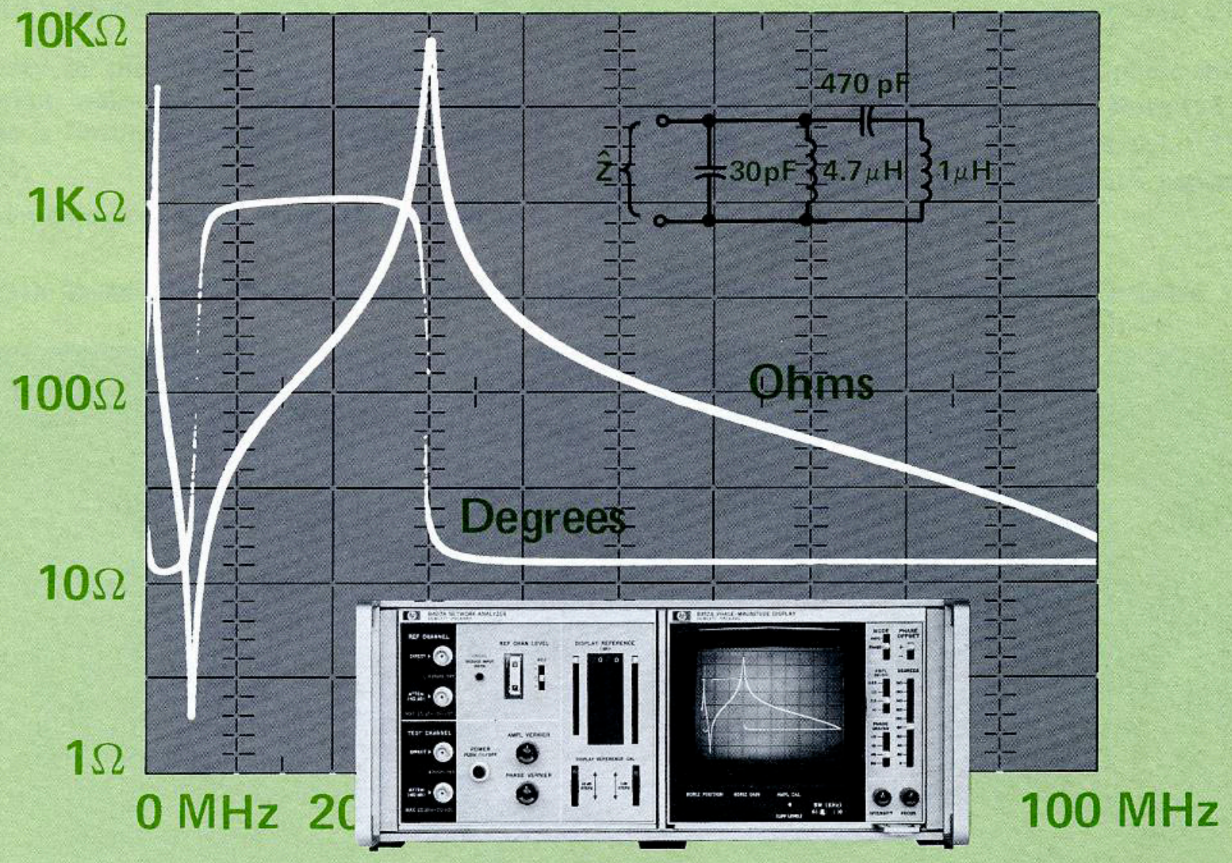
APPLICATION NOTE 121-2

Swept Impedance with the 8407A Network Analyzer 0.1 - 110 MHz



APPLICATIONS

Resistors • Inductors • Capacitors • Diodes • Mixers

Amplifiers • IF Strips • Limiters • Detectors • Modulators • Filters

Ferrites • magnetic materials • read-write amplifiers

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HEWLETT PACKARD

INTRODUCTION

Network Analysis techniques may be used to make swept impedance measurements of components, devices, and sophisticated networks from 0.1 to 110 MHz. The HP 8407A Network Analyzer measures the complex voltage $\hat{V}$ across a device and the complex current $\hat{I}$ through the device, then displays the ratio $\hat{V}/\hat{I} = \hat{Z}$ in a polar or rectangular fashion.

