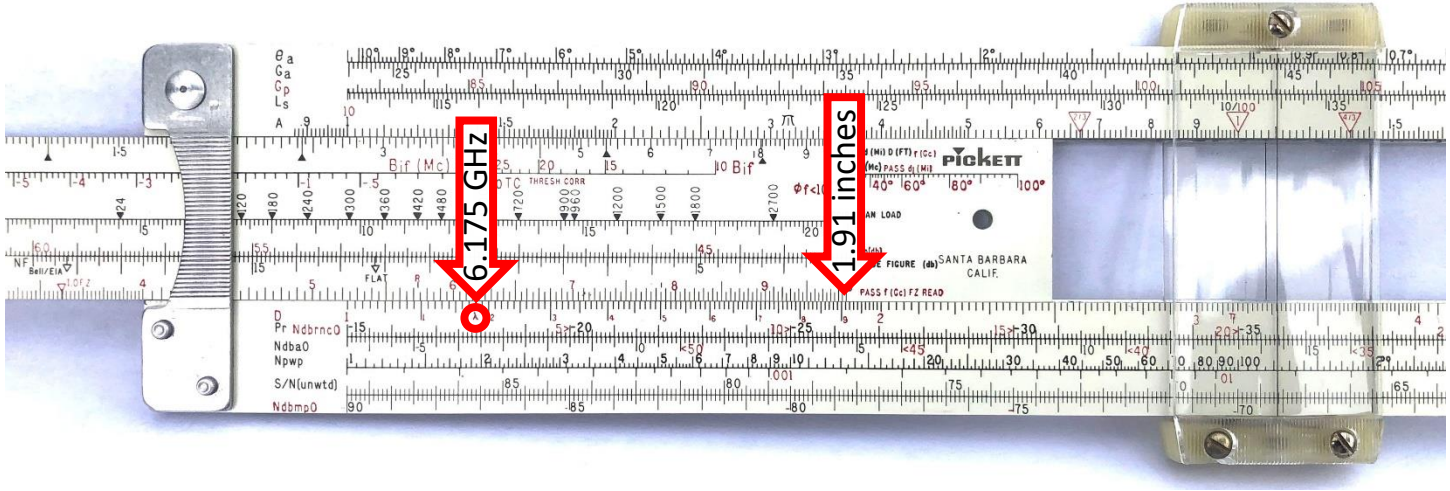
This device could do several microwave related calculations

I'll give you a few examples

Free Space Wavelength

λ(inches) = 11.80 / frequency (GHz)

