Specialized Slide Rules for Electronic Engineers

A Collection of Articles Edited by

Richard Smith Hughes

Monograph Number 2 in a Series by the Oughtred Society

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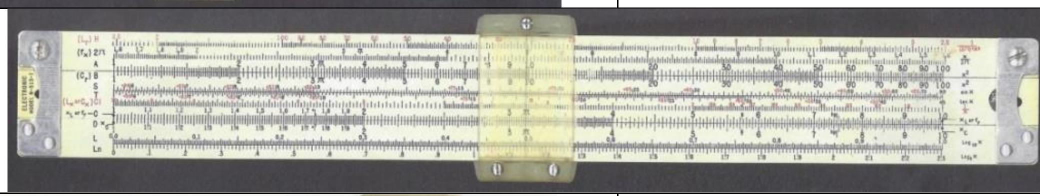
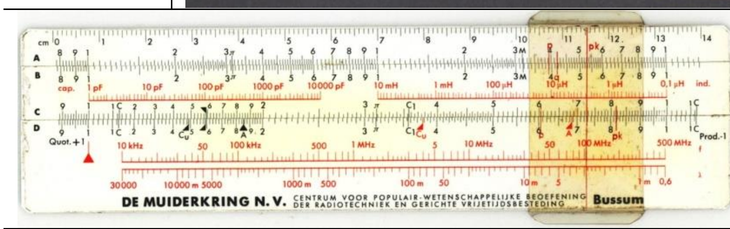
$\lambda_0 = 1885\sqrt{LC}$

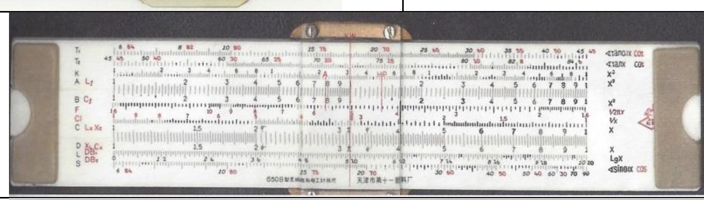
$X_L = 2\pi fL$

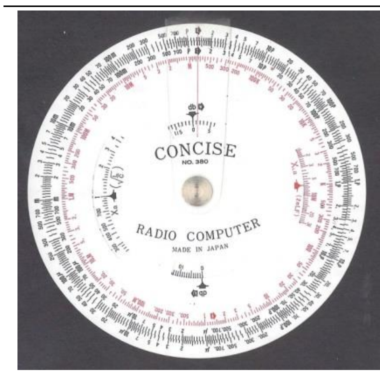


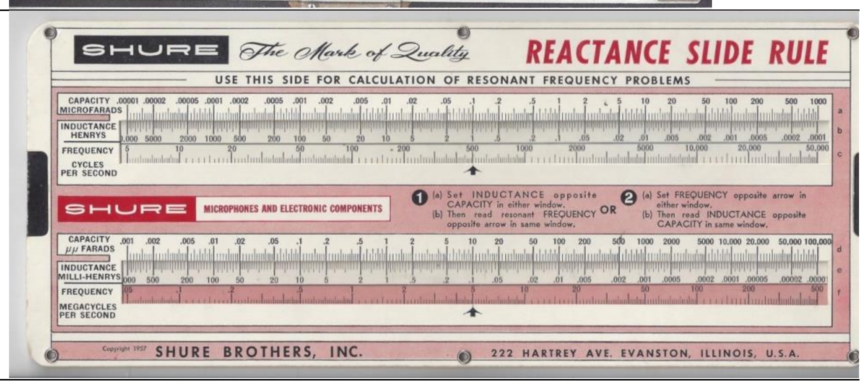


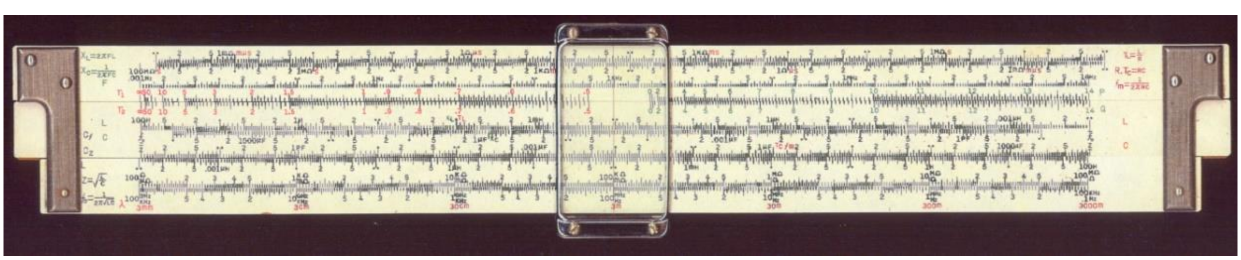
$X_C = 1/2\pi fC$

$f_0 = 1/2\pi\sqrt{LC}$



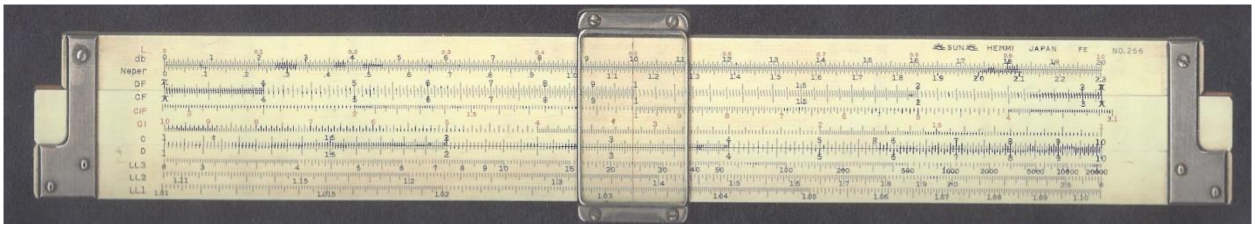


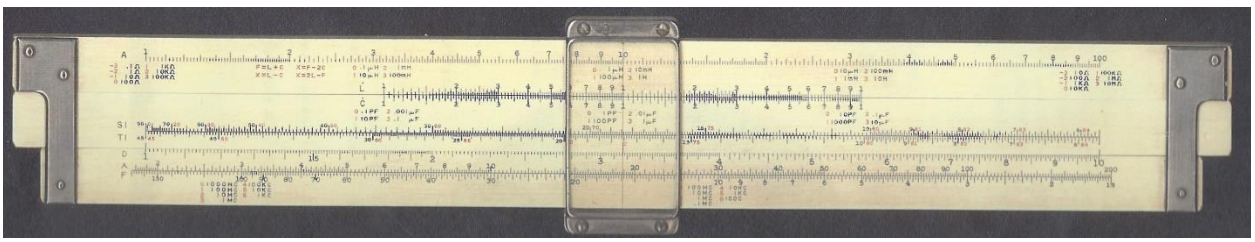




ACKNOWLEDGEMENT

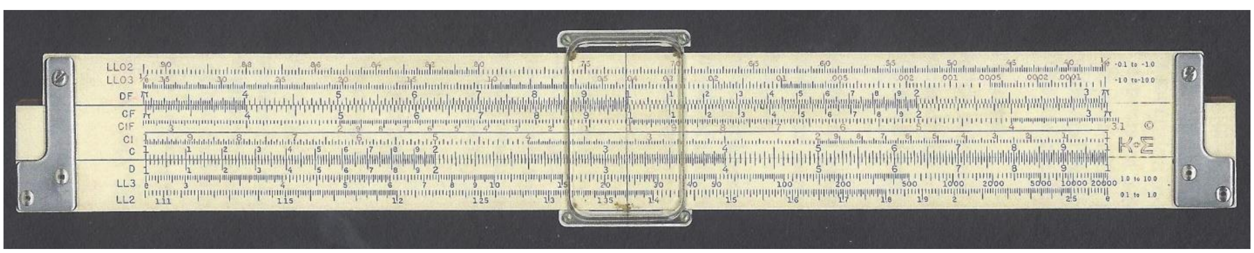
This monograph would never have seen the light of day without the help of David and Donna Sweetman-thanks. This offering is dedicated to my wife Janet, who put up with my 15 year slide rule obsession and son Stan for ferrying me to many of our meetings.

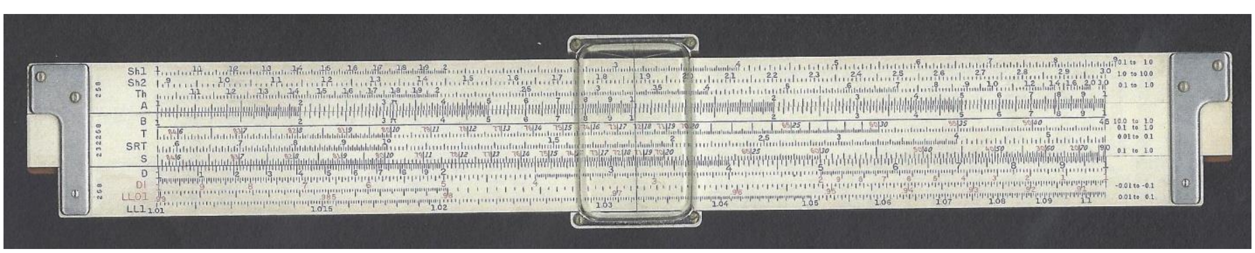




ABOUT THE AUTHOR

I was an Electronic Design Engineer, analog circuits and systems, from my graduation at the University of Nevada in 1960 to retirement in 1998. I have numerous journal publications, 5 books and 25 Patents, and taught AC circuits and Semiconductor circuit design at our local community college for 30 years. The slide rule was my sole computer until I purchased my HP- 45 in 1974.





PREFACE

This monograph discusses the results of my journey studying specialized slide rules for Electronic Engineers in determining Inductive Reactance $X_L = 2\pi fL$, Capacitive Reactance $X_C = 1/(2\pi fC)$, and Resonant Frequency $f_0 = 1/[2\pi\sqrt{LC}]$, and I have included the basic operations for a number of them for those interested. Would any of these specialized slide rules have been of help to you? You have a large selection to choose from. Not an Electronic Engineer? Not to worry, the equations they were designed to help solve are really simple. So sit back and enjoy the results of my journey.

Specialized Slide Rules for Electronic Engineers

Table of Contents

Introduction

I was an analog circuit designer for much of my career, 1960-1998 and designed Intermediate Frequency (IF) amplifiers, signal detectors, and signal processing for Anti-Radiation Missiles (ARM). During the early part of my career, 1960/1974 the slide rule was my primary calculator. Three common circuit equations we had to solve were Inductive Reactance $X_L = 2\pi fL$, Capacitive Reactance $X_C = 1/(2\pi fC)$, and Resonant Frequency $f_0 = 1/[2\pi\sqrt{LC}]$. Sure we had to find the approximate solution to place the decimal point, but that was slide rule life back then. During the slide rule era many slide rule designers wanted to make solving the above equations simpler, and the Electronic slide rule was born. I did not know of their existence at the time and several years ago decided to determine how well they might have helped me. This monograph is the final result of my journey.

Solving for Inductive Reactance $X_L = 2\pi fL$, Capacitive Reactance $X_C = 1/(2\pi fC)$, and Resonant Frequency $f_0 = 1/[2\pi\sqrt{LC}]]$ using our general purpose slide rule is not Rocket Science! However we did have to determine the decimal point.

$$X_L = 2\pi f_L$$

Use the CI/C/D scales. Sometimes it is easier to use 1/2π =0.159, XL = (L/0.159)f

$$X_C = 1/(2\pi fC)$$

Use the CI/C/D scales XC = (0.159/C)(1/f)

$$f_0 = 1/[2\pi\sqrt{LC}]]$$

The proper A/B scales must be used; Left scale, $x.xx10^{+/-\text{ even number}}$, right scale $xx.x10^{+/-\text{ even number}}$. Calculate LC using the A/B scales (LC on the A scale = $\sqrt{LC}$ on the D), place 0.159 (1/2π) on the C scale over √LC on the D scale and read f_o on the C scale above the D index. Knowing f_0, LC = $(0.159/f_0)^2$; Using the C/D scales solve for $0.159/f_0$ on the D scale and LC = $(0.159/f_0)^2$ on the A scale. Divide by L to find C and C to find L.

I will start at the beginning, the electrification of the world by Tesla and Westinghouse in the late 1880's, the rise of "Electronics" in the 1920's, and discuss a number of slide rules designed to aid in the calculations for Inductive Reactance X_L, Capacitive Reactance X_C, and Resonant Frequency f_0. The final section is a brief discussion on how the X_L, X_C, and f_0 were used in every day Electronic Engineering life.

Genesis

Our story begins in the late 1880's with the "current wars"; Edison versus Tesla and Westinghouse regarding who would electrify the world; Edison with his Direct Current (low voltage, high current), Figure 1, or Tesla and Westinghouse with their high voltage, low current Alternating Current, Figure 2. Edison's Direct Current had a major problem: transmission line voltage loss due to the high current. Nikola Tesla had been working on Alternating Current induction motors and power transmission for several years and had a different view on electrifying the world: high voltage and low current (thus much less transmission line loss). Transformers decreased the high voltage to that necessary for the given load. Tesla teamed up with George Westinghouse and the "current wars" began. Eventually Tesla and Westinghouse were victorious (an excellent book on the subject is Jill Jonnes "Empires of Light; Edison, Tesla and Westinghouse and the Race to Electrify the World" [1]). In the early 1900's, slide rule manufacturers produced specialized "Electric" slide rules, called Elektro/Electric, to calculate the voltage drop, resistance, and the weight of the copper for DC transmission lines (see Bob Adams [2] and Rod Lovett [3]).

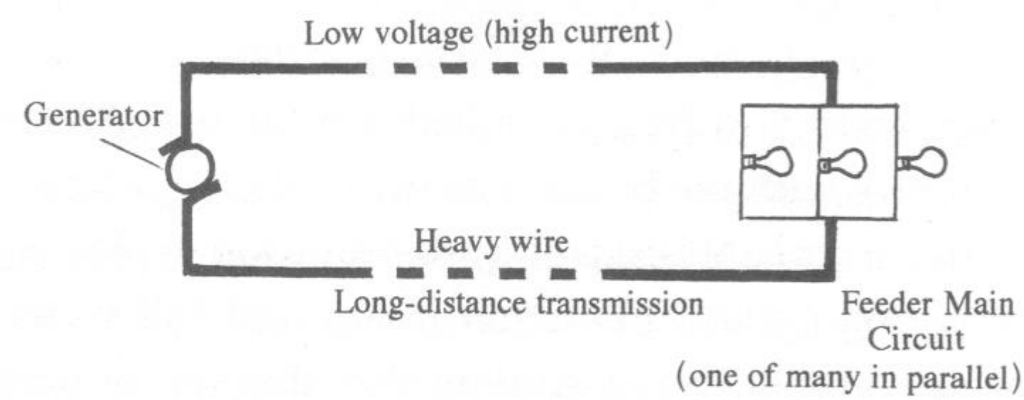


Figure 1. Edison's Direct Current (DC) Power Distribution [1]

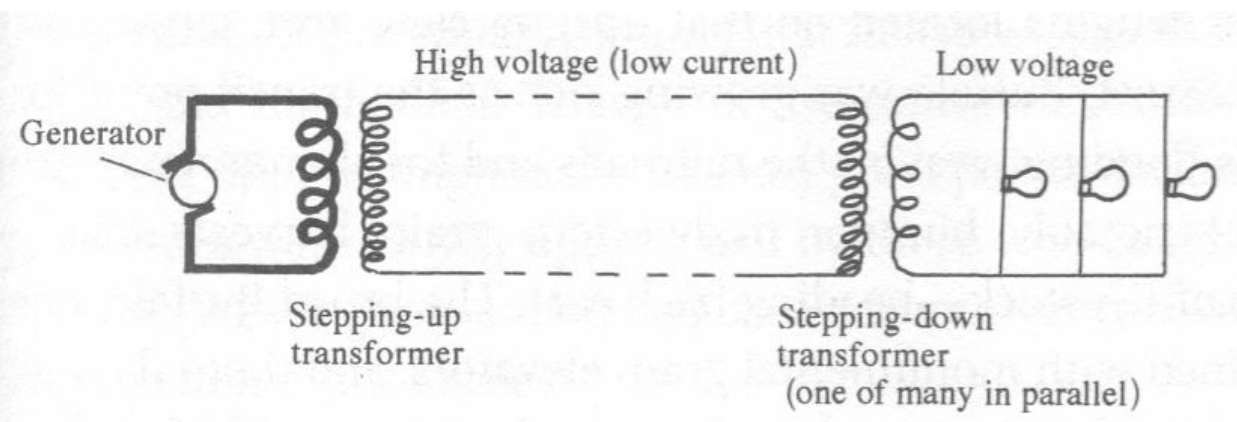
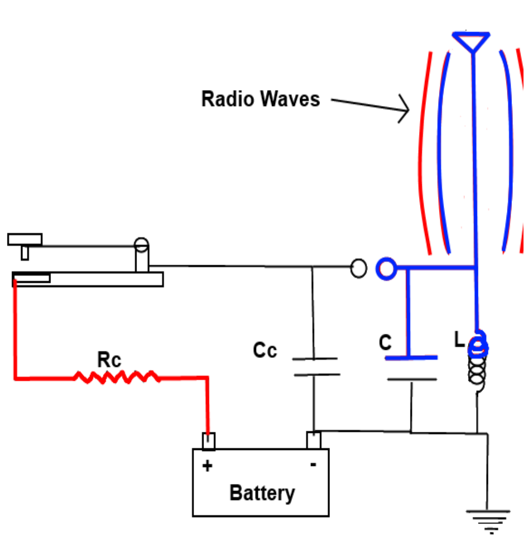


Figure 2. Tesla's Alternating Current (AC) Power Distribution [1]

Alternating Current, AC, theory, and practice soon became college/university subjects and engineering textbooks introduced Inductive Reactance X_L, Capacitive Reactance X_C, and Resonant Frequency f_0, three terms we will be talking about shortly.

Research on Wireless Communication Spark Gap Telegraphy (Morse code), Figure 3, and radio, Figure 4, continued well into the 1920's; Nikola Tesla demonstrated modern radio in 1893 (he had been granted two US patents in 1890) and the evolution of AC (Electrical Engineering) to Electronic Engineering (the early names were Radio and Communication Engineering) began. OK, I know there is still a debate on who invented Radio: Tesla or Marconi? The US Supreme Court upheld Tesla's patents in 1943; thus, he does have priority.



The transmitted frequency, f_T is determined by the resonant values for the inductor, L, and capacitor, C.

$f_T = f_0 = 1/[2\pi\sqrt{LC}]$

Figure 3. Wireless Communication Spark Gap Generation

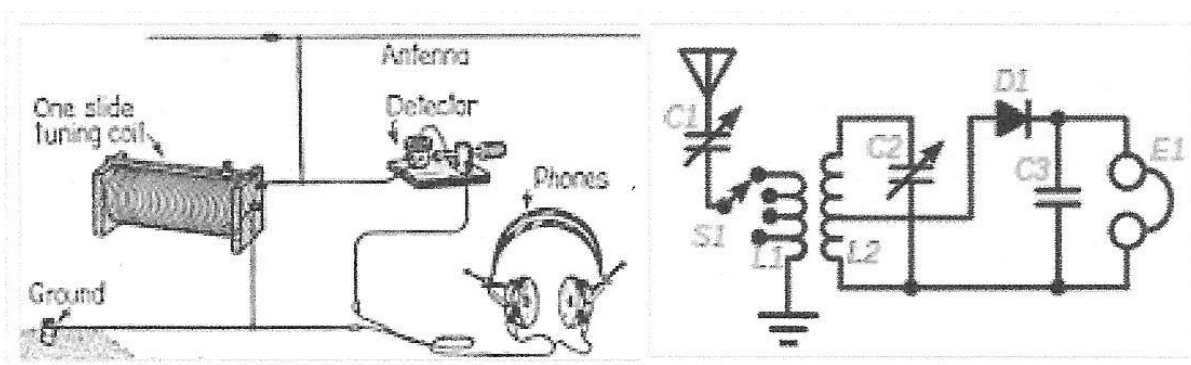


Figure 4. Crystal Radio Receiver

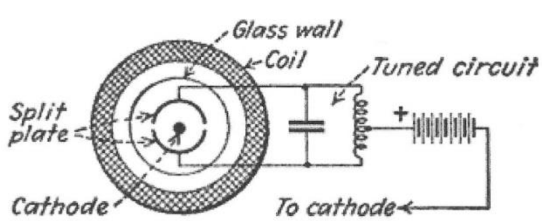
The received signal is the resonant frequency, $f_0 = 1/[2\pi\sqrt{LC}]$

Research on radio transmitters and receivers continued in the 1930's, but it was the research on Television and Radar, Chain Home, prior to World War II that brought more and more "Electronic Engineers" (they were still called Radio/Communication Engineers) into the field. Chain Home was a British early warning radar, Figure 5a, developed around 1936 to warn of any German Luftwaffe attacks. Figure 5b shows the simplified Radar transmitter.

Note that the "Electronics" in Figures 3-5 have the same equation for the transmitted, or received frequency, $f_0 = 1/[2\pi\sqrt{LC}]$. f_0 is called the resonant frequency and is common in electronic receiver and transmitter circuits.

Table 1 (page 5) shows several basic electronic functions that the Electronic Engineering slide rules were designed to solve. The circuits are really part of the overall system design. The most important equations that were, in many cases, used daily in various phases of electronic design are: Capacitive Reactance (impedance) $X_C=1/(2\pi fC)$, Inductive Reactance (impedance) $X_L = 2\pi fL$, Resonant Frequency $f_O = 1/[2\pi\sqrt{LC}]$. The tolerance for inductors and capacitors is seldom better than +/- 10% and absolute accuracy is usually not needed.

Figure 5a. Chain Home Radar

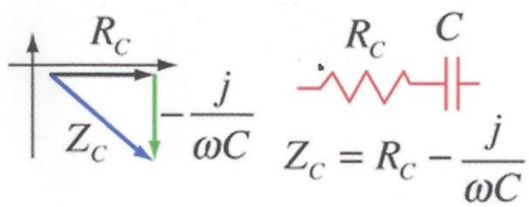
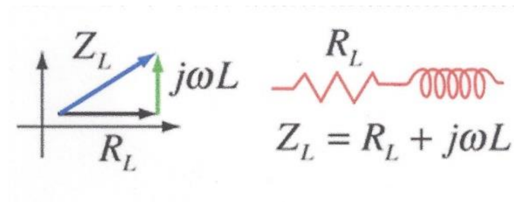
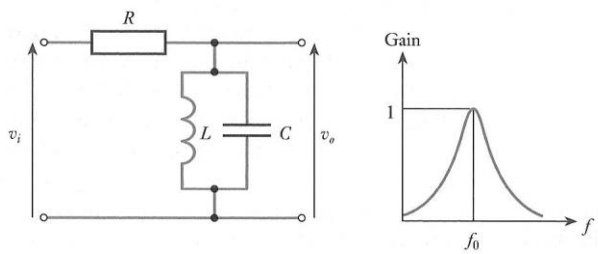
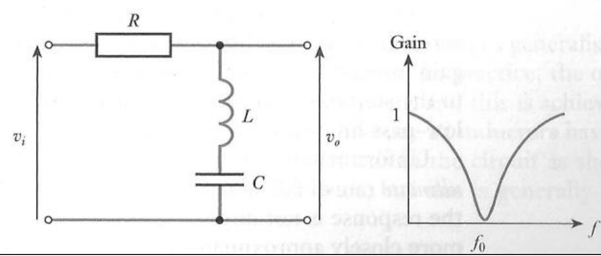


The transmitted frequency, f_T, is determined by the resonant values for the inductor, L, and capacitor, C.

$f_T = f_0 = 1/[2\pi\sqrt{LC}]$

Figure 5b. Chain Home Transmitter Magnetron

Table 1. Some Basic Circuits

Capacitive Reactance $X_C = 1/2\pi fC$	Inductive Reactance $X_L = 2\pi fL$
 $\omega = 2\pi f$ $X_C = 1/2\pi fC$ $Z = \sqrt{R^2 + X_C^2})$ $\theta = -\tan(X_C/R)$	 $\omega = 2\pi f$ $X_L = 2\pi fL$ $Z = \sqrt{R^2 + X_L^2})$ $\theta = \tan(X_L/R)$
Parallel Resonance, $f_0 = 1/[2\pi\sqrt{LC}]$.	Series Resonance, $f_0 = 1/[2\pi\sqrt{LC}]$
Note. C or L, sometimes both, are usually variable for an exact value for f_0	
	

Note the common 2π term. The solution of these equations is not rocket science, however, the decimal point, the bane of all slide rule users, can be tedious. This is especially true for the resonant frequency ($f_0 = 1/[2\pi\sqrt{LC}]$) as the values for capacitance (C) can range from pico-Farads (10^{-12}) to Farads, inductance (L) from micro-Henrys (E^{-6}) to Henrys, and the frequency from Hz (or cycles per second) to Giga-Hz (10^9) depending on the application. I should point out that the values for the Capacitance, C, and Inductance, L, generally have a tolerance of ±10% or worse. Slide Rule manufacturers saw the need for simplifying the solution process for X_L, X_C, and f_0 (as they did in the early 1900's for solving various Electrical Engineer functions), and in the mid 1920's started producing specialized slide rules for Electronic Engineers. Table 2 (page 6) lists the specialized Electronic slide rules I currently know of (as of December 2016) and the evolution of these side rules, from the 1920's until the end of the slide rule era in 1974 will be discussed next.

References

[1] Jonnes, Jill, *Empires of light; Edison, Tesla and Westinghouse and The Race to Electrify the World*, Random House, 2003. A must read for those interested.
[2] Adams, Bob, *Electro Rules; their use and scales*, Paper presented at IM 2007. Another must read for you Electrical types. Click on the link below for a copy.
http://sliderulemuseum.com/Papers/ElektroRules_RobertAdams.pdf
[3] Lovett, Rod, *Rod Lovett's Slide Rules*. A must for all slide rule users and researchers.
http://sliderules.lovett.com/index.html
[4] Bob Adams's Electro and Electronic Slide Rule Archive.

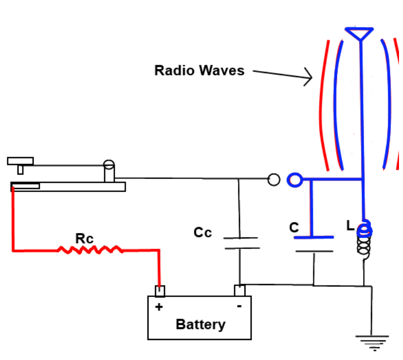
Table 2
Electronic Slide Rule Chronology
$X_L = 2\pi fL$; $X_c = 1/2\pi fC$; $f_0 = 1/[2\pi\sqrt{LC}]$

Approximate Date	Slide Rule	Scales					Comments
		F	2π	LC	Decimal point independent	LL	
1920's	Spark Gap				√		Three slide rules; See Appendix A
1934/1937	Dubilier Capacity				√		Special Scales for $V=IX_C$
1936	K&E 4091- Spc			√		√	First LC scale (inverted A scale folded at $(1/2\pi)^2$)
1937	K&E 4138	√					F scale; D scale folded at 1/2π
1938	K&E Radio Special N 4082-3	√				√	F scale replacing the K scale on a 4081-3 body
1941	K&E Cooke Radio 4139/68-1460		√	√			2π scale; D scale folded at 1/2π and LC scale (inverted A scale folded at $(1/2\pi)^2$)
1950	Sun-Hemmi 256				√	√	Clever design for decimal point independence for f_0
1955	K&E National Union Radio Tubes				√		Six decade decimal point independent scales; X_L, X_C, and f_0
1957	SHURE Reactance				√		Cardboard; Eight decade scales X_L, X_C, and f_0
1958	Aristo 10175		√	√	√		Cooke Radio 2π and LC scales and Decimal point independent scales on the back
1960	Pickett N 16-ES				√	√	Powerful but difficult to master
1962	Pickett N 515-T		√	√	√		Same as the Aristo 10175 Different scale labeling
?	IWA 51903				√		f_0
?	IWA 0268				√		X_C, X_L, f_0
1963	IWA 0272				√		X_C, X_L, f_0
1969	Layfette 99-7128						Unique scales
?	Concise 380				√		Circular; Twelve decade scales for decimal point independent solutions
1968	Sun-Hemmi 266				√	√	One of the best
1966	Tianjin 6504 & 6508	√				√	K&E 4082 F scale on the slide. Excellent general purpose slide rules
?	Pickett 1020-ES		√				A/B/C/D scales to find f_0
?	Pickett 531-ES		√			√	A/B/C/D scales to find f_0
1970	Pickett 535-ES				√		F (1/2π) gauge mark on C scale
1970	Grapoplex 698				√	√	Similar to the Hemmi 266
1974	Nelson-Jones				√	√	Possibly the last of the breed

Specialized Slide Rules for the Electronic Engineer

Wireless Spark Gap Telegraphy

The first of the Electronic slide rules were probably those designed to solve for the transmitted frequency of wireless spark gap telegraphy (Morse code), Figure 6. Thanks to Peter Hopp, I know of three slide rules (Peter Hopp sent me catalog scans of these slide rules; no actual examples are known), all with decimal point independent scales, see Figure 7. They were probably designed and manufactured in the mid 1920's. The three spark gap slide rules are discussed in Appendix A for those interested.



