Ray Fautley shows how to design reliable voltage doubling power supply circuits with the aid of look-up tables.

Voltage doubling

The symmetrical voltage doubler, shown in the diagram, is useful for providing high voltages at low currents.

The term 'symmetrical' is used as the diodes and capacitors are connected in a symmetrical fashion, looking rather like the bridge-rectifier circuit. There is no direct connection between the alternating input and the dc output. (Another type of voltage doubler circuit is the common-terminal circuit where the ac supply and dc output have a common terminal, and so is not 'symmetrical'.)

Alternating voltage is applied to the two rectifier diodes D_1 and D_2. When point x is positive, diode D_1 conducts but D_2 is cut off. Current through D_1 charges capacitor C_A to approximately the peak of the transformer secondary voltage. During the next half cycle point x will be negative with diode D_2 conducting and D_1 cut off.

Current through D_2 charges capacitor C_B, again to approximately the secondary peak voltage.

As the two capacitors C_A and C_B are connected in series, so are the voltages across each of them. The two voltages – being of suitable polarity – add, providing nearly twice the output voltage of a single diode half wave rectifier. This is logical because the voltage doubler is really just two half wave rectifiers in series.

Source resistance is shown as resistor R_s.

Voltage doubler design procedure

The procedure for designing the symmetrical voltage doubler is similar to that used for the rectifier circuits described in my previous articles.

1) Specify required dc output voltage at full load $E_{dc(load)}$ in volts.

2) Specify required maximum load current $I_{dc(load)}$ in amps.

3) Specify maximum ripple voltage acceptable, $V_{r(rms)}$ in volts.

4) Specify the ac mains supply voltage $V_{pri(rms)}$ in volts.

5) Specify frequency of the mains supply f in hertz.

6) Determine the value of equivalent load resistance R_L,

$$R_L = \frac{E_{dc}}{I_{dc(load)}}$$

where E_{dc} is the design value of the dc output voltage. It is the required voltage across the load $E_{dc(load)}$, added to any voltage drop across the diodes.
As this type of rectifier is mostly used for obtaining a high voltage at low current the diode voltage drop can be ignored, so,

$$R_L = \frac{E_{dc(load)}}{I_{dc(load)}}$$

7) Determine the average current I_o through each diode:

$I_o = I_{dc(load)}$

8) Determine a value for the source resistance of the supply R_s. As only high resistance loads – i.e. high voltage and low current – are to be considered; the predominant resistance will be that of the transformer windings. So,

$$R_s = R_{sec} + \frac{R_{pri}}{N^2}$$

However, as it's likely that the transformer winding resistance are not known, assume R_s is about 2% of R_L. So,

$$R_s = R_L \times \frac{2}{100}$$

9) Calculate the ratio of R_s to R_L as a percentage,

$$\frac{R_s}{R_L} \times 100\%$$

10) Determine the percentage ripple voltage from the specified maximum ripple and dc output voltage:

$$V_r\% = \frac{V_{r(rms)}}{E_{dc(load)}} \times 100\%$$

11) From the **Table 1**, determine the value of X required to provide the percentage ripple voltage $V_r\%$ in step (10) above, for $(R_s/R_L)\%$ calculated in step (9).

12) Calculate the value of capacitors C_A and C_B in the circuit diagram.

$$C_A = C_B = C = \frac{X(10^6)}{2\pi f R_L}\mu\text{F}$$

13) Find the nearest standard, or available, value for C_A and C_B, close to, or just above, the value calculated in step (12). If the practical value of C is different from that in step (12), call it C_1 and determine a new value for X (call it X_1) from, $X_1 = 2\pi f C_1 R_L$, or with C in microfarads,

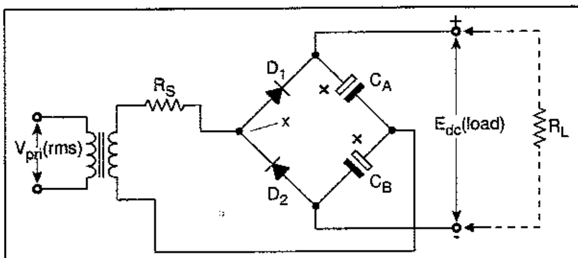
$$X_1 = \frac{2\pi f C_1 R_L}{10^6}$$

14) From the figures in **Table 2**, determine the value of Y for X in step (11), or X_1 in step (13), and $(R_s/R_L)\%$ in step (9).

