DBBT
Digital Broadcasting & Broadband Technologies

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Telekomunikaciona merenja

TM P07 2018

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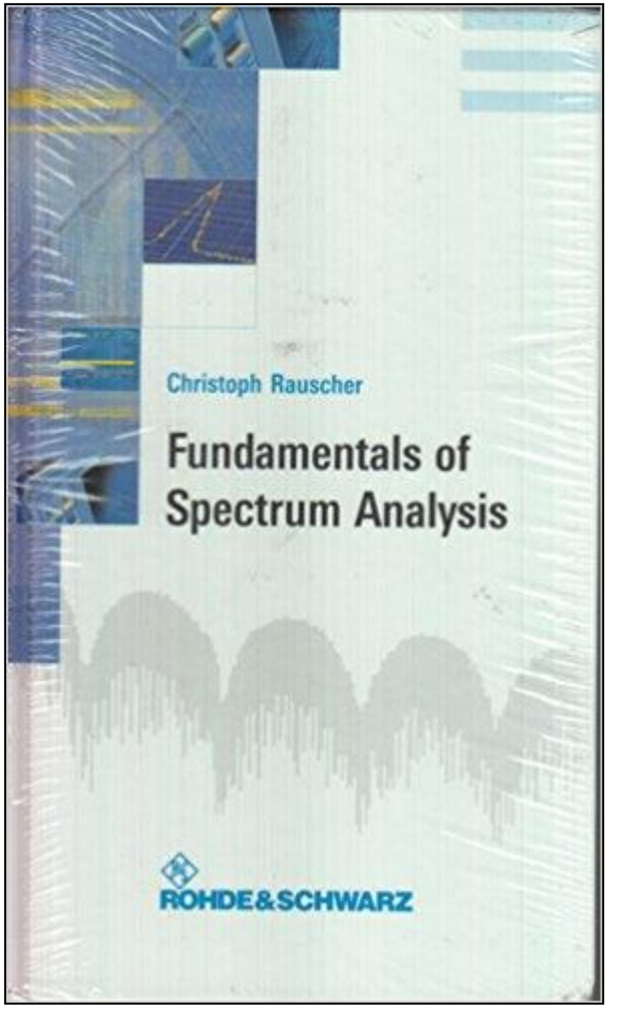
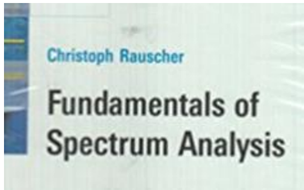
Osnove analize spektra

Rauscher C.,
Fundamentals of Spectrum Analysis,
Rohde & Schwarz, 2006

Poglavlje 5



Performanse analizatora spektra



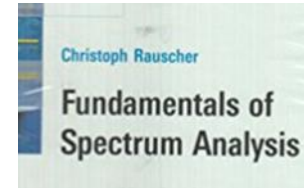
- **Sopstveni šum**
- Termički šum u prijemniku i analizatoru spektra
- Dovodi do redukcije S/N
- Sopstveni šum je mera osetljivosti analizatora spektra
- To je minimalni nivo ulaznog signala koji može da se detektuje
- Bezdimenziona mera, faktor šuma F, mreže sa dva pristupa je odnos između S/N na ulaznom i izlaznom portu mreže

S_1/N_1 = signal-to-noise ratio at the input of the network

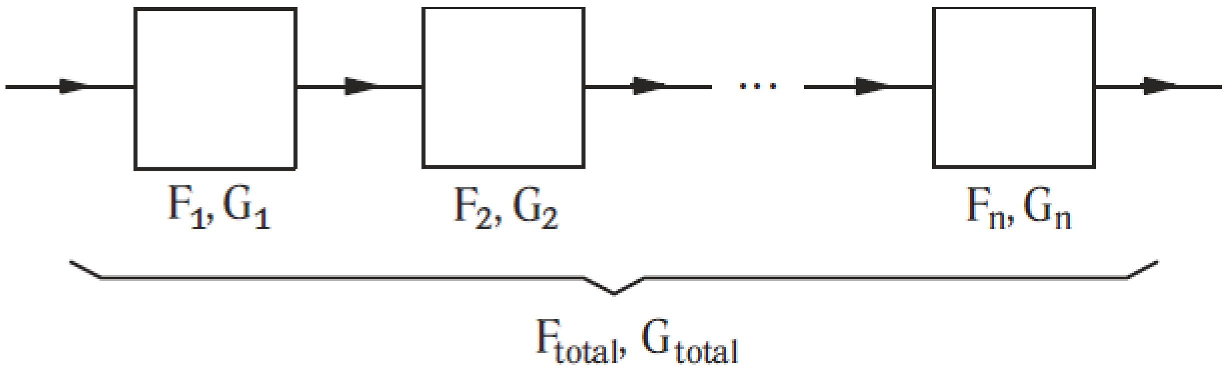
S_2/N_2 = signal-to-noise ratio at the output of the network

$$\boxed{F = \frac{S_1/N_1}{S_2/N_2}}$$

$$NF = 10 \cdot \log F$$



Kakadna veza

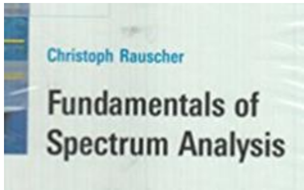


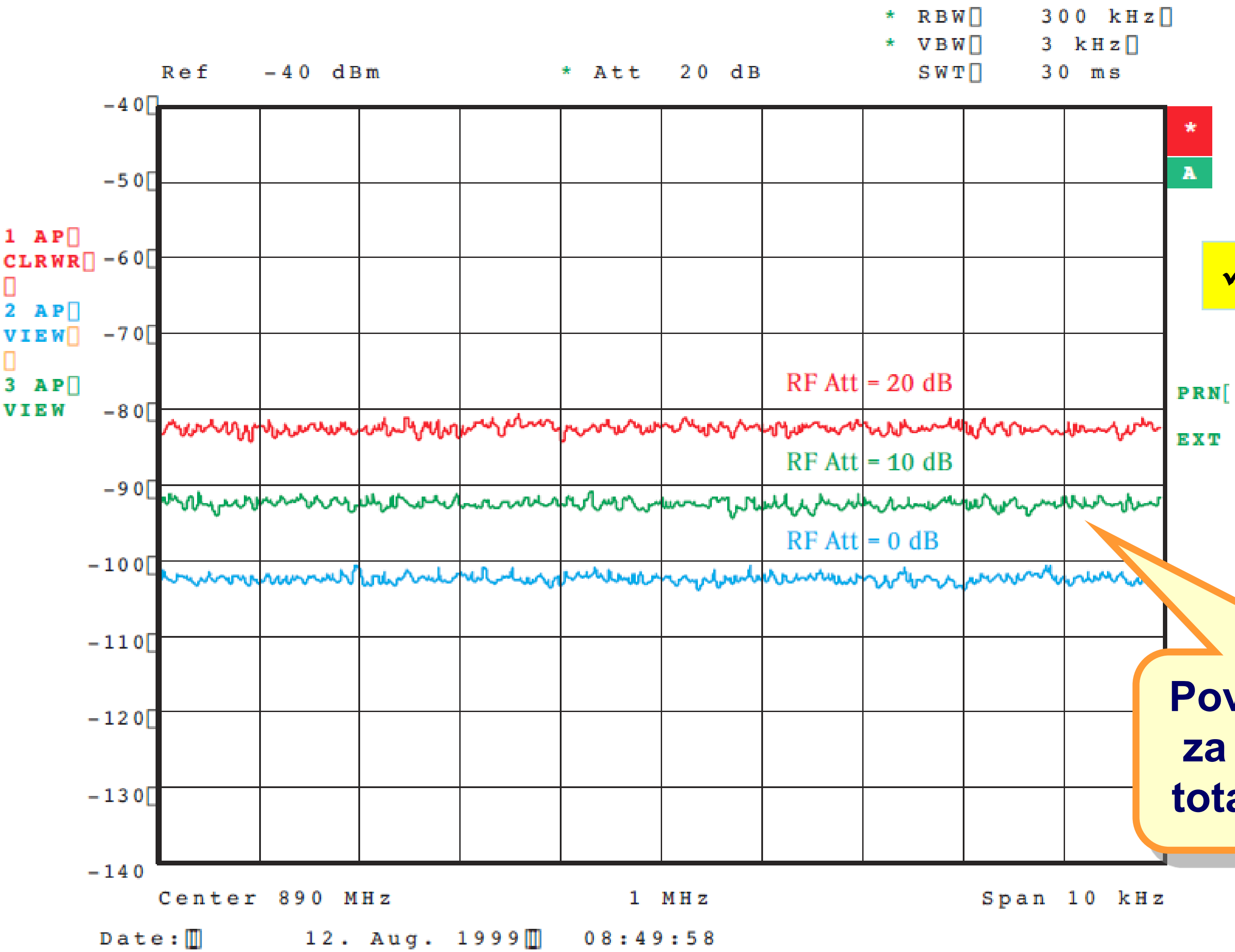
$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \ldots + \frac{F_n - 1}{\prod_{i=1}^{n-1} G_i}$$

F_i = noise factor of an individual stage

G_i = gain of an individual stage

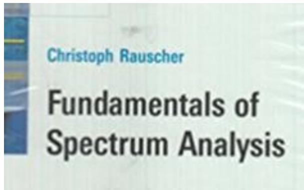
Usrednjen šum i RF slabljenje





- ✓ Gausov šum

Povećanje slabljenja za 10 dB, povećava totalni šum za 10 dB



Prikazani srednji šum

- Spektrakna gustina šuma je konstantna u opsegu

$$L_{DAN} = 10 \cdot \log \left(\frac{k \cdot T \cdot B_{N,IF}}{1 \cdot 10^{-3}\ W} \right) + NF_{SA} - 2.5\ dB$$

L_{DAN}	=	displayed average noise level, in dBm
k	=	Boltzmann's constant, $k = 1.38 \cdot 10^{-23}$ W/Hz
T	=	ambient temperature, in K
$B_{N,IF}$	=	noise bandwidth of IF filter
NF_{SA}	=	noise figure of spectrum analyzer, in dB
–2.5 dB	=	underweighting of noise by sample detector a averaging of logarithmic level values

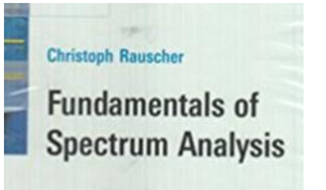
–174 dBm (1 Hz) odgovara raspoloživom termičkom šumu.

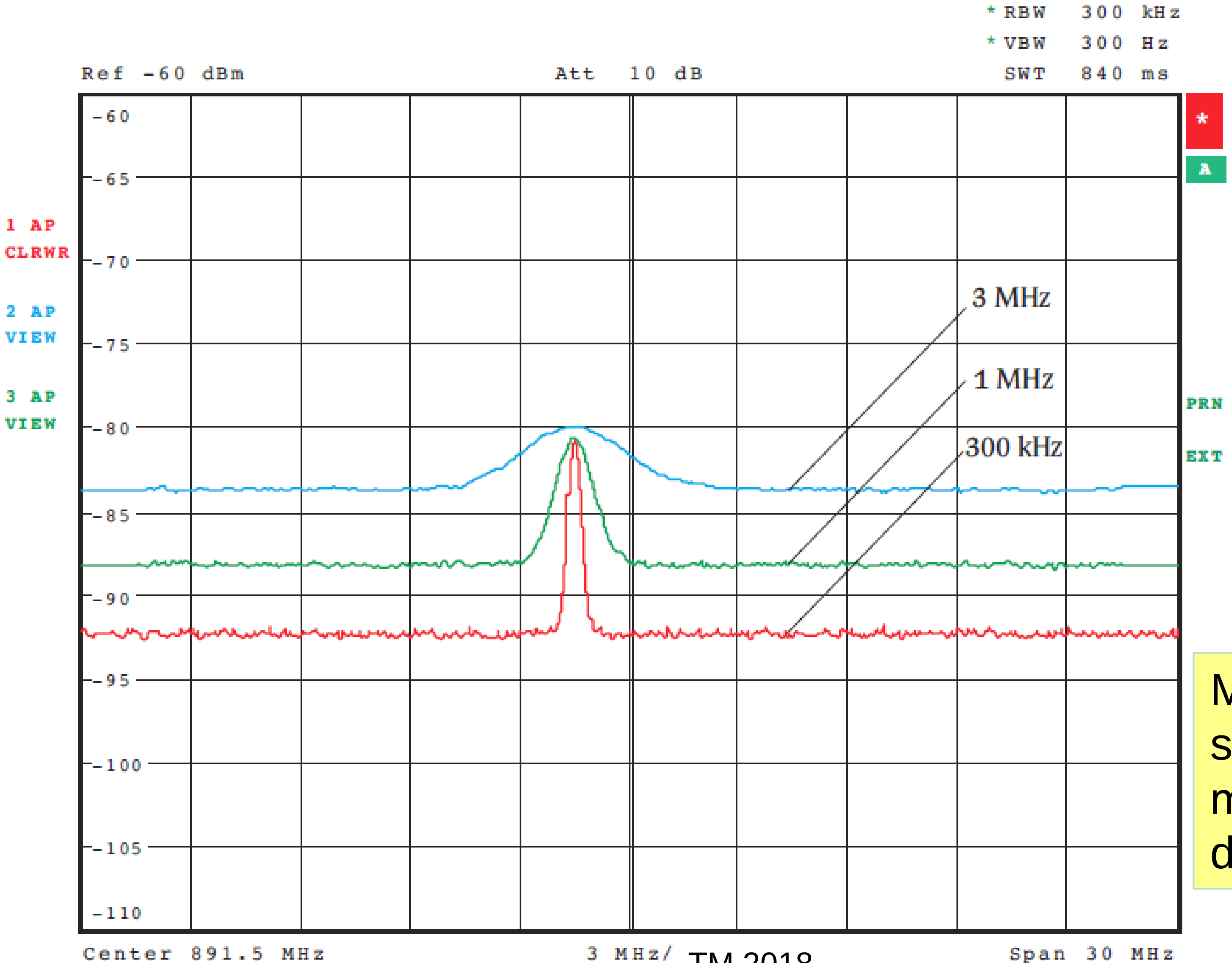
Snaga na otpornosti u opsegu 1 Hz na temperaturi 290 K

ambient temperature of 290 K,

$$L_{DAN} = -174\ dBm\ (1\ Hz) + \left(10 \cdot \log \frac{B_{N,IF}}{Hz} \right) dB + NF_{SA} - 2.5\ dB$$