Figure 1 shows a vector representation of complex impedance, $\hat{Z}$. Figure 2a shows the 8414A Polar Display of the locus of $\hat{Z}$ as a function of frequency. The resistive and reactive components, r ± jX, can easily be read off the horizontal and vertical axes, respectively. Negative resistances which occur, for example, in tunnel diodes, are displayed in the left-hand portion of the impedance plane (refer to Figure 6).

Figure 2b shows the 8412A Phase-Magnitude display of the magnitude $|\hat{Z}|$, and angle θ, of $\hat{Z}$. The main advantage of the 8412A is its display range of 10,000 to 1 or 80 dB. Wide-impedance excursions are displayed as a function of frequency. Resonances, antiresonances and the capacitive ($-\theta$) or inductive ($+\theta$) nature of networks are easily observed. Impedance measurements of 1 ohm to 1 megohm are possible.

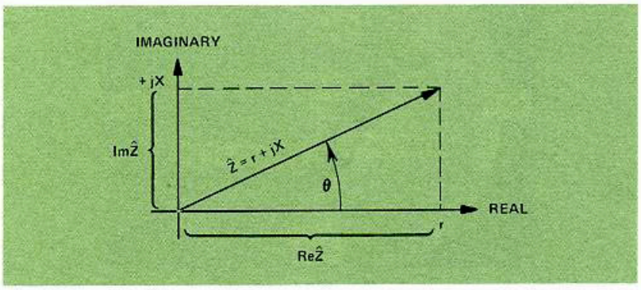


Figure 1. Vector Representattion of Complex Impedance, $\hat{Z}$

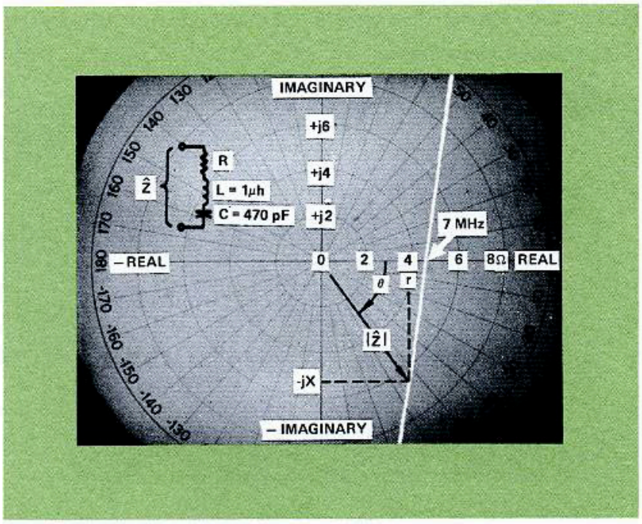


Figure 2a. 8414A Polar Display of locus of $\hat{Z}$ versus frequency.

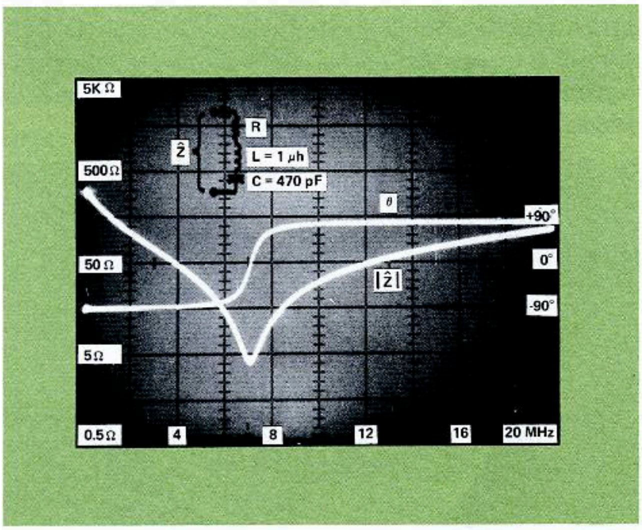


Figure 2b. 8412A Phase-Magnitude Display of $|\hat{Z}|$ and θ versus frequency.

