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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour
inside

Cylindrical cavity method to measure the complex permittivity of low-loss dielectric rods

Mesure de la permittivité complexe des barreaux diélectriques à faibles pertes par la méthode de la cavité cylindrique

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CYLINDRICAL CAVITY METHOD TO MEASURE THE COMPLEX PERMITTIVITY OF LOW-LOSS DIELECTRIC RODS

FOREWORD

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International Standard IEC 62810 has been prepared by subcommittee 46F: R.F. and microwave passive components, of IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This bilingual version (2017-12) corresponds to the monolingual English version, published in 2015-02.

The text of this standard is based on the following documents:

CDV	Report on voting
46F/242/CDV	46F/260/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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CYLINDRICAL CAVITY METHOD TO MEASURE THE COMPLEX PERMITTIVITY OF LOW-LOSS DIELECTRIC RODS

1 Scope

This International Standard relates to a measurement method for complex permittivity of a dielectric rod at microwave frequency. This method has been developed to evaluate the dielectric properties of low-loss materials in coaxial cables and electronic devices used in microwave systems. It uses the TM_{010} mode in a circular cylindrical cavity and presents accurate measurement results of a dielectric rod sample, where the effect of sample insertion holes is taken into account accurately on the basis of the rigorous electromagnetic analysis.

In comparison with the conventional method described in IEC 60556 [2][1], this method has the following characteristics:

- the values of the relative permittivity ε' and loss tangent $\tan\delta$ of a dielectric rod sample can be measured accurately and non-destructively;
- the measurement accuracy is within 1,0 % for ε' and within 20 % for $\tan\delta$;
- the effect of sample insertion holes is corrected using correction charts presented;
- this method is applicable for the measurements on the following condition:
  - – frequency: $1\ \text{GHz} \leqq f \leqq 10\ \text{GHz}$;
  - – relative permittivity: $1 \leqq \varepsilon' \leqq 100$;
  - – loss tangent: $10^{-4} \leqq \tan\delta \leqq 10^{-1}$.

2 Normative references

Void.

3 Measurement parameters

The measurement parameters are defined as follows:

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \tag{1}$$

$$\tan\delta = \varepsilon''/\varepsilon' \tag{2}$$

where ε' and ε'' are the real and imaginary parts of the complex relative permittivity ε_r.

4 Theory and calculation equations

A resonator structure used in these measurements is shown in Figure 1. A cavity, made with copper, with diameter D and height H has sample insertion holes with diameter d_2 and depth g oriented coaxially. A dielectric rod sample of diameter d_1 having ε' and $\tan\delta$ is inserted into the holes.

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[1] Figures in square brackets refer to the Bibliography.

The TM$_{010}$ mode, where the electric field component in the cavity is parallel to the sample rod, is used for the measurement. Taking account of the effect of sample insertion holes calculated on the basis of the rigorous electromagnetic field analysis, ε' and tanδ are determined from the measured values of the resonant frequency f_0 and the unloaded Q-factor Q_u. To avoid the tedious numerical calculation and make the measurements easy, the following process is taken in this measurement:

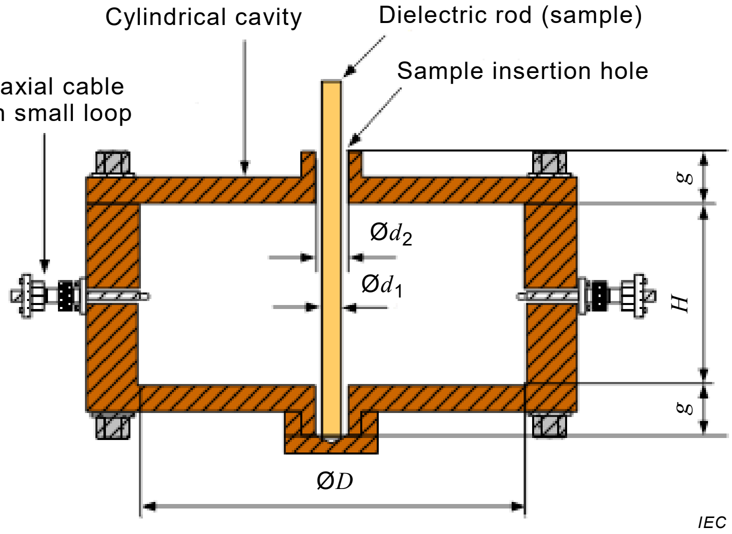


Figure 1 – Structure of a cylindrical cavity resonator

The following steps shall be taken:

1) At the first step, obtain approximate values ε_p and tanδ_p from the f_0 and Q_u values by using the simple perturbation formulas, where the effect of sample insertion holes is neglected. The subscript p denotes the calculated values using the following perturbation formulas:

$$\varepsilon_p = \frac{1}{\alpha}\frac{f_0 - f_1}{f_1}\left(\frac{D}{d_1}\right)^2 + 1 \qquad (3)$$

$$\tan\delta_p = \frac{1}{2\alpha\varepsilon_p}\left(\frac{D}{d_1}\right)^2\left(\frac{1}{Q_{u1}} - \frac{1}{Q_{u0}}\right) \qquad (4)$$

where $\alpha = 1/J_1(x_{01})^2 = 1{,}855$.

$J_n(x)$ is the Bessel function of order n of first kind and $x_{01} = 2{,}405$ is the first root of $J_0(x) = 0$. f_0 and Q_{u0} are the resonant frequency and unloaded Q-factor measured for the cavity without a sample, respectively. f_1 and Q_{u1} are ones measured for the cavity with a sample.

2) In the second step, obtain accurate values ε' and tanδ from ε_p and tanδ_p values by using the following equations with correction factors calculated based on the rigorous analysis:

$$\varepsilon' = C_1\,\varepsilon_p \qquad (5)$$

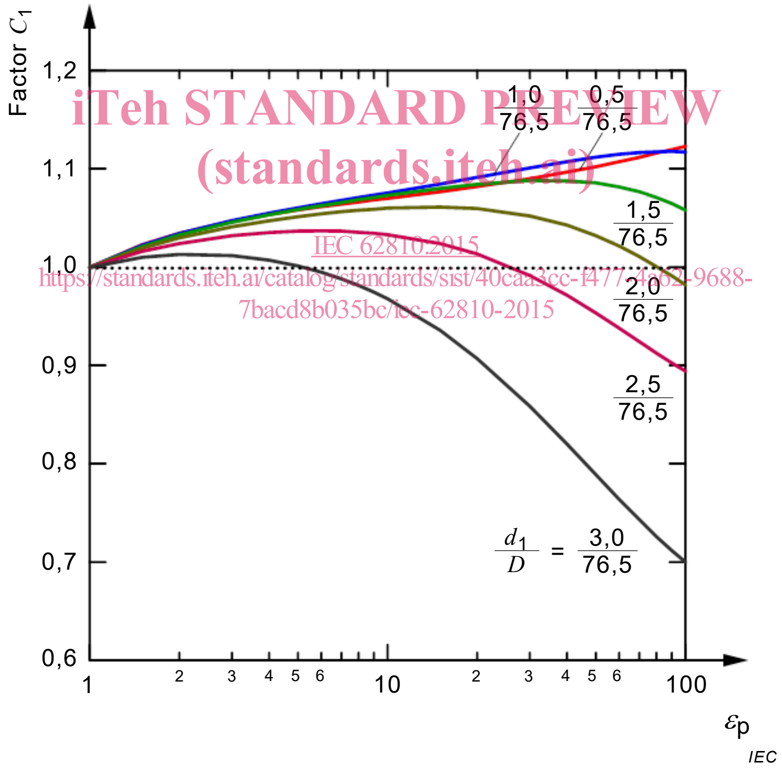
$$\tan\delta = C_2 \tan\delta_p \qquad (6)$$

where correction factors C_1 and C_2, due to the sample insertion holes and errors included in the perturbation formulas, are calculated numerically by using the Ritz-Galerkin method [3][5], as shown in Figure 2 and Figure 3, and the corresponding data are listed in detail in Table 1, 2, and 3. The missing data of C_1 and C_2 can be obtained by interpolation or extrapolation from the tables. The correction factors shown in these figures are calculated for the cavity with D = 76,5 mm, H = 20,0 mm, d_2 = 3,0 mm, and g = 10,0 mm, where the resonant frequency is about 3 GHz. C_1 is also used for a cavity having the same aspect ratios as H/D, d_2/D and g/D.