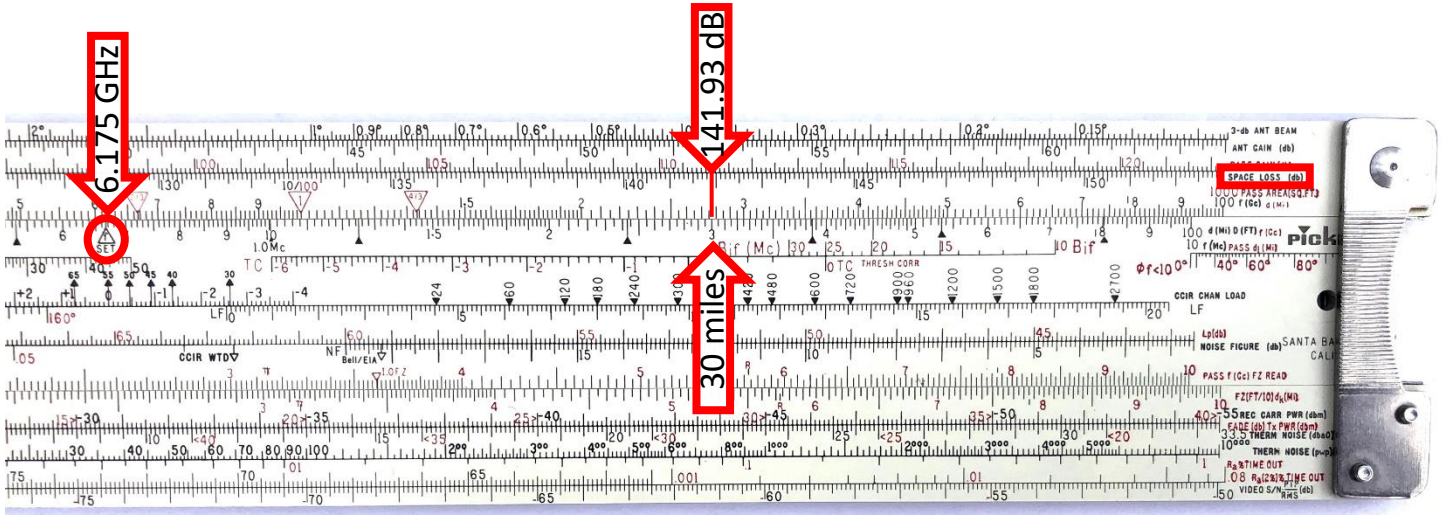
1.91 = 11.80 / 6.175



Free Space Loss

Free Space Loss (dB) = 96.58 + 20 log [distance (miles)] + 20 log [frequency (GHz)]

141.93 dB = 96.58 + 20 log [30 (miles)] + 20 log [6.175 (GHz)]



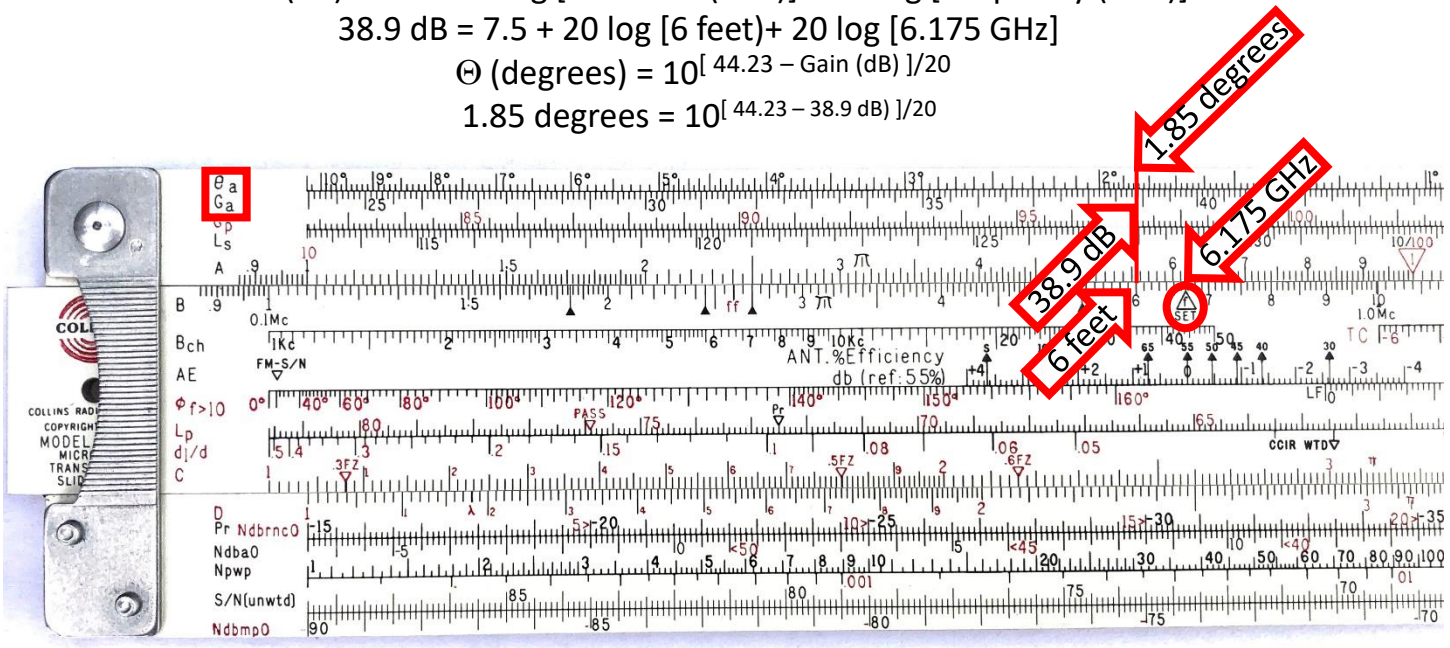
Antenna Gain and 3 dB Beamwidth

Gain (dB) = 7.5 + 20 log [diameter (feet)] + 20 log [frequency (GHz)]