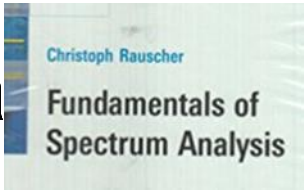
Usrednjen nivo šuma za razne opsege





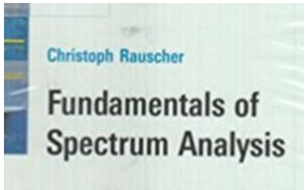
Minimalni nivo signala koji može da se detektuje

Tipične specifikacije šuma koji može da se prikaže na analizatoru spektra



usrednjavanje

Displayed average noise level	
(0 dB RF attenuation, RBW 10 Hz, VBW 1 Hz, 20 averages, trace average, span 0 Hz, termination 50 Ω)	
Frequency	
9 kHz	<–95 dBm
100 kHz	<–100 dBm
1 MHz	<–120 dBm, typ. –125 dBm
10 MHz to 7 GHz	<–138 dBm, typ. –143 dBm



Nelinearnost

- Distorzija signala od ulaza do izlaza mreže sa dva pristupa
- Samo kada se koriste aktivne komponente:
  - pojačavač, mikser - mešač

$$v_{out}(t) = G_V \cdot v_{in}(t)$$

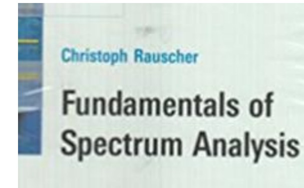
$v_{out}(t)$	=	voltage at output of network
$v_{in}(t)$	=	voltage at input of network
G_V	=	voltage gain of network

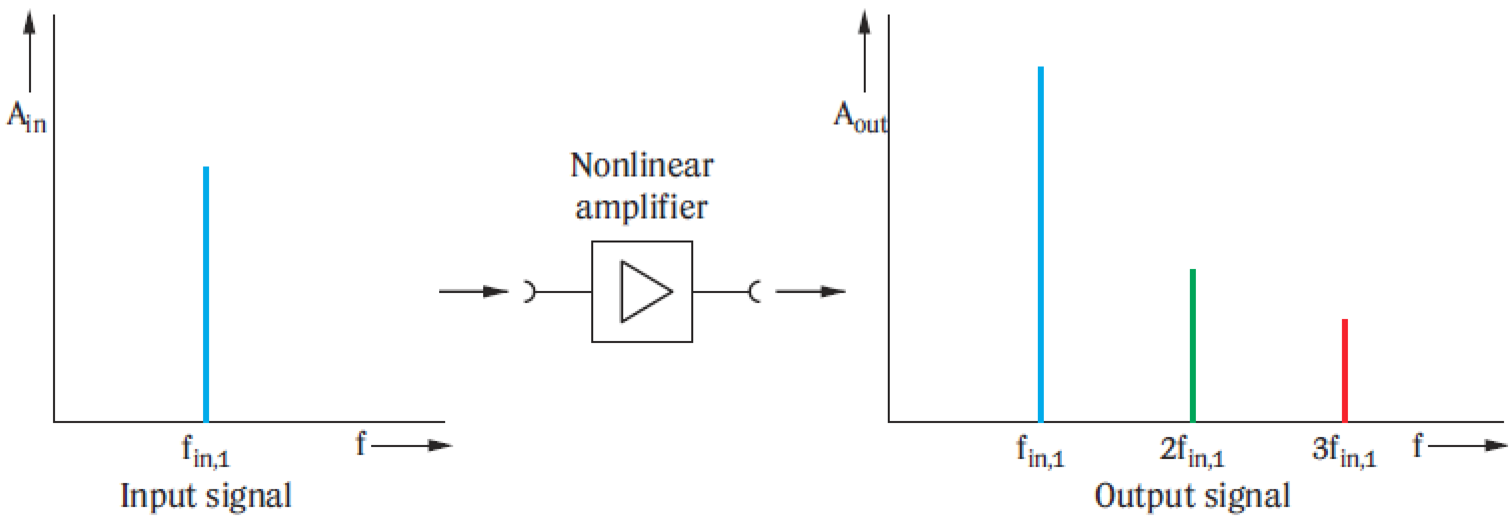
$$v_{out}(t) = \sum_{n=1}^{\infty} a_n \cdot v_{in}^n(t) = a_1 \cdot v_{in}(t) + a_2 \cdot v_{in}^2(t) + a_3 \cdot v_{in}^3(t) + \ldots$$

$v_{out}(t)$	=	voltage at output of network
$v_{in}(t)$	=	voltage at input of network
a_n	=	coefficient of nonlinear element of voltage gain