The transmitted frequency, f_T (and wavelength λ_T) are determined by the resonant values for the inductor, L, and capacitor, C.

$f_T = f_0 = 1/[2\pi\sqrt{LC}]$; λ_T = c (the speed of light)/f_T

Figure 6. Spark Gap Transmission

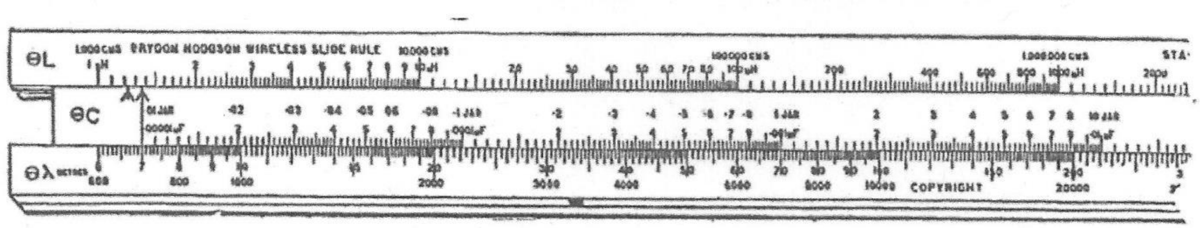
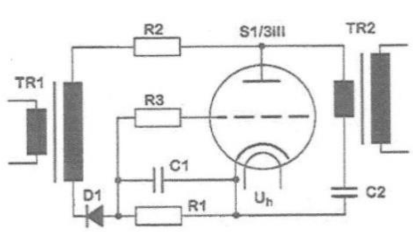


Figure 7. Brydon Hodgson Wireless Slide Rule
(See Appendix A)

The next slide rule is also application specific, solving for the voltage across a capacitor, V_C, knowing the current, I_C, and frequency; $V_C = I_C X_C$.



$V_{C2} = I_{C2}\ X_C = I_C/2\pi fC$

$I_{C2} = V_{C2}(2\pi fC)$

Figure 8. TV / Radar Transmitter

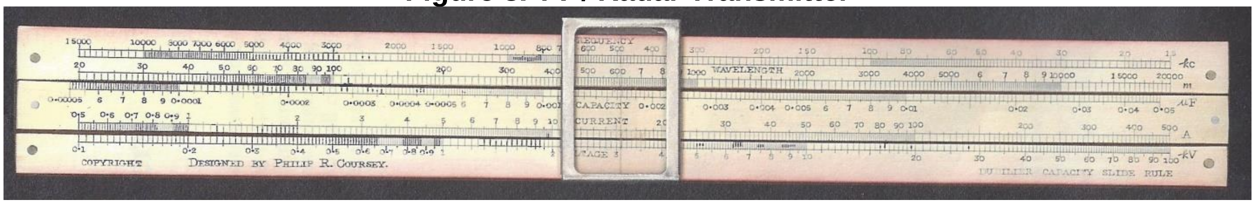
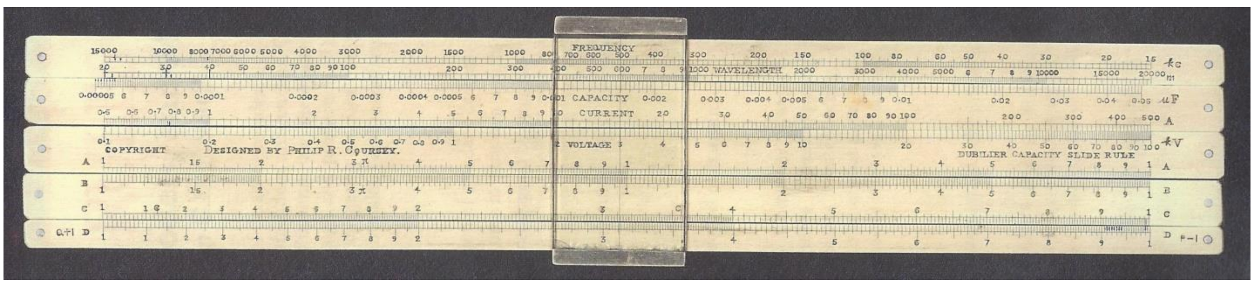


Figure 9a. Version I



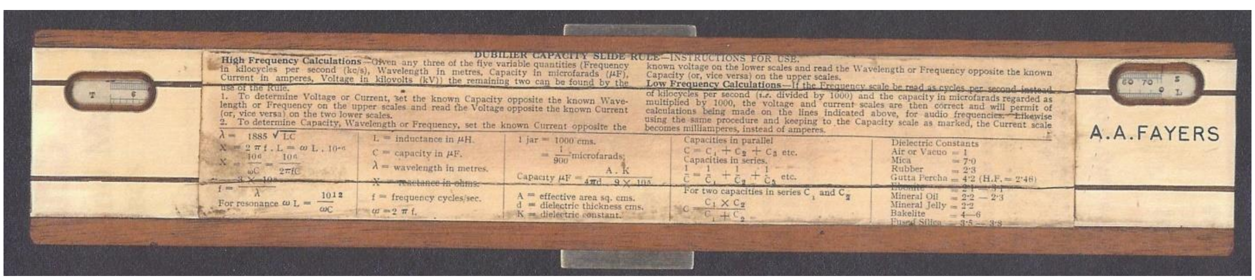


Figure 9. Version II
The two versions of the Dubilier Capacity slide rule
(produced by A. G. Thorton; via Colin Barnes†)

Dubilier Capacity Slide Rules

The Dubilier Capacity slide rule was designed to solve for the voltage across a capacitor knowing the current and frequency in the power output of a TV or Radar transmitter, see Figure 8 (page 7).

The Dubilier Capacity, see Figure 9, was designed by Philip R. Coursey, an engineer who worked for the Dubilier Condenser (1925) limited. The UK Slide Rule Circle reprinted the 1937 Instruction manual for version II; the only difference is the addition of the A/B/C/D scales (sin, tan and log on the back slide) to make the slide rule more versatile. The slide rule solutions are decimal point independent. The date for version I is stated in the manual as “several years before”, a date around 1934/1935.

England was doing research on TV and Radar (Chain Home) and possibly the slide rules were designed to aid these efforts. The version II has the name A. F. Fayers inscribed, who may well be the Alfred Ayton Fayers who worked for EMI, a research firm doing research on TV and Radar. The example below, Table 3, illustrates the basic operation.

Table 3
λ=c (the speed of light)/f, $V_C=I_CX_C=I/2\pi fC$, or $X_C= V_C/I_C$, f=500 kc, C=0.0005 μF, I_C=2 Amp

Scale	Step		$X_C = V_C/I_C$
Frequency (Kc)	(1) below f =500kc		
Wavelength (λ)	(2) read λ=600 meters		
Capacity (μF)	(3) place C=0.0005μF		
Current (A in amps)		(4) below I=2 Amp	(6) below center index (I=10 Amp)
Voltage (V in KV)		(5) read V=1.27 kv	(7) read V=V/I, X_C=6.36kv/10Amp=636 Ω

Reverse the steps if V or I is known.

The next step in the Electronic slide rule evolution is for slide rules to aid in the calculation of X_L, X_C, and f_0.

Keuffel and Esser Electronic Slide Rules

K&E produced the first general purpose Electronic Engineering slide rules, starting with their 4091-3 Spec. (special) in 1936, 4138 Morrison Radio Engineer's Slide Rule a year later, the 4082-3 Radio Special in 1938, and the most long lived of the Electronic Slide rules, the Cooke Radio around 1941 (Clark McCoy, the guru of all things K & E published *Dating K & E Slide Rules* in the Journal of the Oughtred Society, 24:2, Fall 2015, and an excellent historical overview *The Origins of the K & E "Radio" Rule* (reprinted in Appendix B).

K & E 4091-3 Spec. (Special)

K&E produced the first of the general purpose Electronic Engineering slide rules, the 4091-3 Special, see Figure 10, around 1936. This is a rare slide rule, with the only 3 known. The LC scale (Inductance, L and Capacitance, C), located at the top of the back side, is used in finding the resonant frequency, $f_0 = 1/[2\pi\sqrt{LC}]$, or solving for LC, $LC = (1/2\pi f_0)^2$. The LC scale is an inverted A scale folded at $(1/2\pi f)^2$. If the inductance, L, is given in μ Henries (10^{-6}H), the Capacitance, C, in μμ Farads (10^{-12}F) and the resonant frequency, f_0, in MHz (10^6 Hz) (cycles per second, cps, back then), $LC = 159 x 10^6/\sqrt{LC}$). The LC scale limits, 25,300 ← 253, correspond to a resonant frequency from 1 MHz to 10 MHz on the D scale. The operation is shown in Table 4 (page 10). Use the C and D scales for $X_L = 2\pi fL$ and $X_C = 1/2\pi fC$. The approximate solution must be found, for the decimal point, and will be discussed shortly.

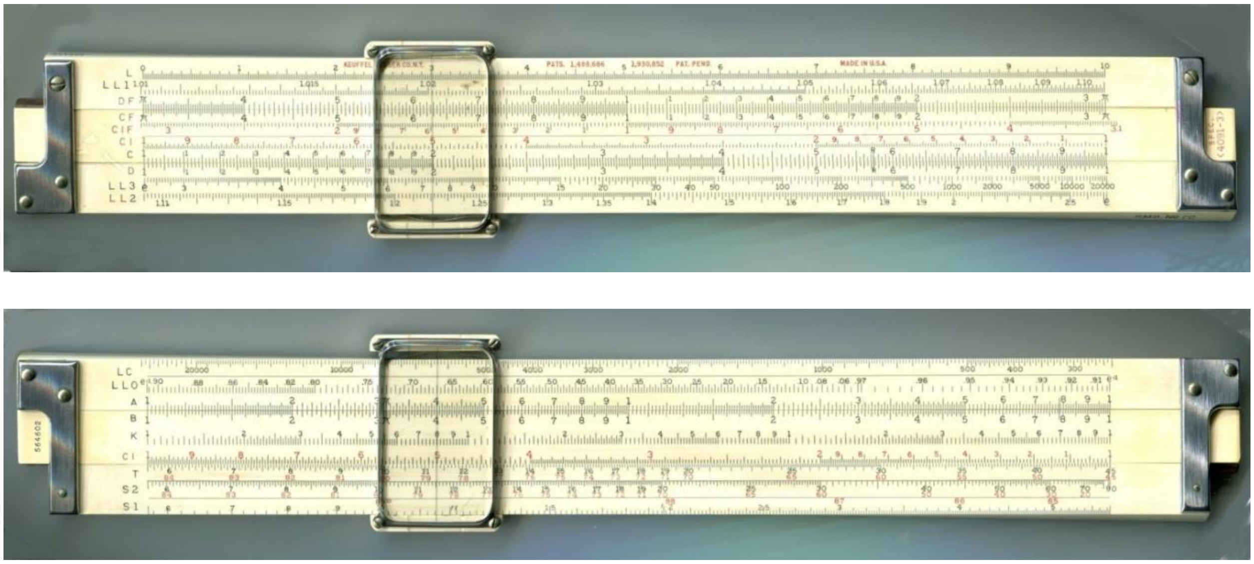


Figure 10. K&E 4091-3 Special
http://www.mccoys-kecatalogs.com

Table 4
K&E LC Scale
(Inverted A scale folded at $(1/2\pi f)^2$, $f_0 = 1/[2\pi\sqrt{LC}]$; $\sqrt{LC} = 1/2\pi f$; $LC = (1/2\pi f_0)^2$

Scale	$f_0 = 1/[2\pi\sqrt{LC}]$	Comment
LC	(L)(C)	The K&E 4091-3 Spec. uses L In µ H and C in µµF; LC 25,300 ← 253 and the frequency f_0 is on D scale, from 1 MHz → 10 MHz
D	$f_0 = 1/[2\pi\sqrt{LC}]$	

K&E 4138 Morrison Radio Engineer's Slide Rule

The K&E 4138 Radio Engineer's slide rule, see Figure 11 (page 11), is the only known example, and the manual can be found in Clark McCoy's web page, http://www.mccoys-kecatalogs.com/. The 4138 was designed by Bell Telephone Laboratories scientist J. F. Morrison and produced by K&E around 1938. The slide rule was designed to aid in the solution of the propagation of Radio Waves over the earth and will not be discussed here. The front side has an F scale and an inverted D scale folded at $1/[2\pi]$. The basic operation is shown in Table 5 (page 11); however, the decimal point must be determined. This simple procedure will be discussed next.

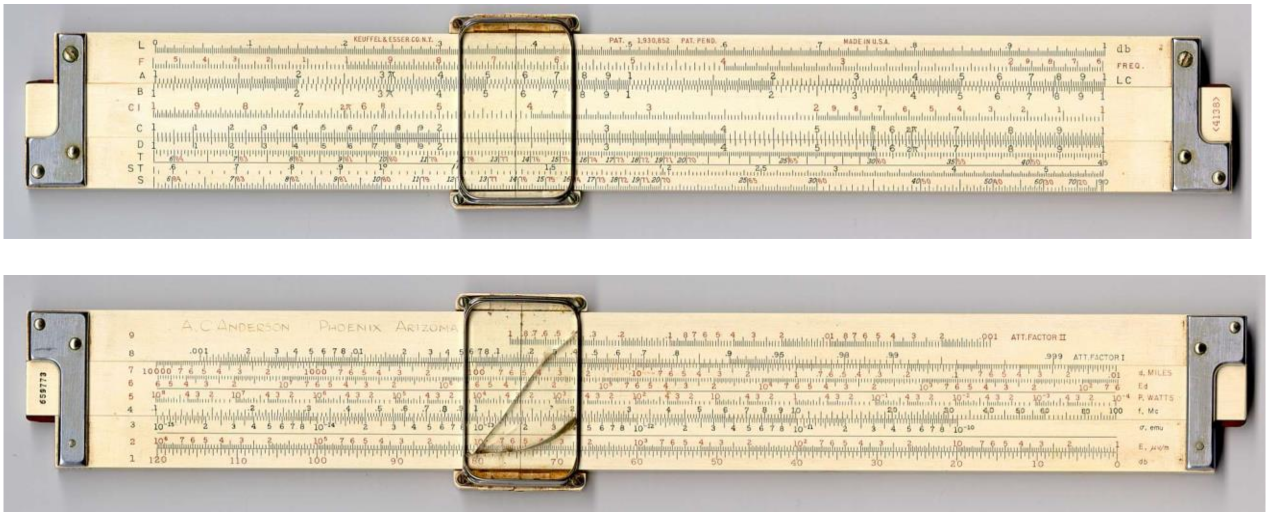


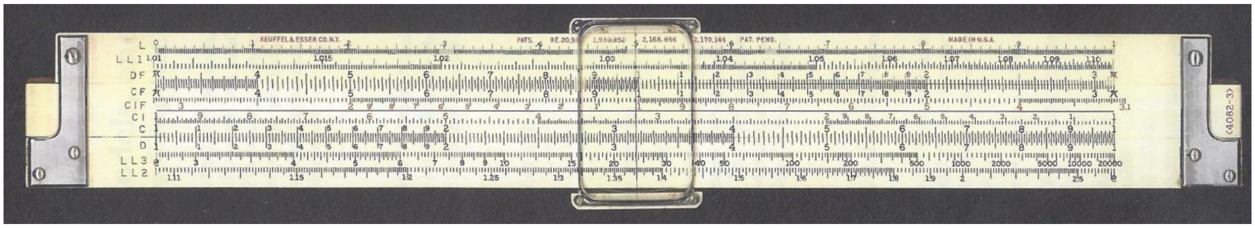
Figure 11. K&E 4138 Radio Engineer's Slide Rule
http://www.mccoys-kecatalogs.com/

Table 5
4138 Scales and Operation
$X_L = 2\pi fL$, $X_c = 1/2\pi fC$ $f_0 = 1/[2\pi\sqrt{LC}]$ $LC = (1/2\pi f_0)^2$

Scale	Function	$X_C = (1/2\pi fC)$	$X_L = 2\pi fL$	$f_0 = 1/[2\pi\sqrt{LC}]$
F	Frequency f	f	f	$f_0 = 1/[2\pi\sqrt{LC}]$
A	LC			LC
C	$1/2\pi f$		$X_L = (2\pi)(fL)$ Place L on the C scale over f on the F scale; Read X_L on the C scale above the D index	f on the F scale = LC = $(1/2\pi f_0)^2$ on the A scale; $L = (1/2\pi f_0)^2(1/C)$ $C = 1/2\pi f_0)^2(1/L)$
D	$1/2\pi f$	$X_C = (1/2\pi f)(1/C)$		

K&E 4082-3 Radio Special

The 4082-3, see Figure 12 (page 12), may be the first mass produced Electronic slide rule, and was sold from 1938 to around 1940. Several examples are known and Clark McCoy's web page has a copy of the instructions. The 4082-3 is a 4081-3 with a special F scale, on the bottom of the back side, and an inverted D scale folded at $1/2\pi$ to aid in the solutions for $X_L = 2\pi fL$ and $X_c = 1/2\pi fC$ (this is the same F scale on the 4138). Table 6 (page 12) shows the basic scale operation.



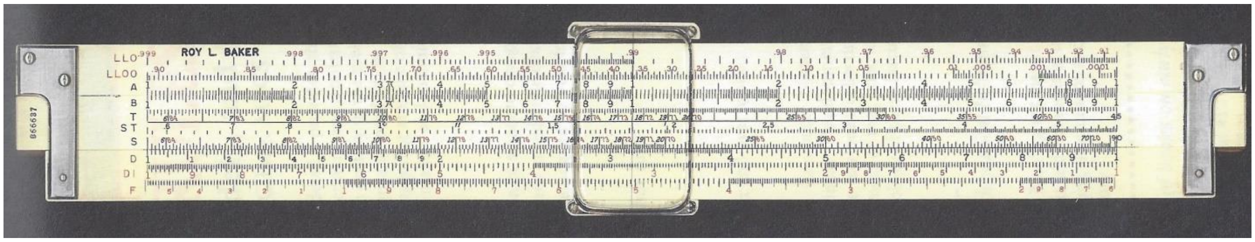


Figure 12. K&E 4082-3 Radio Special

Table 6
F Scale (Inverted D scale folded at 1/2π)
$X_L = 2\pi fL$, $X_c = 1/2\pi fC$ $f_0 = 1/[2\pi\sqrt{LC}]$ $LC = (1/2\pi f_0)^2$

Scale	Function	$X_C = (1/2\pi fC)$ $X_L = 2\pi fL$	$f_0 = 1/[2\pi\sqrt{LC}]$
A			LC
D	$1/2\pi f$	$X_C = (1/2\pi f)(1/C)$	
DI	$2\pi f$	$X_L = (2\pi f)(L)$	
F	Frequency f	f	$f_0 = 1/[2\pi\sqrt{LC}]$ f on the F scale = LC = $(1/2\pi f_0)^2$ on the A scale; $L = (1/2\pi f_0)^2(1/C)$ $C = 1/2\pi f_0)^2(1/L)$

The decimal point must be determined, the bane of all slide rule users. The manual, indeed many reference books, have a “Reactance” graph to find the approximate solution, see Figure 13 (page 13). The diagonal lines are for Inductance and Capacitance with the x-axis for frequency and the y-axis for reactance (I remember using Reactance Plots for the approximate solution way back when - much easier than finding the approximate solution using the slide rule). This graph may be intimidating, so here are a couple of examples:

L = 100 μH, f = 100 kHz
Read $X_L \approx 65\ \Omega$ (actual 62.8 Ω)
C = 0.1 μF, f = 100 kHz
Read $X_C \approx 16\ \Omega$ (actual 15.9 Ω)
L = 2 μH, C = 0.5 μF
Read $f_0 \approx 160$ kHz (actual 159 kHz)
Note; at resonance, f_0, $X_L = X_C \approx 2\Omega$ (actual 2.01 Ω)

Knowing the approximate solution; thus, the decimal point, to use the slide rule for a more accurate answer is now a simple matter. The 4082-3 Radio Special is a great slide rule, containing most of the scales necessary for the rigors of college math and science classes.

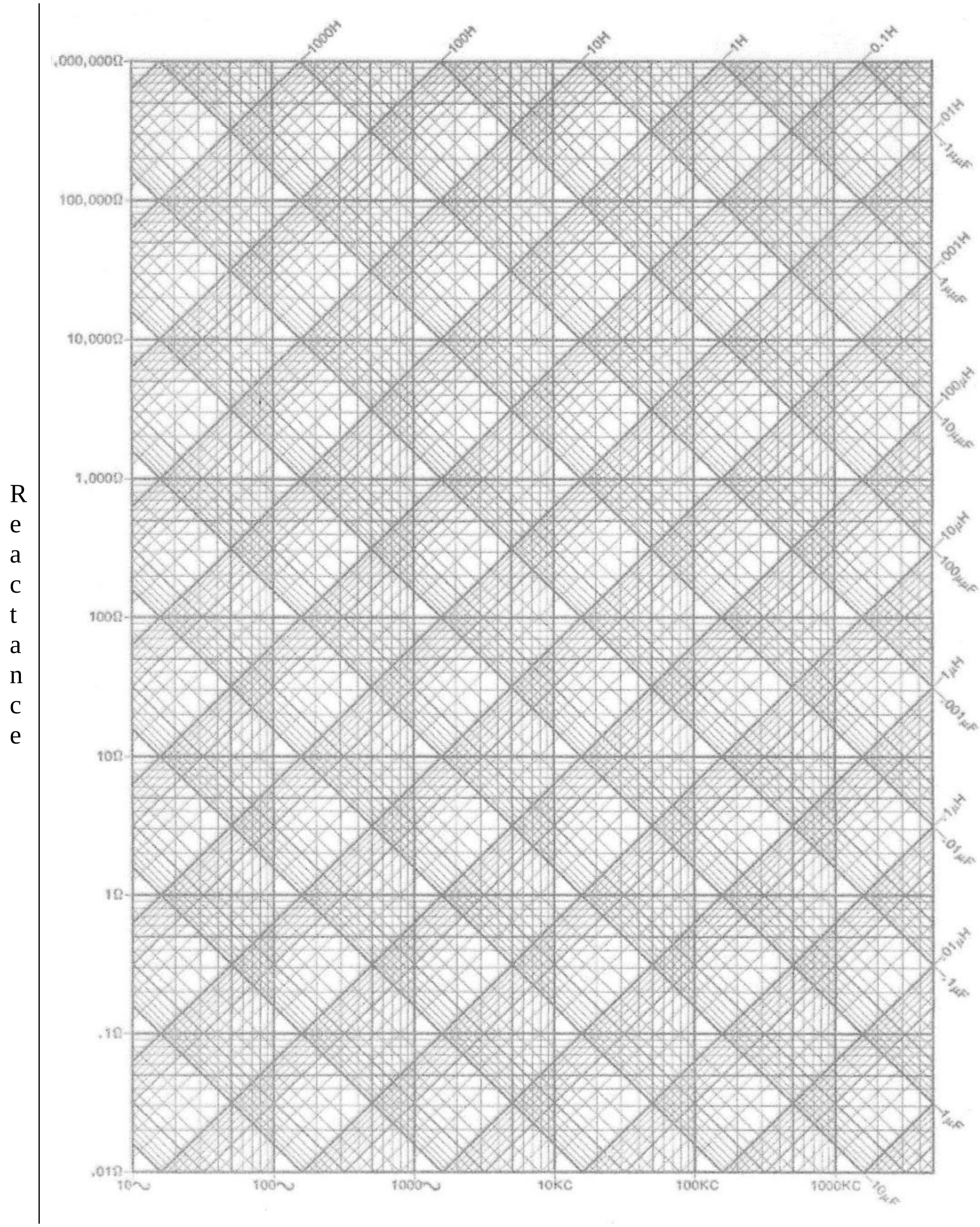


Figure 13. Frequency → Reactance Plot
(from K&E 4082-3 and 4138 Morrison Radio Engineer's manuals)

K&E 4139 / 68-1460 Cooke Radio

The Cooke Radio slide rule, see Figure 14, was designed by Nelson M. Cooke (Chief Radio Technician, U.S.N) and appeared around 1940/1941; Appendix C is a copy of my paper *Keuffel & Esser Cooke Radio Variants* published in the Journal of the Oughtred Society, 24: 2, Fall 2015 for those interested. The Cooke Radio is built on the 4071 Polyphase Duplex Decitrig frame and has the LC and a 2π scale (D scale folded at 1/2π). The Cooke Radio had the longest life span of any of the Electronic slide rules; from around 1940/1941 to 1968 or later! It does not have the LL scales necessary for college/university math/science/engineering classes; however, it obviously had a huge following.

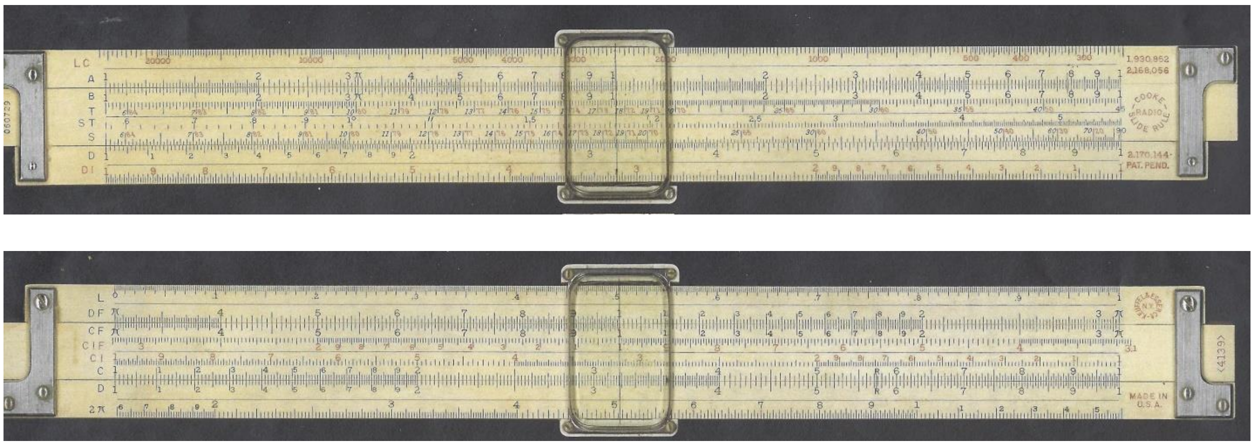


Figure 14. Cooke Radio Slide Rule 4139/68-1460

The 2π scale, a D scale folded at 1/2π, is used in the solution of the Inductive reactance, $X_L = 2\pi fL$ and Capacitive reactance $X_c = 1/2\pi fC$. A copy of the instruction manual can be found on McCoy's web page, http://www.mccoys-kecatalogs.com/. The operation of the LC scale, see Table 7, is the same as the 4091-3. Table 8 is for the 2π scale.

Table 7

LC Scale (Inverted A scale folded at $(1/2\pi f)^2$)

$f_0 = 1/[2\pi\sqrt{LC}]$; $\sqrt{LC} = 1/2\pi f$; $LC = (1/2\pi f_0)^2$

Scale	$f_0 = 1/[2\pi\sqrt{LC}]$	Comment
LC	(L)(C)	L In μH and C in μμF; LC 25,300 ← 253 and frequency f_0 is on D scale, from 1 MHz → 10 MHz
D	$f_0 = 1/[2\pi\sqrt{LC}]$	

Table 8

2π Scale Operation

$X_L = 2\pi fL$, $X_c = 1/2\pi fC$

Scale	Function	$X_C = (1/2\pi fC)$	$X_L = 2\pi fL$
A			
D	2πf		$X_L = (2\pi f)(L)$
DI	1/2πf	$X_C = (1/2\pi f)(1/C)$	
F	Frequency f	f	f

K&E National Union Radio Tubes Slide Rule

The National Union Radio Tubes slide rule, see Figure 15, was produced around 1955, and may have been the first slide rule with extended scales to find the approximate value (thus the decimal point) for $X_L = 2\pi fL$, $X_c = 1/2\pi fC$, and $f_0 = 1/[2\pi\sqrt{LC}]$. Remember the tolerance for inductors, L, and Capacitors, C, is usually ± 10%. If better accuracy was required, you would have had to use your everyday slide rule.

The price of slide rules was a major expense, and purchasing a slide rule to just find the decimal point may not have been a possibility; remember we had access to the Reactance Charts, see Figure 13 (page 13).