38.9 dB = 7.5 + 20 log [6 feet)+ 20 log [6.175 GHz]

Θ (degrees) = $10^{[\ 44.23 - \text{Gain (dB)}\ ]/20}$

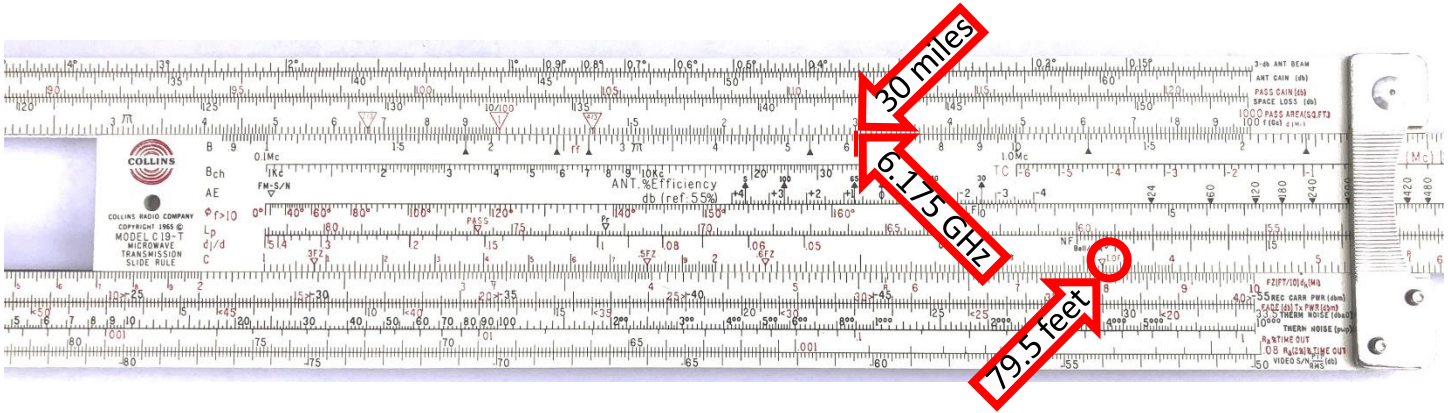
1.85 degrees = $10^{[\ 44.23 - 38.9\ \text{dB})\ ]/20}$



Fresnel Zone Clearance

First Fresnel Zone Clearance (ft) at center of path = F_{1C}= 36.05 SQRT [D (miles) / frequency (GHz)]

79.5 ft = 36.05 SQRT [30 miles / 6.175 GHz]



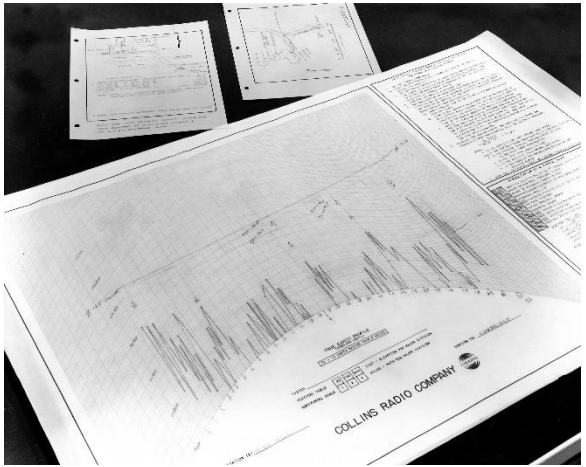
First Fresnel Zone Clearance (ft) at point d_1 = 2 F_{1C} (ft) SQRT [d_1 * (D - d_1)] / D

d_1 = distance from a point on the path to an end point (miles)

D = total distance of path (miles)

SQRT = square root of X

Today the slide rule has gone the way of the paper profile and the pocket protector