U praksi do 3. stepena

Pobuda sa 1 sinusoidom

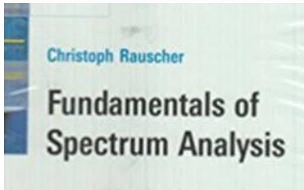


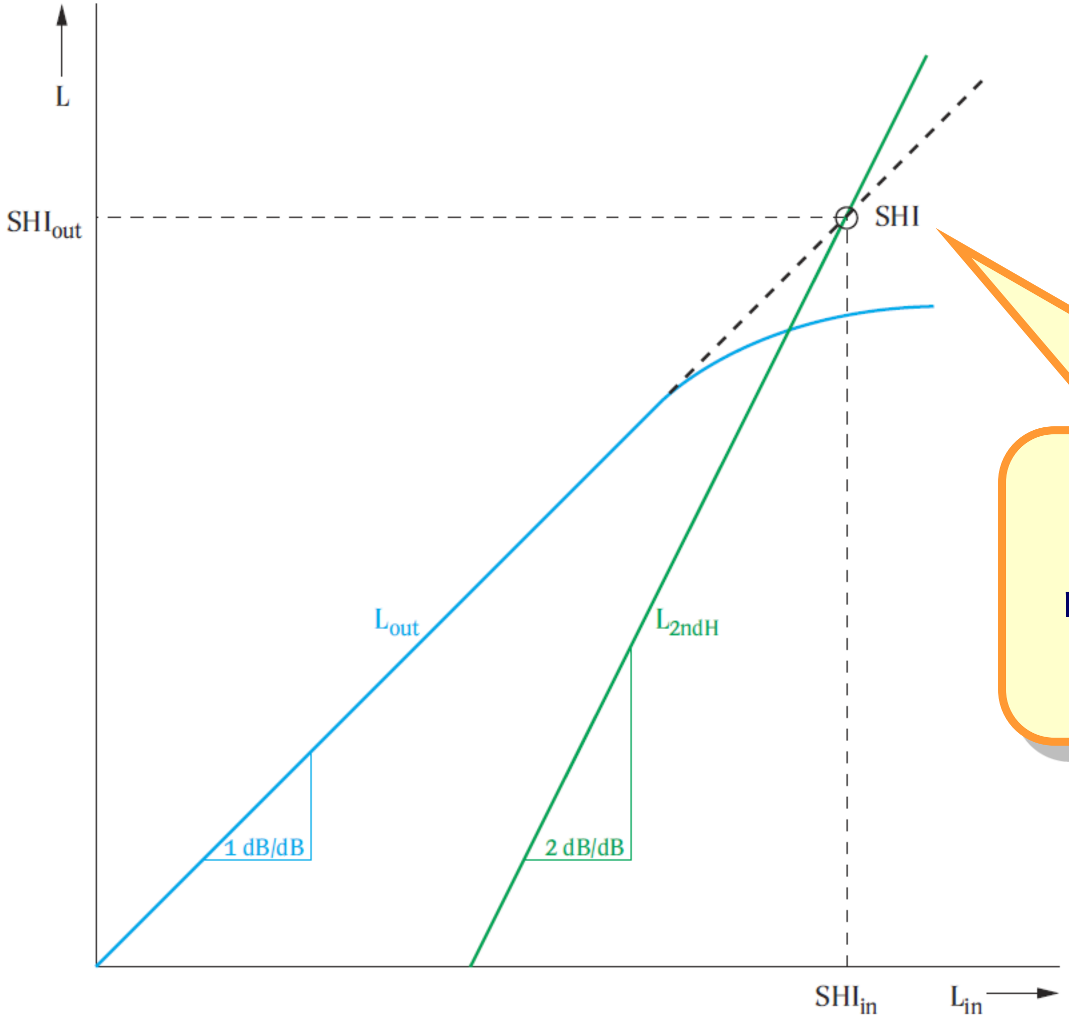


3. harmonik

Kada je nivo signala veći, ima više harmonika

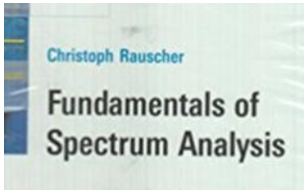
Drugi harmonik

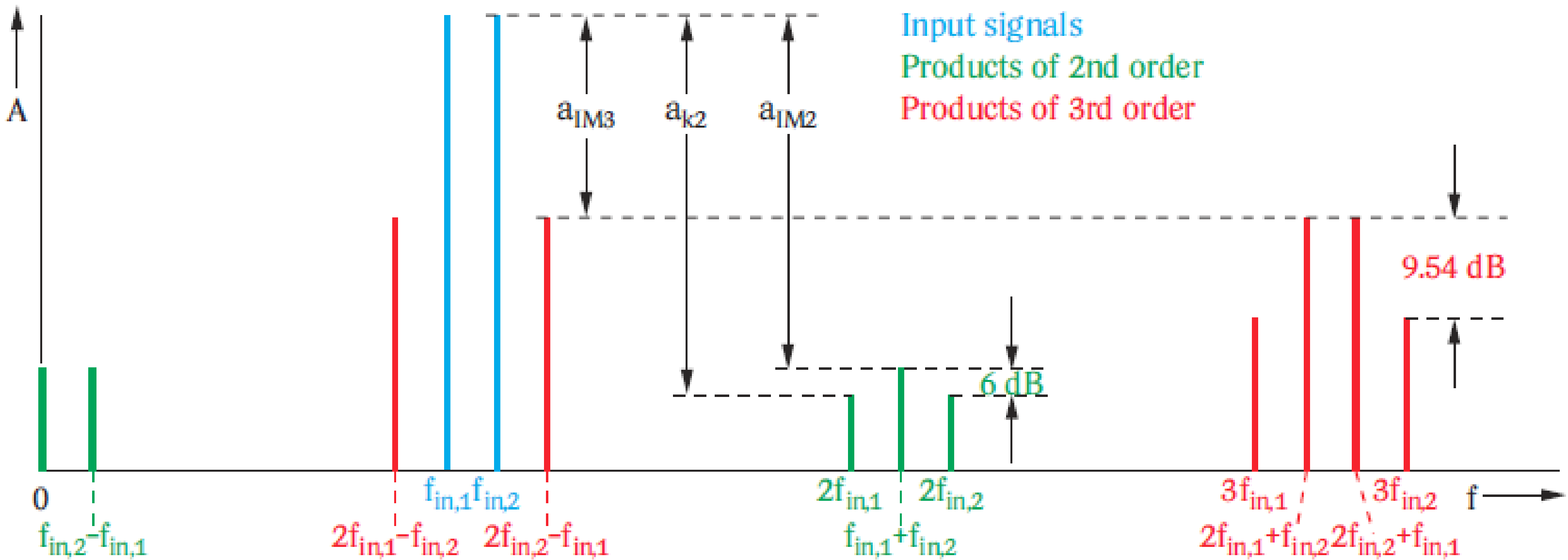




Presečna tačka kada drugi harmonik ima isti nivo kao osnovni signal

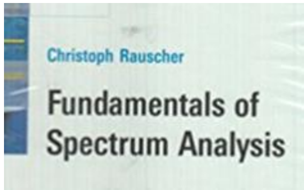
Sa dve sinusoide





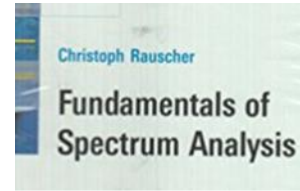
Intermodulacioni produkti

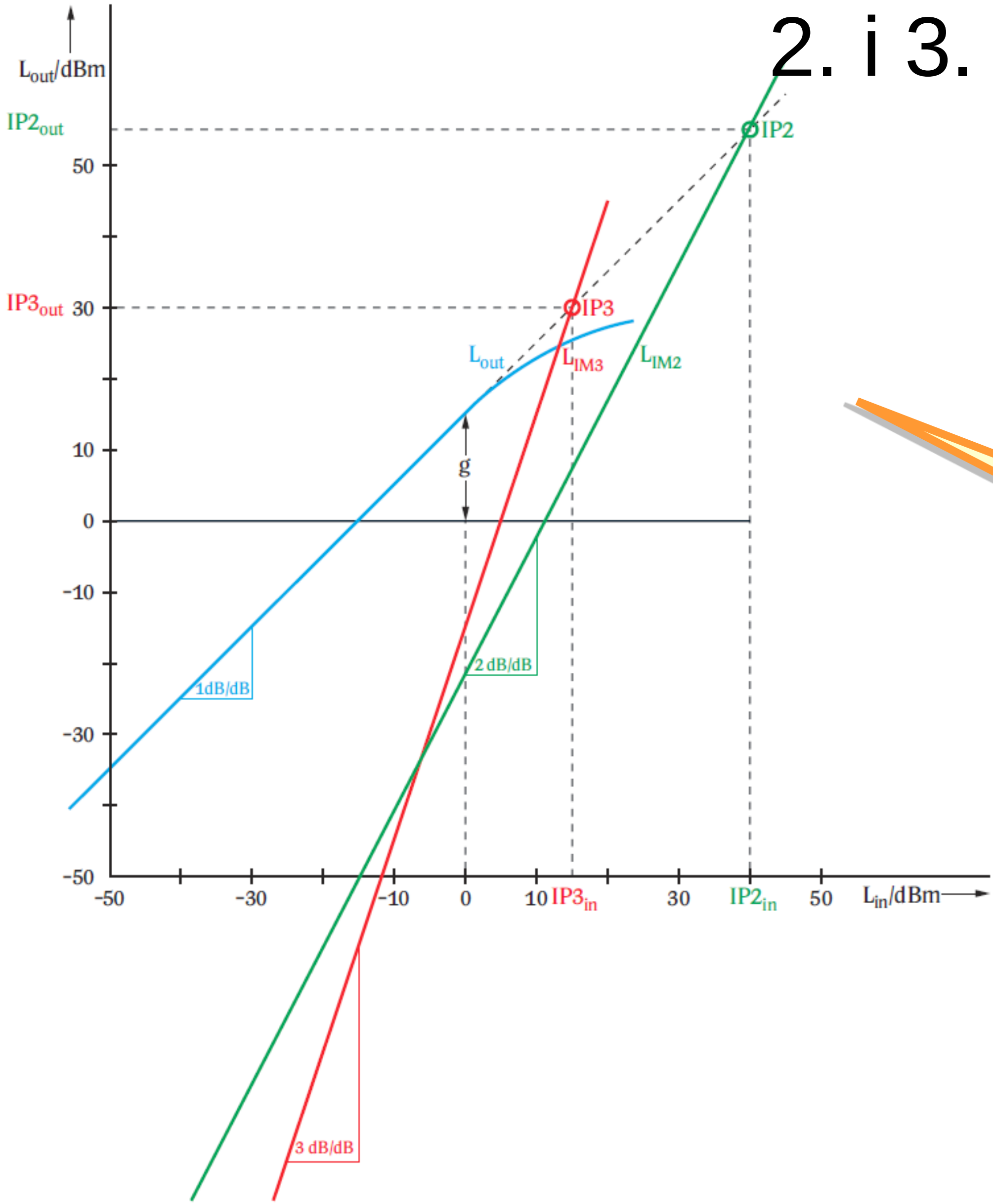
Sa dve sinusoide



DC component	$a_2 \cdot 0.5(\hat{U}_{in,1}^2 + \hat{U}_{in,2}^2)$
Fundamentals	$a_1 \cdot \hat{U}_{in,1} \cdot \sin(\omega_1 t)$ $a_1 \cdot \hat{U}_{in,2} \cdot \sin(\omega_2 t)$
2nd harmonics	$a_2 \cdot 0.5 \cdot \hat{U}_{in,1}^2 \cdot \cos(2 \cdot \omega_1 t)$ $a_2 \cdot 0.5 \cdot \hat{U}_{in,2}^2 \cdot \cos(2 \cdot \omega_2 t)$
Intermodulation products of 2nd order	$a_2 \cdot \hat{U}_{e,1} \cdot \hat{U}_{in,2} \cdot \cos(\omega_1 - \omega_2) t$ $a_2 \cdot \hat{U}_{e,1} \cdot \hat{U}_{in,2} \cdot \cos(\omega_1 + \omega_2) t$
3rd harmonics	$a_3 \cdot 0.25 \cdot \hat{U}_{in,1}^3 \cdot \sin(3 \cdot \omega_1 t)$ $a_3 \cdot 0.25 \cdot \hat{U}_{in,2}^3 \cdot \cos(3 \cdot \omega_2 t)$
Intermodulation products of 3rd order	$a_3 \cdot \hat{U}_{in,1}^2 \cdot \hat{U}_{in,2} \cdot 0.75 \cdot \sin(2\omega_1 + \omega_2) t$ $a_3 \cdot \hat{U}_{in,1}^2 \cdot \hat{U}_{in,2} \cdot 0.75 \cdot \sin(2\omega_2 + \omega_1) t$ $a_3 \cdot \hat{U}_{in,1}^2 \cdot \hat{U}_{in,2} \cdot 0.75 \cdot \sin(2\omega_1 - \omega_2) t$ $a_3 \cdot \hat{U}_{in,1}^2 \cdot \hat{U}_{in,2} \cdot 0.75 \cdot \sin(2\omega_2 - \omega_1) t$

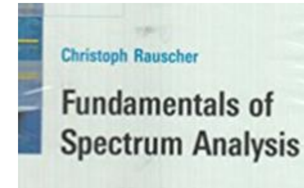
2. i 3. harmonik





Presečne tačke

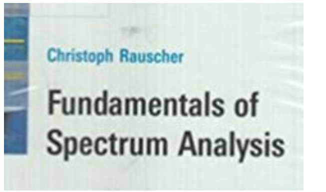
Tipične specifikacije intermodulacije na analizatoru spektra

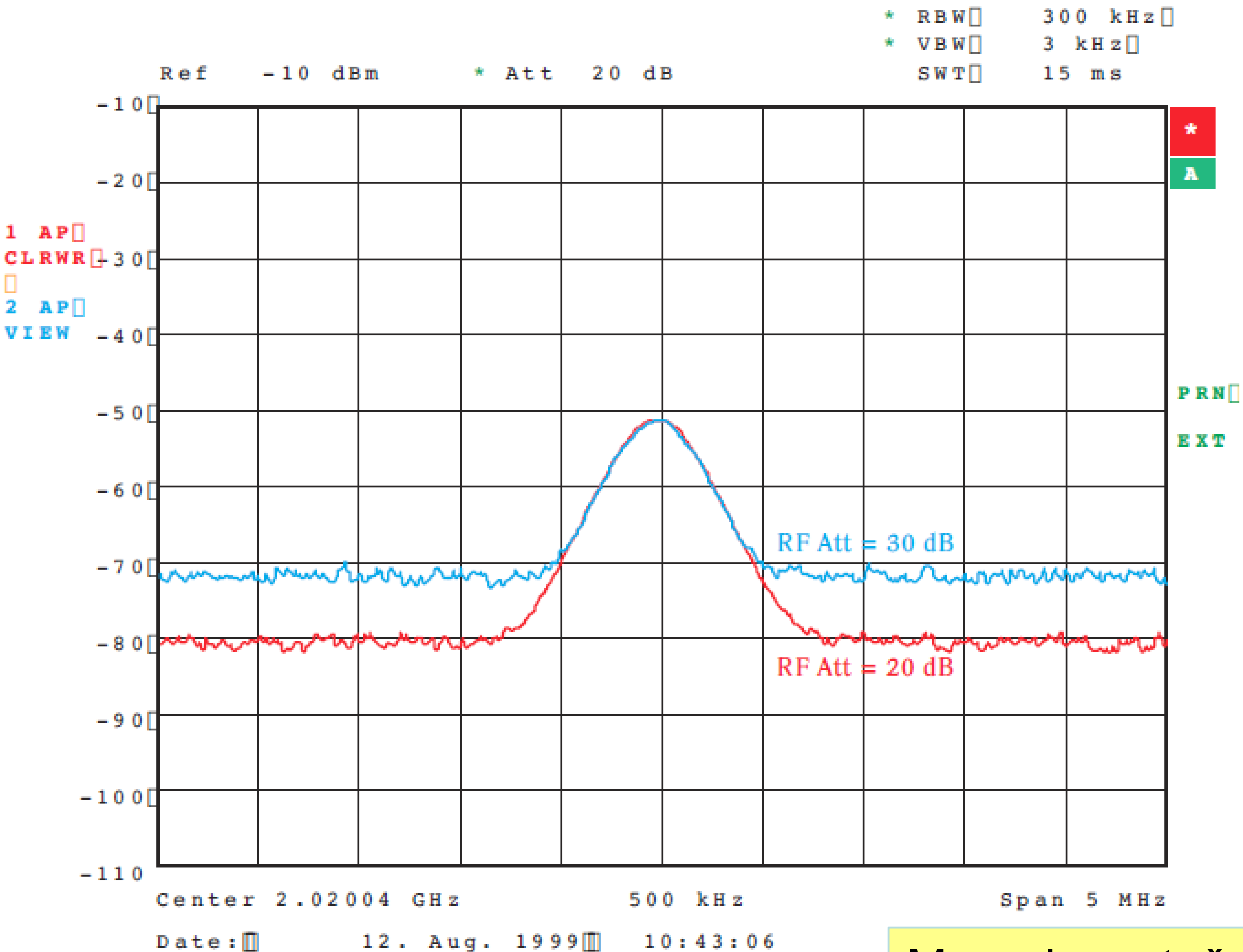


Intermodulation	
3rd order intermodulation	
Intermodulation-free dynamic range level 2 x –30 dBm, Δf >5 · RBW or 10 kHz, whichever is the greater value	
Frequency	
20 MHz to 200 MHz	>70 dBc, TOI >5 dBm
200 MHz to 3 GHz	>74 dBc, TOI >7 dBm
3 GHz to 7 GHz	>80 dBc, TOI >10 dBm
2nd harmonic intercept point (SHI)	
Frequency <50 MHz	25 dBm
50 MHz to 3 GHz	35 dBm
3 GHz to 7 GHz	45 dBm