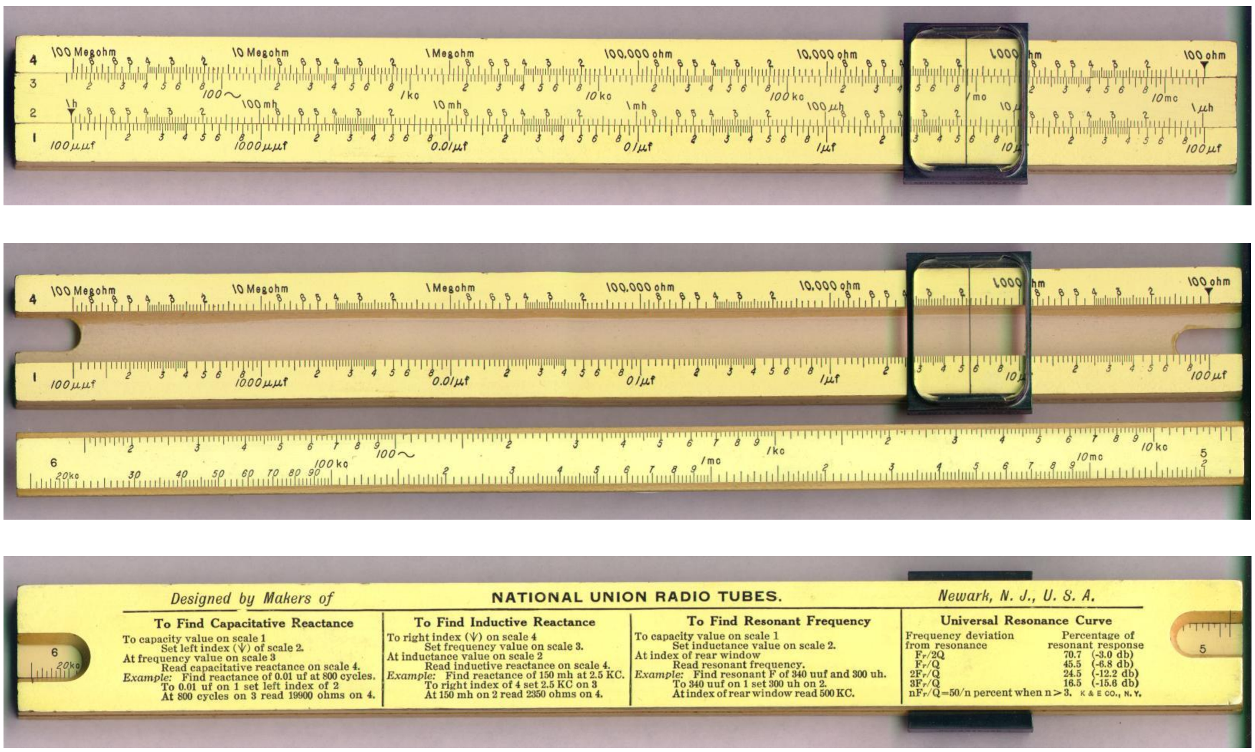


Figure 15. K&E National Union Radio Tubes Slide Rule
http://www.mccoys-kecatalogs.com/

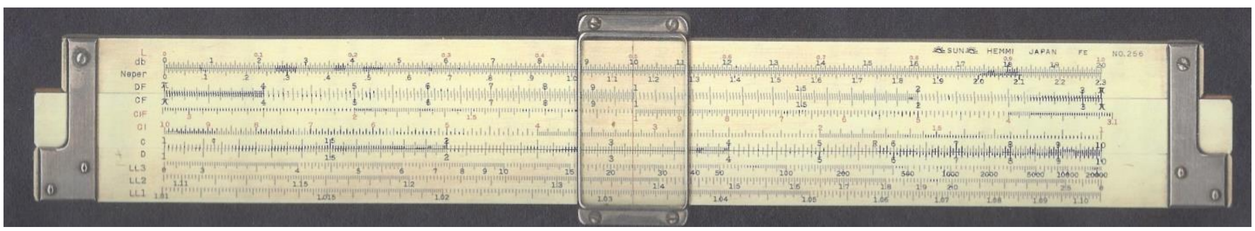
Most of the slide rules discussed next have special scales to find an approximate solution; the decimal point. The Sun-Hemmi 256 is a unique design; however, the 256 takes time to master.

Sun-Hemmi 256 (for electric communication engineers)

The Sun-Hemmi 256, see Figure 16, introduced in 1950, tackles the decimal point problem via special scale design, labeling, and the F gauge mark (on the slide below the tan scale). Referring to Figure 16, back side, note the scale limits:

1) below the left and right indexes of the A, Impedance scale
2) above the left and center and right indexes on the Inductance L scale
3) below the left and center and right indexes on the Inductance Capacitance C scales and
4) below the left and middle indexes on the F, or frequency scale.

The numbers to the left of the scale limits, -1, -2, 0, 1, 2, etc. are used in determining the decimal point as will be seen. The four equations; F=L+C (for Resonant Frequency f_o), X=F-2C (for Capacitive Reactance X_C), and X=2L-F (for Inductive Reactance X_L) define the exponent index of the wanted function. The L, C, and F refer to the exponential scale limits to the left of their individual component values. To avoid confusion all the exponent indexes will be placed in brackets [F] = [L]+[C], etc. Table 9 shows the procedure for finding f_0.



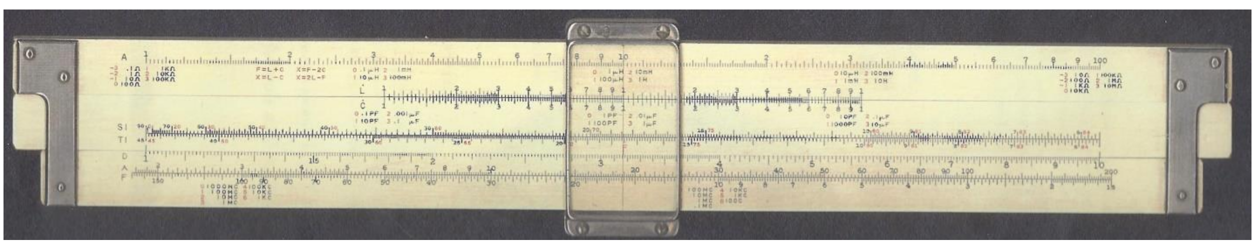


Figure 16. Sun-Hemmi 256
(production date, May, 1955)

Table 9
Resonant Frequency, F (or f_0)=1/[2π$\sqrt{LC}$)]
[F]=[L]+[C]

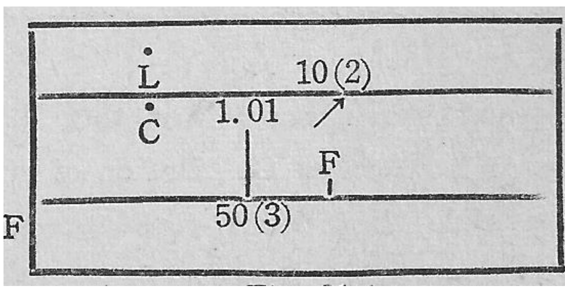
Scale	L=2 µH [0] C=0.3 µF [3]; [F]=[0]+[3]=[3]	
L	(1) below L=2 µH [0]	
C		(3) below C=0.3 µF [3];
F gauge mark	(2) place F gauge mark	
F	frequency	(4) read f_0==206kHz [3]

Reverse steps if f_0 is known. [L]=[F]-[C] and [C]=[F]-[L]

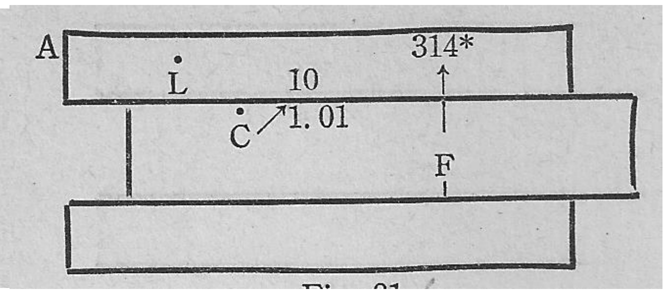
Finding X_L and X_C using the special scales is time consuming. Given inductance L and frequency f, you must assume f is the resonant frequency, f_0, and find the capacitance, C, necessary for resonance (See Table 9). The procedure is shown below in Table 10; provided from the Instruction book for *The Use of Hemmi Bamboo Slide Rules*, Revised Edition, 1957.

Table 10

X_L =2πfL, L = 10 mH [2] f = 500 kHz [3], [XL] = 2[L] – [F]



a



b

a To 10 mH (index 2) on $\dot{L}$ scale, set the gauge line *F* first. Opposite 50 (index 3) on *F* scale, read 1. 01 on $\dot{C}$ scale. b To 10 mH on $\dot{L}$ scale, set 1. 01 on $\dot{C}$ scale.

Opposite the gauge line *F* of the slide, read significant figures 314 on *A* scale.

Answer is 31. 4 *K*Ω by the law of placing decimal point $\dot{X}=2\times2-3=1$ and referring 100 on this scale represents 100kΩ for the symbolic index 1.

(Note) In this case value of *C* is only used as "parameter" and it is not necessary to know its index value.

This is far too complicated; just use the CI/C/D scales for X_L and X_C. The Sun-Hemmi 256 is a clever design, but is the design worth the effort to use? They did have a following; however, without the Trig scales the 256 is severely limited.

The next slide rule, the Shure Reactance Slide Rule (made of cardboard), was a major step forward in the solution for X_L = 2πfL, X_c = 1/2πfC, and $f_0 = 1/[2\pi\sqrt{LC}]$; this rule easily solves for the approximate solution; thus, the decimal point.

Shure Reactance Slide Rule

The Shure Reactance Slide Rule, see Figure 17, removes the need for Reactance Charts to find the approximate answer, thus the decimal point. The Shure rule is easy to use and once the decimal point is known, we can use our everyday slide rule for f_0, X_L, and X_C. The Shure was made in 1957 (bottom left front side) and over the years many electronic component companies had similar cardboard slide rules made and handed them out for free! I still remember using them.

See Appendix E for an excellent discussion on Reactance and Associated Slide Charts.

A circular version of the Shure was made by Concise.

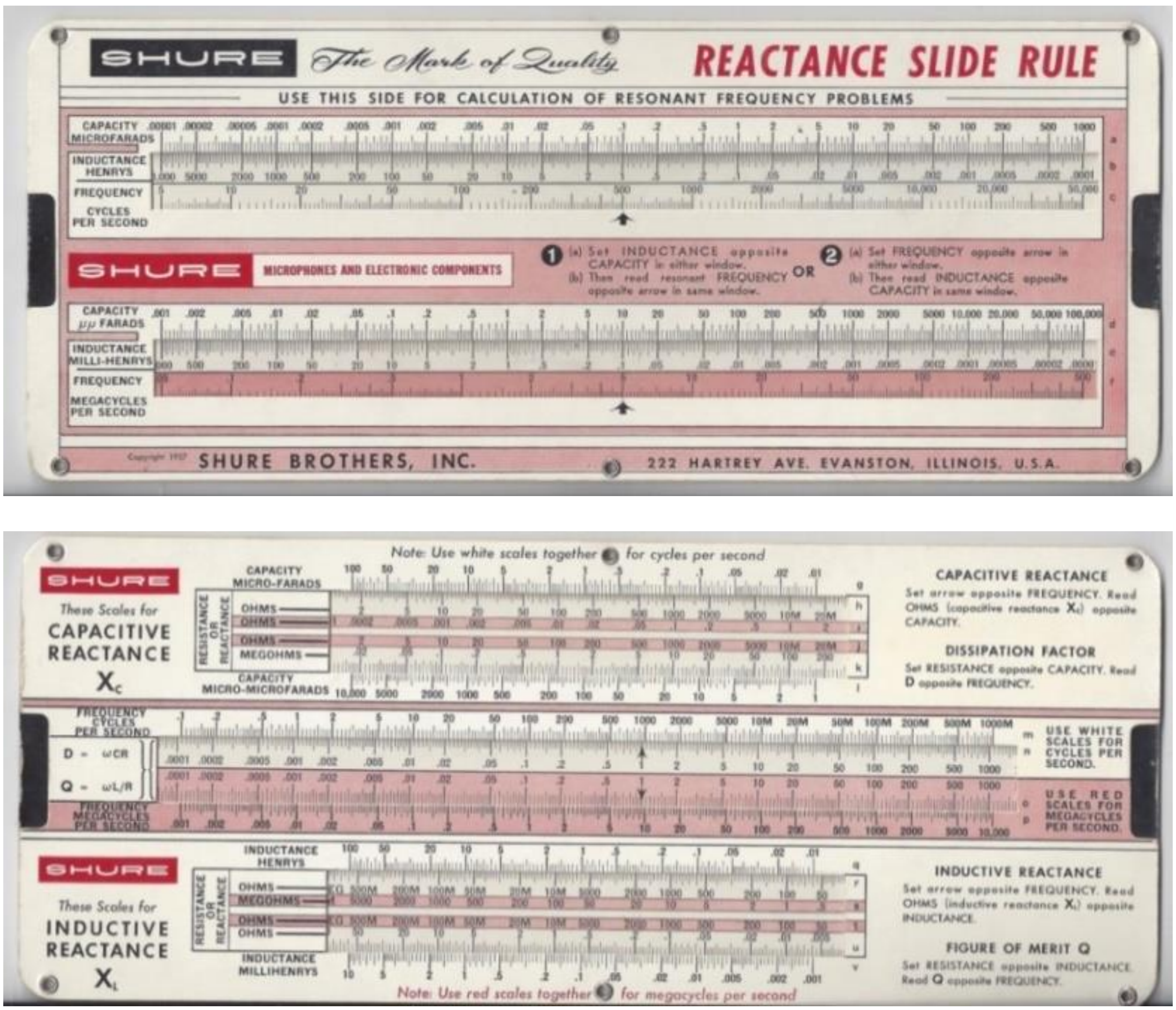


Figure 17. Shure Reactance Slide Rule

Concise 380 Radio Computer

The Concise 380, see Figure 18, (I do not know when this Concise was made; best guess around middle of the 1960's) is a circular slide rule that easily solves for X_L, X_C, and the Resonant Frequency f_0. The decimal point is taken care of in the slide rule design. The impedance and frequency scales are twelve decades in length so the readings really are approximate.

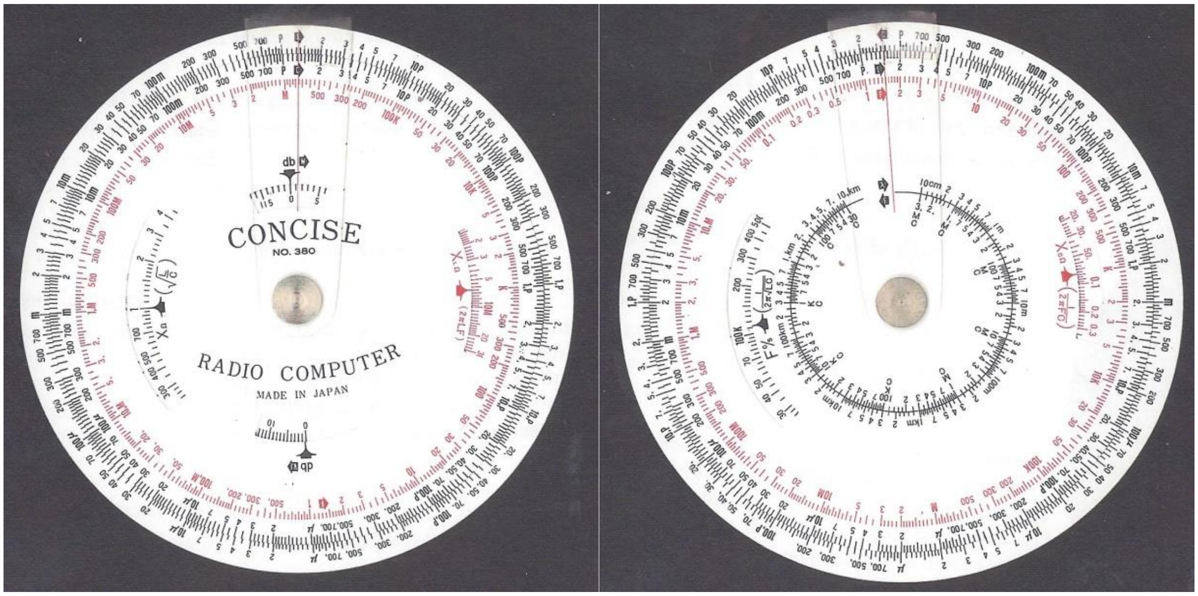
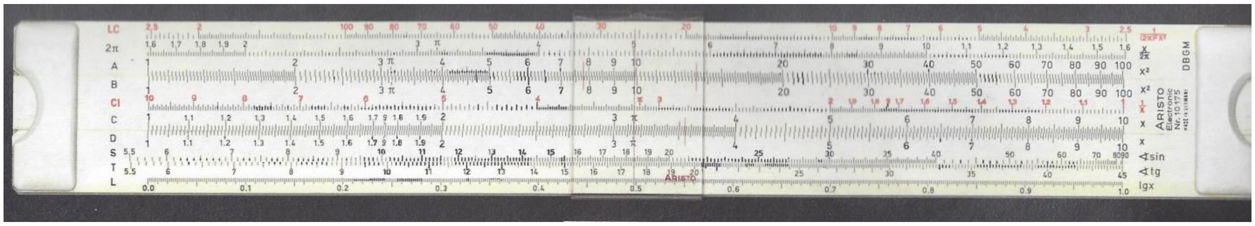


Figure 18. Concise Radio Computer

Aristo 10175

The Aristo 10175, see Figure 19 (page 20), was made for the Cleveland Institute of Electronics. The Manual has a copyright date of 1958. The front side has the same "Electronic" scales as the Cooke Radio; however, they are located on the front side for ease of use. This slide rule is truly unique in that it has several scales on the back side (extended C, L, X_C, X_L, and f scales) that solve for the approximate problem solution; thus, removing the decimal point problem, see Table 11 (page 20). The cursor is single sided and must be reversed when using the scales on the back side. This may be the first slide rule that has decimal point independent scales (for finding the approximate solution) and special Electronic scales (the Cooke Radio 2π and LC scales) and several common scales. This was a major step in the development of "Electronic" slide rules.



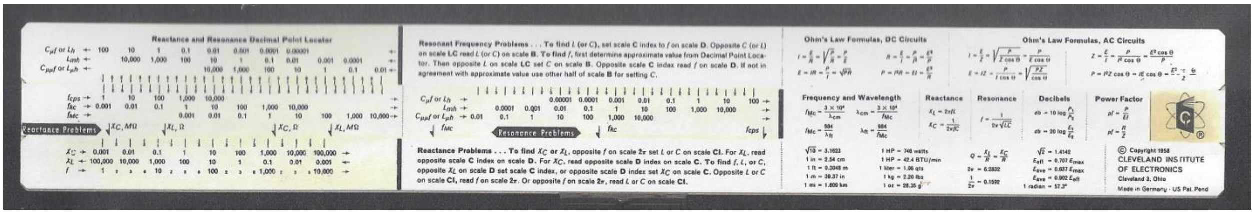


Figure 19. Aristo 10175

Table 11
Using the approximate value scales

$X_L=2\pi fL$

Scale	Step	
L	(1) below L	
f	(2) place f	
X_L gauge mark		(3) below X_L gauge mark
X_L		(4) read X_L

$X_C = 1/(2\pi fC)$

Scale	Step	
C	(1) below C	
f	(2) place f	
X_C gauge mark		(3) below X_C gauge mark
X_C		(4) read $X_C=1/(2\pi fC)$

$f_0 = 1/[2\pi\sqrt{LC}]$

Scale	Step	
C or L	(1) below C (or L)	
C or L	(2) place L (or C)	
f gauge mark		(3) below gauge mark
f		(4) read f_0

Knowing the decimal point, a more accurate answer can be found using Table 12.

Table 12
$X_L = 2\pi fL$, $X_C=1/(2\pi fC)$

Scale	Function	$X_L = 2\pi fL$	$X_C=1/(2\pi fC)$
2π	Frequency f		f
CI			Place C on the CI scale under f on the 2π scale;
C	2πf	$X_L = (2\pi)(fL)$	Read $X_C=1/(2\pi fC)$ on the C scale above the D index

Knowing L and C, the approximate solution for f_o is found as shown in Table 12. To find a more accurate value use the LC scale; place C on the B scale under L on the LC scale and read f_0 on the D scale below the C scale index. If you do not get the approximate answer, move C on the B scale to the other side. The K&E 4082-3 is much easier to use.

The next four slide rules were manufactured by Pickett. An excellent article on these slide rules can be found in Appendix D; Brian Borchers, *Five Pickett Electronics Slide Rules,* Journal of the Oughtred Society, 12:1, Spring 2003 (the fifth, N-16-ES, will be discussed later).

Pickett N-515-T

The Pickett N-515-T, see Figure 20, was, like the Aristo 10175 (1958), made for the Cleveland Institute of Electronics. The manual for the 515 has three copyright dates; 1958 (for the Aristo 10175), 1962, and 1965. Thus the N-515-T was produced from 1965 at the latest and possibly from 1962. The 515 has the same decimal point independent scales as the 10175 and a two sided cursor for ease of operation. The only differences between the 515 and 10175 are the scale placement and labeling, see Table 13, and the addition of an Ln scale. The solution process is exactly the same as the Aristo 10175. See http://sliderule.ozmanor.com/man/man-download.html for a copy of the manual.

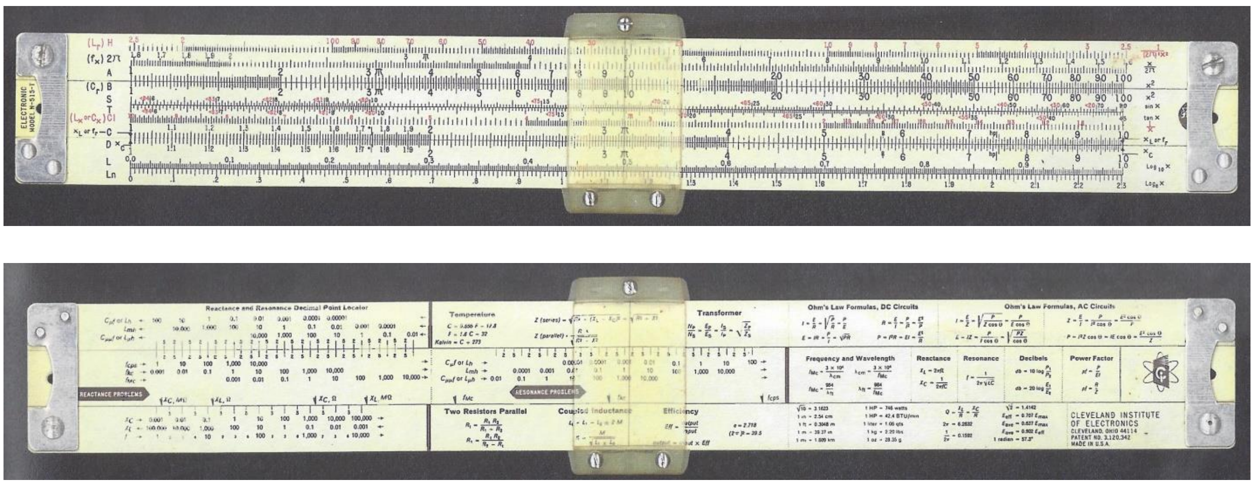


Figure 20. Pickett N-515-T

Table 13
Aristo 10175 and Pickett N-515-T Scale Comparison

Aristo 10175	Pickett N-515-T
LC	(L_r) H
2π	(f_x) 2π
A	A
B	(Cr) B
CI	(L_x or Cx) CI
C	C (indexes labeled X_L or f_r)
D	D (indexes labeled X_C)

Pickett N 531-ES

The Pickett N 531-ES, see Figure 21, was made for the Capital Radio Engineering Institute, CREI; I do not know the date, but probably in the mid 1960's. The 531 has a 2π scale, and the operation for X_L and X_C is the same as the Aristo 10175 and the Pickett N-515-T; use the normal procedure to find f_0. There are no approximate value scales and the decimal point must be approximated.

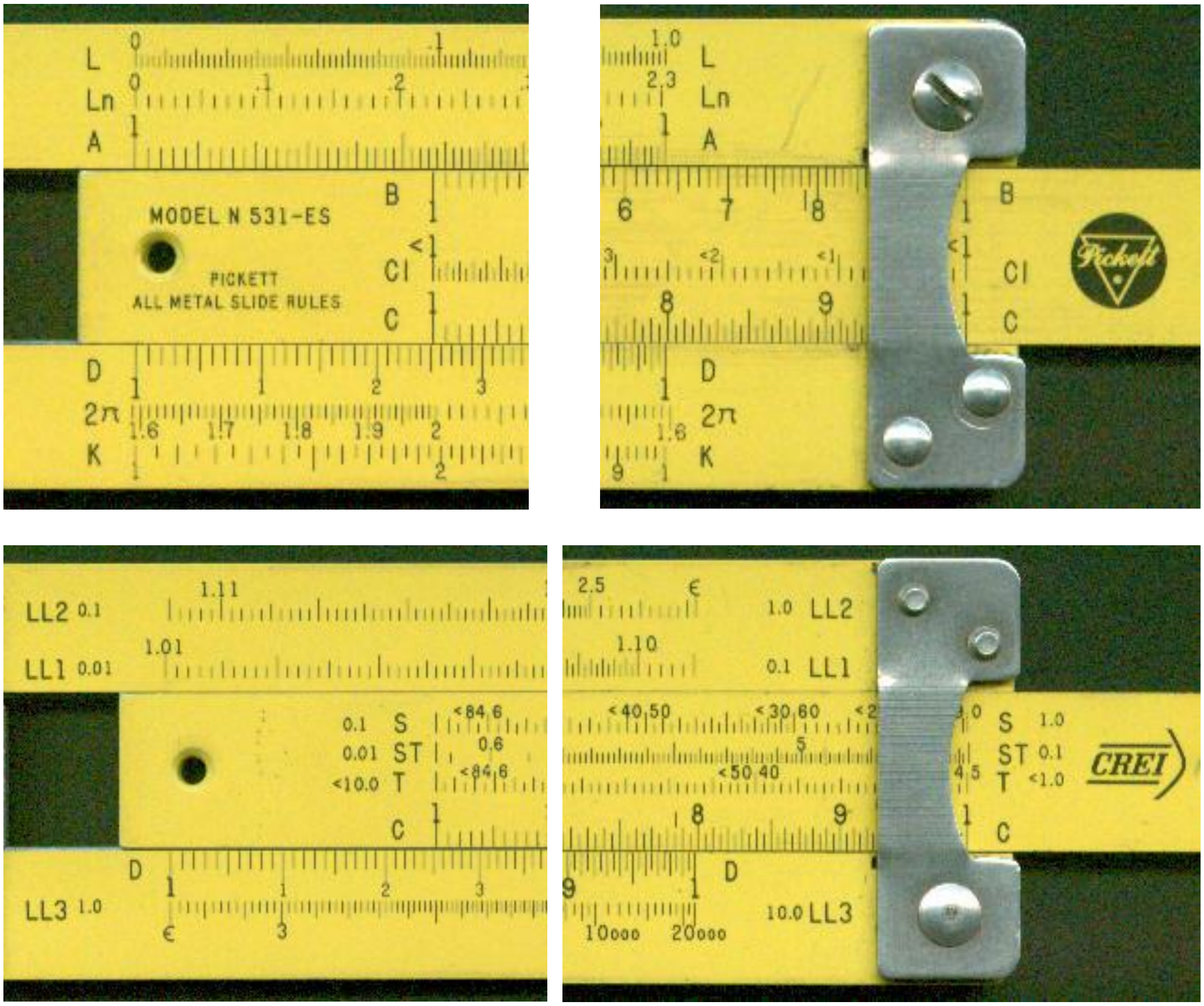


Figure 21. Pickett N 531-ES
http://www.sliderules.info/collection/10inch/060/1064-pickett-531es.htm

Pickett N 535-ES

The N 535-ES, see Figure 22, was designed by Chan Street, and produced by Pickett in 1970. I have seen several of these, and not all have the Eastfield Digital Electronics name. The 535 has approximate value scales on the back and the operation for finding X_L, X_C, and f_0 is the same on both sides; place the F gauge mark↓ ($1/2\pi = 0.159$) on the slide over the frequency f on the F scale, below L on the L scale read X_L on the X_L scale (use the same procedure for X_C, use the L_r and C_r (an inverted A scale) for f_0. The other scale listings are for Ohm's Law and are straight forward and will not be discussed here. The 525 does not have any LL scales; however, the 535 is easy to use, and is a pretty good Electronic slide rule.