It is found from the analysis for a cavity with insertion holes which constitute a cut-off TM_{01} mode cylindrical waveguide that f_0 converges to a constant value for g>10 mm and d_2 = 3 mm. Therefore, the correction factors shown in Figure 2 and Figure 3 are applicable to a dielectric sample rod with d_1<3 mm and ε' below the value calculated by the following equation for the measured value of the resonant frequency:

$$\varepsilon' \le \left(\frac{x_{01}c}{\pi d_2 f_0}\right)^2 \qquad (7)$$

where c is the velocity of light in a vacuum (c = 2,9 979 × 108 m/s).



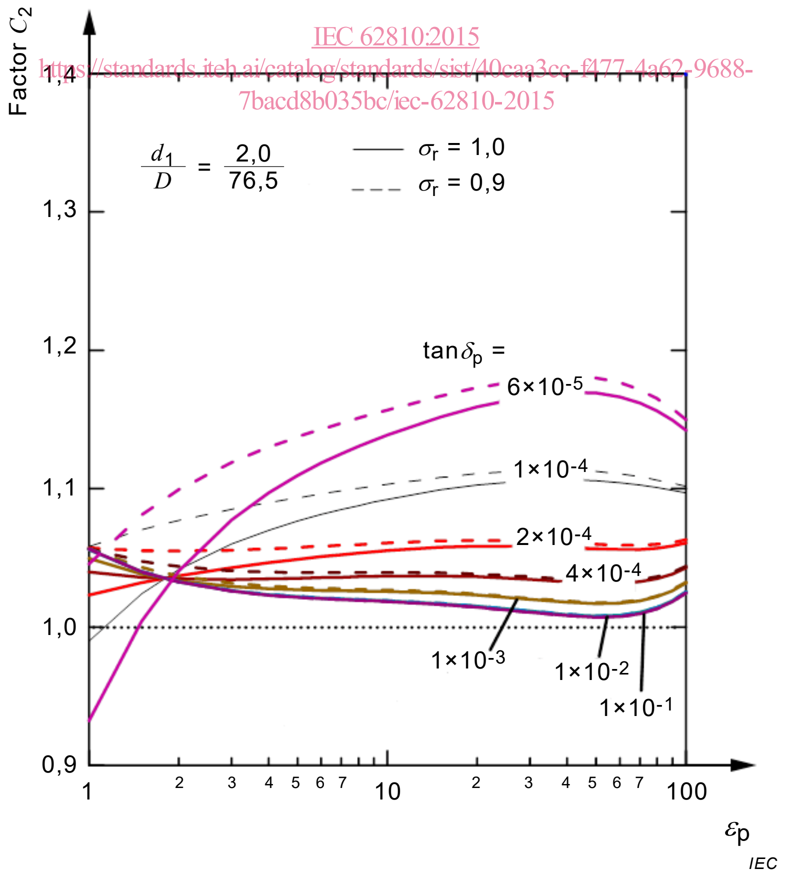
Assumptions

D	76,5 mm	d_2	3,0 mm
H	20,0 mm	g	10,0 mm

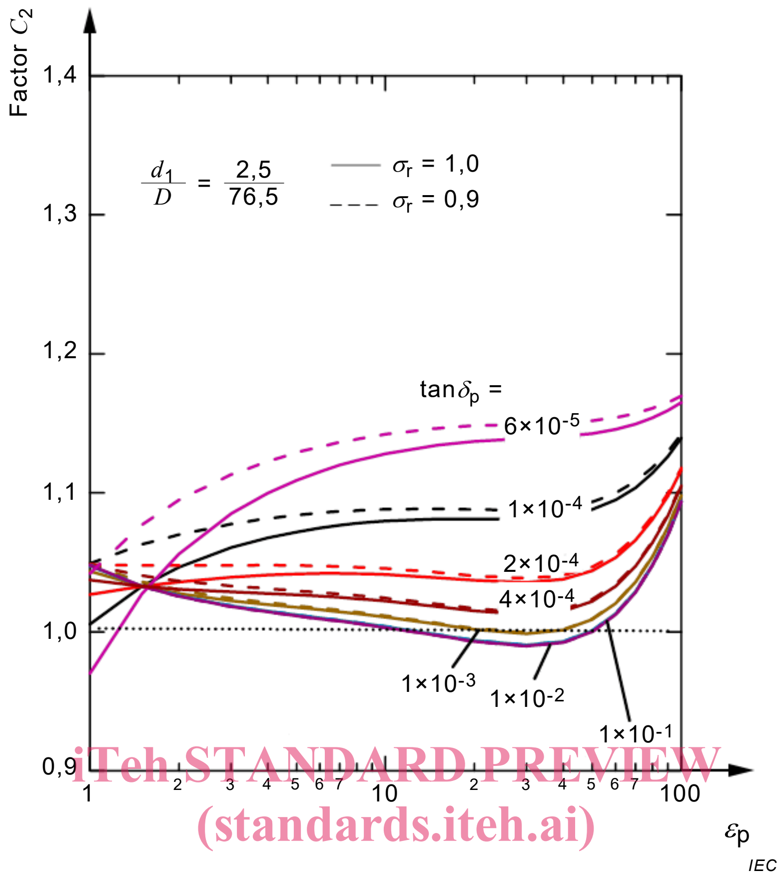
Figure 2 – Correction factor C_1 for ε'

Table 1 – Numerical values of correction factor C_1

ε_p	d_1(mm)					
	0, 5	1, 0	1, 5	2, 0	2, 5	3, 0
1	1, 000	1, 000	1, 000	1, 000	1, 000	1, 000
1, 5	1, 023	1, 022	1, 021	1, 019	1, 016	1, 010
2	1, 035	1, 034	1, 033	1, 030	1, 024	1, 013
3	1, 047	1, 047	1, 046	1, 041	1, 032	1, 012
4	1, 054	1, 055	1, 053	1, 047	1, 035	1, 007