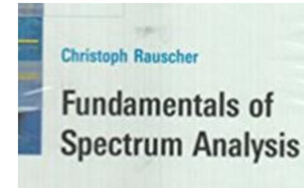
Frekvecijski opseg 200 MHz do 3 GHz

Intermodulacioni produkti

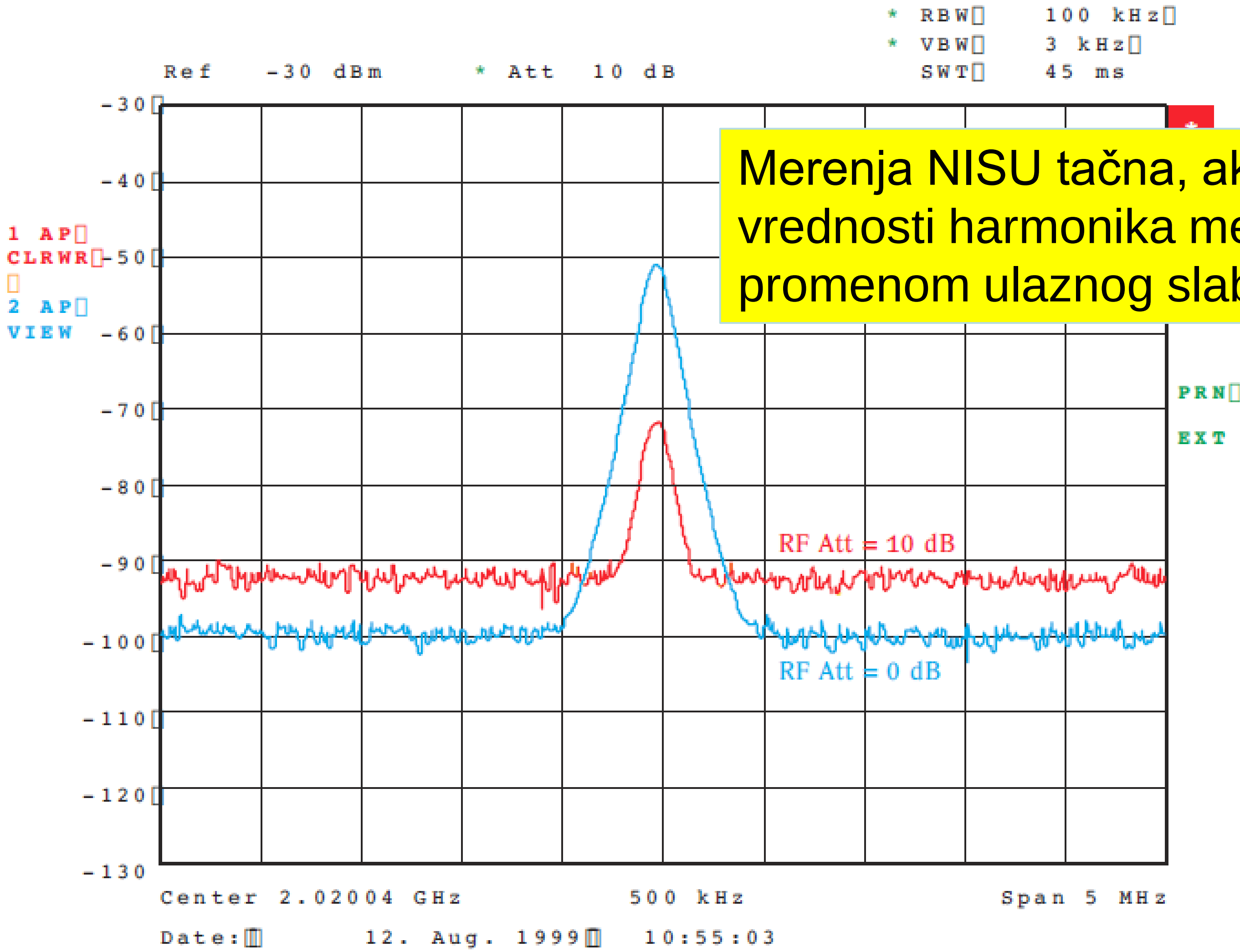




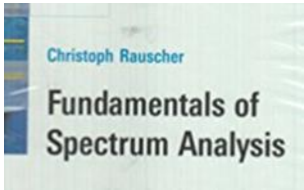
Merenja su tačna



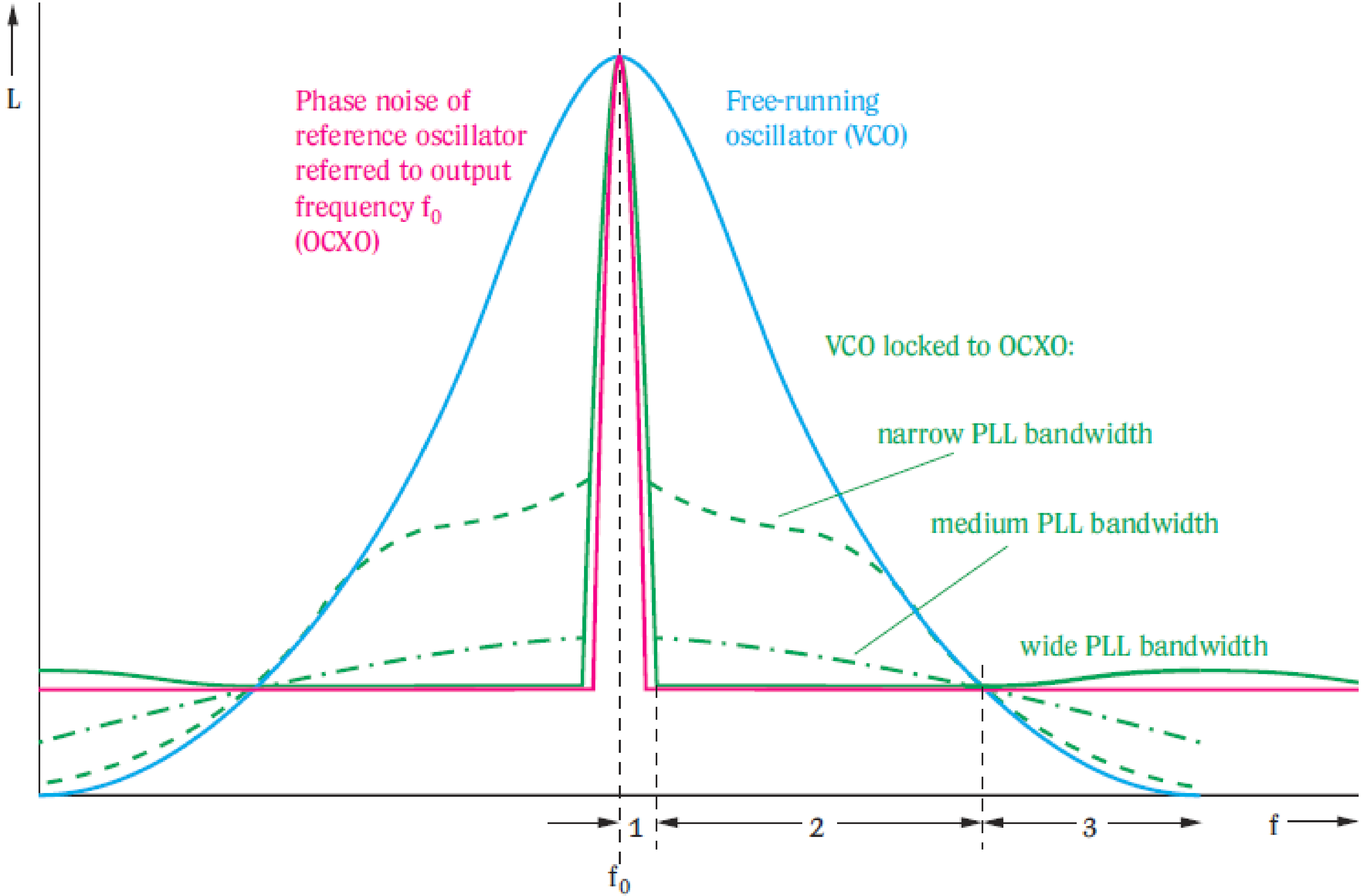
Intermodulacioni produkti



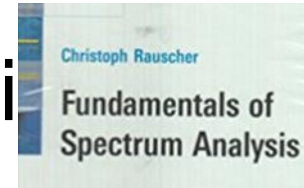
Merenja NISU tačna, ako se relatvne vrednosti harmonika menja, sa promenom ulaznog slabljenja

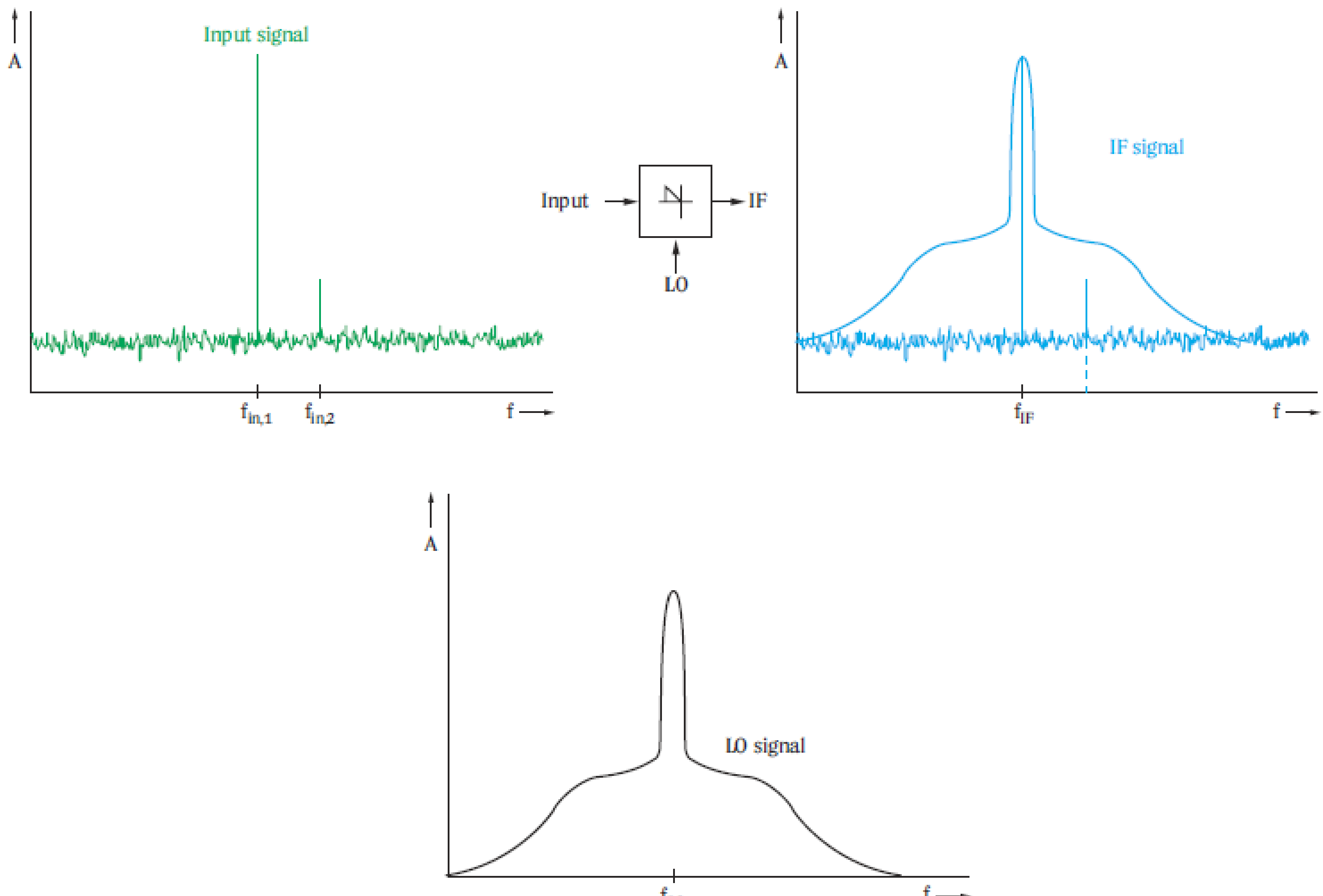

Christoph Rauscher
Fundamentals of
Spectrum Analysis

Fazni šum

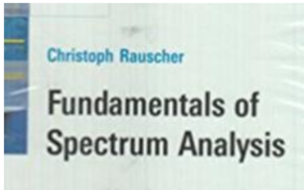

L
Phase noise of
reference oscillator
referred to output
frequency f_0
(OCXO)
Free-running
oscillator (VCO)
VCO locked to OCXO:
narrow PLL bandwidth
medium PLL bandwidth
wide PLL bandwidth
1
2
3
f
f_0

Interni fazni šum transferovan na ulazni signal recipročnim mešanjem





Tipične specifikacije faznog šuma



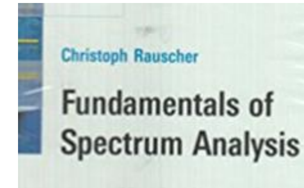
Spectral purity (dBc (1 Hz)) SSB phase noise, f = 500 MHz	
Carrier offset	
100 Hz	<–90. typ. –94
1 kHz	<–100. typ. –108
10 kHz	<–106. typ. –113
100 kHz[1)]	<–110. typ. –113
1 MHz[1)]	<–120. typ. –125
10 MHz	typ. –145
Residual FM (f = 500 MHz, RBW = 1 kHz, sweep time 100 ms)	typ. 3 Hz

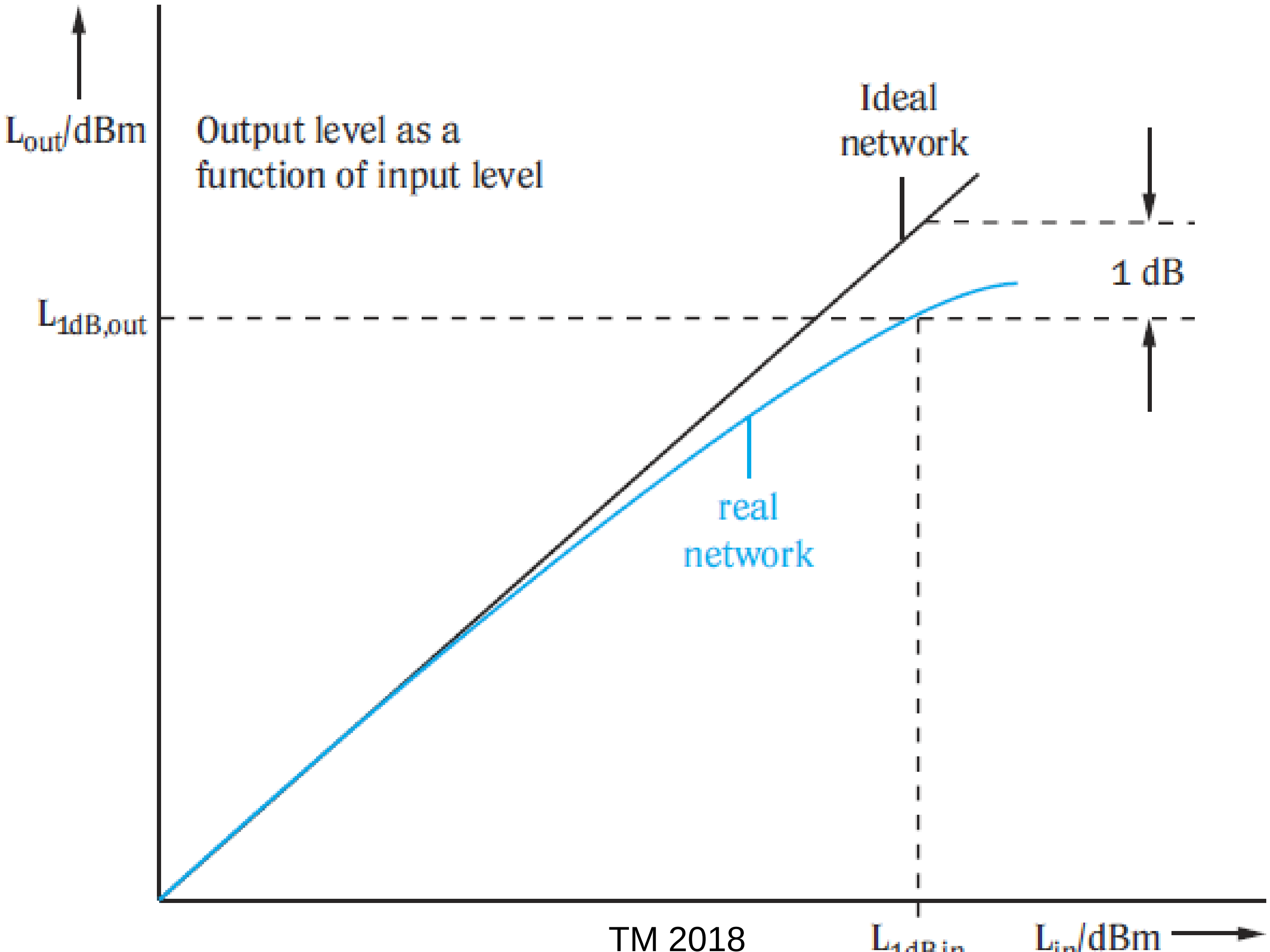
Važi za
span >100 kHz

Typical values for SSB phase noise

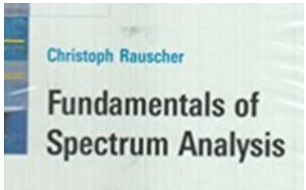
Carrier offset	f_{in} = 500 MHz	f_{in} = 3 GHz	f_{in} = 7 GHz
100 Hz	94 dBc/Hz	90 dBc/Hz	84 dBc/Hz
1 kHz	105 dBc/Hz	100 dBc/Hz	94 dBc/Hz
10 kHz	113 dBc/Hz	108 dBc/Hz	104 dBc/Hz
100 kHz	113 dBc/Hz	108 dBc/Hz	106 dBc/Hz
1 MHz	125 dBc/Hz	118 dBc/Hz	118 dBc/Hz

1 dB tačka kompresije



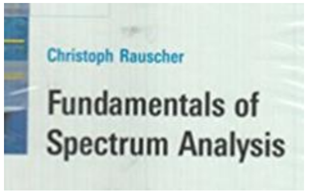


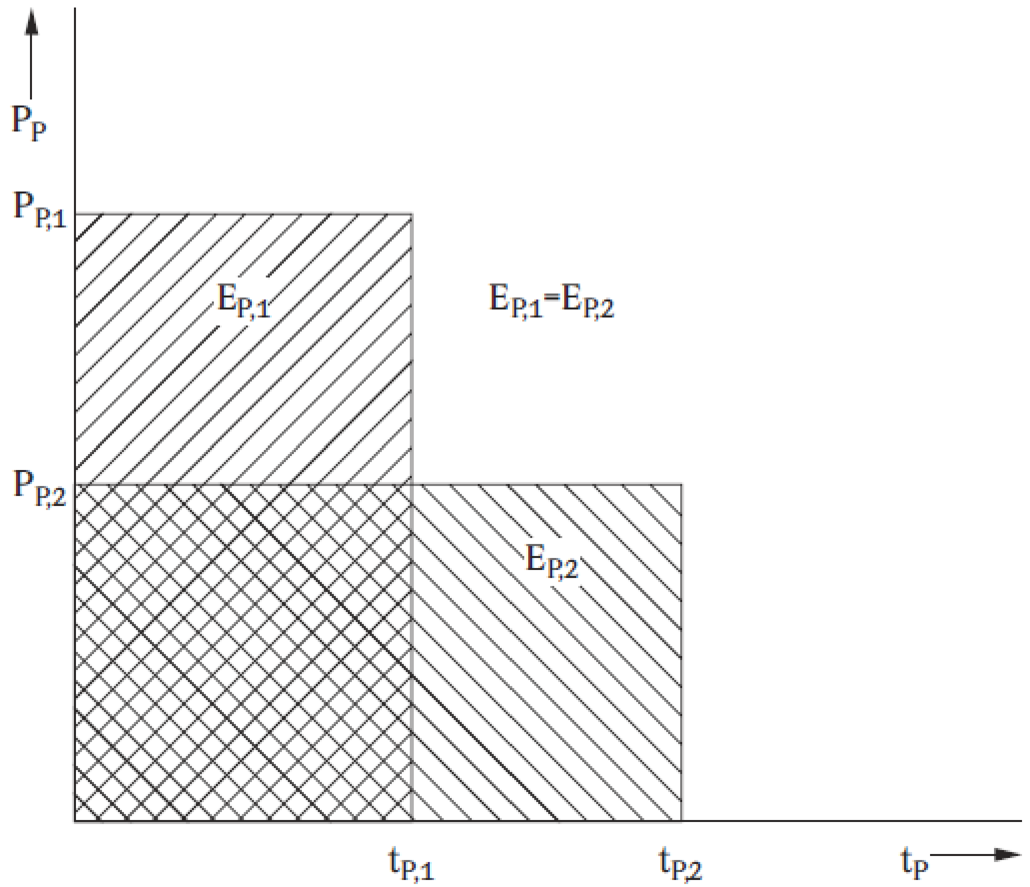
Tipične specifikacije
1 dB tačka kompresije