MEASUREMENT TECHNIQUE

The basic technique is to establish a reference value of impedance on the display, then to compare the unknown impedance with the reference value. For example, a precision 50-ohm termination supplied with the Network Analyzer may be used to establish a full-scale, 0-degree reference on the 8414A Polar Display (Figure 3a) or a 50Ω, 0-degree level on the 8412A Phase-Magnitude Display (Figure 3b).

The calibration standard is then replaced with the unknown impedance and the measurement made.

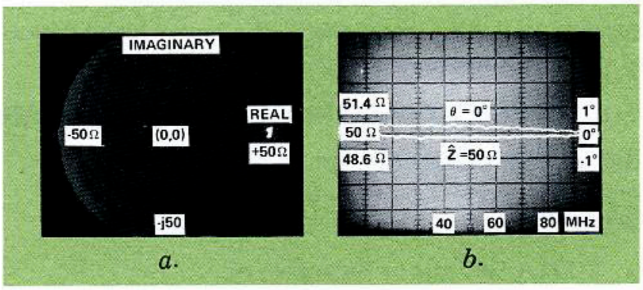
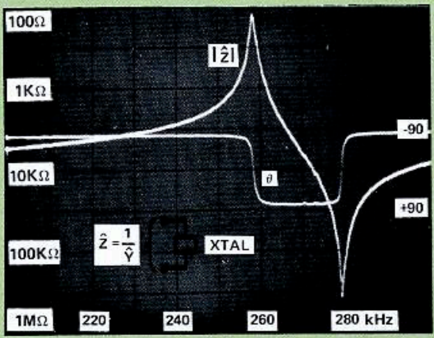


Figure 3a. Establishing a reference level of Z = 50 ohms + jOohms on the 8414A Polar Display.

Figure 3b. Establishing a reference level of Z = 50 e^{jO}ohms on the 8412A Phase-Magnitude Display.

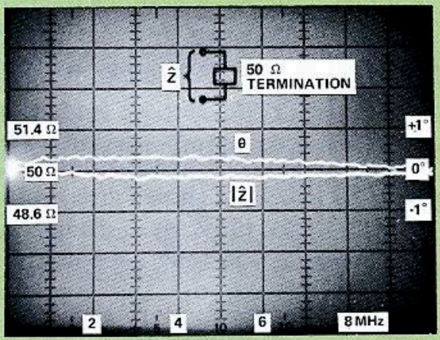
CAPABILITY III

Here are some examples of impedance measurements which show the basic capability of the Network Analyzer:



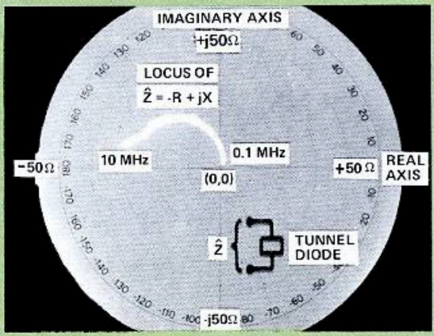
Wide Dynamic Range: 1 Ohm to 1 Megohm

Figure 4. Any 80 dB (10,000:1) portion of the 1 ohm to 1 megohm measurement range may be displayed on the 8412A (refer to Section VI). The series resonance of this ceramic filter is 100 ohms at 258 kHz; the anti-resonance is approximately 400,000 ohms at 279 kHz. (Since $\hat{Y}$ is being measured, $\hat{Z}$ increases downward.)