And so has Collins Radio

COLLINS

COLLINS

Rockwell International

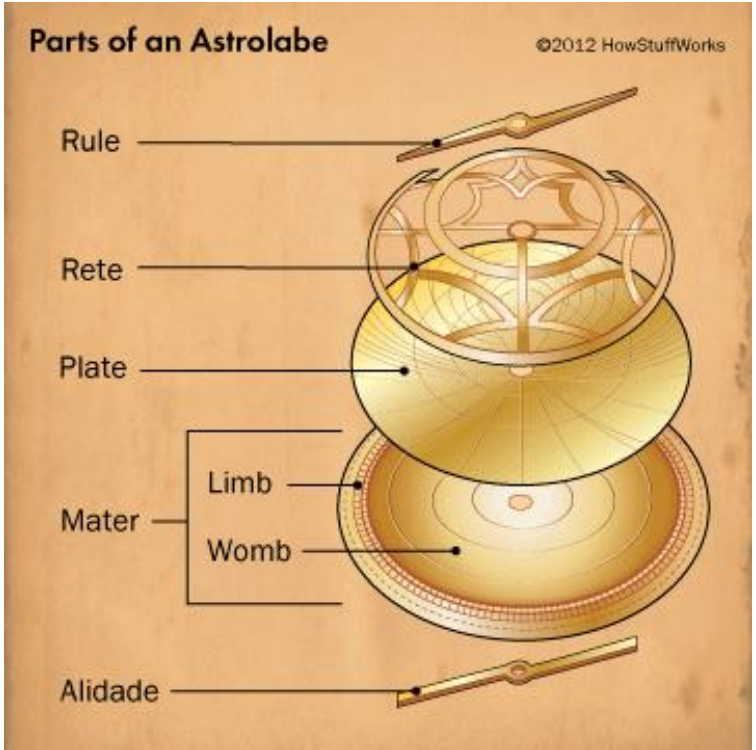
Joe Sandri
President, NSMA:

A quick look at a slide-rule predecessor

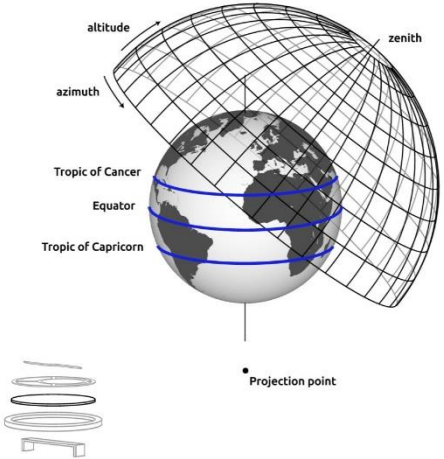
NSMA
National Spectrum
Management Association

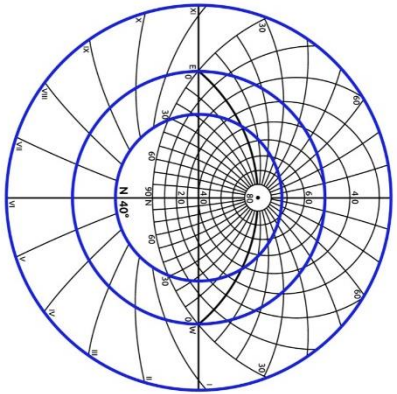
Astrolabe:

- **<u>Precursor to the Slide-Rule</u>: In the 10th Century over 1,000 uses were documented, ranging from seasonal and daily timekeeping to tide tables, astronomical, astrological and religious.**
- **<u>Replaced by the Clock & Sextant</u> starting in the 1700-1800s**



Astrolabe:





<u>Sample Users</u>:

- **Claudius Ptolemy, a famous Greek astronomer who lived in the Roman Empire during the 2nd century AD**
- **Galileo**
- **Christopher Columbus**
- **Religious**

<u>Modern day Astrolabe researchers</u>:

- **John Huth, Harvard University, Physicist**
- **Alexander Jones, NYU, Ancient Astronomy**
- **Owen Gingerich, Harvard University, Professor Emeritus, Astronomy and History of science**
- **Louise Devoy, curator at the Royal Observatory Greenwich in England, (which includes a collection of astrolabes).**

PANEL Q & A

QUESTIONS?

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