15) Determine the transformer secondary voltage $V_{sec(rms)}$ required, from the value for Y in step (14),

$$V_{sec(rms)} = \frac{E_{dc(load)}}{\sqrt{2} \times Y}$$

$$= \frac{0.707 \times E_{dc(load)}}{Y}$$



Used for providing high voltages at low current, this circuit produces nearly twice the voltage of a single-diode half-wave rectifier.

16) Determine the peak voltage, or PIV, that each of the rectifiers must withstand,

$$PIV=2\times V_{sec(peak)}$$
$$=2\times\sqrt{2}\times V_{sec(rms)}$$
$$=2.828V_{sec(rms)}$$

17) Find the value for Z from **Table 3** for $0.5X$ (or $0.5X_I$) where X was found in step (11) or X_I in step (13), and for $(R_s/0.5R_L)\%$, where $(R_s/R_L)\%$ was found in step (9),

$$Z=\frac{I_{(rms)}}{I_o}$$

18) From the value of Z found in step (17), determine the current through each rectifier diode from $I_{(rms)}=I_o\times Z$.

19) Determine recurrent peak current I(peak) through each rectifier diode. From **Table 4**, for $0.5X$ (or $0.5X_1$) and $(R_s/0.5R_L)\%$ find W, which is $I_{(peak)}/I_o$. Next find $I_{(peak)}$ from $I_o\times W$.

20) Determine initial switch-on current I_{on}. As capacitors C_A and C_B are initially discharged, the load on the rectifier diodes will be nearly a short circuit at the instant of switch-on, limited only by the source resistance R_s. As a result,

$$I_{on}=V_{sec(peak)}/R_s.$$

This very high current flows for only a very short time, but the rectifier diodes must be capable of withstanding it. If suitable devices with such high pulse ratings are not available, the source resistance R_s must be increased by adding an external resistor R_{ext} where R_s is shown in the circuit diagram. The value of R_{ext} to limit the switch-on current to an acceptable lower value $I_{on(L)}$ is determined in step (28).

21) Decide on a suitable rectifier diode type. The device must have *all* its ratings equal to, or greater than, the following,

PIV or $2\times V_{sec(peak)}$ (sometimes V_{RRM}), see step (16)

Initial switch-on current or I_{on} (sometimes I_{FSM}), see (20)

Average current or I_o (sometimes $I_{F(AV)}$), see (7)

22) Determine rms ripple current $I_{c(rms)}$, flowing through capacitors C_A and C_B,

$$I_{c(rms)}=\sqrt{[(I_{(rms)}{}^2)-(I_{dc(load)}{}^2)]}$$

for $I_{(rms)}$ see (18) and for $I_{dc(load)}$ see (2).

23) Decide on the specification for capacitors C_A and C_B. Each capacitor must have ratings equal to, or greater than, the following,

Capacitance C_A and C_B see (12) or (13)

Working dc voltage $\sqrt{2}\times V_{sec(rms)}$, see (15)

Ripple current $I_{c(rms)}$, see (22)

24) Total transformer secondary current $I_{t(rms)}$ comprises two currents, one in each rectifier, which must be summed by,

$$I_{t(rms)}=\sqrt{[(I_{(rms)}{}^2)+(I_{(rms)}{}^2)]}$$
$$=\sqrt{2}\times I_{(rms)}=1.414\times I_{(rms)}$$

For $I_{(rms)}$ see step 18.

25) Transformer volt-amp, or VA rating T_{VA} is,

$$T_{VA}=V_{sec(rms)}\times I_{t(rms)}$$

This determines the size of the transformer.

26) Transformer requirements:

Volt-amp rating T_{VA}, see step (25)
Primary winding $V_{pri(rms)}$, see (4)
Secondary winding $V_{sec(rms)}$ see (15)
Secondary current $I_{t(rms)}$, see (24)

Table 1. Finding the value of X for the voltage doubler design.