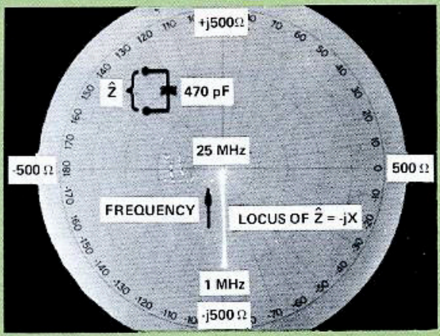
High Resolution: 0.5%, 0.2°

Figure 5. The high resolution capability of the 8412A Phase Magnitude Display enables you to observe small variations in magnitude-or phase-versus-frequency. This photo shows the swept impedance of a precision 50 ohm termination from 0.1 to 10 MHz. Variations as small as 0.5% of magnitude, 0.2° of phase are easily observed.



Characteristics of Active and Passive Networks

Figure 6. The complex impedance of active and passive networks may be characterized. This photo shows the negative resistance characteristic of a tunnel diode. Values of -R and +jX are easily determined.



Swept Display: 0.1—110 MHz

Figure 7. This photo shows the swept impedance of a capacitor from 0.1 to 25 MHz. Notice that the display reveals the purely reactive nature of the capacitor, i.e., 0 - jX, with X decreasing with increasing frequency.

EQUIPMENT NEEDED IV

(Check one in each group)

