Agilent Technologies Training

Agilent
ESA 系列
通用频谱分析仪

安捷伦科技有限公司
电子仪器与系统集团
技术支援中心

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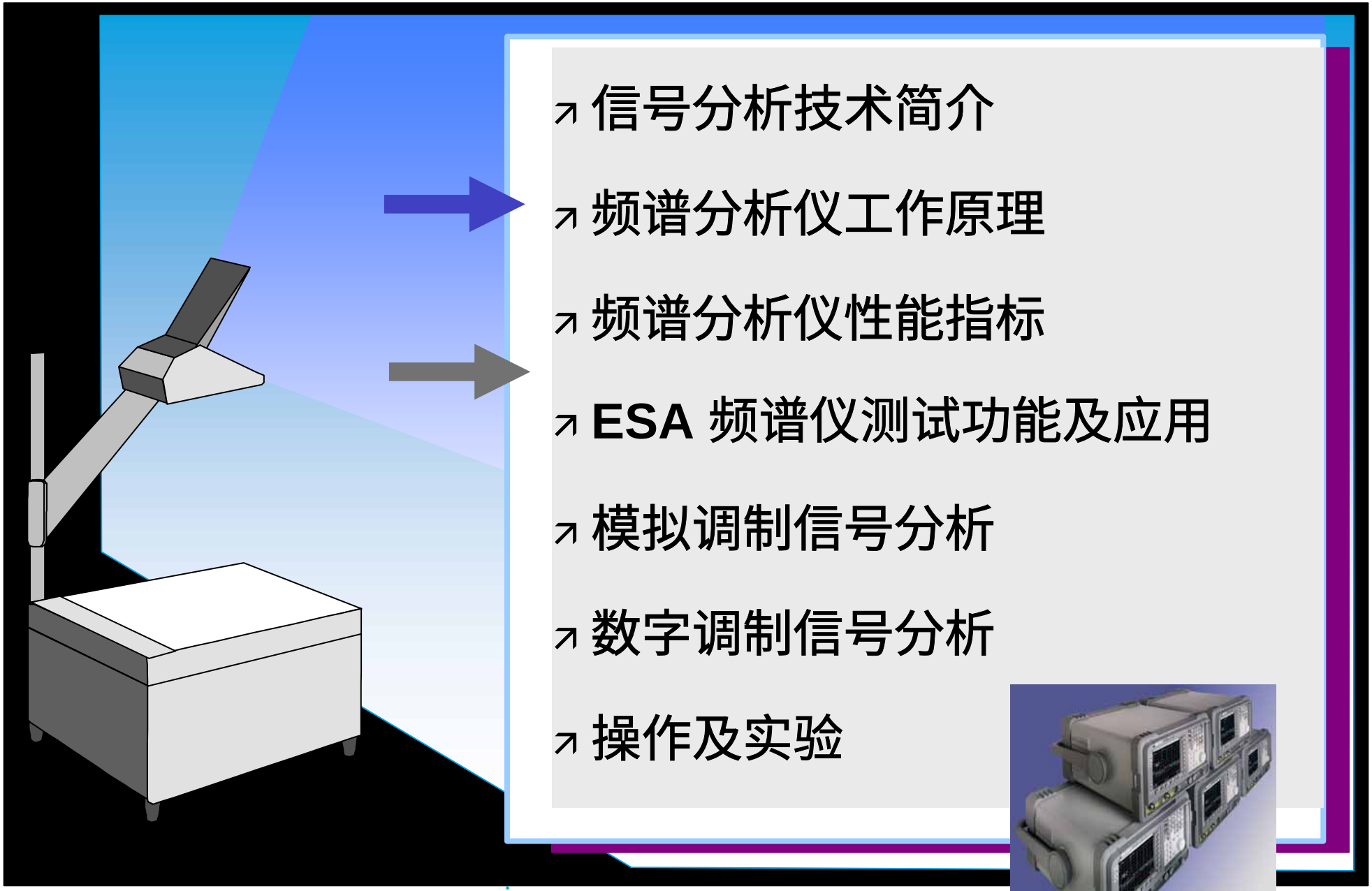
ESA 频谱分析仪课程内容



- 信号分析技术简介
- 频谱分析仪工作原理
- 频谱分析仪性能指标
- ESA 频谱仪测试功能及应用
- 模拟调制信号分析
- 数字调制信号分析
- 操作及实验

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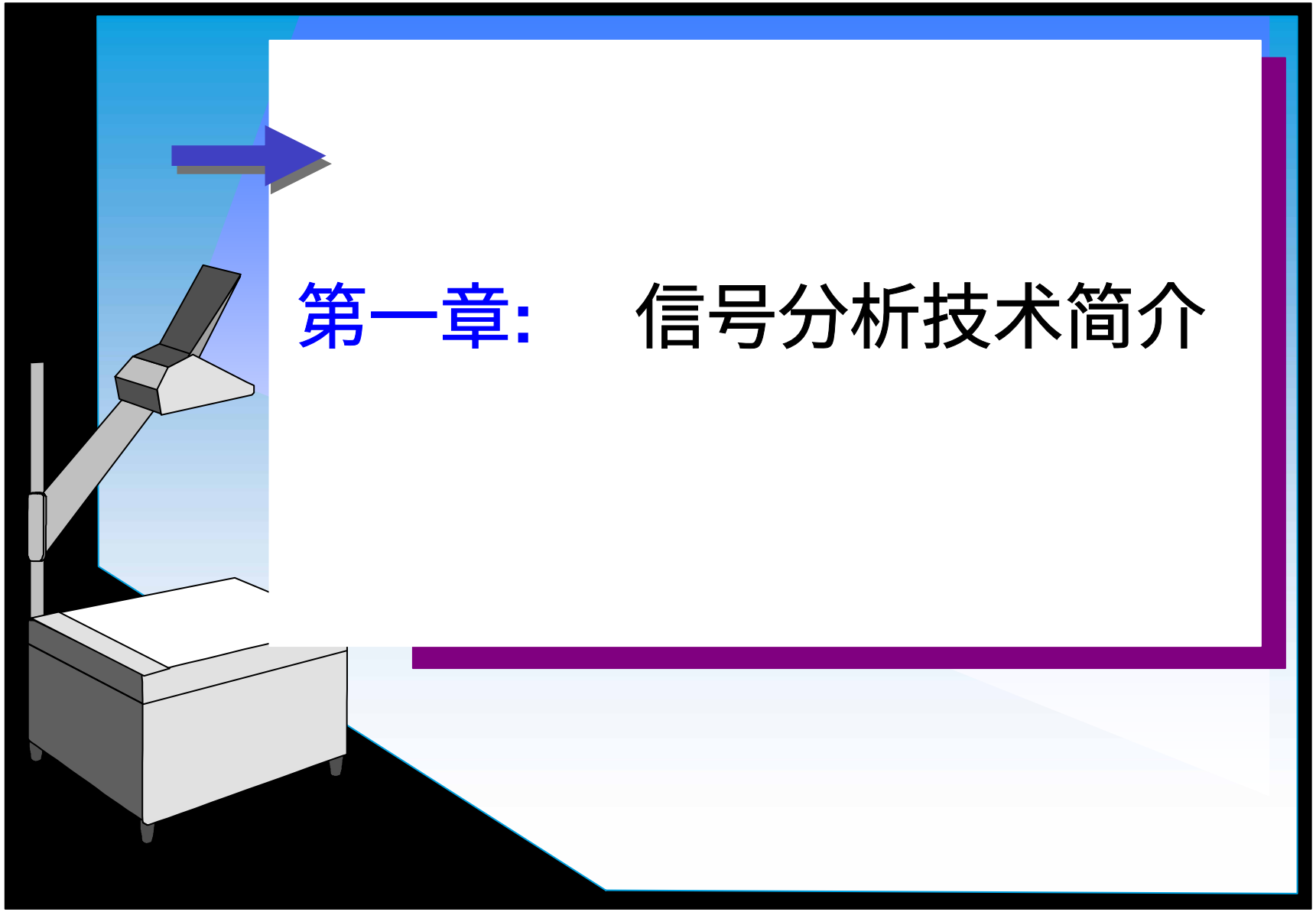
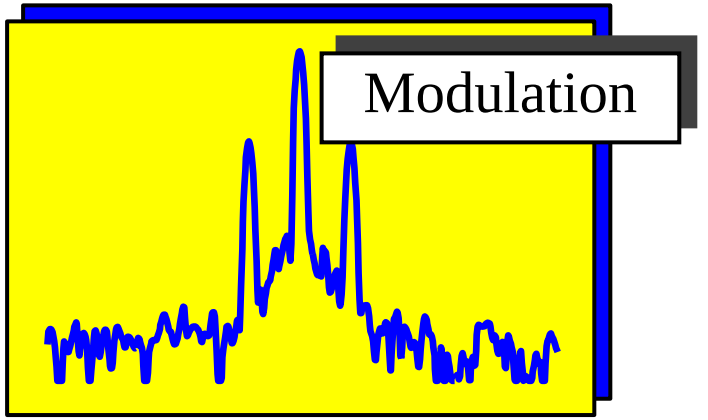
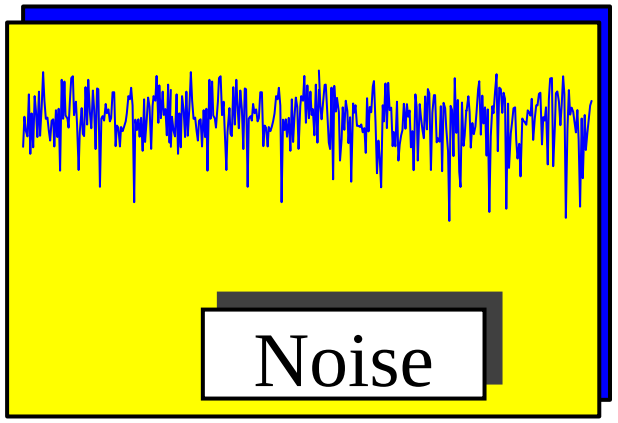


第一章:　信号分析技术简介

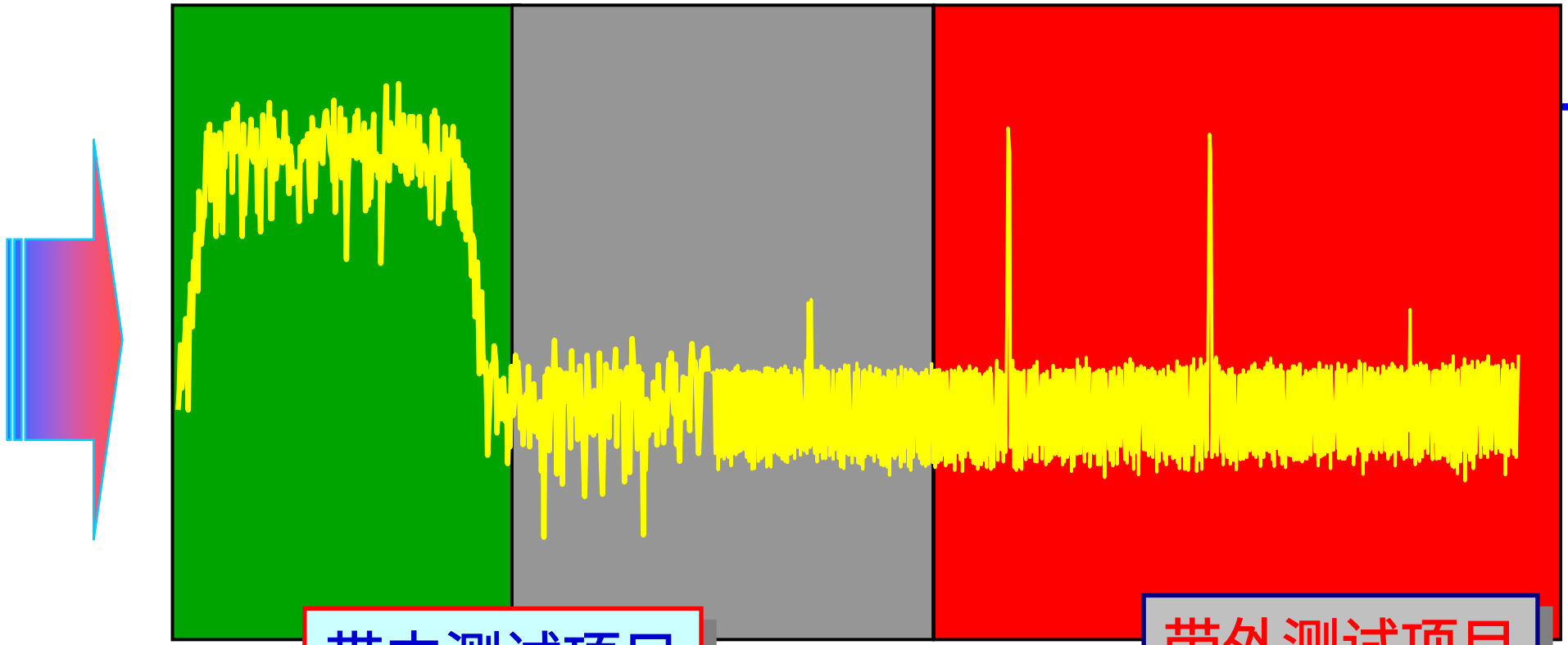
连续波信号
模拟调制信号
数字调制信号
噪声信号



时域分析
频域分析
调制域分析



完整的信号分析内容



频道内（In-channel）

- 信号频率
- 信号功率/时间，平均/峰值功率
- 调制精度

频道外（out of channel）

- 邻道功率比(ACPR)

- 谐波
- 远端杂波

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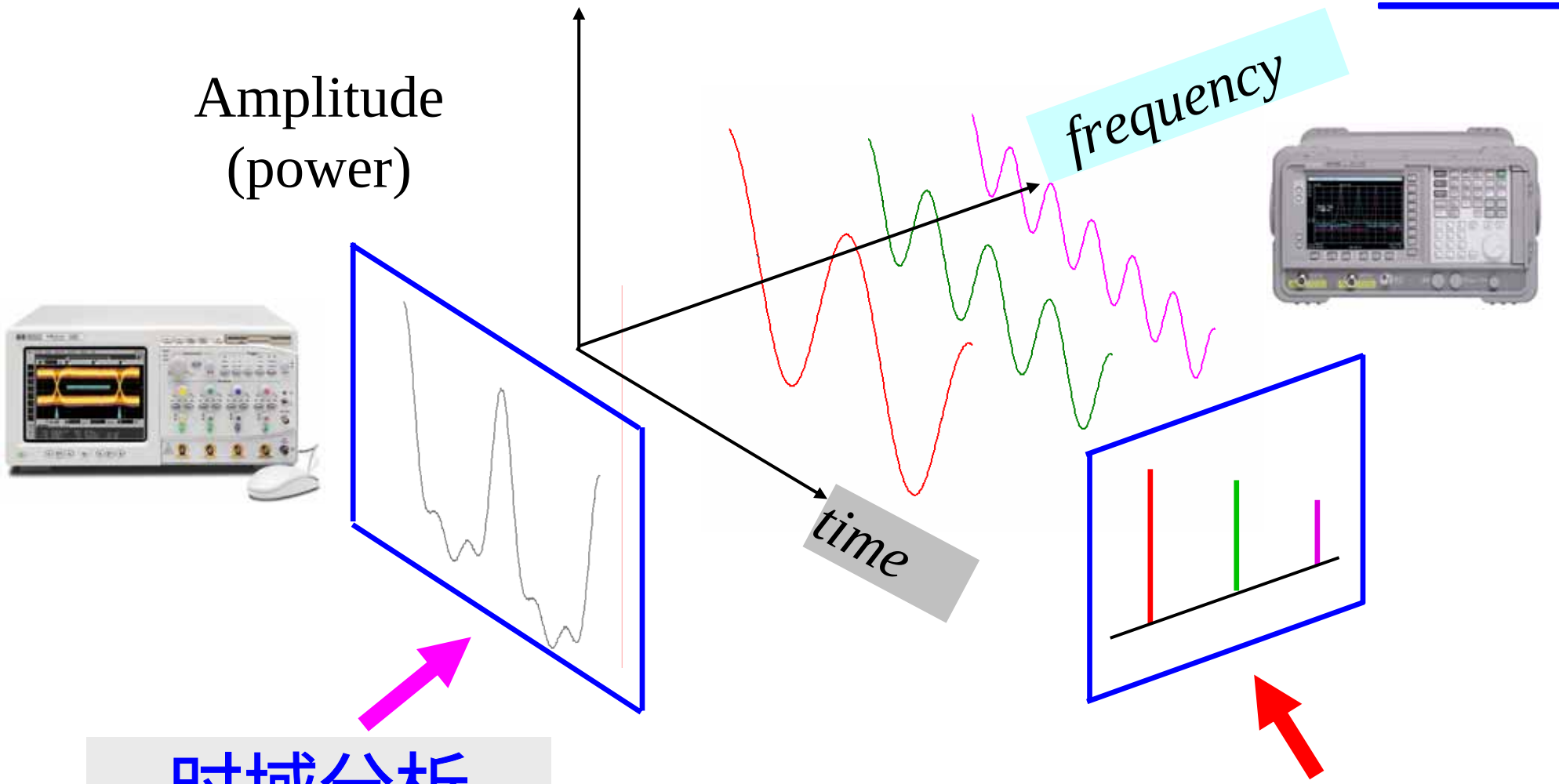
信号的基本分析方法



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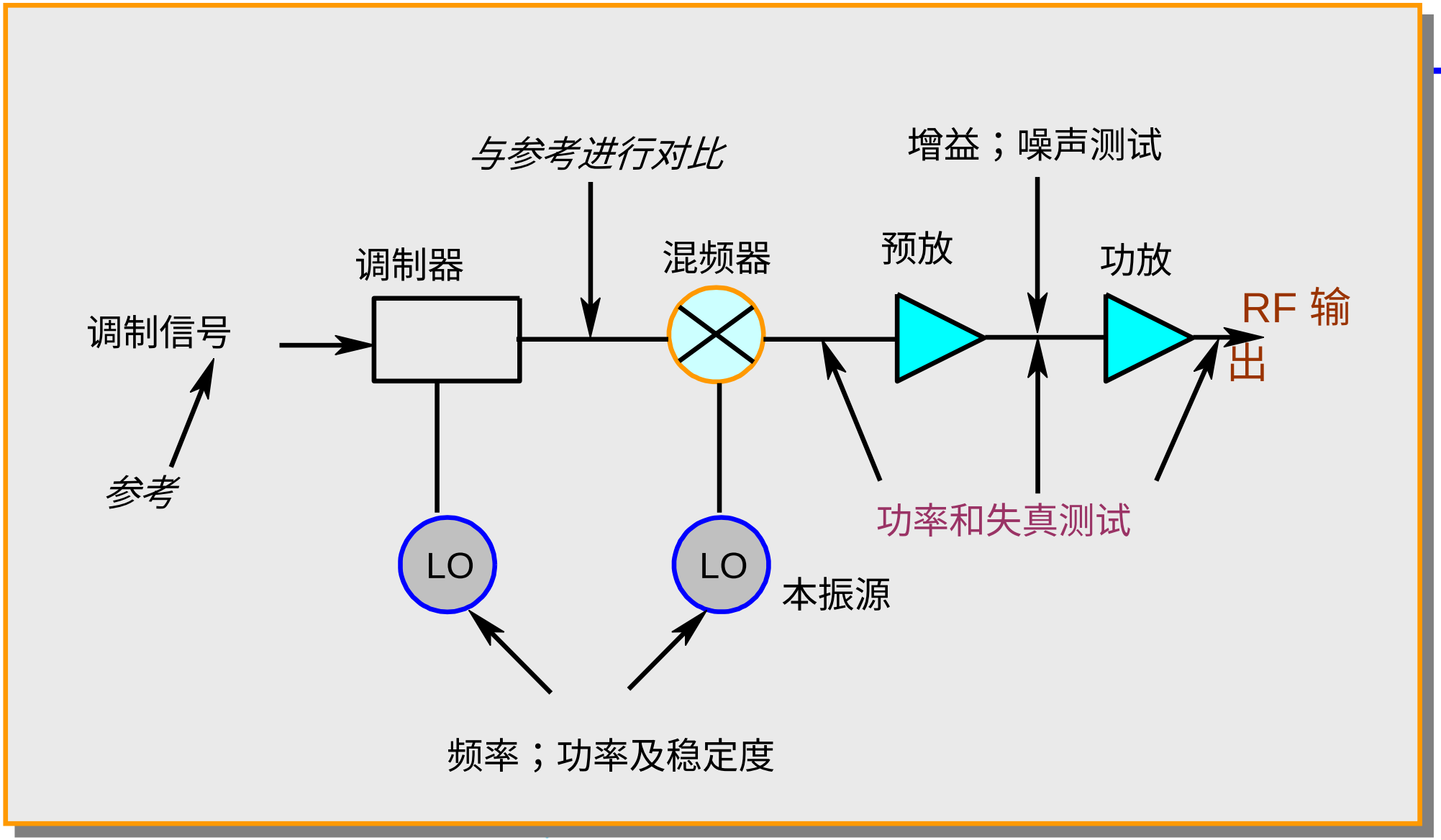
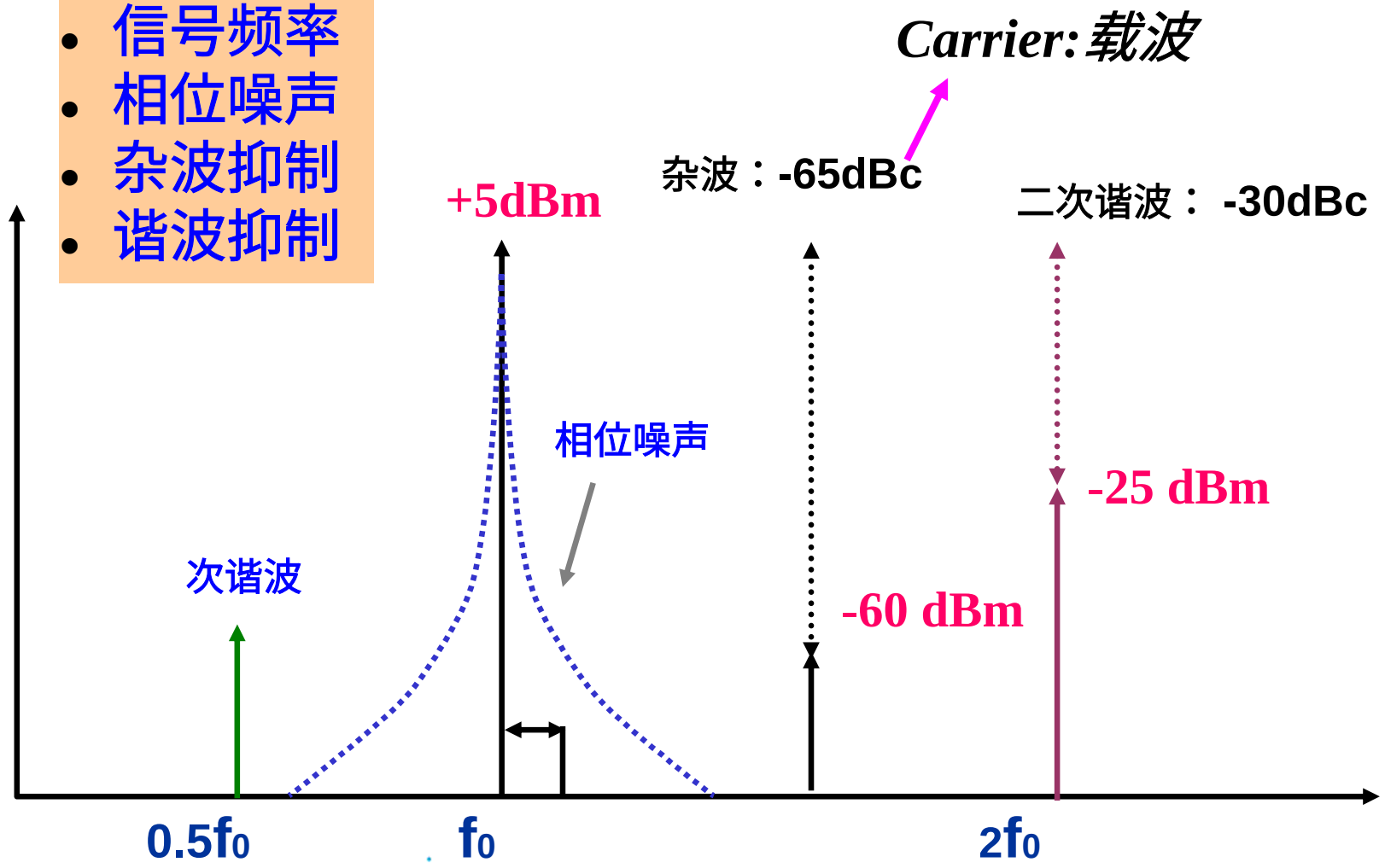
频谱分析仪典型应用



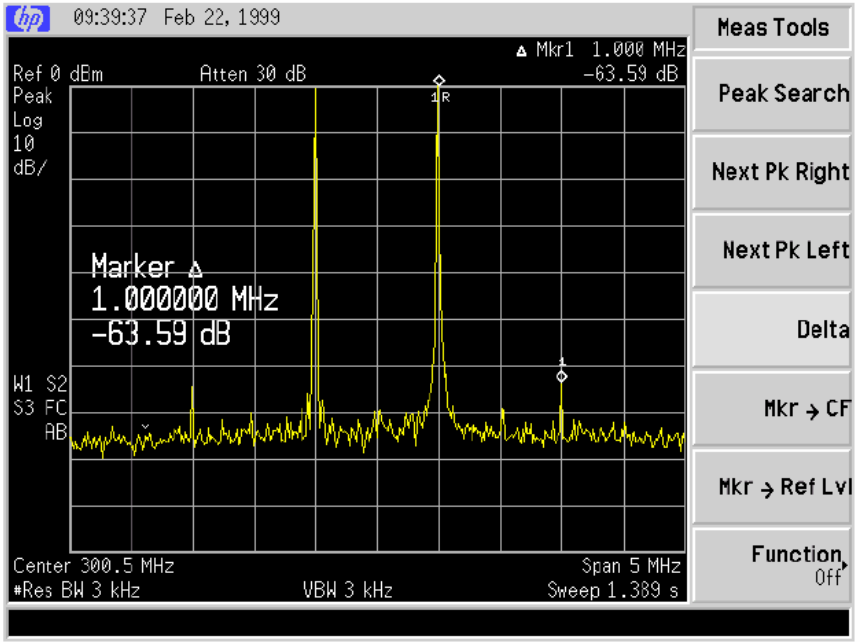
信号的频域指标

- 信号功率
- 信号频率
- 相位噪声
- 杂波抑制
- 谐波抑制

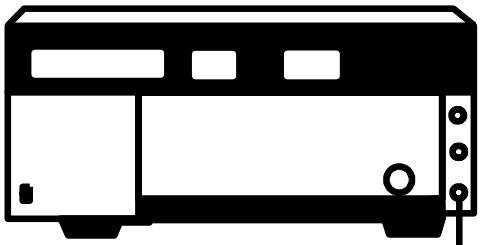


器件三阶交调性能测试

频谱仪

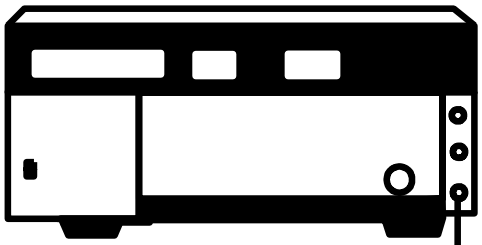


信号源1

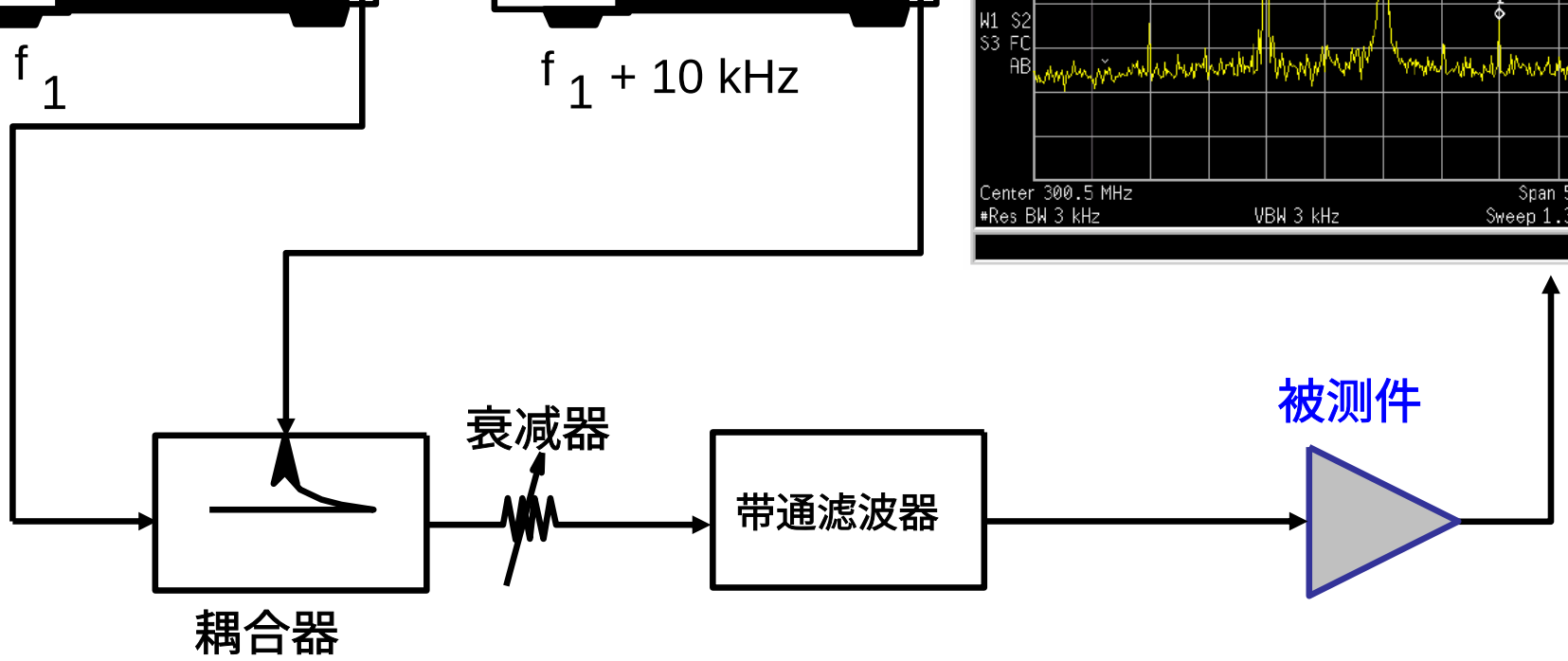


f_1

信号源2



f_1 + 10 kHz



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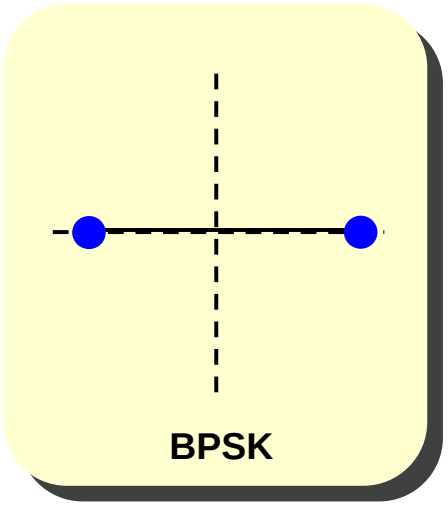
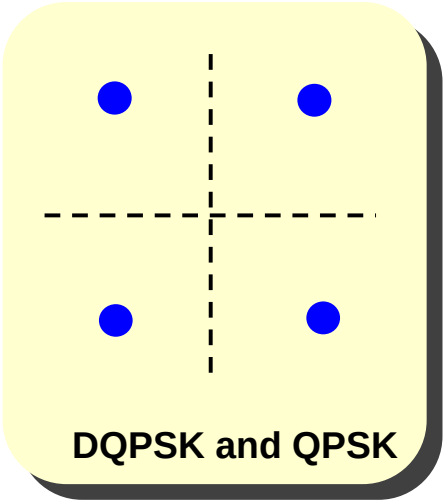
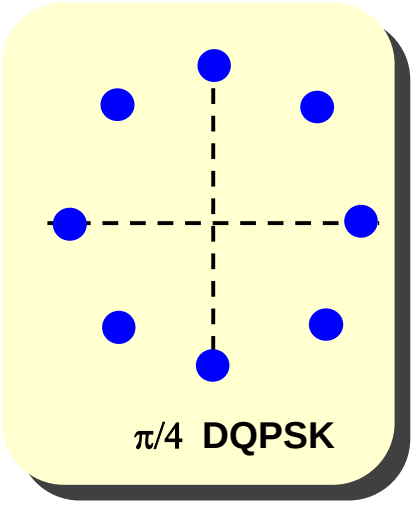
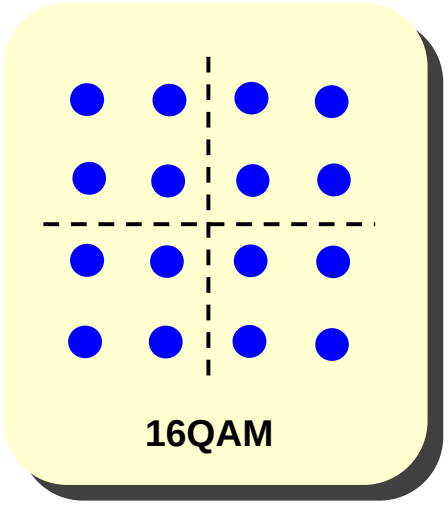
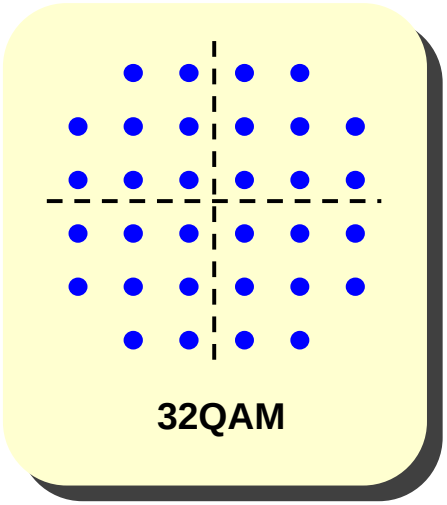
调制信号的矢量描述

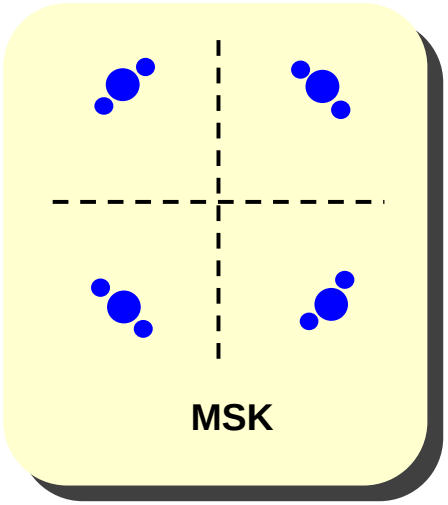


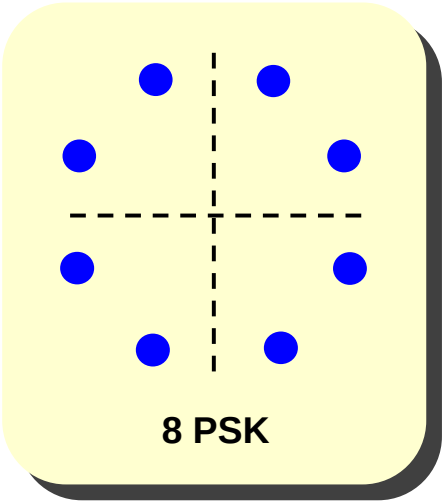




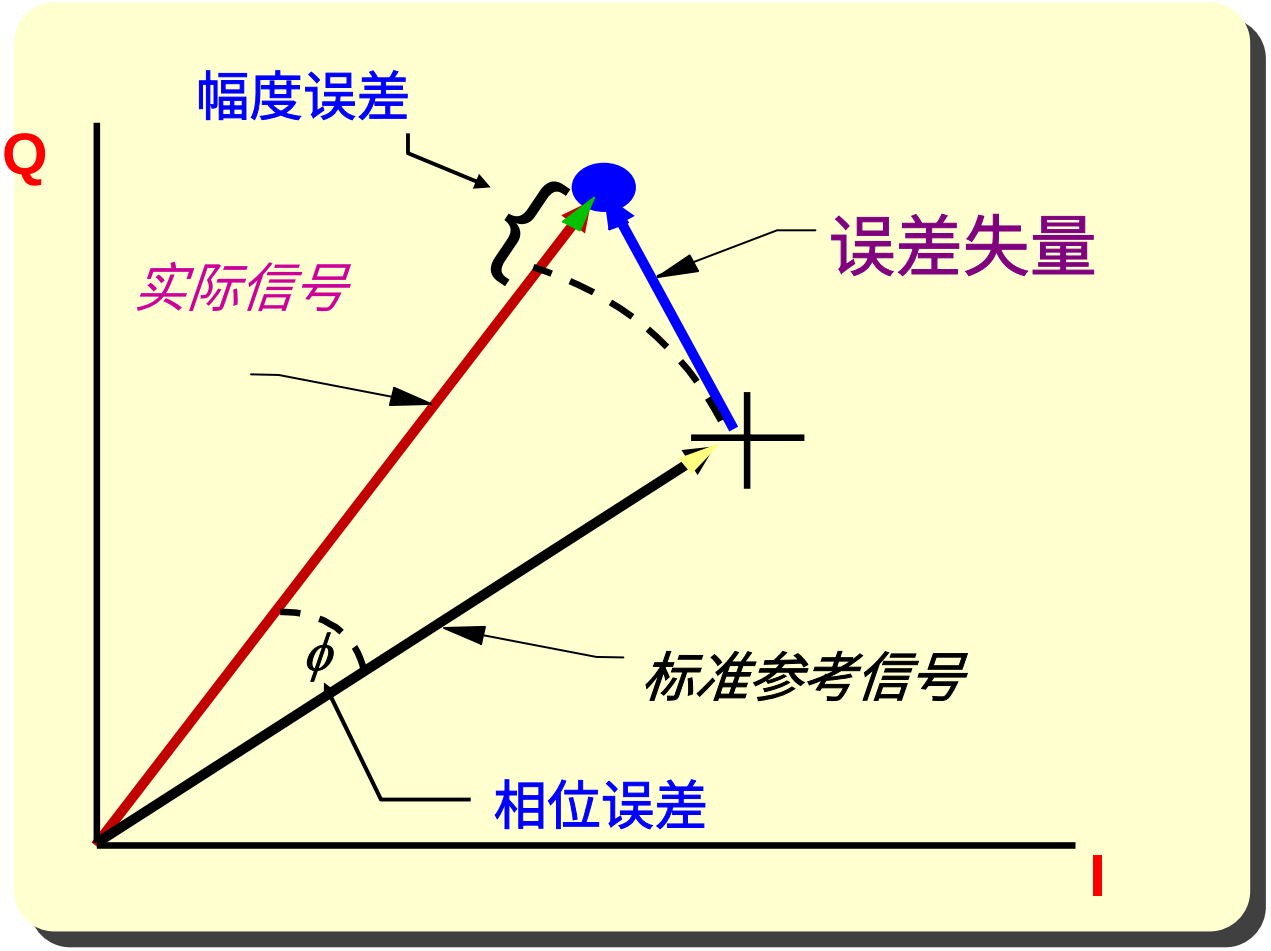








调制信号的误差



Error Vector Magnitude **(EVM)** = $\frac{\text{(average error magnitude)}}{\text{(maximum symbol magnitude)}}$ **x 100%**

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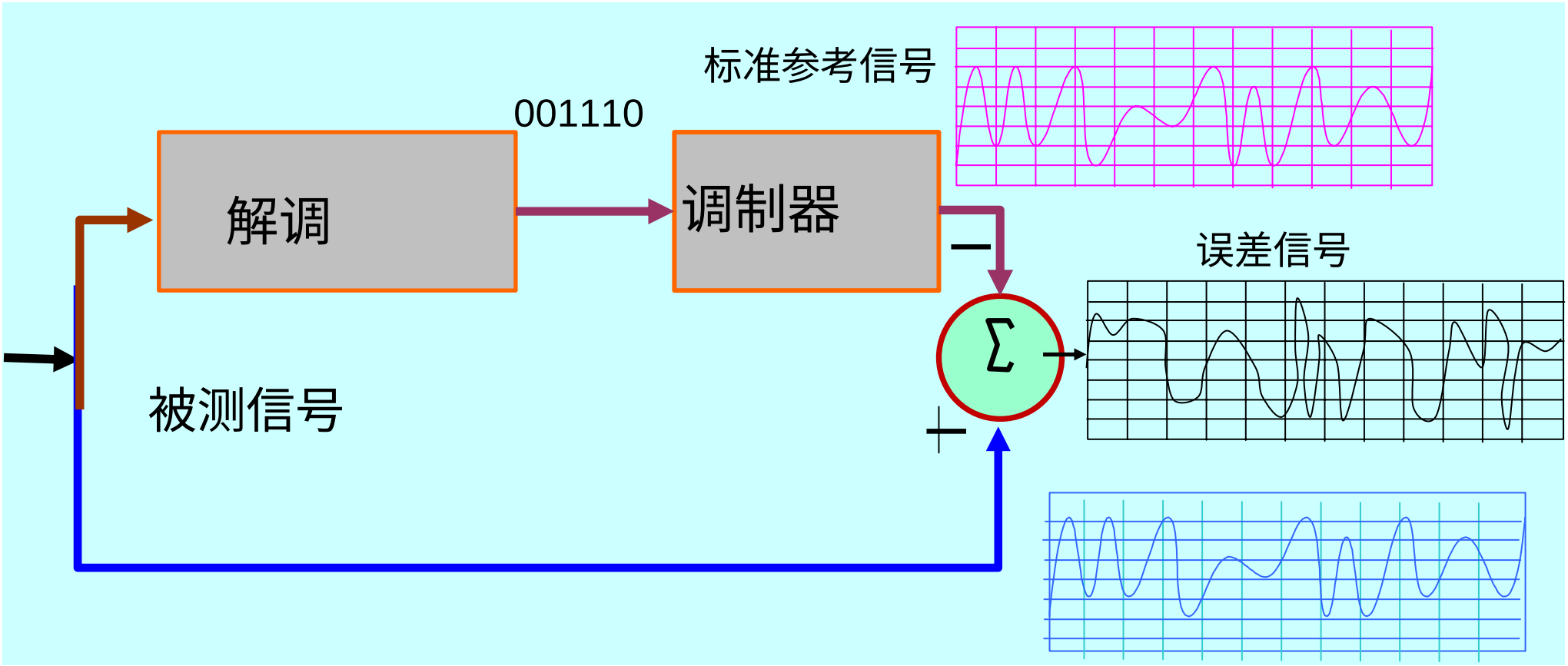
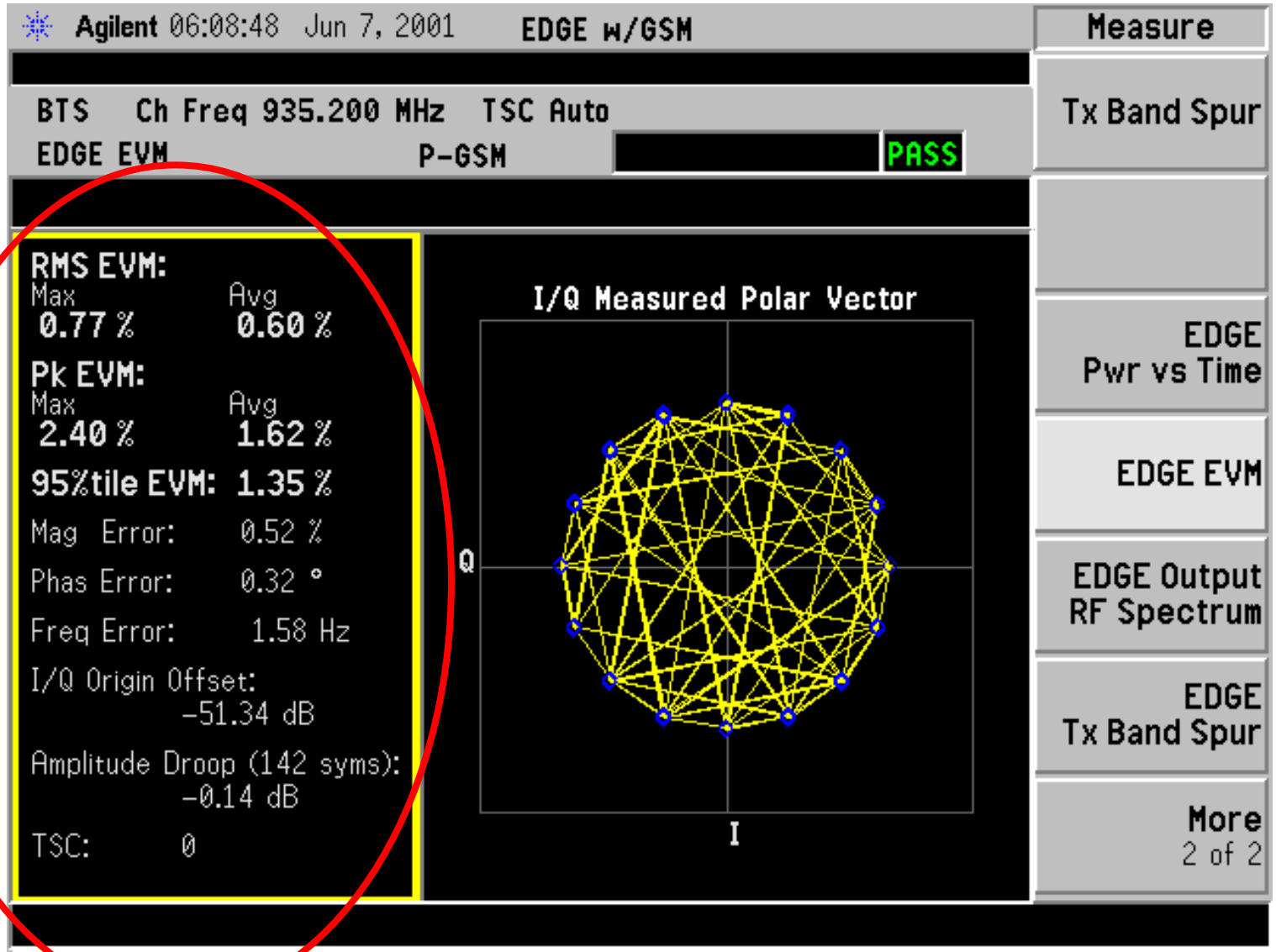
调制信号精度分析过程



