Spectrum Analysis

Fundamentals

Definitions

and

Functionalities

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Signal Analysis

Signals in Time- and Frequency domain

Electrical signals can be analysed both in time- and frequency domain. Both presentations are completely different, yet mathematically equivalent. In time domain an oscilloscope is used, in frequency domain a spectrum analyser.

Spectrum Analyser

A measuring instrument designed to graphically present the energy distribution of an electrical signal as a function of frequency

Types of Spectrum Analysers

Spectrum Analysers can be distinguished in:

- Real Time Analysers
  using a bank of filters, connected in parallel
- FFT (Digital) Analysers
- Swept-tuned Spectrum Analysers
  - Front-end principle
  - Superheterodyne principle

Superheterodyne analysers are the most common ones in the RF field

Frequency Range Classifications / Market Shares

LF / Audio	**< 100 kHz/ 1 MHz**	**see FFT**

UHF / RF	**< 3 GHz**	**40 %**
Semi-Microwave	**< 6 / 8 GHz**	**10 %**
Microwave	**< 26 / 32 GHz**	**40 %**
mm - Wave	**> 40 / 50 GHz up to 325 GHz with external mixers**	**10 %**

Spectrum Analysers are available since about 50 years. They have changed from measuring instruments for specialists to universal usable precise measuring tools for abundant applications with great operation comfort .

Comparison

Oscilloscope / Spectrum Analyser

Features	*Oscilloscope*	*Spectrum Analyser (Superheterodyne)*
Frequ. Range	DC ... 1 GHz	10 Hz ... 325 GHz
Time Base Error	1 % ...1 ppm	-
Frequ. Error	-	5 % ... 1 ppm
Frequ. Resolution	-	1 Hz ... 10 MHz
Amplitude Range	µV ... 100 V	nV ... 100 V
M Ohm Input	mV ... 100 V	µV ... 100 V
50 Ohm Input	µV ... 10 V	nV ... 10 V
Level Display	lin 30... 40 dB	log 80 ...110 dB
Level Error	2 ... 30 %	lin < 2 ... 20 % log < 1... 3 dB

RF Spectrum Analyser

- Superheterodyne principle -

Application as:

Selective Power Meter
Selective Voltmeter
Frequency Counter
Modulation Analyser
Adjacent Channel Meter
Distortion Meter
Noise Gain Analyser
Radio Monitor

with tracking generator:

Scalar Network Analyser
VSWR Meter

Spectrum Analyser Definitions and Terms

Center frequency -	frequency at the center of a span, corresponds to the center of the screen
Frequency span -	a selected frequency range across the display, determining the horizontal axis scale ; difference between start and stop frequency
Span linearity -	accuracy of the horizontal axis of the display
Frequency resolution -	ability to separate closely spaced spectral components; determined by RBW and bandwidth selectivity
Sweep time -	the time it takes the local oscillator to tune across the selected span
Reference level -	calibrated vertical position on the display (top grid line), used as a reference for amplitude measurements

Sensitivity - Noise floor	Analyser's capability to detect small signals. Limited by the inherent average noise, thermal noise and noise resulting from the active elements. Sensitivity is a function of the resolution bandwidth. A decade decrease in bandwidth results in 10 dB lower noise level
Optimum input level -	refers to the signal level into the input mixer generating minimum distortion products
Maximum input level -	damage level of the analyser front-end; either burn-out level of the mixer or the RF input attenuator
Flatness -	displayed amplitude variation within the tuned frequency range
Residual responses -	responses with no input signal connected; internal distortion
Spurious responses -	undesired responses generated in the analyser; harmonics of the input signals and non-harmonics like intermodulation and residual responses
Full span -	entire operating frequency range
Zero span -	LO remains fixed at a given frequency; the analyser becomes a fixed-tuned receiver. Used to view a demodulated signal in time domain; resolution bandwidth must be as wide as the signal bandwidth
Video filter -	a post-detection low pass filter, with its bandwidth smaller than the resolution bandwidth, the trace is smoothed
LO feedthrough -	internal signal at 0 Hz (LO frequency = first IF)
External mixer -	used for frequency range extension, e.g. above 26 GHz; LO (and mixer bias) signal is required
Preselector -	a tunable band pass filter (bandwidth 20-40 MHz), typically used above 500 MHz - made by Yttrium-Iron-Garnet (YIG) - ; eliminates multiple signals, image responses, harmonics and improves dynamic range with a microwave spectrum analyser. Also used with fixed BP filters (CISPR ranges) for EMI applications