Sweeper

☐ 8601A Generator Sweeper, or

☐ 8690B/8698B Sweep Oscillator-RF Unit

Transducer

☐ 11654A Passive Probe Kit, or

☐ 10020 Voltage Divider Kit and 11654-60001 Current Probe

Mainframe

☐ 8407A Network Analyzer

Display

☐ 8412A Phase Magnitude-Display and/or

☐ 8414A Polar Display

MEASUREMENT PROCEDURE V

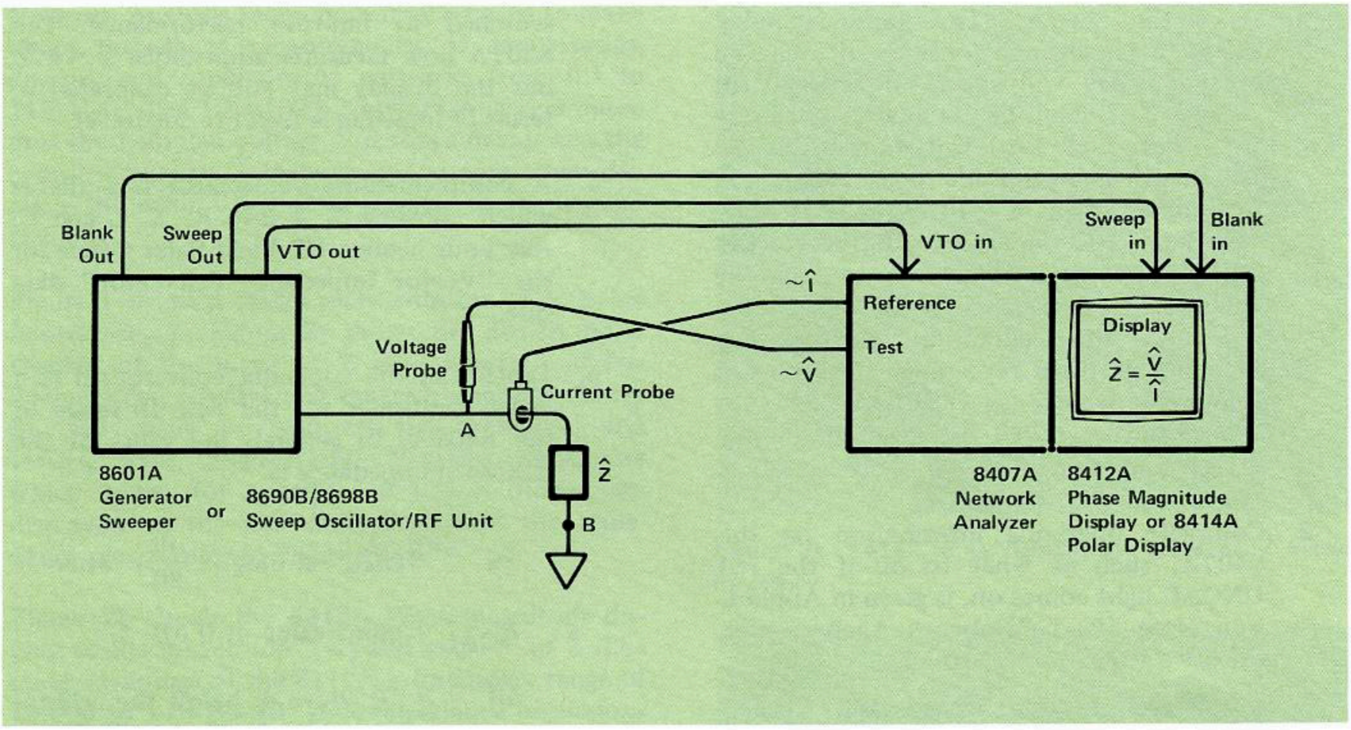


Figure 8. Setup for Making Swept Impedance Measurements with the 8407A.

A. Setup

Set up the equipment as shown in Figure 8. Measure the voltage across the load by using either a tee at point A or probing directly with a probe from the 11654A Passive Probe Kit.

B. Calibrate

1. Place a known value of impedance in the position shown for $\hat{Z}$ in Figure 8.
2. Establish a reference level on the display (assuming the calibration standard is a 50-ohm termination) as follows:

8412A

Vertical:

a. Adjust the magnitude and phase traces for a mid-screen position by using the DISPLAY REFERENCE and AMPLITUDE VERNIER controls for magnitude and the PHASE and PHASE VERNIER controls for phase (Figure 3b . By increasing resolution, you may determine this position precisely.) The PHASE OFFSET should be set at 0 for a resistor.

b. Set the DISPLAY REFERENCE CAL thumbwheel so that -6 dB shows through the windows. This means 0 dB = 100 ohms.

Horizontal:

Calibrate the display for frequency by using the HORIZ POSITION and HORIZ GAIN to set the starting point and length of the trace, respectively.

8414A

a. Push the BEAM CENTER on the 8414A and position the dot at mid-screen by using the HORIZ POS and VERT POS controls. Release the button.

b. Position the trace at the outer edge of the display at 0 degrees (Figure 3a) by using the 8407A DISPLAY REFERENCE and AMPLITUDE VERNIER controls for magnitude and PHASE VERNIER control for phase.

c. Set the DISPLAY REFERENCE CAL thumbwheel so that -6 dB shows through the windows. This means 0 dB = 100 ohms.

C. Test.

Replace the calibration standard with the unknown impedance. The display now shows the swept impedance response of the network.

D. Notes

1. Since the 8407A/8412A presents impedance in logarithmic form, a 10:1 change in impedance will show up as a 20 dB change in magnitude. Similarly, a change by a factor of 1/10 will show up as -20 dB change in magnitude. Once the system is calibrated where 0 dB represents some value, say 100 ohms, the DISPLAY REFERENCE control will always indicate the value of the reference graticule with respect to the calibration resistor. For example, if 0 dB represents 100 ohms at mid-screen, then a DISPLAY REFERENCE setting of +6 dB means that mid-screen now has a value of 2 x 100 = 200 ohms.

2. Complete operating information on the 8407A, such as what to do if the red UNCAL light comes on, is given in Application Note 121-1 "Network Analysis with the HP 8407A, 0.1 — 110 MHz."

3. For wide excursions of impedance, the reference and test channels may be switched to improve performance. The 8407A now measures admittance $\hat{Y} = 1/\hat{Z}$, but the display may still be calibrated in terms of impedance (refer to Figure 4).