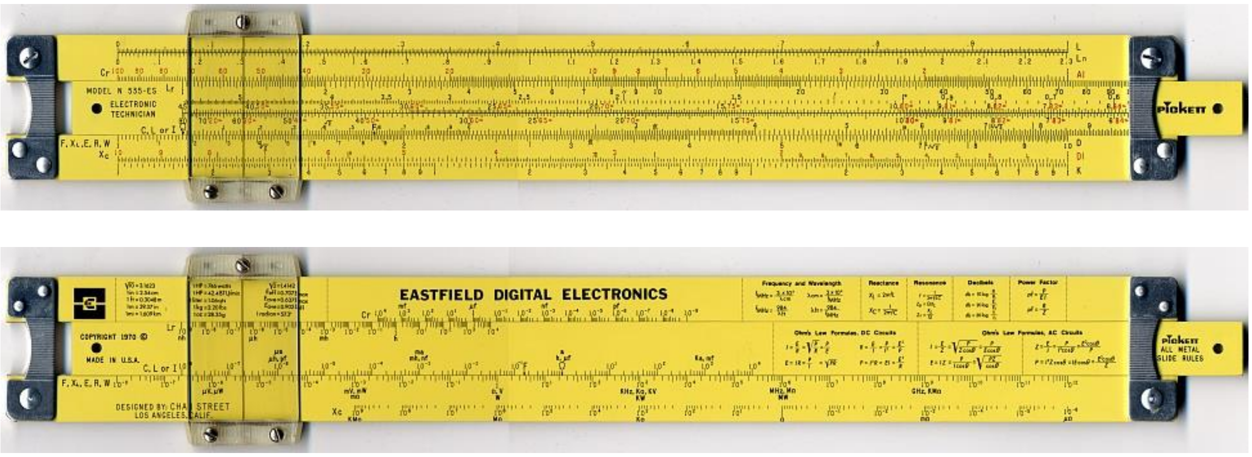


Figure 22. Pickett N 535-ES
http://marksmath.com/slide-rules/index.html

Pickett N 1020-ES

The Pickett N 1020-ES, see Figure 23, was made for the National Radio Institute, NRI; however, I do not know the date. The 1020 has 2π and DI scales. See Table 14 for the operation. Again no LL scales, so the slide rule is of limited use in University science and engineering classes.

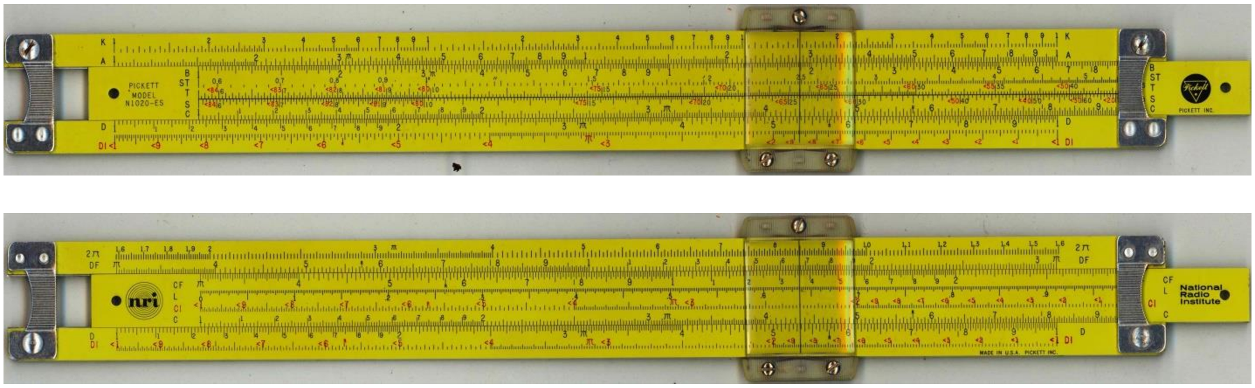


Figure 23. Pickett N 1020-ES
http://steves-sliderules.info/allrules.html

Table 14
Pickett N 1020-ES Operation

Scale	Function	$X_L = 2\pi fL$, $X_C = 1/2\pi fC$	$f_0 = 1/[2\pi\sqrt{LC}] = 0.159/\sqrt{LC}]$
2π	f		
A			LC
C			
D	2πf	$X_L = (2\pi f)(L)$	
DI	1/2πf	$X_C = (1/2\pi f)(1/C)$	$f_0 = (1/\sqrt{LC}](0.159)$

The following three slide rules were made by IWA, a German firm who produced a number of slide rules for various firms; apparently they are still producing slide rules.

IWA 0268

The IWA 0268 (See Figure 24) easily solves for X_L, X_C, and f_0; all with decimal point independence. I do not know when the 0268 was made, but possibly in the early 1960's. I do not have any of the IWA slide rules, or their manuals; however, I think the following descriptions are accurate.

The front side is used to find X_L and X_C. The top scale is for the capacitance C (3 → 3,000), in Farads, on the slide, the next scale is for the X_C frequency, in Hz, (1,000 ← 2) on the slide and the third is for X_L and X_C, in **Ω** , labeled Z, (5 → 300) on the body. The next two scales are L, in Henrys, (on the body (3,000 ← 4) and the X_L frequency f, in Hz, on the slide (2 → 10,000). Finding X_C and X_L is really simple: below C place f (inverted scale) and read X_C below the left or right hairline index. The same procedure is used to find X_L. But how do we find what exponents the scale should have? The four "boxes" (See Table below) give the scale readings. The capacitance, C, is from 1μF to 1mPF (0.001pF), and the inductance, L, from 1H to 1mμ H (0.001μH). These values correspond to the C and L scales. Placing the frequency of interest, f, under the wanted C or L range (the f scale reading), the exponent for X_C and X_L are given on the bottom left and right "boxes". Say the C range is to be read in pF (or L in μH) and we want the frequency in kHz; move the bottom slide for f in kHz under C in pF (above L in μH). The X_C (Z) scale reading will be in M**Ω** if read under the left hairline and k**Ω** if under the right. The X_L (Z) reading will be in k**Ω** under the left hairline and **Ω** if under the right.

← F		10kHz	1kHz			F →
L x	1H	10mH	0.1mH	1μH	0.01μH	X L
C X	1pF	100pF	10kpF	1μF	100μF	X C

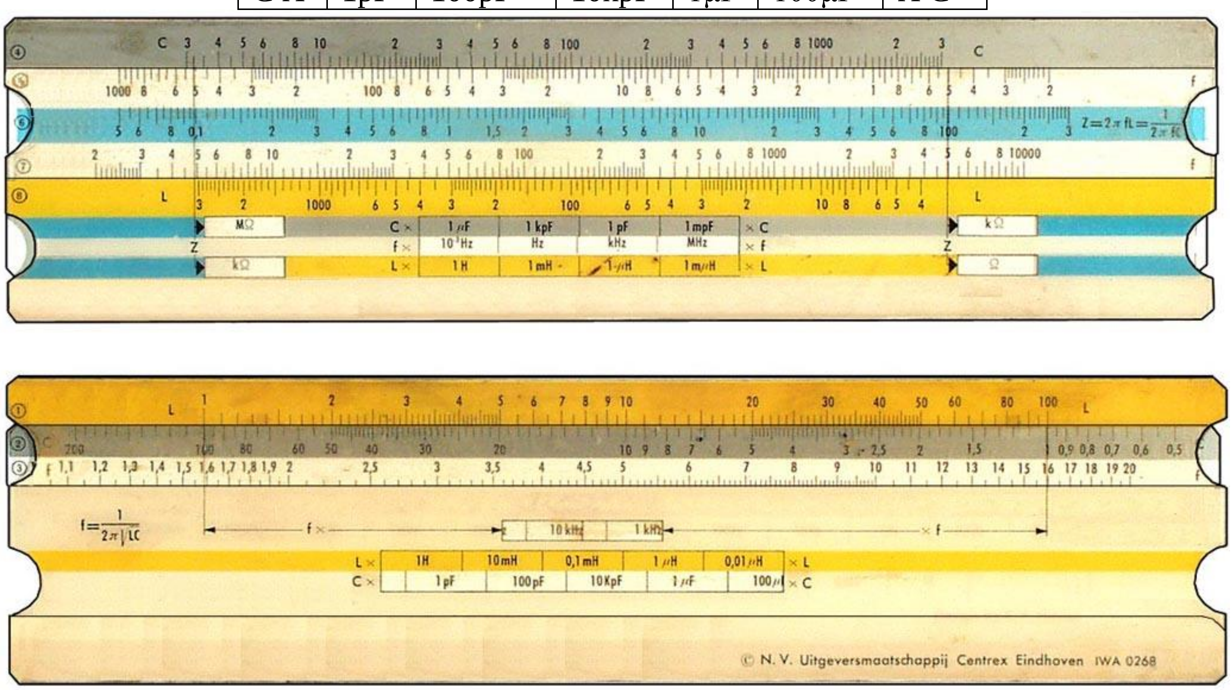


Figure 24. IWA 0268

http://sliderulemuseum.com/HSRC/13991.jpg

The back side is used to find f_o, and the operation is similar as the front; place C, in F, on the C scale (inverted 200 ← 0.5) under L, in H, on the L scale (1 → 100) and read f_o, in Hz, below the left or right hairline. Use the table below the scales to determine the C, l, and f_o exponents; I think the f scale is shown wrong and should be as shown in the bottom of Figure 23. Set C on the slide below the known L, say L in µH (the L scale is to be read in µH) and C in µF (the C scale in µF), the frequency, f_o, will be 10 kHz if read on the left hairline, and 1 kHz on the right.

IWA 51903

I do not know when the IWA 51903 (See Figure 25) was made, but possibly in the mid/late 1960's. The 51903 has C and L on the slide, and a frequency scale on the bottom for the resonant frequency f_0; place C over the gauge mark Δ (the left D index), move the cursor to L, and read f_0 on the frequency scale. We must use the $0.159 = 1/2\pi$ gauge mark to find X_C and X_L. The back side has a scale for V_2/V_1 in dB, (20Log (V_2/V_1) and P_2/P_1 in dB (10Log (P_2/P_1), and the color coding for resistor values and tolerance. The back of the slide has sin, Log, lg (inverted), and tan, tg.

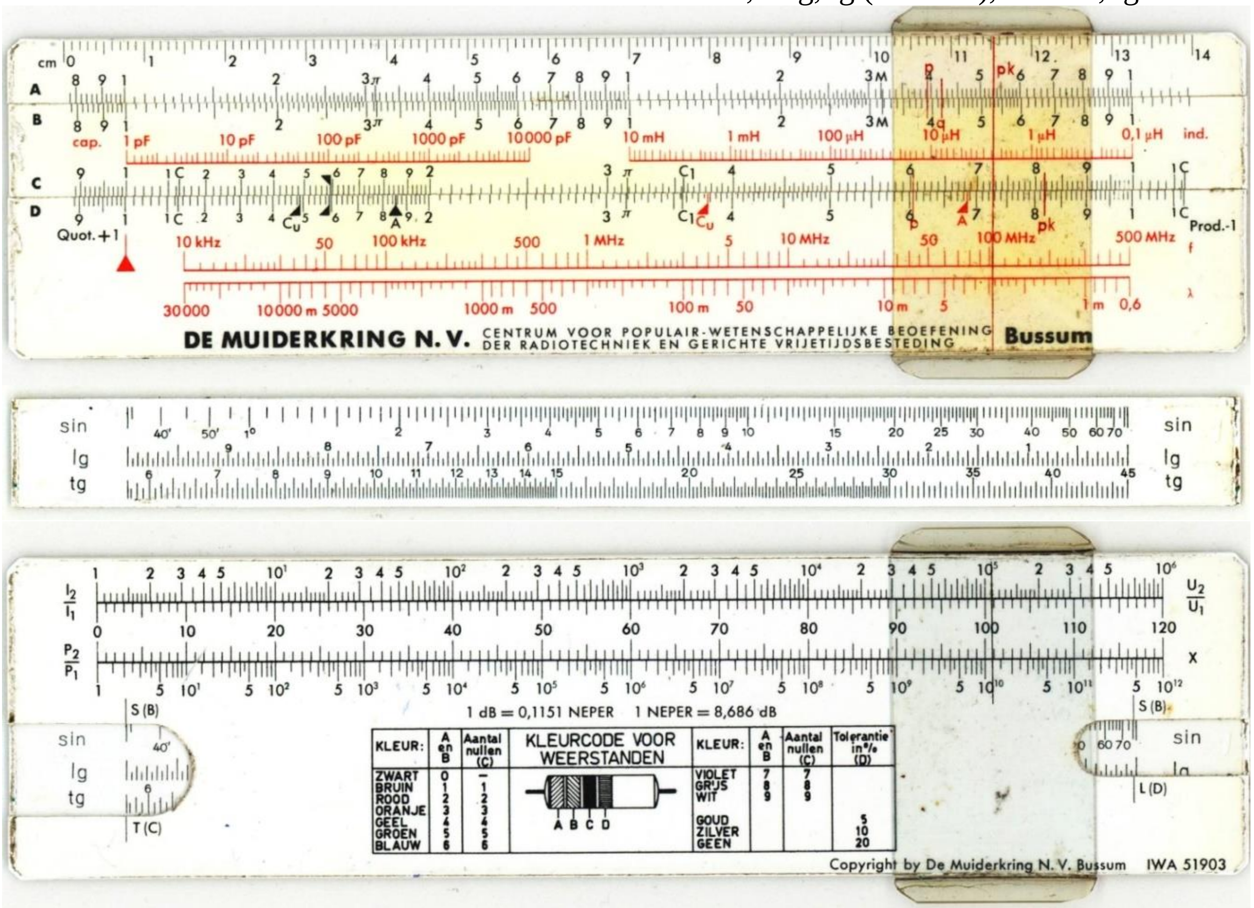


Figure 25. IWA 51903
https://sliderulemuseum.com/HSRC/13981.jpg

IWA 0272

The IWA 0272 (See Figure 26) was produced in 1963 and, like the other IWA's, I only know of it via Internet pictures. The IWA 0272 was designed to solve X_L, X_C, and f_0 with decimal point independence. To find f_0, knowing L and C, move the slide for C (on the slide) over L. f_0 is under the Δ gauge mark (on the top left on the slide) on the f scale. As the slide is moved right, the right C scale is off scale; the maximum f_o, on the f scale, above the gauge mark Δ, is 159 MHz. Transistor Intermediate Frequency (IF) amplifiers during the early 1960's were limited to around 60MHz due to transistor limitations, and the slide rules limitation to 159 MHz is not unreasonable.

Using the combined C and L scale, solving for X_C (R_C on the slide) and X_L (R_L on the body) is really simple: set the gauge mark Δ under the frequency, and above C, or below L, read X_C, or XL on the R_C, or X_L scale. Unfortunately, the minimum inductance value is 1 mH, much too large for high frequency design or analysis. The front side has many of the common scales.

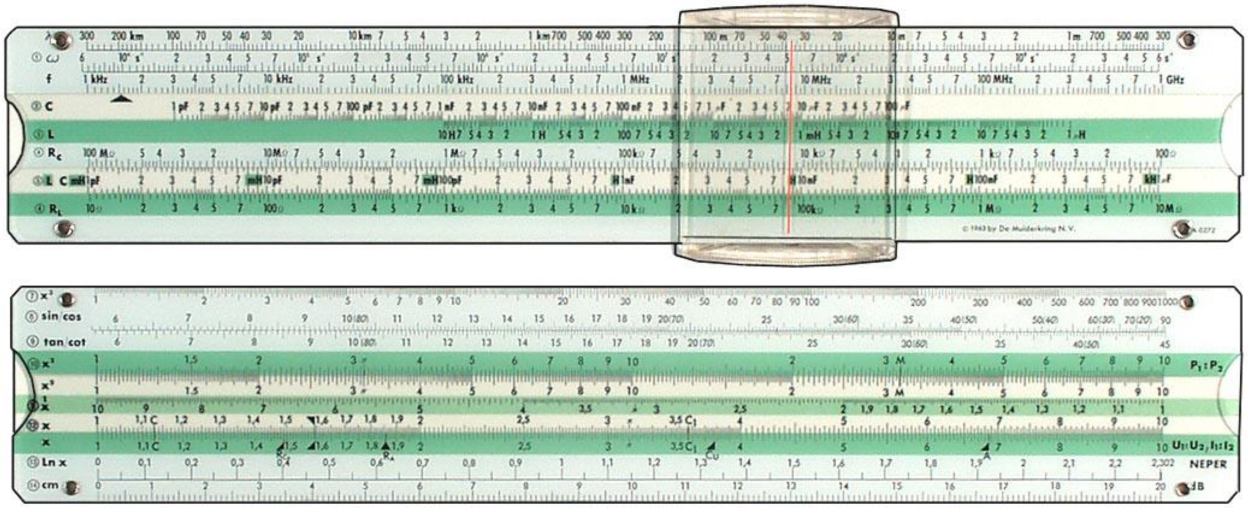


Figure 26. IWA 0272
http://sliderulemuseum.com/HSRC/14001.jpg

Tianjin 6504 and 6508

The next two slide rules were produced by the Tianjin Slide Rule Factory in China. The Chinese Tianjin 6504 and 6508 (pocket version of the 6504) (See Figures 27a and b on page 27) were probably made in the mid-1960's. The 6504 has an inverted C scale folded at $1/2\pi$ scale, labeled F, on the slide (referenced to the C scale). This scale, excepting for the placement, is the same K&E 4082-3 F scale. The 6504/6508 use the F scale and the A(Lf)/B(C_f)/C(L_x and X_C)/D(X_C and C_x) scales to solve for X_L, X_C, and f_0. The decimal point must be found by conventional methods. I have a manual, in Chinese (See Figure 28 on page 28); the operation for f_0 is shown on the right. The slide rule operation is shown in Table 15 (on page 28).

Figure 27a. Tianjin 6504

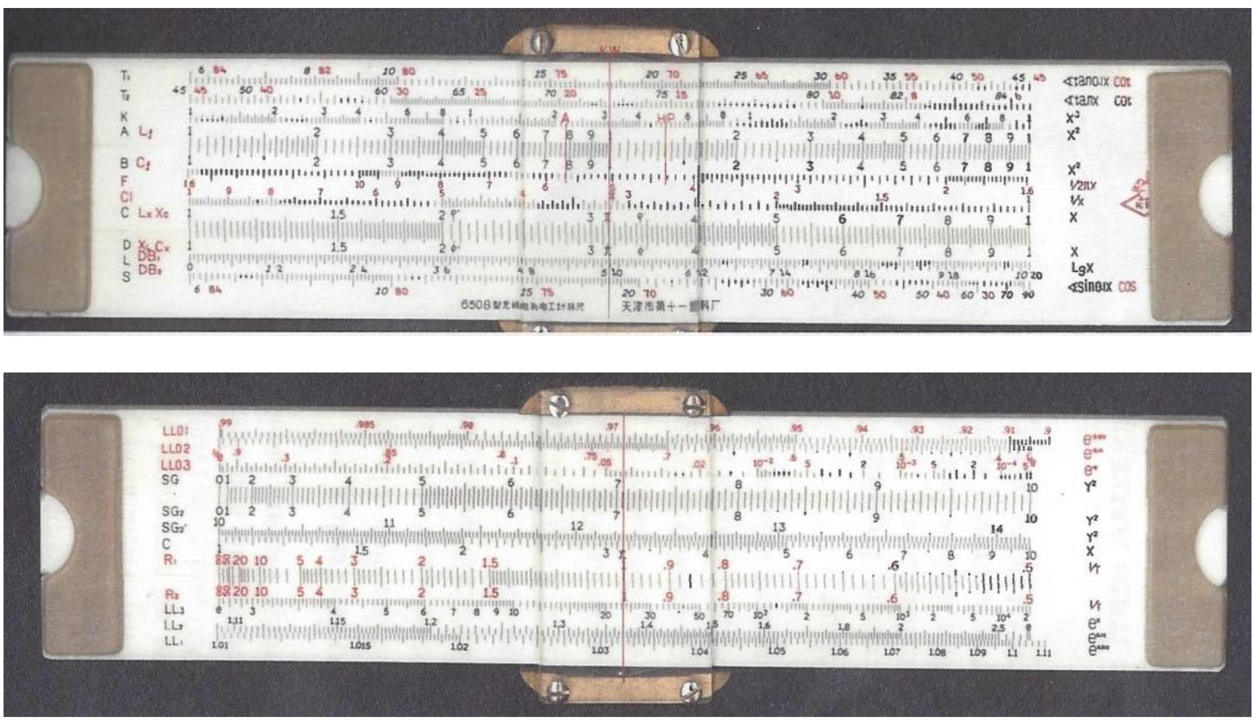
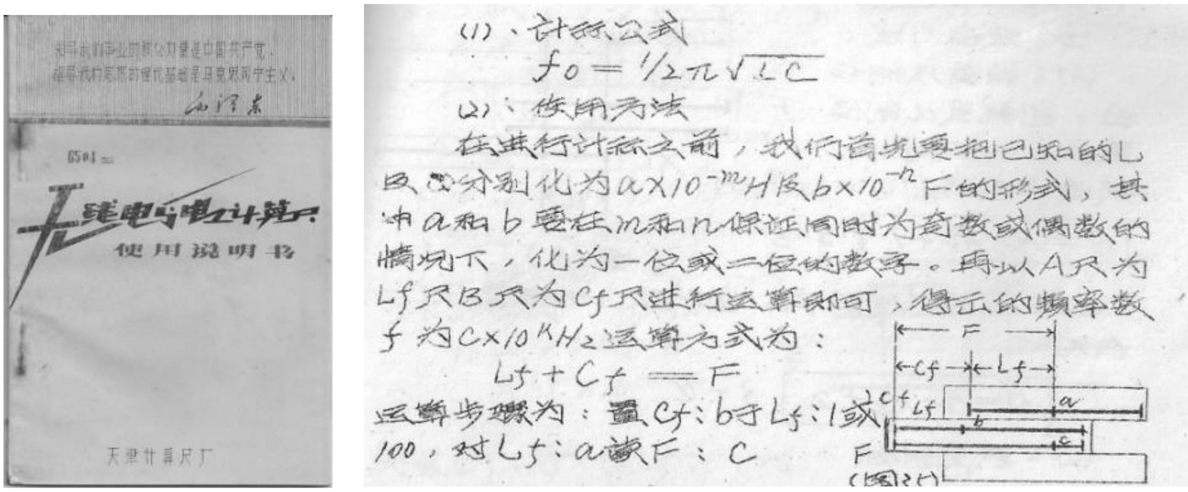


Figure 27b. Tianjin 6508 (Squirrel)



(1)、计算公式

$f_0 = 1/2\pi\sqrt{LC}$

(2)、使用方法

在进行计算之前，我们首先要把已知的L及C分别化为$a\times10^{-m}H$及$b\times10^{-n}F$的形式，其中a和b要在m和n保证同时为奇数或偶数的情况下，化为一位或二位的数字。再以A尺为Lf尺B尺为Cf尺进行运算即可，得出的频率数f为$c\times10^{k}Hz$运算方式为：

Lf + Cf = F

运算步骤为：置Cf：b于Lf：1或100，对Lf：a读F：c

Figure 28. Tianjin Manual

Table 15
Tianjin Operation

$X_L=2\pi fL$

Scale	Step	
F	(2) place f	
$C(L_X)$		(3) below L
$D(X_L)$	(1) above index	(4) read $X_L=2\pi fL$

$X_C=1/2\pi fC$

Scale	Step	
F	(2) place f	
$C(X_C)$		(4) read $X_C=1/2\pi fC$
$D(C_X)$	(1) above C	(3) above index

$f_0=1/[2\pi\sqrt{LC}]$

Scale	Step	
$A(L_f)$,	(1) below index	3) below L
$B(C_f)$	(2) place C	
$F(f_0)$		(4) read $f_0=1/[2\pi\sqrt{LC}]$

These two slide rules are quite easy to use. OK the decimal point must be found, but this was the accepted procedure for slide rule users. The slide rules have R_1 and R_2 scales for solving resistors in parallel and capacitors in series and the Sun-Hemmi Pythagorean P, Q, and Q' (labeled SG, SG_2, and SG_1) for solving the sides of a right triangle. The slide rules also have six LL scales (three LL_0 and three LL), a K, S, and two T scales, and an L scale for solving $dBW=10Log(P_{out}/P_{in})$ and $dBV=20Log(V_{out}/V_{in})$. Both of these slide rules would have been serious weapons for the Electronic Engineer. I really like these two slide rules and the pocket 6508 would have been my bench (laboratory) slide rule of choice.

Lafayette 99-7128

The Lafayette 99-7128 (See Figure 29 on page 29) was produced around 1969/1970 and has unique scales to solve for X_L, X_C, and f_0. The X_C scale is an inverted K scale folded at $1/2\pi$, the X_L scale is a K scale folded at 2π, and the K scale is the frequency scale. The two inverted F scales at the bottom are used for f_0. The decimal point must be found via conventional techniques, or using the "decimal point" tables given in the manual. Table 16 shows the Lafayette 99-7128 operation.

The 99-7128 is a clever design; however, it does not have the B scale (it does have the A scale) or any LL scales.

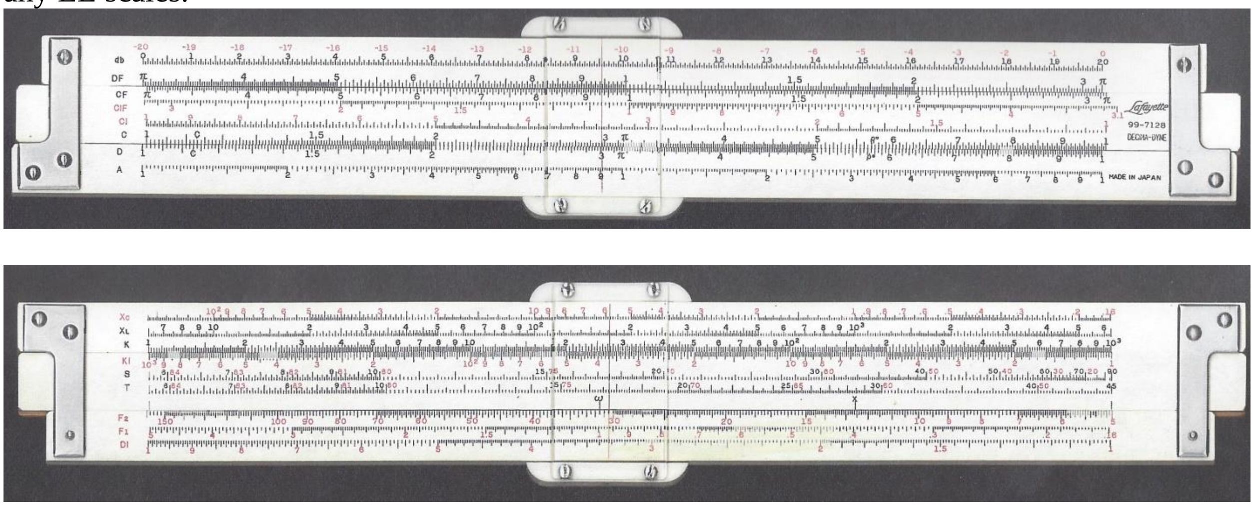


Figure 29. Lafayette 99-7128

Table 16
Lafayette 99-7128 Operation
X_L=2πfL
Decimal point

f (K)	cycles	kc	Mc	cycles	kc	Mc
L (KI)	m H (10^{-3})			μH (10^{-6})		
X_L (opposite right KI index)	m Ω	Ω	k Ω	M Ω	m Ω	Ω
X_L (opposite left KI index)	Ω	k Ω	M Ω	m Ω	Ω	k Ω

Slide Rule Operation

Scale	Step	
X_L		(4) read X_L
K (f)	(1) below f	
KI (L)	(2) place L	(3) above index

X_C=2πfL
Decimal Point

f (K)	cycles	kc	Mc	cycles	kc	Mc	cycles	kc	Mc
L (KI)	μF (10^{-6})			mF(10^{-9})			pF (10^{-12})		
X_C (opposite right KI index)	k Ω	Ω	m Ω	M Ω	k Ω	Ω	10^3 M Ω	M Ω	k Ω
X_C (opposite left KI index)	Ω	m Ω	μ Ω	k Ω	Ω	m Ω	M Ω	k Ω	Ω

Slide Rule Operation

Scale	Step	
X_C		(4) read X_C
K (f)	(1) below f	
KI (C)	(2) place C	(3) above index

$f_0=1/[2\pi\sqrt{LC}]$

Decimal Point

L (K)	mH	μH	mH	μH	mH	μH
C (KI)	μF		nF (10^{-9})		pF	
f_0 (opposite right KI index)	F_1 kc	F_2 kc	F_2 kc	F_1 Mc	F_1 Mc	F_2 Mc
f_0 (opposite left KI index)	F_2 c	F_1 kc	F_1 kc	F_2 kc	F_2 kc	F_1 Mc

Slide Rule Operation

Scale	Step	
X_C		(4) read X_C
K (f)	(1) below f	
KI (C)	(2) place C	(3) above index

Nelson-Jones Circuit Designers Slide Rule

The Nelson-Jones Circuit Designers slide rule (See Figure 30) was produced by Key Electronics in 1974, and was probably the last of the Electronic slide rules (the HP-45 was introduced a year earlier). The Nelson-Jones easily solves for X_L and X_C, with decimal point independence; however, not for f_o! So much for the Circuit Designer name.