Harmonic mixing - a technique used to extend the analysers frequency range. Mixing is accomplished with the harmonics (N = harmonic number) of the LO

Application Areas

● **Mobile Communication**	● **TV Sat /Video**
● **EMI / EMS**	● **CATV**
● **Broadcasting**	● **Radar**
● **ISM**	o **Sat. Communication**
● **Microwave Links**	o **Universiti./Education**
o **Navigation / Avionics**	o **Meteorology**
o **Telemetry**	o **Radio Astronomy**
o **Spectroscopy**	

Market Areas

◆ **Manufacturing**	◆ **Research & Developm.**
◆ **Engineering**	◆ **Quality Assurance**
◆ **Service / Installation**	◆ **Maintenance**

Typical Applications

Frequency selective Observation and Measurement of real and spurious Signals

Distortion and Harmonics

Signal Sources Frequency Stability

Parameters of (spurious) Modulation

Frequency Monitoring / Field Strength

TDMA signals (Bursts) in Time domain

Bandwidth Measurements of modulated Signals

Frequency Response Measurements (with T. Gen.)

Interference / Susceptibility / Emission

Signal identification (Demodulation with speaker)

Measurement Parameters

- **Frequency / Drift**
- **Power / Attenuation / Ratio**
- **Harmonic Power**
- **Intermodulation Distortion**
- **Modulation Parameters**
- **Noise / Signal-Noise-Ratio**
- **Phase Noise**

Main Parameters

Center Frequency

Frequency Span

Resolution Bandwidth

Reference Level

Sweep Time

RF Attenuator

Critical Specifications

Frequency Stability

Resolution Bandwidth

Residual FM

Phase Noise

Noise Floor / Sensitivity

Dynamic Range
displayed, usable, spurious-free

Sweep Time

Functional principle

The input signal, fed through a low pass filter and RF attenuator, is mixed with an time varying local oscillator signal. In general there are two further IF mixer stages and after an IF amplifier the signal is fed through an bandpass filter (resolution filter) with a constant center frequency and a constant, selectable bandwidth. Finally a logarithmic amplifier, the detectors and the display follows. The RF input attenuator attenuates the input signal to a level, that is optimum for the mixer; the low pass filter limits the spectrum for the mixer and suppresses the IF feedthrough and oscillator responses.

Noise / Phase Noise

Using a Spectrum Analyser for direct phase noise measurements of a device under test, following corrections have to be made:

Resolution bandwidth RBW to Equivalent Noise bandwidth NBW for Gaussian type filters:

correction factor
NBW = 1,1 x RBW = -0,8 dB

correction factor for peak detection
1,128 = 1,05 dB

correction factor for the logarithmic amplifier
1,4 = 1,45 dB

Total correction factor : 1,7 dB

This correction is done automatically in today's Analysers

The phase noise of the DUT should be at least 6 dB higher than the Analyser noise floor

Residual FM of the Spectrum Analyser should be negligible

Normalization to 1 Hz bandwidth is made

Noise Power Density [dBm/Hz] = noise level (e.g. marker) + correction factor - 10 log RBW(Hz) / 1 Hz

Example: noise level at RBW = 1 kHz --> -60 dBm

NPD ===> - 88,3 dBm/Hz

For SSB phase noise the marker difference between signal peak and distance from carrier is used instead of the signal level.

Sweep Time

Tuning speed of the local oscillator across the selected frequency range. Fastest speed for calibrated measurements is a function of the resolution filter settling time. The smaller the RBW, the longer the sweep time.

Formula: $T_{min} = K \times Span / RBW^2$

T_{min} = minimum sweep time
K = factor depending on the resolution filter type

Today's analysers offer a coupled mode. Depending on a selected frequency span, the resolution filter, video bandwidth and sweep time are selected automatically for optimum operation, even depending on the input signal type.
With digital filters - narrow resolution - the sweep time depends linear from the RBW.