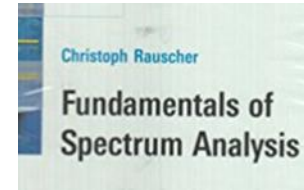
Maximum input level	
RF attenuation 0 dB	
DC voltage	50 V
CW RF power	20 dBm (= 0.3 W)
Pulse spectral density	97 dBμV/MHz
RF attenuation 10 dB	
CW RF power	30 dBm (= 1 W)
Max. pulse voltage	150 V
Max. pulse energy (10 μs)	1 mWs
1 dB compression of output mixer	
0 dB RF attenuation, f > 200 MHz	0 dBm nominal

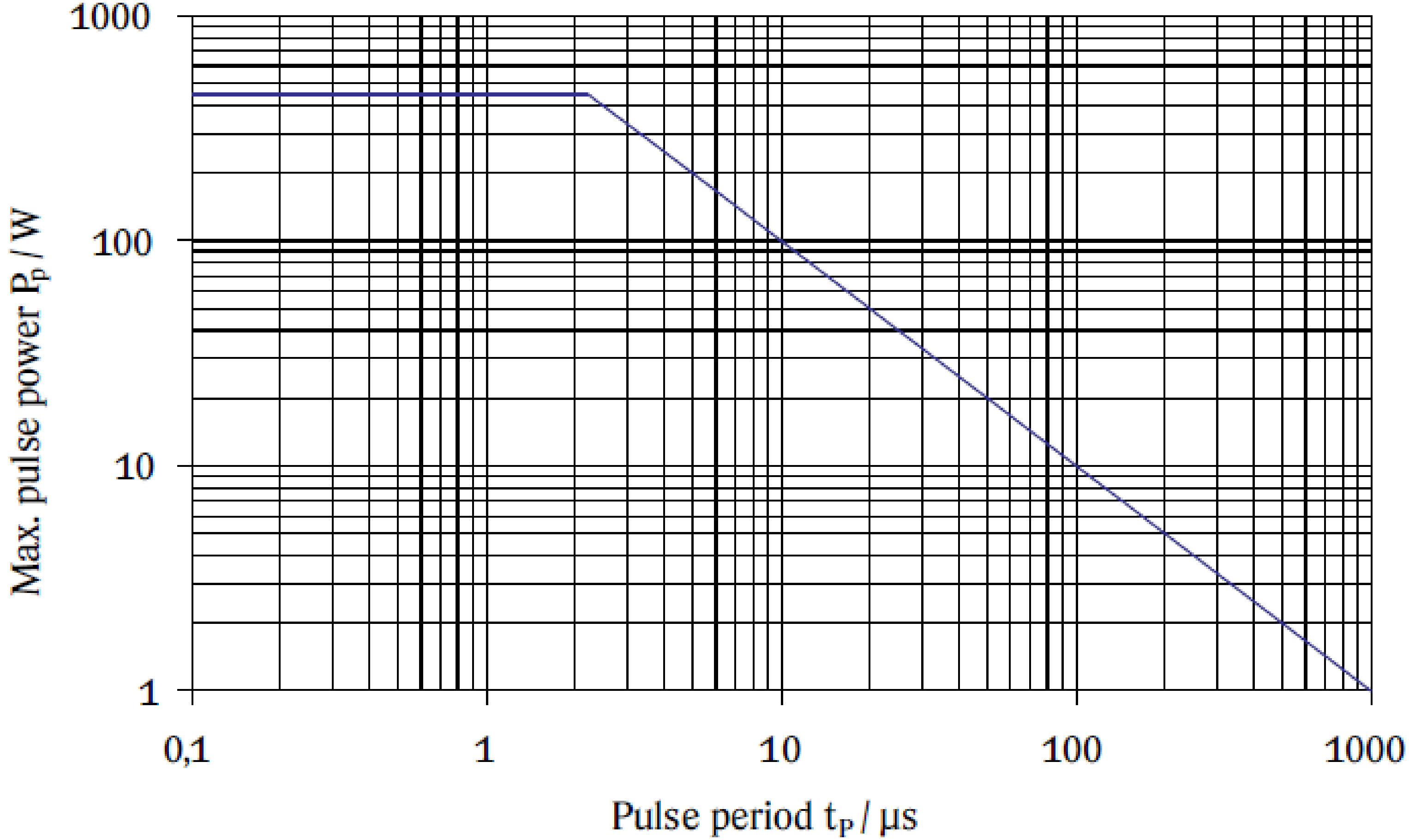
Impulsni signal različite širine a iste energije



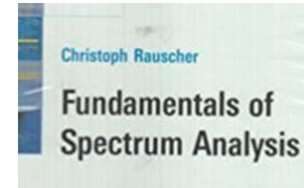


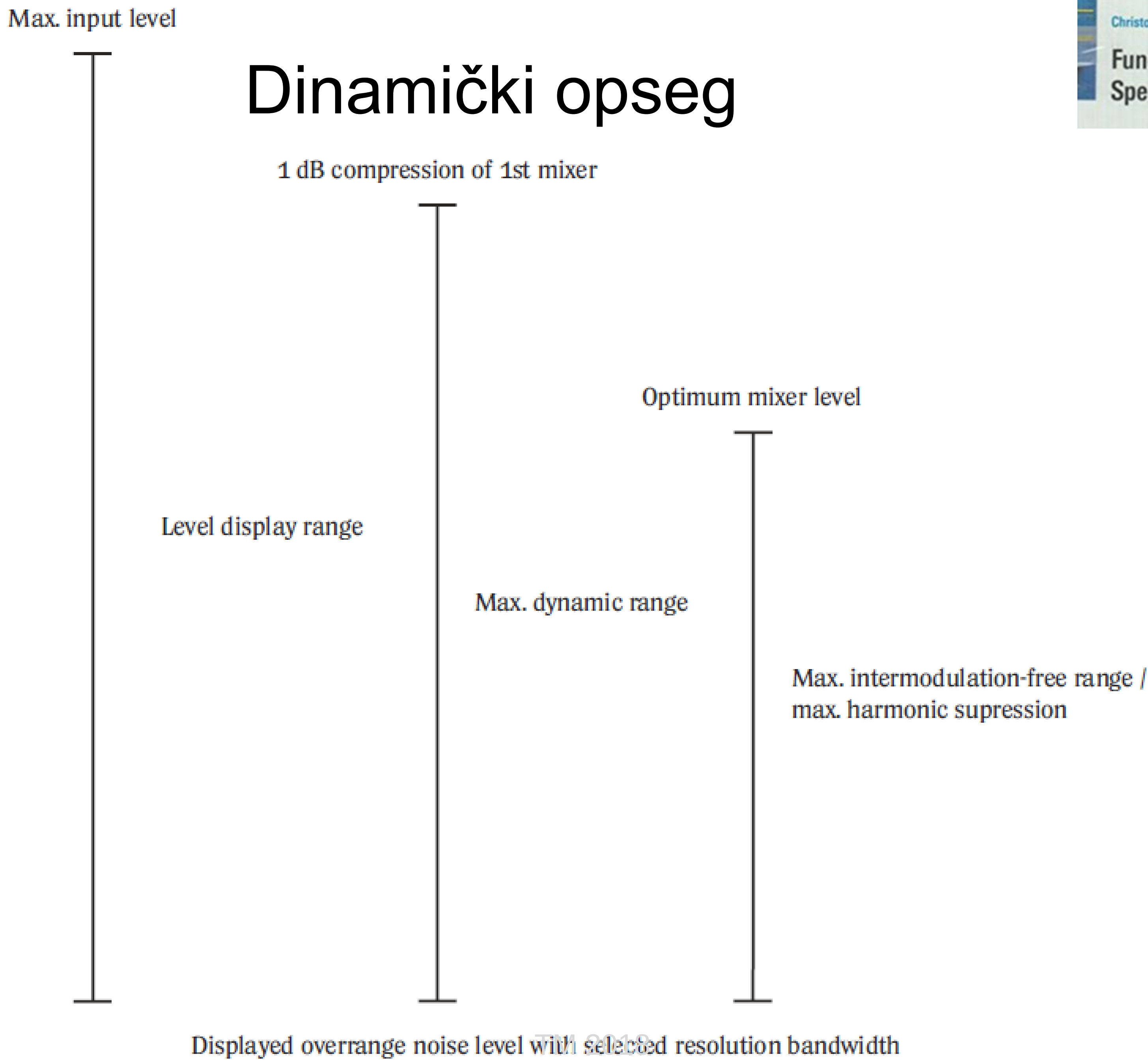
Maksimalna snaga Impulsnog signala u funkciji širine

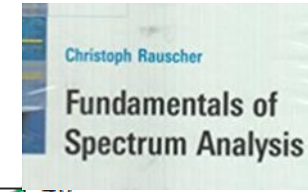




Dinamički opseg







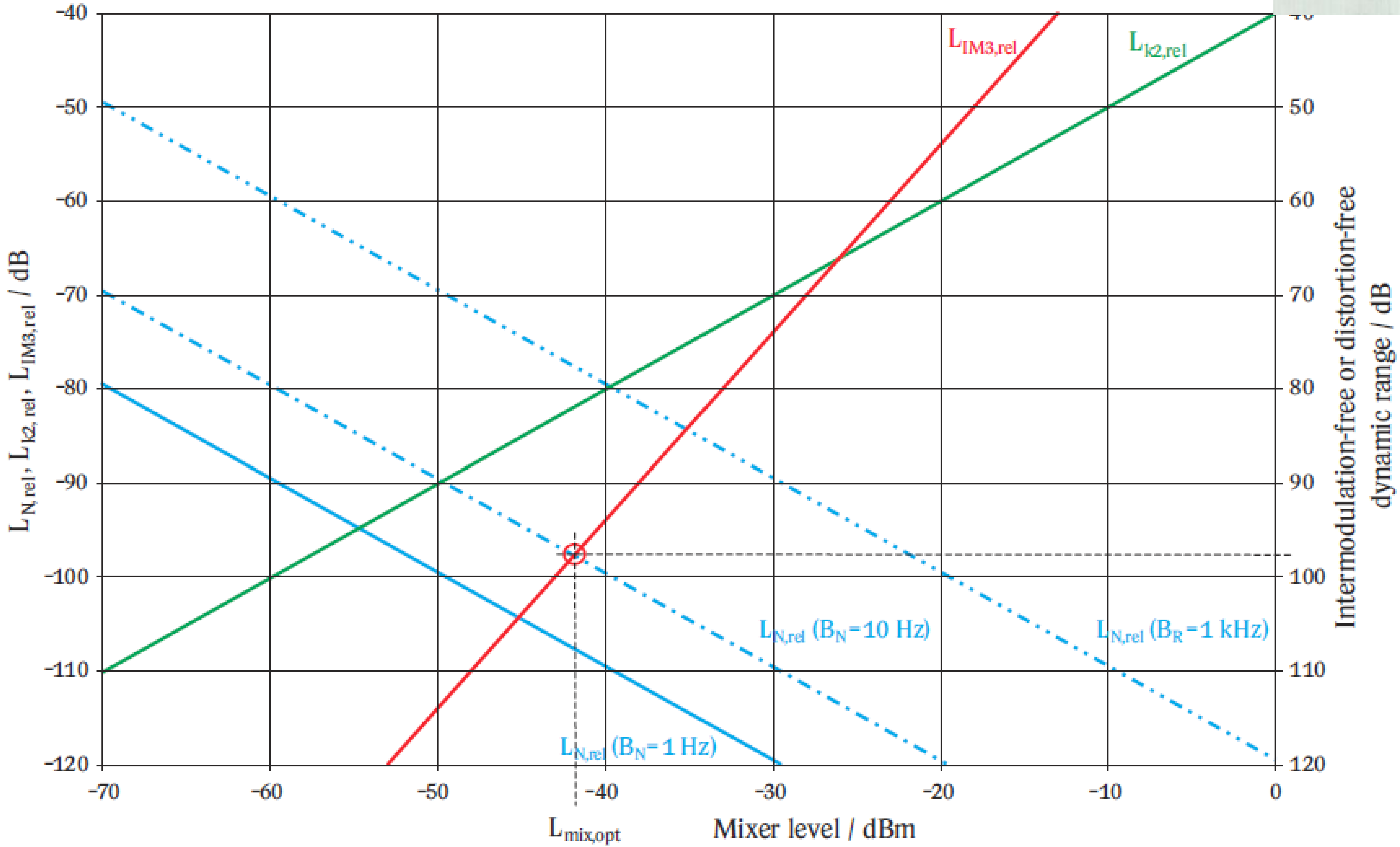
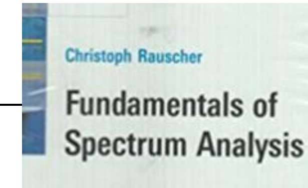


Fig. 5-19 Intermodulation-free range and maximum harmonic suppression as a function of mixer level (NF = 24.5 dB, $IP3_{in}$ = 7 dBm, SHI_{in} = 40 dBm)