调制信号精度测试



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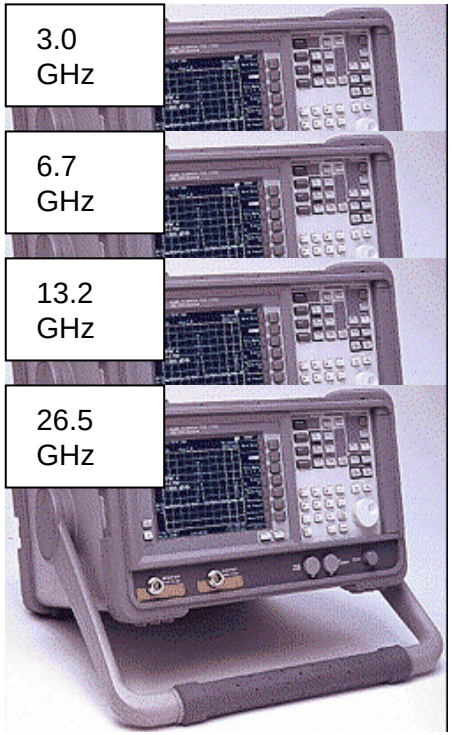
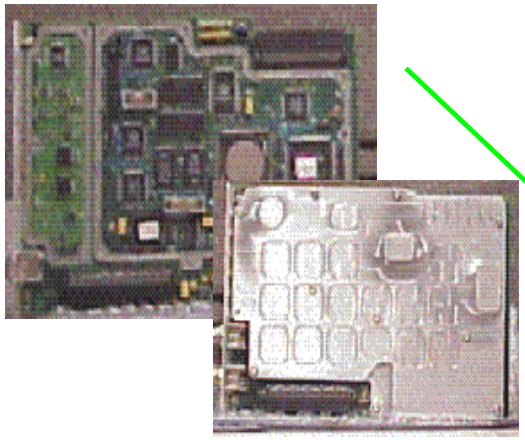
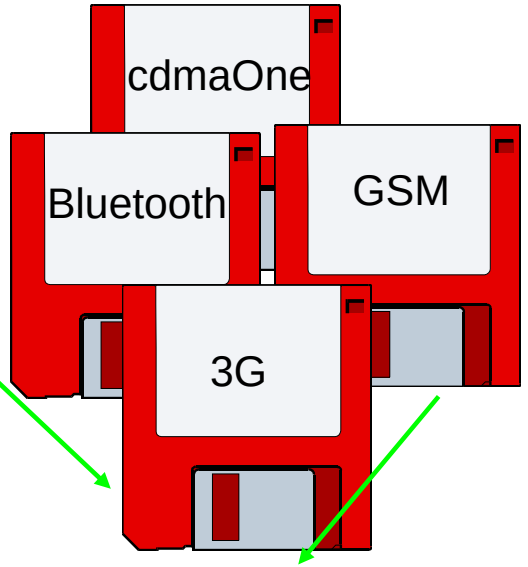
ESA的数字调制信号分析能力

ESA-E Series Spectrum Analyzer + Digital demod hardware + Measurement Personality







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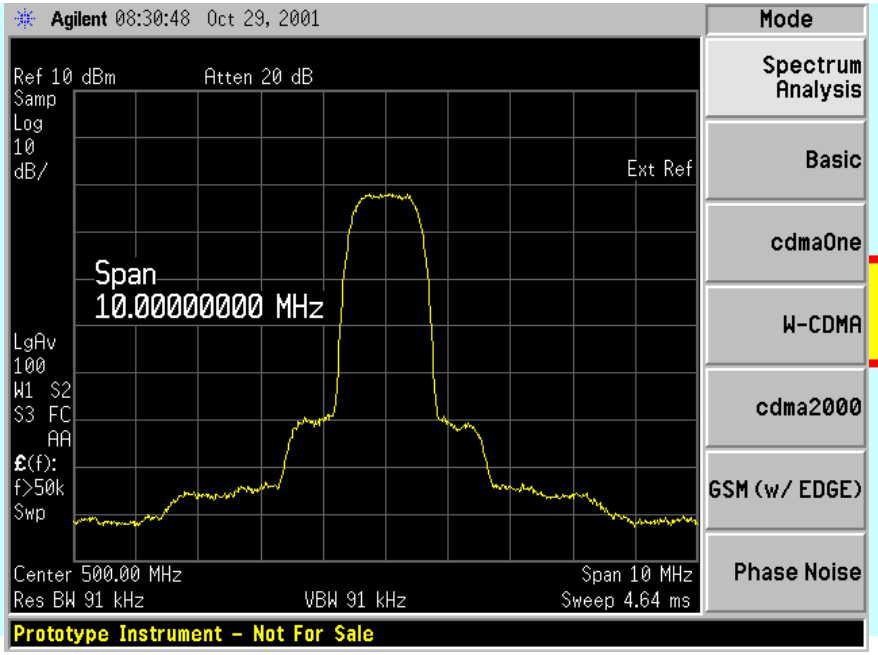
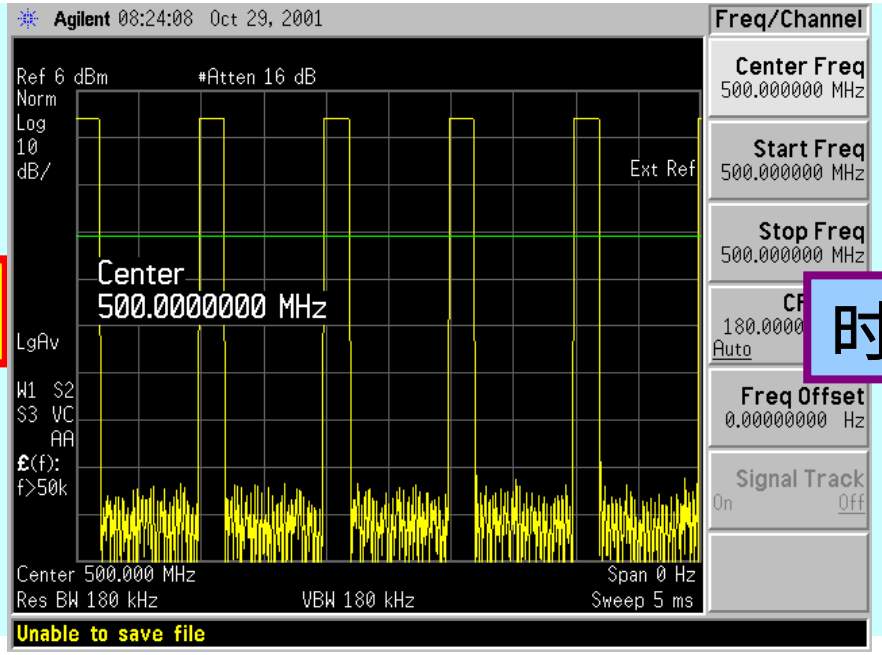
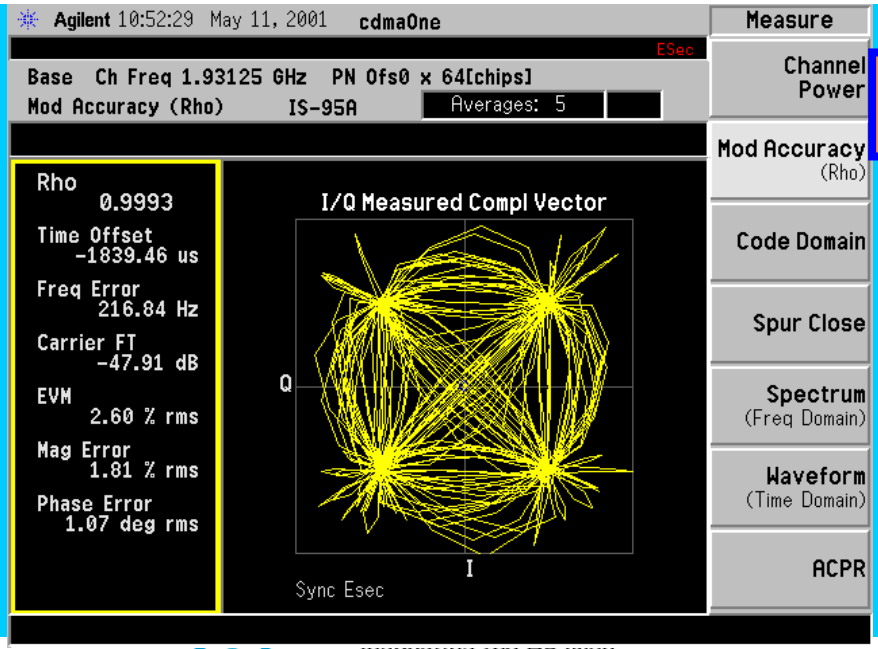
ESA 分析功能



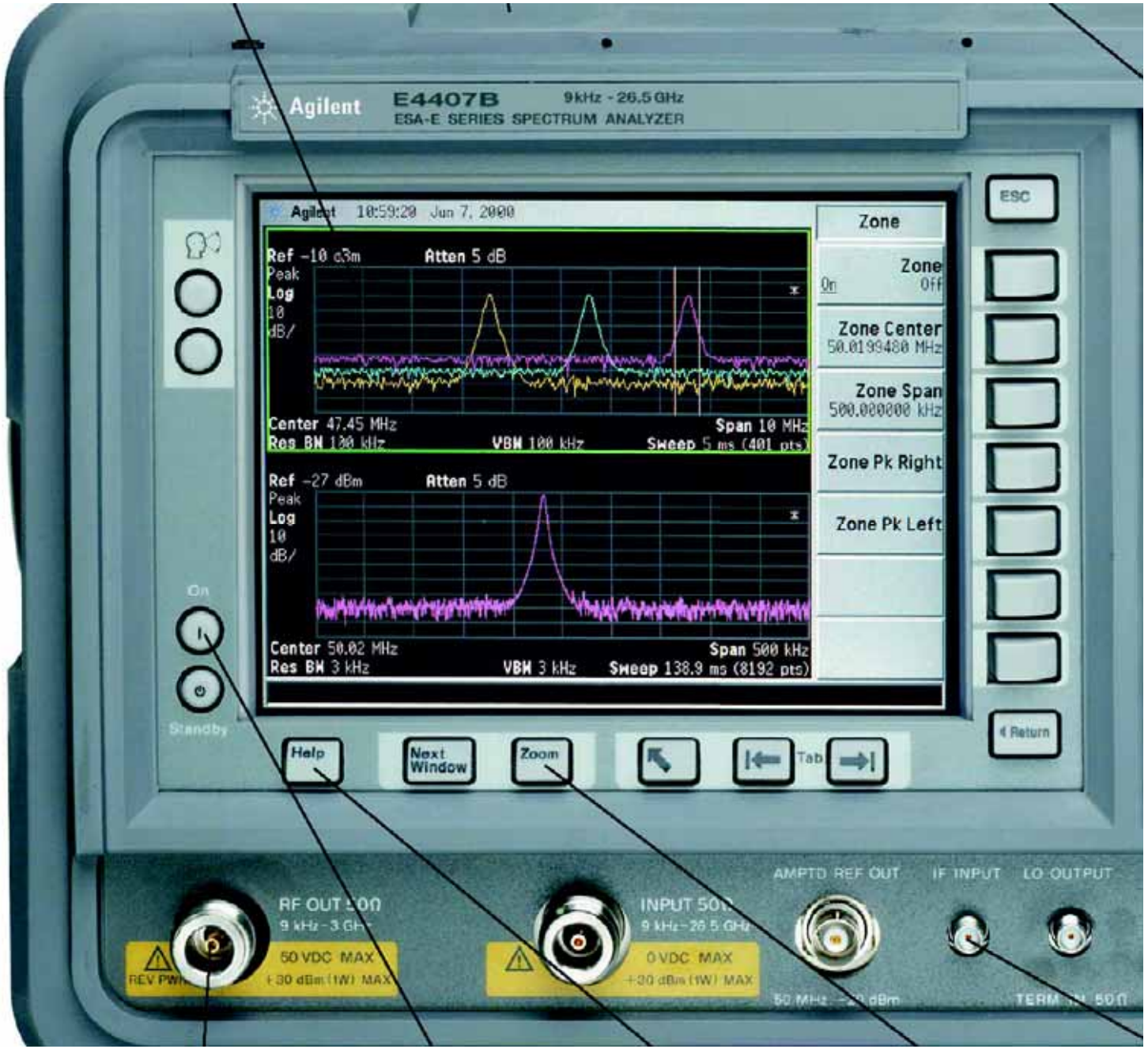
频域



时域



解调域



ESA
显示面板

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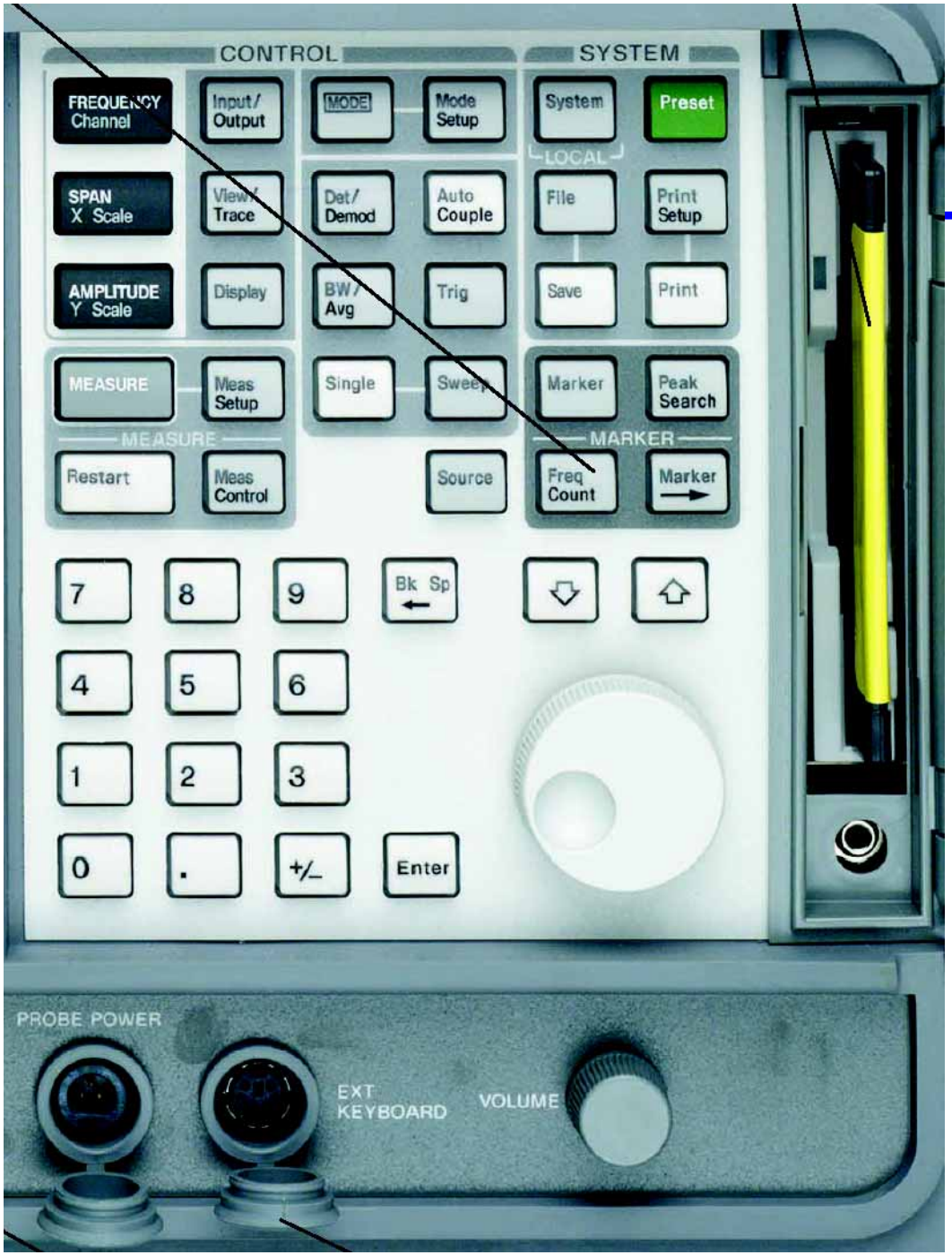
ESA
操作面板



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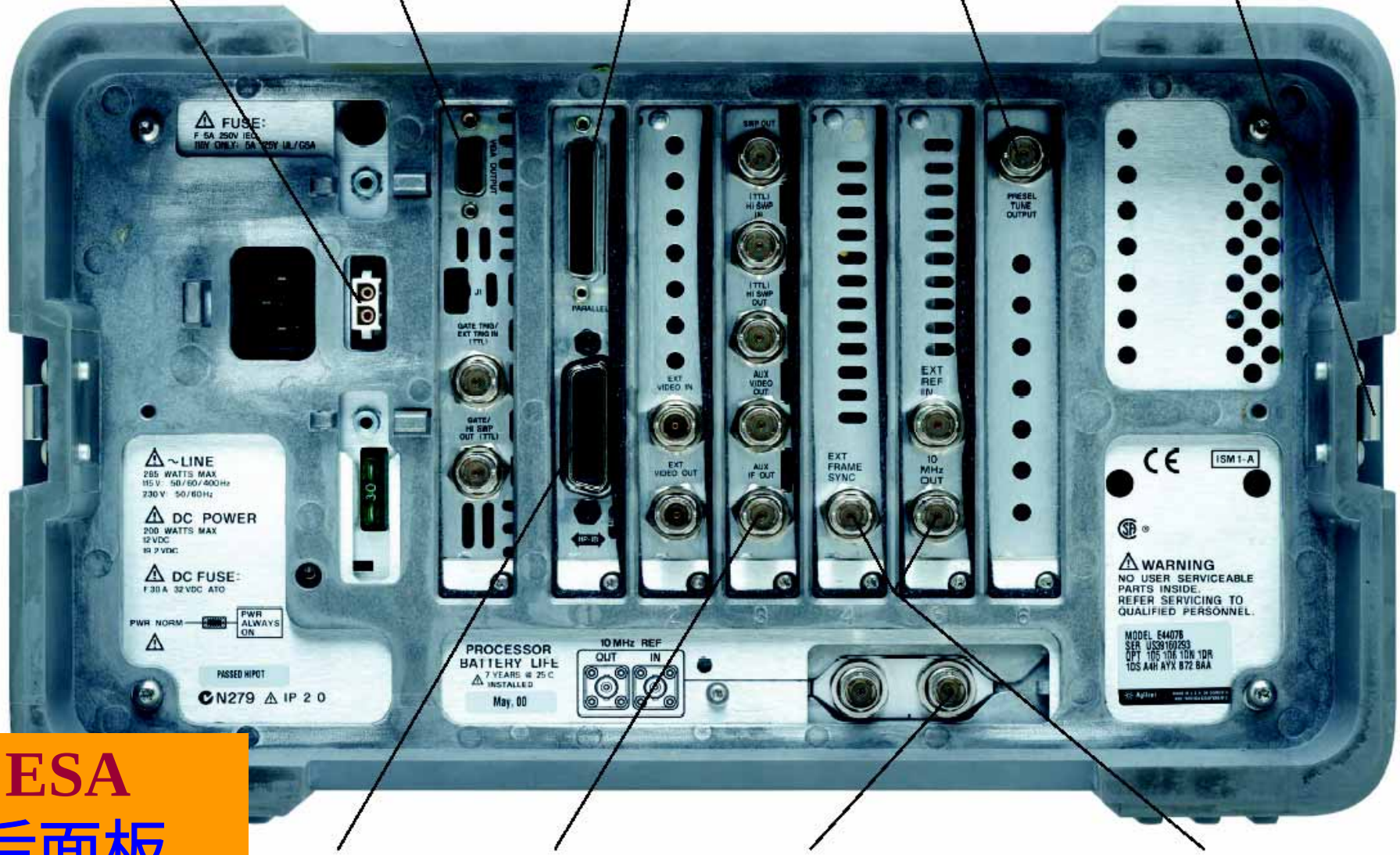
12 Vdc operation from automotive batteries.

Add an external VGA color monitor.

Parallel port supports most HP printers (optional).

Supports Agilent preselected external mixers (optional).

Snap-on battery pack for portability (optional).



ESA
后面板

High speed GPIB interface (optional).

Input signal down converted to 21.4 MHz. (optional).

Use a external frequency reference for even more accuracy.

Digital demodulation hardware for current and future communications systems (optional).

技术小结

⇩ 根据信号的特性，可将信号分为：

非调制连续波信号（CW信号）；调制信号

⇩ 根据存在形式，信号可分为：

连续稳定信号； 周期变化信号（例如：脉冲TDMA信号）；瞬变信号等

⇩ 分析CW信号可利用时域和频域分析法；

⇩ 分析调制信号精度需进行解调分析；

⇩ 分析周期变化信号，需利用选时分析能力；

⇩ 分析瞬变信号，需具备存储分析功能。

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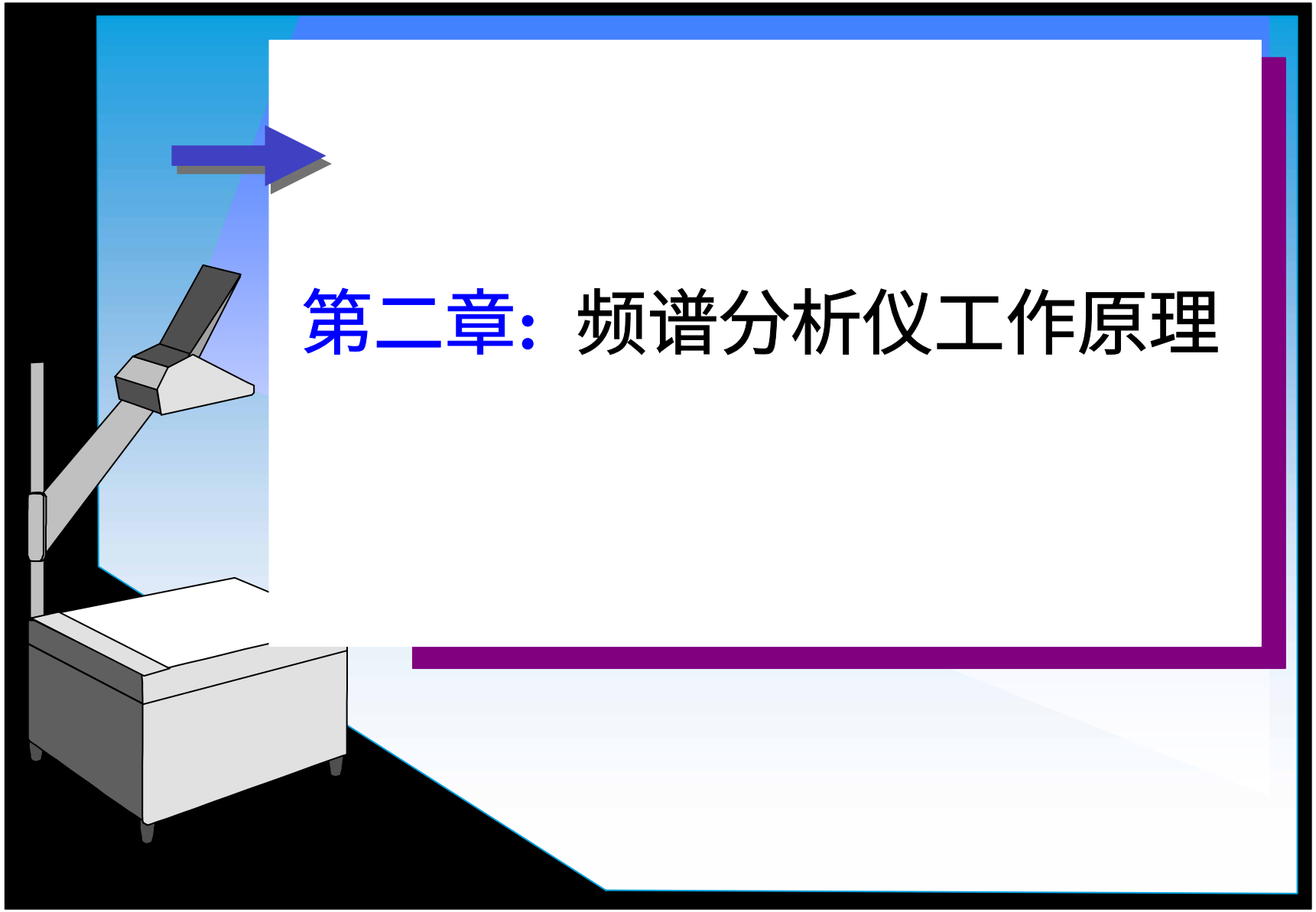
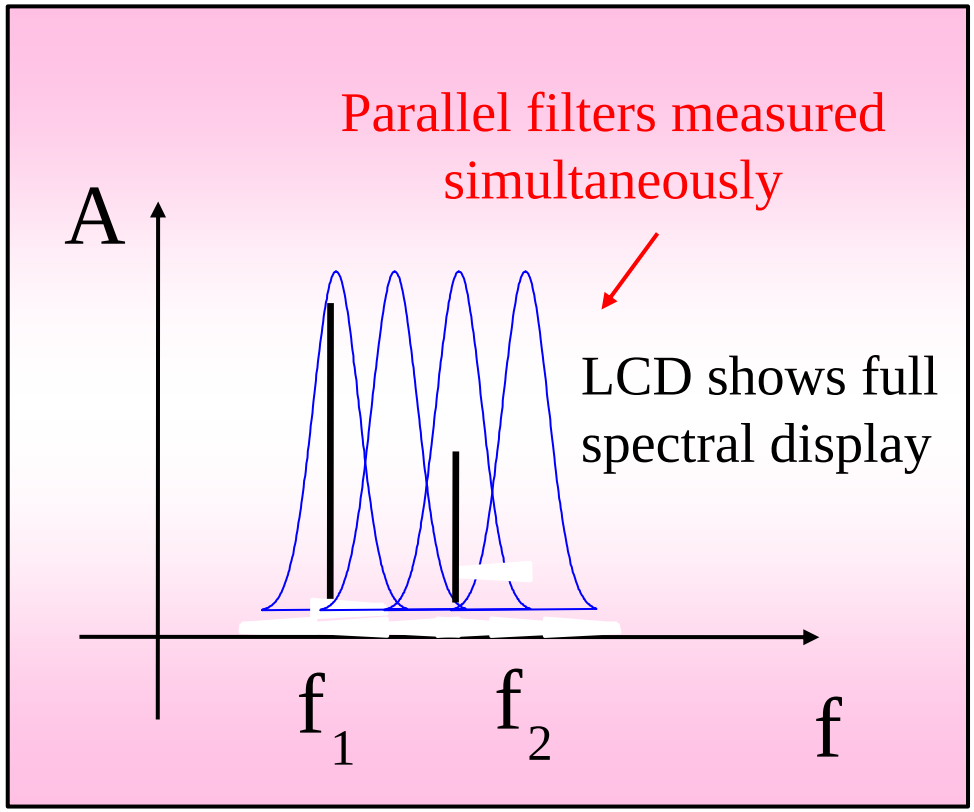


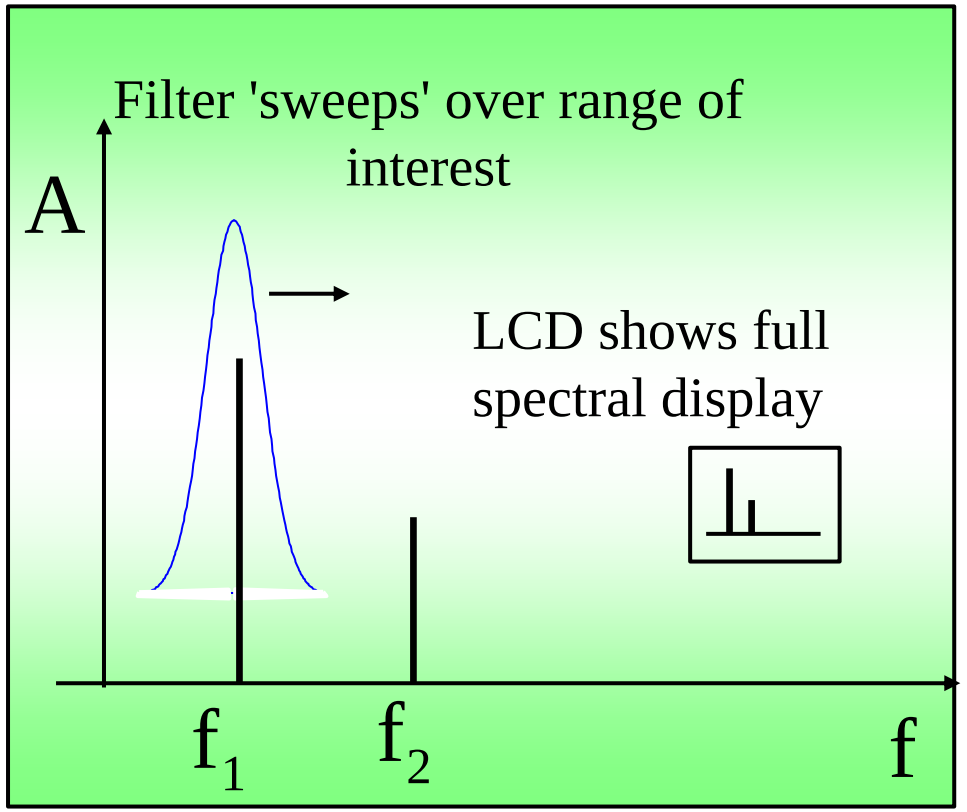
第二章：频谱分析仪工作原理

信号频域分析技术

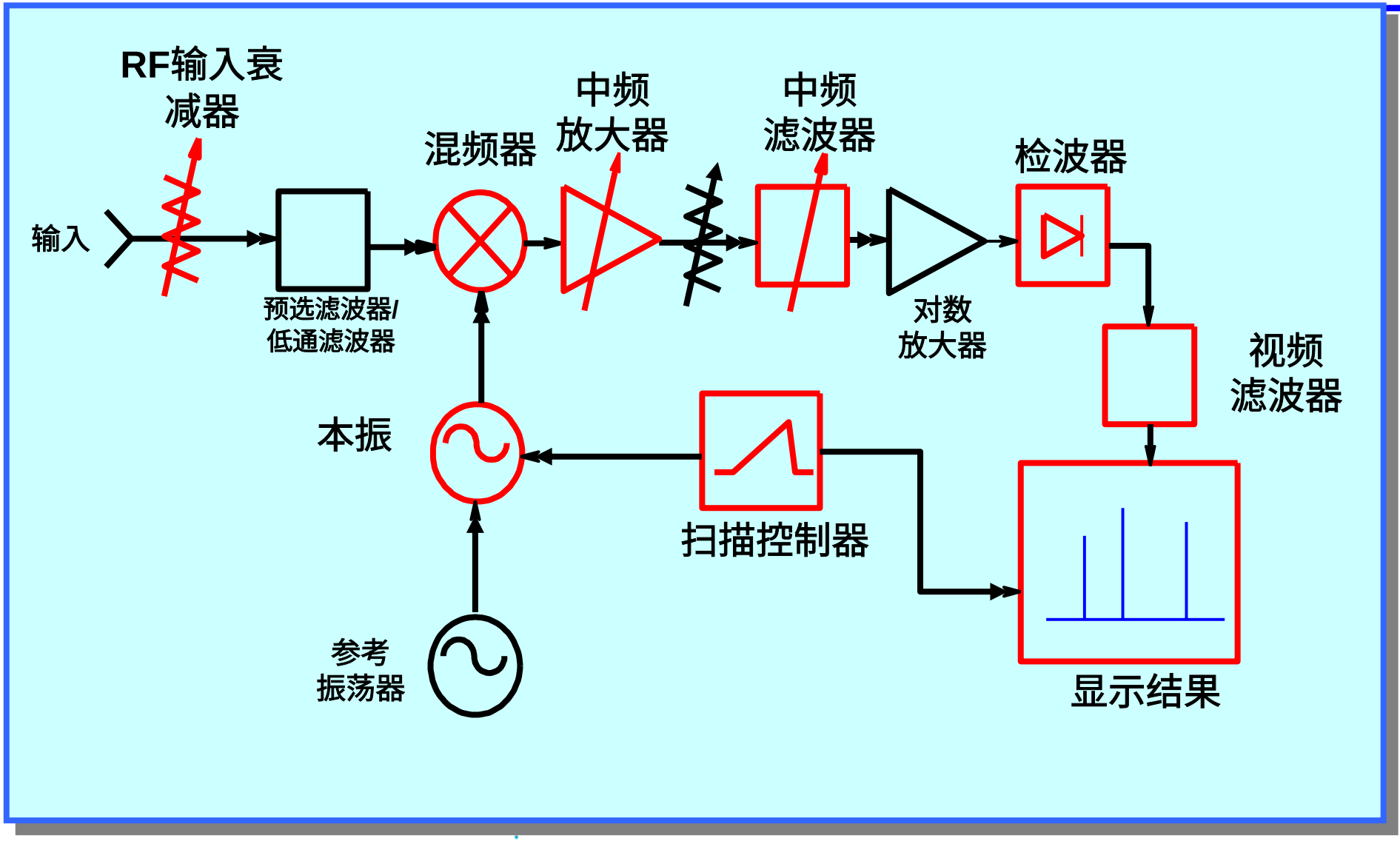
FFT(快速傅立叶变换)