Noise floor / Sensitivity / Noise figure

Thermal noise of a resistor at room temperature in a 1 Hz bandwidth is:

$$4 \times 10^{-21} \text{ W/Hz} = -174 \text{ dBm}$$

at 50 Ohm voltage is:

$$4{,}5 \times 10^{-10} \text{ V} = -67 \text{ dB}\mu\text{V}$$

Comparing the noise floor of Spectrum Analysers we have to consider, that it is specified for a certain resolution bandwidth. If for example the noise floor is -140 dBm at 10 Hz RBW, it is -120 dBm at 1 kHz resolution bandwidth. The analyser input noise figure is easy to calculate from above equation:

$$174 \text{ dBm} - 150 \text{ dBm/ Hz} = 24 \text{ dB}$$

High-end analysers offer a noise figure of about 12 dB.

IF Filter Resolution Bandwidth (RBW)

Filter bandwidth is specified for an attenuation of 3 dB or 6 dB.
Selectivity of a filter is specified by its Shape factor, defining the slope of the filter skirt (BW_{60} / BW_{3})

Definition of Shape Factor

The ideal rectangular filter has a Shape factor of 1,
Gaussian filters theoretically 4,5; usual Analyser filters have a shape factor of 12...15 (4-pole) or 10...12 (5-pole).

Relationship Span, Amplitude and Resolution Bandwidth:

With a Filters Shape factor of 15 : 1 two signals whose amplitudes differ by 60 dB must differ in frequency by 7,5 times the IF bandwidth before they can be distinguished separately.

Intermodulation Distortion / Intercept Point

When an active device is sufficiently driven by two or more signals, Intermodulation (IM) Distortion Products are generated.
Intercept Points are the theoretical points, at which the fundamental (wanted) signals and the distortion products have equal amplitudes.

Calculating Intercept Points requires knowledge of

N	=	order of the distortion product (2nd or 3rd)
S	=	input drive level [dBm]
IMD	=	desired or specified suppression of intermodulation products [dB]

Equation: $IP = S - IMD / (N-1)$

IP = Intercept Point in dBm

Dynamic range due to intermodulation:

$$D_2 = H + 1/3\ (S - H - E)$$

$$D_3 = T + 2/3\ (S - T - E)$$

E = Noise floor
H = 2nd order intermodulation
T = 3rd order intermodulation

Example:

with E = -135 dBm, T = 70 dB, S = - 30 dBm

$$D_3 = 93{,}3 \text{ dB}$$

1 dB Compression point

The 1 dB compression point is the level, at which the actual gain is 1 dB lower than the nominal gain. It defines the dynamic range limit too.
This point is some 10 dB below the TOI (IP_3). Typical values for Spectrum analysers are -10 ... + 10 dBm.

Dynamic range and distortion

Distortion specification define the level of intermodulation products or second harmonics produced relative to a specific level of signal input, e.g. -30 dBm or -10 dBm at the mixer.

Because the IM products are 3rd order, they will drop by 30 dB for every 10 dB drop in input signal level. If the input level is decreased until the IM products are just at noise floor, then the dynamic range will be maximized.

Detector types

4 types of detectors are used with Spectrum Analysers, normal (pos./neg.), positive peak, negative peak and sample detectors. E.g. sample detector is used with averaging, negative peak detector with TV Cross Modulation measurements.
Today a further detector is in use, a ‘rms’ detector.

Amplitude Level Errors
Error Sources

Frequency Response (mixer and RF attenuator)*
IF Amplifier *
Resolution Bandwidth Filter Switching *
Log. Amplifier Linearity *
Scale fidelity
Range switching
internal Calibrator Source
Temperature Effects

Worst Case / Sum of all errors :	+- 4 dB
Root Mean squared errors:	+- 2,5 dB

The * marked Parameter can be compensated by internal calibration routines (CAL).
With defined Setup conditions - some parameters fixed - a total amplitude error of less than +- 1.0 dB can be achieved, allowing more tolerance for a DUT.

Signal-to-Noise Level Error

When measuring a sinusoidal signal being equal in level to the noise floor, the indication with average detection mode will be 3 dB above noise floor, which is 3 dB too high. Thus for a S/N ratio of 0 dB the error is 3 dB.

Signal / Noise Ratio (dB)	*Average detector Indication*	*Average detector error*	*Peak detector Indication*	*Peak detector error*
0	3,01	3,01	13,15	13,15
5	6,19	1.19	14,52	9,52
10	10,41	0,41	16,53	6,53

Video Filter

In the video section of the analyser a low-pass filter is used behind the detector, in order to smooth the broad noise floor indication. The smaller the filter the longer the sweep time. In the coupled mode the bandwidth is selected in relation to the resolution bandwidth. For sinusoidal signals the ratio for the resolution- and video filter is 1 : 1, for pulsed signals or in time domain (zero span) the video filter has to be selected as broad as possible. For noise signals it should be about 10 times smaller than the resolution filter.