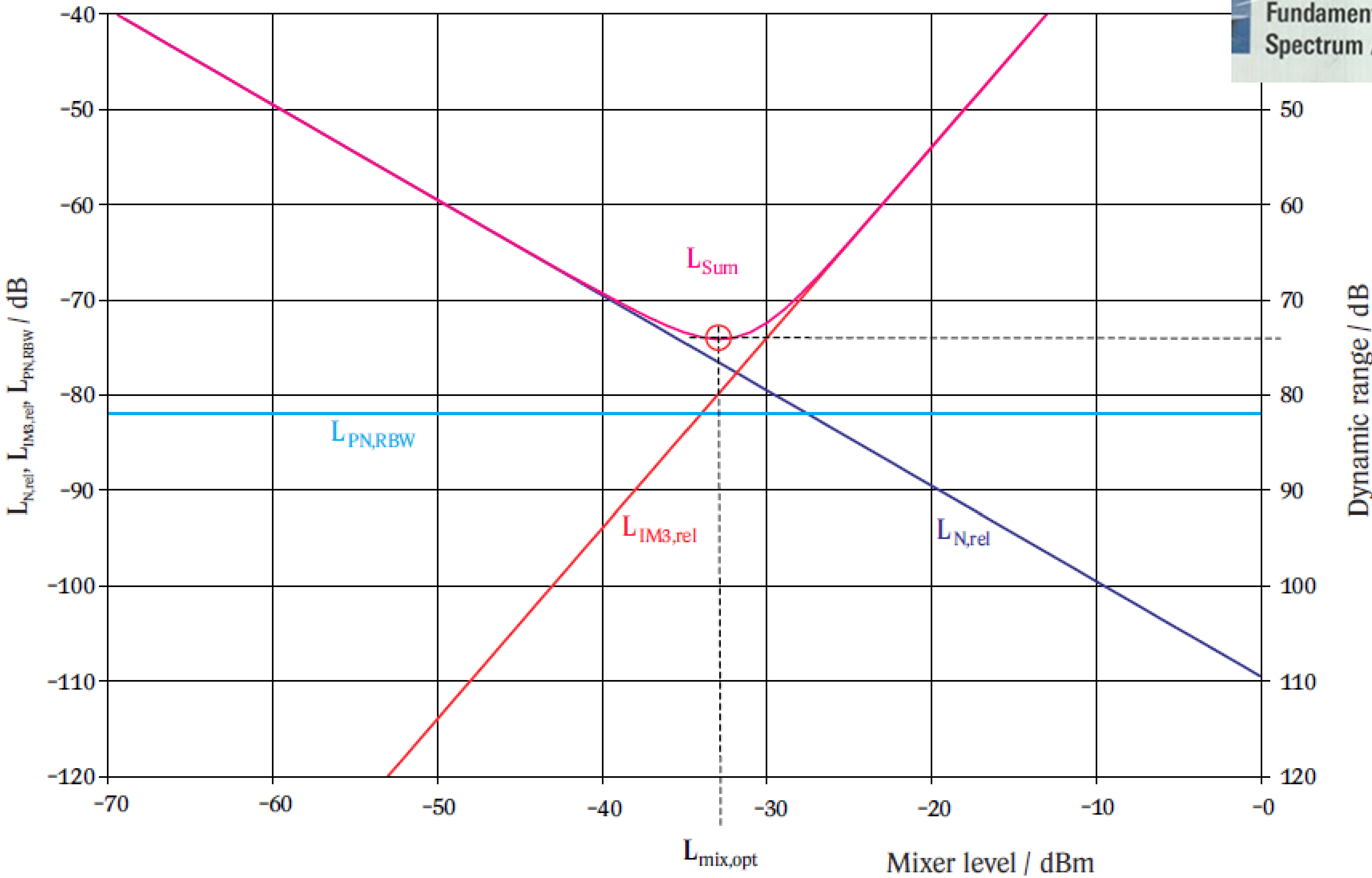
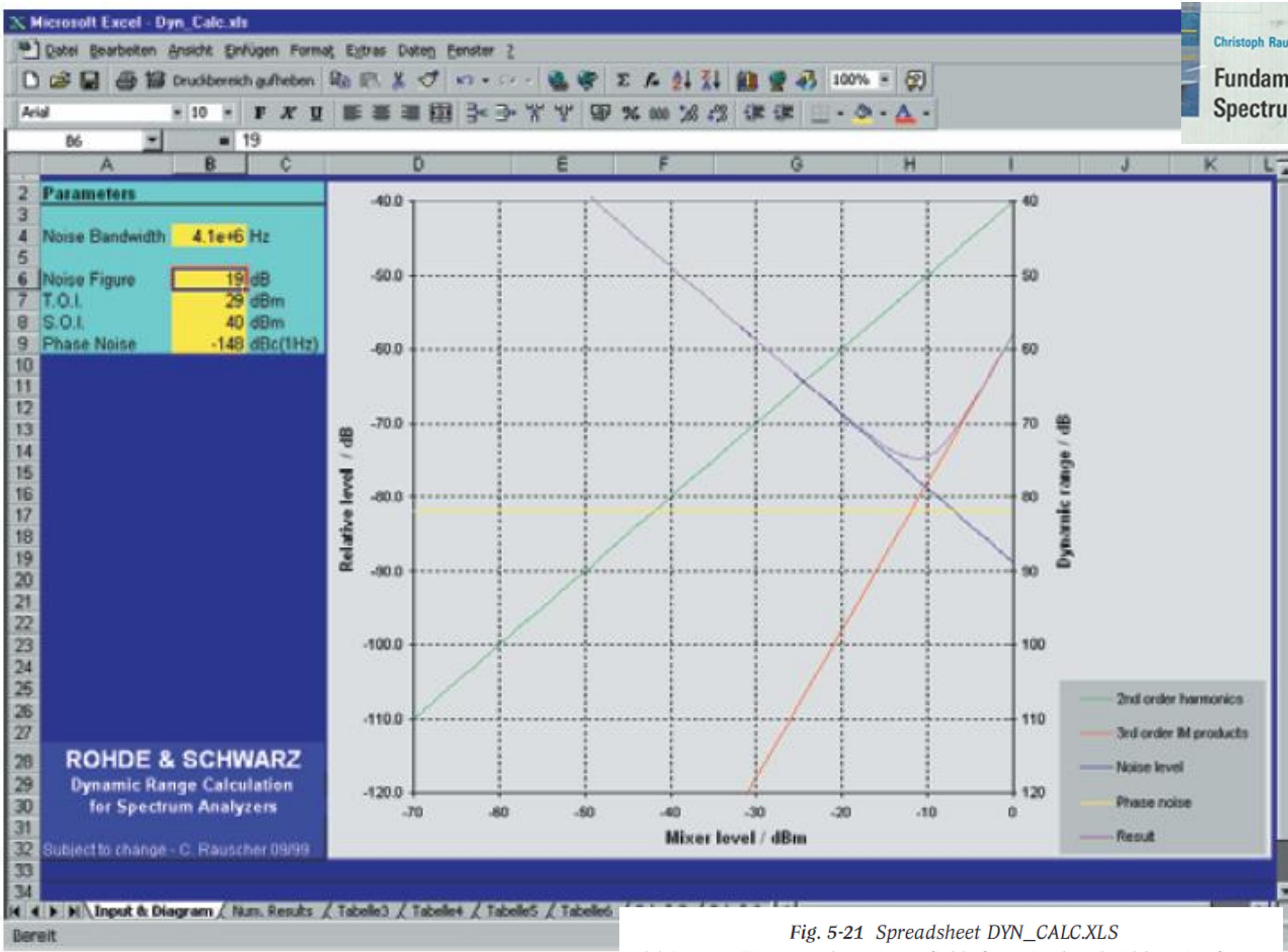


Fig. 5-20 Dynamic range taking into account thermal noise, phase noise and 3rd order intermodulation products
(NF = 24.5 dB, $IP3_{in}$ = 7 dBm, $L(f_{off})$ = −122 dBc (1Hz), $B_{N,IF}$ = 10 kHz)



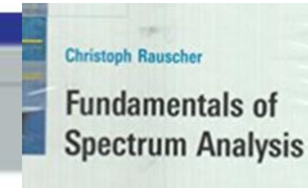
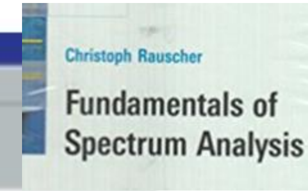
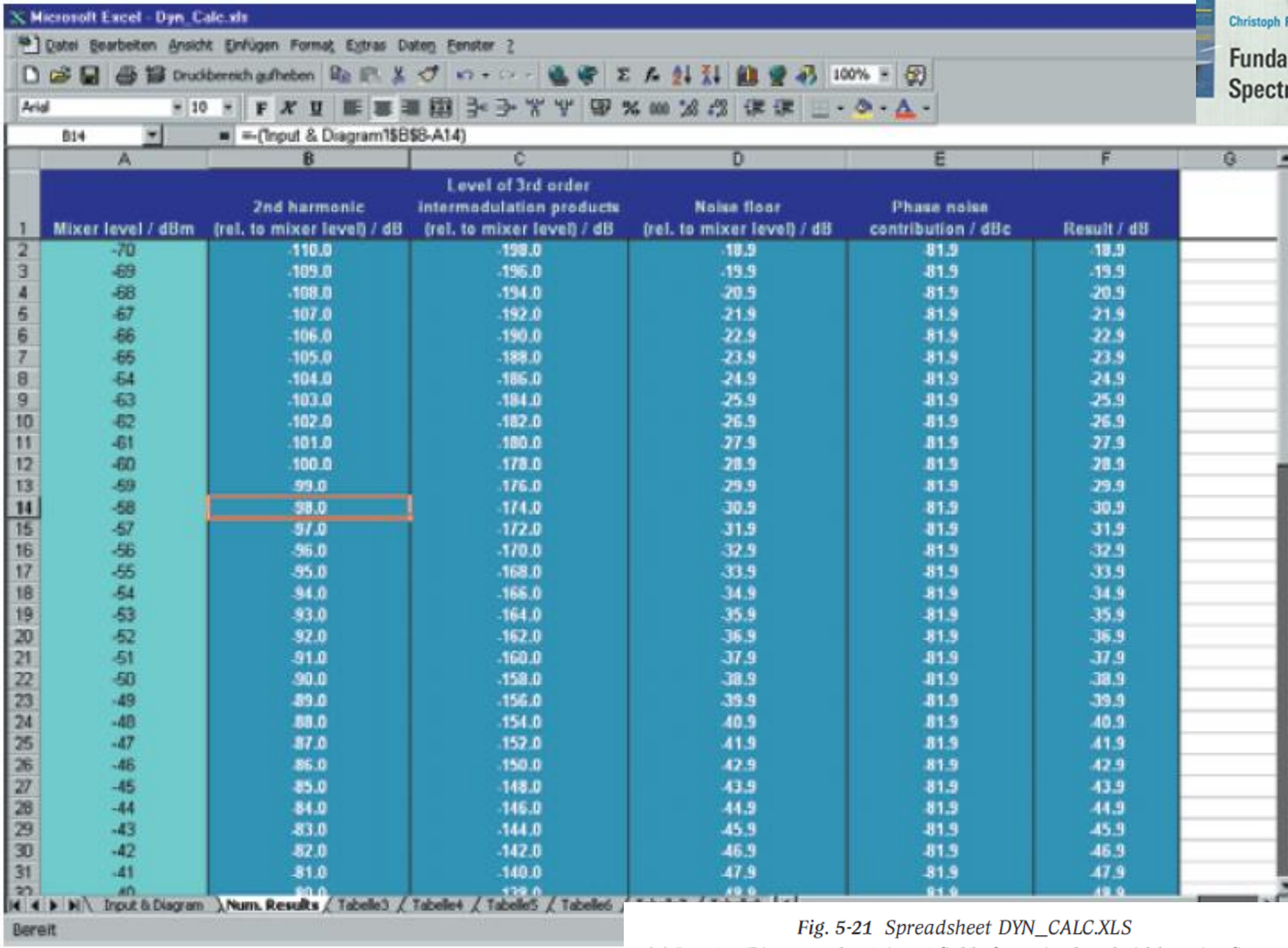


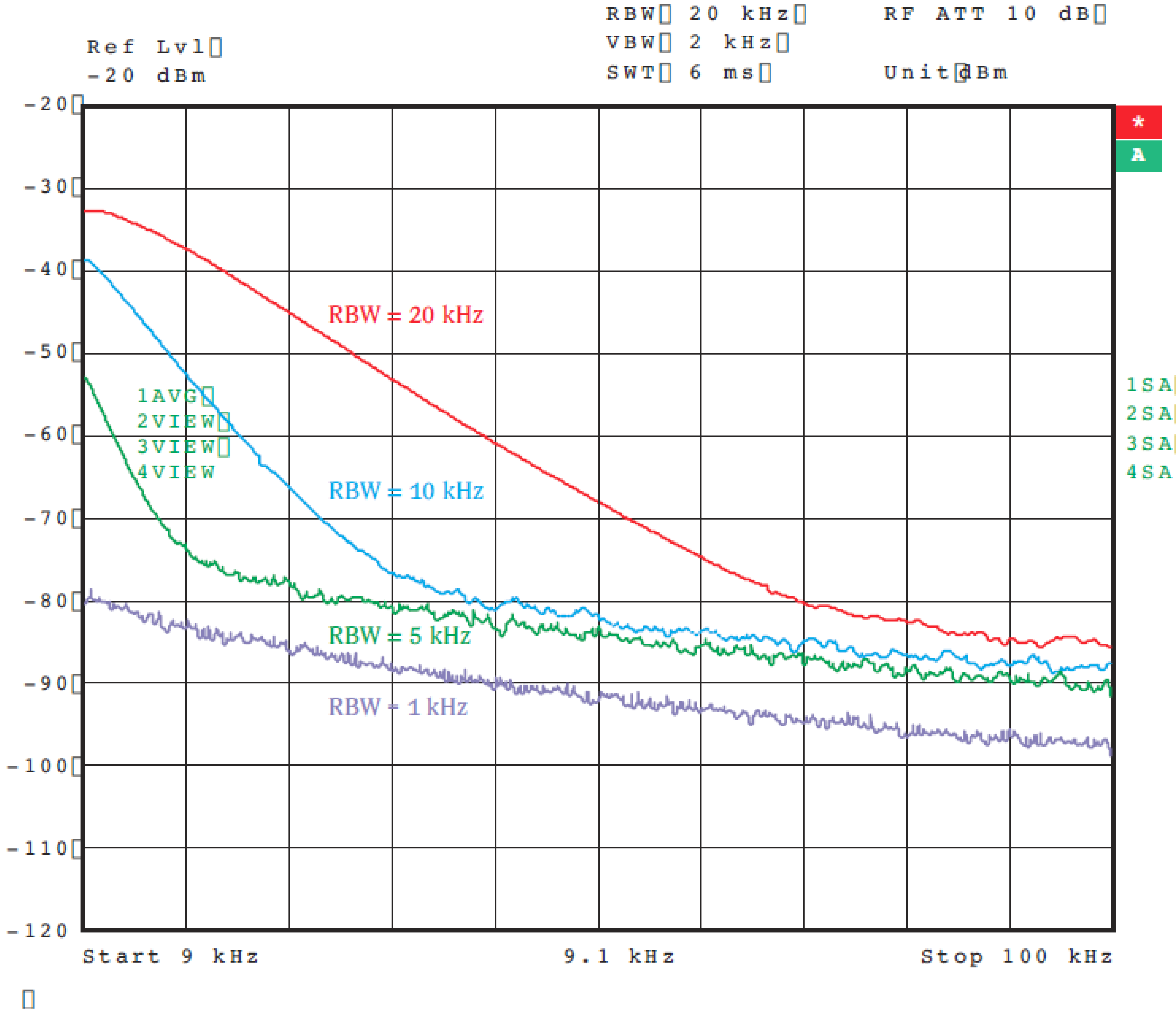
Fig. 5-21 Spreadsheet DYN_CALC.XLS
(a) Input & Diagram sheet: input fields for noise bandwidth, noise figure, TOI, SHI and phase noise as well as graphical representation of resulting dynamic range
(b) Num. Results sheet: numeric output of results