V_r%	(R_s/R_L)% 0.1	0.3	1.0	3.0	5.0	10
0.1	1780	1594	1428	1279	1210	1145
0.2	863	772	691	618	585	553
0.3	561	506	456	411	390	370
0.4	418	375	337	302	286	271
0.5	332	299	270	243	231	219
0.6	280	250	224	200	189	179
0.7	238	214	193	174	165	157
0.8	203	183	165	149	141	134
0.9	183	165	148	133	126	120
1.0	163	147	131	120	114	109
2.0	80	72	64	58	55	52
3.0	52	47	42	38	36	34
4.0	39	37	35	33	32	32
5.0	30	27	24	22	21	20
6.0	24	22	20	18	17	16
7.0	20	18	17	15	14	14
8.0	18	16	15	13	12	12
9.0	14	13	12	11	10.7	10.5
10	13	12	11	10	9.6	9.2
20	4.8	4.5	4.3	4.0	3.9	3.8
30	2.3	2.2	2.1	2.0	2.0	2.0
40	1.1	1.07	1.04	1.02	1.01	1.0

Table 2. Finding the value of Y.

X	(R_s/R_L)% 0.1	0.25	0.5	1	1.5	2	3	4	5	6	7	8	10	13	20
[illegible].3	0.60	0.59	0.59	0.58	0.58	0.58	0.57	0.57	0.56	0.55	0.55	0.54	0.53	0.51	0.49
1.5	0.66	0.65	0.64	0.64	0.63	0.63	0.63	0.63	0.62	0.62	0.61	0.60	0.59	0.56	0.54
2	0.77	0.76	0.75	0.74	0.74	0.73	0.73	0.72	0.71	0.70	0.69	0.69	0.68	0.66	0.62
3	0.93	0.92	0.92	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.85	0.85	0.83	0.77	0.71
4	1.04	1.03	1.03	1.02	1.01	1.00	0.98	0.97	0.96	0.95	0.94	0.93	0.89	0.81	0.74
5	1.13	1.12	1.12	1.10	1.09	1.08	1.06	1.03	1.03	1.02	1.00	0.98	0.94	0.93	0.75
6	1.19	1.18	1.17	1.16	1.15	1.14	1.12	1.06	1.08	1.07	1.03	1.01	0.97	0.84	0.75
7	1.25	1.24	1.24	1.22	1.20	1.19	1.16	1.14	1.12	1.09	1.06	1.02	0.98	0.85	0.75
8	1.31	1.30	1.29	1.27	1.25	1.24	1.21	1.18	1.15	1.12	1.08	1.04	0.99	0.85	0.75
9	1.35	1.34	1.32	1.30	1.29	1.27	1.24	1.21	1.17	1.13	1.09	1.05	1.00	0.85	0.75
10	1.39	1.38	1.36	1.34	1.32	1.31	1.27	1.23	1.19	1.15	1.10	1.06	1.01	0.86	0.75
15	1.51	1.50	1.48	1.44	1.42	1.39	1.33	1.27	1.22	1.17	1.13	1.08	1.02	0.86	0.75
20	1.62	1.61	1.59	1.54	1.52	1.47	1.39	1.31	1.25	1.19	1.15	1.10	1.03	0.87	0.75
30	1.77	1.72	1.68	1.62	1.57	1.51	1.42	1.34	1.27	1.21	1.16	1.11	1.03	0.87	0.75
40	1.79	1.77	1.73	1.65	1.60	1.53	1.43	1.35	1.28	1.21	1.17	1.11	1.03	0.87	0.75
50	1.82	1.79	1.75	1.67	1.61	1.54	1.44	1.35	1.28	1.22	1.17	1.12	1.03	0.87	0.75
60	1.84	1.81	1.76	1.68	1.61	1.55	1.45	1.35	1.28	1.22	1.17	1.12	1.03	0.88	0.76
70	1.85	1.82	1.77	1.68	1.62	1.55	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
80	1.86	1.83	1.78	1.69	1.62	1.55	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
90	1.87	1.83	1.78	1.69	1.62	1.56	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
100	1.88	1.84	1.78	1.69	1.62	1.56	1.45	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
200	1.91	1.85	1.78	1.70	1.63	1.56	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
300	1.92	1.86	1.79	1.70	1.63	1.56	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
[illegible]0	1.93	1.86	1.79	1.71	1.63	1.57	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76

27) When a suitable transformer has been chosen, measure the resistance of both windings. If the *measured* source resistance,

$$R_{s(m)} = R_{sec} + \frac{R_{pri}}{N^2}$$

is *less* than R_s calculated in step (8), then an external resistor,

$R_{ext}=R_s-R_{s(m)}$

must be added, see (28), to limit I_{on} to the value found in (20).