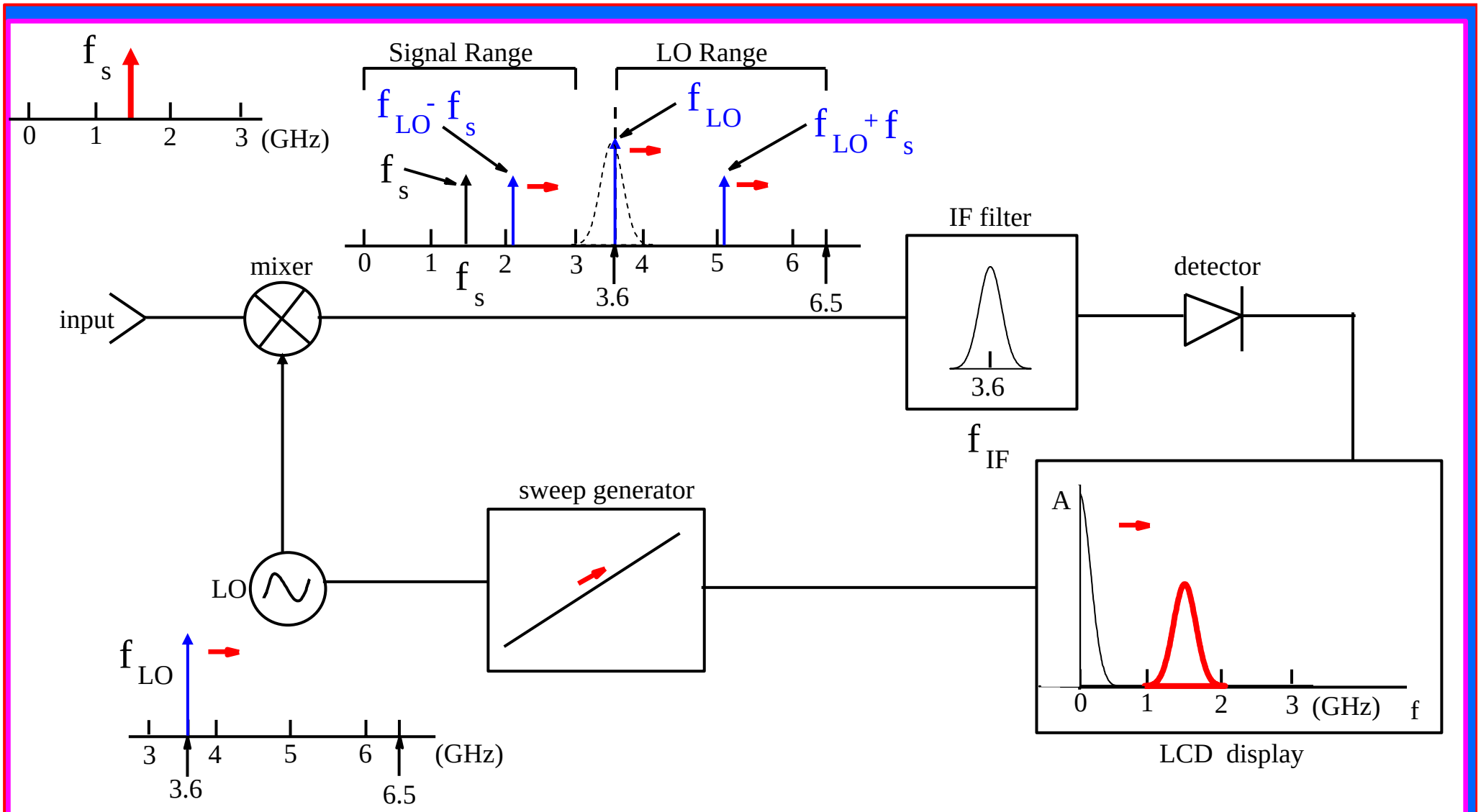
扫频频谱仪



扫频式频谱仪组成框图

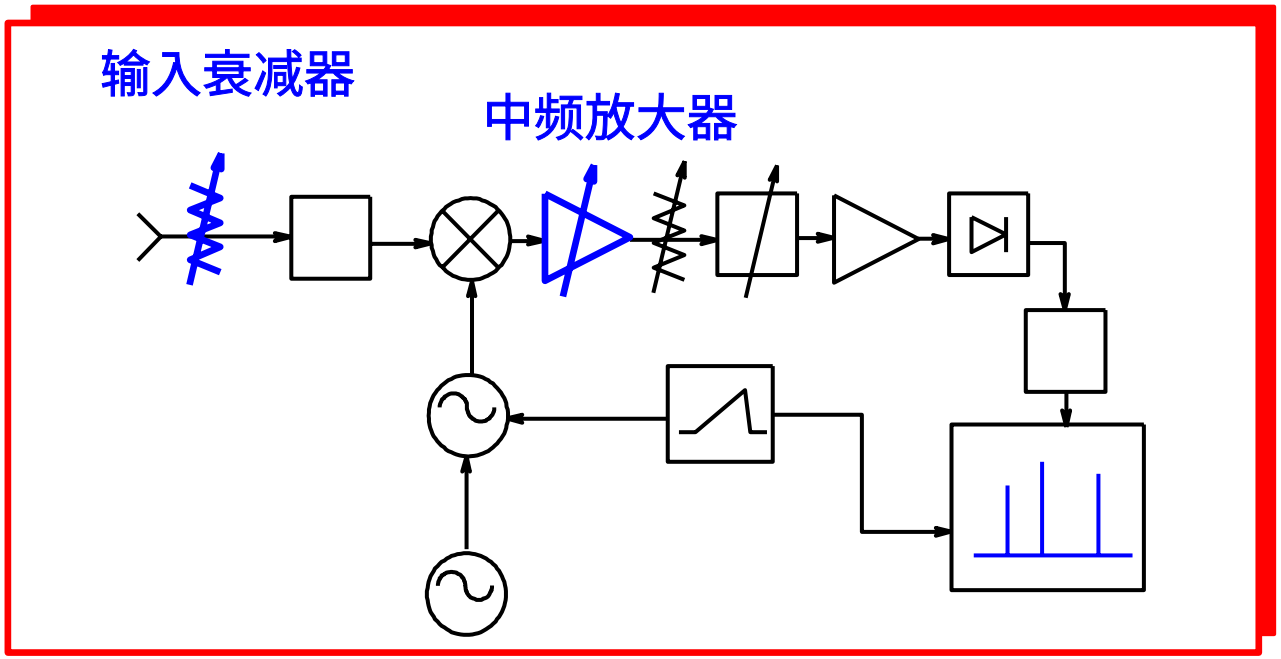

RF输入衰减器
输入
预选滤波器/低通滤波器
混频器
中频放大器
中频滤波器
对数放大器
检波器
视频滤波器
本振
扫描控制器
参考振荡器
显示结果

扫频式频谱仪工作过程

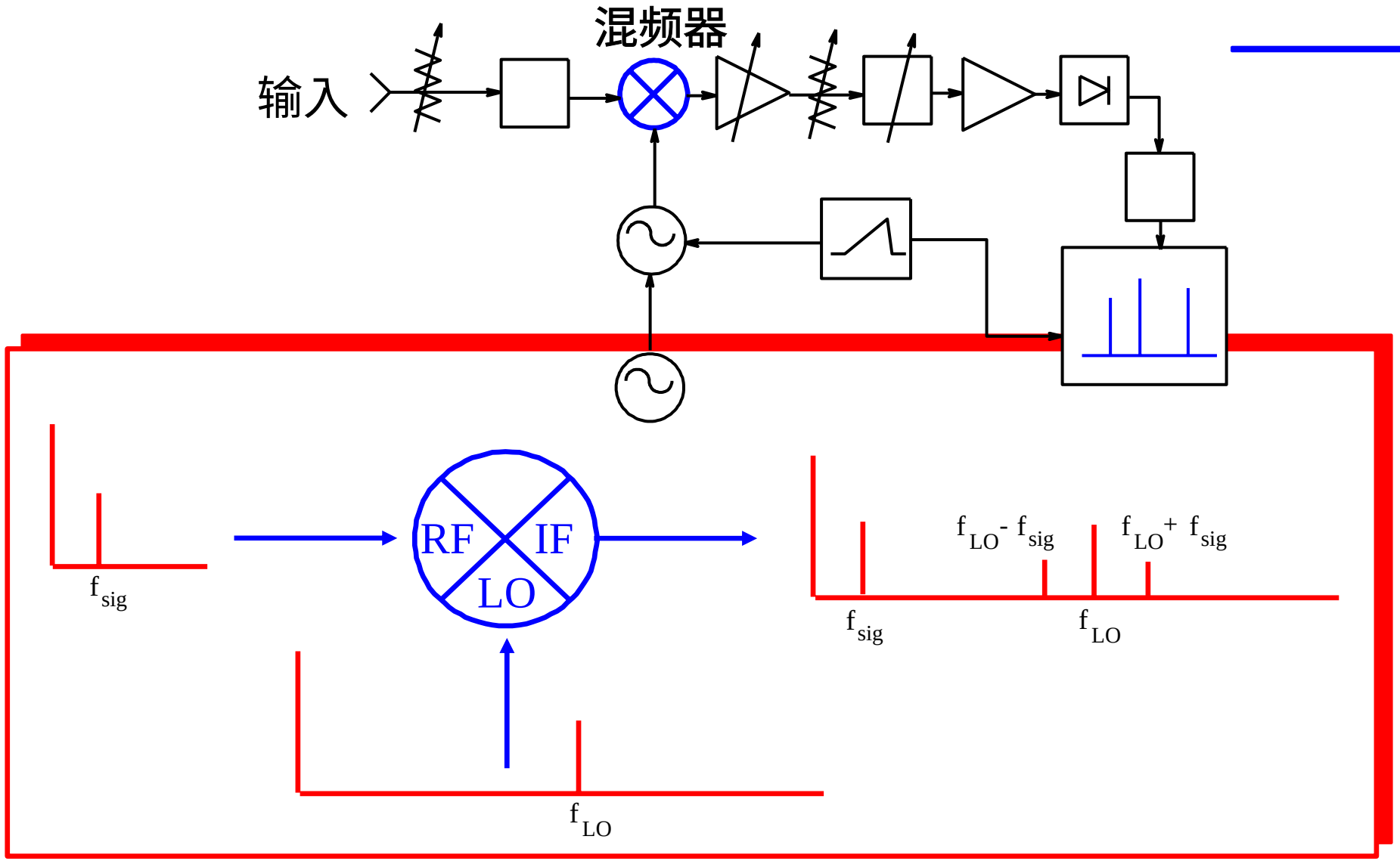


单点频信号在频谱上测试显示结果为中频滤波器的频响形状

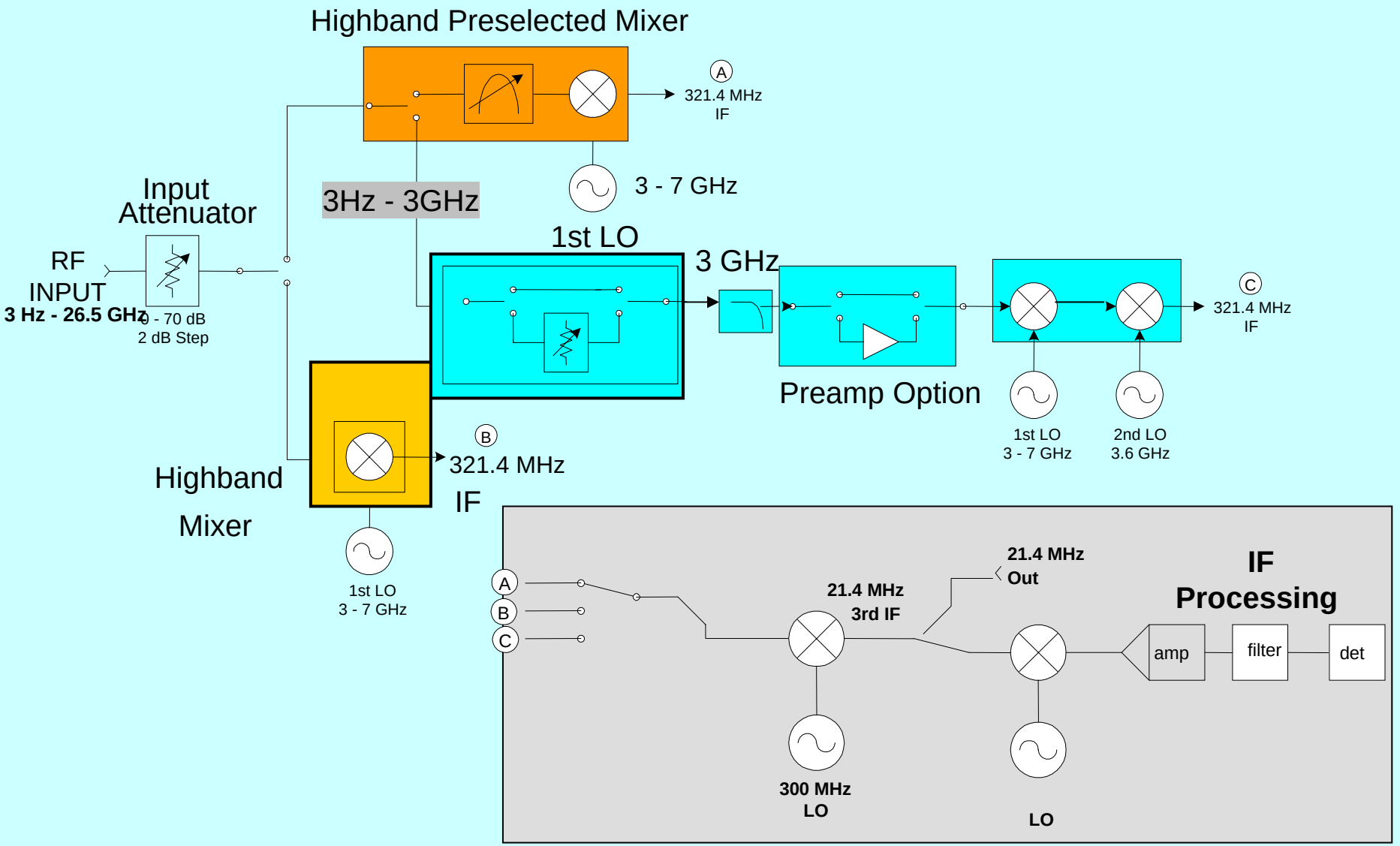
输入衰减器



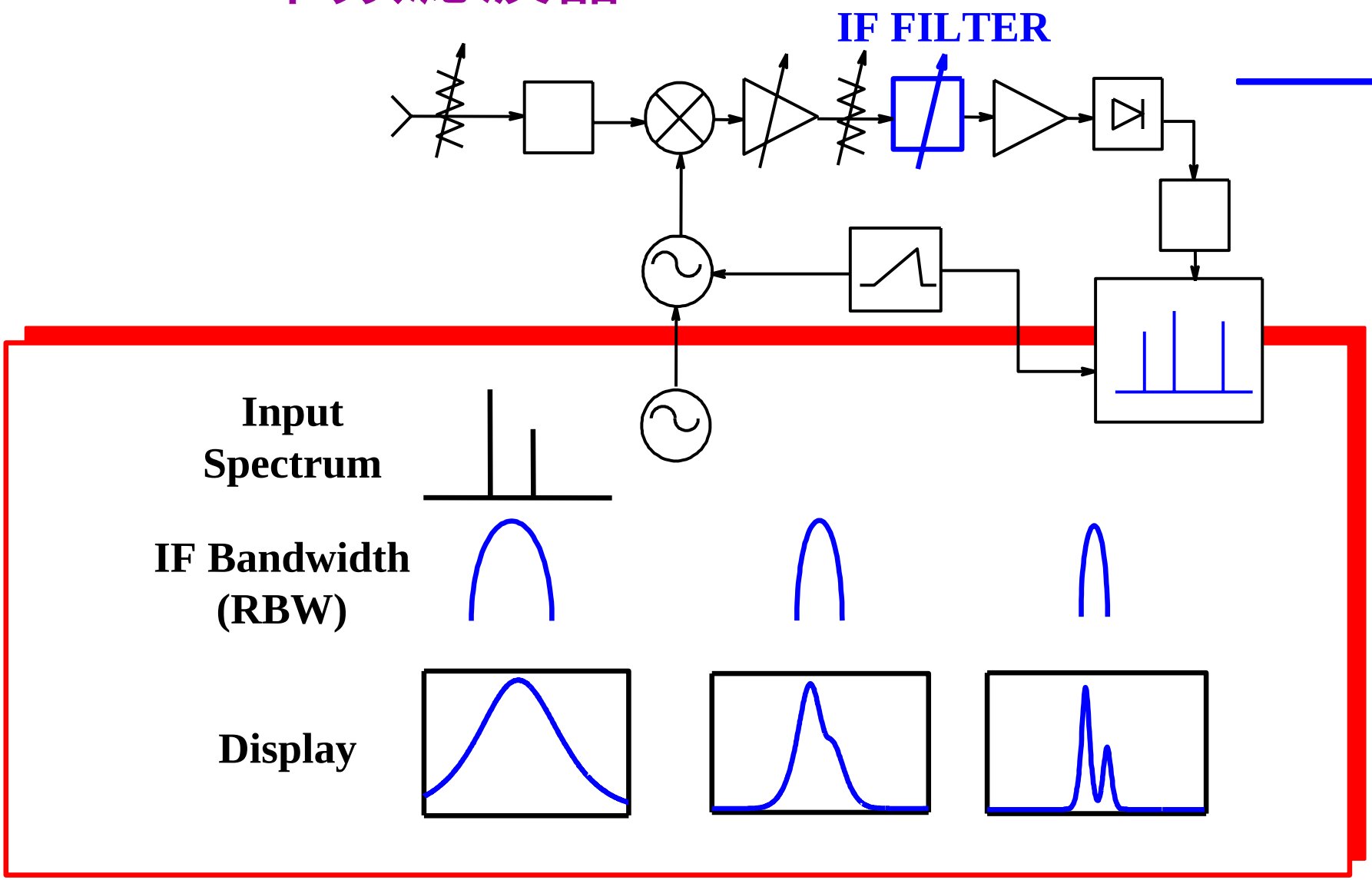
混频器



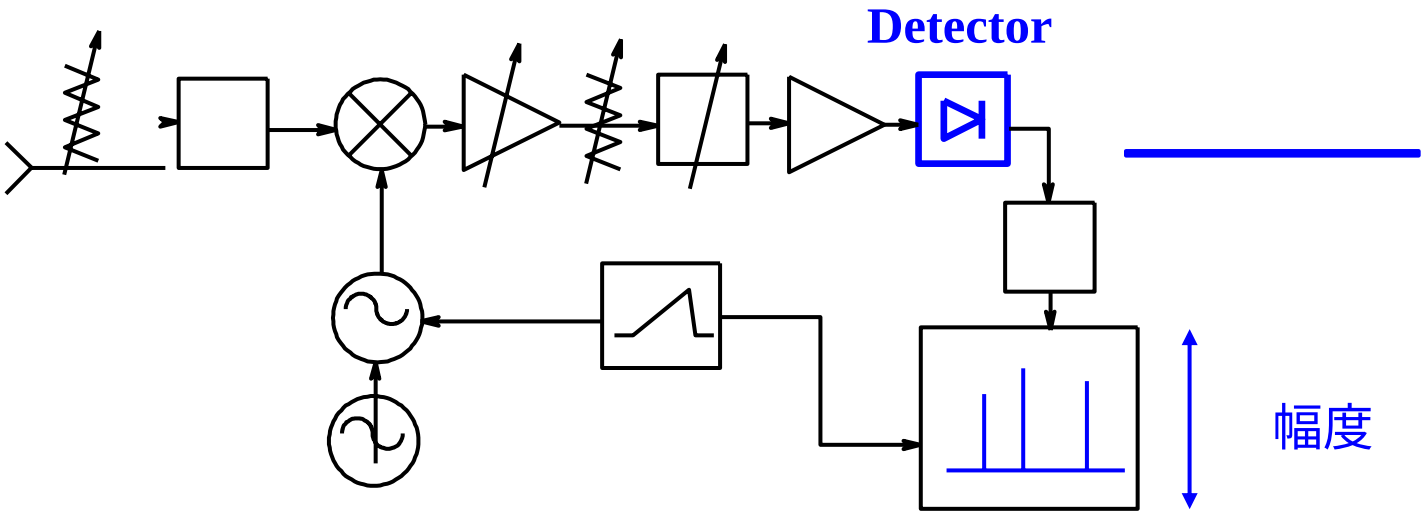
ESA 对信号的变频处理

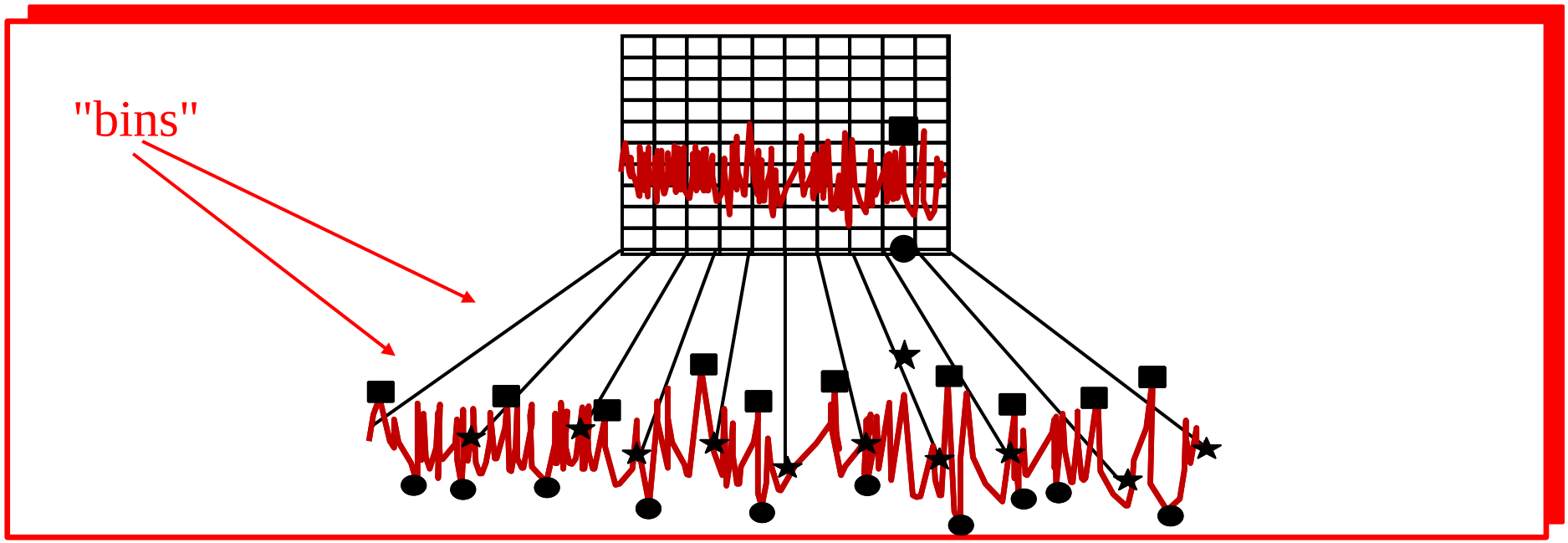


中频滤波器



检波器





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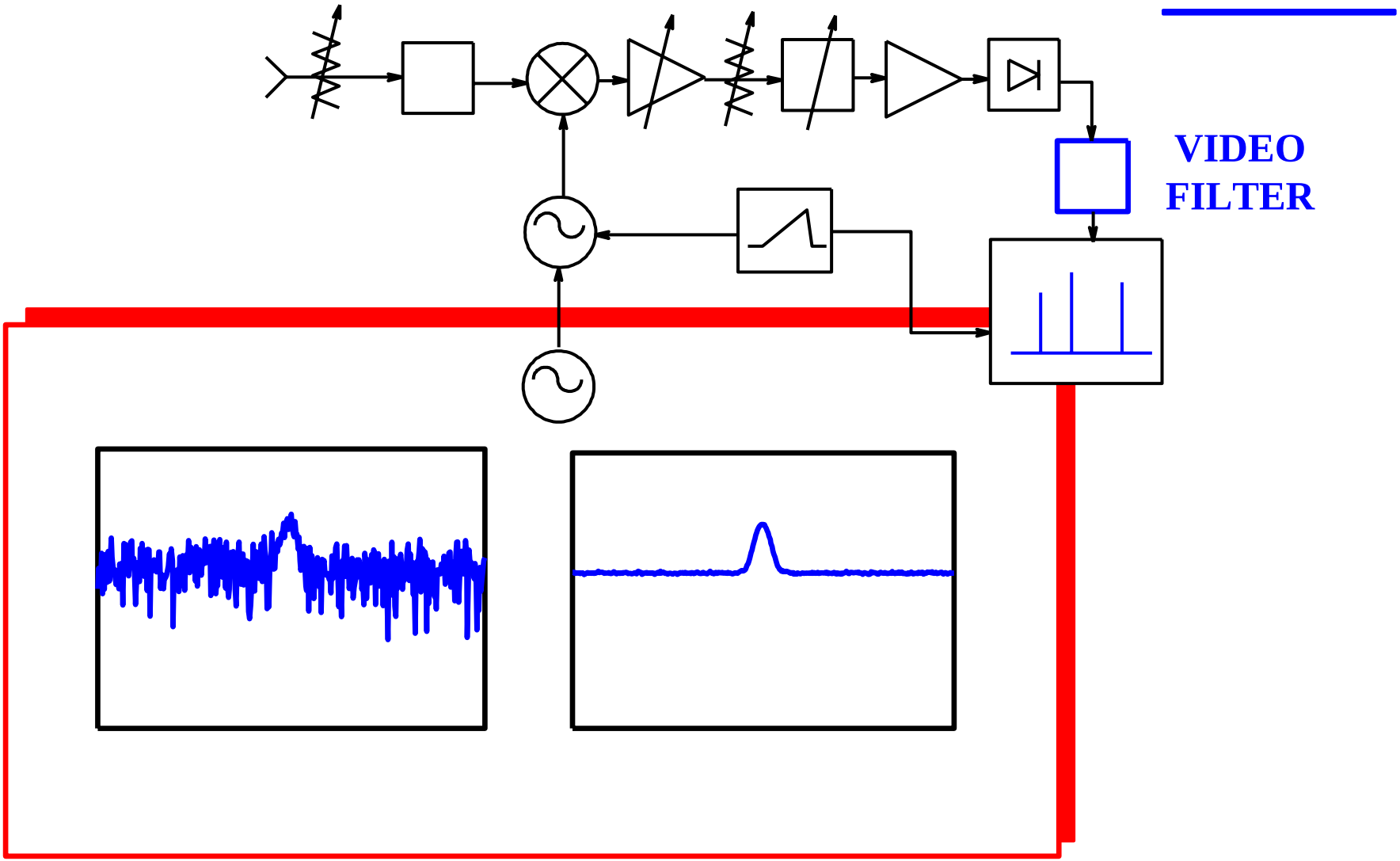
视频滤波器



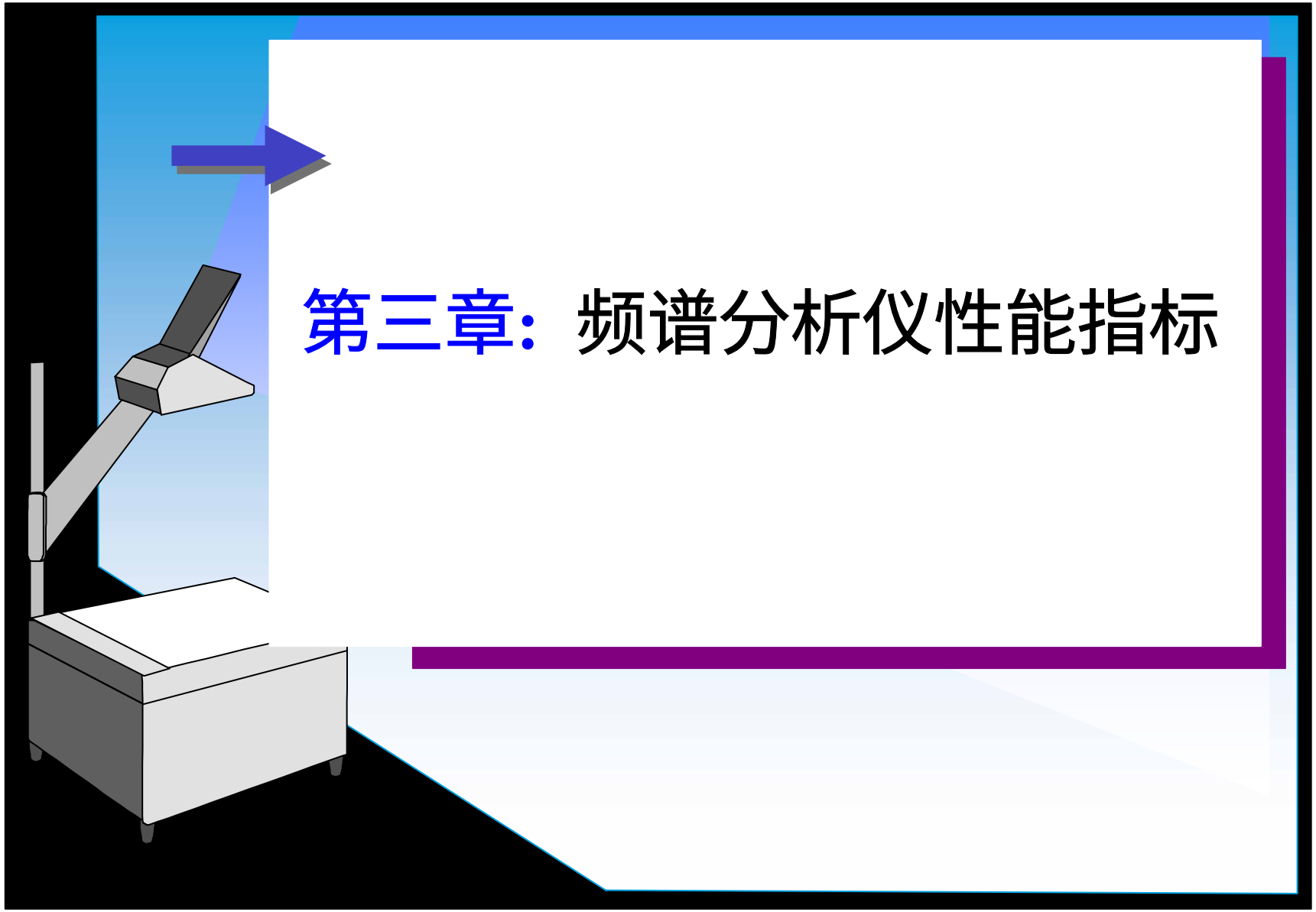
技术小结

⇩ 完成频谱分析有：扫频式和FFT两种方式；

⇩ FFT适合于窄分析带宽，快速测量场合；

⇩ 扫频方式适合于宽频带分析场合；

⇩ 单点频CW信号在扫频式频谱仪上测试显示的结果 为中频滤波器形状。



第三章：频谱分析仪性能指标

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频谱分析仪基本性能指标

频率
- 工作频率范围
- 频率分辨率 (分辨频率间隔信号能力)

幅度
- 测量动态范围
  - 内部失真 (测量大信号能力)
  - 灵敏度 (测量小信号能力)

测试精度

测试速度

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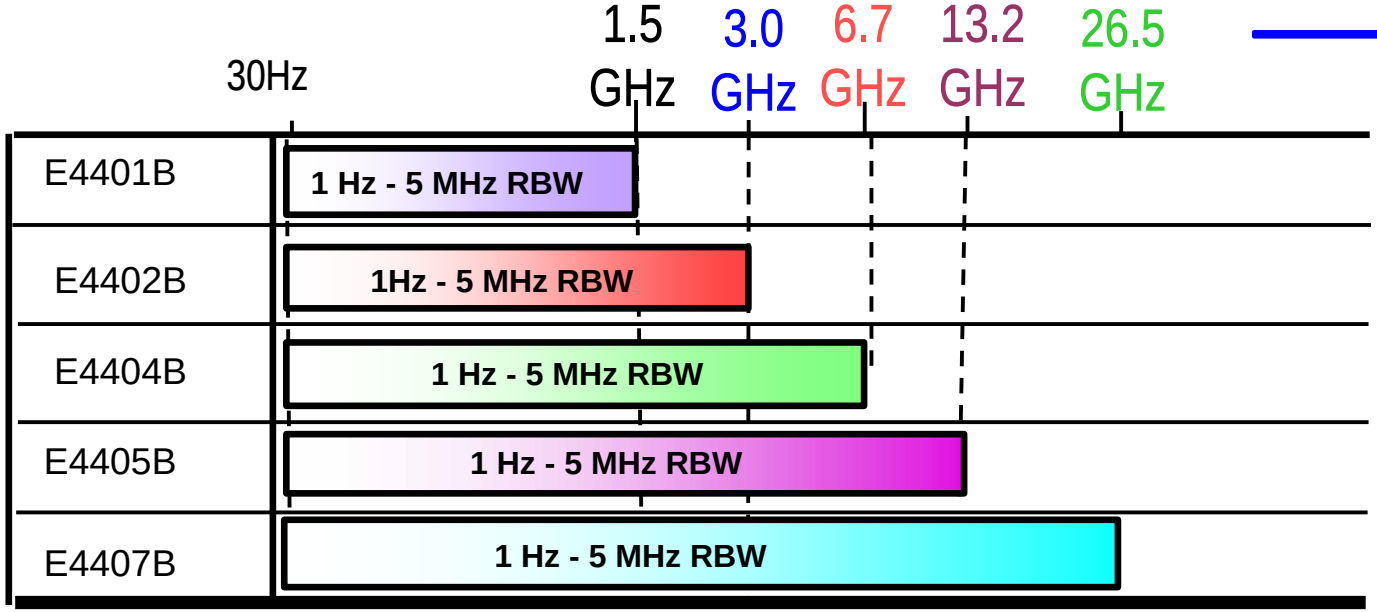
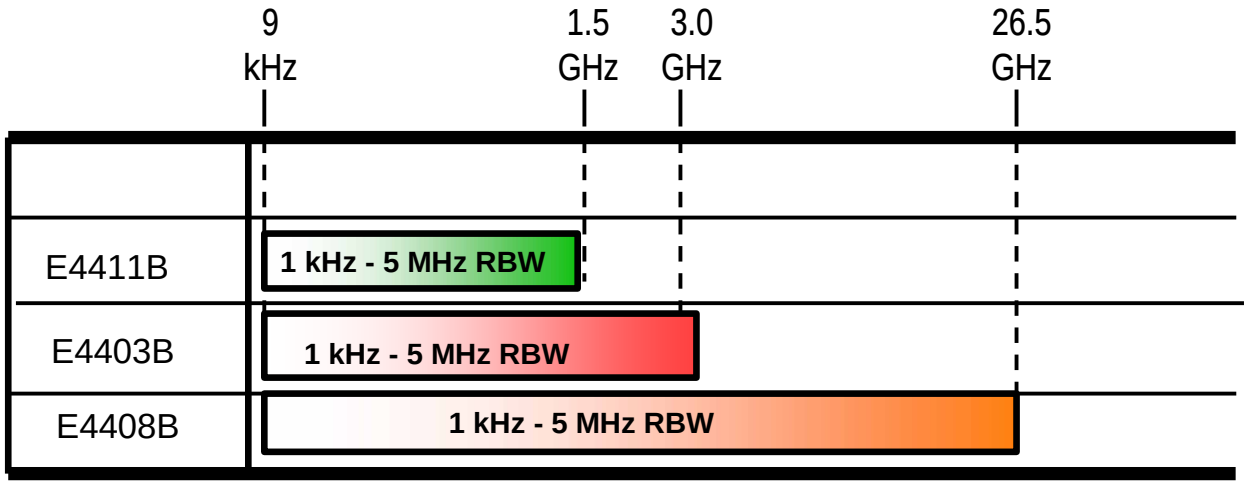
频率测量范围

ESA-E



ESA-L



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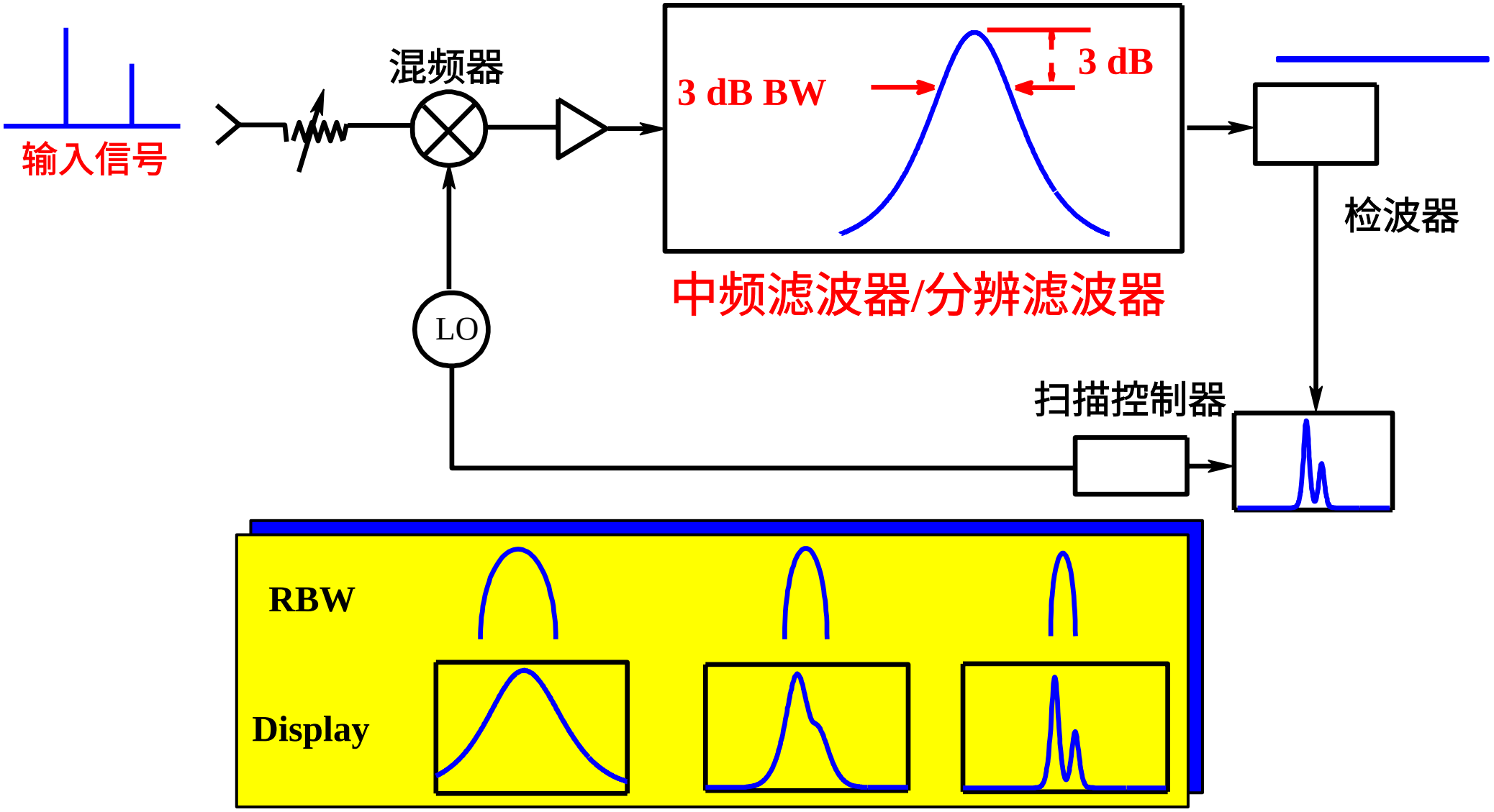
频率分辨率



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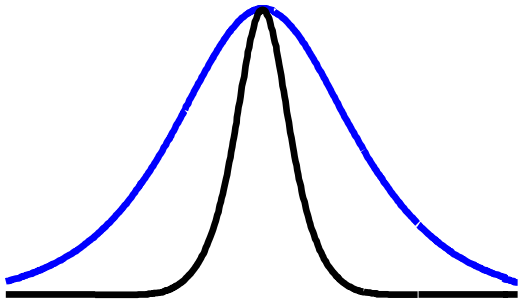
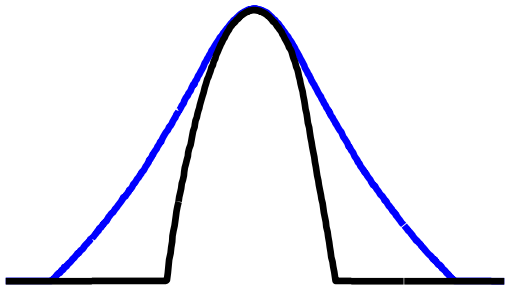
影响频谱分析仪频率分辨率性能的因素

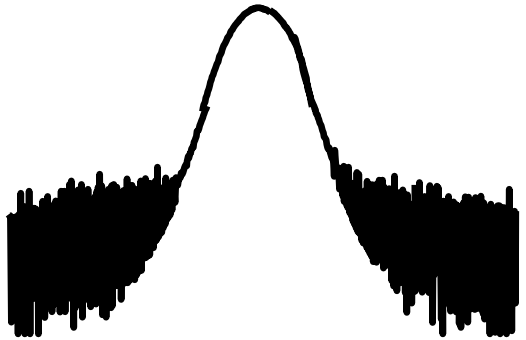


RBW

本振寄生调频



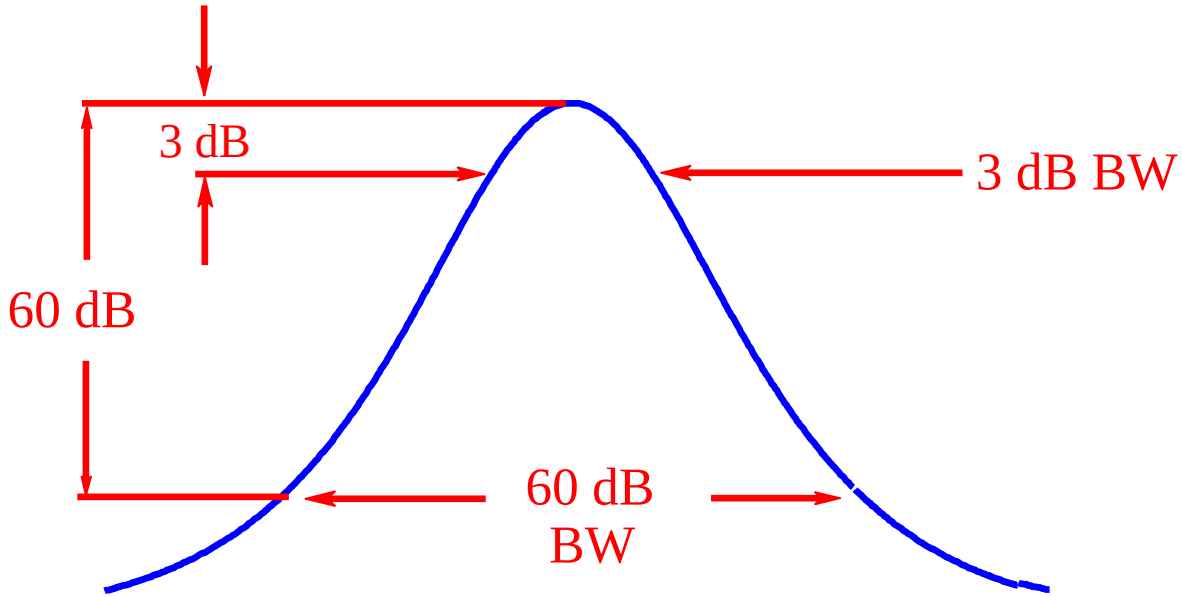
中频滤波器矩形系数



本振相位噪声

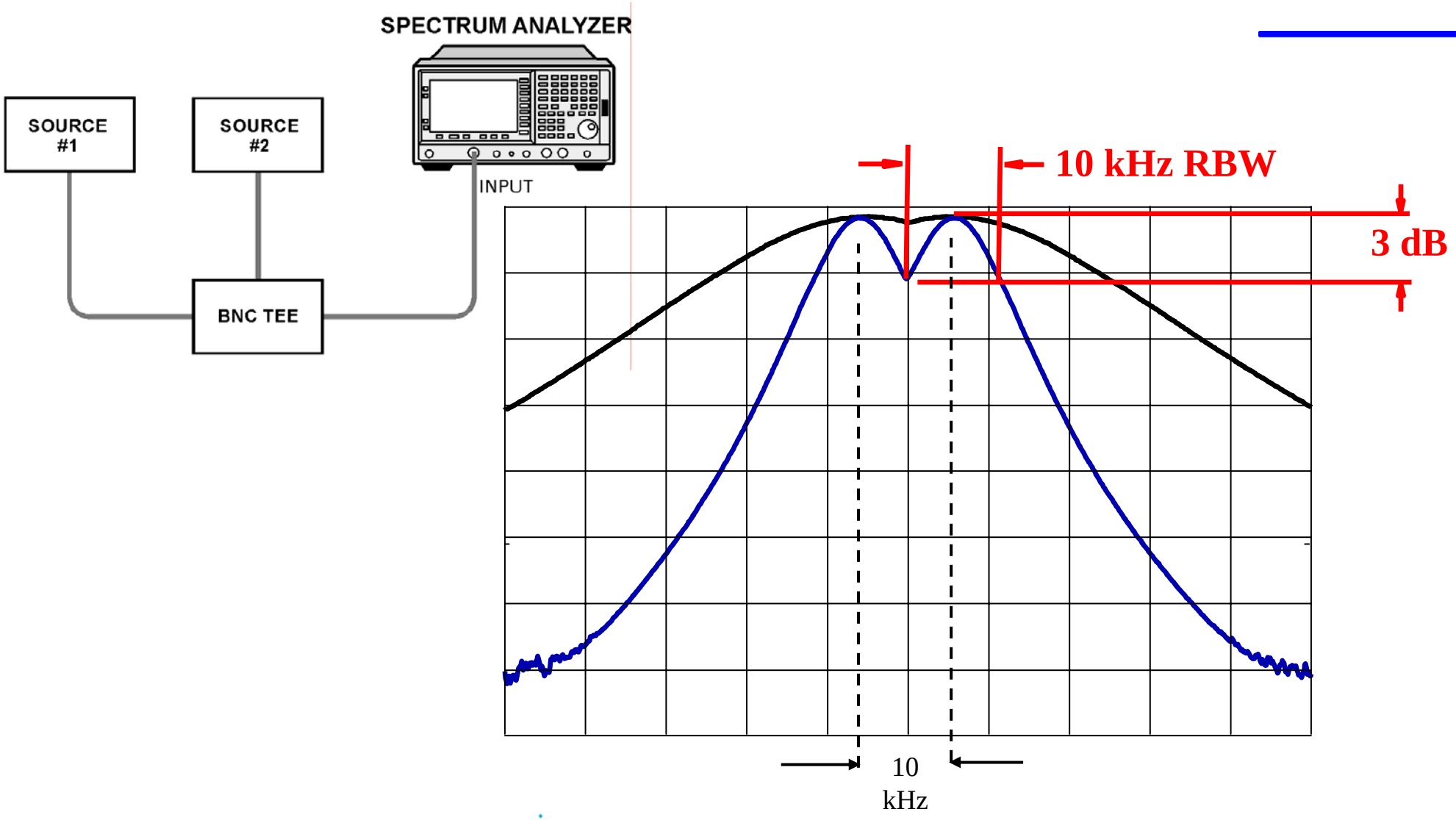
RBW 是中频滤波器 3dB 带宽

单点频信号在频谱上测试显示结果为中频滤波器的频响形状



$$\text{滤波器矩形系数} = \frac{\text{60 dB BW}}{\text{3 dB BW}}$$

RBW 对频谱仪分辨率的影响



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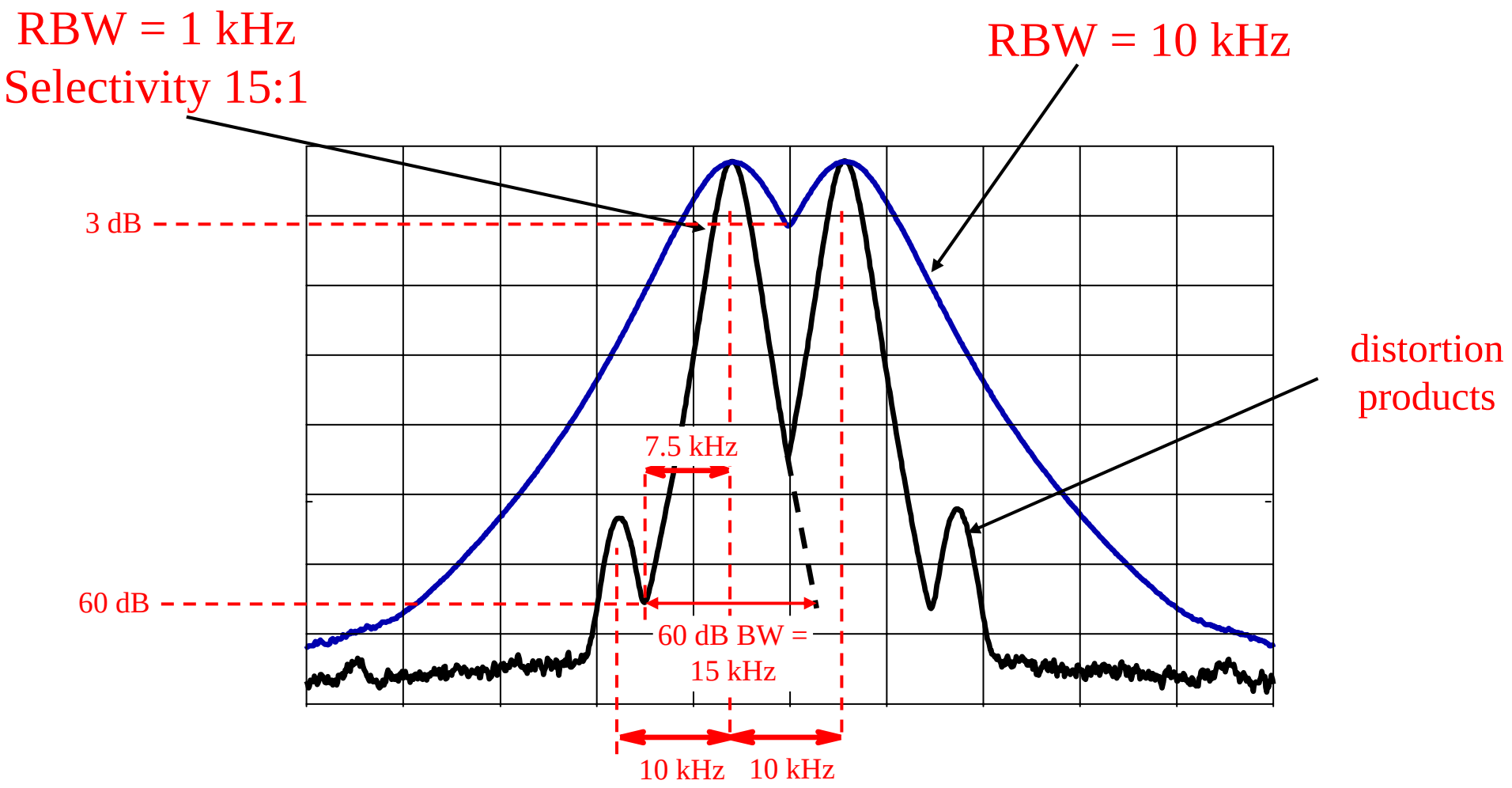
中频滤波器矩形系数影响
频谱仪对不等幅信号的分辨能力



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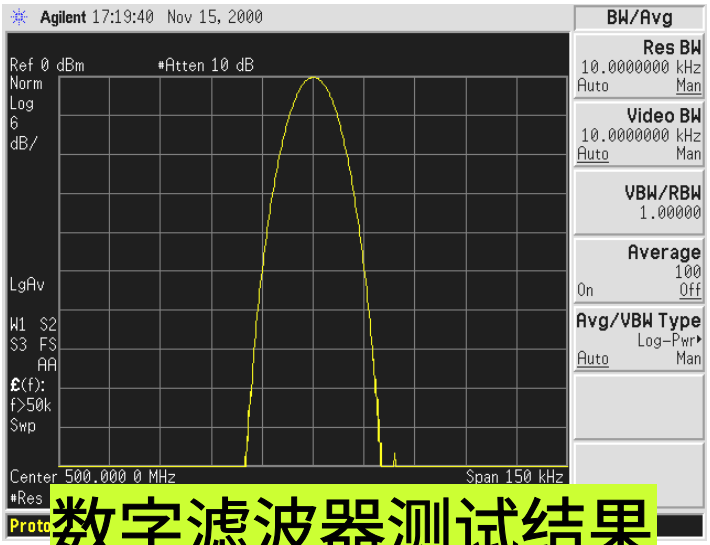
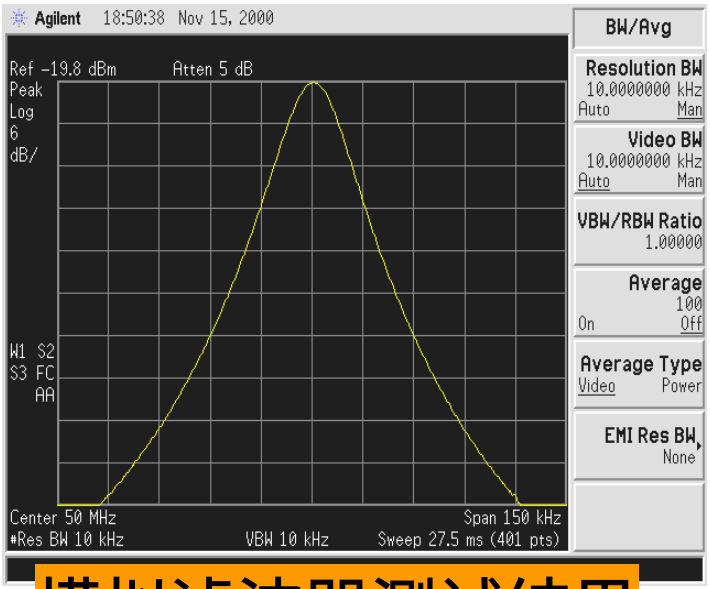
ESA 中频滤波器性能



数字滤波器测试结果



模拟滤波器测试结果

Resolution bandwidth	1 kHz to 5 MHz (–3 dB) in 1-3-10 sequence. 9 kHz and 120 kHz (–6 dB) EMI bandwidths.
Option 1DR	Adds 10, 30, 100, and 300 Hz (–3 dB) bandwidths and 200 Hz (–6 dB) EMI bandwidth.
Option 1DR and 1D5[25]	Adds 1, 3 Hz (for spans ≤ 5 MHz)
Accuracy	
1 kHz to 3 MHz	±15%
5 MHz	±30%
1 Hz to 300 Hz (Option 1DR)	±10%
Selectivity (characteristic)	
–60 dB/–3 dB	
10 Hz to 300 Hz	<5:1[6] digital, approximately Gaussian shape
1 kHz to 5 MHz	<15:1[6] synchronously tuned four poles, approximately Gaussian shape