	A	B	C	D	E	F
1	Mixer level / dBm	2nd harmonic (rel. to mixer level) / dB	Level of 3rd order intermodulation products (rel. to mixer level) / dB	Noise floor (rel. to mixer level) / dB	Phase noise contribution / dBc	Result / dB
2	-70	-110.0	-198.0	-18.9	-81.9	-18.9
3	-69	-109.0	-196.0	-19.9	-81.9	-19.9
4	-68	-108.0	-194.0	-20.9	-81.9	-20.9
5	-67	-107.0	-192.0	-21.9	-81.9	-21.9
6	-66	-106.0	-190.0	-22.9	-81.9	-22.9
7	-65	-105.0	-188.0	-23.9	-81.9	-23.9
8	-64	-104.0	-186.0	-24.9	-81.9	-24.9
9	-63	-103.0	-184.0	-25.9	-81.9	-25.9
10	-62	-102.0	-182.0	-26.9	-81.9	-26.9
11	-61	-101.0	-180.0	-27.9	-81.9	-27.9
12	-60	-100.0	-178.0	-28.9	-81.9	-28.9
13	-59	-99.0	-176.0	-29.9	-81.9	-29.9
14	-58	-98.0	-174.0	-30.9	-81.9	-30.9
15	-57	-97.0	-172.0	-31.9	-81.9	-31.9
16	-56	-96.0	-170.0	-32.9	-81.9	-32.9
17	-55	-95.0	-168.0	-33.9	-81.9	-33.9
18	-54	-94.0	-166.0	-34.9	-81.9	-34.9
19	-53	-93.0	-164.0	-35.9	-81.9	-35.9
20	-52	-92.0	-162.0	-36.9	-81.9	-36.9
21	-51	-91.0	-160.0	-37.9	-81.9	-37.9
22	-50	-90.0	-158.0	-38.9	-81.9	-38.9
23	-49	-89.0	-156.0	-39.9	-81.9	-39.9
24	-48	-88.0	-154.0	-40.9	-81.9	-40.9
25	-47	-87.0	-152.0	-41.9	-81.9	-41.9
26	-46	-86.0	-150.0	-42.9	-81.9	-42.9
27	-45	-85.0	-148.0	-43.9	-81.9	-43.9
28	-44	-84.0	-146.0	-44.9	-81.9	-44.9
29	-43	-83.0	-144.0	-45.9	-81.9	-45.9
30	-42	-82.0	-142.0	-46.9	-81.9	-46.9
31	-41	-81.0	-140.0	-47.9	-81.9	-47.9

Fig. 5-21 Spreadsheet DYN_CALC.XLS
(a) Input & Diagram sheet: input fields for noise bandwidth, noise figure, TOI, SHI and phase noise as well as graphical representation of resulting dynamic range
(b) Num. Results sheet: numeric output of results



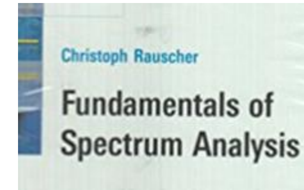


Fig. 5-23 LO feedthrough as a function of selected resolution bandwidth

Improvement of input matching

The RF attenuation of a spectrum analyzer should always be set to at least 10 dB provided that the sensitivity is sufficiently high. In this way the first mixer is protected against damage by too high input signals and the input matching is improved. For example, if an ideal attenuator pad with an attenuation $a = 6$ dB is connected ahead of a twoport with a return loss of $a_r = 10$ dB at the input, the total return loss $a_{r,total}$ is $a_r + 2 \cdot a$ or 22 dB. Fig. 5-26 shows the spectrum analyzer with the attenuator pad.

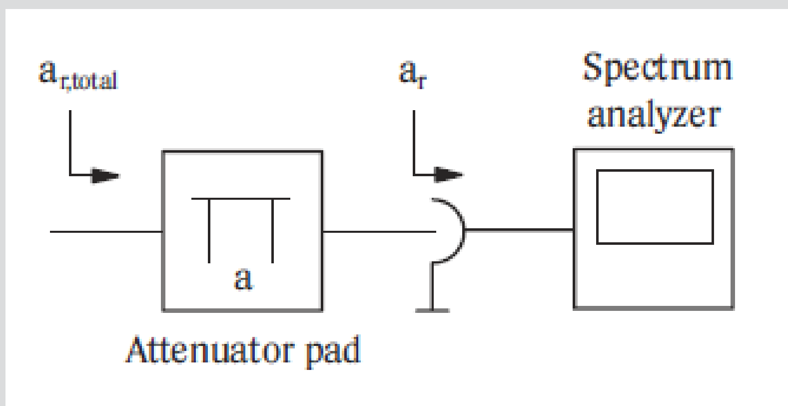
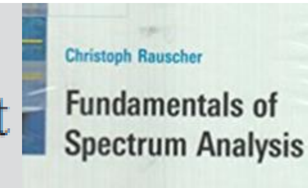
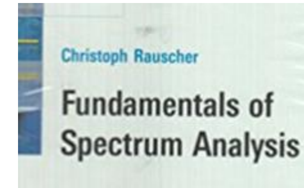


Fig. 5-26 Improvement of spectrum analyzer input matching by connecting an attenuator pad ahead of analyzer

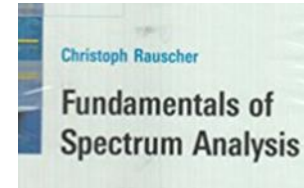




Merna nesigurnost. Doprinos greškama

Measurement / Error contribution	Absolute level of CW signal	Harmonic distortion	3rd order intermodulation products (close to carrier)	3rd order intercept	Channel power	Adjacent-channel power ratio	Power versus time (e.g. for TDMA signals), relative	Phase noise, far off carrier, with variation of RF attenuation and reference level	Phase noise, close to carrier
Absolute error	•			•	•				
Frequency response	•	•		•	•				
Attenuator error	•			•	•			•	
IF gain error	•			•	•			•	
Linearity error	•	•	•	•	•	•	•	•	•
Bandwidth switching error	•			•	•				
Bandwidth error					•	•		•	•
Error due to limited number of samples					•	•			
Mismatch error	•	•		•	•				

Table 5-2 *Error contributions in typical measurements using a spectrum analyzer*



Opseg poverenja

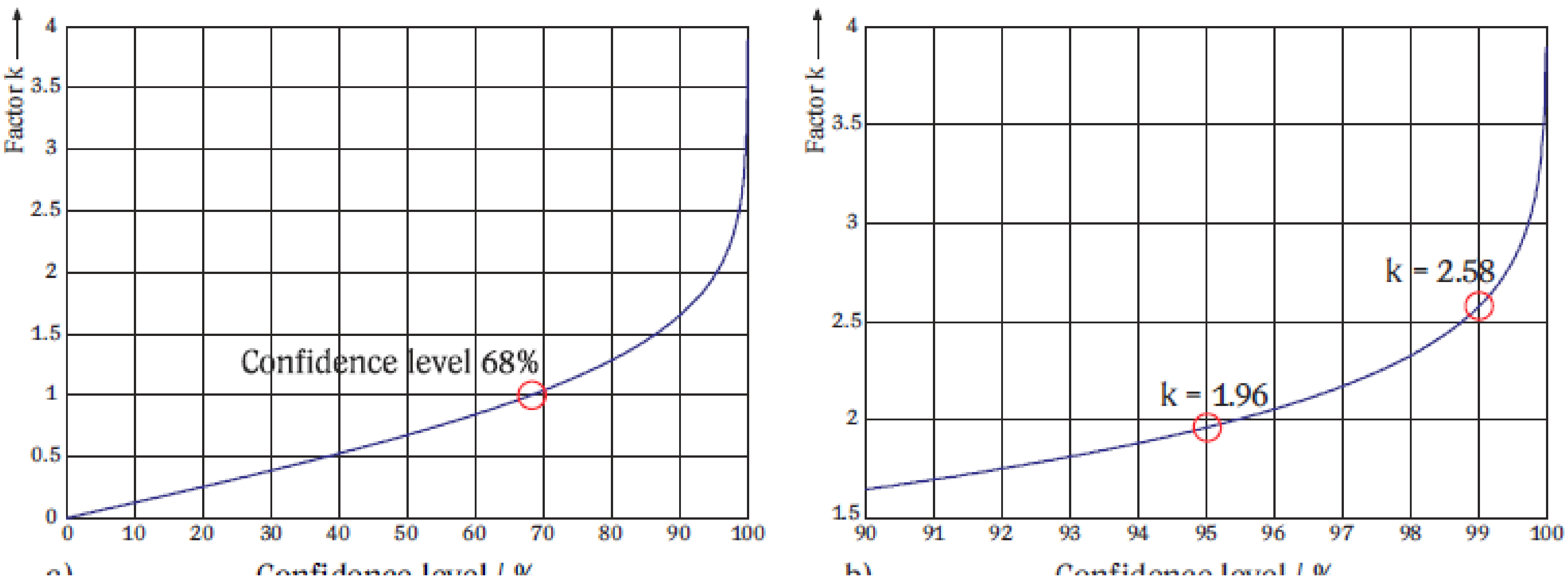
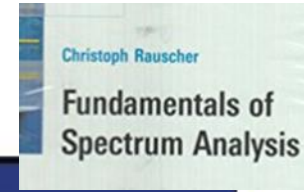


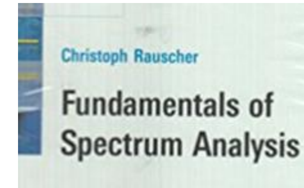
Fig. 5-27 Coverage factor k as a function of confidence level
a) confidence level 0% to 100%, b) confidence level 90% to 100% (zoomed)



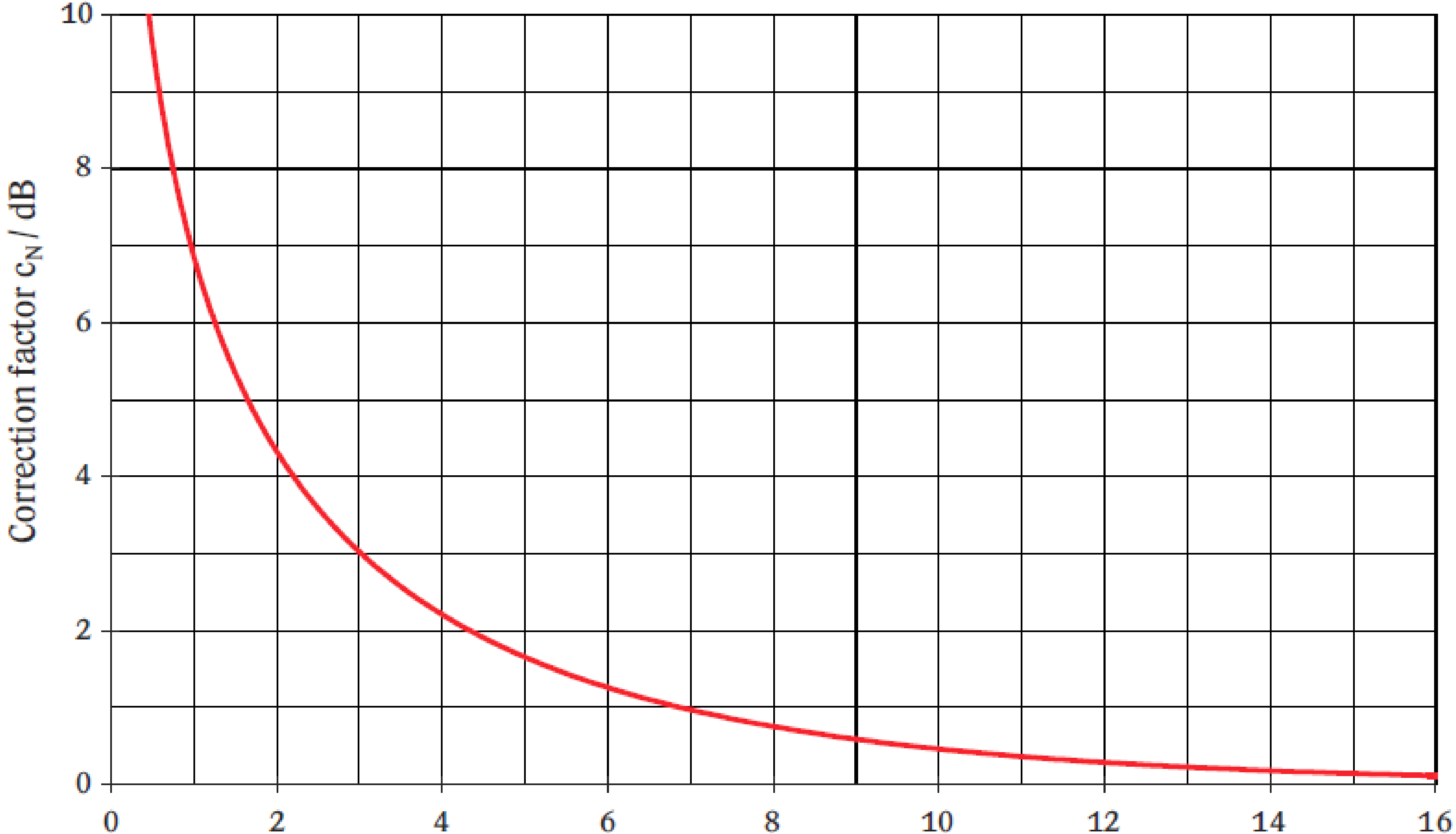
Error Calculation for Rohde & Schwarz Spectrum Analyzers