28) If an external resistor R_{ext} was found necessary in (20) or (27) to be fitted where R_s is shown to limit switch-on current to a lower level $I_{on(L)}$, its value will be,

$$R_{ext} = \frac{V_{sec(peak)}}{I_{on(L)}} - R_s$$

29) Power dissipated in R_{ext}, if used, is given by,

$P_r=[I_{t(rms)}{}^2]\times R_{ext}$

A suitable resistor should have a power rating of about twice the value of P_r for reliable operation.

30) If R_{ext} is used, the regulation of the supply can be improved by adding a shorting-out device, as recommended for the bridge rectifier circuit described my article in the September 1996 issue.

Voltage doubler design example

Finally, here is a worked example for the voltage-doubler circuit. Assume that a supply of 1000V at 100mA is required, having an acceptable ripple level of 10V rms.

1) $E_{dc(load)}$=1000V

2) $I_{dc(load)}$=100mA or 0.1A

3) $V_{r(rms)}$=10V rms

4) $V_{pri(rms)}$=240V rms

5) f=50Hz

6)
$$R_L = \frac{E_{dc(load)}}{I_{dc(load)}} = \frac{1000}{0.1} = 10\text{k}\Omega$$

7) $I_o=I_{dc(load)}$=100mA

8) Let R_s=2% of R_L, i.e.,

$$R_s = R_L \times \frac{2}{100} = \frac{10^4 \times 2}{100} = 200\Omega$$

9)
$$\frac{R_s}{R_L}\% = \frac{200}{10^4} \times 100\% = 2\%$$

10)
$$V_r\% = \frac{V_{r(rms)}}{E_{dc(load)}} \times 100\% = \frac{10}{1000} \times 100\% = 1\%$$

11) The value of X for V_r% and (R_s/R_L)%, i.e. V_r%=1 and (R_s/R_L)%=2 from **Table 1** is found to be 125.

12)
$$C = \frac{X(10^6)}{2\pi f \times R_L}\mu\text{F} = \frac{125 \times 10^6}{2\pi \times 50 \times 10^4}\mu\text{F} = \frac{125}{\pi}\mu\text{F} = 39.8\mu\text{F}$$

13) The nearest standard value above 39.8μF is 47μF, so,

$X_1=2\pi f \times C_1 \times R_L$
$=2\pi \times 50 \times 47 \times 10^{-6} \times 10^4=148$

14) From **Table 2**, the value of Y for X_1 and (R_s/R_L)%, i.e. X_1=148 and (R_s/R_L)%=2, is found to be 1.56

15)
$$V_{sec(rms)} = \frac{0.707 \times E_{dc(load)}}{Y} = \frac{0.707 \times 1000}{1.56} = 453\text{V rms}$$

16) PIV=$2.828V_{sec(rms)}$=2.828×453=1281V

17) From **Table 3**, the value of Z for $0.5X_1$ and $(R_s/0.5R_L)$%, i.e. $0.5X_1$=0.5×148=74 and $(R_s/0.5R_L)$%=2/0.5=4, is found to be 2.46.

18) $I_{(rms)}=I_o \times Z$=0.1×2.46=0.246A or 246mA

19) From **Table 4**, the value of W for $0.5X_1$ and $(R_s/0.5R_L)$%, i.e. $0.5X_1$=74 and $(R_s/0.5R_L)$%=4, is found to be 7.02. As a result, $I_{(peak)}=I_o \times W$=0.1×7.02=0.702A, or 702mA.