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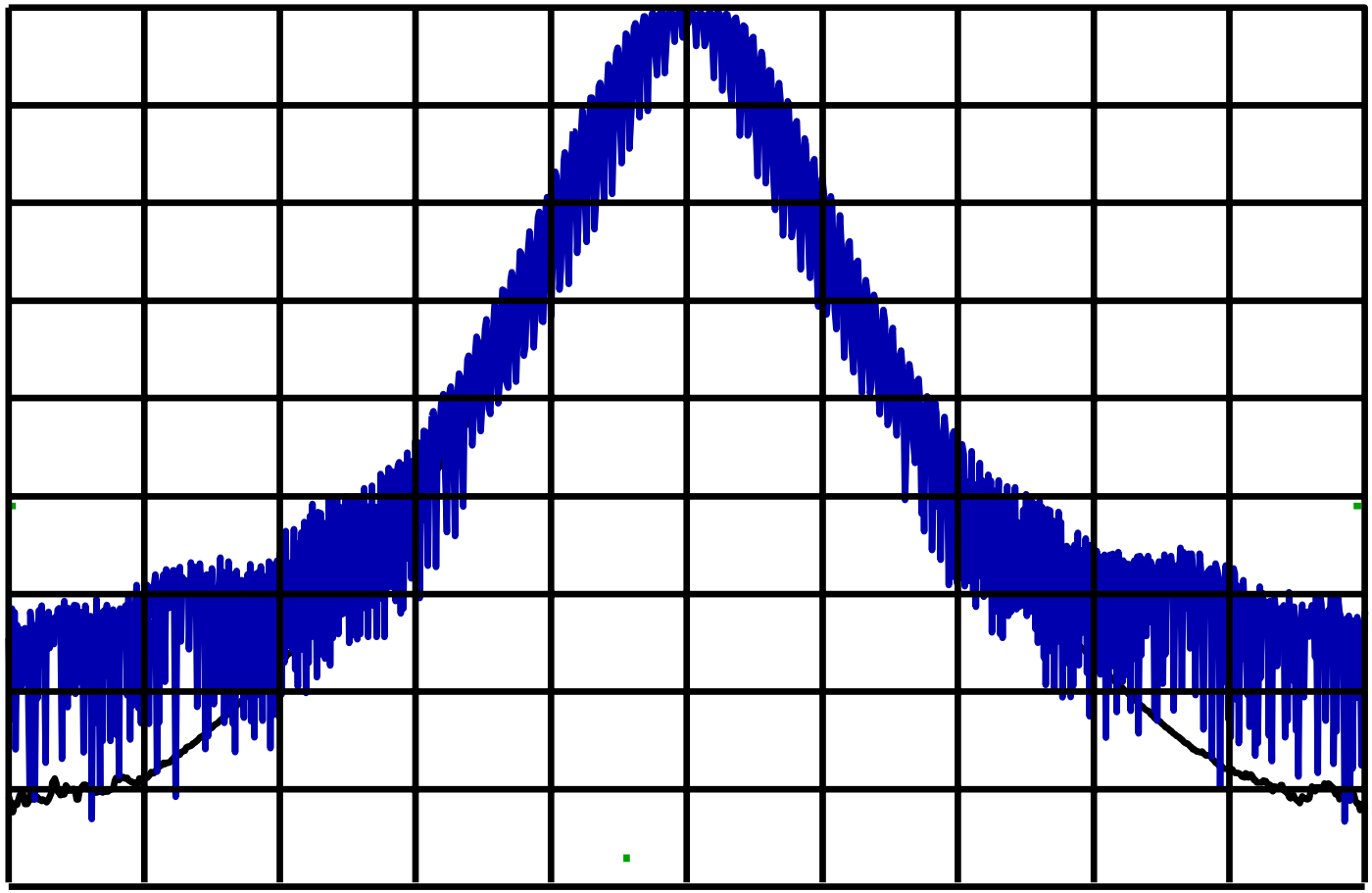
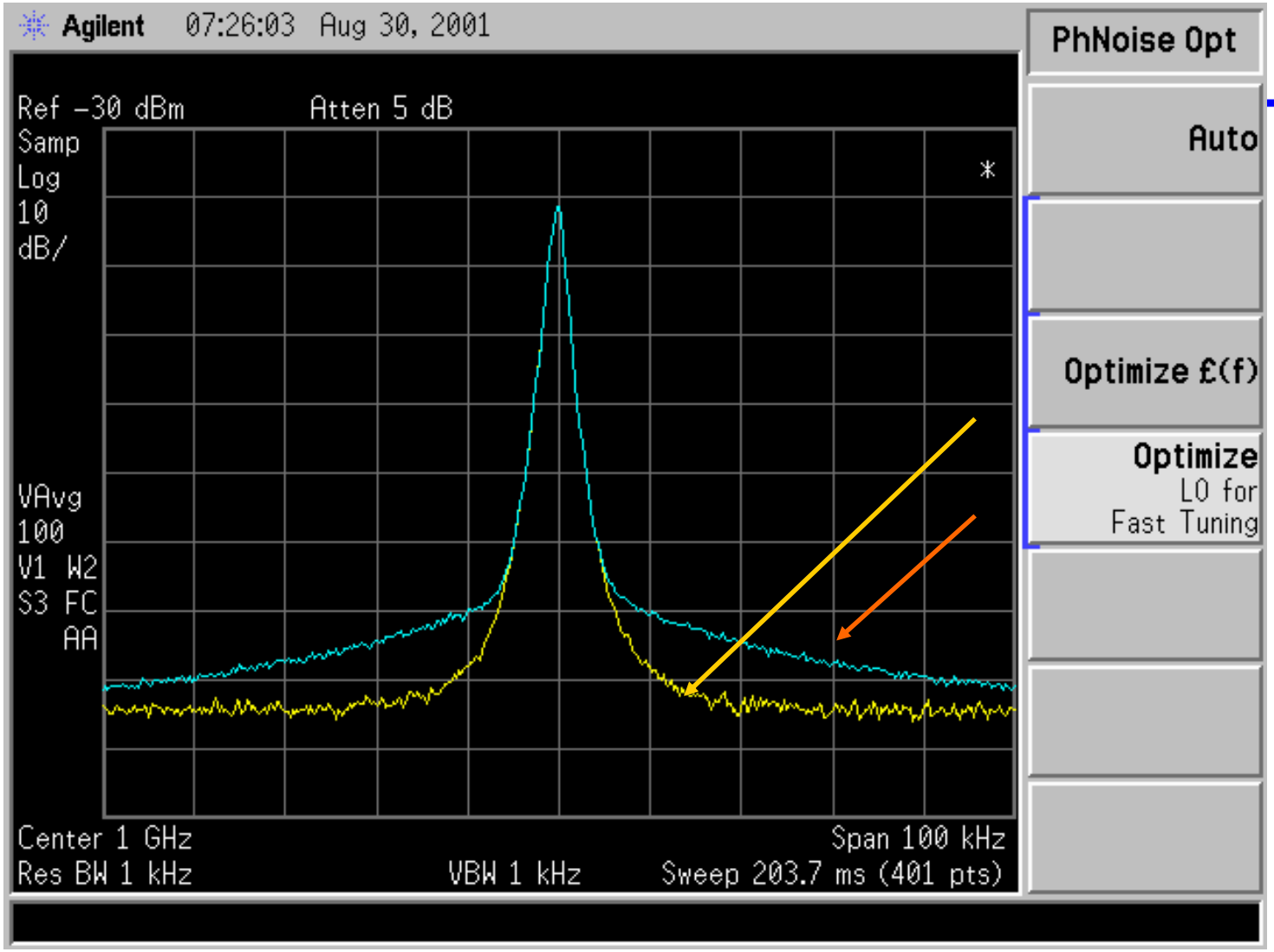
本振寄生调频对测量的影响



本振相位噪声对测量的影响



本振相位噪声在频谱上表现为信号噪声边带

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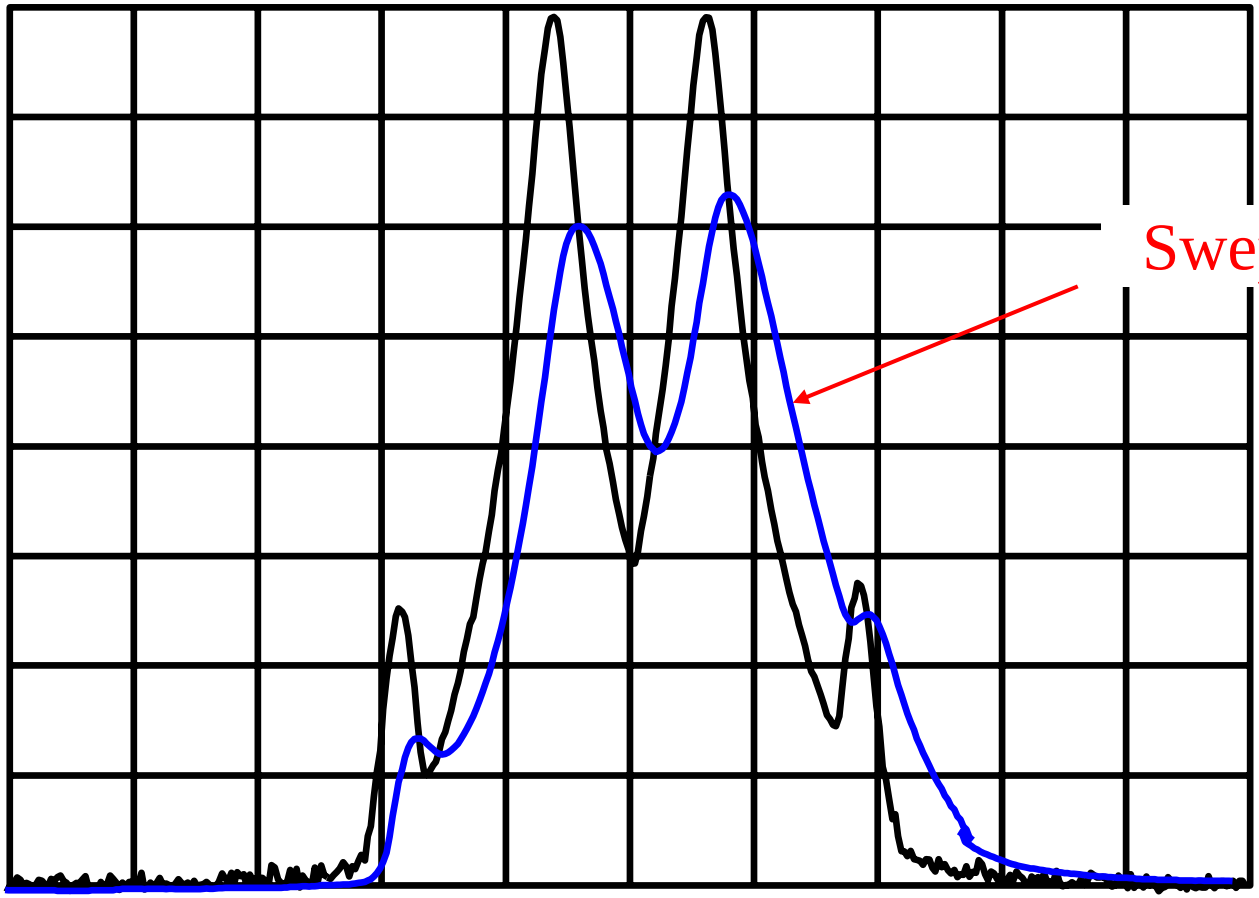
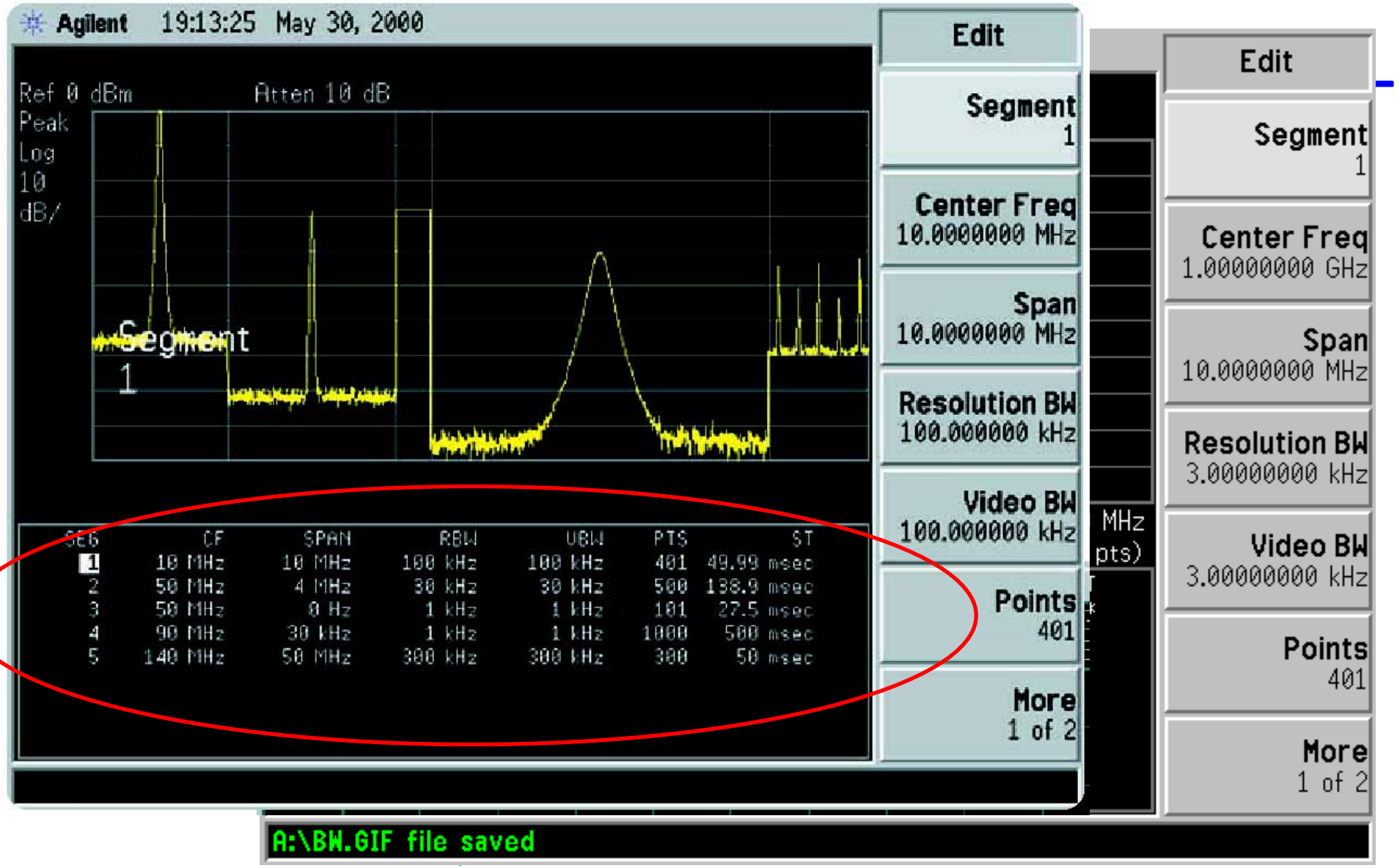
RBW设置会影响频谱仪测试速度



当滤波器带宽小时,其响应时间会相应变长

ESA Segment 分段扫描功能



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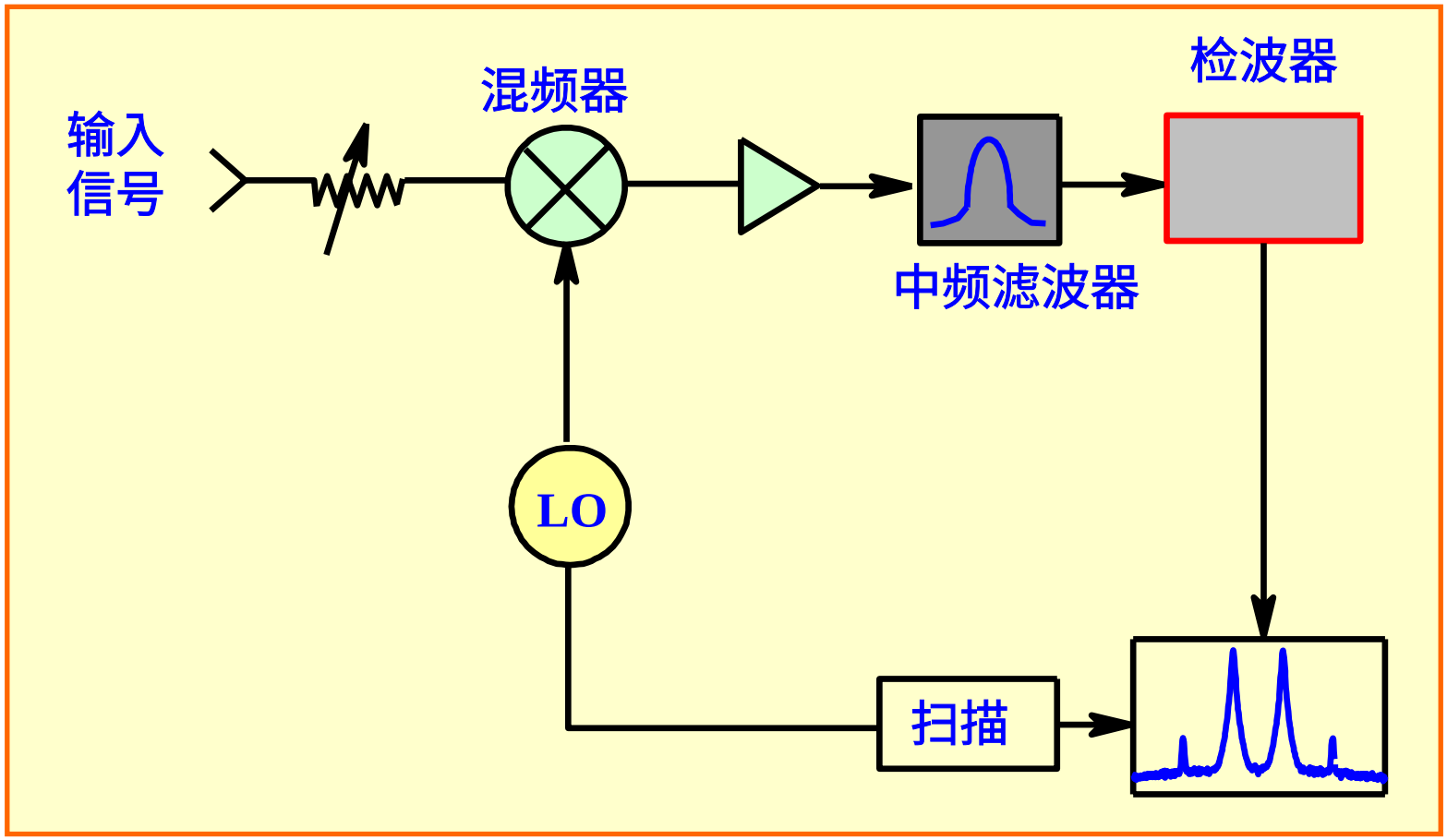
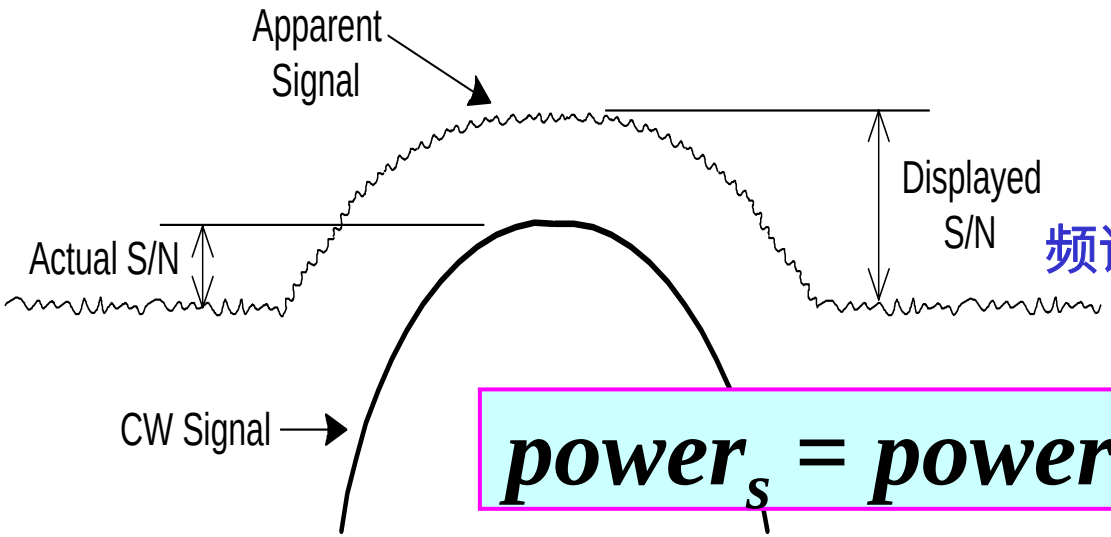
频谱仪测量灵敏度



频谱仪内部混频器及各级放大器会产生噪声,
通过检波器会反映为显示白噪声电平 ***(DANL)***

频谱仪噪声会影响被测信号功率测试



频谱仪显示信号=输入信号+内部噪声

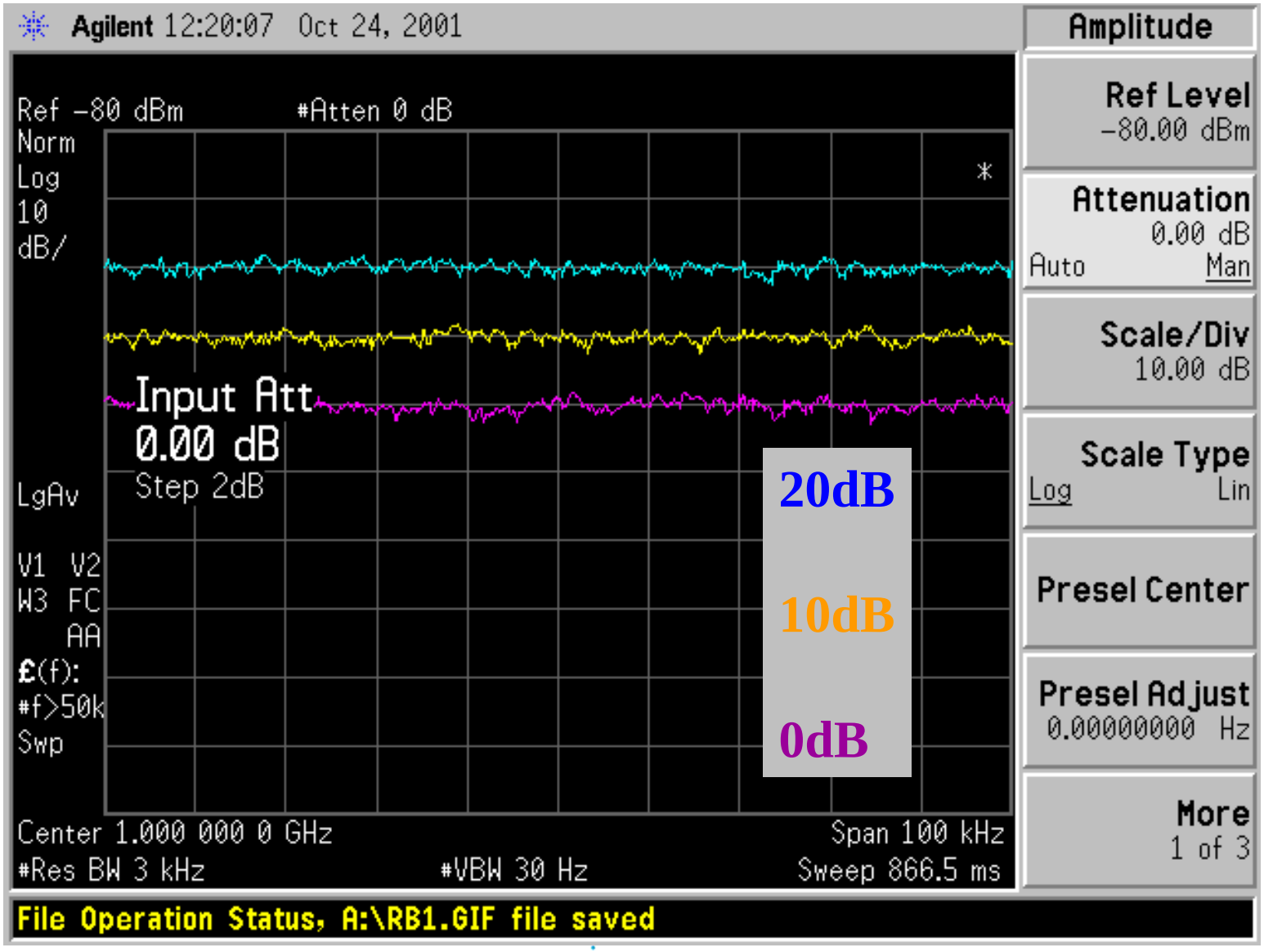
$$power_s = power_{s+n} - power_n \ [mW]$$

修正参数

Measured noise level relative to internal noise	Measurement Error
1 dB	6.87 dB
3 dB	3.02 dB
5 dB	1.65 dB
10 dB	0.46 dB
15 dB	0.14 dB
20 dB	0.04 dB

影响频谱仪灵敏度的因素

---- 衰减器设值



衰减器设值大
噪声电平高

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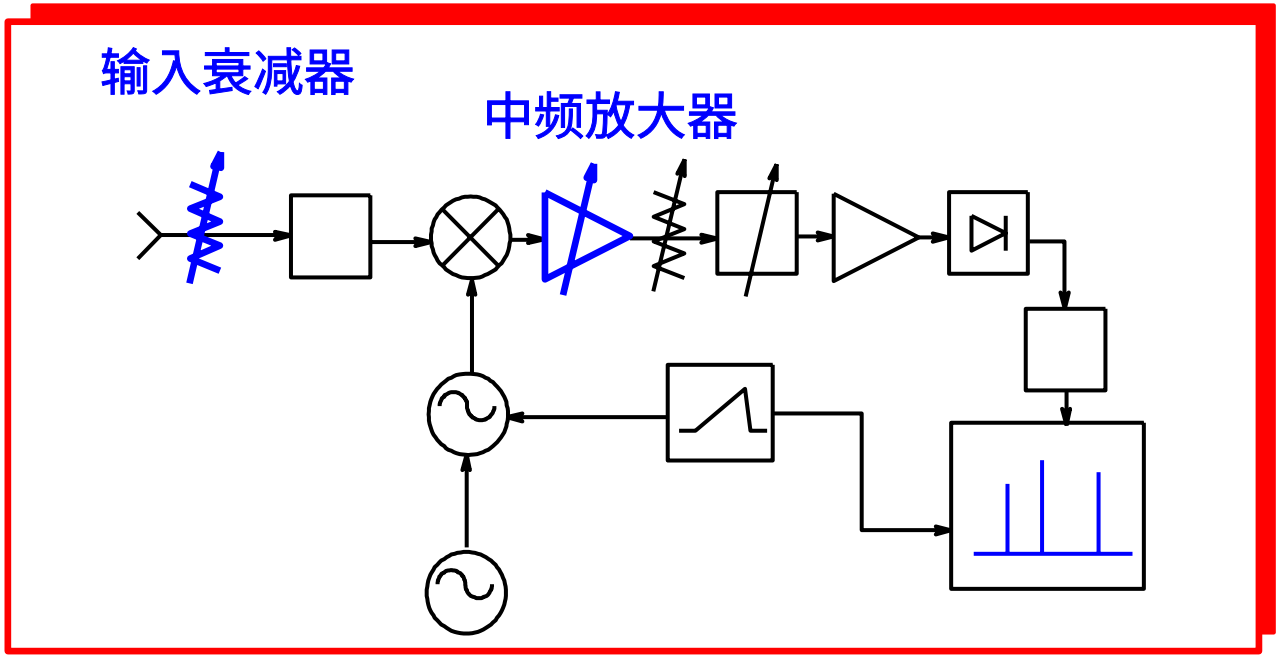
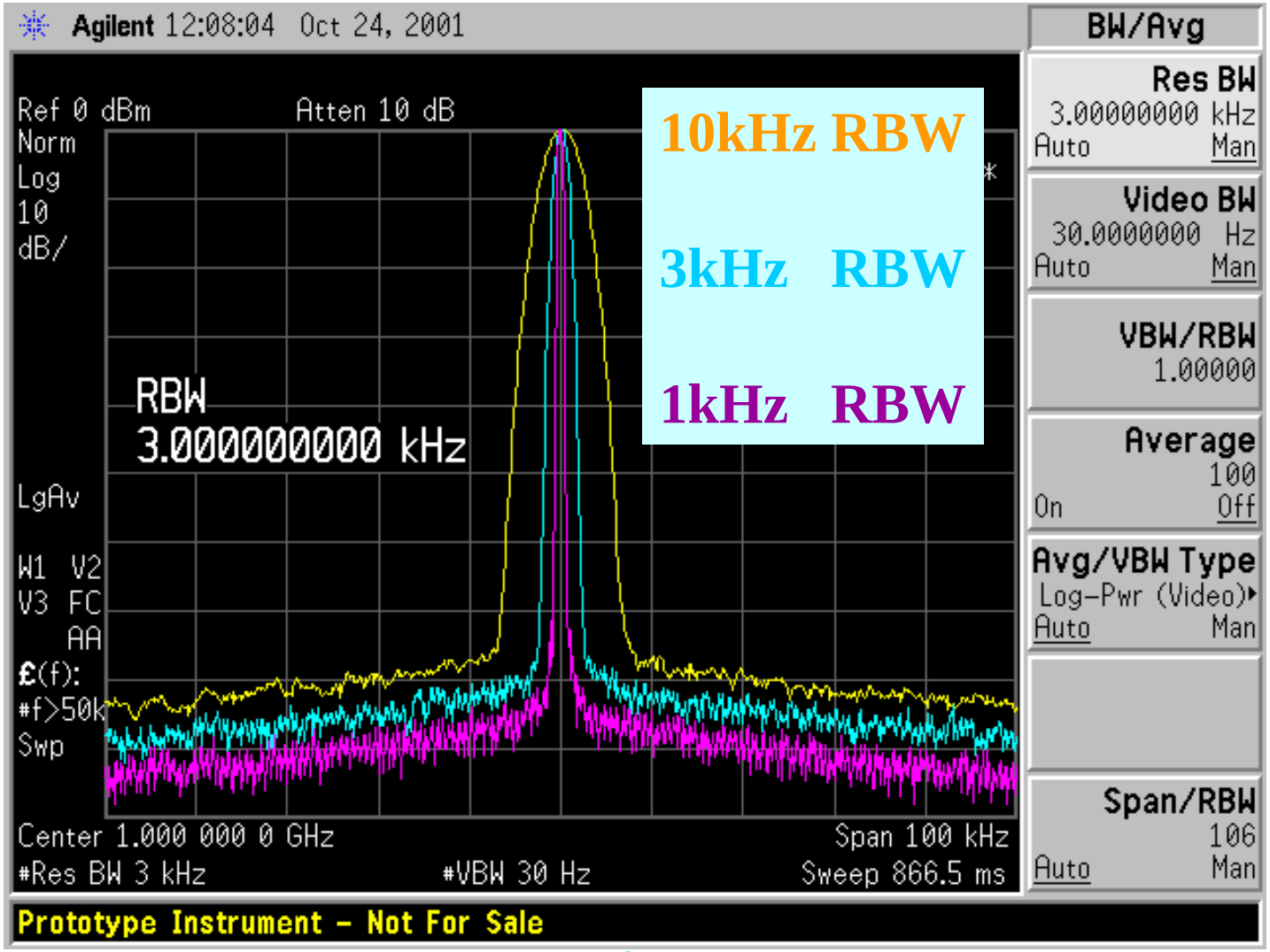
影响频谱仪灵敏度的因素
---- 衰减器设值



为保证正确测量信号电平，
频谱仪内部衰减器和中频放大器联动工作

影响频谱仪灵敏度的因素

---- RBW



噪声电平随**RBW** 按

$$10\log\frac{RBW1}{RBW2}$$

规律变化

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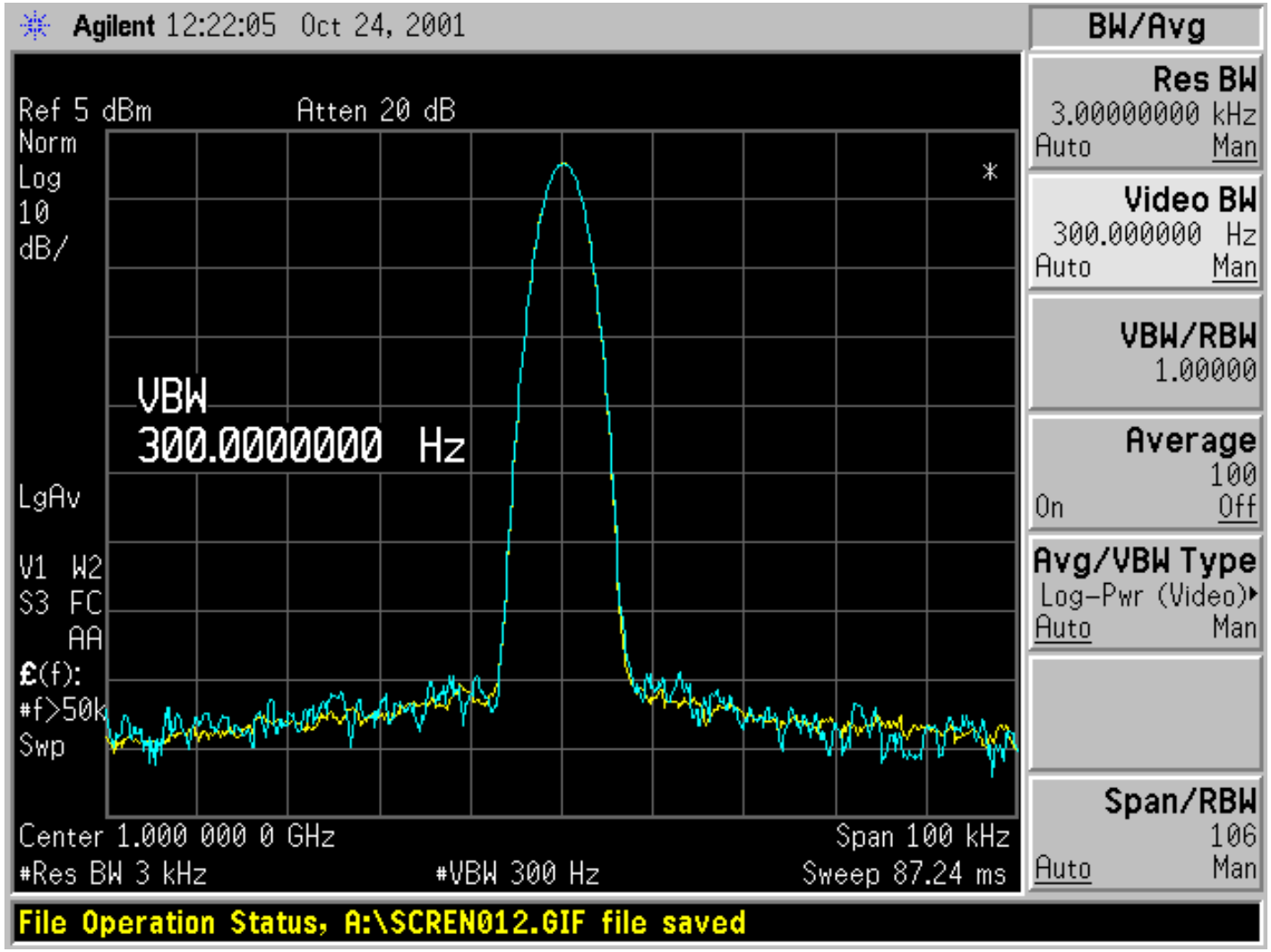
影响频谱仪灵敏度的因素

---- VBW



VBW影响显示噪声电平的方差，减小VBW得到其平均值

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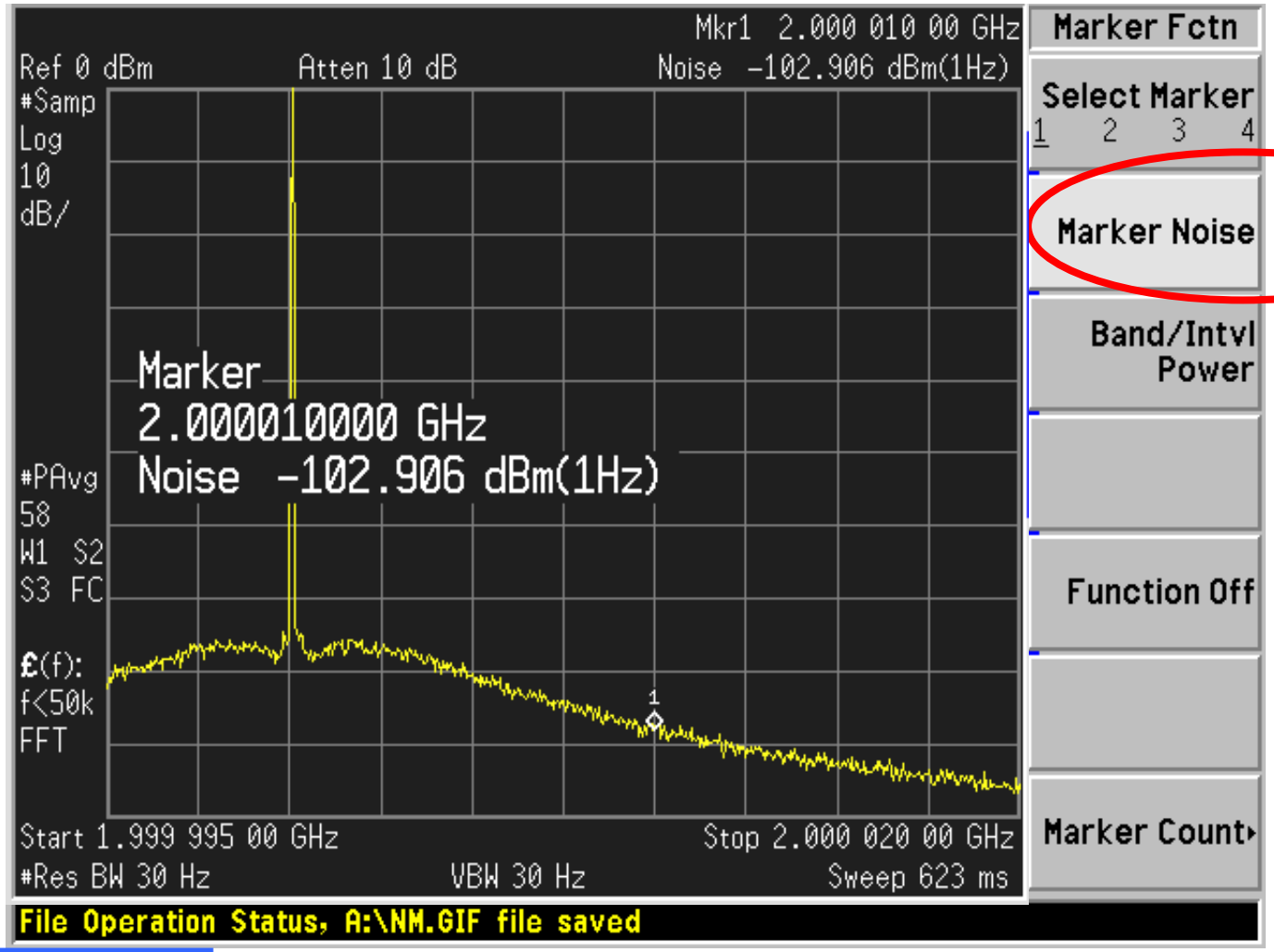
利用频谱分析仪正确测量噪声信号的方法



Maker Noise

功能自动设置频谱仪检波方式为:sample,
进行功率平均处理及带宽归一化

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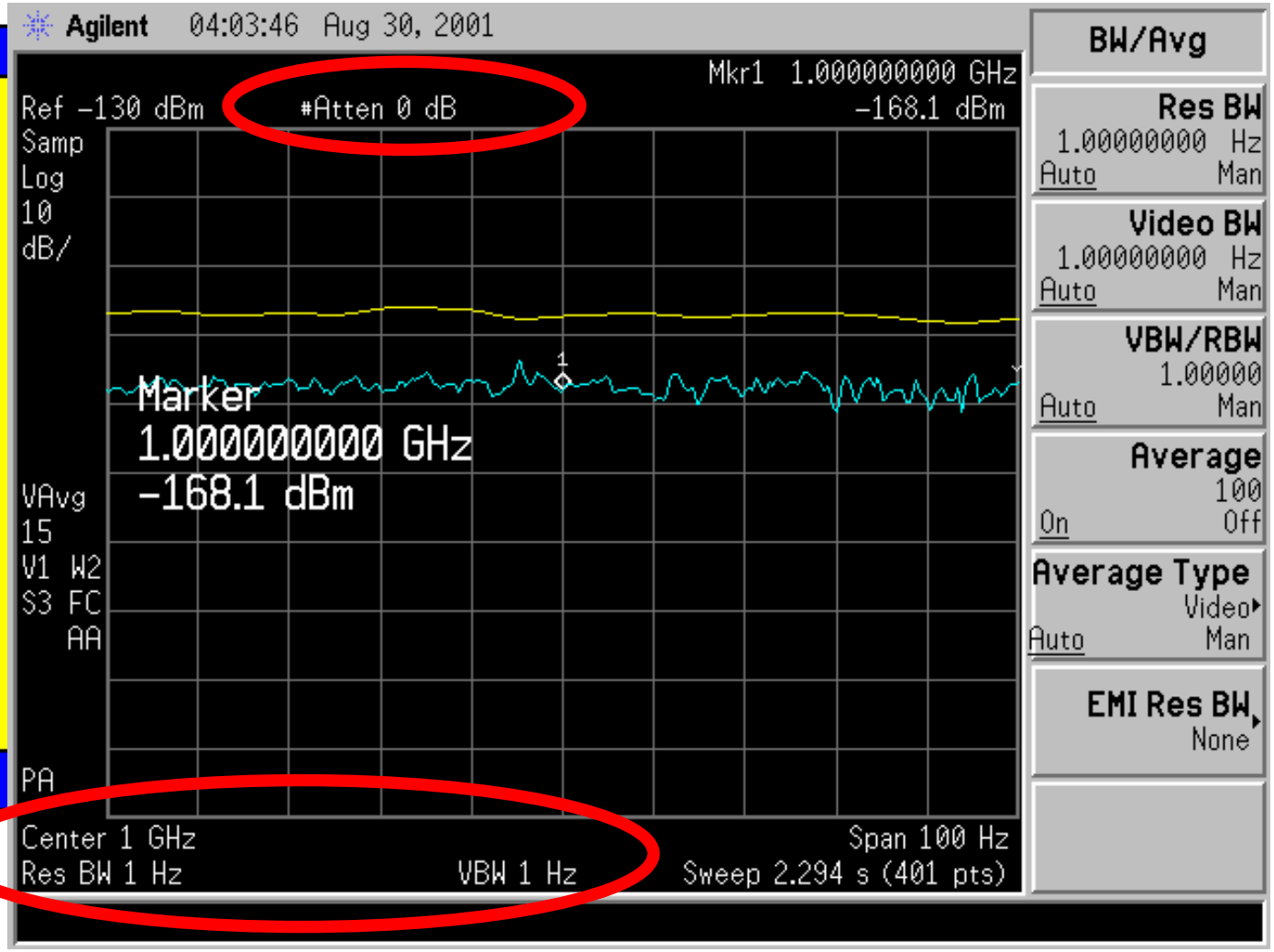
提高频谱仪灵敏度的技术方法

- 最小RBW设值
- 最小衰减器设值
- 减少VBW
- 前置放大器

  （增益>噪声系数）



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ESA
灵敏度指标

1 kHz RBW	1kHz RBW	10 Hz RBW (Option 1DR)	10 Hz RBW (Option 1DR) (w/preamp Option 1DS)	10 Hz RBW (Option 1DR) (w/preamp Option 1DS) typical	1Hz RBW (Option 1DR and 1D5)[25] typical	1Hz RBW (Option 1DR and 1D5)[25] (w/preamp Option 1DS) typical
E4401B						
400 kHz to 10 MHz	≤–115	≤–134	≤–150	≤–155	≤ –149	≤–165
10 MHz to 500 MHz	≤–119	≤–138	≤–154	≤–156	≤–151	≤–166
500 MHz to 1 GHz	≤–117	≤–136	≤–152	≤–156	≤–150	≤–166
1 GHz to 1.5 GHz	≤–114	≤–133	≤–150	≤–155	≤–148	≤–165
E4402B						
30 Hz to 9 kHz[22] (Option UKB)	na	≤–93	na	na	≤–103	na
9 kHz to 100 kHz[22]	na	≤–109	na	na	≤–119	na
100 kHz to 1 MHz[22]	na	≤–135	na	na	≤–145	na
1 MHz to 10 MHz[22]	≤–120[26]	≤–139[26]	na	≤–152	≤–149[26]	≤–162[19]
10 MHz to 1 GHz	≤–117	≤–136	≤–152[19]	≤–156	≤–150	≤–166[19]
1 GHz to 2 GHz	≤–116	≤–135	≤–153[19]	≤–156	≤–150	≤–166[19]
2 GHz to 3 GHz	≤–114	≤–133	≤–151[19]	≤–154	≤–150	≤–164[19]
E4404/05B/07B						
30 Hz to 9 kHz[22] (Option UKB)	na	≤–93	na	na	≤–103	na
9 kHz to 100 kHz[22]	na	≤–109	na	na	≤–119	na
100 kHz to 1 mHz[22]	na	≤–135	na	na	≤–145	na
1 MHz to 10 MHz[22]	≤–120[26]	≤–139[26]	na	≤–155	≤–149[26]	≤–165[19]
10 MHz to 1 GHz	≤–116	≤–135	≤–151[19]	≤–157	≤–149	≤–167[19]
1 GHz to 2 GHz	≤–116	≤–135	≤–151[19]	≤–155	≤–150	≤–165[19]
2 GHz to 3 GHz	≤–112	≤–131	≤–149[19]	≤–152	≤–148	≤–162[19]
3 GHz to 6 GHz	≤–112	≤–131	na	≤–138	≤–148	na
6 GHz to 12 GHz	≤–111	≤–130	na	≤–137	≤–147	na
12 GHz to 22 GHz	≤–107	≤–126	na	≤–134	≤–107	na
22 GHz to 26.5 GHz	≤–106	≤–125	na	≤–132	≤–142	na

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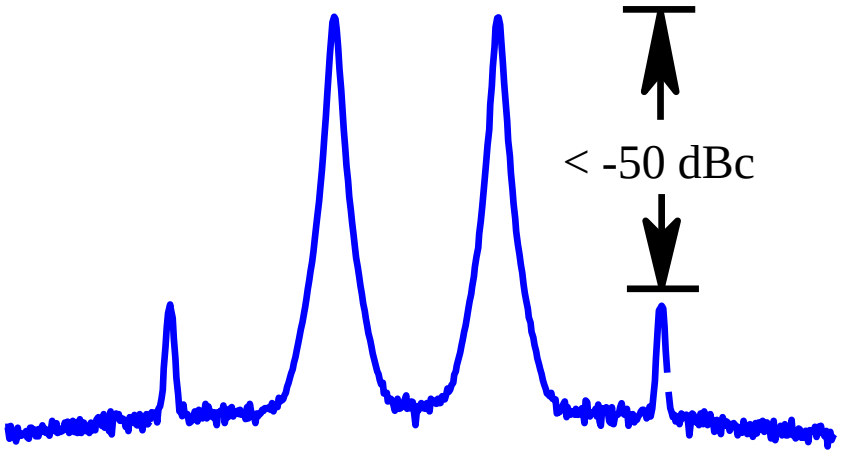
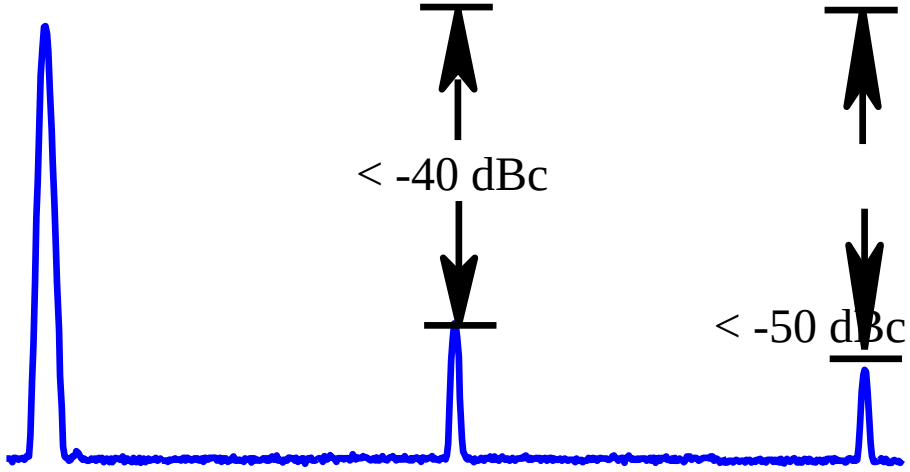
频谱分析仪性能指标