Delayed Sweep

Delayed sweep is used in Time Domain - quite similar to a delayed time base in oscilloscopes - to add a delay to the triggering point and to allow 'zooming in' for detailed analysis, e. g. looking at the rising and falling edge of a burst signal. This function requires an additional high-speed A/D converter in order to get a time resolution in the order of µsec.

Gated Sweep

Gated Sweep is used in the frequency domain. A conventional Spectrum Analyser shows the *sin(x)/x* envelope of a pulse modulated signal. It requires a time-selective analysis, masking the pulse switching process, for looking at the spectral purity of a carrier. Including a gate circuit acting as a time filter, signals not corresponding to the desired time are rejected. The spectrum analyser receives the signal only when passing through the gate and thus displays results from the portion of the signal selected by the gate. It can be set to a certain position and width. Positon is set by an external trigger signal; with an internal IF trigger detector a trigger can be generated automatically from the signal to be measured. This allows analysis of burst signals to be performed., e.g. monitoring the carrier of a pulsed RF signal, the modulation spectrum of TDMA signals or a single horizontal line of a TV signal.

Power Measurements

In addition to ‘normal’ power measurements with Spectrum Analysers, e. g. using a marker for convenience, also total, average and channel power measurements can be made with modern analysers. Conventionally a power meter is used to measure transmission power. With digital mobile communication using TDMA signals, spectrum analysers offer a convenient method to measure power during burst on or off, featuring a measuring window, that allows measurement in a specified frequency or time window.

Microwave/ mm wave - Mixing

In the mm-wave frequency bands above 26 or 40 GHz external harmonic mixers are mostly used with Spectrum Analysers. The output of the external mixer is connected to the analyser input and the L.O. output of the analyser is connected to the mixer L.O. port. Since the harmonics are lower in level than the fundamental, the conversion loss increases with the number of the harmonic in use. This results in a stepwise increase in the displayed noise level for higher frequency bands.

Preselector

A preselector is a tunable band-pass filter with about 30 MHz bandwidth in a frequency range of about 2 GHz to 26 GHz, used in microwave spectrum analysers, operating with a harmonic mixing principle. It eliminates multiple and image responses, harmonics distortion and improves the dynamic range. Further advantages are:

- high level signals outside the selected frequency band are suppressed
- first LO radiation is suppressed

Disadvantages are its attenuation (6 dB), decreasing the sensitivity and deteriorating the flatness.
With RF spectrum analysers up to 2 or 3 GHz, the classic frequency concept with a first IF above the input frequency range is used with a low-pass filter at the RF input for multiple and image response suppression.

Preamplifier

One of the most important aspects of a Spectrum Analyser is its ability to measure ultra low signals. Therefore the design must be optimised to add as little noise to the measurement as possible.
Additionally it is possible to use a preamplifier to boost the signal, but amplifiers inherently add noise to the system. Beside external preamplifiers there are specially designed low noise HEMT amplifiers, positioned in the first IF stage, which can help to give some dB more measurement range with just about 2 dB noise figure.

Pseudo-Analog display

A display mode of modern Spectrum Analysers with digital display, that digitally simulates an analog display, well known from former Analysers and quite useful for evaluation of video signals. The Analyser takes several samples of the signal amplitude at each horizontal point when it sweeps across the screen. The samples are displayed as individual dots not connected to a single trace.

Occupied bandwidth (OBW) / 99 % power

with modern Analysers the bandwidth occupied by the carrier of a transmitter can be measured automatically.
Normally this bandwidth is related to 99% of the total mean carrier power. It can be measured by determining the lower (0,5% of the total power) and upper (99,5%) frequency limits. 2 markers show graphically on the display the total power, bandwidth and the signal frequency at those trace points.

Recommended Analyser setting:
SAMPLE detector, Signal in center of display with smallest span,
vertical resolution 10 dB/div.

Adjacent Channel Power (ACP)

with a bad limitation of sidebands the output spectrum of a transmitter is broadened. This may cause interference in adjacent channels.
The adjacent channel power measurement determines the power, which is transmitted into the upper and lower adjacent channels and indicates the ratio between those power values and the power in the real used channel.
With the two parameters channel spacing and channel bandwidth the power is calculated by integrating across the bandwidth.