20)
$$I_{on} = \frac{V_{sec(peak)}}{R_s} = \frac{1.414 \times V_{sec(rms)}}{R_s} = \frac{1.414 \times 453}{200} = 3.2\text{A}$$

21) Diode ratings required:

PIV (V_{RRM})=1281V
I_{on} (I_{FSM})=3.2A
I_o ($I_{F(AV)}$)=0.1A

For safe operation, two *BYX38-1200* type diodes should be used in series for each of the two diodes in the voltage doubler circuit.

22)
$$I_{c(rms)} = \sqrt{[I_{rms}^2] - [I_{dc(load)}^2]} = \sqrt{0.246^2 - 0.1^2} = \sqrt{0.0605 - 0.01} = \sqrt{0.0505} = 0.225\text{A}$$

23) Capacitor ratings required, $C_A=C_B=C$
C=capacitance=47μF
$V_{sec(peak)}=V_{DC(wkg)}=\sqrt{2}\times453$=641V
$I_{c(rms)}$=ripple current=0.225A

Table 3. To Find the value for Z.

0.5*X*	**$(R_s/0.5R_L)$%**										
	0.02	**0.05**	**0.1**	**0.2**	**0.5**	**1.0**	**2**	**5**	**10**	**30**	**100**
1	1.80	1.80	1.79	1.79	1.79	1.78	1.77	1.77	1.73	1.70	1.66
2	2.03	2.02	2.01	2.00	1.99	1.98	1.97	1.96	1.89	1.77	1.67
3	2.19	2.17	2.16	2.14	2.13	2.11	2.10	2.03	1.95	1.79	1.67
4	2.32	2.30	2.28	2.26	2.24	2.22	2.17	2.08	1.98	1.80	1.68
5	2.43	2.40	2.36	2.32	2.27	2.23	2.19	2.10	2.01	1.82	1.68
6	2.50	2.48	2.46	2.44	2.42	2.40	2.28	2.13	2.04	1.83	1.68
7	2.58	2.53	2.51	2.49	2.47	2.45	2.31	2.16	2.05	1.84	1.68
8	2.66	2.63	2.61	2.60	2.58	2.50	2.35	2.17	2.06	1.84	1.68
9	2.73	2.70	2.68	2.66	2.64	2.57	2.38	2.18	2.07	1.85	1.68
10	2.80	2.78	2.75	2.73	2.70	2.62	2.40	2.19	2.08	1.86	1.68
20	3.30	3.20	3.17	3.15	2.83	2.82	2.53	2.26	2.12	1.88	1.68
30	3.64	3.50	3.40	3.29	3.05	2.89	2.59	2.30	2.15	1.90	1.68
40	3.91	3.72	3.55	3.40	3.13	2.92	2.62	2.32	2.16	1.90	1.68
50	4.08	3.87	3.68	3.48	3.22	2.93	2.64	2.33	2.17	1.91	1.68
60	4.23	3.97	3.78	3.55	3.25	2.94	2.66	2.35	2.18	1.91	1.68
70	4.35	4.03	3.87	3.60	3.27	2.95	2.67	2.36	2.18	1.91	1.68
80	4.45	4.10	3.94	3.65	3.30	2.96	2.68	2.36	2.18	1.91	1.68
90	4.52	4.18	3.98	3.67	3.31	2.97	2.68	2.37	2.19	1.91	1.68
100	4.62	4.23	4.02	3.69	3.32	2.98	2.69	2.37	2.19	1.91	1.68
200	5.03	4.60	4.27	3.86	3.37	3.00	2.69	2.38	2.19	1.91	1.68
300	5.20	4.79	4.33	3.88	3.38	3.00	2.69	2.38	2.19	1.91	1.68
400	5.35	4.86	4.37	3.88	3.38	3.00	2.70	2.38	2.19	1.91	1.68
500	5.45	4.90	4.38	3.89	3.38	3.00	2.70	2.39	2.19	1.91	1.68
600	5.51	4.03	4.38	3.89	3.39	3.00	2.70	2.39	2.19	1.91	1.68
700	5.60	4.96	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
800	5.67	4.98	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
900	5.70	4.99	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
1000	5.75	5.00	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68