------内部失真



三阶交调测试

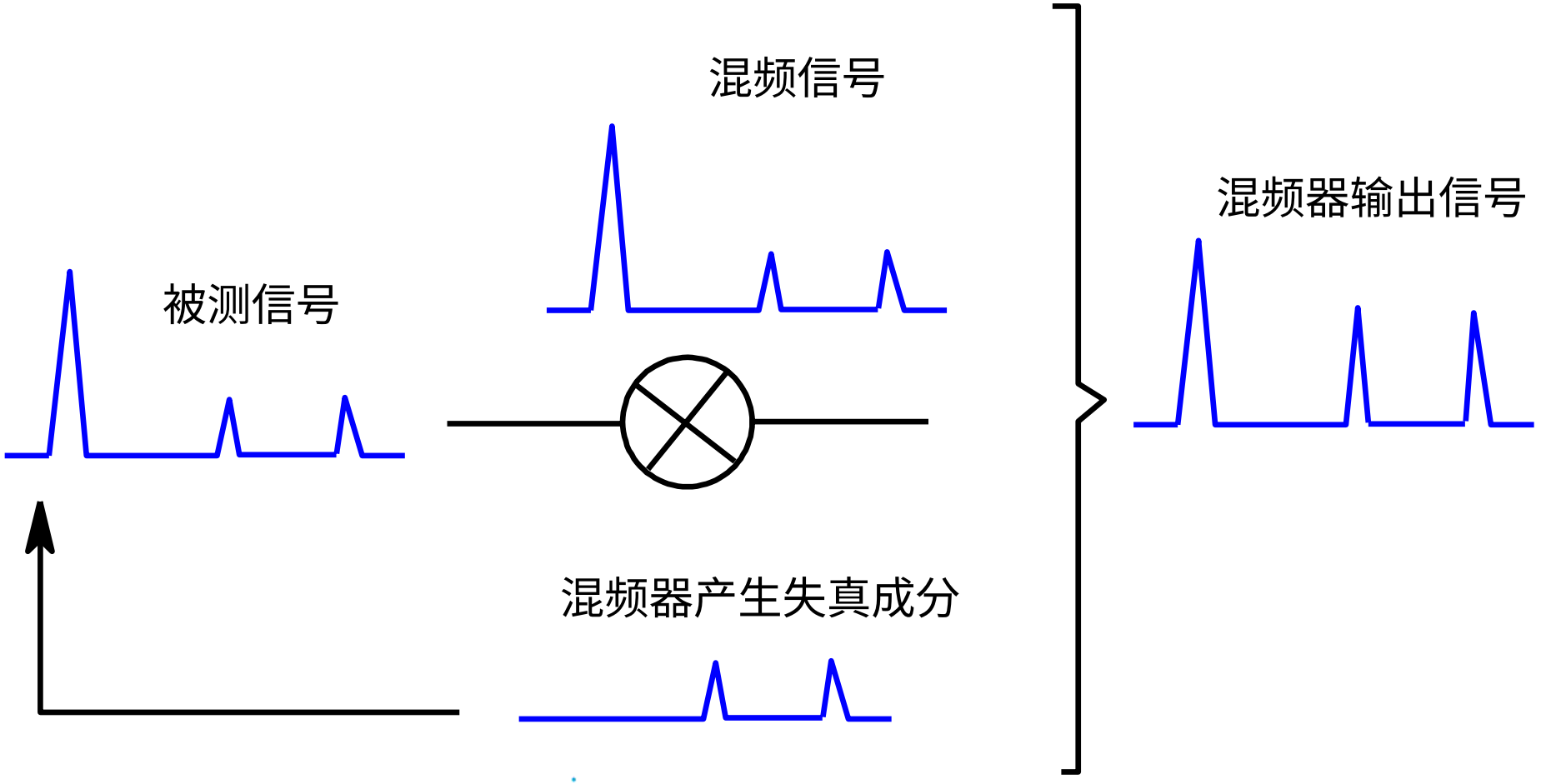


各次谐波测试

频谱分析仪典型测试应用

频谱分析仪产生内部失真的原因

混频器非线性作用



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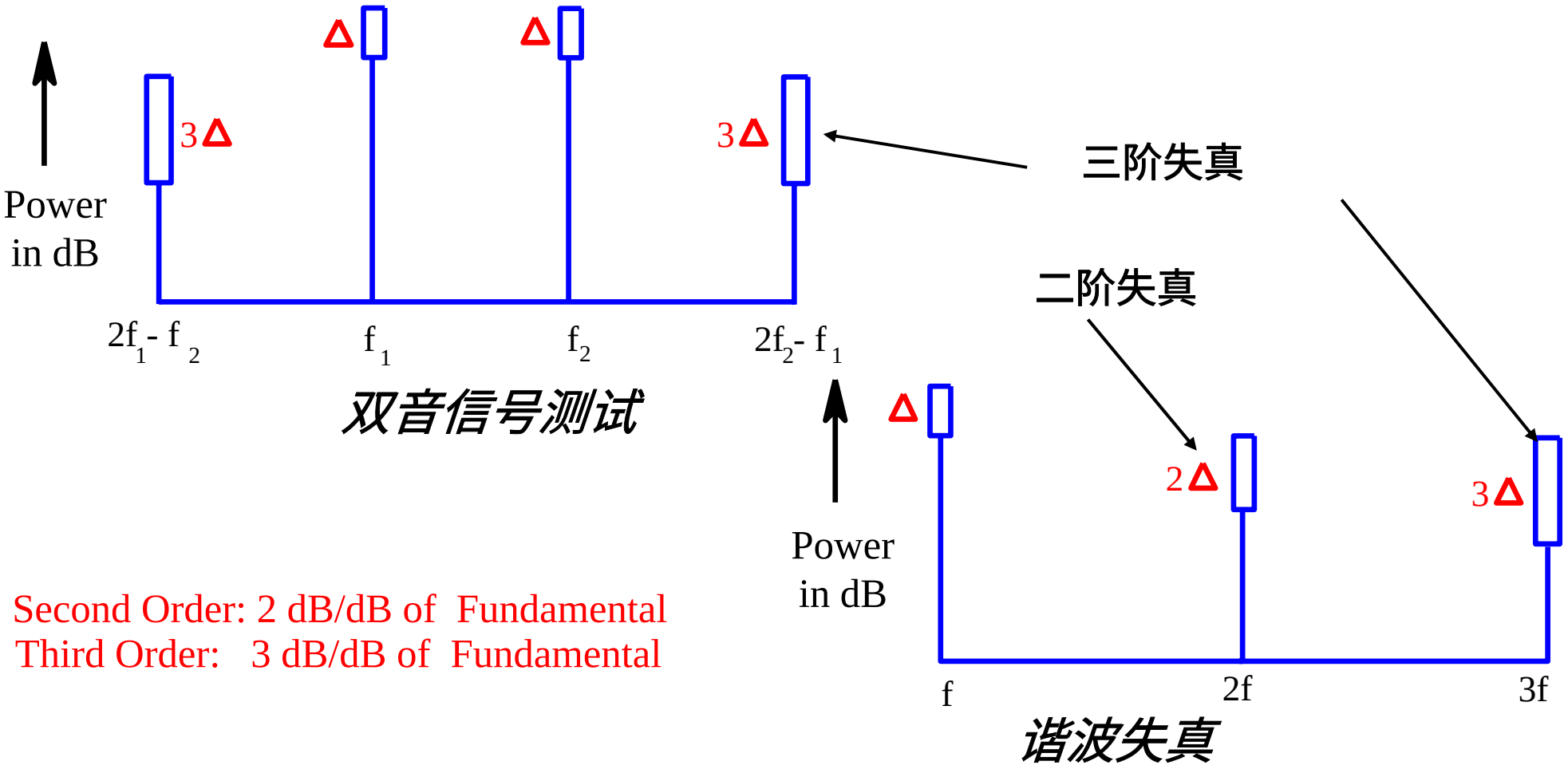
各阶非线性失真变化规律

高阶失真信号幅度比基波信号变化速度快



Second Order: 2 dB/dB of Fundamental
Third Order: 3 dB/dB of Fundamental

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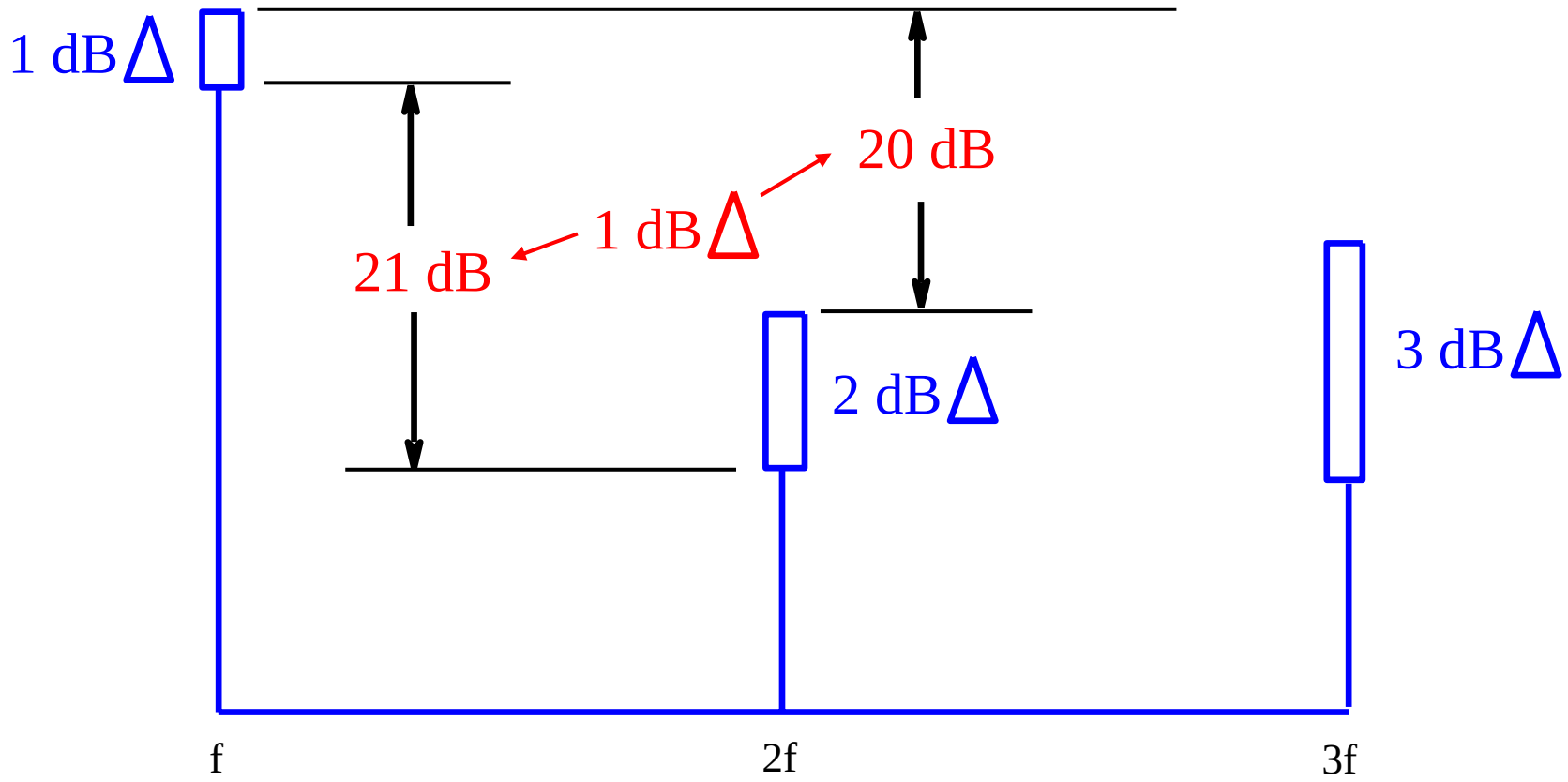
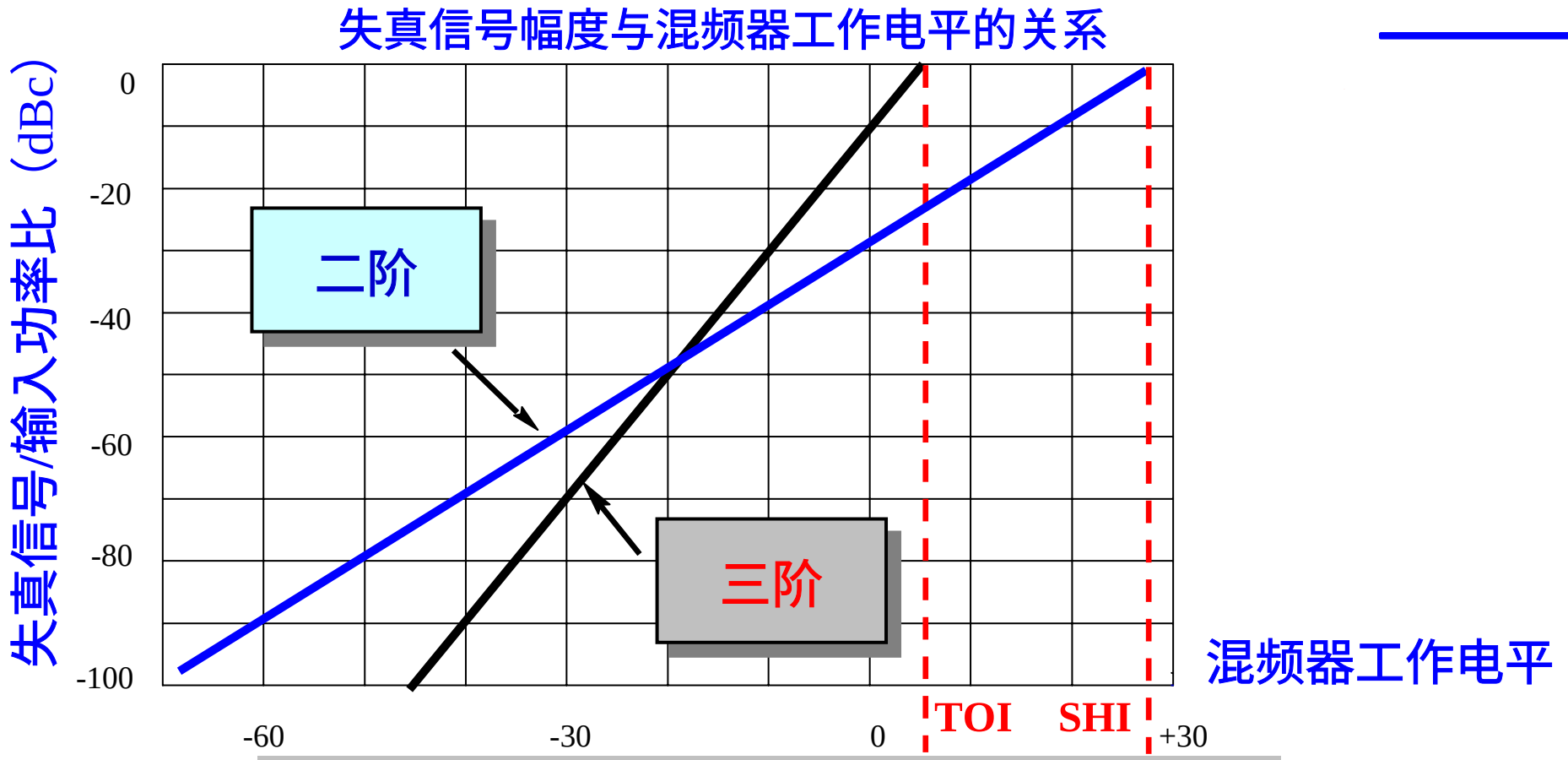
失真信号变化举例



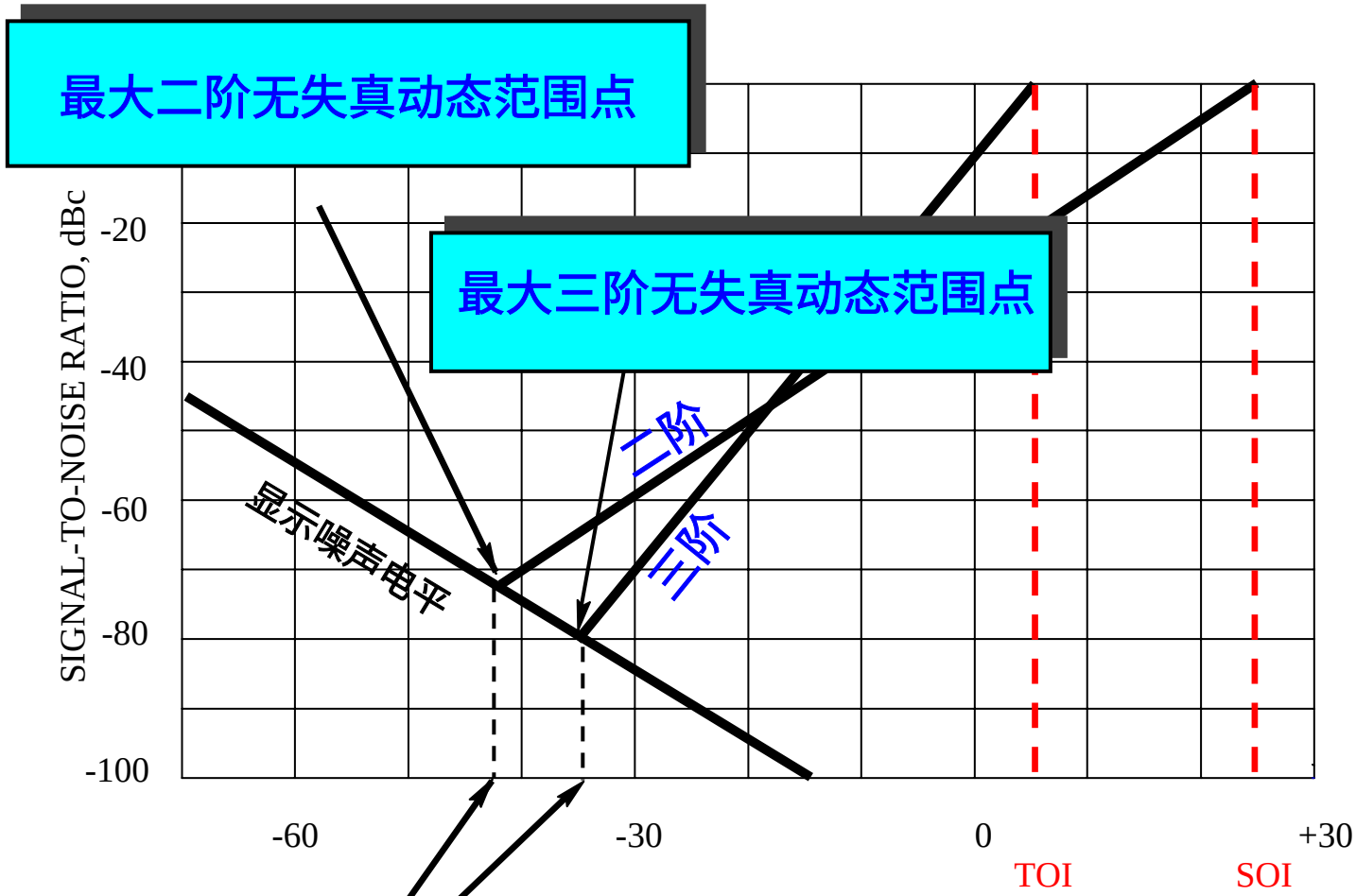
非线性引起失真信号变化规律



混频器工作电平 = 输入信号电平 - 衰减器设值

为减小频谱分析仪内部失真，混频器应工作在尽量低电平，应加大衰减器设值

动态范围：频谱分析仪同时测量大小信号能力



混频器工作电平 = 参考电平 - 衰减器

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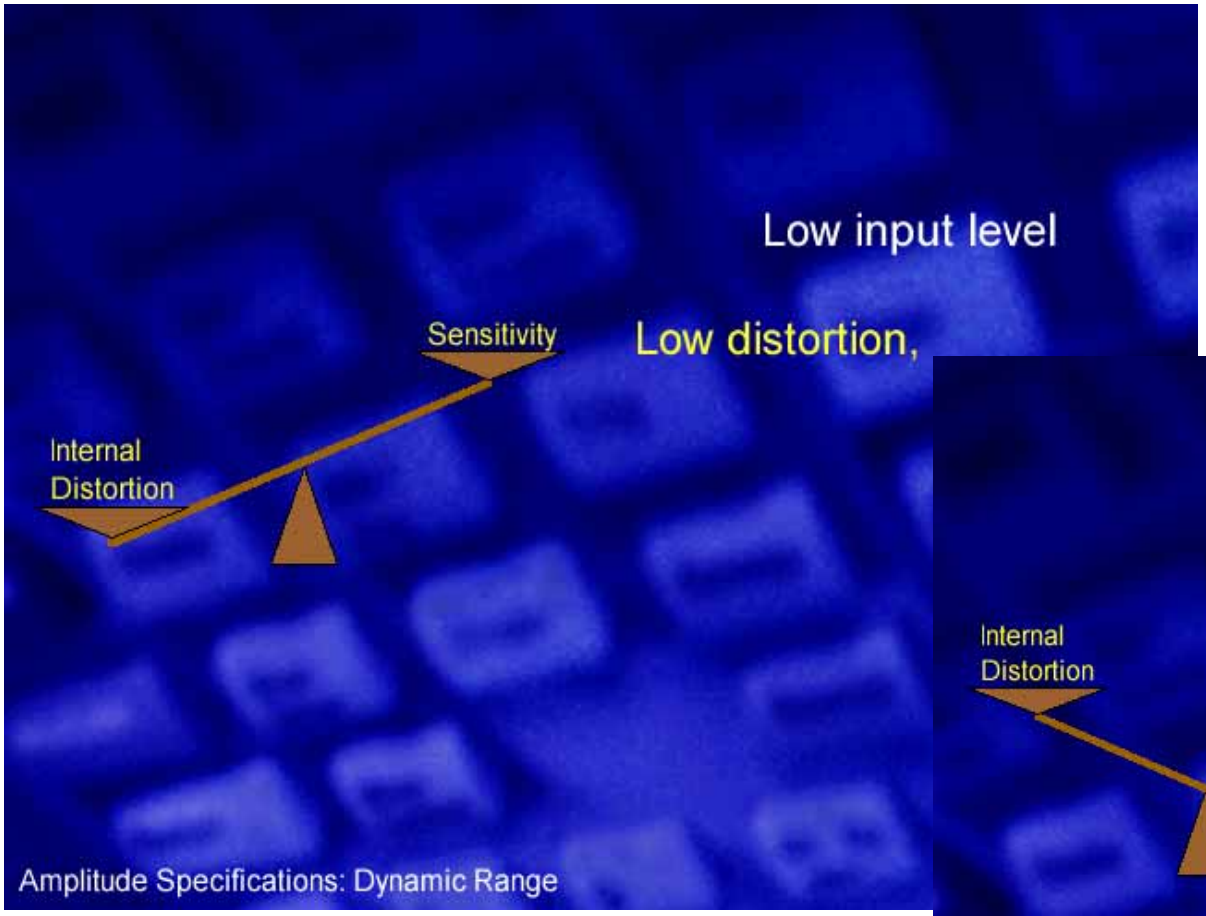
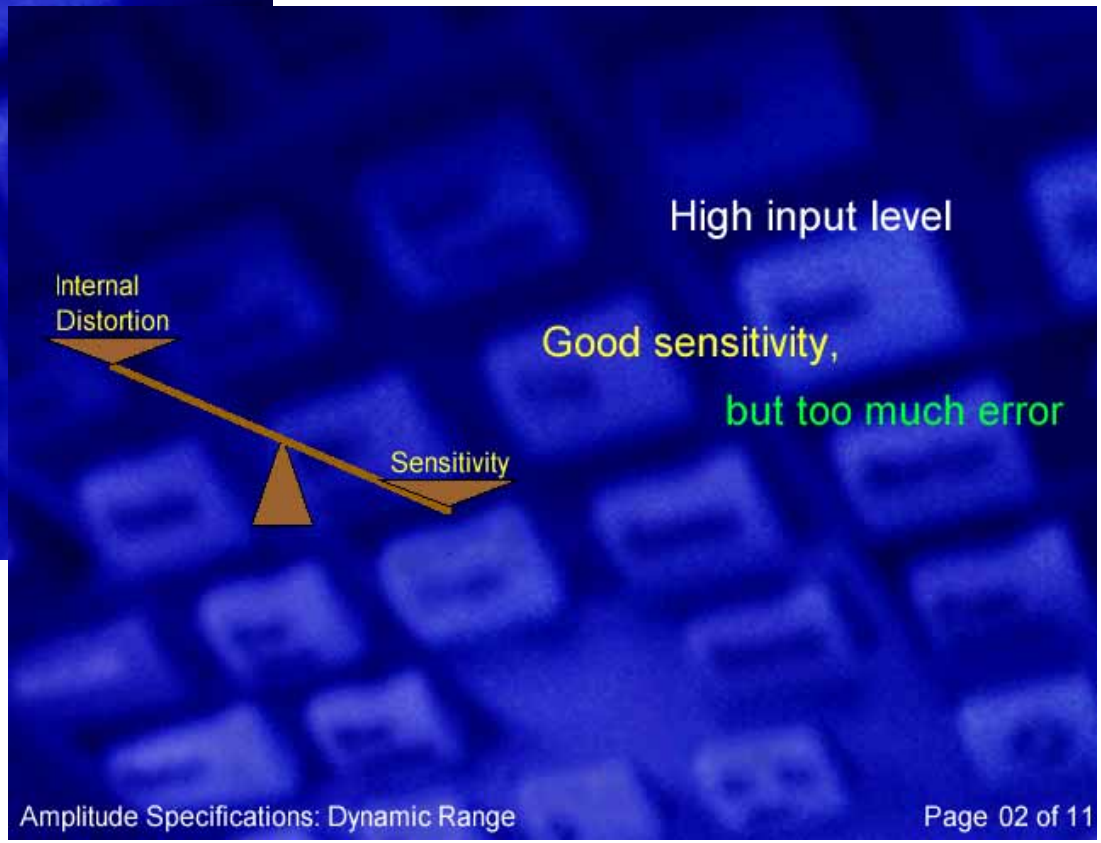
无失真测试动态范围在内部失真和噪声电平间折衷



衰减器设值小时

频谱仪内部失真大；噪声电平低



衰减器设值大时

频谱仪内部失真小；噪声电平高

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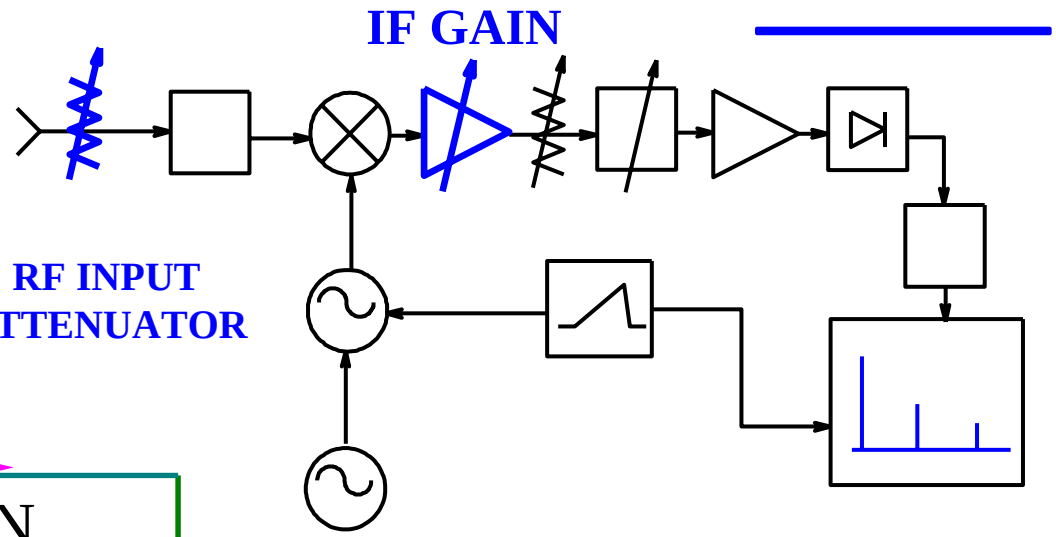
改变衰减器来判断频谱仪测试结果的真实性



改变衰减器设置

频谱仪显示结果变化？

N

Y

测试杂波或噪声来源于被测

测试杂波或噪声有仪表内部产生成份

增加衰减器，直到显示的杂散不再变化为止

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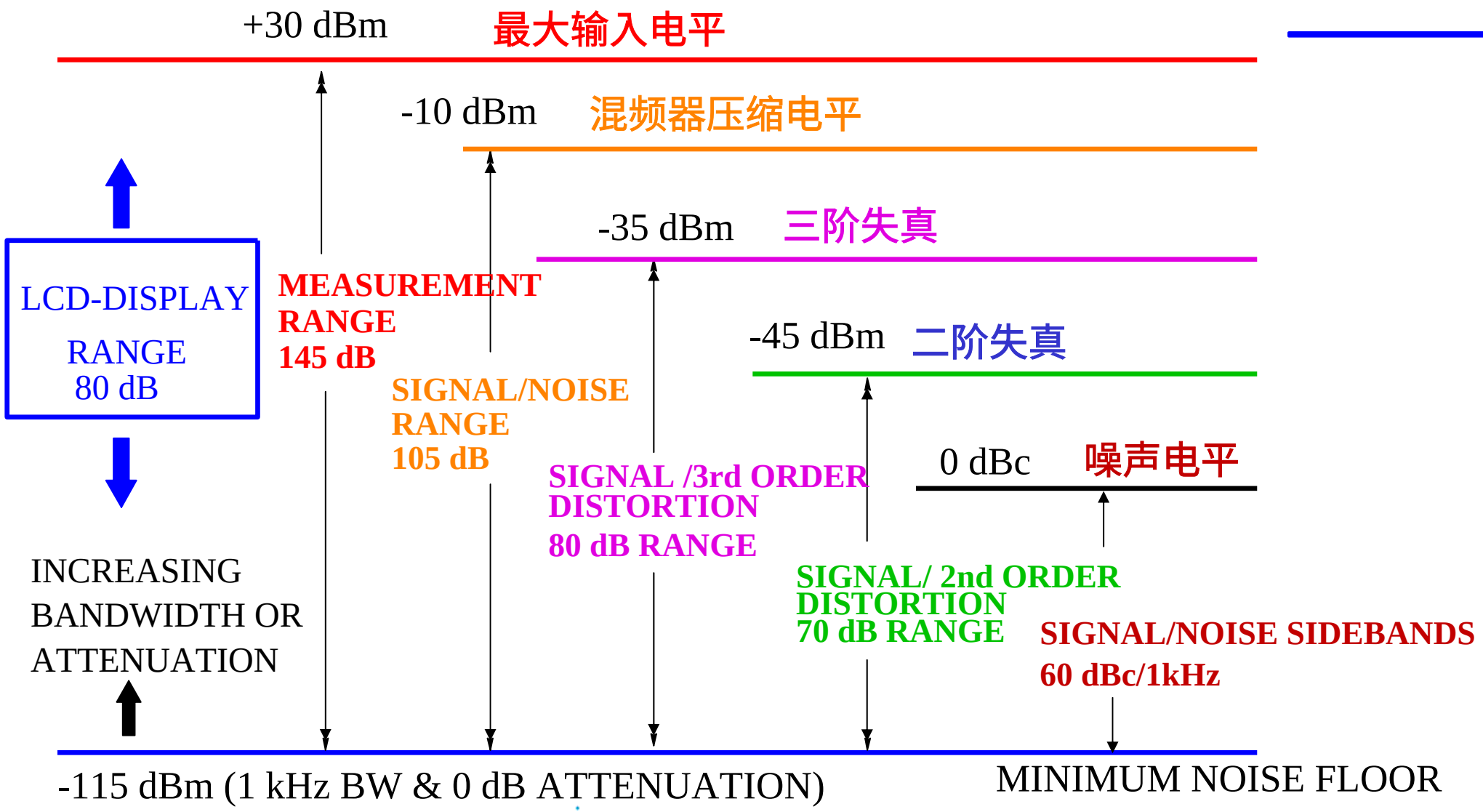
频谱分析仪动态范围定义



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ESA 动态范围性能

Second harmonic distortion

E4401B	
2 MHz to 750 MHz	<–75 dBc for –40 dBm tone at input mixer[5]. (+35 dBm SHI)
E4402/04/05/07B	
10 MHz to 500 MHz	<–65 dBc for –30 dBm tone at input mixer[5].
500 MHz to 1.5 GHz	<–75 dBc for –30 dBm tone at input mixer[2]. (+45 dBm SHI)
1.5 GHz to 2.0 GHz	<–85 dBc for –10 dBm tone at input mixer[2].
>2.0 GHz	<–100 dBc for –10 dBm tone at input mixer[5] (or below displayed average noise level).

二阶失真动态范围性能

三阶失真动态范围性能

Third-order intermodulation distortion

E4401B	
10 MHz to 1.5 GHz	<–87 dBc for two –30 dBm tones at input mixer[5] and >50 kHz separation. (+13.5 dBm TOI, +19 dBm typical)
E4402B/04B/05B/07B	
100 MHz to 3.0 GHz	<–85 dBc for two –30 dBm tones at input mixer[5] and >50 kHz separation. (+12.5 dBm TOI, +16 dBm typical)
>3.0 GHz to 6.7 GHz	<–82 dBc for two –30 dBm tones at input mixer[5] and >50 kHz separation. (+11 dBm TOI, +18 dBm typical)
>6.7 GHz	<–75 dBc for two –30 dBm tones at input mixer[5] and >50 kHz seperation.

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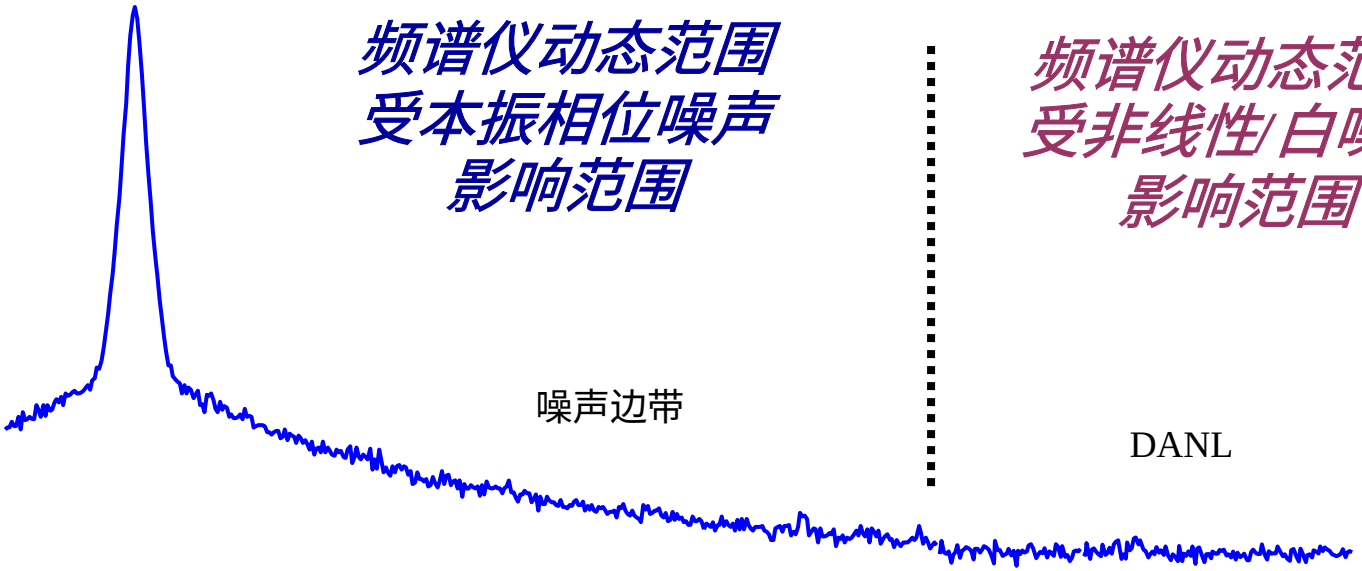
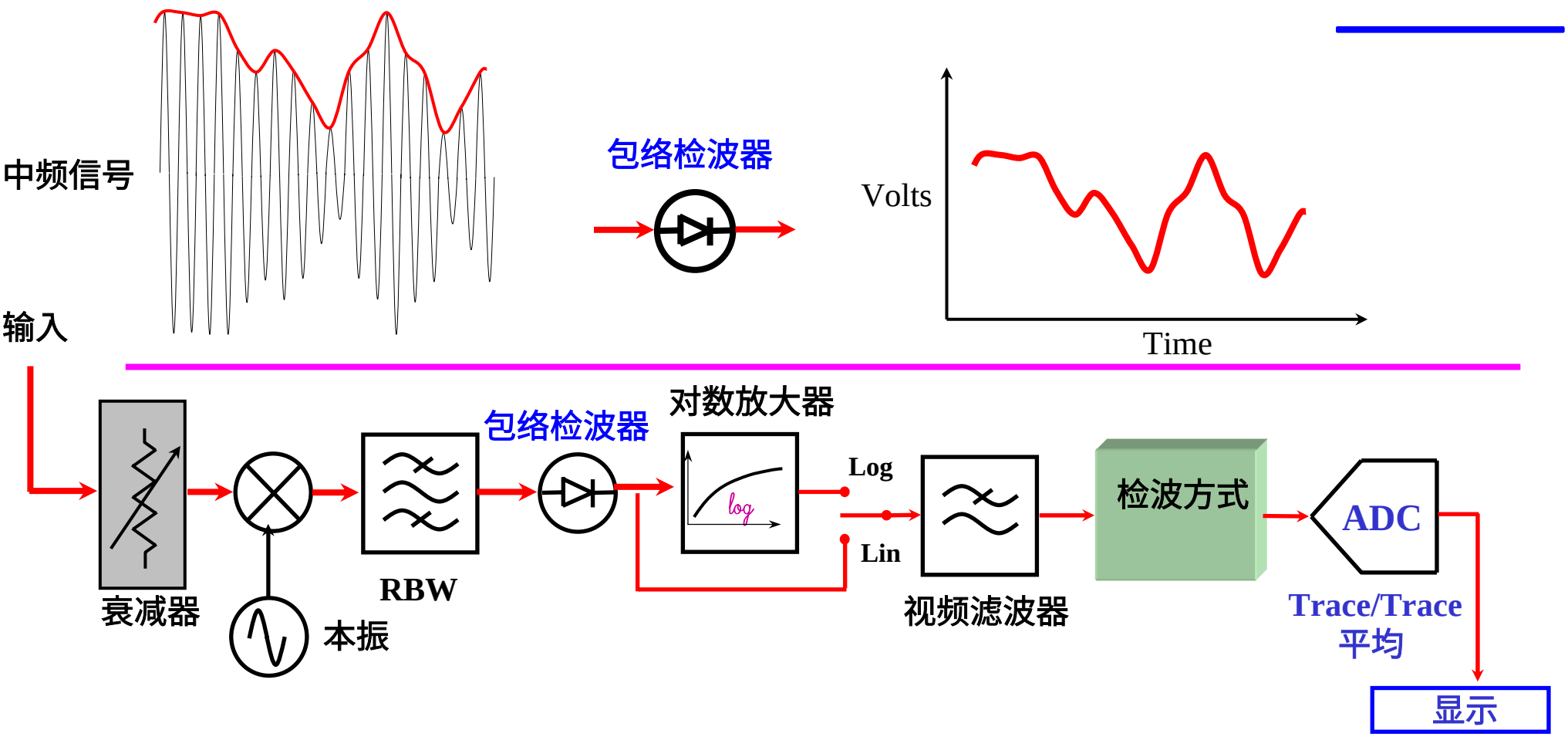
近端测试动态范围受本振相位噪声影响

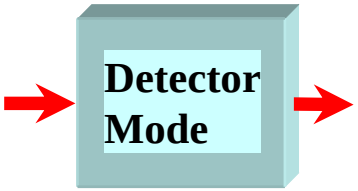


频谱仪对信号功率的测量过程

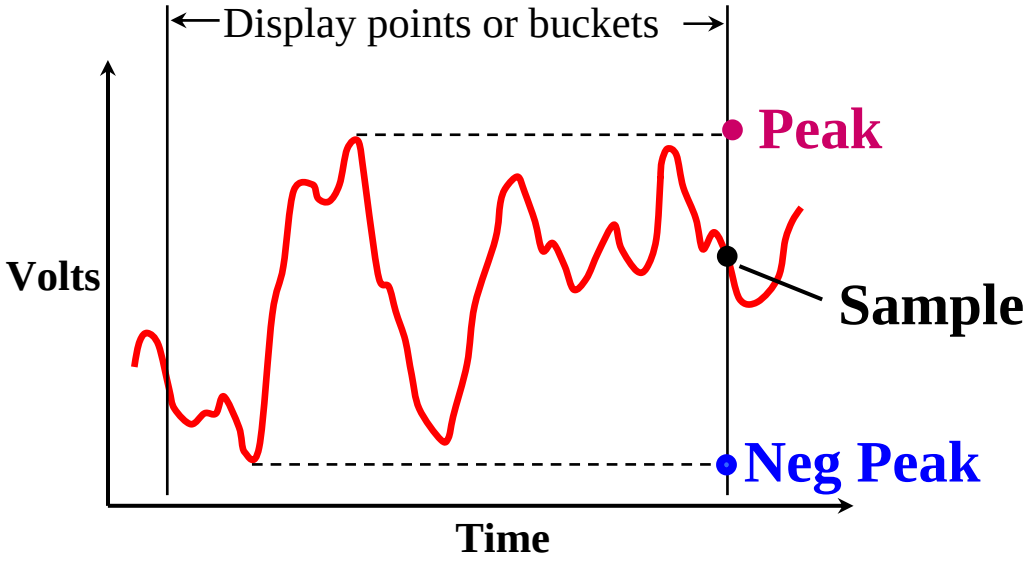


不同性质信号功率的测试结果与检波方式，平均方式有关

频谱仪检波方式: Peak, Negative Peak, Sample



Peak
Neg Peak
Sample



Peak检波方式： 适合CW 信号及信号搜索测试

Sample检波方式：适合于噪声信号测试

Neg Peak检波方式：适合于小信号测试

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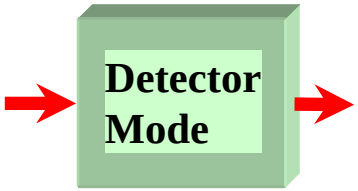
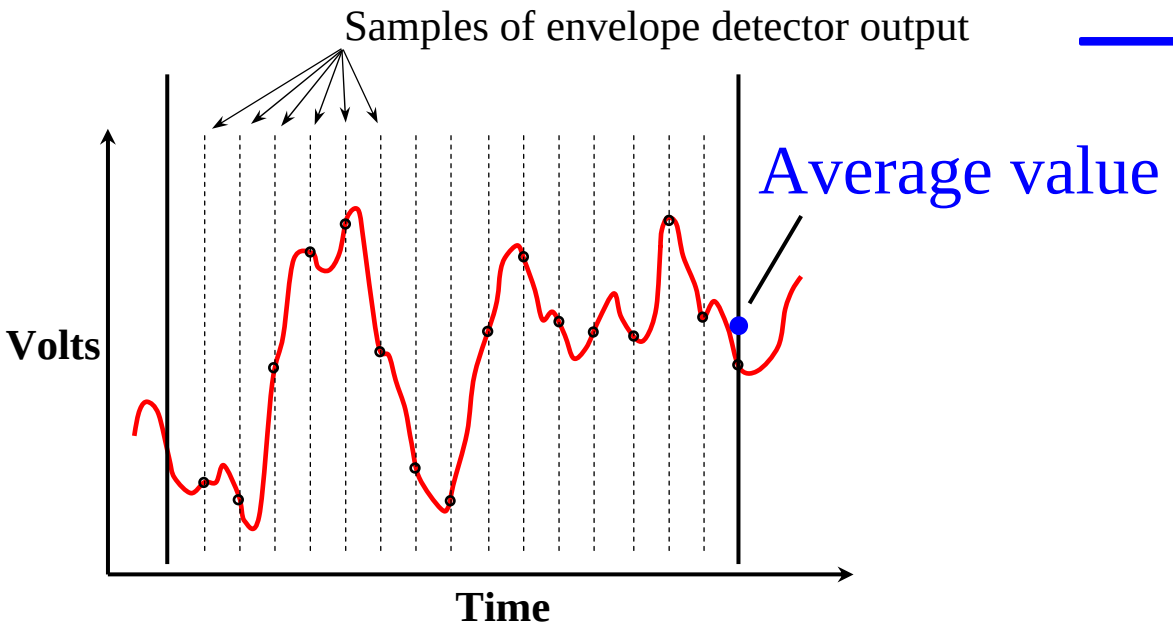
频谱仪检波方式： Averaging Detectors