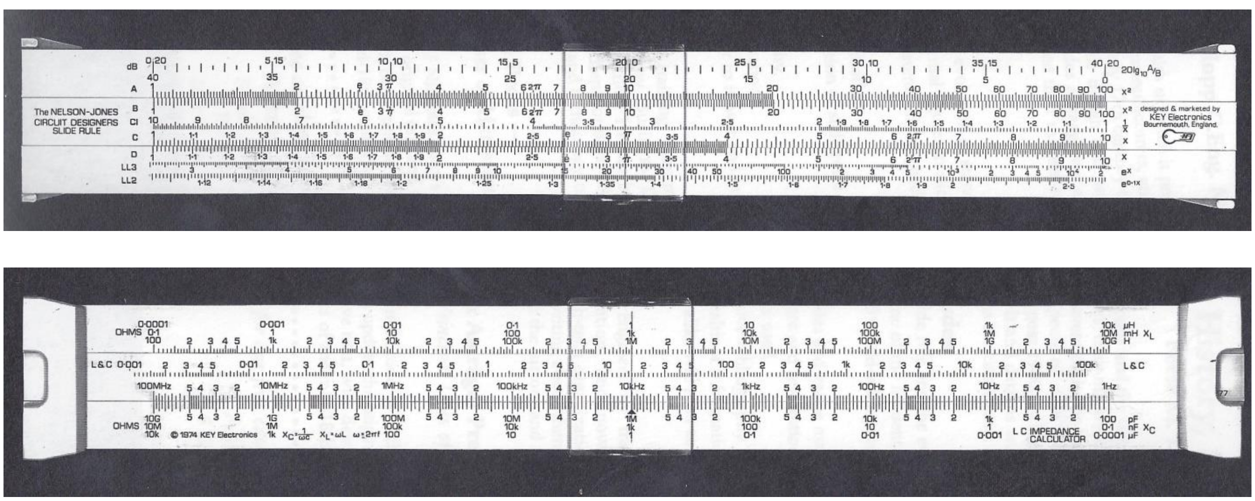


Figure 30. Nelson-Jones Circuit Designers Slide Rule

Finding X_L and X_C is quite simple; place f over the Δ gauge mark (above 1M on the lower body), move the cursor to L or C (without the exponent) on the L&C scale and read X_L or X_C on the proper L or C exponent scale (Peter Hopp sent me a copy of the instructions, and only two pages are for solving X_L and X_C).

I have saved the next three slide rules, Pickett N-16-ES, Hemmi 266, and Graphoplex 698, for last; they are, in my opinion, the best of the Electronic slide rules.

Pickett N-16-ES

The Pickett N-16-ES (See Figure 31) was designed by Chan Street, was introduced in 1960, and may be the most powerful of the Electronic slide rules; however, it is not a piece of cake to master. One must first determine the decimal point via the special scales on the bottom of the back side. The right side end bracket is the decimal point index. The examples will demonstrate the process. Once the decimal point is found, solving for X_L, X_C, f_0 is easy and several other functions that will not be discussed. Table 17 shows the basic operation. For a copy of the manual see http://sliderule.ozmanor.com/man/man-download.html.

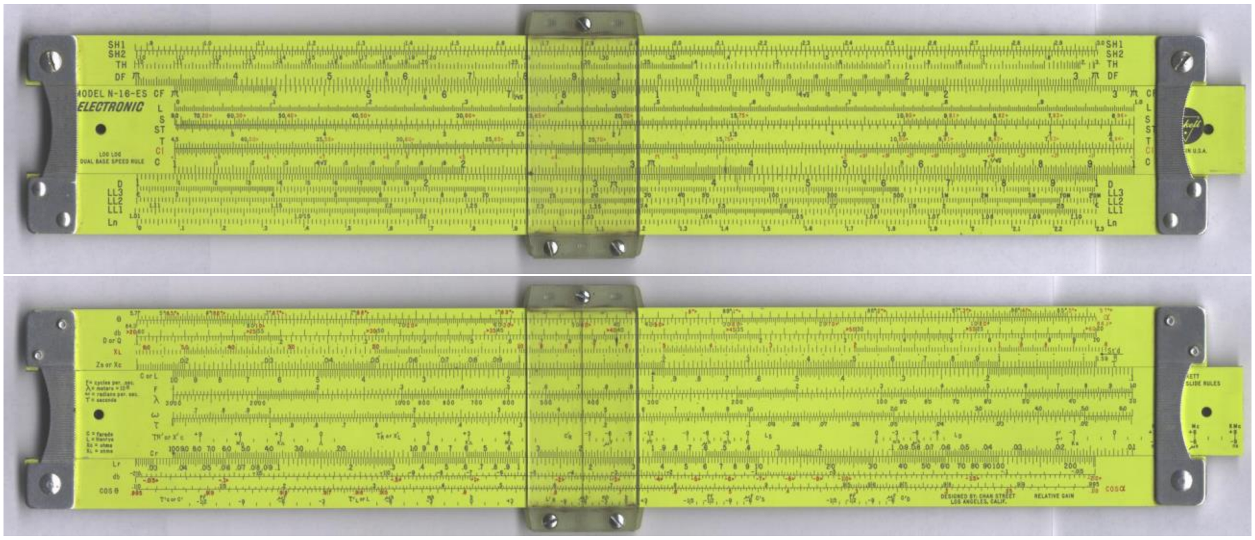


Figure 31. Pickett N-16-ES

Table 17
Pickett N-16-ES Operation
X_C=1/(2πfC)

The decimal point must first be found; write C as (o.xxx or x.xx)10^c, the frequency F as (o.xxx or x.xx)10^f and X_C as (o.oxxx, o.xxx or x.xx)10^{xc}. These are the individual scale limits.

Decimal Point Location

Scale	Step		F=30MHz=(0.3)10^8, f=+8	
	1) move slide	2) move cursor	C=25 pF=(2.5)10^{-11}, c=-11	
F' (slide)	(2) place exponent f		(2) place f=8	
Right end bracket	(1) against end bracket		(1) against end bracket	
X'_C (slide)		(4) read X_C exponent		(4) read X_C=+3
τ'_C/C' (body)		(3) above exponent c		(3) above C=-11

The Capacitive Reactance may now be found.
X_C=1/(2πfC)

Scale	Steps		F=30Mhz=(0.3)10^8; F=0.3	
	1) move slide	2) move cursor	C=25 pF=(2.5)10^{-11}; C=2.5, X_C=+3	
D/Q	(1) below gauge mark ↓		(1) below gauge mark ↓	
Z_S/X_C		(4) read X_C [10^{xc}]		(4) read X_C=0.212[10^{+3}]=212 Ω
C/L		(3) above C		(3) above C=2.5
F	(2) place f		(2) place f=0.3	

The solution process is somewhat cumbersome!

X_L=2πfL

The decimal point must first be found: write L as (o.xxx or x.xx)10^L, the frequency F as (o.xxx or x.xxx)10^f and X_L as (o.oxxx, o.xxx or x.xx)10^{xL}. Again, this method is based on the individual scale limits.

Decimal Point Location

Scale	Step		F=30Mhz=(0.3)10^{+8}; f=+8 L=1.125µH= (1.125)10^{-6}; L= --6	
	1) move slide	2) move cursor		
F′ (slide)	(1) place f		(1) place f=+8	
Right end bracket	(2) against end bracket		(2) against end bracket	
X_L′ (slide)		(4) read X_L exponent		(4) read X_L=+2
τ′$_L$/L (body)		(3) above L		(3) above L=-6

X_L=2πfL

Scale	Step		F=30Mhz=(0.3)10^{+8}; F=0.3 L=1.125µH= (1.125)10^{-6}, L=1.125 X_L=+2	
	1) move slide	2) move cursor		
D/Q	(1) below gauge mark ↓		(1) below gauge mark ↓	
X_L		(4) read X_L exponent		(4) read X_L=2.12(10^{+2})=212 Ω
C/L		(3) above L		(3) above L=1.125
F	(2) place f		(2) place f=0.3	

Again not a simple task.

Resonant Frequency

f_0=1/[2π√(LC)]. The decimal point must be found; write C= (o.oxxx, o.xxx or x.xx)10^c, L= (o.oxxx, o.xxx or x.xx)$10^L$and f= (o.xxx or x.xx)10^f. The sum of the C and L exponents, C + L, must be even.

Scale	Step		L=1.125µH= (1.125)E^{-6}; L=-6, C=25, pF=(25)10^{-12}; C=-12	
	1) move slide	2) move cursor		
F′ (slide)		(3) below end bracket		(3) below end bracket
Right end bracket		(4) read f exponent		(4) read f_0=+8
C′$_R$ (slide)	(2) place c		(2) place c=-12	
L′$_R$ (body)	(1) above L		(1) above L=-6	

f_0=1/[2π$\sqrt{LC}$]

Scale	Step		L=1.125 µH= (1.125)10^{-6}; L=1.125, C=25, pF=(25)10^{-12}; C=-25, f=+8	
	1) move slide	2) move cursor		
D/Q		(3) below gauge mark ↓		(3) below gauge mark ↓
F		(4) read f		(4) read f_0=0.3 [10^{+8}]=30 MHz
C_r	(2) place C		(2) place C=25	
L_r	(1)above L		(1) above L=1.125	

With practice, the N-16-ES can be mastered and, as mentioned, it is a serious weapon for the Electronic Engineer; however, remember the tolerance for capacitors and inductors is typically ± 10% and absolute accuracy is seldom needed. Also, the N-16-ES does not have the A or B scales.

Hemmi 266

This powerful slide rule (See Figure 32) was introduced in 1966 and easily solves X_C, X_L, and the resonant frequency f_0, and various other electronic functions - no decimal point problems with this slide rule (See http://udel.edu/~mm/sliderule/manuals/266.pdf a copy of the manual). The 266 also has the Sun-Hemmi Pythagorean P and Q scales and r_1 and r_2 for finding resistors in parallel or capacitors in series. The scale labeling and gauge marks are color coded, as to function, for ease of use. The 266 has twelve decades for X_C, X_L, F (frequency), and six decades (for the square root) for the resonant frequency, f_0. Table 18 shows the operation.

Figure 32. Hemmi 266

Table 18
Hemmi 266 Operation
X_L=2πfL Green Scales

Scale	Step		L=1.125 µH f =30 MHz	
	1) move slide	2) move cursor		
X_L		(4) read X_L		(4) read X_L=212 Ω
F	(1) below f		(1) below f = 30 MHz	
L	(2) place L	(3) above X_L gauge mark ↑ on the X_L sale	(2) place L=1.125 µH	(3) above X_L gauge mark ↑ On the X_L scale

X_C=1/(2πfC) Green Scales

Scale	Step		C=25 pF f =30 MHz	
	1) move slide	2) move cursor		
X_C		(4) read X_C		(4) read X_C=210 Ω
F	(1) below f		(1) below f =30 MHz	
C	(2) place C	(3) above X_C gauge mark ↑ on the X_C scale	(2) place C=25 pF	3) above X_C gauge mark ↑ on the X_C scale

Resonant Frequency, f_0=1/[2π√(LC)] Black scales. Note the left index on the C_f scale f_{0-} and f_0^- on the right index. When reading f_0 under the left index, f_{0-}, use the lower f_0 scale labeling. If the right C_f index is used, f_0^-, the upper f_0 scale labeling is used.

Resonant Frequency, f_0=1/[2π$\sqrt{LC}$] Black Scales

Scale	Step		C=25 pF L=1.125 μH	
	1) move slide	2) move cursor		
C_f	(2) place C	(3) below C_f index	(2) place C=25 pF	(3) below right C_f index, f_0^-
L	(1) above L		(1) above L=1.125 μH	
f_0		(3) read f_0		(4) read f_0 (upper scale)=30 MHz

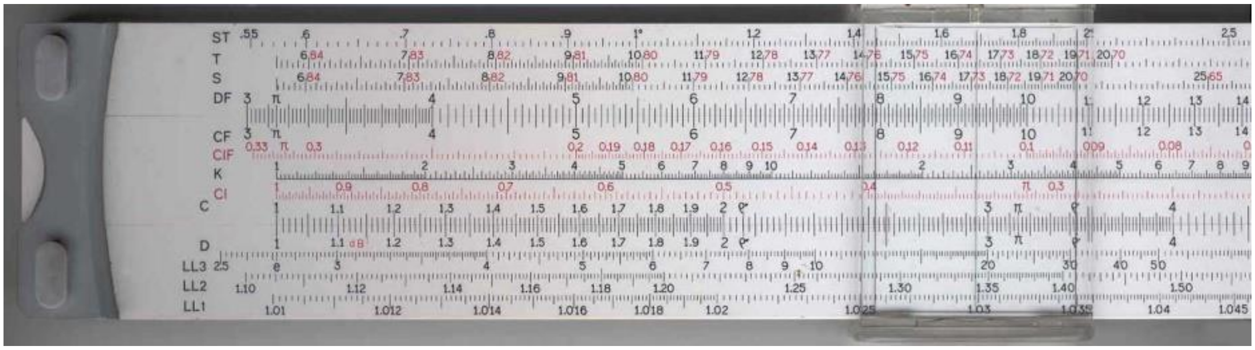
The Sun-Hemmi 266 is a piece of cake to use. The addition of several other specialized scales, time constant τ =RC and τ =L/R, the 3db frequency response f_{3db}=1/(2πRC), and the inclusion of r_1 // r_2 the Sun-Hemmi Pathogen P/Q and LL2, LL01, LL02, and LL03, referenced to the A scale makes it a candidate for the universal "Electronic" slide rule. I certainly would have purchased the 266 if I knew of its existence. This slide rule, in my opinion, is the best of Electronic slide rules.

I have not discussed the transmission line Surge Impedance, $Z_S = \sqrt{L/C}$. Several of the slide rules have special scales; however, the impedance is easily solved using the C/D and A scales.

Graphoplex 698

I only know the existence of the Graphoplex 698, introduced in 1970, see Figure 33, from Rod Lovett's web page: http://sliderules.lovett.com/ and the manual on http://www.photocalcul.com/Calcul/Regles/Notices-regles/notice_Graphoplex%20698.pdf.

The operation to find X_L, X_C, and f_0 is similar to the Hemmi 266, and is given in Table 19 on page 35 and in Table 20 on page 36. The Electronic scale nomenclature is on the right side of the slide rule (See Figure 33 on page 35, last image).



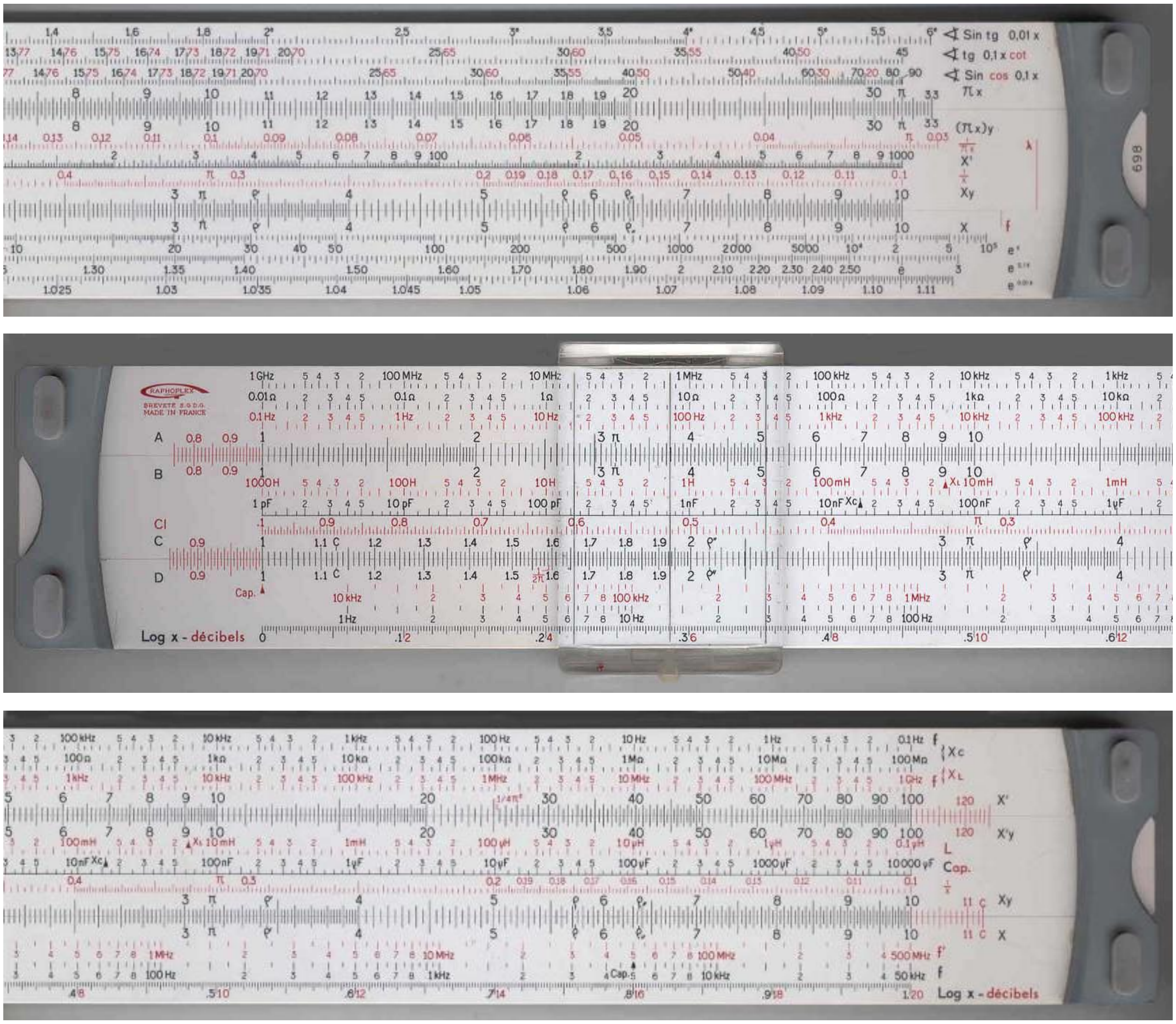


Figure 33. Graphoplex 698
http://sliderules.lovett.com/graphoplex698/graphoplex698.htm

Table 19
Graphoplex 698 Operation
$X_C=1/(2\pi fC)$

Scale	Operation	
F (above X_C)	(1) Below f	
X_C		(4) Read X_C
Cap	(2) Place C	(3) Above X_C gauge mark ↑

$X_L= (2\pi fL)$

Scale	Operation	
F (below X_L)	(1) Below f	
X_L		(4)Read X_L
L	(2)Place L	(3)Above X_L gauge mark ↑

Table 20

f_0=1/[2π$\sqrt{LC}$]

Scale	Operation	
L		(3)Below L
Cap	(2)Place C	
f'		(4a)Read f_0
f	(1)Above the Cap gauge mark ↑	(4b) if the f_0 reading is off scale, we must recalculate f_0 using the Cap gauge mark ↑ (the left D index) and read f_0 on the f scale

I wish I had one of these!

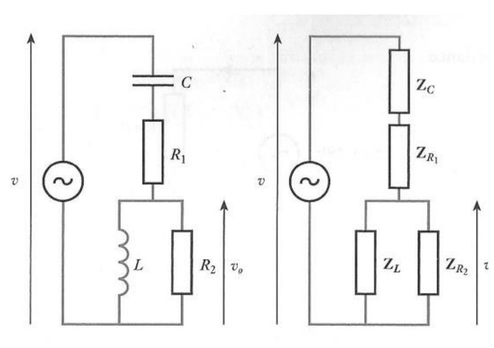
This ends the Electronic slide rule section. A brief discussion on how X_L, X_C, and f_0 were used in every day Electronic Engineering life will be given next.

X_L, X_C, and f_0 in Every Day Electronic Life

Table 21 is a simple (?) filter using a capacitor and inductor. Deriving the equation is straight forward; however, solving the equation with a slide rule is tedious (Rectangular to Polar conversion and vice versa), but that is the way things were back then.

Table 21

Simple (?) Filter

	$X_C = -j/(2\pi fC)$ Z_A = Magnitude$_A$ < θ_A $Z_A \equiv Z_{R1} + X_C = \sqrt{[R_1^2 + (X_C)^2]} < -\tan^{-1}(X_C/R_1)$
	$X_L = 2\pi fL$ Z_B = Magnitude$_B$ <θ_B $Z_B \equiv Z_{R1} // X_L = X_L R_2\sqrt{[R_2^2 + (X_L)^2]} < \tan^{-1}(R_2/X_L)$
$v_o = v_i[Z_B <\theta_B/(Z_B<\theta_B + Z_A<\theta_A)]$ The filter gain, v_o/v_i, in dB = 20Log[$Z_B <\theta_B/(Z_B<\theta_B + Z_A<\theta_A)$]	

The resonant frequency, f_0, is really important in the design of Intermediate Frequency, IF, amplifiers, see Figure 34. The resonant frequency for Transistor Radios was 455 kHz; however, for my applications, during the 1960's, the resonant frequency was between 30 and 120 MHz. We knew the f_0 that was wanted and had to determine the correct value for L and C; because the tolerance for capacitors and inductors is typically ± 10% either C or L is variable (sometimes both). We have seen that for our wanted f_0, LC = $(1/2\pi f_0)^2$; say we want f_0 = 60 MHz, LC = 7(10-^{18}), and we have a bunch of 1 μH inductors; thus, C = 7(10^{-18})/1 (10^{-6}) = 7pF (10^{-12}).

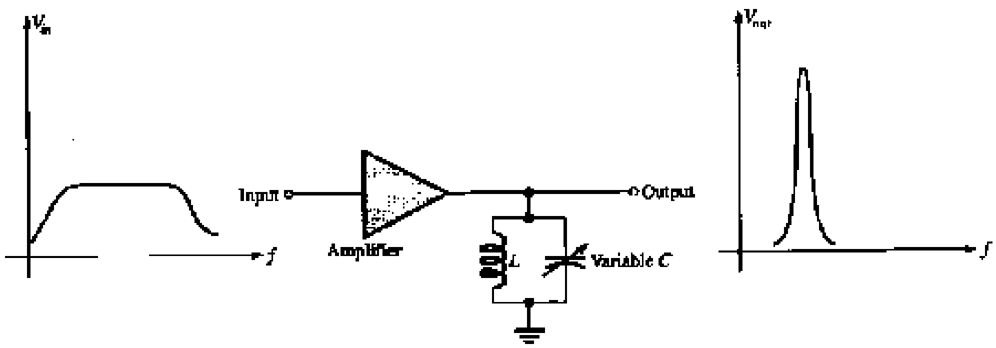


Figure 34. Intermediate Frequency Amplifier

Well, that is the story. You have seen some pretty good Electronic slide rules, and you may wonder which one is my favorite: the K&E 4083-3 Vector, see Figure 35. Why was my slide rule of choice a Vector (hyperbolic scales)? The basic Differential Amplifier, see Table 22 on page 38, was a basic building block for many of my discrete transistor designs (and virtually all my Integrated Circuit designs) and as can be seen has a hyperbolic tangent transfer function (output current as a function of input voltage). My K&E 4083-3 served me quite well until I purchased my HP-45 in 1974.

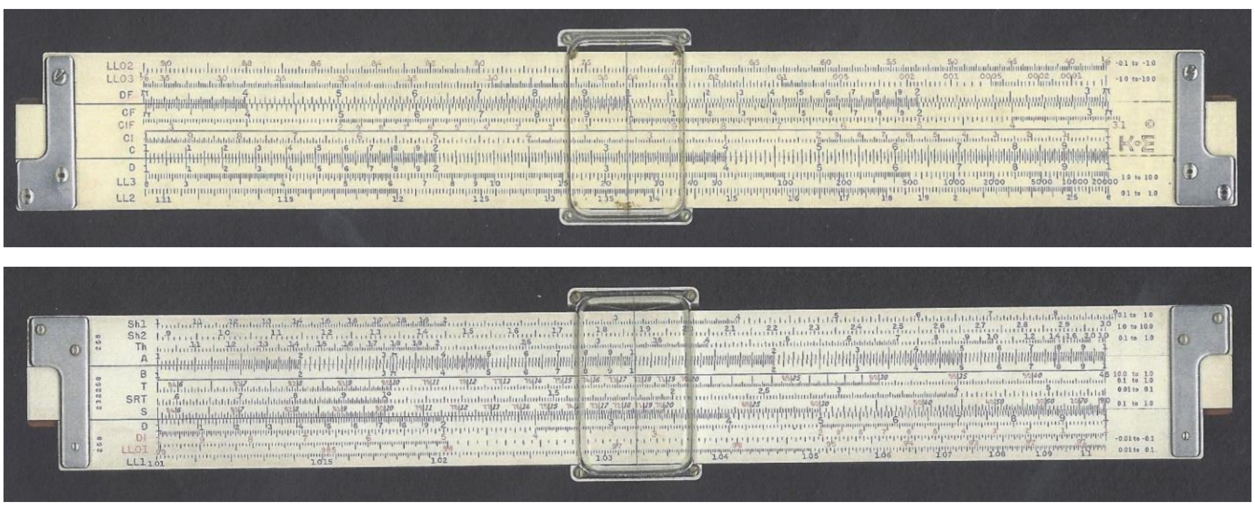
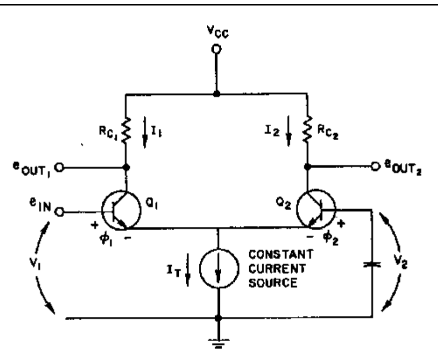


Figure 35. K&E 4083-3 (Vector)

Table 22
Differential Amplifier

	Exact Equations: $i_1(mA) = -i_2(mA) = [I_T(mA)/2]\ Tanh[5.8e_{in}(mV)/T(^oK)]$ *$e_{in}(mV) > 0.0173T(^oK)$ Use Th /D Scales* $i_1(mA) = -i_2(mA) = [I_T(mA)/2]\ Tanh[5.8e_{in}(mV)/T(^oK)]$ *$e_{in}(mV) < 0.0173T(^oK)$ Use CI/C/D/DI Scales* $i_1(mA) = -i_2(mA) = [I_T(mA)/2][\ 5.8e_{in}(mV)/T(^oK)]$

APPENDIX A

SIGNAL; the Journal of the Vintage and Amature Radio Society.

Three slide rules for wireless (spark gap) telegraphy

Richard Smith Hughes

While researching a paper on specialized slide rules for Electronic Engineering for the International Meeting of Slide Rules & Historical Calculating Instrument Collectors, IM 2008, Peter Hopp (Editor of the Slide Rule Gazette) sent the author information on two slide rules used in the design of wireless (spark gap) telegraphy. Subsequently, information on a third slide rule arrived. Hating to have a slide rule that the author did not understand he set about the following journey of enlightenment.

Principles

Having little knowledge of wireless (spark gap) telegraphy, the author obtained Morecroft's 'Principles of Radio Communication', 1931 **[1]** that has an extensive discussion on 'Spark Gap Telegraphy' in Chapter V and Bucher's 'Practical Wireless Telegraphy', 1917 **[2]**. **Figure 1** is a basic overview of the author's spark gap 'journey'. The three slide rules presented here solve for the wavelength, λ, of the transmitted signal.

The resonant frequency, f_0 (in Hz), of an L-C tuned circuit is given by,

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where L is the inductance in Henry and C the capacitance in Farads. In terms of wavelength (in metres), λ,

$$\lambda = \frac{c}{f_0}$$

where c is the velocity of light which may be taken to be 3×10^8 m/s. Thus,

$$\lambda = (3 \times 10^8)(2\pi)\sqrt{LC}$$

If L is given in μH and C in pF,

$$\lambda = 1885\sqrt{LC}$$

or if L is given in nH and C in μF,

$$\lambda = 59.6\sqrt{LC}$$

The three slide rules are designed to solve these equations, with decimal point independence. Not exactly rocket science if one is equipped with a slide rule with A/B(BI)/C/D scales.

Davis-Martin Wireless

The Davis-Martin slide rule is only known from Bruce Williams **[3]** and a short description in Pickworth **[4]**. It was patented in 1916 **[3]** and has an Inductance scale (standard A scale), an inverted capacitance scale (standard BI scale), a wavelength scale (standard D scale) and eight gauge marks (**Figure 2**). Pickworth **[4]** offers the following:

"Determining the gauge marks M/F and M_1/F_1 is fairly easy, **Figure 2**. However M_2/F_2 and M_3/F_3 required more thought. I believe they are for the open circuit antenna wavelength with an external 'tuning' inductor L_3. My gauge mark values may be slightly off – Davis-Martin may not have used the same table as found in Bucher **[2]**, page 308.

Brydon-Hodgson M 3714

Peter Hopp found this slide rule in a 1924 WF Stanley catalogue. The slide rule possibly dates from around the same time as the Davis-Martin. **Figure 3** describes the scales and equations the slide rule solves.