4. A complementary calculator is available which converts Z, θ into R, X, L and C. Ask your nearest HP Field Sales Office for the "Vector Impedance Calculator" slide rule.

5. Table 1 in the appendix converts dB to a linear multiplier for the ±80 dB range of the 8407A. In general, the value of the unknown impedance is

$$Z_x = R_{CAL} \cdot \text{antilog}\left(\pm \frac{dB}{20}\right) \text{ where}$$

R_{CAL} = ohms value of 0 dB

dB = dB above or below the calibration value (antilog ± dB/20 is listed in Table 1).

MEASUREMENT RANGE VI

In general, impedances from less than 1 ohm to approximately 1 megohm may be measured. As the frequency increases, the range of impedance is affected by the parasitic impedance of the probes, fixtures, etc. Figure 9 is an equivalent circuit of the measurement.

If measurements are made above 10 MHz, care must be given to the design of the fixture. Values of L and C for a particular test setup may be determined by observing $\hat{Z}$ of short circuit and $\hat{Y}$ of short circuit, respectively.

For Figure 9,

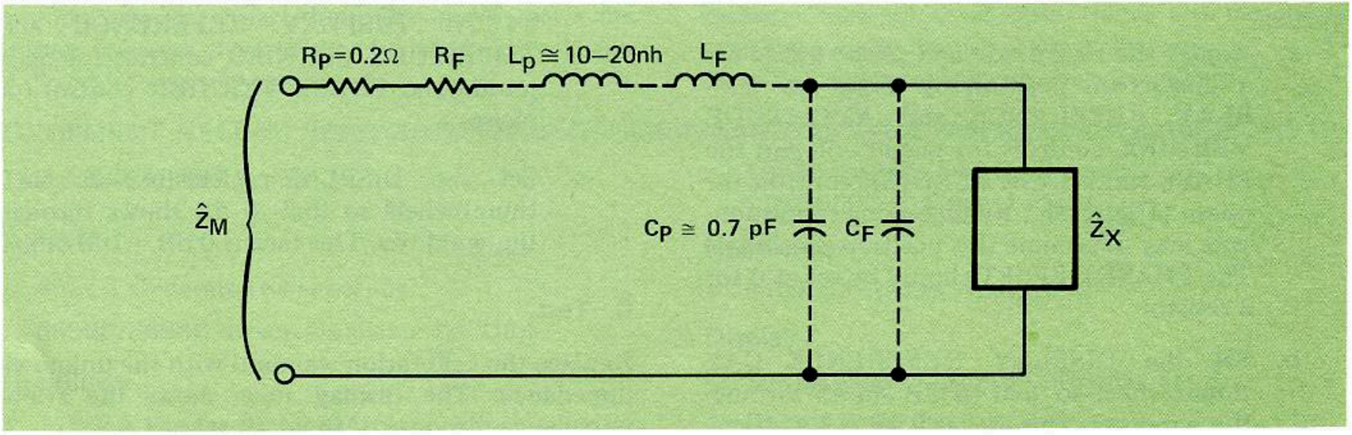
$\hat{Z}_M$ = the observed value of impedance

$\hat{Z}_X$ = actual value of unknown impedance

R_P, L_P, C_P = parasitic effects of probe (typical values shown)

R_F, L_F, C_F = parasitic effects of fixture

Figure 9. Equivalent Measurement Circuit.



ACCURACY VII

The accuracy of the measurement depends mainly upon the following parameters.

a. Parasitic impedance of the probes (refer to Figure 9). The error increases as the observed impedance approaches the parasitic impedance.

b. Stray impedance of the test fixture.

c. Accuracy of the calibration standard. For the 50-ohm precision termination (P/N 11652-60001), this error is typically less than 1% from 0.1 to 110 MHz.

d. Tracking and instrumentation error (refer to AN 121-1). For best results, the unknown impedance should be approximately equal to the calibration standard.

SUMMARY VIII

The ability of the 8407A Network Analyzer to make swept, wide-dynamic range impedance measurements is further enhanced by the instrument's versatility.