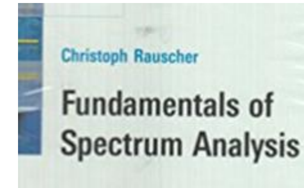
Inherent errors	unit	s = stand. uncertainty w = worst case	specified error	variance σ_i^2	contribute y = yes , n = no
Absolute error 120 MHz	dB	1 w	2 0.3	0.03 3	y 4
Frequency response	dB	w	0.2	0.01	y
Input attenuator	dB	w	0.2	0.01	y
If gain	dB	w	0.2	0.01	y
Log linearity	dB	w	0.2	0.01	y
Bandwidth switching error	dB	w	0.2	0.01	y
Bandwidth error	%		10.00	0.07	y
Combined variance		$\sigma_{tot}^2 = \sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2$		0.17	
Combined standard uncertainty		$\sigma_{tot} = \sqrt{\sigma_{tot}^2}$		0.41	
Total error **(95% confidence level)**	dB			0.80 5	
(99% confidence level)	dB			1.05	
Error due to source mismatch		a = return loss / dB v = VSWR	specified values		
VSWR of SA		6 v	7 3.1		
VSWR of DUT		v	1.57	0.55	
Combined variance		$\sigma_{tot}^2 = \sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2$		0.71	
Combined standard uncertainty		$\sigma_{tot} = \sqrt{\sigma_{tot}^2}$		0.85	
Error including source mismatch **(95%)**	dB			1.66 8	
(99%)	dB			2.18	

Fig. 5-28 Spreadsheet FSP_ERR.XLS

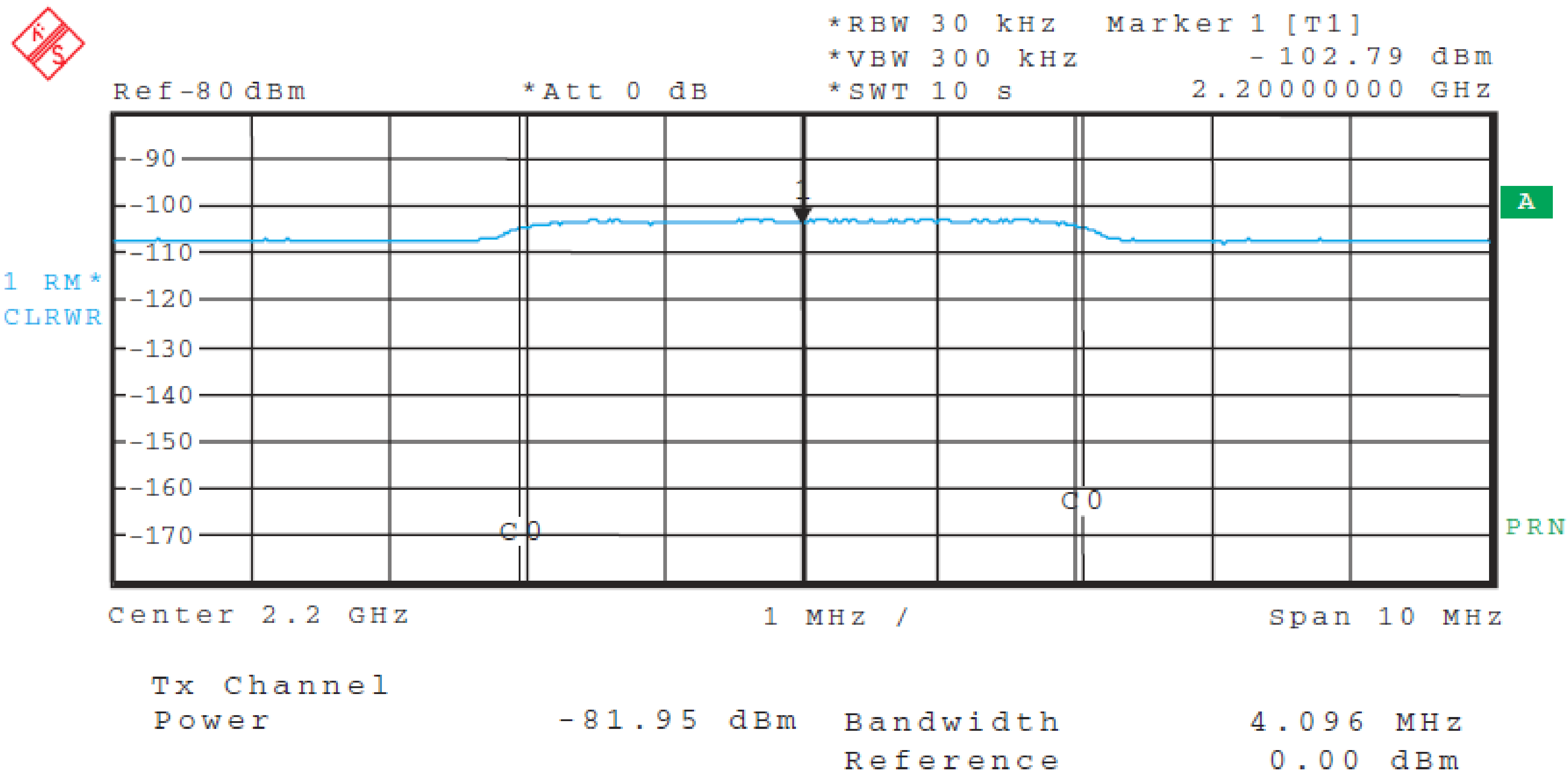


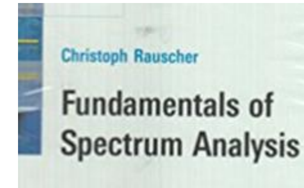
Ukupna snaga / inherentni šum / dB



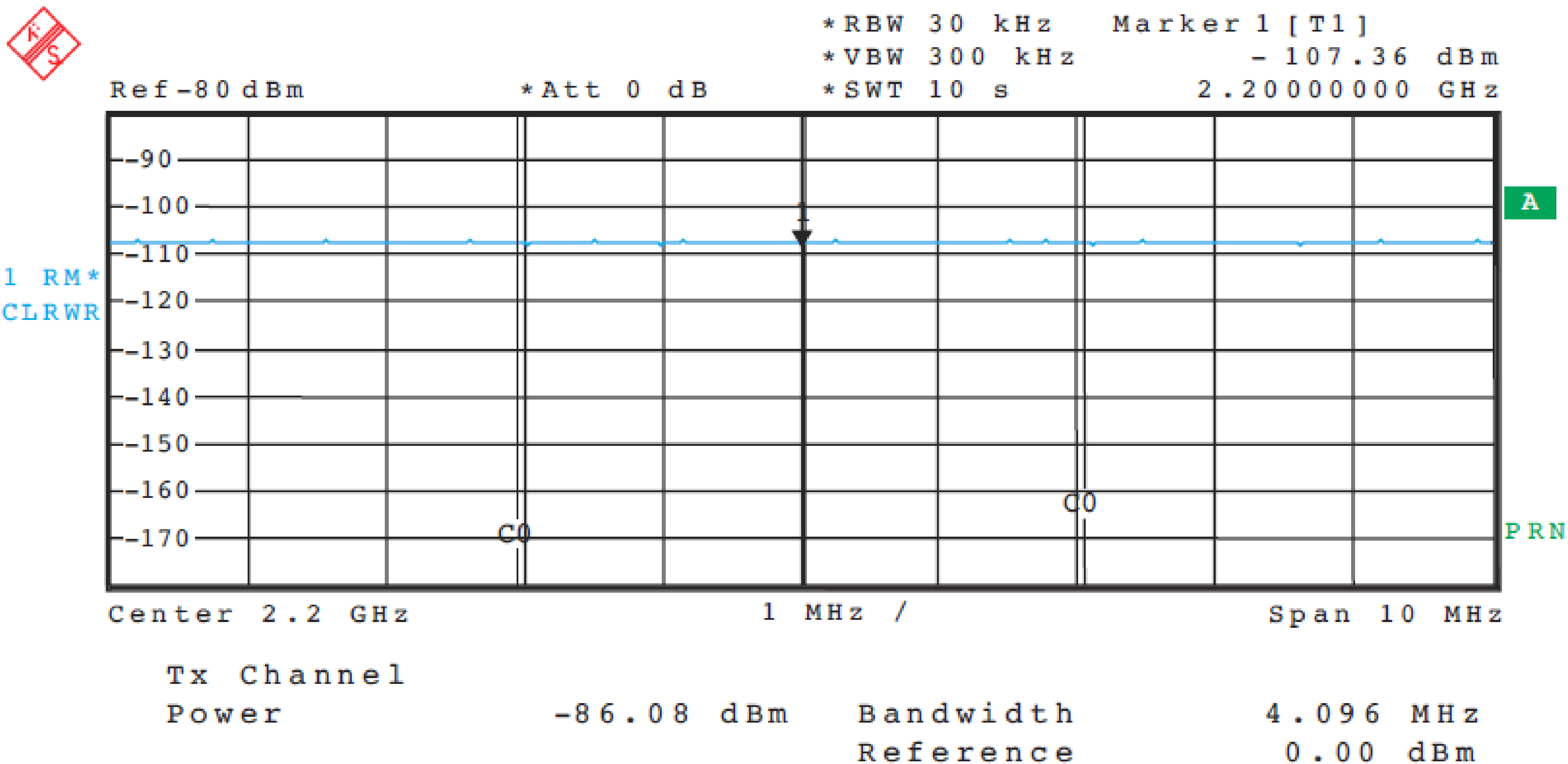


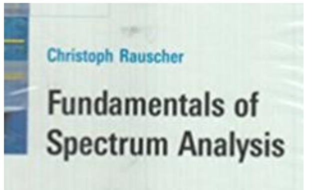
Merenje ukupne snage kanala



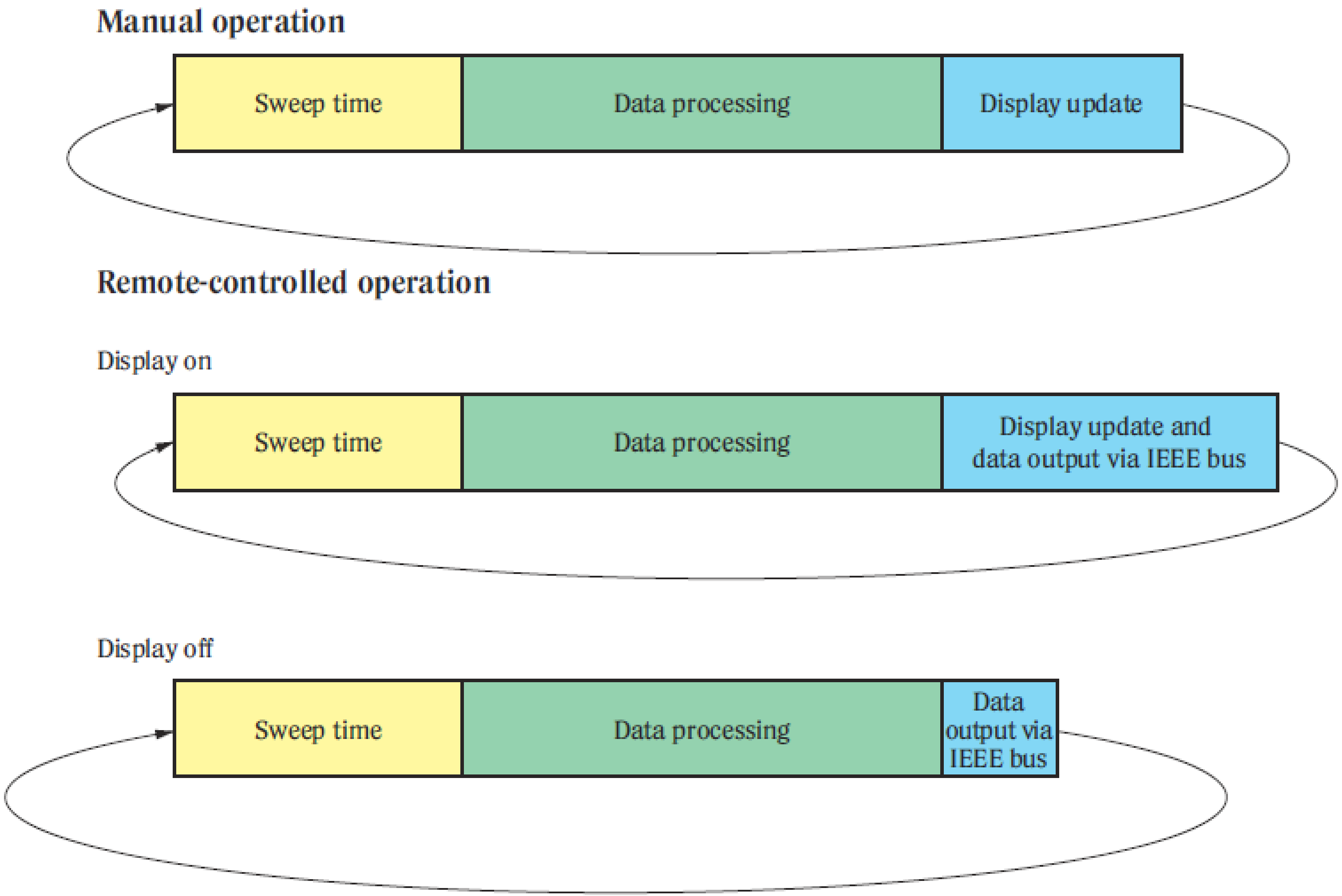


Merenje snage inherentnog šuma





Sekvence merenja



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