5	1, 058	1, 060	1, 059	1, 051	1, 037	1, 001
6	1, 061	1, 064	1, 063	1, 054	1, 037	0, 995
7	1, 064	1, 068	1, 066	1, 056	1, 037	0, 988
8	1, 066	1, 071	1, 069	1, 058	1, 036	0, 981
9	1, 068	1, 073	1, 071	1, 059	1, 035	0, 975
10	1, 070	1, 076	1, 073	1, 060	1, 033	0, 968
15	1, 077	1, 085	1, 080	1, 061	1, 024	0, 936
20	1, 082	1, 091	1, 084	1, 060	1, 013	0, 907
30	1, 090	1, 101	1, 088	1, 052	0, 992	0, 859
40	1, 097	1, 107	1, 088	1, 043	0, 971	0, 820
50	1, 102	1, 112	1, 086	1, 032	0, 953	0, 789
60	1, 107	1, 115	1, 082	1, 021	0, 938	0, 764
70	1, 112	1, 117	1, 077	1, 011	0, 924	0, 743
80	1, 116	1, 118	1, 071	1, 001	0, 912	0, 726
90	1, 119	1, 118	1, 065	0, 991	0, 903	0, 712
100	1, 123	1, 117	1, 058	0, 982	0, 894	0, 700



a) Dielectric sample rod with d_1 = 2,0 mm



b) Dielectric sample rod with d_1 = 2,5 mm

Assumptions

D	76,5 mm	d_2	3,0 mm
H	20,0 mm	g	10,0 mm

Figure 3 – Correction factor C_2 for tanδ with the different values of d_1

Table 2 – Numerical values of correction factor C_2

(Dielectric sample rod with d_1 = 2,0 mm)