Recommended Analyser setting:
Span at 2 x channel spacing + channel bandwidth
SAMPLE detector

Total Harmonic Distortion

you can measure a single harmonic signal or the total harmonic distortion THD as a ratio to the fundamental signal with rms values. The table shows the calculation in % or dB

dB <---> %

dB	%		dB	%
20 (40;60)	10 (1;0.1)		30 (50;70)	3,16 (0.31;0.031)
21	8,90		31	2,87
22	7,94		32	2,51
23	7,08		33	2,24
24	6,31		34	2,00
25	5,62		35	1,78
26	5,01		36	1,59
27	4,47		37	1,41
28	3,98		38	1,26
29	3,55		39	1,12

Correction factor:

dB difference	0	1	2	3	4	5	6	7	8	9
add to higher level	3,01	2,54	2,13	1,76	1,46	1,19	0,97	0,79	0,64	0,51

Modulation measurements

AM Modulation

with a Spectrum Analyser the following AM modulation parameters can be measured:

- Carrier frequency
- carrier amplitude
- modulation frequency
- % modulation

dB <---> % **% = 200 x 10 $^{-(x\ dB/20)}$**

% Modulation	Sideband level below Carrier (dB)		Sideband level below carrier (dB)	% Modulation
1	46		10	63
2	40		15	36
10	26		20	20
20	20		25	12,5
30	16,5		30	6,3
40	14		35	3,6
50	12		40	2
60	10,4		45	1,25
70	9,1		50	0,63
80	7,9		60	0,2
90	6,9		70	0,063
100	6		80	0,02

FM Modulation

We can distinguish between narrowband FM (modulation index $m < 1$), broadband ($1 < m < 10$) and ultrabroadband FM ($m > 10$).
Only the magnitude of the spectral signals are displayed, not their phase relation. The following parameters can be measured:

Carrier frequency
Frequency deviation
Carrier amplitude
Modulation frequency
Modulation index
occupied bandwidth

Phase modulation

Compared to FM the phase angle of the sinewave signal is modulated. The phase deviation remains constant, the frequency deviation is proportional with the modulation frequency and the phase deviation is increased with an amplitude increase of the modulating signal.

Pulse modulation

Following parameters can be measured:

Carrier frequency	Carrier amplitude
Repetition frequency	occupied bandwidth
Pulse width	

The repetition frequency is defined by the distance of two spectral lines, the pulse width by the distance between two zero points. Depending on the resolution bandwidth you can display a line spectrum or the envelope spectrum. Changing the pulse width results in an amplitude change and width of the envelope; the line distances remain constant. With a line spectrum display the number of lines change with the Frequency span, not with the sweep time; with the envelope spectrum display it is vice versa.

Digital Modulation Measurements

for the current measurements of digital modulated signals in mobile communication the conventional spectrum analyser needs additional functions. In order to make RF measurements according to the recommendations, the following functions and features are required:

- a fast zero span sweep speed for burst signal measurements in time domain
- a delayed sweep time to look close to the rise- and fall times
- gated sweep function with flexible triggering
- low phase noise for adjacent channel leakage measurements
- sufficient dynamic range
- occupied bandwidth measurements
- DSP's and fast A/D converters for vector analysis

demodulation and analysis of digital mobile radio signals down to single bits for modulation standards like GMSK, QPSK, pi/4DQPSK, which are used with

GSM, DCS1800, PCS1900, NADC, PDC, PHS,
DECT, CDMA and others

Results can be displayed graphically and numerically like:

In Phase / Quadrature signal	Magnitude and phase
Eye diagram	Vector diagram
Constellation diagram	demodulated bit data
Trellis diagram	Phase/frequency errors
	further error displays (with FFT in frequency domain)

additional Features

Frequency counter
for precise frequency masurements, also with delta marker

two or more trace memories and signal arithmetics

Normalisation

Window function

Autotune

Auto range

Antenna correction factors

Amplitude / frequeny offsets

Documentation / Label text

logarithmic frequency span

User define

Split screen

Limit lines / Tolerance templates with comparator

Marker Functions

Marker	**Marker -> Center**
Delta Marker	**Marker -> Reference**
Fixed Marker	**Marker -> CF Step**
1/Delta Marker	**Marker Delta -> Span**
Peak Marker	**Marker Delta -> CF**
Next Peak	**Marker Delta -> CF Step**
Next Right/Left	**Marker -> Marker Step**
Next Max/Min	**Multimarker**
Cont. Peak	**Peak List**
Min. Marker	**Next Min**
dB Down	**Signal Track**
Noise marker	