Tavernier-Gravet M. Fromy Radio

Peter Hopp found this slide rule (**Figure 4**) in **[5]**. As the name states, this is for Radio Engineering, a natural evolution of Wireless Communication. This slide rule was probably produced in the mid-1930s or earlier. An earlier version was produced in 'antiquity' (page 10 of **[5]**) that is certainly for Wireless Telegraphy and may predate the Davis-Martin.

Conclusion

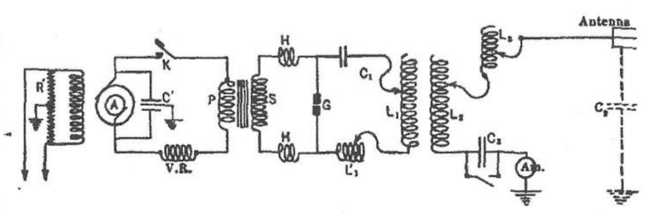
The operation of all the slide rules is relatively basic multiplication using the A/B (or BI) scales and finding the wavelength on the D scale.

References

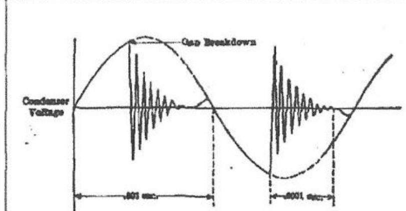
1. JH Morecroft. *Principles of Radio Communication*. Third edn. John-Wiley, 1931. Chapter V.
2. EE Bucher *Practical Wireless Telegraphy*. Wireless Press, 1917.
3. B Williams Patents. *GB Slide Rules and Calculating Apparatus : Indexes to Abridged Patent Specifications 1636-1963 and Slide Rule Patent Numbers to 1990*. Colin A Barnes, 2002. ISBN 9780953503940.
4. CN Pickworth. *The Slide Rule*. 24th edn. 1945, p. 111.
5. Paul Berche. *Appenez a Vous de la Libraire de la Radio*. Les Editions de la Libraire de la Radio, 1955, pp. 107–110.

Acknowledgement

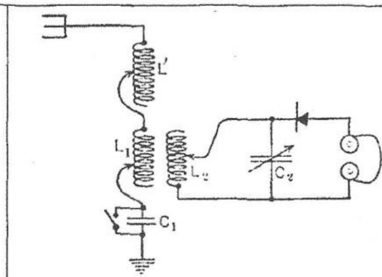
This article was first published in the *Slide Rule Gazette* (Autumn 2010, Issue 11, pp. 82–87) the journal of the The UK Slide Rule Circle, UKSRC, and is re-cast here with thanks to the Editor Peter Hopp and the Author. The Circle was formed in the mid-1990s as an informal group of slide rule enthusiasts to provide a discussion forum and enable contact between members. Its newsletter, *Skid Stick*, is published three times each year. The diversity of slide rules, the analogue predecessors of digital computers, is celebrated through the newest exhibit at The National Museum of Computing at Bletchley Park and is curated by the UKSRC.



Spark Gap Transmitter



Transmitted Waveform



Receiver

Basic Operation

Note; *nano* = E^{-9} and $\mu = E^{-6}$

When the switch K is pressed, a high voltage (10,000/20,000 Volts) at the generator frequency (250/500 Hz) appears at the spark gap, G, which "arcs" over causing an oscillation in the closed loop transmitter oscillator C_1, L_1, and tuning inductor L'_1. This circuit oscillates at a much higher frequency (300kHZ/3MHzHz) than the generator frequency. The wavelength of the closed circuit oscillator may be given as

$$\lambda_{\text{closed circuit}} = 1885\sqrt{[(L_1 + L'_1 \text{ in } \mu\text{ H})(C_1 \text{ in } \mu\text{ F})]} = 59.6\sqrt{[(L_1 + L'_1 \text{ in nano H})(C_1 \text{ in } \mu\text{ F})]} \text{ Meter}$$

For proper operation of the antenna open circuit oscillator:

$$(L_1 + L'_1)C_1 = L_2C_2$$

where

L_2 = total effective inductance of the antenna circuit: C_2 = total effective capacitance of the antenna circuit (C_2 (the antenna capacitance) << C_1)

Inductor L3 is for fine tuning the antenna: $\lambda_{\text{closed circuit}} = \lambda_{\text{antenna}}$

$$\lambda_{\text{antenna}} = [59.6/K]\ \sqrt{[(L_2 \text{ in nano H})(C_2 \text{ in } \mu\text{ F})]} \text{ Meters}$$

where K is a nonlinear function of L_3/L_2 (Bouchers [2])

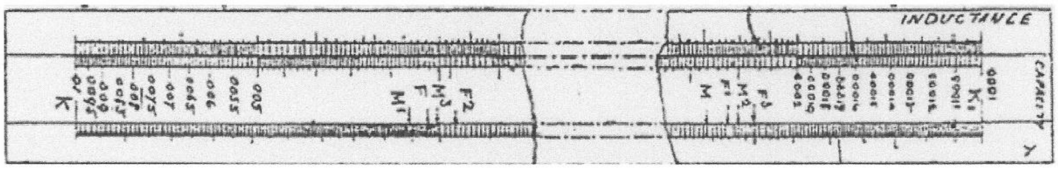
$K = 1$ ($L_3/L_2 = 0$): $\lambda_{\text{antenna}} = [59.6]\ \sqrt{[(L_2 \text{ in nano H})(C_2 \text{ in } \mu\text{ F})]}$ Meters

$K = 0.95$ ($L_3/L_2 \approx 0.75$): $\lambda_{\text{antenna}} = [62.8]\ \sqrt{[(L_2 \text{ in nano H})(C_2 \text{ in } \mu\text{ F})]}$ Meters

$K = 0.31$ ($L_3/L_2 \approx 10$): $\lambda_{\text{antenna}} = [192.5]\ \sqrt{[(L_2 \text{ in nano H})(C_2 \text{ in } \mu\text{ F})]}$ Meters

The receiver operates much the same: the antenna and detector tuned for the transmitted λ.

Figure 1. Basic Wireless (Spark Gap) Telegraphy [1,2] c. 1917



The Davis-Martin Wireless Slide Rule.—In wireless telegraphy it is frequently necessary to determine wave-length, capacity, or self-induction when one or other of the factors of the equation, $\lambda = 59{\cdot}6\sqrt{LC}$., is unknown. The Davis-Martin wireless rule is designed to simplify such calculations. The upper scale in the stock (inductance) runs from 10,000 to 1,000,000; the adjacent scale on the slide (capacity) runs from 0·0001 to 0·01, but in the reverse direction. The lower scale on the stock (wave-length) runs from 100 to 1000, giving square roots of the upper scale; while on the lower edge of the scale are several arrows to suit the various denominations in which the wave-length and capacity may be expressed.

$\lambda_{closed\ circuit} = 59.6\sqrt{[L(nH)C(\mu F)]}$ Meters
gauge mark; M = 59.6

The author's scale designation	Scale Limits	Comments
Inductance L	10,000 nH (10 µH) →1,000,000 nH (1 mH)	Normal A scale
// Capacitance C	0.01 µF ← 0.0001µF (1,000 pF)	Inverted B scale (BI)
// Gauge Marks	M (59.6)	See below
Wave Length λ	100 m (3 MHz) → 1,000 m (300 kHz)	Normal D scale
For λ 10 → 100; divide L or C by 100, or both by 10.		
For λ 1,000 → 10,000; multiply L or C by 100, or both by 10.		

$\lambda_{closed\ circuit} = 195.5\sqrt{[L(nH)\ C(\mu F)]}$ feet Gauge mark; F = 195.5

$\lambda_{closed\ circuit} = 1885\sqrt{[L(\mu H)\ C(\mu F)]}$ m Gauge mark; M_1 = 1885

$\lambda_{closed\ circuit} = 6183\sqrt{[L(\mu H)\ C(\mu F)]}$ feet Gauge mark; F_1 = 6183

Antenna Open Circuit Oscillator Possibilities for M_2/F_2 and M_3/F_3

With an external loading coil, L_3, the antenna will resonate at (**Table 1**)

$\lambda_{antenna} = [59.6/K]\sqrt{[L_1(nH)\ C_1(\mu F)]}$ m

Where L_2 and C_2 are the effective antenna inductance and capacitance and K is dependent on the ratio L_3/L_1 **[2]**.

For $L_3/L_1 \approx 0.75$, $K \approx 0.95$ (approximated from [Bucher "Practical Wireless Telegraphy" 1917]

$\lambda \approx 62.8\sqrt{[L_2(nano\ H)\ C_2(\mu F)]}$ Meters

Gauge mark M_2 = 63.03

$\lambda \approx 207\sqrt{[L_2(nano\ H)\ C_2(\mu F)]}$ Feet

Gauge mark F_2 = 207

For $L_3/L_1 = 10$, $K \approx 0.31$ **[2]**

$\lambda \approx 192.5\sqrt{[L_2(nH)\ C_2(\mu F)]}$ m

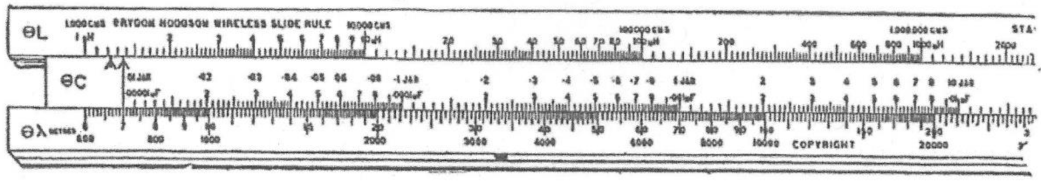
Gauge mark M_3 = 192.5

$\lambda \approx 631\sqrt{[L_2(nH)\ C_2(\mu F)]}$ feet

Gauge mark F_3 = 631

AJ Martin may not have used the K values given in Bucher **[2]**, however the author believes the above equations for the transmitted wavelength to be reasonably correct.

Figure 2. The Davis-Martin Wireless Slide Rule



Brydon-Hodgson Wireless Slide Rule, Stanley's, designed to meet the needs of those engaged in the construction of high frequency apparatus for Wireless and other purposes (diathermy, etc.).

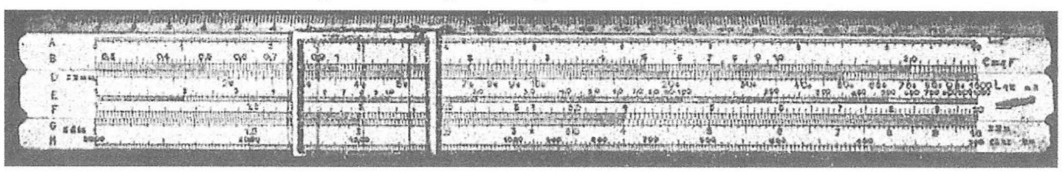
The equation λ = K √L.C. where
λ = wave length
L = inductance
C = capacity
K = constant depending upon the units used
is commonly used in Wireless calculations, and is readily obtained by this rule .. ..

Scale Designation		Function	Scale Limits	Comments	
L	CMS	Inductance	1,000 CMS to > 10^6 CMS	Multi-decade D scale	
	μH		1 μH to > 1,000 μH		
C	JAR	Capacitance	0.01 JAR to > 10 JAR	Multi-decade C scale	
	μF		0.00001 μF to > 0.01 μF		
λ Meters	6	Wavelength λ Meters	6 m to > 200 m	Use with μF scale	Multi-decade D scale folded at 1885
	600		600 m to >20,000 m	Use with JAR scale	

1 cm (CMS) = 0.001 μH, 1 JAR = 10 μF

Note the cursor mark to the left of the primary cursor line. The separation is 2 π referenced to the λ scale. This arrangement was possibly used to find the inductive reactance of the RF choke (H) shown in **Table 1**, $X_L = 2\pi fL$: Left Index under L, under the right index read 2πL on the λ scale, multiply by f using the C and λ scales. The term JAR may refer to the 'capacity' of a Leyden Jar (page 406 of **[1]**).

Figure 3. The Brydon Hodgson Wireless Slide Rule



Scale Designation	Function	Scale Limits	Comment
A	Log_{10}	0 →1	Normal Log scale
B	Capacitance C	0.281 nF → 28.15 nF	Normal B scale folded at $(59.6)^2$ B = $(59.6)^2$ [C(nF)]
// D	Inductance L	10 μH → 1,000 μH	Normal B scale
// E	Cube Scale	1 → 1,000	Normal K scale
// F	Normal C Scale	1 → 10	Normal C scale
G	Wavelength λ	100 m→ 1,000 m	Normal D scale λ = 59.6√[L(μH) C(nF)]
M	Frequency f (Hz or cps)	3,000 kHz ← 300 kHz	Inverted D scale folded at $3x10^8$ f = $3x10^8$/λ
For λ 10 → 100 (f from 30,000 kHz ← 3,000 kHz); divide L or C by 100, or both by 10.			
For λ 1,000 → 10,000 (f from 300kHz ← 30 kHz); multiply L or C by 100, or both by 10.			

The back of the slide has sin and tan (degrees + minutes)

Reference **[5]** mentions, on page 110, a similar 'antique' slide rule that is almost certainly for spark gap transmission. The scales are: D (L) $1x10^{-3}$ H to $100x10^{-3}$ H; G (λ) 1 km to 10 km; H (f) 300 kHz to 30 kHz. This slide rule may well predate the Davis-Martin and Brydon-Hodgson slide rules.

Figure 4. Tavernier-Gravet M. Fromy Radio Slide Rule

~ ~ ~

APPENDIX B[*]
The Origins of the K&E "Radio" Rule

Clark McCoy

The 1930s were a time of great change in the K&E slide rule line of products. New slide rule designs, scale sets, and construction methods evolved greatly during this time frame. Hyperbolic scales, pocket sized rules made of all celluloid, and new cursor designs were released at this time. The K&E catalogs show a number of special purpose slide rules for many different disciplines, but they failed to offer anything for the new (at that time) electronics field.

In the last year, I have been made aware of a special production rule that K&E apparently made for the Navy in 1936. This slide rule has the model number 4091-3 SPEC. printed on the rule. This is a standard 4091-3 from the 1933-1936 time frame with an LC* scale added on the top of the front side (See Figure 1 on page 43). The serial number places manufacturing about 1936 - 1937. The owner stated that she found this slide rule in her desk at the China Lake facility when she started working there. This rule started me thinking that this special production rule could be the birth of the "Radio" slide rules for K&E.

> *LC refers to L for inductance and C for capacitance. An LC circuit is an original basic radio circuit consisting of an inductor and a capacitor. Each LC circuit has a characteristic oscillating frequency. LC circuits now have a variety of uses in electronics.

In early 1937, K&E produced a Morrison Radio Engineer's Rule with specialized scales for propagation of radio waves. The model number 4138 was assigned to this slide rule. This rule also has a manual and just appears in the 1939 slide rule only catalog. One to two years later we see a slightly different rule that is a variant of the 4081-3, and that variant was designated Model 4082-3. The K scale was replaced with an F scale, which is folded at the constant $1/(2\pi)$. The 4082-3 never showed up in K&E catalogs. However, I do have the manual for this slide rule. Finally, in 1942, K&E released the "Cooke Radio Rule" with a model number of 4139. This rule stayed in the catalogs until 1972. This paper will document these early variants and their time line.

The SPEC. 4091-3

The 4090-3, 4091-3, and 4093-3 were released in 1930 and 1931. They featured an enhanced version of the scale set found on the older 4092-3. The major change was that the trig scales were referenced to the D scale rather than to the B scale with a second sine scale to accommodate the range. The 4091-3 (See Figure 1 on page 43) is the first use of decimal trig scales, while the 4093-3 featured the first use of hyperbolic scales on a production slide rule.

Apparently around 1935 - 1936, the US Navy requested a rule specialized for electronic calculations. Obviously K&E was already collaborating with several math instructors at the Naval Academy to write the manual for their soon to be released 4080-3/4081-3 family of slide rules.

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[*] This article is from Journal of the Oughtred Society, 24:2, Fall 2012.

The specimen shown in Figure 1 has a serial number of 564602, which dates the production of the rule to around 1937. I have pictures of two other rules with serial numbers 486592 and 517903, which are probably from 1936. There is a curious inscription on the bottom of this rule "RMS No 72" (See Figure 2). At this time I do not know the significance of the inscription. One, of the other two rules that I have pictures of, has an "RMS No 38" inscription. The third rule has no such inscription (See Figure 3).

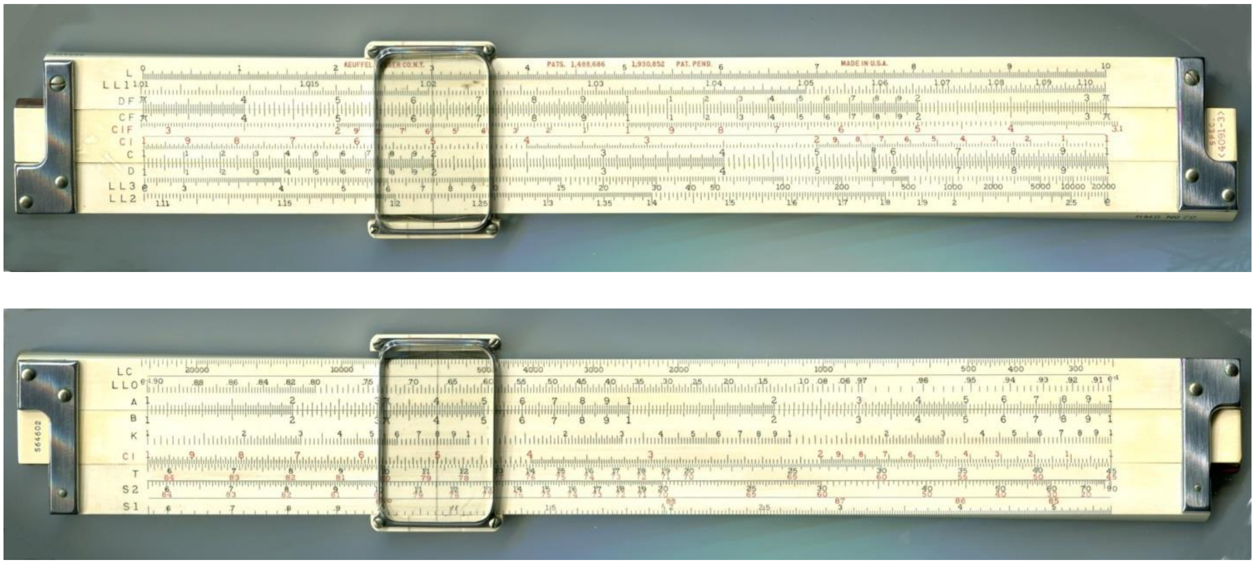


FIGURE 1. The SPEC. K&E 4091-3

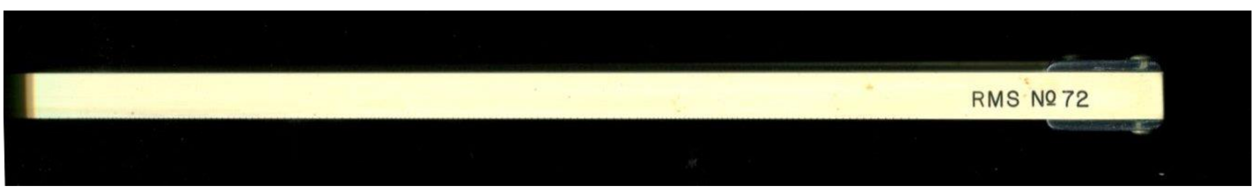


FIGURE 2. The K&E SPEC. 4091-3 with a Curious Inscription

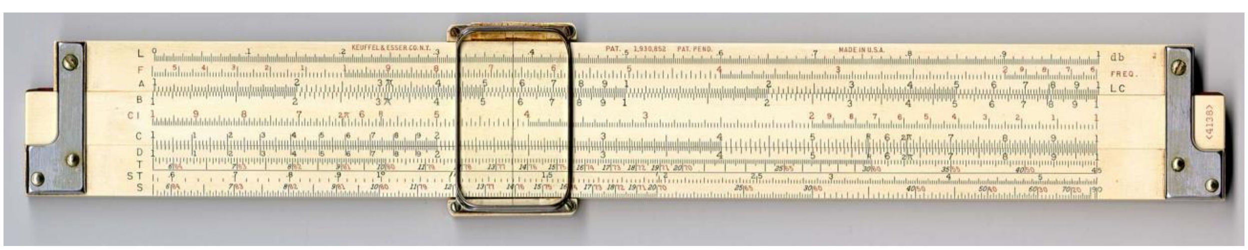


FIGURE 3. The K&E 4138

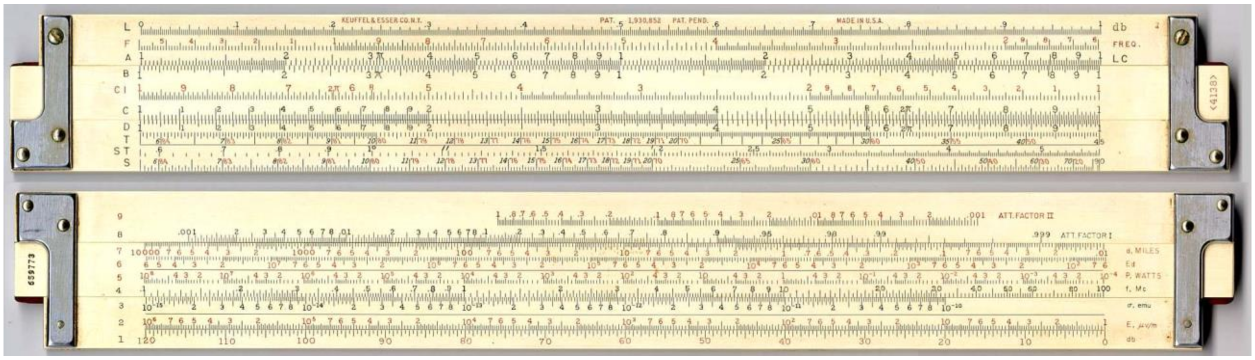


FIGURE 4. The K&E 4138 (without cursor)

4138 - The Morrison Radio Engineer's Slide Rule

The manufacturing group for Bell Labs, Western Electric, was producing broadcast equipment for the broadcast industry and was very involved with broadcasting in the 1930s. Performing the calculations used in this industry was tedious. J. F. Morrison of Bell Labs designed this slide rule to handle the general problems encountered in electronics, and he also added a set of specialized scales for predicting RF propagation. The 4138 shown in Figures 3 and 4 was produced in 1937, and the manual has a copyright date of 1937 (See Figure 6 on page 46). The 4138 was only listed in the 1939 K&E slide rule catalog and does not show up in any other catalog.

Figure 6 is a copy of the first page of the manual for the 4138.

4082-3 – The Log Log Duplex Decitrig Slide Rule with the F Scale

Between the years of 1938 and 1940, K&E introduced a variant of the newly released 4081-3 Log Log Duplex Decitrig slide rule. The 4082-3 (See Figure 5 on page 45) features an F scale, which is in the place of the K scale on a 4081-3. The F scale is a C scale folded at the constant $1/(2\pi)$. Note, this constant $1/(2\pi)$ is used for reactance and other frequency related calculations. The rule was given a model number, but the 4082-3 never showed up in any K&E catalogs. However, a manual was printed for this slide rule (See Figure 7 on page 47).I have seen an early version of this rule that did not have a model number, but rather had a label on the top of the front stating "Radio Rule". Unfortunately I have not been able to get scans of this rule as this rule is lost in the basement of one of our well known collectors.

The 4082-3 slide rules show up on eBay from time to time. How many of these rules were manufactured is unknown. The serial number distribution of these rules indicate that the 4082-3 was produced for several years.

Figure 7 is a copy of the first page of the manual for the 4082-3. The cover of the manual is damaged enough that a copyright date is not available.

4139 – The Cooke Radio Slide Rule

The Cooke Radio Slide Rule was the final version of a "Radio Rule" and stayed in the K&E product line until the end of slide rule production. The rule is named for Nelson M. Cooke, a Lieutenant Commander in the United States Navy. Cooke was a teacher of electronics in the Navy. I assume that the rule was designed by Cooke and licensed to K&E. Note that all of the Cooke Radio Slide Rules to the end of production carry the old K&E circular logo even though the logo was dropped on the rest of the K&E line in about 1945.

For a more detailed analysis of the variants of the Cooke Radio rule the reader is referred to the article by Richard Smith Hughes (see Appendix C on page 48).

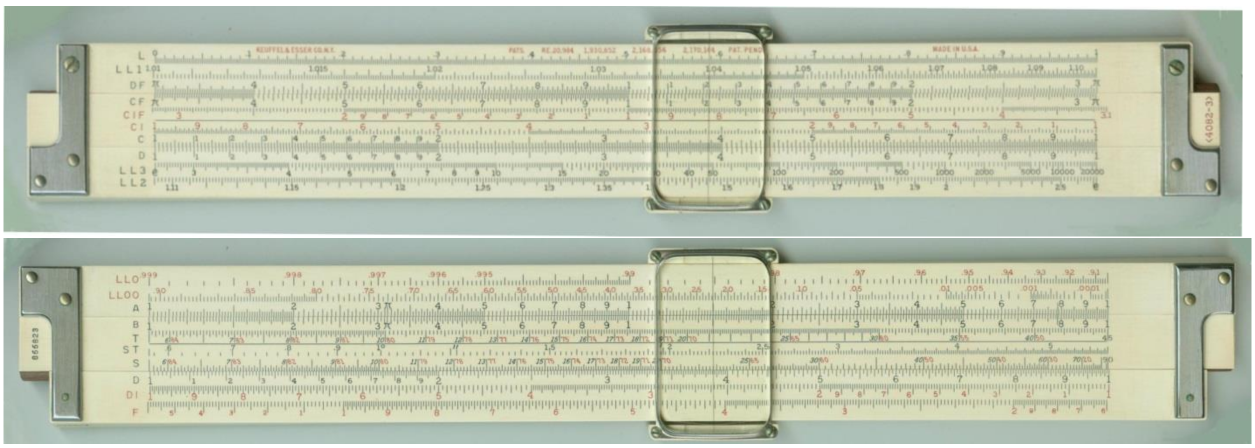
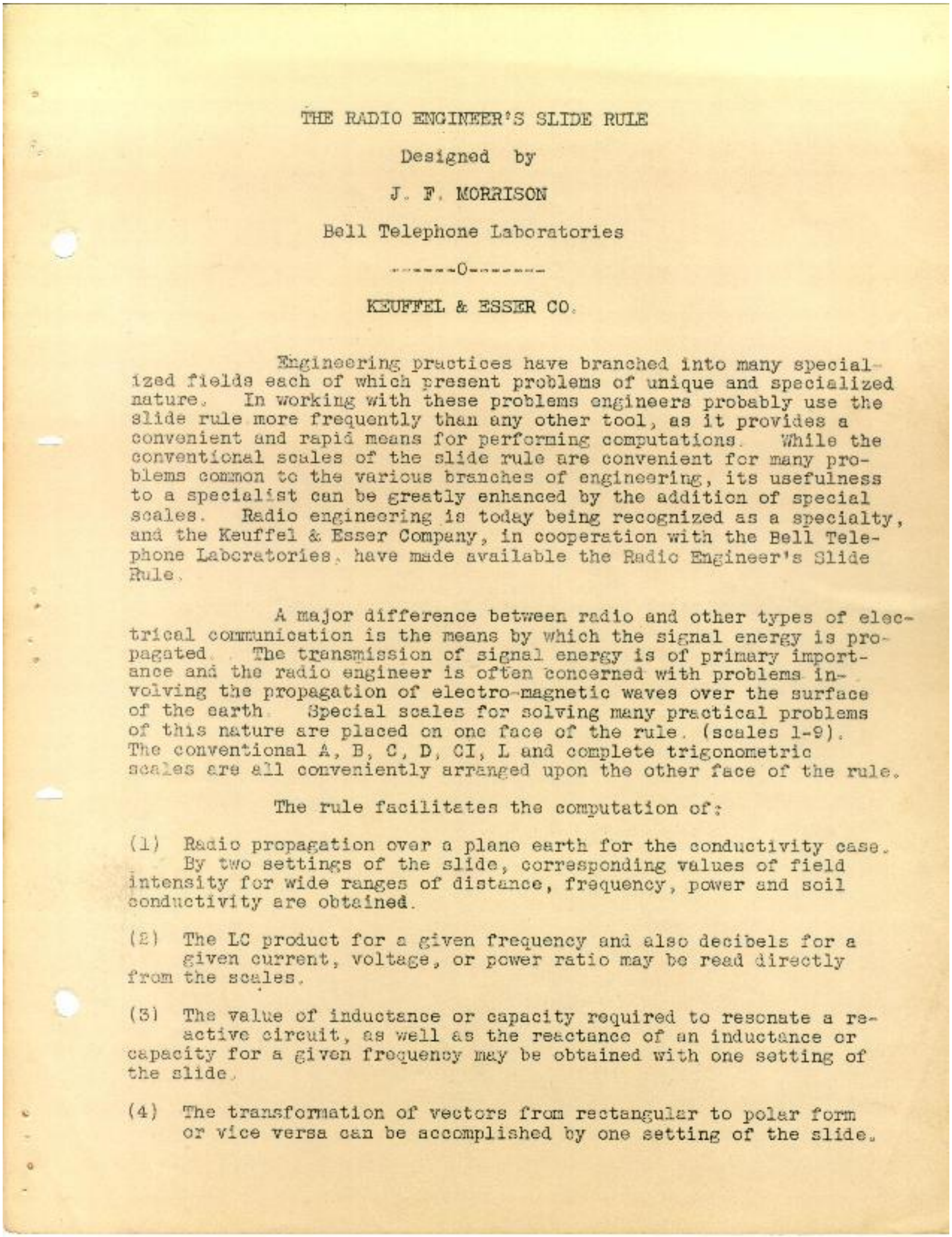


FIGURE 5. The K&E 4082-3


THE RADIO ENGINEER'S SLIDE RULE

Designed by

J. F. MORRISON

Bell Telephone Laboratories

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KEUFFEL & ESSER CO.