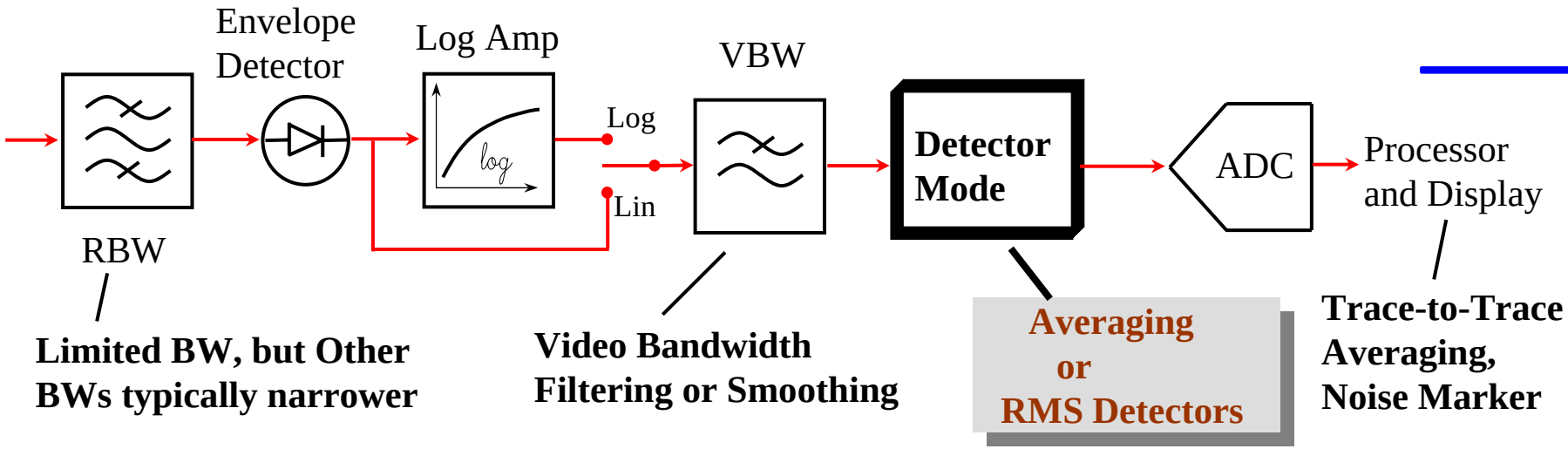
Average



- 功率测量显示由多个包络电平值的平均得到
- 可减少显示信号的抖动，扫描速度越高，平均效果越明显
- 适合于ACPR及通道功率指标测试

平均处理

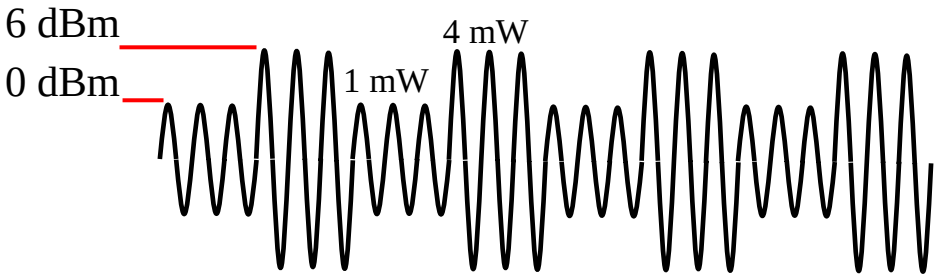
- 减小噪声或类似噪声信号显示方差



平均方式—
Log, Lin, Power

- **Log平均** — CW signals
  - 窄 VBW, trace 平均
  - 适合于低电平CW信号测试
- **电压平均** — voltage envelopes
  - 适合于脉冲信号上升下降时间测量
- **功率平均** — time-varying signals
  - 信号平均功率测量

平均处理举例



Log 平均 结果

= 3 dBm=(0 dBm + 6 dBm)/2

功率平均 结果

= 3.98 dBm=(1 mW + 4 mW)/2 = 2.5 mW

- **Log 平均与功率平均 结果不相同**
- **窄VBW及trace平均为 Log 平均，测量时变信号时存在误差**
- **RMS 检波等效为功率平均**

RMS 检波方式

Average Type

Video Averaging (Y - axis):

- (Avg [P_1+ P_2+P_3 ....]) *"average of the log"*

Power Averaging (also known as RMS)

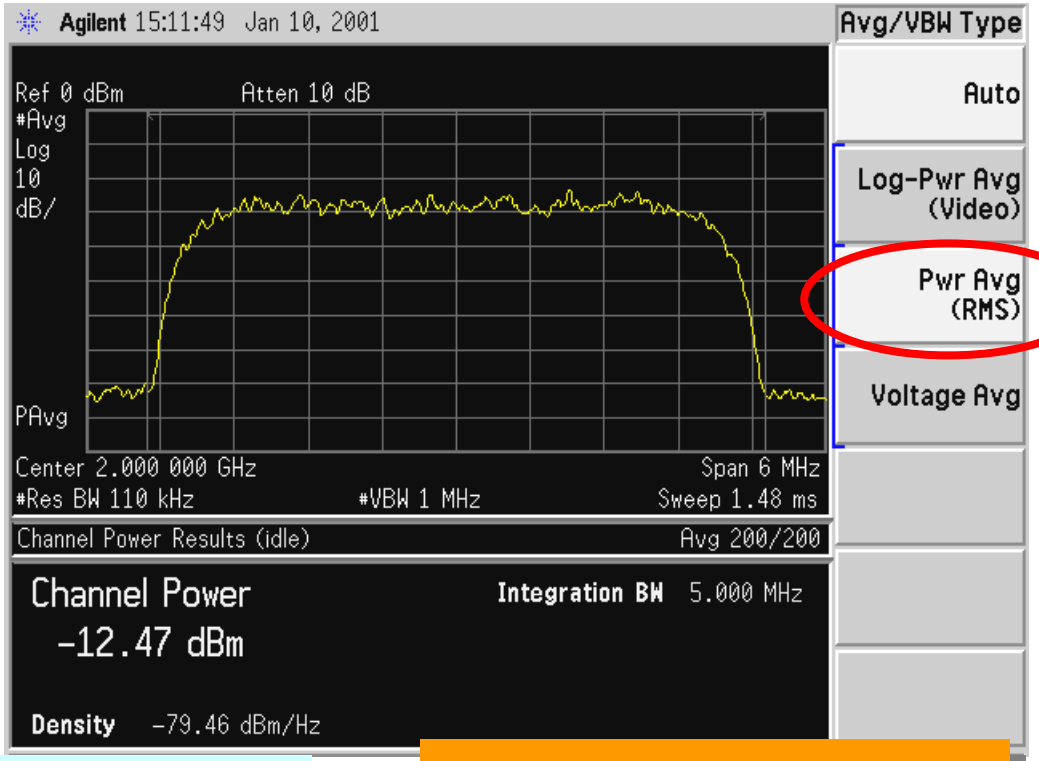
-(*log{Avg [10* $^{P1/10}$+ $10^{P2/10}$+$10^{P3/10}$…..]}) *"log of the average"*

Difference of about 2.5 dB

频谱仪检波方式：RMS Detection and Detectors

BW/Avg ▶ | Average ▶ Type | Pwr Avg (RMS) ▶

Det/Demod ▶ | Detector ▶ Average | Average ▶ (Video/ (RMS)



- 功率平均作用
- 适合于对类噪声信号（CDMA）总功率测量
- 为保证测量精度，VBW>3×RBW

Normal
Average(Log/RMS/V)
Peak
Sample
Negative Peak

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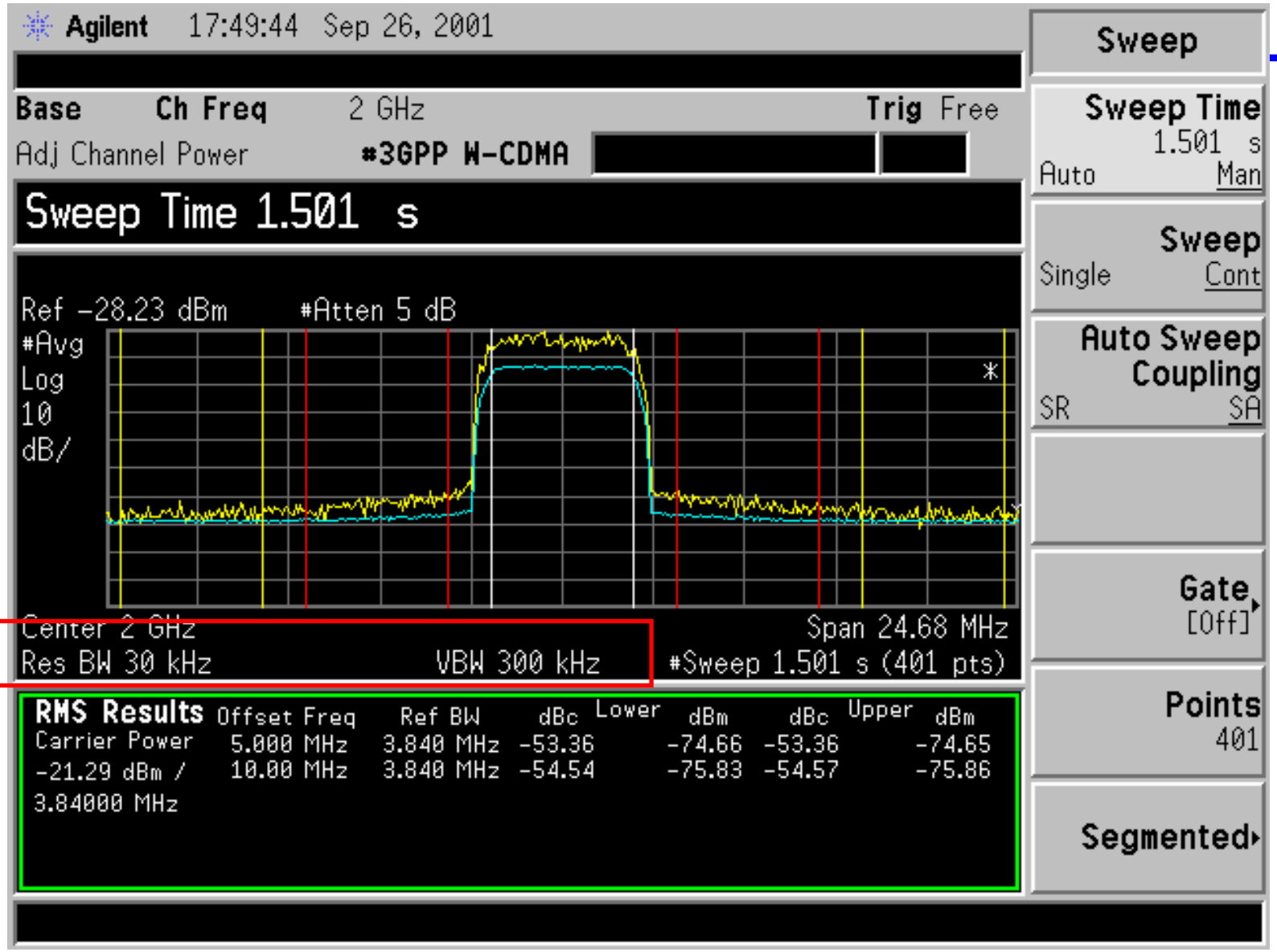
ESA 信号功率测量设置



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信号功率测量状态设置

Measurement	Detector	Average Scale Log/Lin/Pwr	Video BW	Trace Avg
Channel power, non-sine mod.	RMS	Pwr	No VBW≥3XRBW	Pwr (RMS)
Spurious, harmonics	Peak	Log	Yes	Log-pwr (video)
Output RF spect.	Average	Log	No VBW≥3XRBW	Log-pwr (video)
ACPR	Average	Pwr	No VBW≥3XRBW	Pwr (RMS)
RF envelope, rise/fall	Sample	Lin	No VBW≥3XRBW	Voltage
Carr/Ph. Noise	Peak/sample	Pwr	No VBW≥3XRBW	Pwr (RMS)

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ESA 频率测量误差

- 10 MHz OCXO 恒温晶振
- Frequency Counter （1 Hz 分辨率）
- 全频率合成本振

Frequency readout accuracy

(Start, Stop, Center, Marker)	±(frequency indication x frequency reference error[1] + span accuracy +15% of RBW + 10 Hz + 1 Hz x N[4])

Marker frequency counter[2]

Accuracy [3]	±(marker frequency ¥ frequency reference error[1] + counter resolution)
Counter resolution	Selectable from 1 Hz to 100 kHz

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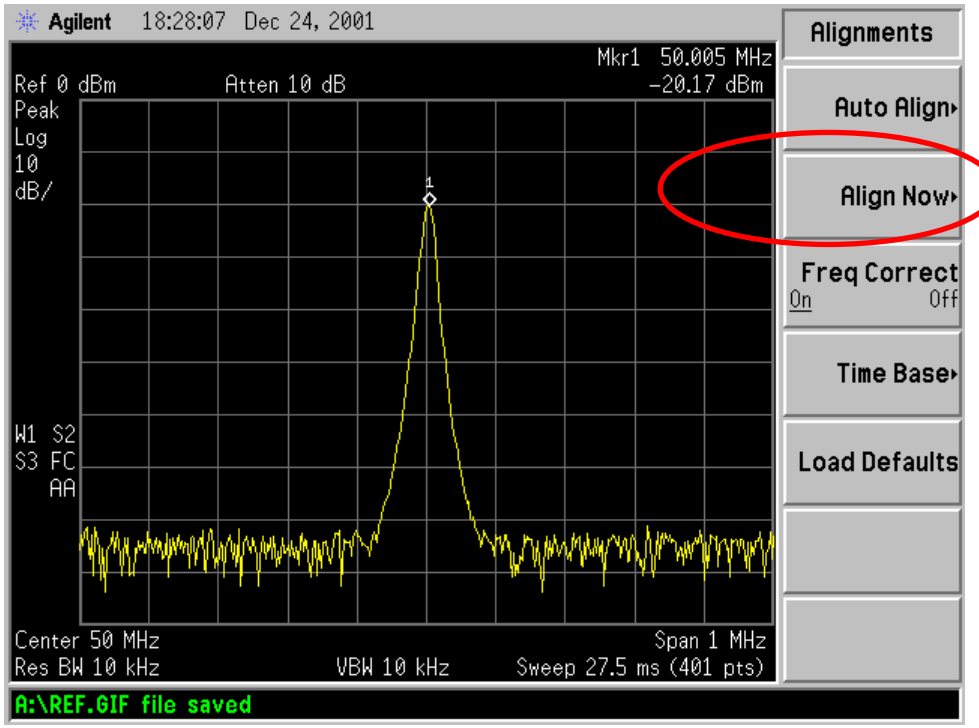
ESA 幅度测量误差

Absolute amplitude accuracy

		Typical
At reference settings[15]	±0.34 dB	±0.13 dB
E4401B	±0.30 dB	±0.10 dB
Preamp on[16] (Option 1DS)	±0.37 dB	±0.14 dB
External mixer (Option AYZ)	IF INPUT absolute amplitude accuracy + external mixer conversion loss accuracy[17]	
Overall amplitude accuracy[9]	±(0.54 dB + absolute frequency response)	



技术小结

⇩ 扫频式频率分析仪分析频率范围由本振范围决定；

⇩ 扫频式频率分析仪频率分辨率与中频率滤波器和本振有关；

测试中可通过减小RBW来提高频率分析分辨率

⇩ 扫频式频率分析仪分析灵敏度与中频率滤波器；衰减器设值；视频滤波器和本振有关；

测试中可通过减小RBW；VBW，衰减器设值和前置放大来提高分析灵敏度

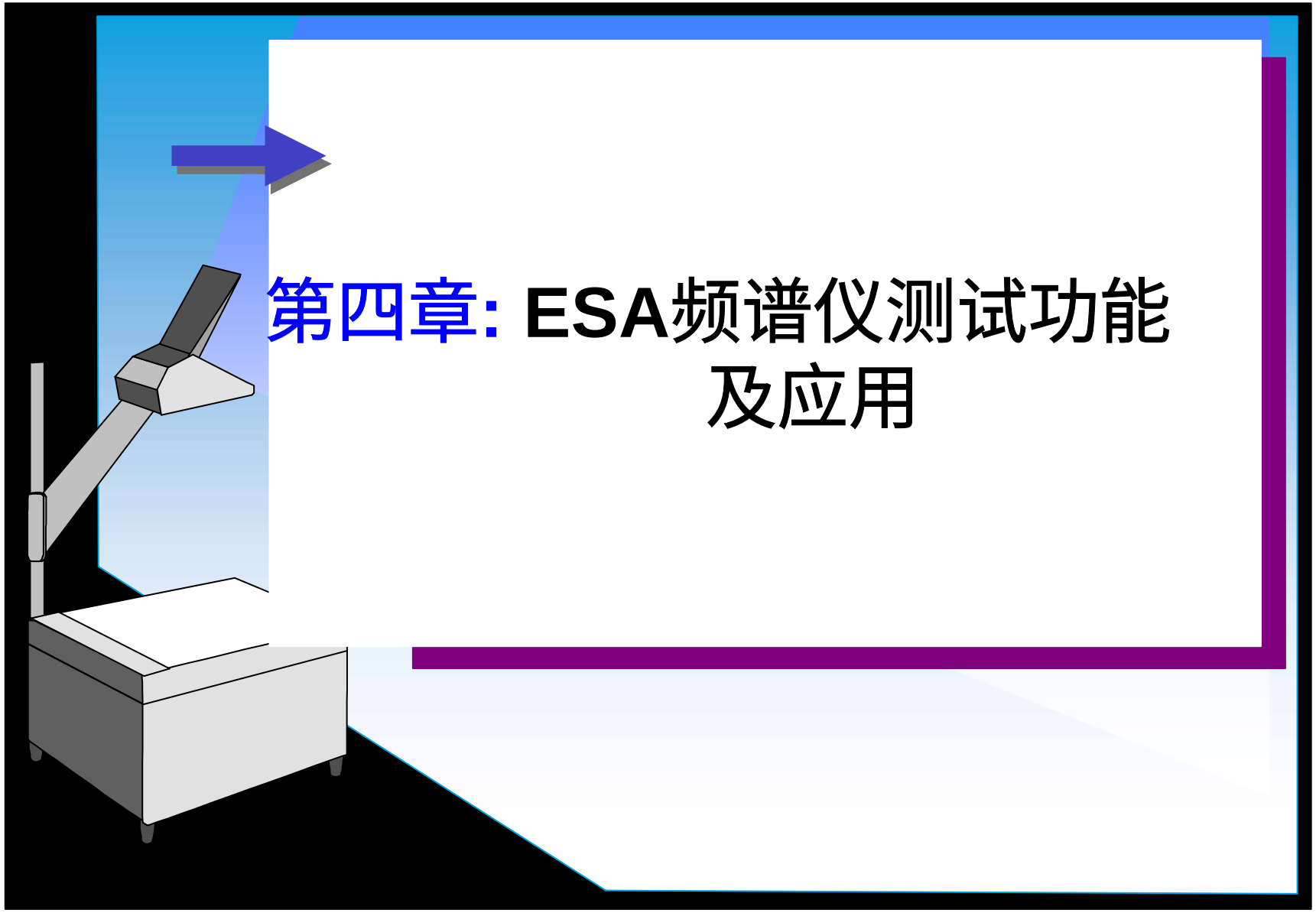
⇩ 扫频式频率分析仪分析内部失真与混频器工作电平，中频放大器性能有关；

测试中可通过减小混频器工作电平（增加衰减器设值）来减小内部失真

⇩ 扫频式频率分析仪分析灵敏度与中频率滤波器；衰减器设值；视频滤波器和本振有关；

⇩ 扫频式频率分析仪衰减器设置在灵敏度指标和内部失真指标间折。通过改变衰减器设置可判断频谱分析仪测试结果的真实性；

⇩ 扫频式频谱仪测量功率结果与其检波方式和平均方式有关。



第四章: ESA频谱仪测试功能及应用

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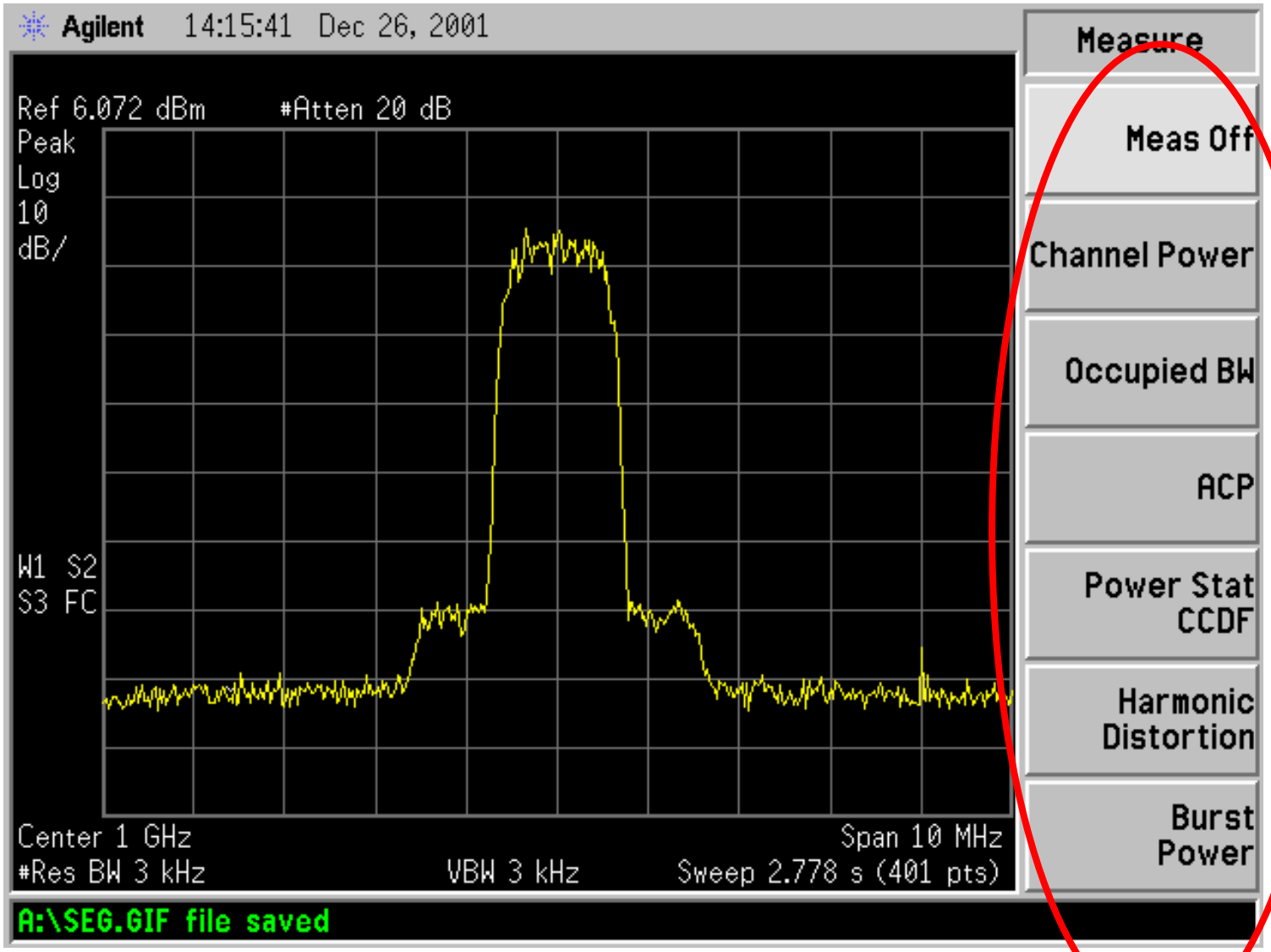
ESA 功能测试



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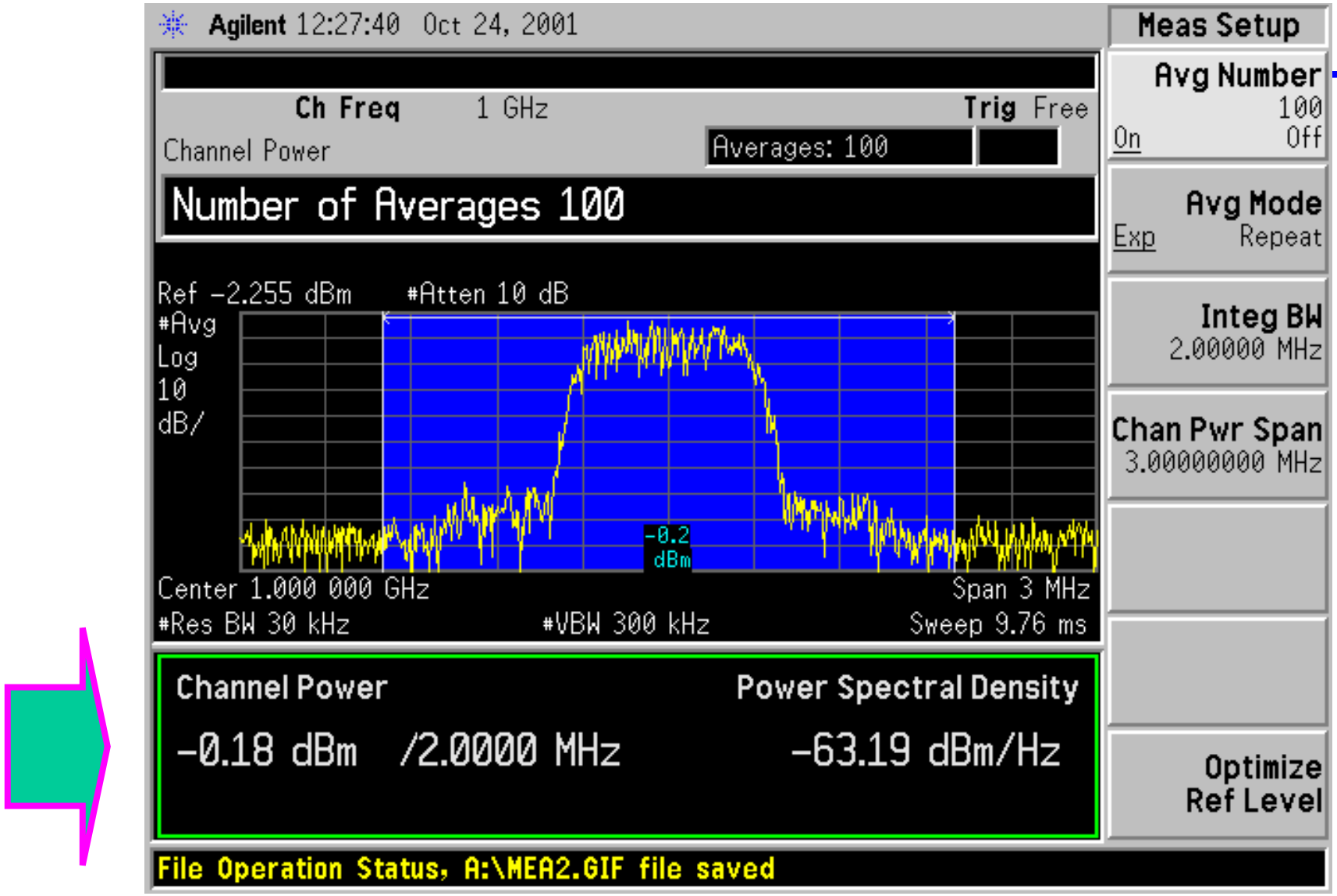
Channel power 功能键用于调制信号功率测量



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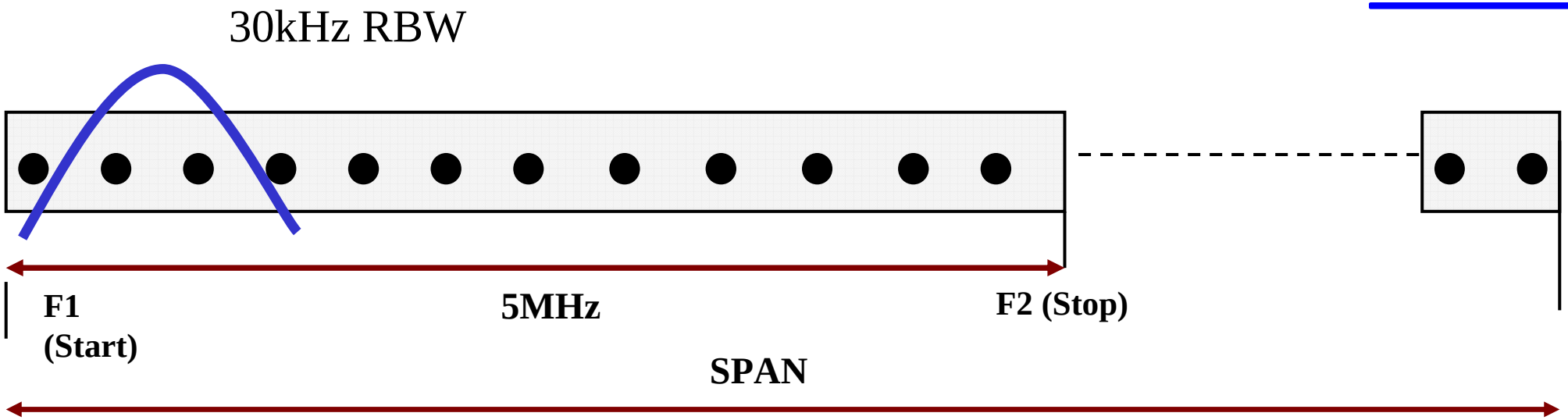
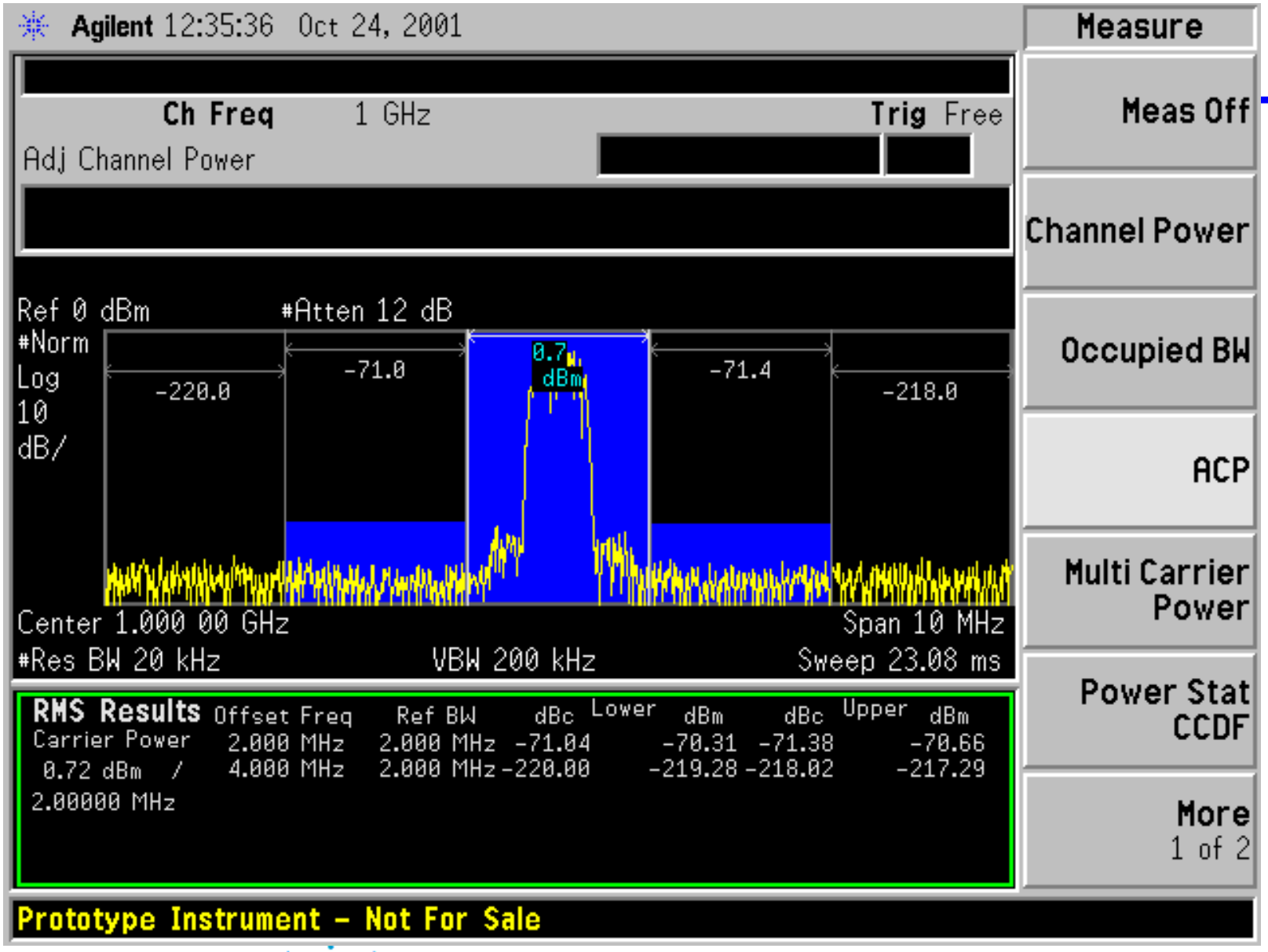
Channel (Bandwidth) Power 计算



$$Channel\,Power = 10\log\left\{\left(\frac{Span}{\frac{(Nbuck-1)}{NBW}}\right)\sum_{i=I(f_1)}^{i=I(f_2)}10^{P_i/10}\right\}$$

NBW:等效噪声带宽

ACPR 邻道功率比测量



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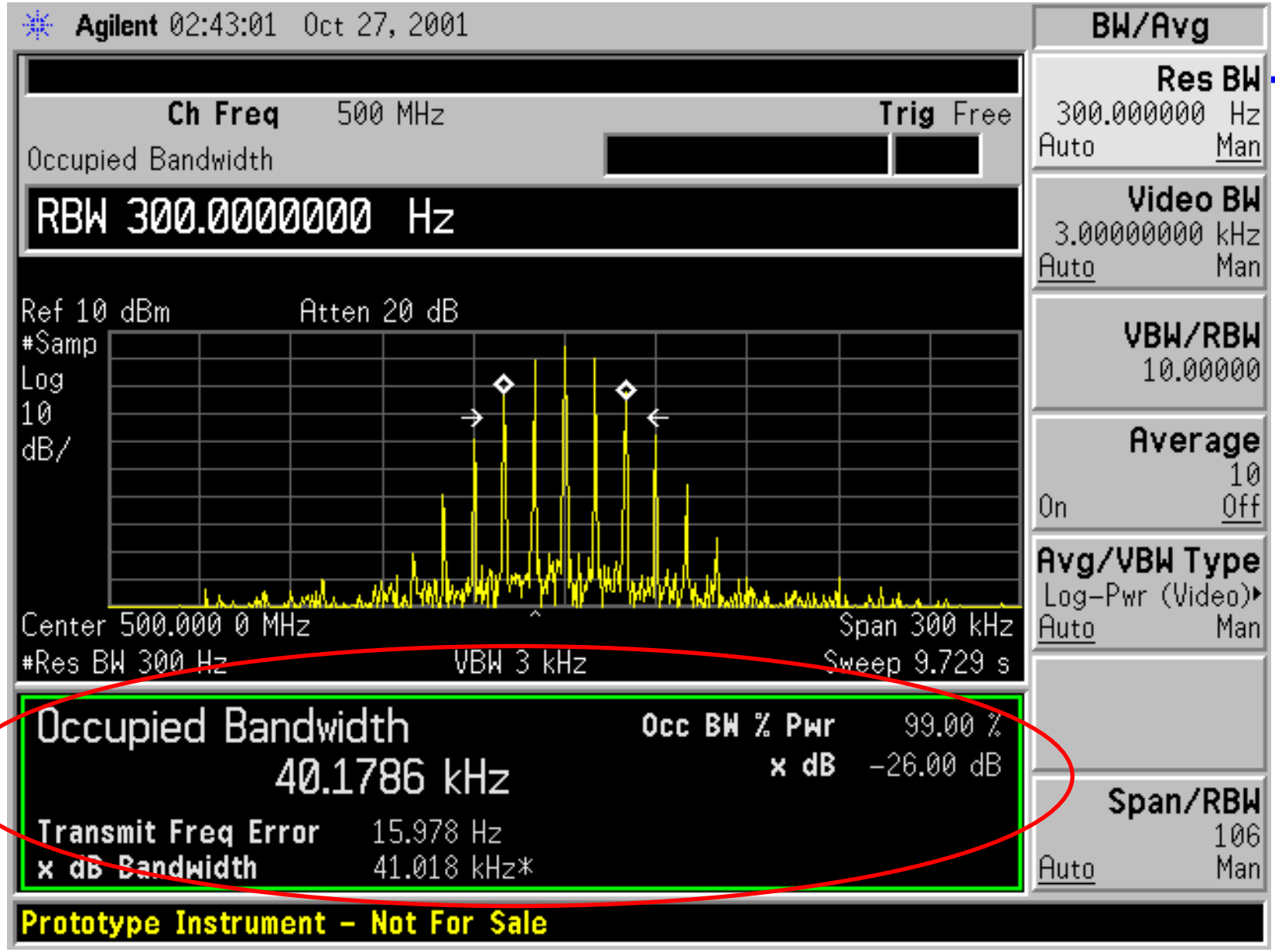
信号频谱占用带宽测量



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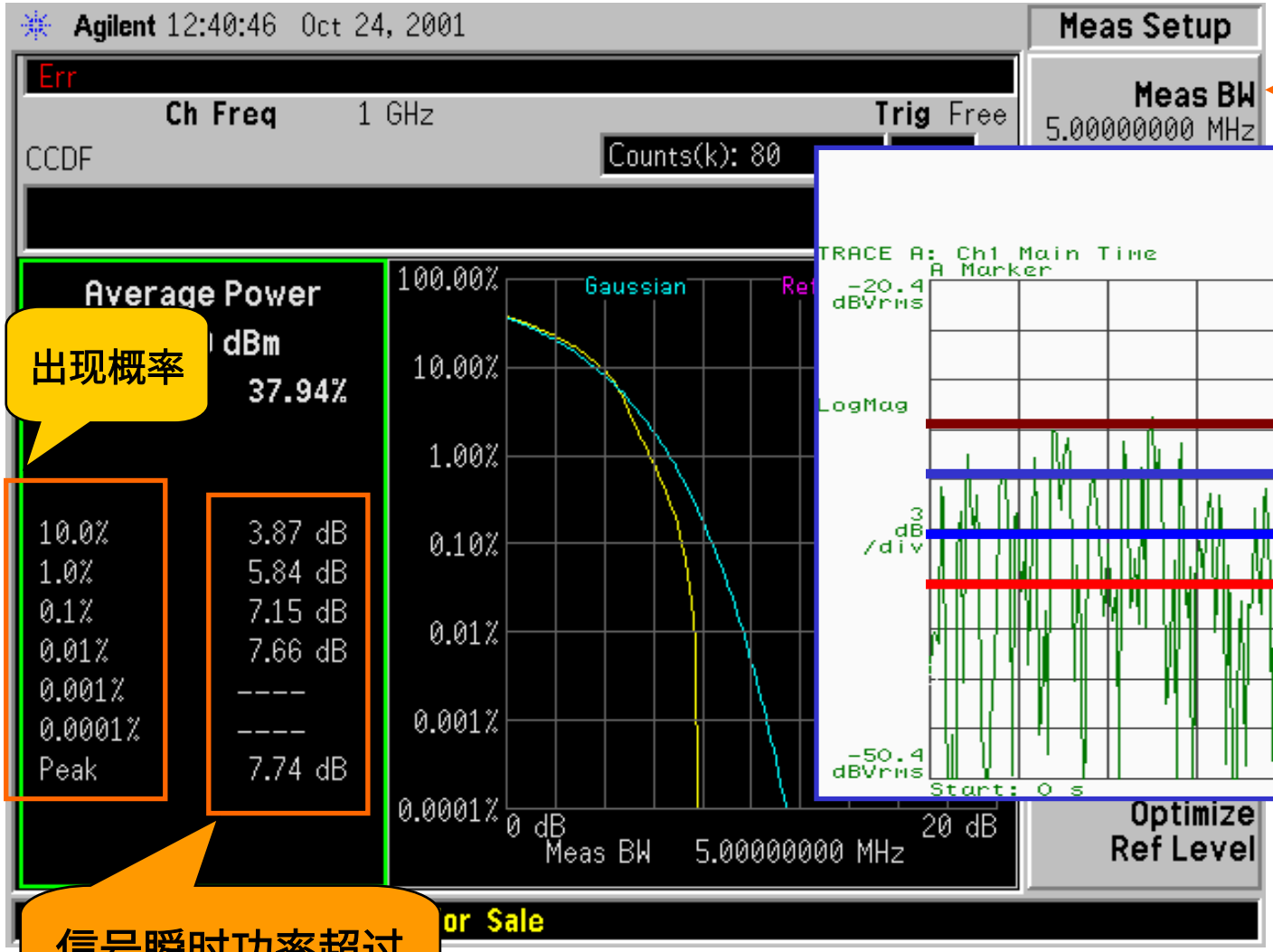
CCDF （互补积累分布函数）测量

对信号功率变化分布情况进行统计分析

Opt AYX: 快速时域扫描
+B7D: DSP处理



分析带宽<5MHz

dB above average power

9dB
6dB
3dB

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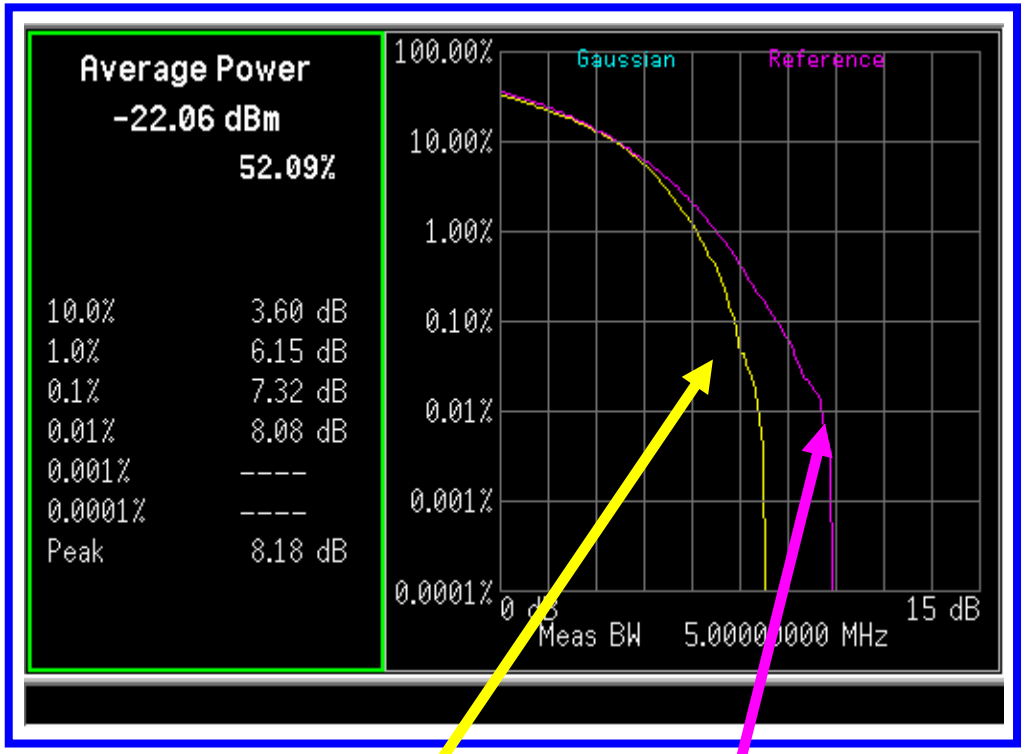
CCDF 测试应用

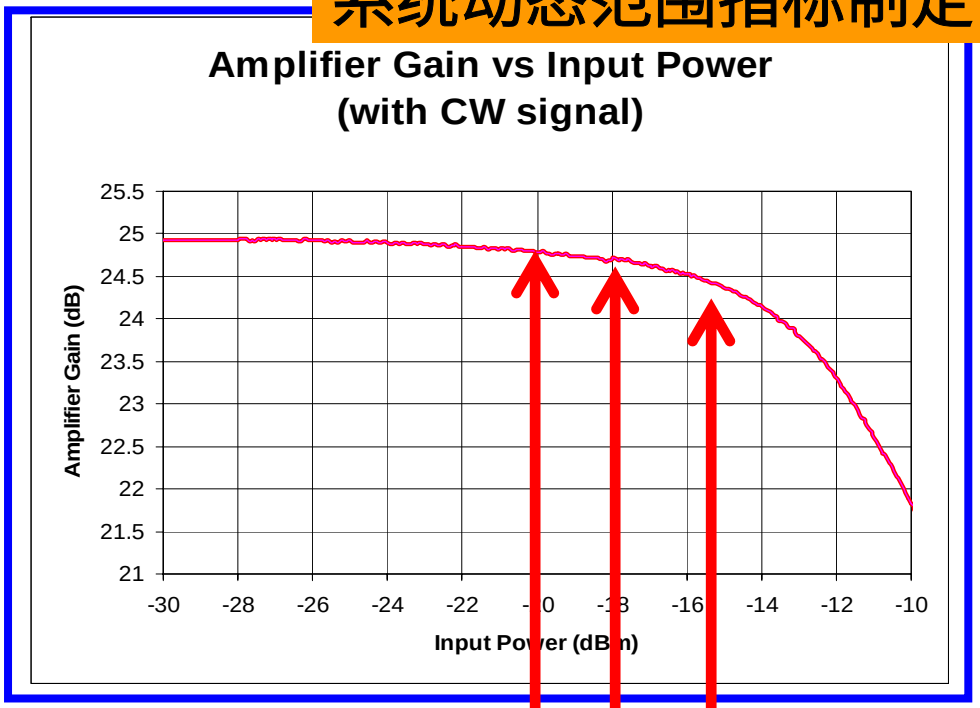
被测件压缩性能检测

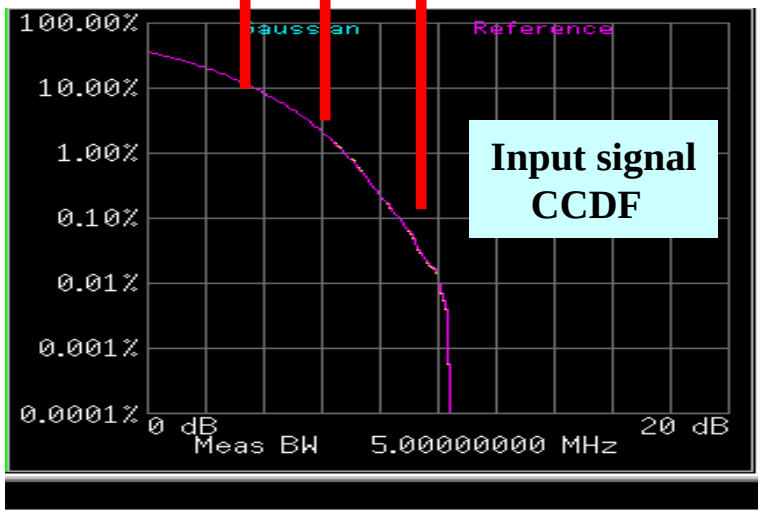


Amplified signal CCDF

Input signal CCDF

系统动态范围指标制定





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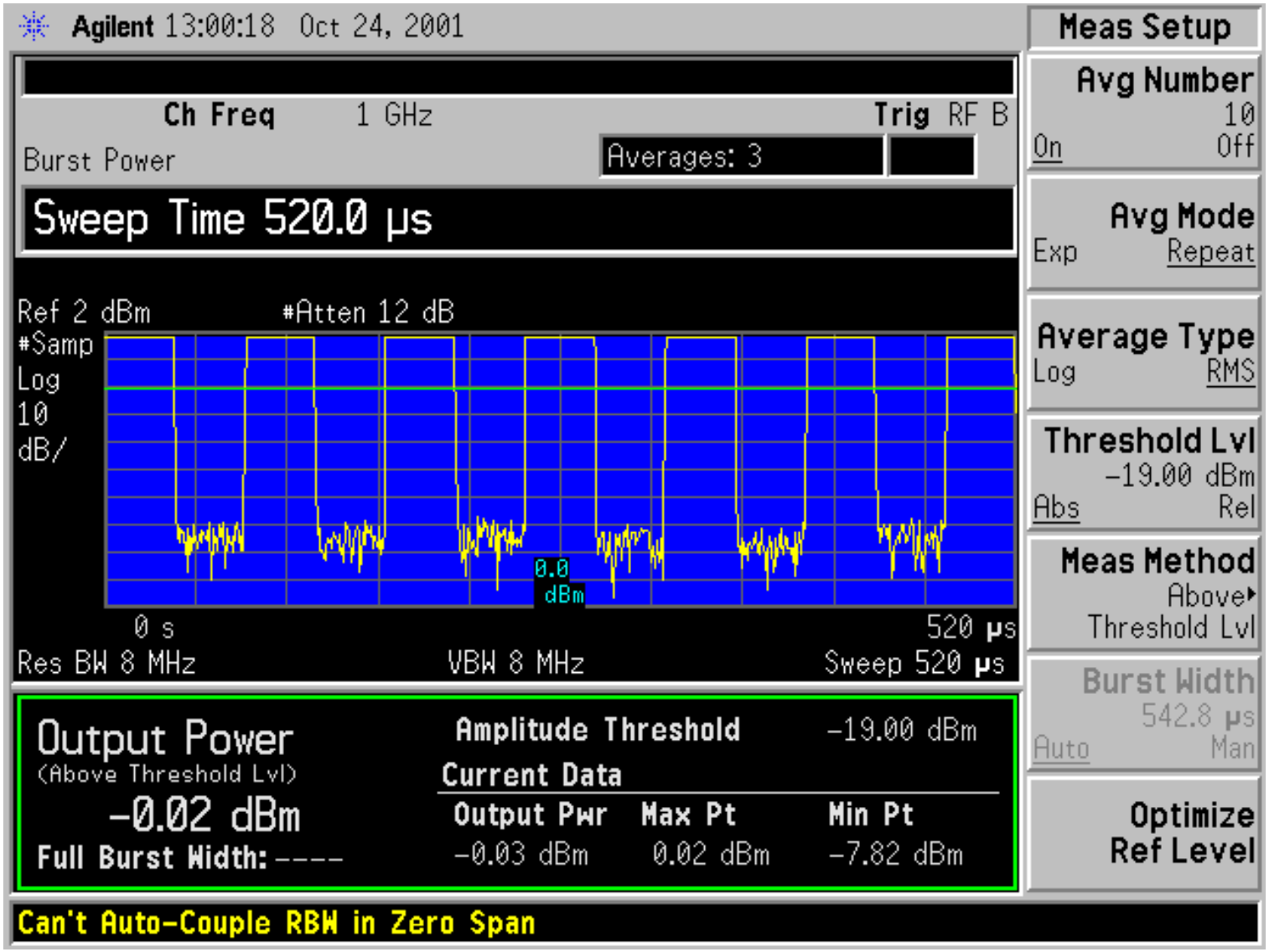
Burst power 测量显示信号包络