σ_r=0,9

ε_p	$\tan\delta_p$						
	6×10^{-5}	1×10^{-4}	2×10^{-4}	4×10^{-4}	1×10^{-3}	1×10^{-2}	1×10^{-1}
1	1, 045	1, 058	1, 057	1, 057	1, 057	1, 056	1, 056
1, 5	1, 081	1, 070	1, 055	1, 048	1, 043	1, 040	1, 040
2	1, 099	1, 077	1, 055	1, 044	1, 037	1, 033	1, 033
3	1, 119	1, 085	1, 055	1, 041	1, 032	1, 026	1, 026
4	1, 130	1, 090	1, 056	1, 040	1, 030	1, 024	1, 023
5	1, 137	1, 093	1, 057	1, 039	1, 029	1, 022	1, 021
6	1, 143	1, 096	1, 058	1, 039	1, 028	1, 021	1, 020
7	1, 147	1, 098	1, 059	1, 039	1, 028	1, 020	1, 020
8	1, 151	1, 100	1, 060	1, 039	1, 027	1, 020	1, 019
9	1, 154	1, 102	1, 060	1, 039	1, 027	1, 019	1, 019
10	1, 157	1, 103	1, 061	1, 039	1, 027	1, 019	1, 018
15	1, 167	1, 108	1, 062	1, 039	1, 025	1, 017	1, 016
20	1, 173	1, 111	1, 063	1, 038	1, 024	1, 015	1, 014
30	1, 179	1, 113	1, 062	1, 036	1, 021	1, 012	1, 011
40	1, 181	1, 114	1, 061	1, 034	1, 019	1, 009	1, 008
50	1, 180	1, 113	1, 060	1, 033	1, 018	1, 008	1, 007
60	1, 177	1, 111	1, 059	1, 033	1, 018	1, 009	1, 008
70	1, 172	1, 109	1, 059	1, 034	1, 019	1, 011	1, 010
80	1, 165	1, 106	1, 060	1, 036	1, 022	1, 014	1, 013
90	1, 158	1, 104	1, 061	1, 040	1, 027	1, 019	1, 018
100	1, 150	1, 102	1, 063	1, 044	1, 032	1, 025	1, 025

σ_r=1,0

ε_p	$\tan\delta_p$						
	6×10^{-5}	1×10^{-4}	2×10^{-4}	4×10^{-4}	1×10^{-3}	1×10^{-2}	1×10^{-1}
1	0, 932	0, 990	1, 023	1, 040	1, 050	1, 056	1, 056
1, 5	1, 004	1, 024	1, 032	1, 036	1, 038	1, 040	1, 040
2	1, 040	1, 042	1, 037	1, 035	1, 033	1, 033	1, 032
3	1, 077	1, 060	1, 043	1, 034	1, 029	1, 026	1, 026
4	1, 097	1, 070	1, 046	1, 035	1, 028	1, 023	1, 023
5	1, 110	1, 077	1, 049	1, 035	1, 027	1, 022	1, 021
6	1, 118	1, 081	1, 051	1, 036	1, 026	1, 021	1, 020
7	1, 125	1, 085	1, 052	1, 036	1, 026	1, 020	1, 020
8	1, 131	1, 088	1, 053	1, 036	1, 026	1, 020	1, 019
9	1, 135	1, 090	1, 054	1, 037	1, 026	1, 019	1, 019
10	1, 139	1, 092	1, 055	1, 037	1, 026	1, 019	1, 018
15	1, 152	1, 099	1, 058	1, 037	1, 024	1, 017	1, 016
20	1, 159	1, 103	1, 058	1, 036	1, 023	1, 015	1, 014
30	1, 167	1, 106	1, 058	1, 034	1, 020	1, 012	1, 011
40	1, 170	1, 107	1, 057	1, 033	1, 018	1, 009	1, 008
50	1, 169	1, 106	1, 056	1, 032	1, 017	1, 008	1, 007
60	1, 166	1, 104	1, 056	1, 032	1, 017	1, 008	1, 008
70	1, 162	1, 103	1, 056	1, 033	1, 019	1, 010	1, 010
80	1, 156	1, 101	1, 057	1, 035	1, 022	1, 014	1, 013
90	1, 150	1, 099	1, 059	1, 038	1, 026	1, 019	1, 018
100	1, 142	1, 097	1, 061	1, 043	1, 032	1, 025	1, 025

Table 3 – Numerical values of correction factor C_2

(Dielectric sample rod with d_1 = 2,5 mm)