Engineering practices have branched into many specialized fields each of which present problems of unique and specialized nature. In working with these problems engineers probably use the slide rule more frequently than any other tool, as it provides a convenient and rapid means for performing computations. While the conventional scales of the slide rule are convenient for many problems common to the various branches of engineering, its usefulness to a specialist can be greatly enhanced by the addition of special scales. Radio engineering is today being recognized as a specialty, and the Keuffel & Esser Company, in cooperation with the Bell Telephone Laboratories, have made available the Radio Engineer's Slide Rule.

A major difference between radio and other types of electrical communication is the means by which the signal energy is propagated. The transmission of signal energy is of primary importance and the radio engineer is often concerned with problems involving the propagation of electro-magnetic waves over the surface of the earth. Special scales for solving many practical problems of this nature are placed on one face of the rule. (scales 1-9). The conventional A, B, C, D, CI, L and complete trigonometric scales are all conveniently arranged upon the other face of the rule.

The rule facilitates the computation of:

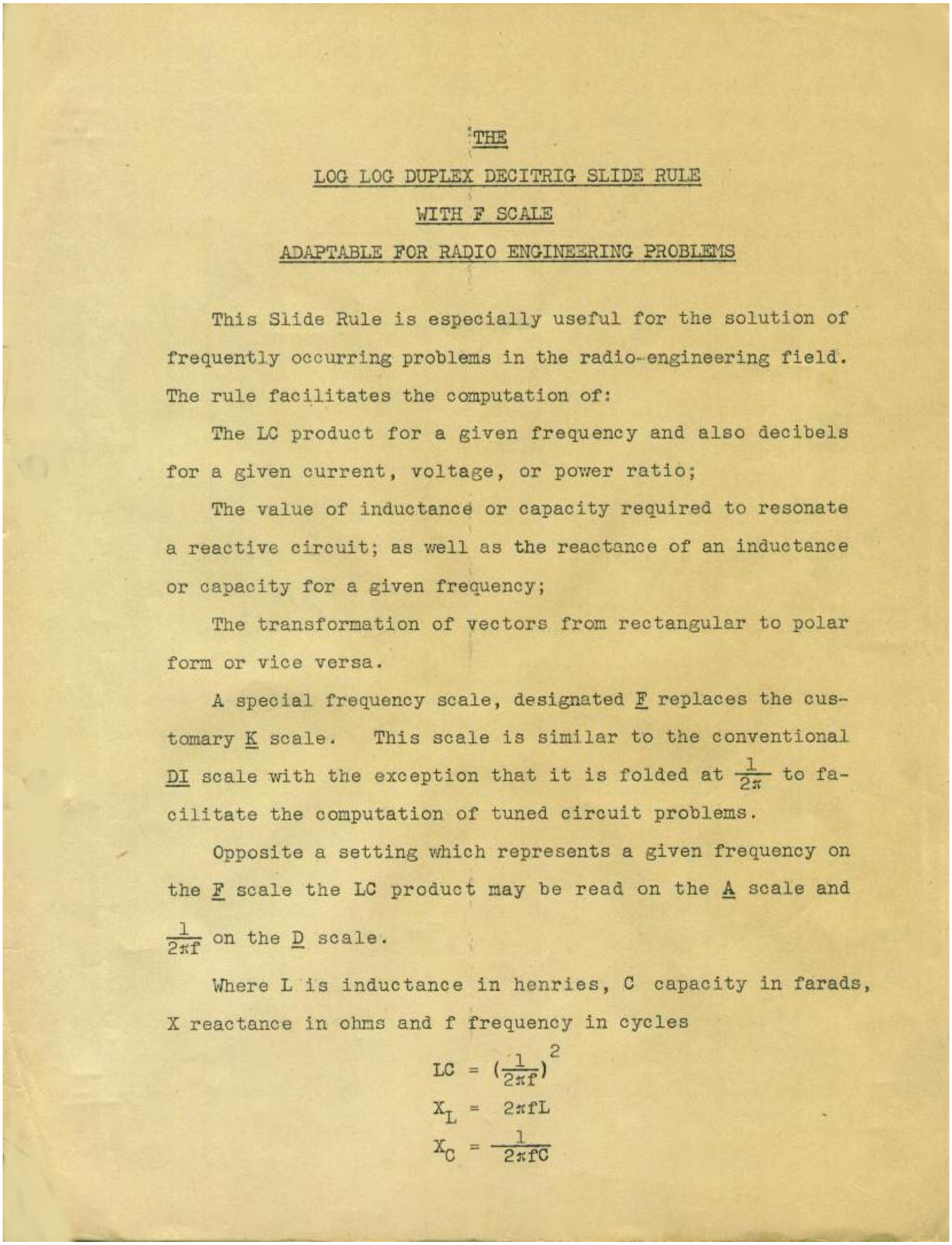
(1) Radio propagation over a plane earth for the conductivity case. By two settings of the slide, corresponding values of field intensity for wide ranges of distance, frequency, power and soil conductivity are obtained.

(2) The LC product for a given frequency and also decibels for a given current, voltage, or power ratio may be read directly from the scales.

(3) The value of inductance or capacity required to resonate a reactive circuit, as well as the reactance of an inductance or capacity for a given frequency may be obtained with one setting of the slide.

(4) The transformation of vectors from rectangular to polar form or vice versa can be accomplished by one setting of the slide.

FIGURE 6. First Page of the Manual for the K&E 4138



THE

LOG LOG DUPLEX DECITRIG SLIDE RULE

WITH F SCALE

ADAPTABLE FOR RADIO ENGINEERING PROBLEMS

This Slide Rule is especially useful for the solution of frequently occurring problems in the radio-engineering field. The rule facilitates the computation of:

The LC product for a given frequency and also decibels for a given current, voltage, or power ratio;

The value of inductance or capacity required to resonate a reactive circuit; as well as the reactance of an inductance or capacity for a given frequency;

The transformation of vectors from rectangular to polar form or vice versa.

A special frequency scale, designated F replaces the customary K scale. This scale is similar to the conventional DI scale with the exception that it is folded at $\frac{1}{2\pi}$ to facilitate the computation of tuned circuit problems.

Opposite a setting which represents a given frequency on the F scale the LC product may be read on the A scale and $\frac{1}{2\pi f}$ on the D scale.

Where L is inductance in henries, C capacity in farads, X reactance in ohms and f frequency in cycles

$$LC = \left(\frac{1}{2\pi f}\right)^2$$

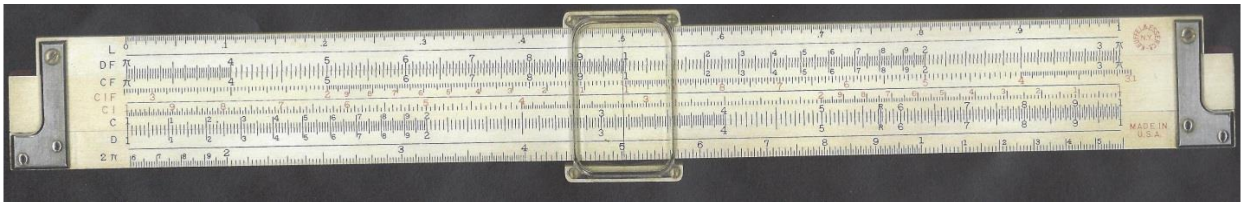
$$X_L = 2\pi f L$$

$$X_C = \frac{1}{2\pi f C}$$

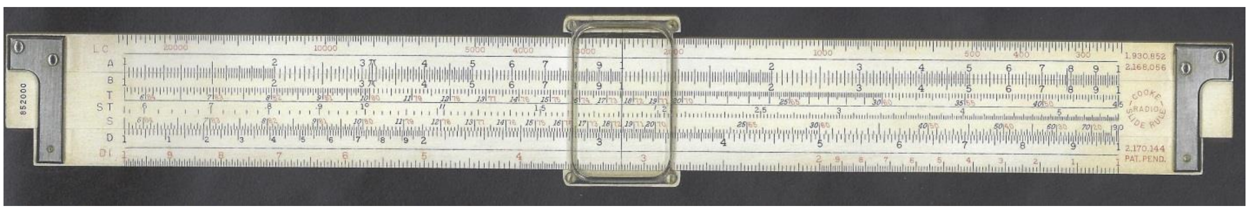
FIGURE 7. First Page of the Manual for the K&E 4082-3

*APPENDIX C**
K&E Cooke Radio, 4139/68-1460
Variants from 1940 to the End of Production (prior to 1972)

Richard Smith Hughes



Front



Back

FIGURE 1. Cooke Radio 4139, Variant IA

No model number on the slide, serial number 852000 (1940).

Clark McCoy and I published in 2011 an article[1] on dating K&E Mahogany slide rules, and I decided to find and date the evolution of the Cooke Radio "electronic" slide rule. That was some five years ago, so now is the time to present the results of my research.

The K&E Cooke Radio slide rule was designed around the 4070-3/4071-3 Polyphase Duplex body, which was first advertised in their 1939 catalog. The first listing of the Cooke Radio, 4139, was in the K&E price list dated January 1, 1943. K&E continued producing the Cooke Radio until the early 1970's; the Cooke Radio is listed in their 1968 catalog, but not in their 1972 catalog. The model number had changed around 1962 to 68-1460. The first Cooke Radio slide rule was built around 1940 and did not have the 4139 model number on the front slide, variant IA, See Figure 1. This begins the variants. The model number was on the front slide from 1941 to end of production. The scales remained unchanged to the end of production; however, the ST scale changed to SRT around 1957.

Several attributes that changed over time have been defined and given in Figure 2 on page 49. Table 1 on page 50 is a listing of the six variants I have identified (certainly more may exist) with their approximate production dates; see Note 1 for an in depth discussion on dating K&E Mahogany slide rules. When possible I have given the lowest and highest serial numbers for a variant. Table 2 on page 51 gives the simple equations to find the production date for a given variant. Pictures for several variants can be found on Clark McCoy's web page on all things K&E[2].

Notes

1. Hughes, Richard Smith and McCoy, Clark, *Determining K&E Slide Rule Production Dates; 1922 to 1976*, Journal of the Oughtred Society 20:1 Spring 2011. This article is for Mahogany slide rules.
2. Clark McCoy's K&E website on all things K&E; http://www.mccoys-kecatalogs.com/

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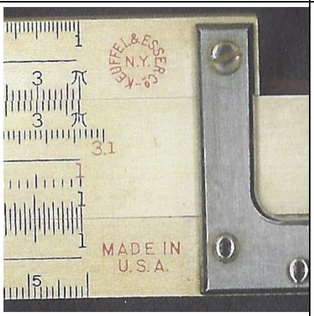
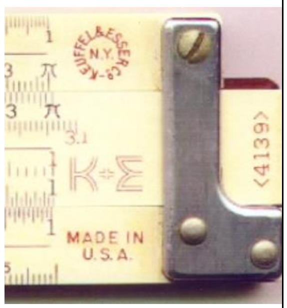
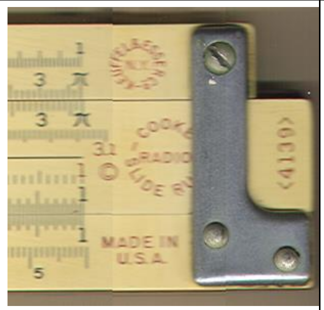
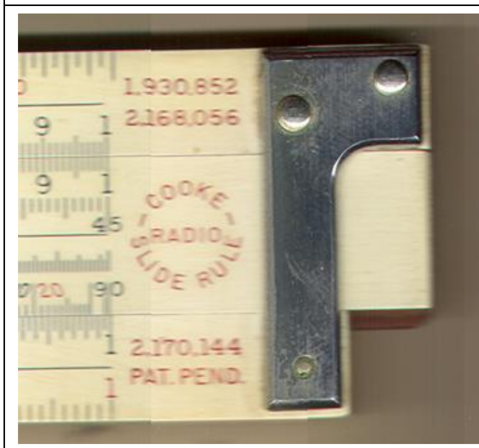
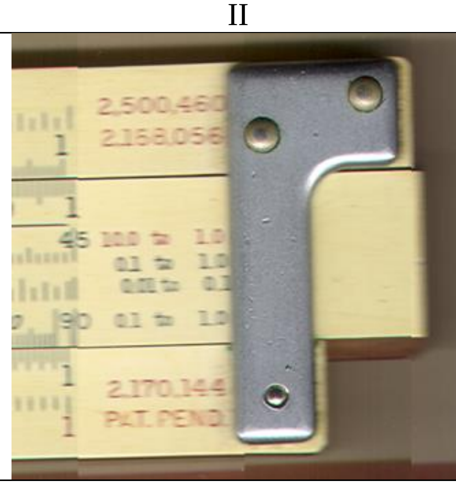
* This article is from Journal of the Oughtred Society, 24:2, Fall 2012.

I	II	III	IV
			
No model number on the slide, 1940. Model number from 1941 to end of production.	Note K&E on the slide, 1945	Note © on the slide, 1951. The Cooke Radio logo on the slide unchanged to end of production.	No © on the slide. Also Model number changed to 68-1460 around 1962.

Front Side

I	II
	
Patent numbers prior to 1951. Cooke Radio logo on the slide from 1941 to 1951.	Note the scale limits and the different patent numbers; from around 1951 to end of production. The ST scale changed to SRT around 1957.

Back Side

FIGURE 2. K&E 4139/68-1460 Cooke Radio Key Attributes
See Table 1 for the variants

TABLE 1
Cooke Radio 4139/68-1460 Variant Evolution
See Figure 2 for the Attributes

Variant	Scale Set	Serial Number	Attributes; Figure 2 Front I	Front II	Front III	Front IV	Top/Bottom Laminated Inlayed	Back I	Back II	Patents	Production Date (1)	Comments
Serial Number Series A; 1940 to 1942												
IA	1	852000	√				L	√		A	1940	No model number on the slide.
IA	1	852096	√				L	√		A	1940	
1B	1	980500	√				L	√		A	1941	Model number on slide; to end of production
Serial Number Series B; 1942 to 1956												
IB	1	060729	√				L	√		A	1942	
IB	1	167442	√				L	√		A	1943	
IC	1	293310		√			L	√		A	1945	K&E on front slide
IC	1	496441		√			L	√		A	1945	
ID	1	681122			√		I		√	B	1951	© on the slide Serial number left top and left back slide.[1] Start of scale limits.
Serial Number Series C; 1956 to 1968												
IIA	2	120134				√	I		√	B	1957	SR scale changed to SRT around 1957
IIA	2	493773				√	I		√	B	1962	
Possible IIB	2					√	I		√	B		Model 68 1460[2]. Serial number > 500,000
Serial Number Series D; 1968 to the end of Cooke Radio production												
IIB	2	060053				√	I		√	B	1969	Model 68 1460; serial numbers < 280,000

Patents

A) 1,930,852 2,168,056 2,170,144 PAT. PEND.

B) 2,500,460 2,168,0562 2,168,144 PAT. PEND.

[1] All the slide rules with laminated top/bottom have the serial number on the left top and left back slide. K&E adopted the inlayed top/bottom around 1951, and for a short time the inlayed slide rules continued this system. However, the serial numbers were soon moved to the left back top, last three digits, left back slide, six digits, and left back bottom, last three digits.

[2] The model changed from 4139 to 68 1460 around 1962 (serial number series C (1)); not advertised in the 1972 catalog.

Inlayed Top/Bottom Body Layout Changes

The introduction of the inlayed top/bottom in 1951 also saw a change in the body design:
Laminated top/bottom; there are horizontal lines between the L/DF, CIF/CI, D/2π, LC/A, T/ST, and D/DI scales. The red cos and tan numbers are to the right of the black. Inlayed top/bottom; horizontal lines only between the D/DF and B/T sales. Red cos and tan numbers to the left of the black.

TABLE 2
Determining the Production Date for K&E Mahogany Slide Rules
Adapted from Note 1

Serial Number Series	Serial Numbers	Proposed Dates
A (1922 to 1942)	0 to 380,000 (1922 to 1930)	Date ≈ 1922 + (Serial Number) / 50,000
	380,000 to 450,000 (1930 to 1933)	Date ≈ 1930 + (Serial Number – 380,000) / 23,300
	450,000 to 510,000 (1933 to 1937)	Date ≈ 1933 + (Serial Number – 450,000) / 15,000
	510,000 to 640,000 (1937 to 1939)	Date ≈ 1937 + (Serial Number – 510,000) / 65,000
	640,000 to 999,999 (1939 to 1942)	Date ≈ 1939 + (Serial Number – 640,000) / 120,000
B (1942 to 1956)	0 to 420,000 (1942 to 1947)	Date ≈ 1942 + (Serial Number) / 84,000
	420,000 To 999,999 (1947 to 1956)	Date ≈ 1947 + (Serial Number – 420,000) / 64,400
C (1956 to 1968)	0 to 999,999 (1956 to 1968)	Date ≈ 1956 + (Serial Number) / 83,300
D (1968 to 1976)	0 to 420,000 (1968 to 1974)	Date ≈ 1968 + (Serial Number) / 70,000
	420,000 to 492,000 (1974 to 1976)	Date ≈ 1974 + (Serial Number – 420,000) / 36,000

*APPENDIX D**
Five Pickett Electronics Slide Rules

Brian Borchers

Introduction

The five Pickett slide rules described in this article were especially designed for electronics calculations. Several of these rules were manufactured by Pickett for various correspondence courses in electronics. In the following, I will describe these slide rules and their specialized scales, and present some examples of how these slide rules could be used to solve some common problems in electrical engineering.

The Rules

The model **N515–T** was made for the Cleveland Institute of Electronics. This slide rule had conventional A, B, S, T, CI, C, D, L, and Ln scales on the front, along with two specialized scales for electronics applications. The H scale is an inverse A scale folded at $\frac{1}{(2\pi)^2}$.

It can be used to compute $\frac{1}{2\pi\sqrt{x}}$.

As we shall see, this is important in computing the resonant frequency of an LC oscillator. The 2*ir* scale is simply a C scale folded at 2*ir*. This scale can be used to multiply or divide by 2*ir*. On the back of this slide rule are special decimal keeper scales for resonance and reactance problems. The back of the slide rule also has a collection of useful formulas and constants. A virtually identical rule, in plastic instead of aluminum, was manufactured by Aristo with the model number 10175.

The model **N531–ES** was made by Pickett for the Capitol Radio Electronics Institute. This slide rule has conventional L, Ln, A, B, CI, C, D, K, S, ST, T, and LL scales. Like the N515–T, this slide rule also has a 2*ir* scale. However, it lacks the H scale and decimal keeper scales of the N515–T.

The model **N535–ES** was designed for Pickett by Chan Street. On the front side, this slide rule has conventional L, Ln, AI, B, ST, T, S, C, D, DI, and K scales. The AI scale is particularly useful for resonant frequency calculations. The back side of this rule has decimal keeper scales for use in resonance and reactance calculations. These scales are longer than the decimal keeper scales on the N515–T, and they have ten graduations per decade.

The model **N1020–ES** is another electronics school rule. This rule was made for the National Radio Institute (NRI). The scales on the front side of this rule are identical to the scales on the front of the N1010–ES. Like the model N531–ES, this slide rule has a 2*ir* scale on the back.

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* This article is from Journal of the Oughtred Society, 12:1, Spring 2003.

The model **N16–ES** is by far the most sophisticated of the five rules. Like the N535–ES, this slide rule was designed by Chan Street. This rule has conventional scales on the front side, including a two-part scale of hyperbolic sines and a scale of hyperbolic tangents. The reverse side of this rule has a large number of specialized circuits for electrical engineering applications. These include conventional and decimal keeper scales for resonance problems, reactance problems, and frequency response problems for filters. One particularly nice feature of this slide rule is that many of the scales have special gauge points for the resistance and capacitance of standard electronic components.

Their Function

All of these slide rules are designed to help in solving problems associated with electronic circuits made of inductors (L), capacitors (C), and resistors (R). Two important quantities associated with these circuits are the inductive reactance:

$$XL = 2irfL$$

and the capacitive reactance

$$XC = \frac{1}{2\pi fC}$$

The factor of $2ir$ is very common in electronics calculations, so several of these electronics slide rules include scales folded at $2ir$ to help in multiplying or dividing by $2ir$. The N535–ES avoids the use of a scale folded at $2ir$ by including a gauge mark at $1/2ir$ on the C scale. This gauge mark is labeled “F”.

Another very important issue is that typical values of the inductance L range from 10^{-6} (microhenries) to 10 (Henries) while typical values of C range from 10^{-9} (picofarads) all the way up to 1 (farads). Similarly, the frequency can range from tens of cycles per second to millions of cycles per second. Locating the decimal point by estimation can be quite difficult in these problems. The decimal keeper scales on the N515–T, N535–ES, and N16–ES are designed to make it easy to locate the decimal point.

In working with these electronics scales we may need to find a point on the scale when our value is either larger or smaller than the labeled values on the scale. As usual with slide rules, we can multiply or divide the quantity by factors of 10 to find a point on the scale. However, because of the presence of square roots it is sometimes necessary to adjust by factors of 100. The C/L, Cr, and Lr scales on the N16–ES each cover four orders of magnitude, so that it is easy to make this adjustment.

A common computation is the determination of the resonant frequency of a circuit with an inductor and a capacitor. The resonant frequency is given by the formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The reciprocal square root in this formula is something not often encountered in slide rule computations. The N515–T, N535–ES, and N16–ES have special scales for computing this reciprocal square root.

As a specific example, consider the problem of finding the resonant frequency of an LC circuit with L=25 mH, and C=2 *j*f. Using the decimal keeper scales on the back of the N515–T, we set the indicator to 2 on the $C\mu f$ scale and adjust the slide so that 25 mH appears on the Lmh scale under the indicator. We can then read under the $fcps$ arrow that the resonant frequency is approximately 700 cycles per second. On the front of the rule, we can use the H scale to obtain a more accurate value. First, we find that the product of L and C is 5. The exponent isn't an issue at this point, since we already know the magnitude of the answer. We then move the indicator to 5 on the H scale, and read the resonant frequency of 711 cycles per second from the D scale. Note that we know that the answer is not found under 50 on the H scale, since that would give an answer of about 220 cycles, which is clearly wrong from our earlier work with the decimal keeper scales.

Using the decimal keeper scales on the model N535–ES, it's also easy to find that the resonant frequency is approximately 700 cycles per second. To find a more precise value we use the AI scale to find 1/ LC and then divide by 2π using the "F" gauge mark.

The N16–ES also has decimal keeper scales that can be used to see the answer in hundreds of cycles per second. Once the approximate magnitude of the answer is known, the user can obtain a more accurate answer. First, set the indicator at 25 mh on the Lr scale. It happens that 25 mh is at the value where we would change our final answer by a factor of $\sqrt{10}$. Instead, extreme end of the scale, if we moved up the scale to 250 mh, we move up the scale by a factor of 100 to 2.5 h. This will change our final answer by a factor of 10. Next, we move the slide so that 2 µf on the Cr scale is under the indicator, and then move the indicator to the right index and read off the resonant frequency of 711 cycles per second.

On the N1020–ES and N531–ES, we can use the 2π scale to simplify the calculation slightly, but without the decimal keeper scales and specialized scales for the reciprocal square root, the calculations are somewhat harder. The user must keep track of the decimal point by hand.

For a more complicated example that demonstrates the power of the N16–ES, consider the problem of determining the frequency response and phase shift of a simple RC high-pass filter. The relative gain is given by

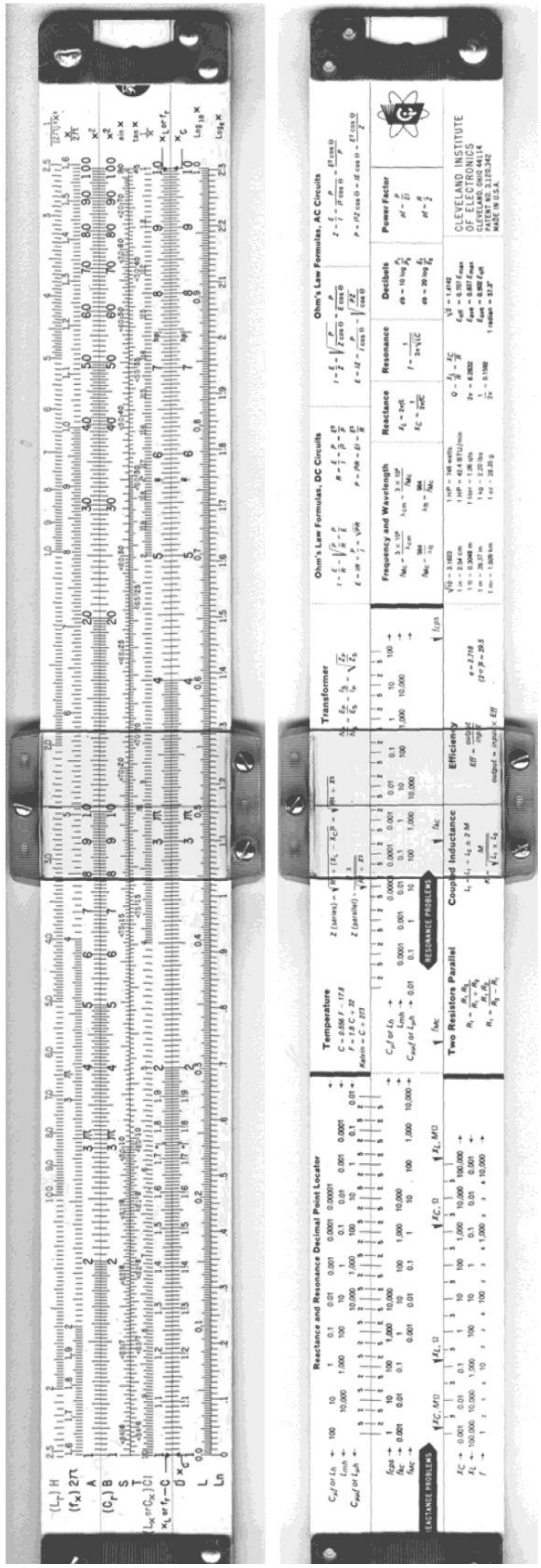
$$\cos(\theta) = \frac{1}{\sqrt{1 + \left(\frac{1}{2\pi fRC}\right)^2}}$$

while the phase shift is given by

$$\alpha(f) = \cot^{-1}(2\pi fRC).$$

The relative gain and phase shift depend entirely on the quantity 2πfRC. Once the product 2πfRC has been computed by using the f, Xc, and C/L scales, the relative gain, relative gain in db, and phase shift can all be read directly.