Spectrum Analyser

+

Tracking Generator

↓

Scalar Network Analyser

Features

Synchronized Operation
High Stability
High Dynamic Range
No harmonics
Precise frequency

Analyser accessories

RF cables	**Filters**
Adapters	**Couplers**
VSWR Bridges	**Terminations**
Preamplifiers	**Probes**
Antennae	**DC blocks**
Attenuators	**Ear/Head phones**

RF Connector Types and Frequency Ranges

Type	*usable up to*
BNC	2 GHz
N	12,4 GHz
N Precision	18 GHz
APC 7 (7 mm)	18 GHz
SMA	18 GHz
APC 3,5	26,5 GHz
K (2,9 mm)	40 GHz
2,4 mm	50 GHz

Microwave Frequency Bands

Standard Designation

HF	3 MHz - 30 MHz		
VHF			30 - 300 MHz
UHF			300 MHz - 1 GHz
L	1 - 2 GHz		
S	2 - 4 GHz		
C	4 - 8 GHz		
X	8 - 12 GHz		
Ku	12 - 18 GHz		
K	18 - 26,5 GHz		
A(Ka)		26,5 - 40 GHz	
U	40 - 60 GHz	Q	33 - 50 GHz
E	60 - 90 GHz	V	50 - 75 GHz
F	90 - 140 GHz	W	75 - 110 GHz
G	140 - 220 GHz	D	110 - 170 GHz
J	220 - 325 GHz		

Voltage- and power ratios in dB

dB	voltage ratio	power ratio
0	1,000	1,000
0,1	1,012	1,023
0,2	1,023	1,047
0,3	1,035	1,072
0,4	1,047	1,096
0,5	1,059	1,122
0,6	1,072	1,148
0,8	1,096	1,202
1	1,122	1,259
1,5	1,189	1,413
2,0	1,259	1,585
2,5	1,334	1,778
3	1,413	1,995
4	1,585	2,512
5	1,778	3,162
6	1,995	3,981
7	2,239	5,012
8	2,512	6,310
9	2,818	7,943
10	3,162	10,00
11	3,548	12,59
12	3,981	15,85
13	4,467	19,95
14	5,012	25,12
15	5,623	31,62
16	6,310	39,81
17	7,079	50,12
18	7,943	63,10
19	8,913	79,43
20	10,00	100,00
21	11,22	125,89
22	12,59	158,49
23	14,13	199,53
24	15,85	251,19
25	17,78	316,23
26	19,95	398,11
27	22,39	501,19
28	25,12	630,96
29	28,18	794,33
30	31,62	1.000,0
31	35,48	1.258,9
32	39,81	1.584,9
33	44,67	1.995,3
34	50,12	2.511,9
35	56,23	3.162,3

dB	voltage ratio	power ratio
36	63,10	3.981
37	70,79	5.012
38	79,43	6.310
39	89,13	7.943
40	100,00	10.000
41	112,20	12.589
42	125,89	15.849
43	141,25	19.953
44	158,49	25.119
45	177,83	31.623
46	199,53	39.811
47	223,87	50.119
48	251,19	63.096
49	281,84	79.433
50	316,23	100.000
51	354,81	125.893
52	398,11	158.489
53	446,68	199.526
54	501,19	251.189
55	562,34	316.228
56	630,96	398.107
57	707,95	501.187
58	794,33	630.957
59	891,25	794.328
60	1.000,0	1.000.000
61	1.122,0	1.258.925
62	1.258,9	1.584.893
63	1.412,5	1.995.262
64	1.584,9	2.511.886
65	1.778,3	3.162.278
66	1.995,3	3.981.072
67	2.238,7	5.011.872
68	2.511,9	6.309.573
69	2.818,4	7.943.282
70	3.162,3	10.000.000
71	3.548,1	12.589.254
72	3.981,1	15.848.932
73	4.466,8	19.952.623
74	5.011,9	25.118.864
75	5.623,4	31.622.777
76	6.309,6	39.810.717
77	7.079,5	50.118.723
78	7.943,3	63.095.734
79	8.912,5	79.432.823
80	10.000	100.000.000