Nearly any two-port active or passive network can be characterized for gain, attenuation, phase shift, and VSWR by the 8407A. Application Note 121-1, "Network Analysis with the HP 8407A, 0.1 — 110 MHz," further describes the instrument's capability.

APPENDIX IX

TABLE 1. CONVERSION FACTORS FOR CONVERTING DB TO OHMS M=ANTILOG (DB/20)

DB	M: POS DB	M: NEG DB	DB	M: POS DB	M: NEG DB	DB	M: POS DB	M: NEG DB
0	1	1	7	2.23872	.446683	14.	5.0119	.199525
.2	1.02329	.977237	7.2	2.29087	.436515	14.2	5.12864	.194984
.4	1.04713	.954993	7.4	2.34423	.426579	14.4	5.2481	.190545
.6	1.07152	.933254	7.6	2.39884	.416869	14.6	5.37034	.186208
.8	1.09648	.912011	7.8	2.45471	.40738	14.8	5.49544	.181969
1	1.12202	.891251	8.	2.51189	.398107	15.	5.62344	.177827
1.2	1.14815	.870963	8.2	2.5704	.389045	15.2	5.75443	.173779
1.4	1.1749	.851138	8.4	2.63027	.380189	15.4	5.88847	.169823
1.6	1.20226	.831764	8.6	2.69154	.371535	15.6	6.02563	.165958
1.8	1.23027	.81283	8.8	2.75423	.363077	15.8	6.16598	.16218
2	1.25893	.794328	9.	2.81839	.354813	16.	6.30961	.158488
2.2	1.28825	.776247	9.2	2.88404	.346736	16.2	6.45658	.154881
2.4	1.31826	.758577	9.4	2.95121	.338844	16.4	6.60697	.151355
2.6	1.34896	.74131	9.6	3.01996	.331131	16.6	6.76087	.14791
2.8	1.38038	.724436	9.8	3.0903	.323593	16.8	6.91835	.144543
3.	1.41254	.707946	10.	3.16228	.316227	17.	7.0795	.141253
3.2	1.44544	.691831	10.2	3.23594	.309029	17.2	7.2444	.138038
3.4	1.47911	.676083	10.4	3.31132	.301995	17.4	7.41315	.134895
3.6	1.51356	.660693	10.6	3.38845	.29512	17.6	7.58582	.131825
3.8	1.54882	.645654	10.8	3.46738	.288402	17.8	7.76252	.128824
4.	1.58489	.630957	11.	3.54814	.281838	18.	7.94333	.125892
4.2	1.62181	.616595	11.2	3.63079	.275422	18.2	8.12836	.123026
4.4	1.65959	.602559	11.4	3.71536	.269153	18.4	8.31769	.120226
4.6	1.69824	.588843	11.6	3.80191	.263026	18.6	8.51144	.117489
4.8	1.7378	.57544	11.8	3.89046	.257039	18.8	8.7097	.114815
5.	1.77828	.562341	12.	3.98108	.251188	19.	8.91258	.112201
5.2	1.8197	.549541	12.2	4.07382	.24547	19.2	9.12018	.109647
5.4	1.86209	.537032	12.4	4.16871	.239882	19.4	9.33261	.107151
5.6	1.90546	.524807	12.6	4.26581	.234422	19.6	9.55	.104712
5.8	1.94985	.512861	12.8	4.36518	.229086	19.8	9.77245	.102328
6.	1.99526	.501187	13.	4.46685	.223871	20.	10.	9.99996E-02
6.2	2.04174	.489779	13.2	4.5709	.218775	40	100.001	9.99993E-03
6.4	2.0893	.47863	13.4	4.67737	.213795	60	1000.01	9.99990E-04
6.6	2.13796	.467735	13.6	4.78632	.208929	80	10000.1	9.99986E-05
6.8	2.18776	.457088	13.8	4.89781	.204173			

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