Zero span 状态
RBW，VBW 设置

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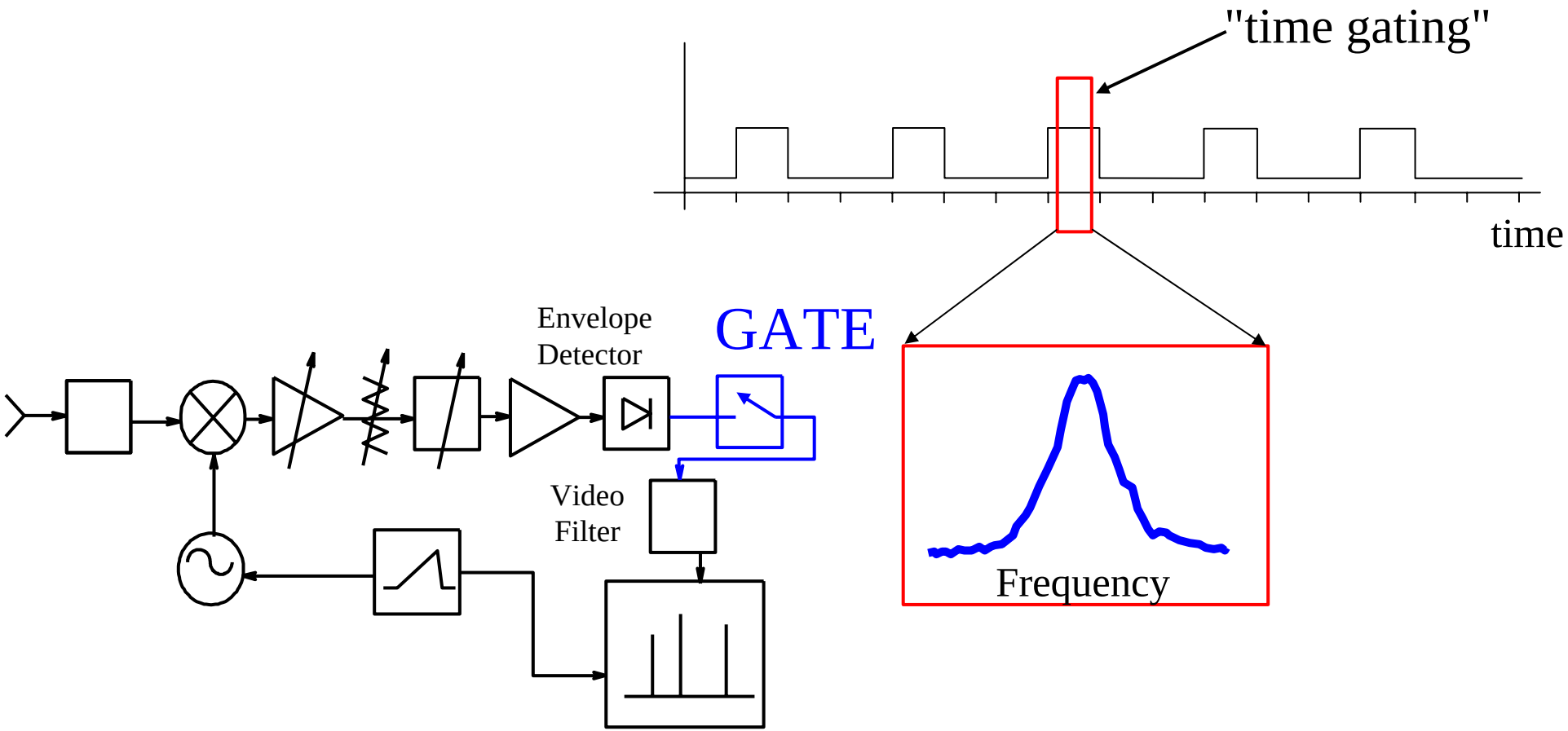
时间门功能可使频谱仪对信号进行选时分析 (Opt 1D6)



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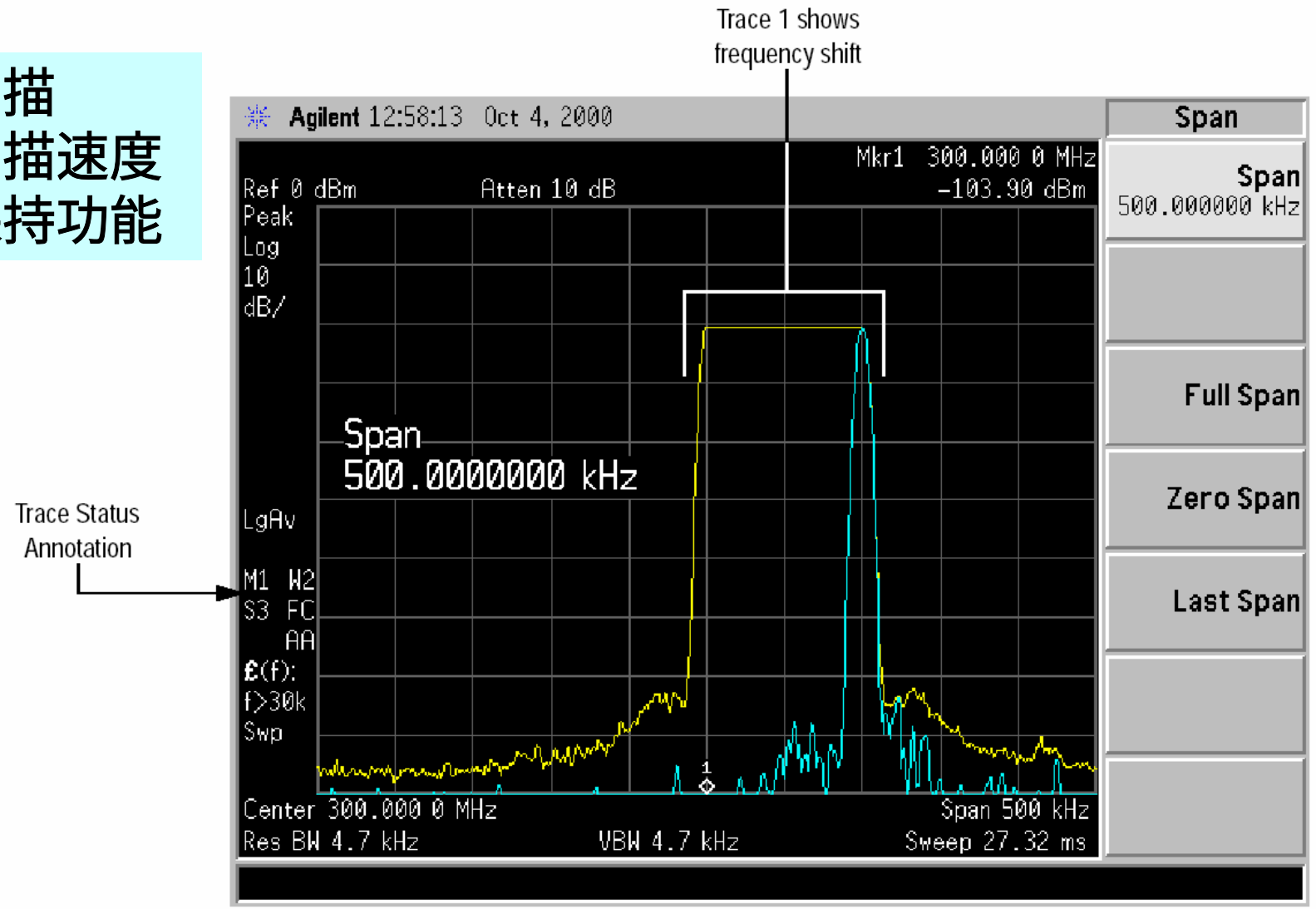
扫频式频谱仪对瞬变信号的测量

- 单次扫描
- 提高扫描速度
- 最大保持功能



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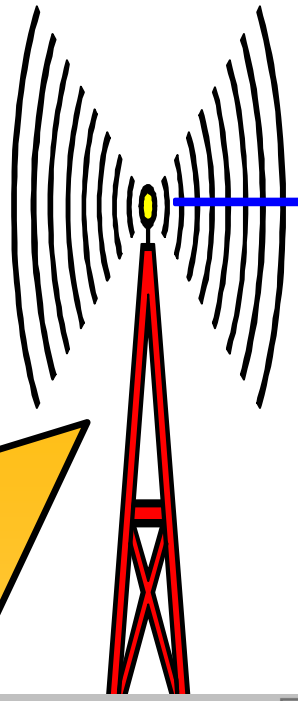
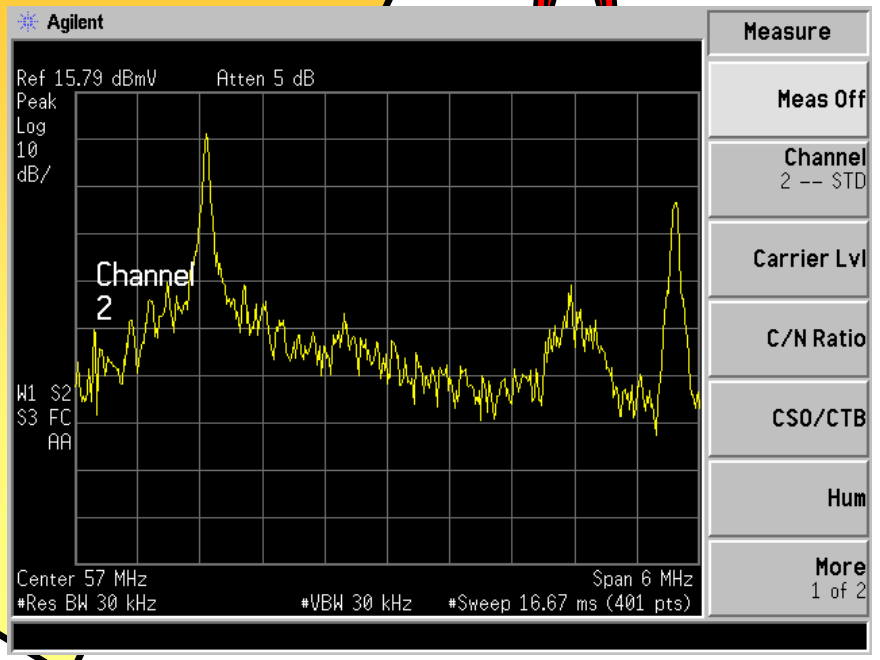
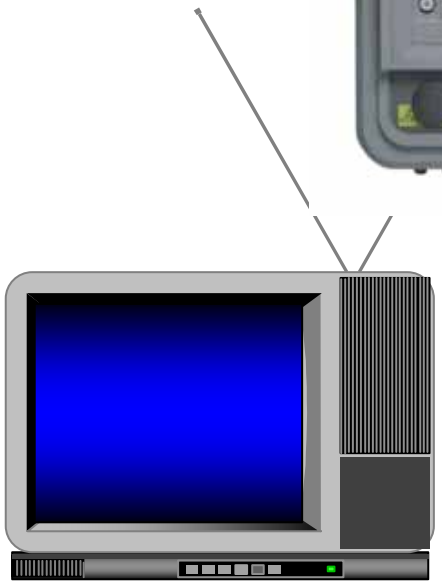
ESA 信号解调功能

Opt BAA: FM
Opt 227: Cable TV
Opt B7B: TV trigger（OPT BAA 必需）







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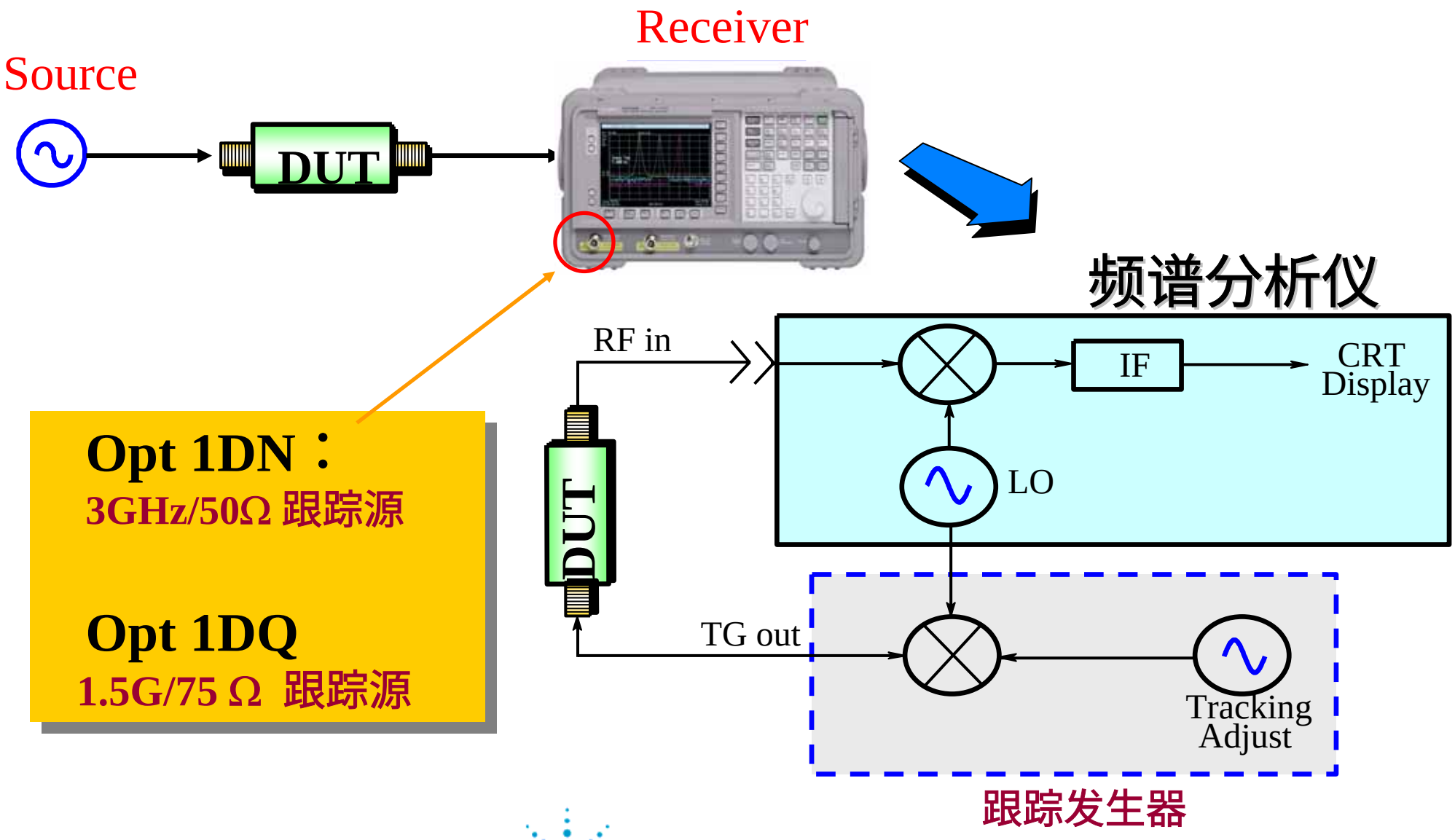
频谱分析仪跟踪源选件



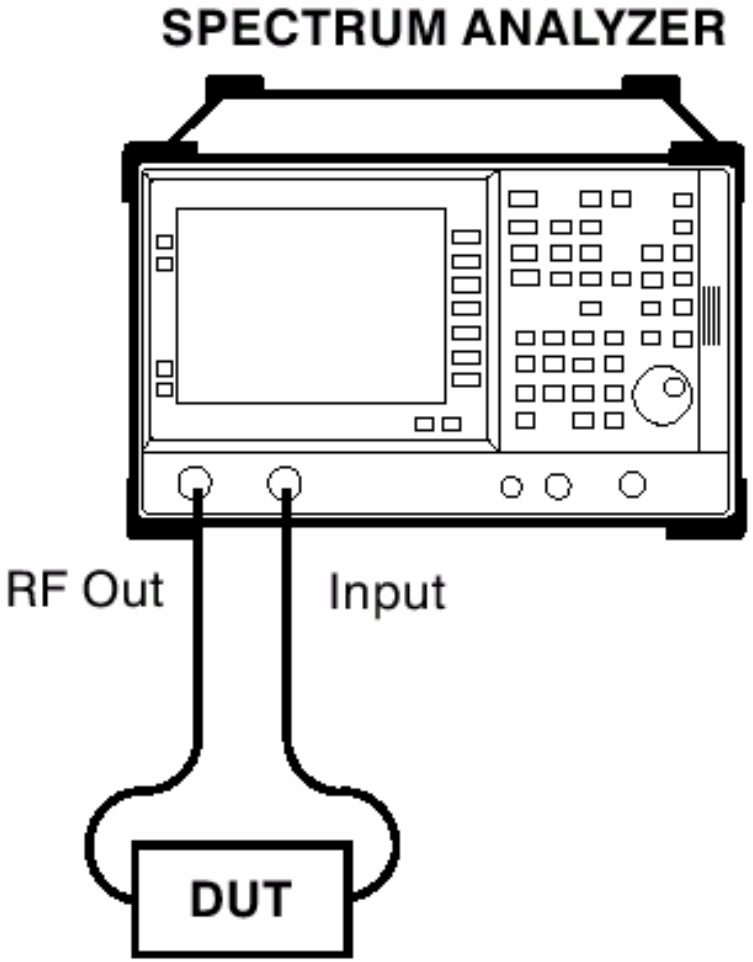
Opt 1DN：
3GHz/50Ω 跟踪源

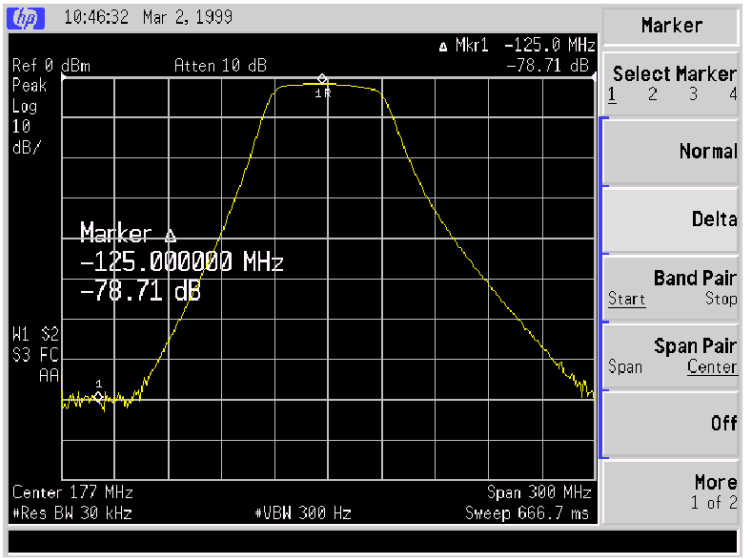
Opt 1DQ
1.5G/75 Ω 跟踪源

ESA跟踪源应用

----传输频响测试

Transmission Measurement Test Setup





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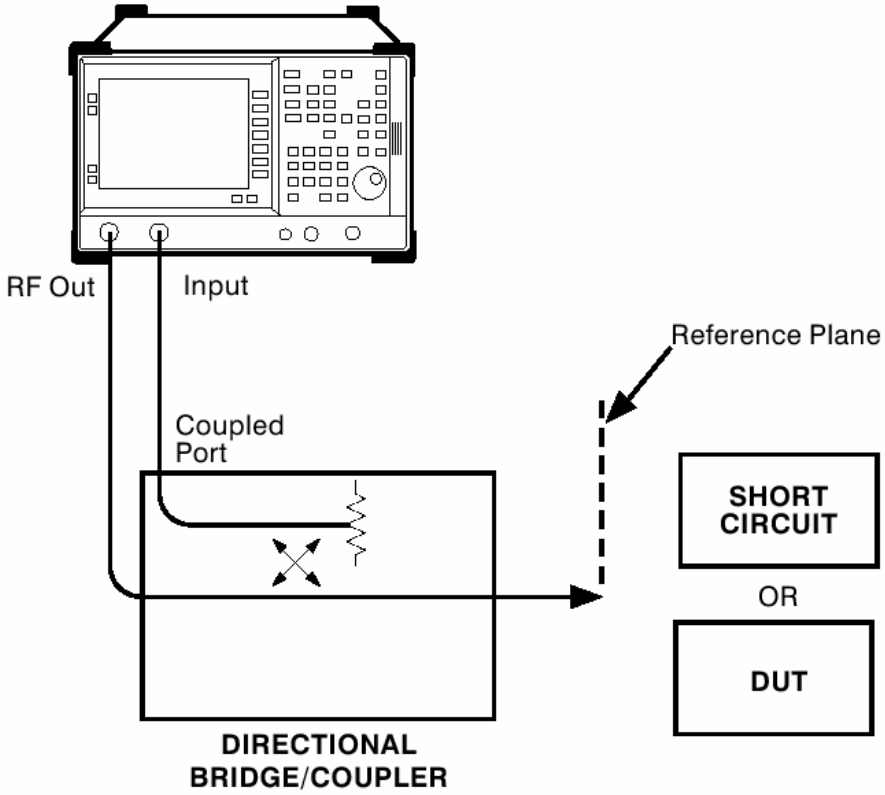
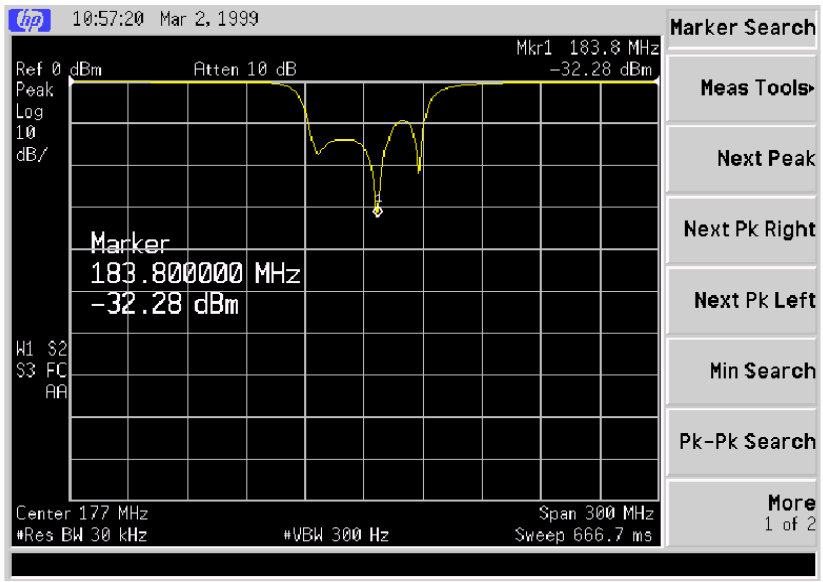
ESA跟踪源应用

----反射频响测试

Reflection Measurement Short Calibration Test Setu





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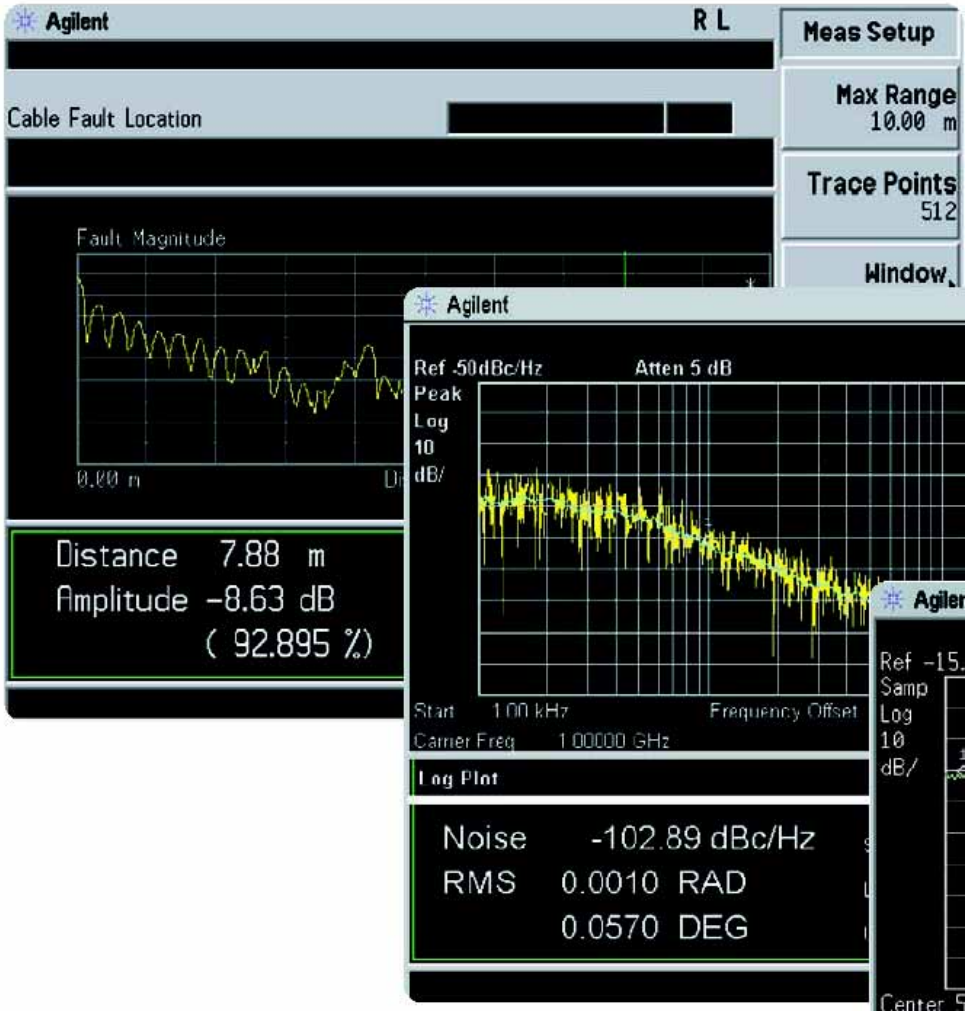
ESA跟踪源应用

----故障定位(Opt 225+B7K)



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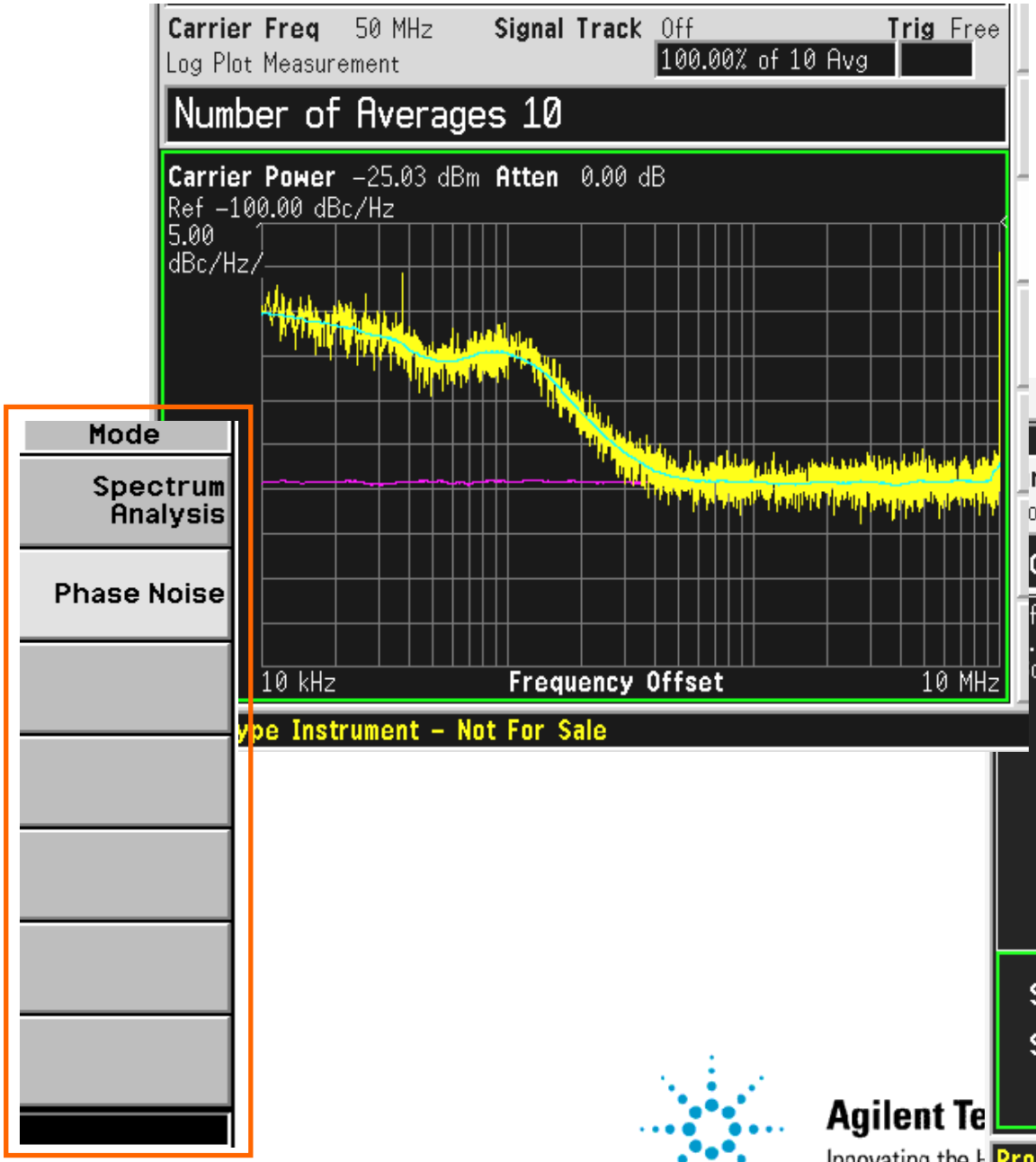
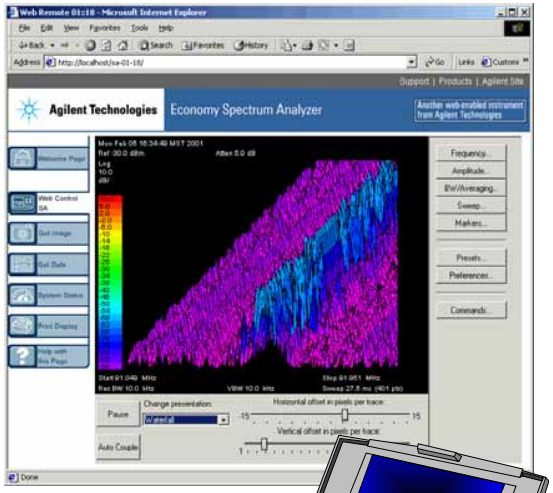
信号相位噪声测试（Option 226）

- One-button PN log plot
- DANL display
- One-button single freq. PN (real-time)
- Carrier freq. drifting



Agilent Te
Innovating the H

ESA 的网络控制功能 (选件230)

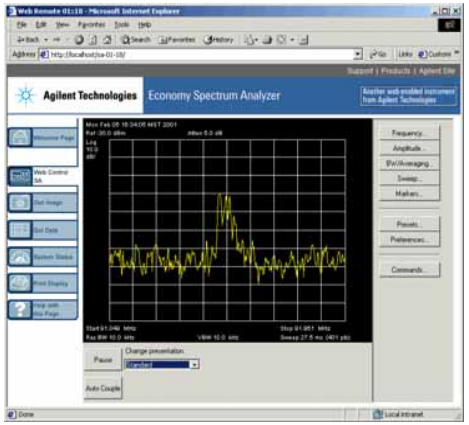


Client

Client

Internet/
Intranet

GPIB



Server

Client

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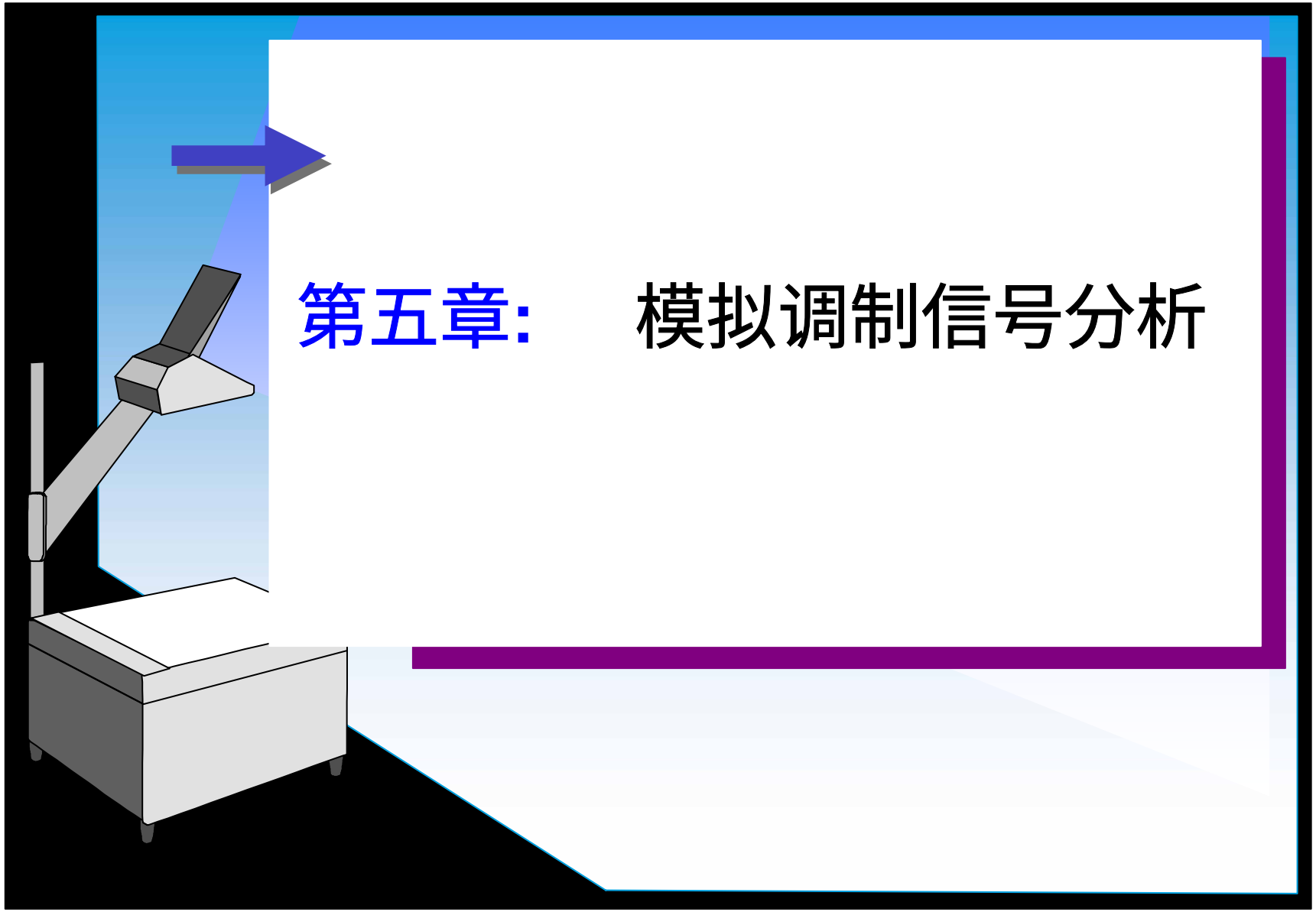
技术小结

⇩ 频谱分析仪可准确测量各种调制和非调制信号的功率和频率；

⇩ 信号功率的完整测试内容应包含：平均功率；峰值功率，功率变化的概率统计。



第五章:　模拟调制信号分析

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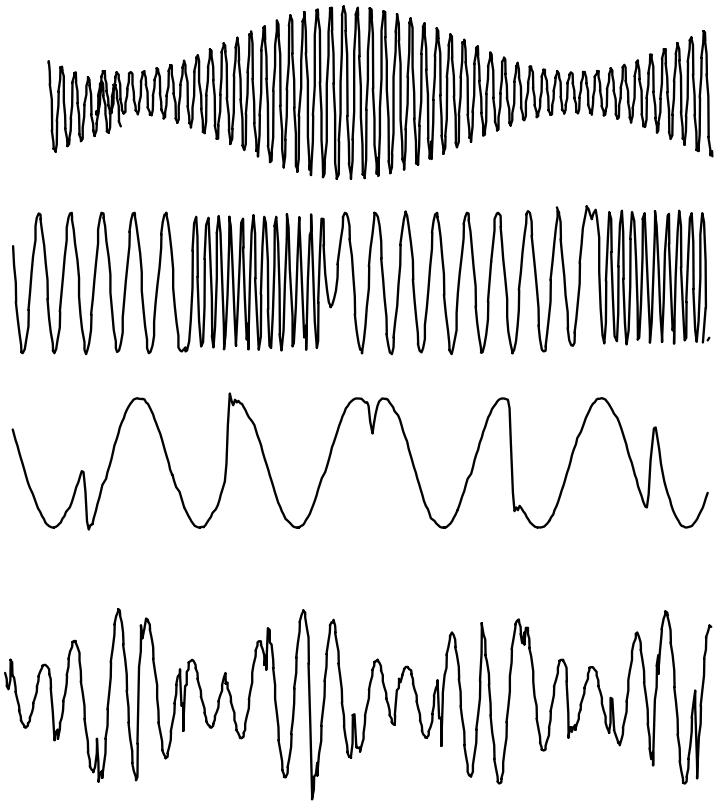
调制信号

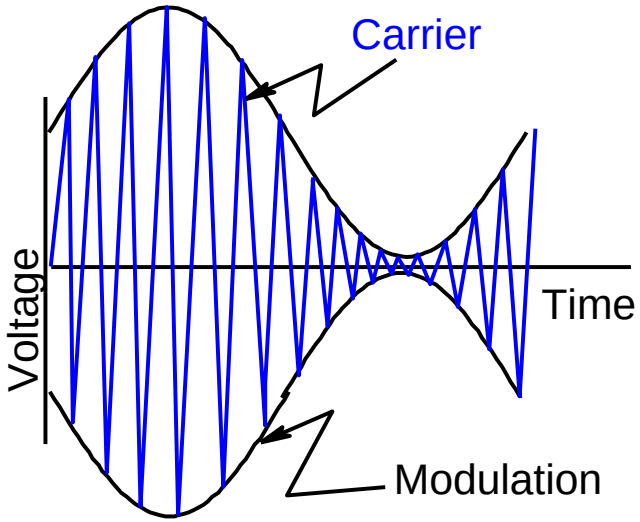
$V = V(t) \sin[2\pi f(t) + \phi(t)]$

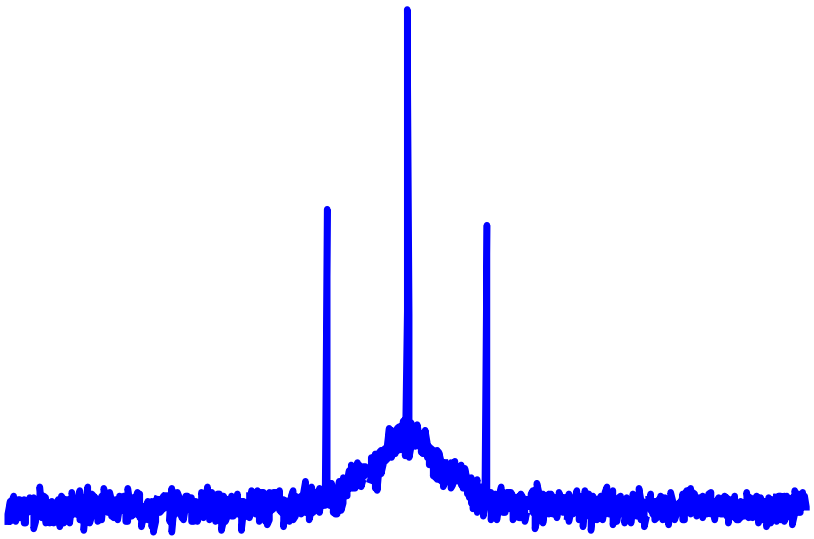
AM, Pulse　　FM　　PM

$V = V(t) \sin[\theta(t)]$



调幅信号特性





定义AM信号的参数

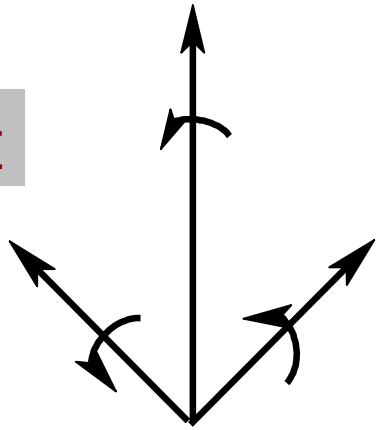
- **Linear AM**
- **Log AM**

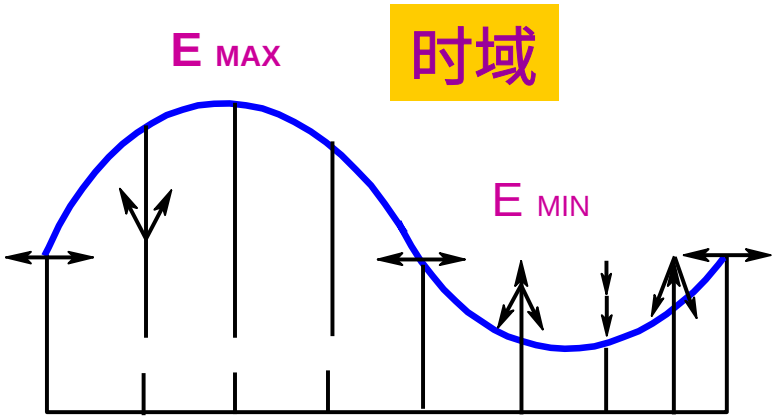
- 载波频率
- 功率
- 调制信号频率
- 调制指数

- 精度

AM 信号描述方法

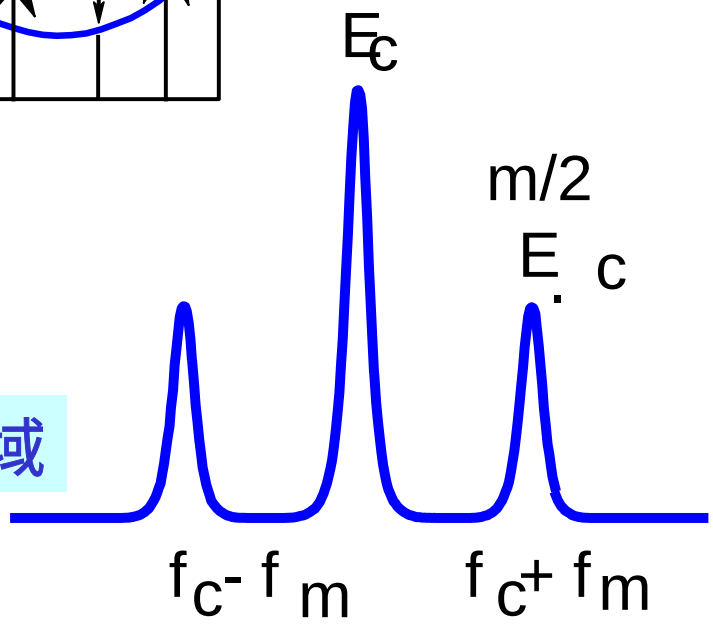
矢量





时域

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} = \frac{1 - E_{min}/E_{max}}{1 + E_{min}/E_{max}}$$