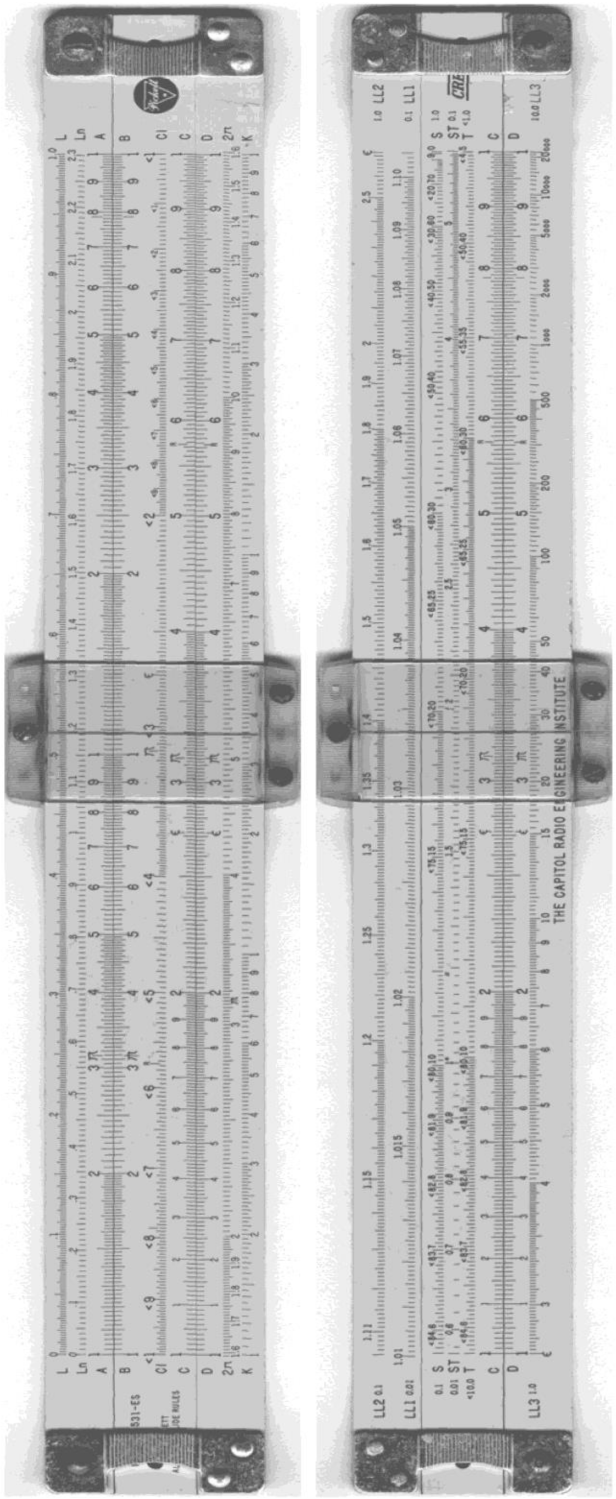
For example, we can find the relative gain and phase shift at 5 Hz for an RC filter with R=30 k ohms and C= 1.0 µ f. The relative gain is cos(θ) = 0.686 or -3.28 db, and the phase shift is α = 46.7 degrees. To perform this computation on the N16–ES, set the indicator at 0.03 M ohms on the Xc scale. Move 1.0 µf on the C/L scale under the indicator. Move the indicator to 5 Hz on the F scale. The relative gain of 0.686 (-3.28 db) can be read on the cos(θ) and db scales. The phase shift of 46.7 degrees can be read directly from the α scale.



Pickett N515–T
Cleveland Institute of Electronics.

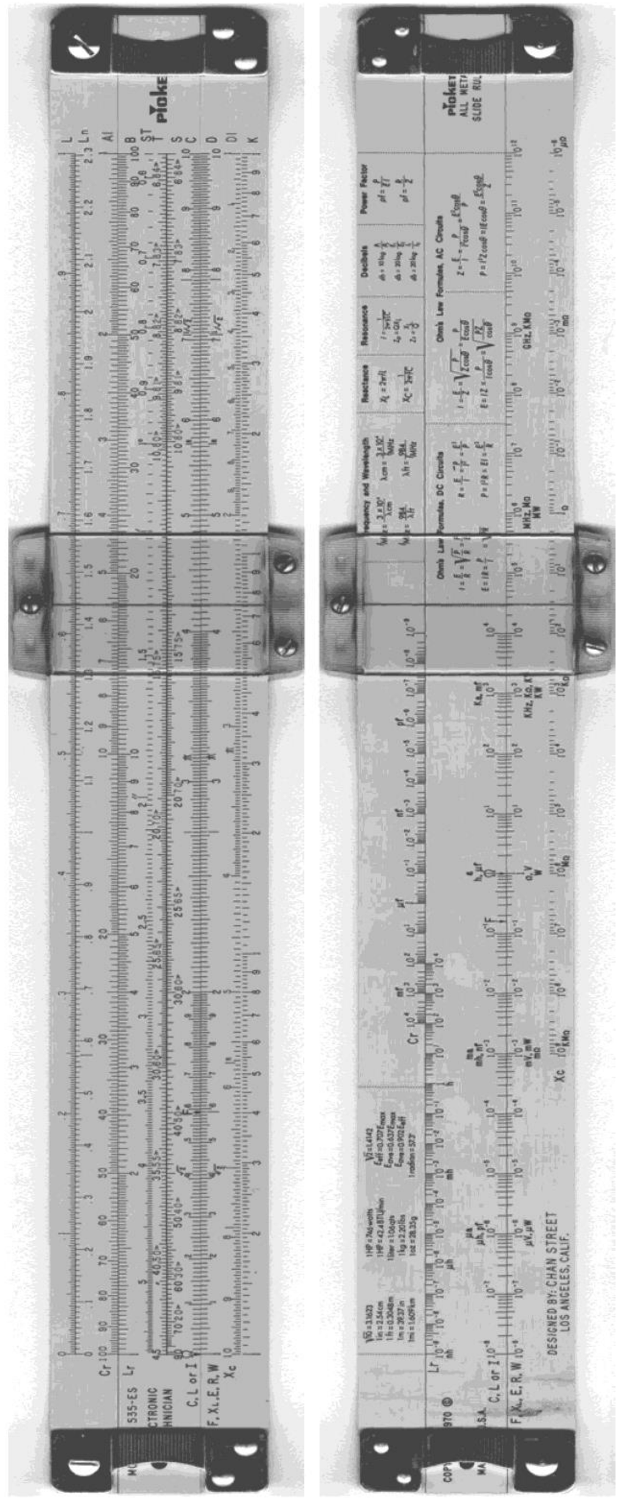
Front: Lr/H, (fx)/2Pi, A, [Cr/B, S, T, Lx/Cx/CI, Xl/fr/C], D/Xc, L, Ln

Back: Decimal Keeper Scales for Reactance/Resonance Problems



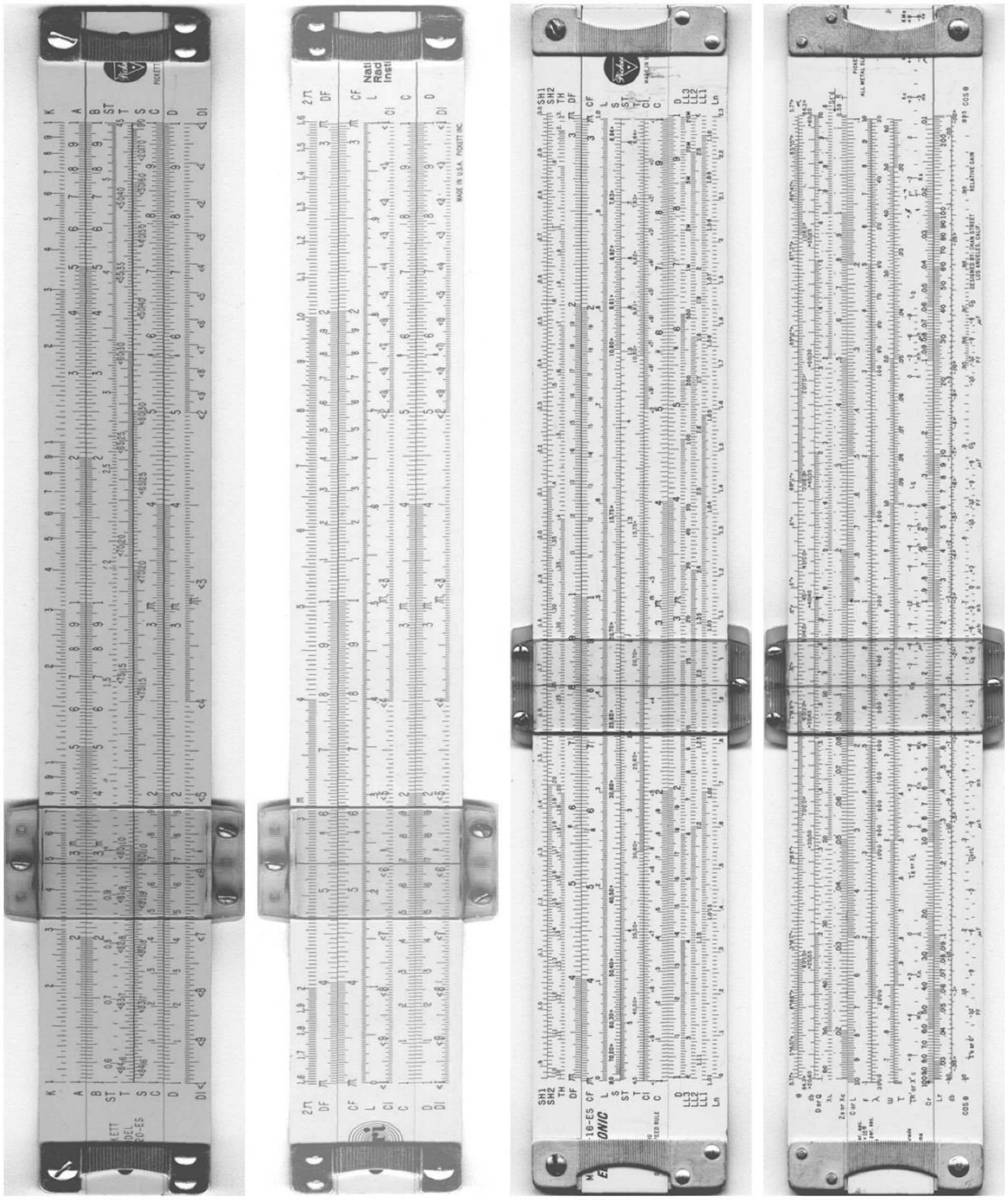
Pickett N531–ES
Capitol Radio Engineering Institute.

Front: L, Ln, A, [B, CI, C], D, 2Pi, K
Back: LL2, LL1, [S, ST, T, C], D, LL3



Pickett N535–ES Electronic Technician.

Front: L, Ln, Cr/AI, [Lr/B, ST, T, S, C/L/I], F/Xl/E/R/W/D, Xc/DI, K
Back: Decimal Keeper Scales Cr, Lr, C/L/I, F/Xl/E/R/W, Xc



Pickett N1020-ES National Radio Institute.
Front: K, A, [B, ST, T, S, C], D, DI
Back: 2Pi, DF, [CF, L, CI, C], D, DI
Pickett N16–ES
Electronic Log Log Dual Base Speed Rule.

Front: SH1, SH2, TH, DF, [CF, L, S, ST, T, CI, C], D, LL3, LL2, LL1, Ln
Back: Theta/alpha, db, D/Q, Xl, Zs/Xc, [C/L, F, Lambda, Omega, Tau, TauR’/X’c, Cr], Lr, db, COS Theta

APPENDIX E
*Reactance and Associated Slide Charts**

David Sweetman

Introduction

Journal of the Oughtred Society (JOS) articles have included references to calculations of reactance and other electronic problems using traditional slide rules [1, 2]. Additionally, specialty slide rules/charts have been mentioned [3]. This article will focus on some of these specialty slide rules/charts used for reactance and related calculations.

Basics

There are a number of electrical and electronic problems that require the calculation of fundamental properties of circuits, such as capacitive reactance (X_C), inductive reactance (X_L), resistance (R) of parallel resistors, resonant frequency (R_0), and angular frequency ($\omega = 2\pi f$). Other features, such as an Ohm's Law Calculator and a resistor color code guide help the technician or engineer when trouble-shooting or designing circuits.

While the equations for reactance are relatively simple, their solution requires a number of operations when using a standard mathematical slide rule. The specialty slide rule/chart reduces the number of operations, so is quicker and easier to use.

The applicable equations are [4]:

$$X_C = \frac{1}{2\pi f C} \qquad X_L = 2\pi f L \qquad R_0 = \frac{1}{2\pi\sqrt{LRC}}$$

Where:
X_C = capacitive reactance (ohms), f = frequency (hertz), C = capacitance (farads)
X_L = inductive reactance (ohms), L = inductance (henrys)
R_0 = resonant frequency (hertz), R = resistance (ohms)

Resonant frequency is achieved when the inductive and capacitive reactances are equal, resulting in minimum circuit impedance and maximum circuit current.

While using a standard or standard electronic slide rule to calculate these equations is not particularly difficult, these specialty slide rules/charts greatly simplify the operations, resulting in quick and sufficiently accurate answers.

Some companion slide charts that complement the reactance slide rules are the *Parallel Resistance Calculator*, the *Ohm's Law Calculator*, and the *Resist-O-Guide*. These tools simplify the calculation of total resistance for two resistors in parallel, to calculate the related values for watts, ohms, volts, and amperes, or to rapidly find the ohms of a resistor from the color code on the resistor.

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* Originally published in the Journal of the Oughtred Society, 21:2, Fall 2012.

The Kemet® *Microfarad Manipulator* was copyrighted in 1972 by Union Carbide Corporation and produced by the Graphic Calculator Company, Barrington, Illinois. The body is plastic, with a cardboard slide and a plastic spring-tension cursor. On Side A, the manipulator relates reactance, resistance, frequency, and dissipation factor; along with a Celsius/Fahrenheit temperature converter. The dissipation factor calculator is important when you are interested in calculating the power consumed by a capacitor, usually in an electric circuit with large capacitors. On Side B, the manipulator relates ripple voltage, power dissipation, impedance, and resistance, along with a Millimeters/Inches converter.

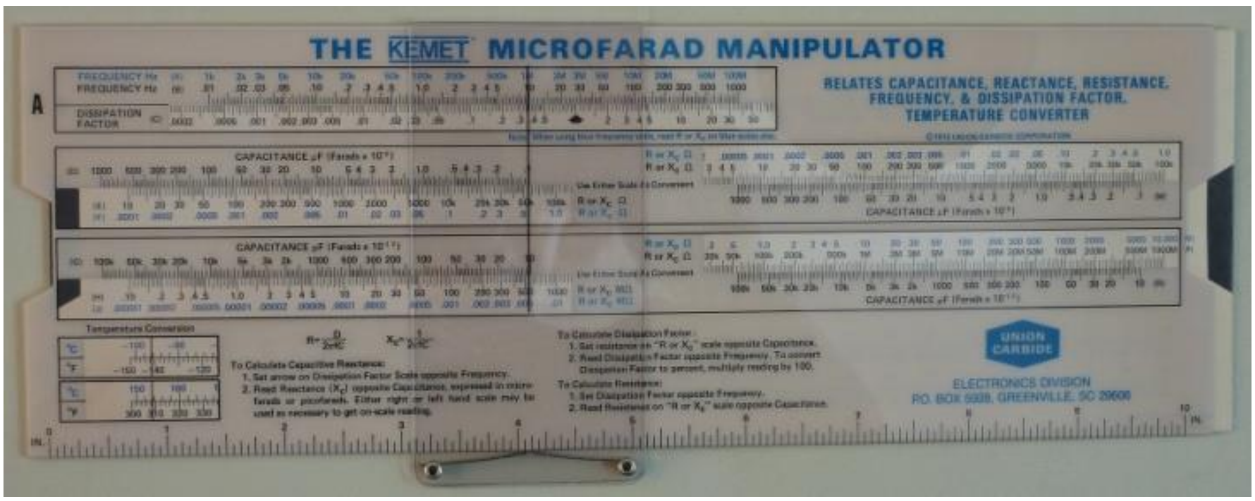

Figure 1. Side A, Kemet® Microfarad Manipulator

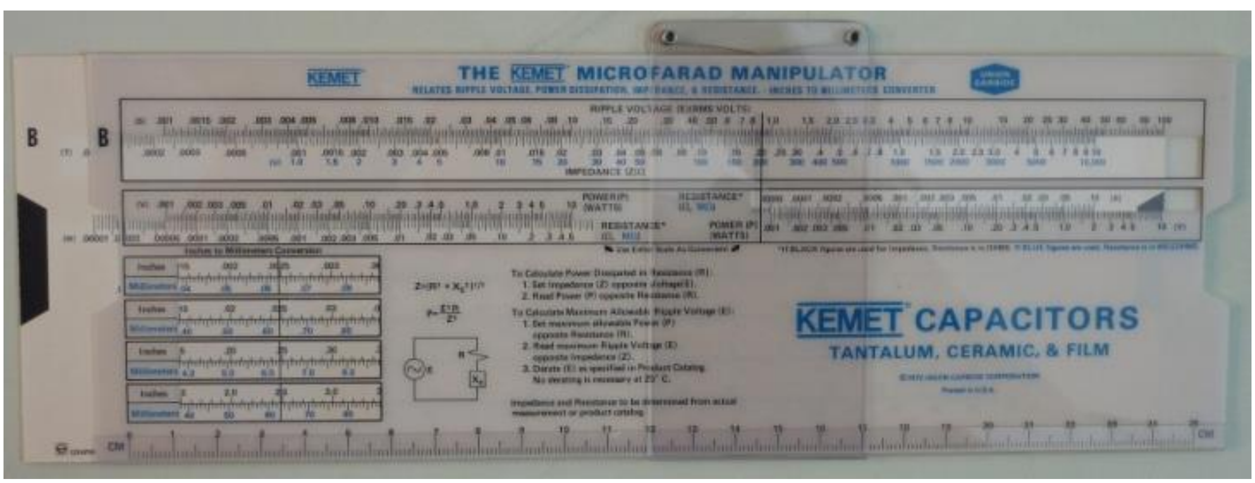

Figure 2. Side B, Kemet® Microfarad Manipulator

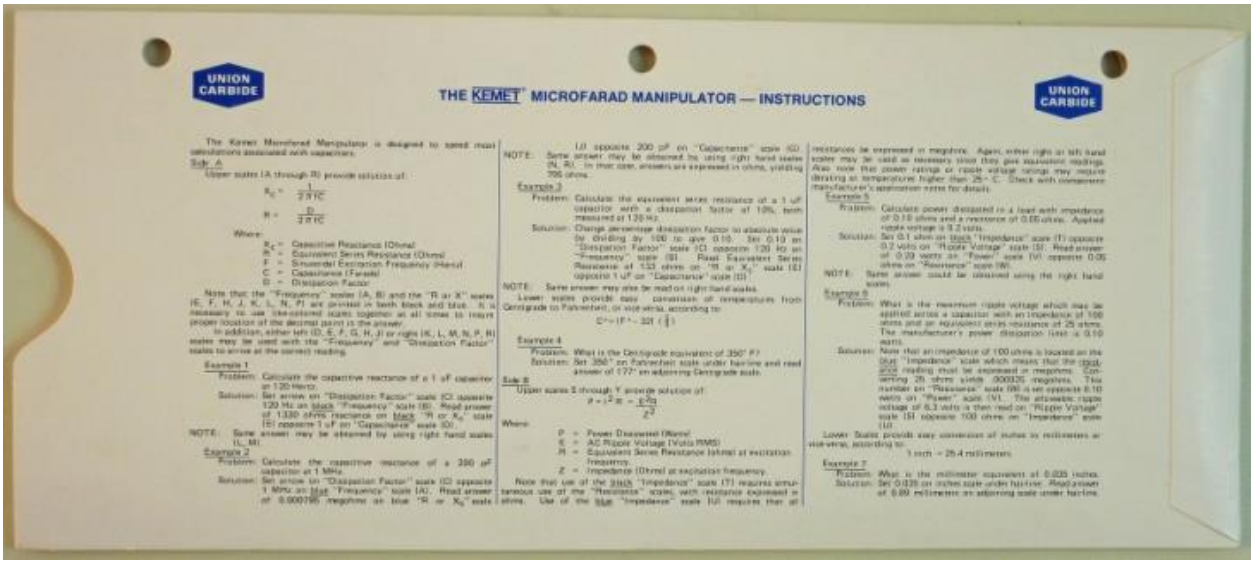

Figure 3. Kemet® Microfarad Manipulator Instructions

The Shure *Reactance Slide Rule* was copyrighted in 1957 by Shure Brothers, Inc., Evanston, Illinois, and produced by PERRYGRAF, Maywood, Illinois. The body and slide are cardboard and held together with metal rivets. Side A relates capacitance, inductance, and resonant frequency. Side B relates capacitance, capacitive reactance, and frequency or inductance, inductive reactance, and frequency, along with the dissipation factor for capacitors and the figure of merit for inductors.

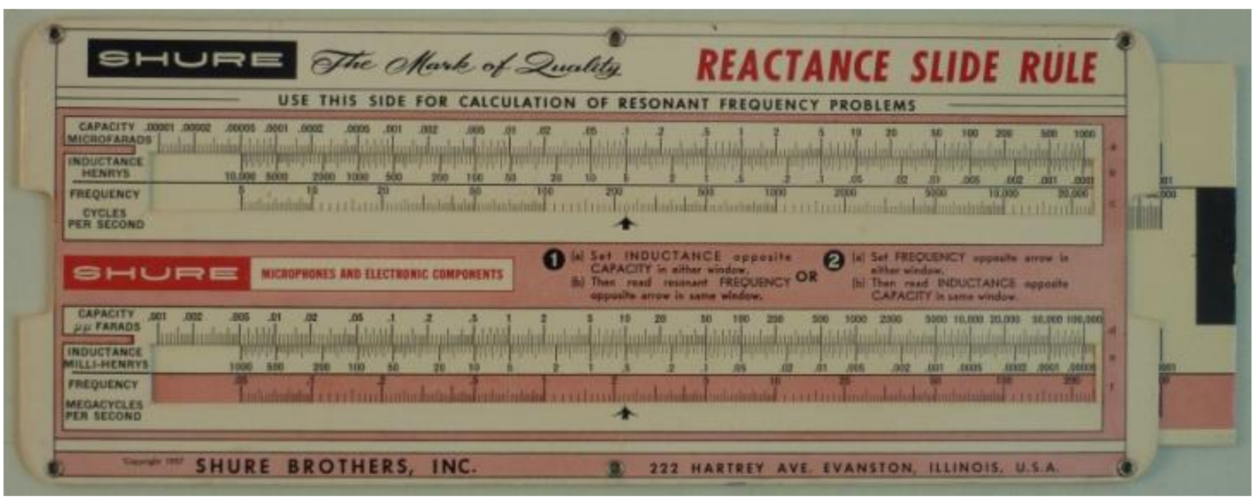

Figure 4. Side A, Shure Reactance Slide Rule

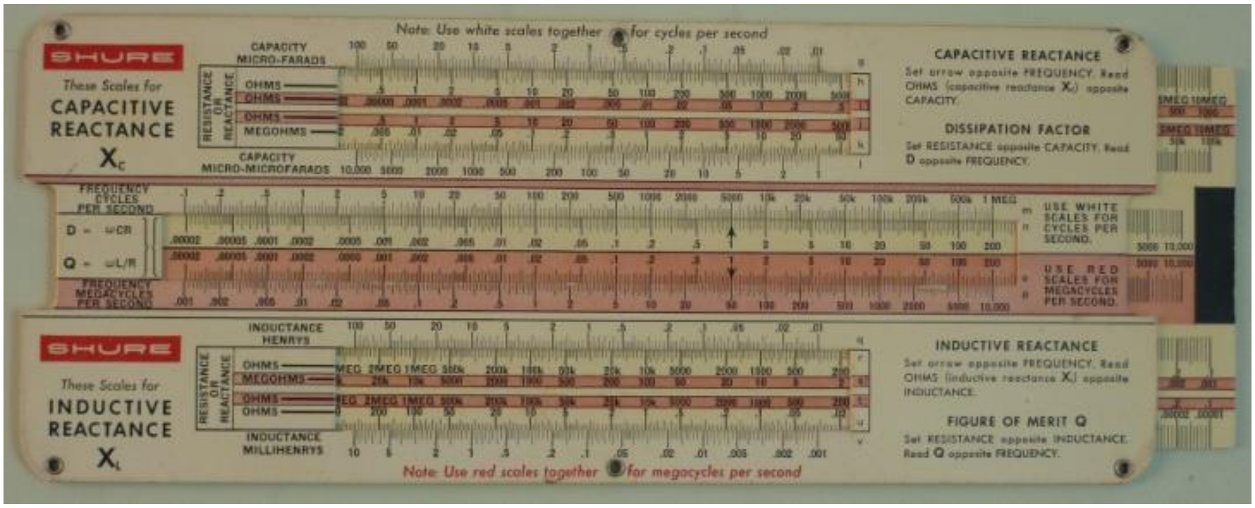

Figure 5. Side B, Shure Reactance Slide Rule

The Ohmite *Parallel Resistance Calculator* was copyrighted in 1949 by the Ohmite Manufacturing Company, Skokie, Illinois, and produced by PERRYGRAF, Maywood, Illinois. The body and slide are cardboard and held together with metal rivets. Side A contains the scales for calculating the equivalent resistance of two parallel resistors, along with the A,B,C,D scales for a standard slide rule (with no cursor). The equation for calculating the total resistance for two parallel resistors is: $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$. Side B calculates the unknown for any two known factors from Ohm's Law, where E = I·R (voltage = current × resistance), along with calculating power, since W (Watts) = E·I (voltage × current).

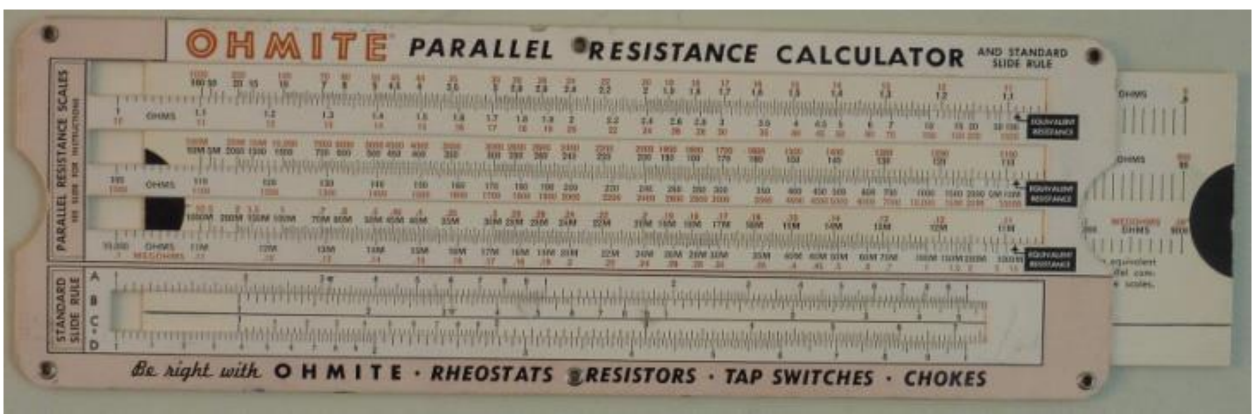

Figure 6. Side A, Ohmite Parallel Resistance Calculator

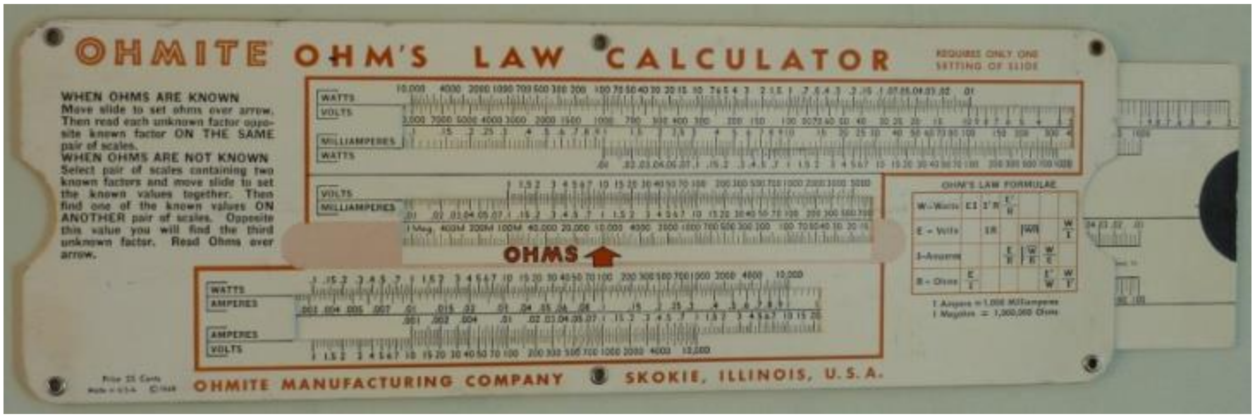

Figure 7. Side B, Ohmite Ohm's Law Calculator

The IRC *Resist-O-Guide* was copyrighted in 1946 by the Perry Graf Corp. The body and disks are plastic coated paper and held together with metal rivets. The slide chart uses 3 disks, with one window showing the color and the other window showing the numerical value at each of the 3 positions of the color code.

Figure 8. Side A, IRC *Resist-O-Guide*

References

1. Hughes, Richard Smith, *Specialized Slide Rules for Electronic Engineers*, Journal of the Oughtred Society, 19:1, 2010.
2. Hughes, Richard Smith, *The Hemmi 301 and the Boonshaft & Fuchs Slide Rules*, Journal of the Oughtred Society, 20:2, 2011.
3. Shawlee, Walter 2, *Millions of Slide Rules are Still Made Today, with Thousands of Variations*, Journal of the Oughtred Society, 20:1, 2011.
4. Bureau of Naval Personnel, *Basic Electronics*, Dover Publications, New York, 1973. This is a commercial reprint of a later edition of the manual I learned from in the US Navy.