24) $I_{t(rms)}=\sqrt{2}\times I_{rms}=\sqrt{2}\times 0.246=0.348A$, or 348mA

25) $T_{VA}=V_{sec(rms)}\times I_{t(rms)}=453\times 0.348 =158VA$

26) Mains transformer ratings required,

T_{VA}	volt/ampere rating	158VA
$V_{pri(rms)}$	primary winding	240V
$V_{sec(rms)}$	secondary winding	453V
$I_{t(rms)}$	secondary current	348mA

I hope that the four simple procedures for designing the four key types of rectifier circuits that I have described over the past few months will prove as useful to you as they have to me over the years. ■

Designing reliable rectifiers

Ray Fautley has produced three earlier articles along similar lines to this one, covering:

Full-wave bridge rectifier
September 1996 issue, p. 691
Half-wave rectifiers
December 1996 issue, p. 980
Full-wave rectifier with centre tap
February 1997 issue, p. 133

Table 4. To Find the value for W.

0.5X	(R_s/0.5R_L)% 0.02	0.05	0.1	0.2	0.5	1.0	2	5	10	30	100
1	3.70	3.70	3.70	3.64	3.62	3.60	3.60	3.59	3.58	3.57	3.46
2	4.60	4.57	4.55	4.53	4.52	4.50	4.28	4.20	4.08	3.72	3.51
3	5.50	5.40	5.33	5.30	5.20	5.10	5.00	4.67	4.33	4.00	3.55
4	6.20	6.17	6.13	6.10	6.00	5.98	5.45	5.20	4.95	4.05	3.57
5	7.30	6.95	6.90	6.85	6.80	6.75	6.51	5.60	5.00	4.10	3.62
6	8.00	7.90	7.70	7.60	7.50	7.30	6.90	5.84	5.09	4.19	3.63
7	8.70	8.55	8.50	8.30	8.10	7.82	7.30	6.00	5.10	4.22	3.64
8	9.60	9.50	9.35	9.00	8.50	8.20	7.69	6.15	5.14	4.23	3.64
9	10.3	9.80	9.60	9.50	9.10	8.55	7.72	6.23	5.21	4.25	3.65
10	10.9	10.7	10.5	10.1	9.50	8.64	7.74	6.30	5.28	4.26	3.66
20	16.0	15.0	14.4	13.0	11.1	9.44	7.83	6.47	5.29	4.27	3.66
30	19.7	18.0	16.3	14.3	11.7	9.60	7.92	6.50	5.31	4.27	3.66
40	21.9	20.0	17.3	14.7	12.1	9.64	8.01	6.51	5.33	4.28	3.66
50	23.7	20.8	18.2	15.2	12.2	9.70	8.10	6.51	5.34	4.28	3.66
60	24.9	21.1	18.5	15.4	12.3	9.77	8.12	6.51	5.34	4.29	3.66
70	25.9	21.4	18.9	15.6	12.4	9.84	8.14	6.51	5.34	4.29	3.66
80	26.7	21.8	19.4	15.7	12.4	9.90	8.16	6.51	5.34	4.30	3.66
90	27.5	22.2	19.5	15.8	12.5	9.93	8.18	6.51	5.34	4.30	3.66
100	28.5	22.5	19.7	15.9	12.5	9.96	8.19	6.52	5.35	4.31	3.66
200	30.5	23.0	20.0	16.3	12.6	10.0	8.19	6.52	5.36	4.31	3.67
300	31.6	23.3	20.5	16.9	12.7	10.0	8.20	6.53	5.38	4.32	3.67
400	32.8	23.5	20.9	17.0	12.7	10.0	8.20	6.54	5.40	4.32	3.67
500	33.3	23.8	21.0	17.1	12.8	10.0	8.20	6.55	5.42	4.33	3.68
600	33.8	24.0	21.1	17.2	12.8	10.1	8.20	6.56	5.44	4.33	3.68
700	34.2	24.5	21.2	17.3	12.9	10.1	8.20	6.57	5.46	4.33	3.69
800	34.4	24.9	21.4	17.4	12.9	10.1	8.20	6.58	5.48	4.33	3.69
900	34.5	25.8	21.5	17.5	13.0	10.1	8.20	6.59	5.52	4.33	3.70
1000	34.7	27.0	21.6	17.6	13.0	10.1	8.20	6.60	5.56	4.33	3.70