σ_r=0,9

ε_p	$\tan\delta_p$						
	6×10^{-5}	1×10^{-4}	2×10^{-4}	4×10^{-4}	1×10^{-3}	1×10^{-2}	1×10^{-1}
1	1, 042	1, 049	1, 049	1, 048	1, 048	1, 048	1, 048
1, 5	1, 077	1, 063	1, 048	1, 040	1, 036	1, 033	1, 033
2	1, 095	1, 070	1, 048	1, 037	1, 030	1, 026	1, 026
3	1, 113	1, 078	1, 048	1, 033	1, 024	1, 019	1, 018
4	1, 123	1, 081	1, 048	1, 031	1, 021	1, 015	1, 014
5	1, 129	1, 084	1, 048	1, 030	1, 019	1, 012	1, 012
6	1, 133	1, 086	1, 047	1, 028	1, 017	1, 010	1, 009
7	1, 136	1, 087	1, 047	1, 027	1, 015	1, 008	1, 008
8	1, 139	1, 087	1, 047	1, 026	1, 014	1, 007	1, 006
9	1, 141	1, 088	1, 046	1, 025	1, 013	1, 005	1, 004
10	1, 142	1, 088	1, 046	1, 024	1, 011	1, 004	1, 003
15	1, 146	1, 088	1, 043	1, 020	1, 006	0, 998	0, 997
20	1, 148	1, 088	1, 040	1, 017	1, 002	0, 994	0, 993
30	1, 150	1, 088	1, 039	1, 014	0, 999	0, 991	0, 990
40	1, 150	1, 089	1, 041	1, 016	1, 002	0, 993	0, 992
50	1, 152	1, 094	1, 047	1, 023	1, 009	1, 001	1, 000
60	1, 154	1, 100	1, 056	1, 034	1, 021	1, 013	1, 012
70	1, 157	1, 108	1, 068	1, 048	1, 036	1, 029	1, 028
80	1, 161	1, 118	1, 083	1, 065	1, 055	1, 048	1, 048
90	1, 165	1, 130	1, 100	1, 084	1, 075	1, 070	1, 069
100	1, 170	1, 142	1, 118	1, 106	1, 098	1, 094	1, 094

σ_r=1,0

ε_p	$\tan\delta_p$						
	6×10^{-5}	1×10^{-4}	2×10^{-4}	4×10^{-4}	1×10^{-3}	1×10^{-2}	1×10^{-1}
1	0, 970	1, 006	1, 027	1, 037	1, 044	1, 048	1, 048
1, 5	1, 027	1, 033	1, 033	1, 033	1, 033	1, 033	1, 033
2	1, 056	1, 046	1, 036	1, 031	1, 028	1, 026	1, 026
3	1, 085	1, 060	1, 039	1, 029	1, 022	1, 019	1, 018
4	1, 100	1, 068	1, 041	1, 028	1, 020	1, 015	1, 014
5	1, 109	1, 072	1, 042	1, 027	1, 018	1, 012	1, 012
6	1, 115	1, 075	1, 042	1, 026	1, 016	1, 010	1, 009
7	1, 120	1, 077	1, 042	1, 025	1, 014	1, 008	1, 008
8	1, 123	1, 078	1, 042	1, 024	1, 013	1, 007	1, 006
9	1, 126	1, 079	1, 042	1, 023	1, 012	1, 005	1, 004
10	1, 128	1, 080	1, 041	1, 022	1, 011	1, 004	1, 003
15	1, 134	1, 081	1, 039	1, 018	1, 006	0, 998	0, 997
20	1, 137	1, 081	1, 037	1, 015	1, 002	0, 994	0, 993
30	1, 139	1, 081	1, 035	1, 012	0, 999	0, 990	0, 990
40	1, 141	1, 083	1, 038	1, 015	1, 001	0, 993	0, 992
50	1, 143	1, 088	1, 044	1, 022	1, 009	1, 001	1, 000
60	1, 146	1, 095	1, 054	1, 033	1, 021	1, 013	1, 012
70	1, 150	1, 104	1, 066	1, 047	1, 036	1, 029	1, 028
80	1, 154	1, 114	1, 081	1, 064	1, 054	1, 048	1, 048
90	1, 159	1, 126	1, 098	1, 084	1, 075	1, 070	1, 069
100	1, 165	1, 139	1, 116	1, 105	1, 098	1, 094	1, 094