频域

AM 信号调制指数与频谱幅度对应关系

$$m = \frac{2E}{E_c} \text{ SB} \quad \text{or} \quad \Delta \text{dB} = 20 \log (m/2)$$

%AM	△dB
100%	-6dBc
50%	-12dBc
10%	-26dBc
5%	-32dBc
1%	-46dBc

$$AM\% = 200 \times 10^{-(\Delta dB/20)}$$

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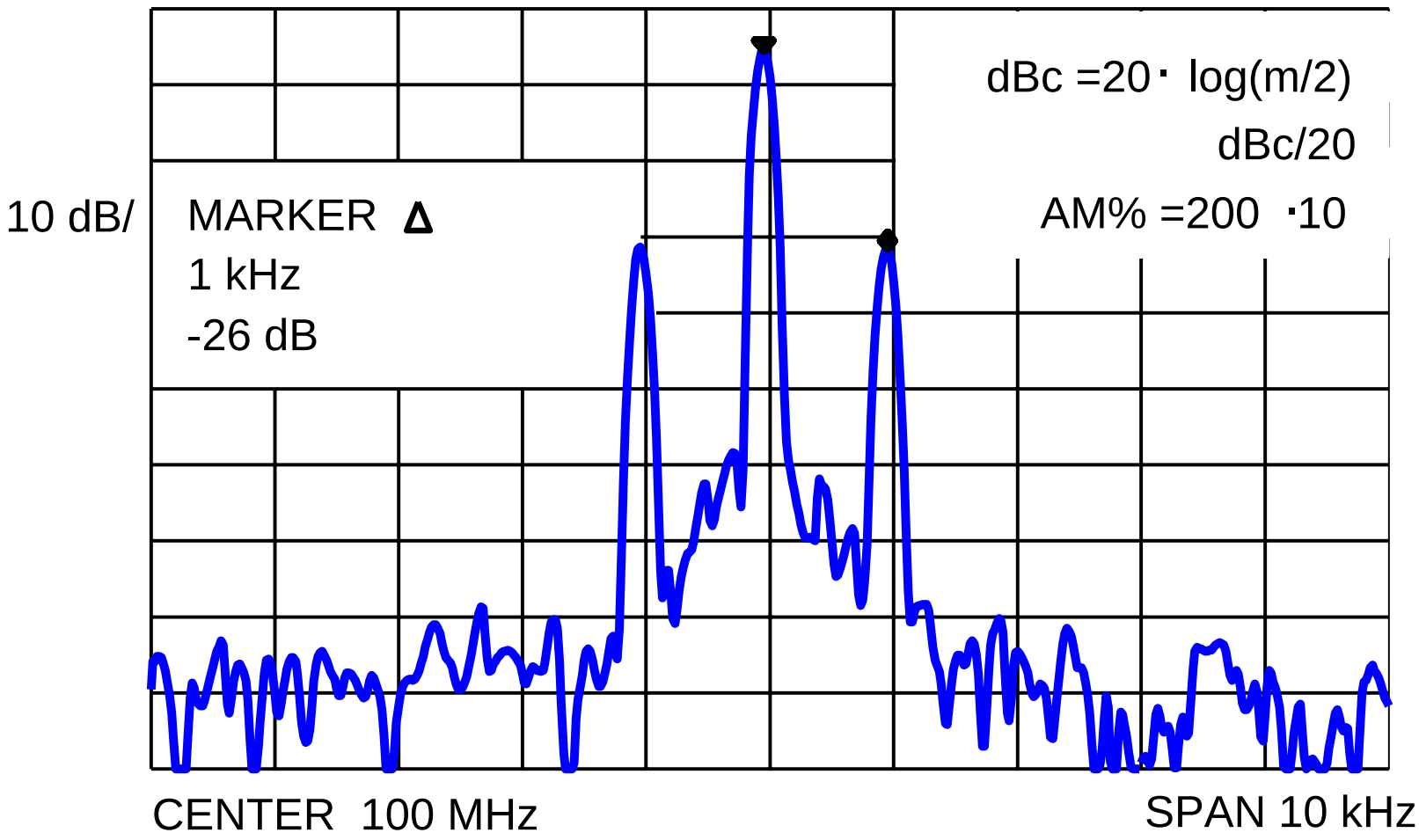
AM 信号频域测试


10 dB/
MARKER Δ
1 kHz
-26 dB
dBc =20· log(m/2)
dBc/20
AM% =200 ·10
CENTER 100 MHz
SPAN 10 kHz

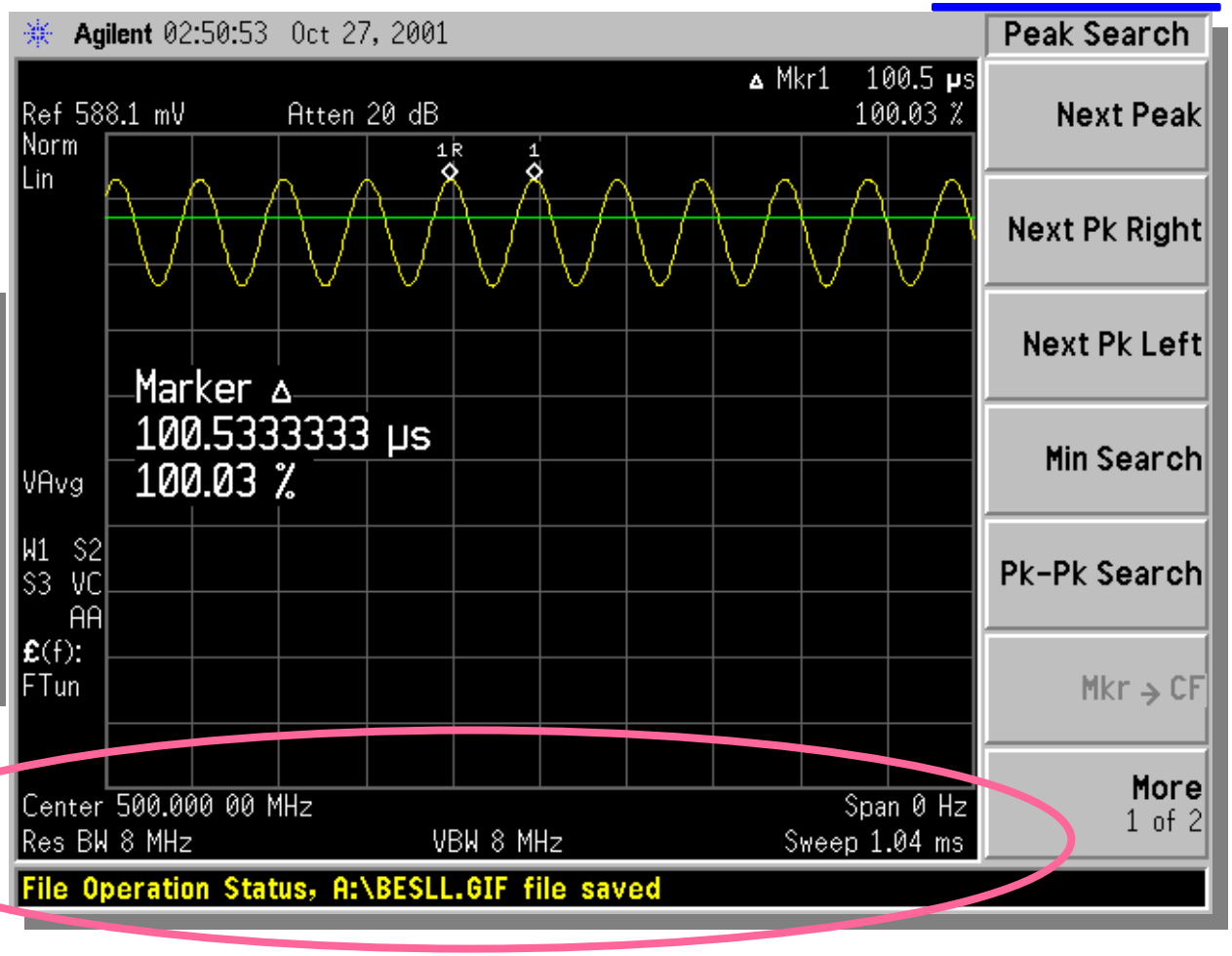
AM 信号时域测试

- Zero Span
- RBW，VBW 尽量设大
- 幅度线性显示

频谱仪为时域测量状态，
作为工作在Center frequency，
带宽为RBW的接收机
显示信号包络波形

扫描时间调整
触发调整

稳定显示



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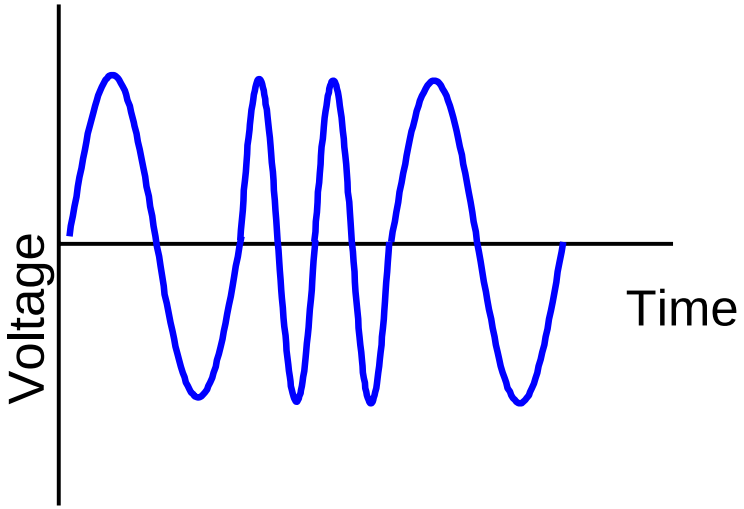
调频信号特性

$$V = V(t) \sin[2\pi f_c t + \beta m(t)]$$

- 调制指数 $\beta = \Delta F_{dev} / F_{mod}$



定义FM信号的参数

- 载波频率
- 功率

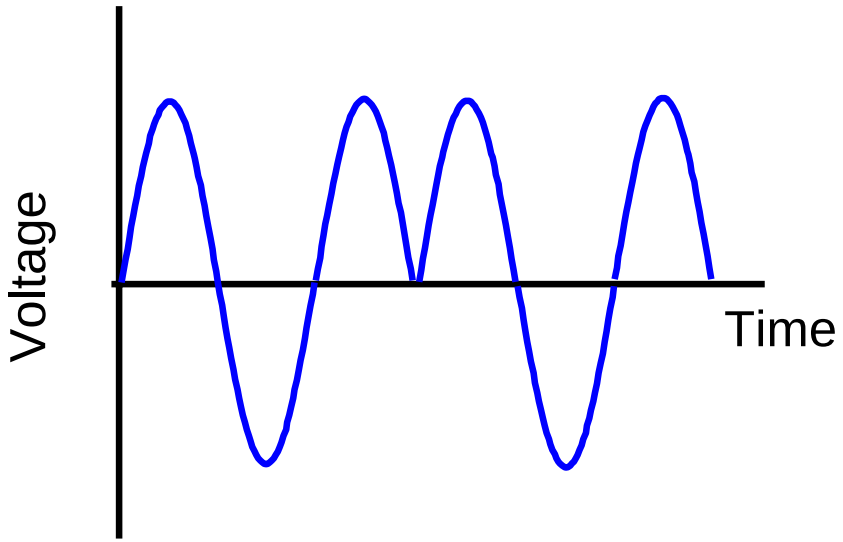
- 调制频偏
- 调制信号频率
- 调制指数

- 精度

调相信号特性

$$V = V(t)\sin[2\pi f_c t + \beta m(t)]$$

$$\beta = \Delta\phi_{peak}$$

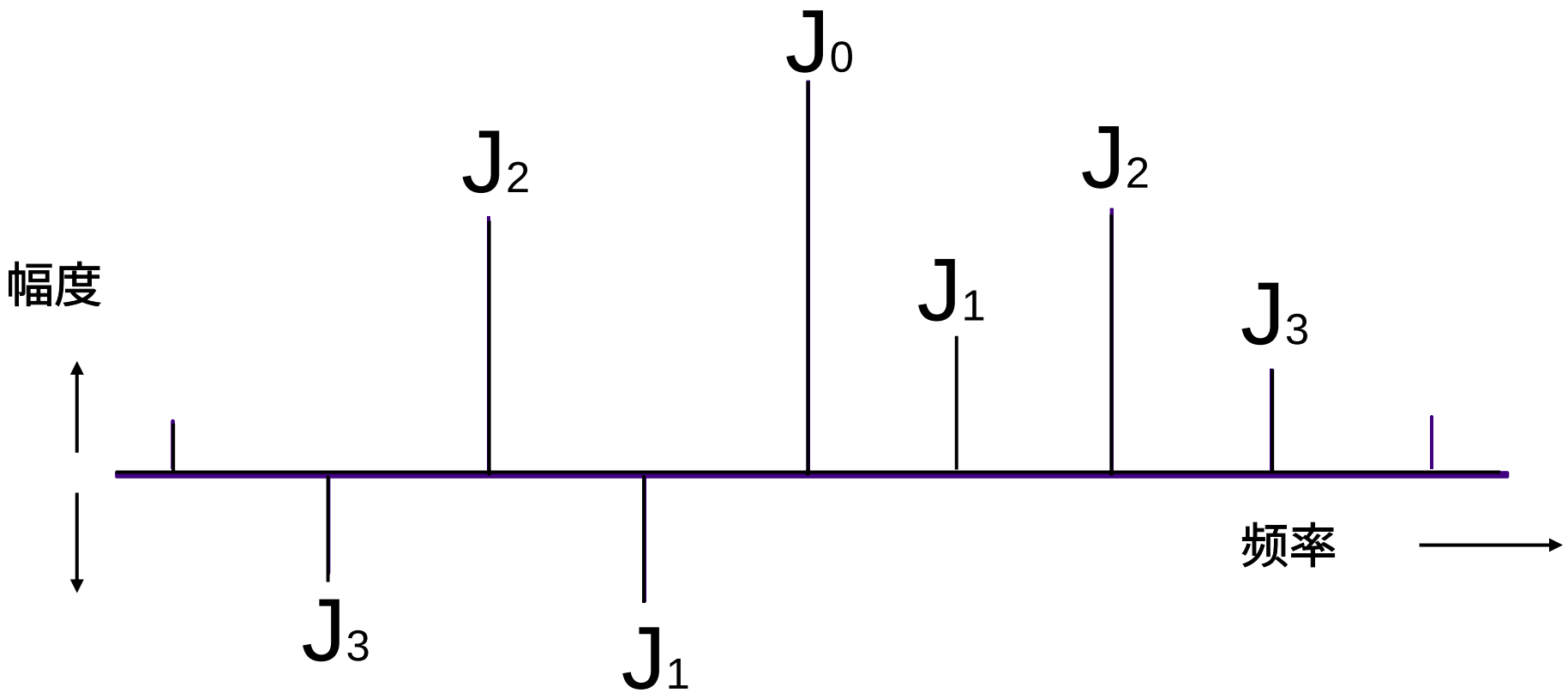


定义PM信号的参数

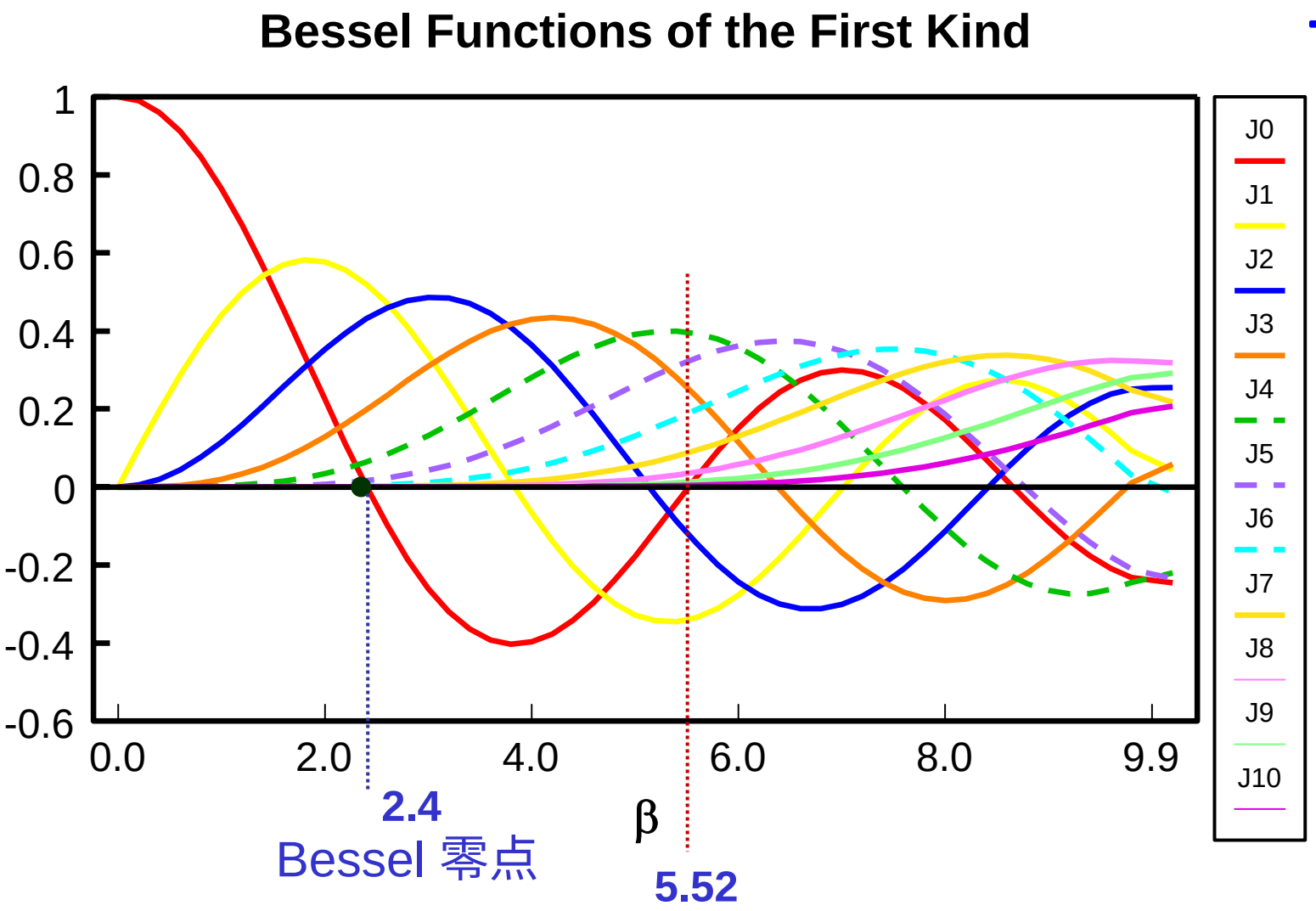
- 载波频率
- 功率
- 调制相偏（调制指数）
- 调制信号频率
- 精度

FM/PM 信号频谱特性

FM/PM 信号载波及各阶调制边带功率关系符合各阶贝塞尔函数规律



贝塞尔函数分布



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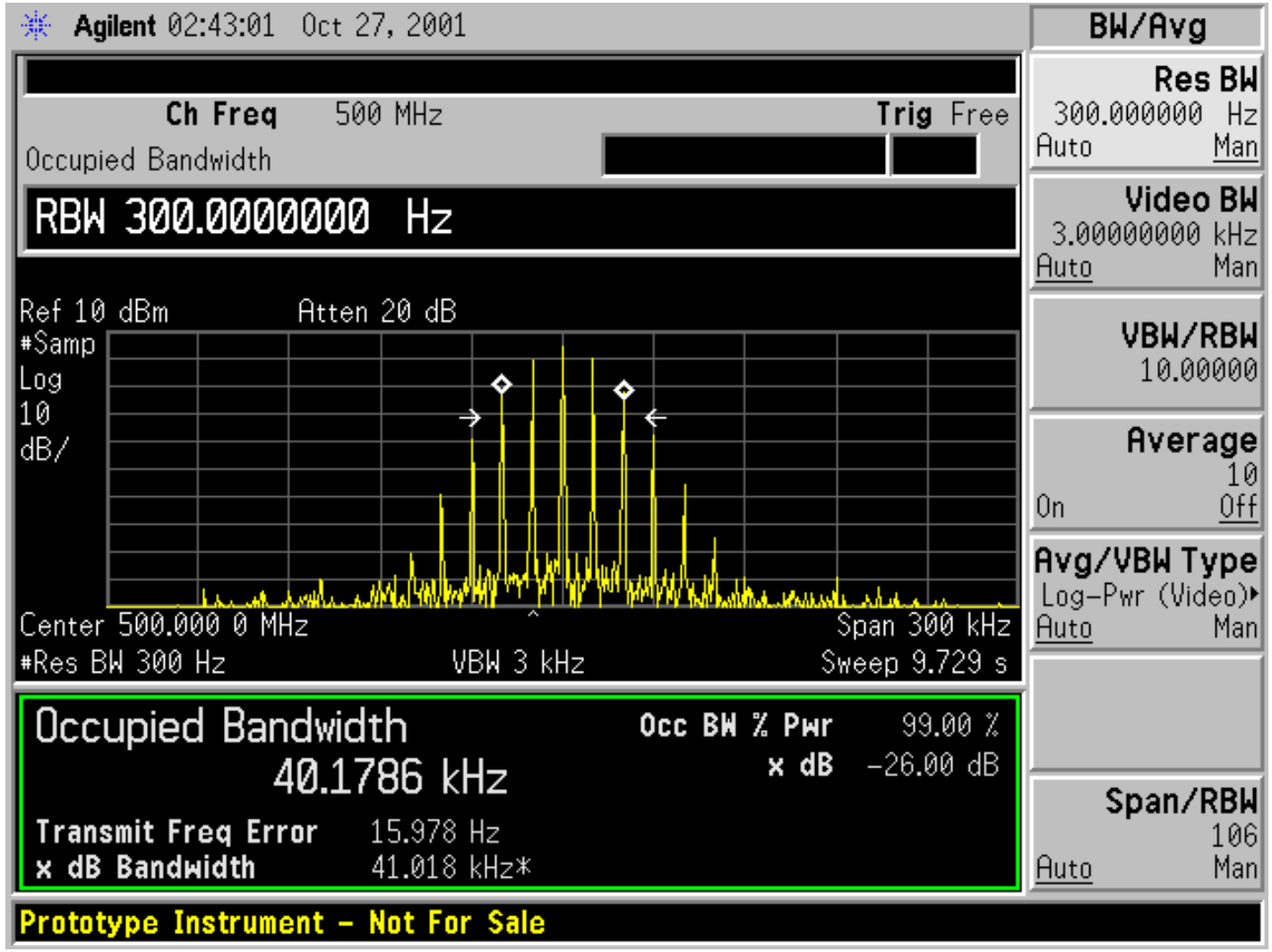
FM 信号频谱显示



FM 信号带宽 = 2 ×（调制频偏 + 调制信号频率）

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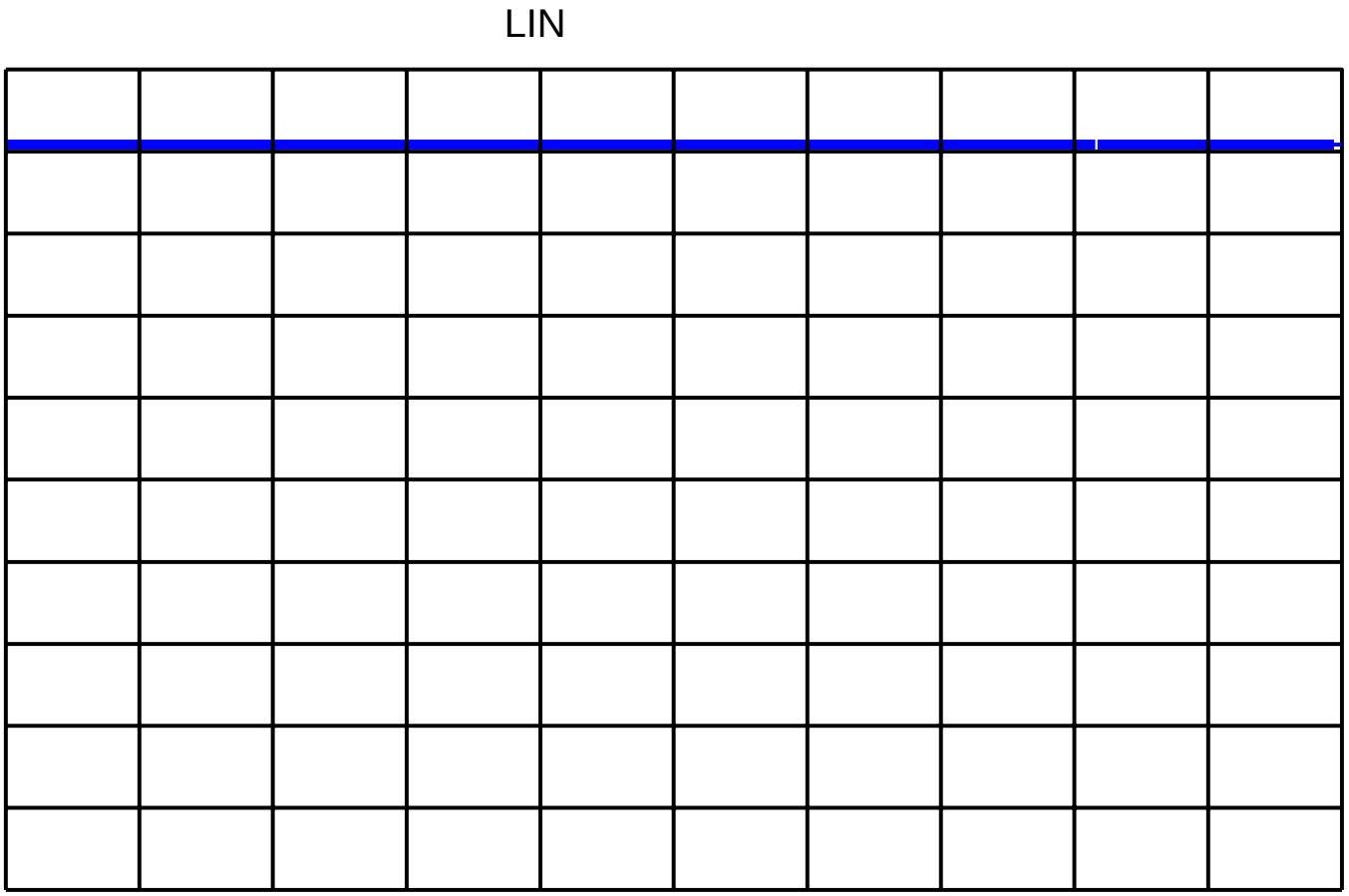
FM 信号时域显示



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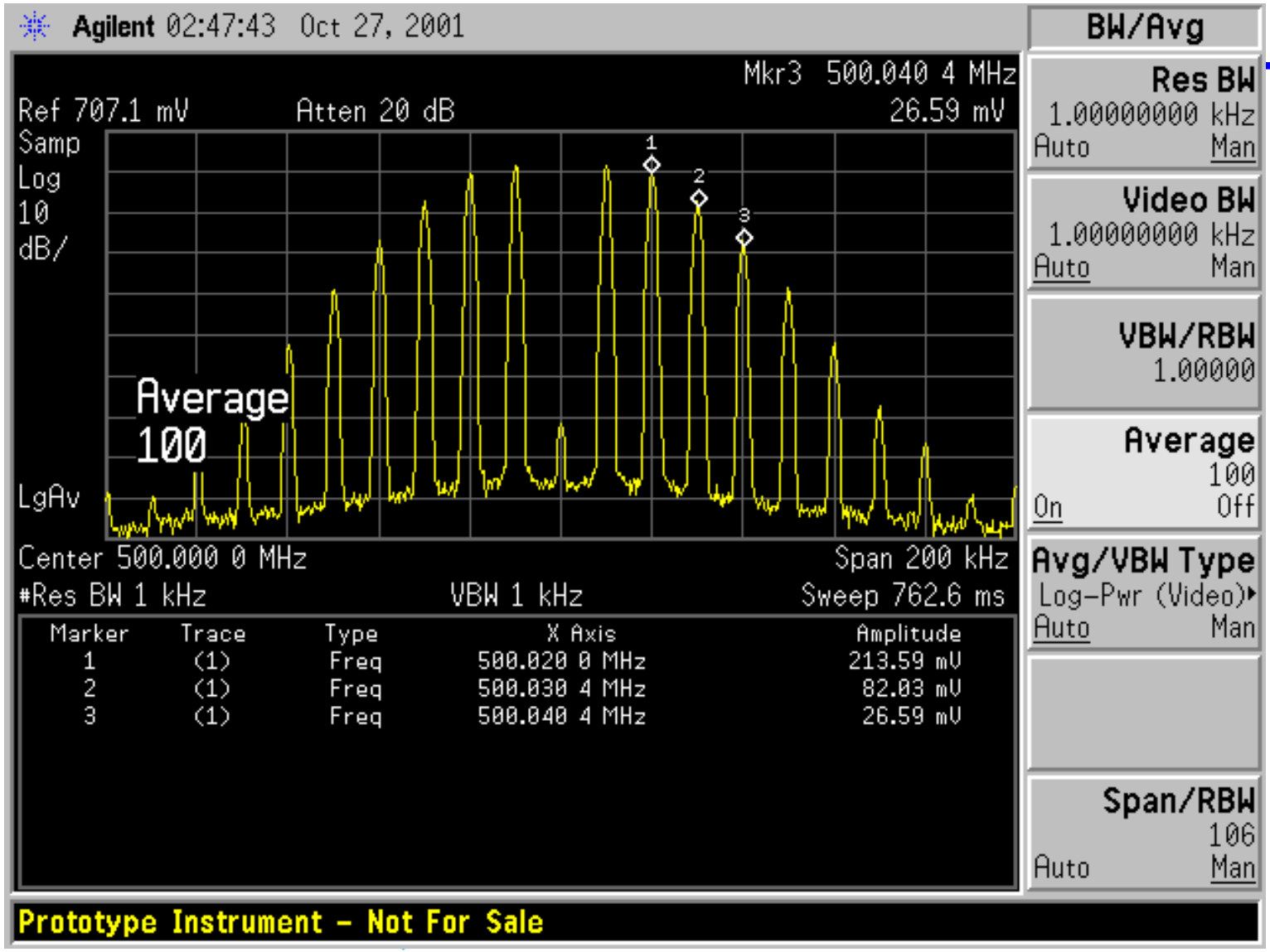
Bessel Null 法 测 FM 信号



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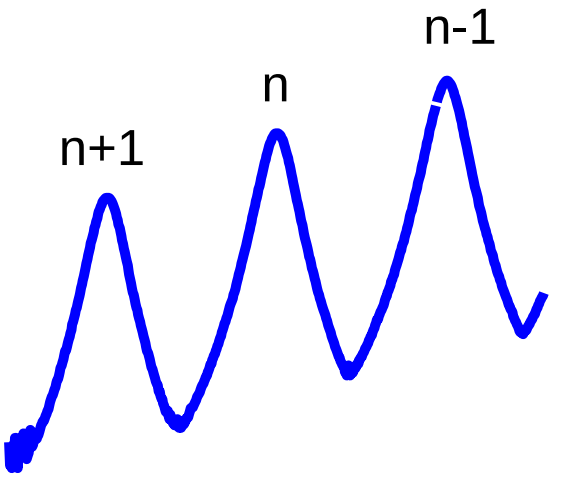
Haberly 法 测FM 信号

Haberley's Formula

$$\beta = \frac{2\ n\ V_n}{V_{n-1} + V_{n+1}}$$

$$V_{n+1} < V_n < V_{n-1}$$



Res BW << f_{mod}

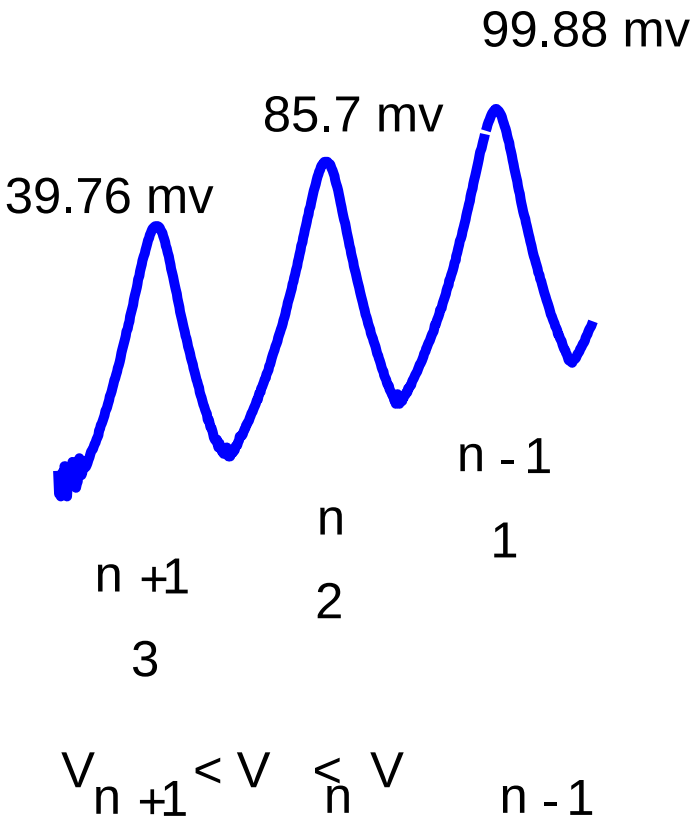
载波处：n=0

Calculation for N = 2

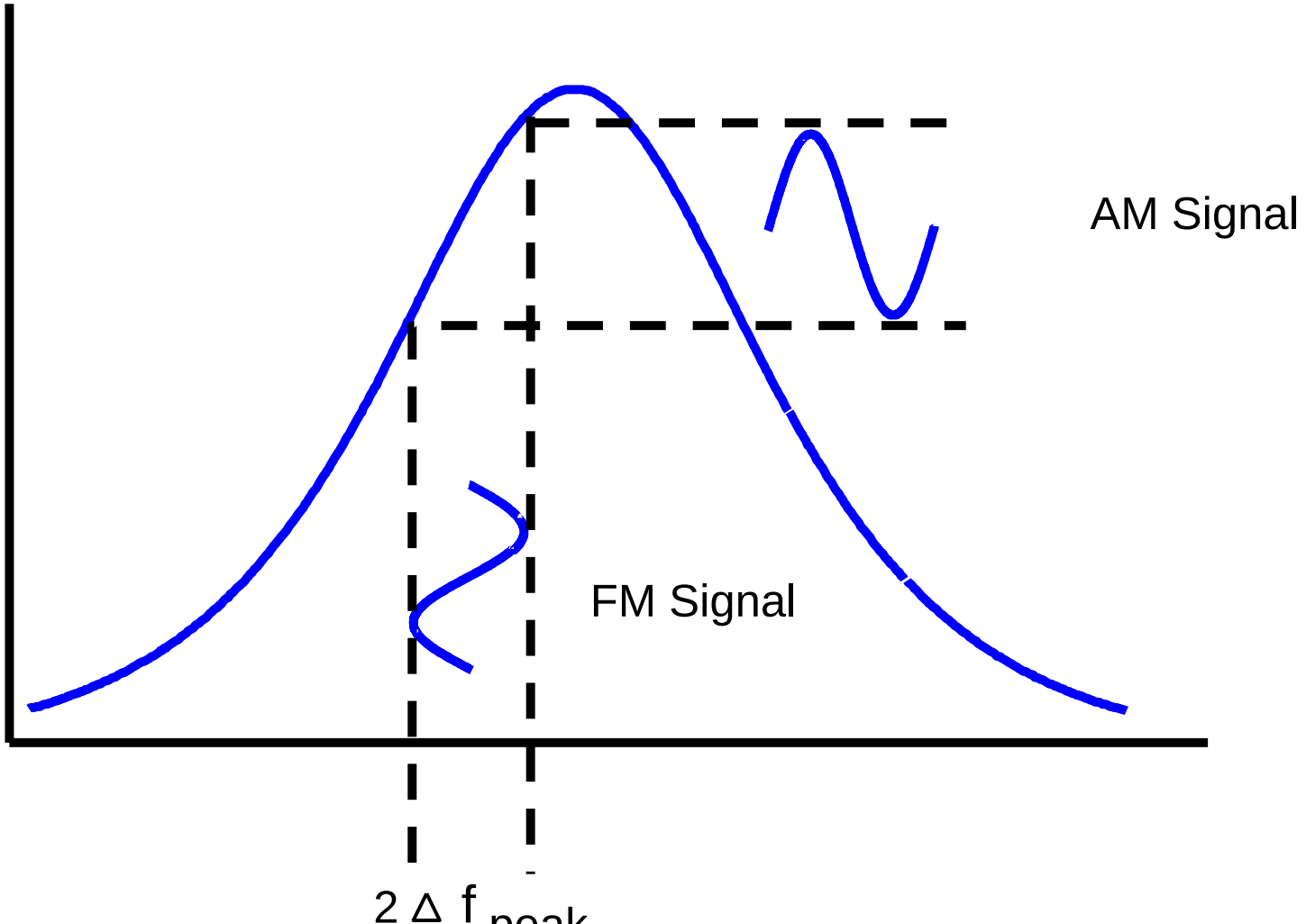
Example

Haberley's Formula

$$\beta = \frac{2 - 2 \cdot 85.7}{99.88 + 39.76} = 2.45$$



Slope Detection法 测FM 信号



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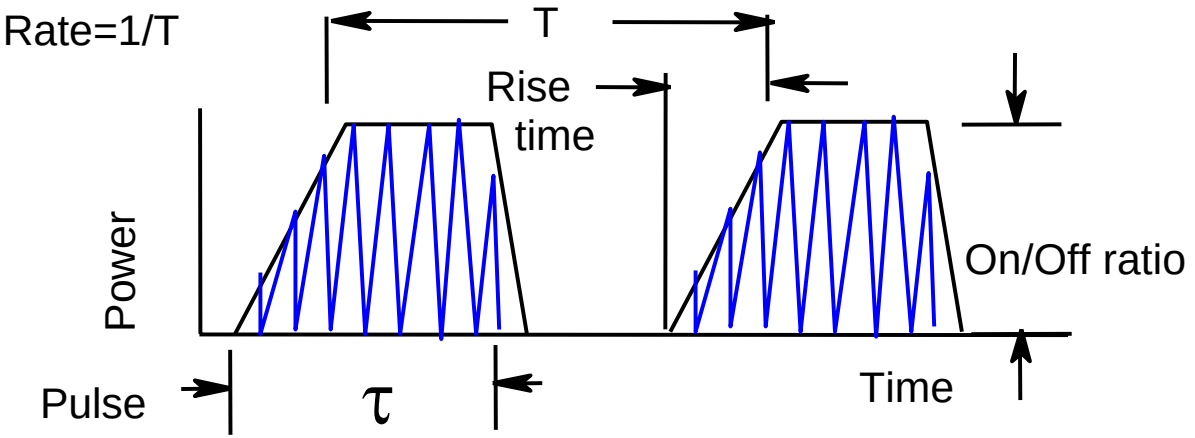
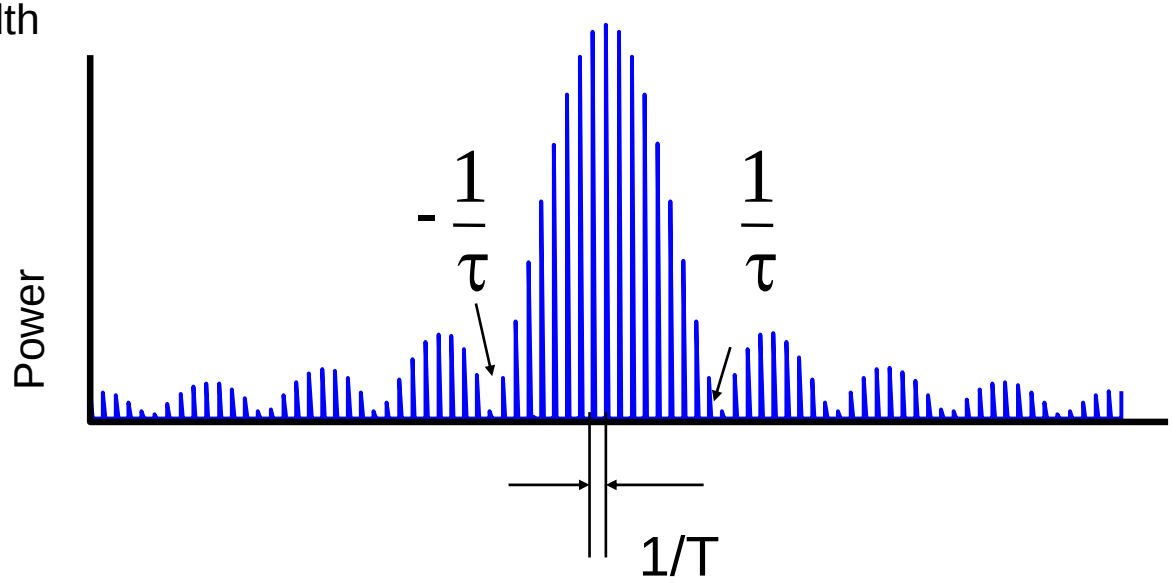
脉冲调制信号





定义脉冲调制信号的参数

- 载波频率
- 功率

- 脉冲宽度τ
- 脉冲重复周期 T
  （脉冲重复频率PRF=1/T）

- 上升/下降时间
- 开关比
- 精度

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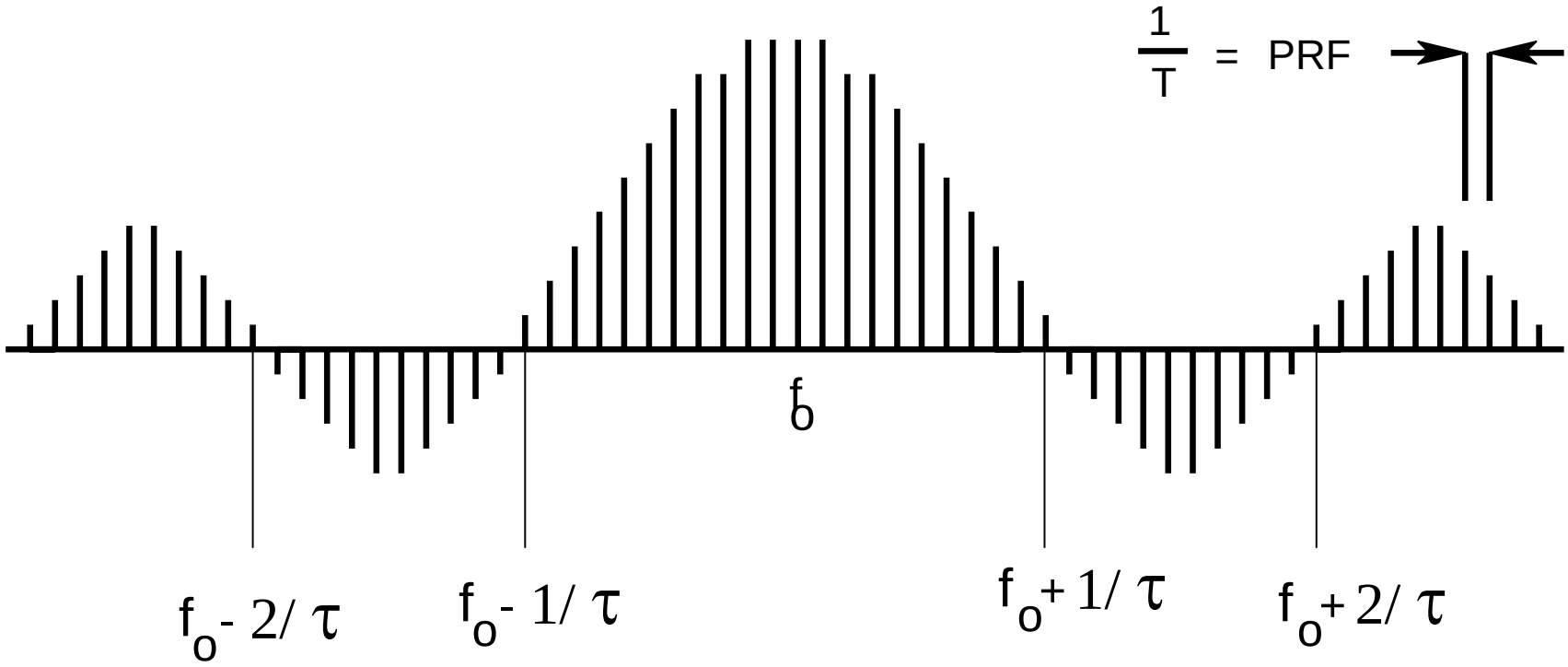
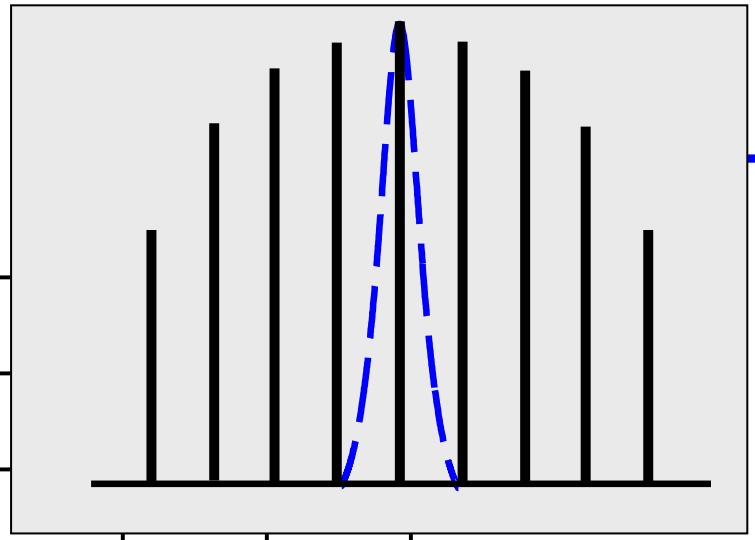
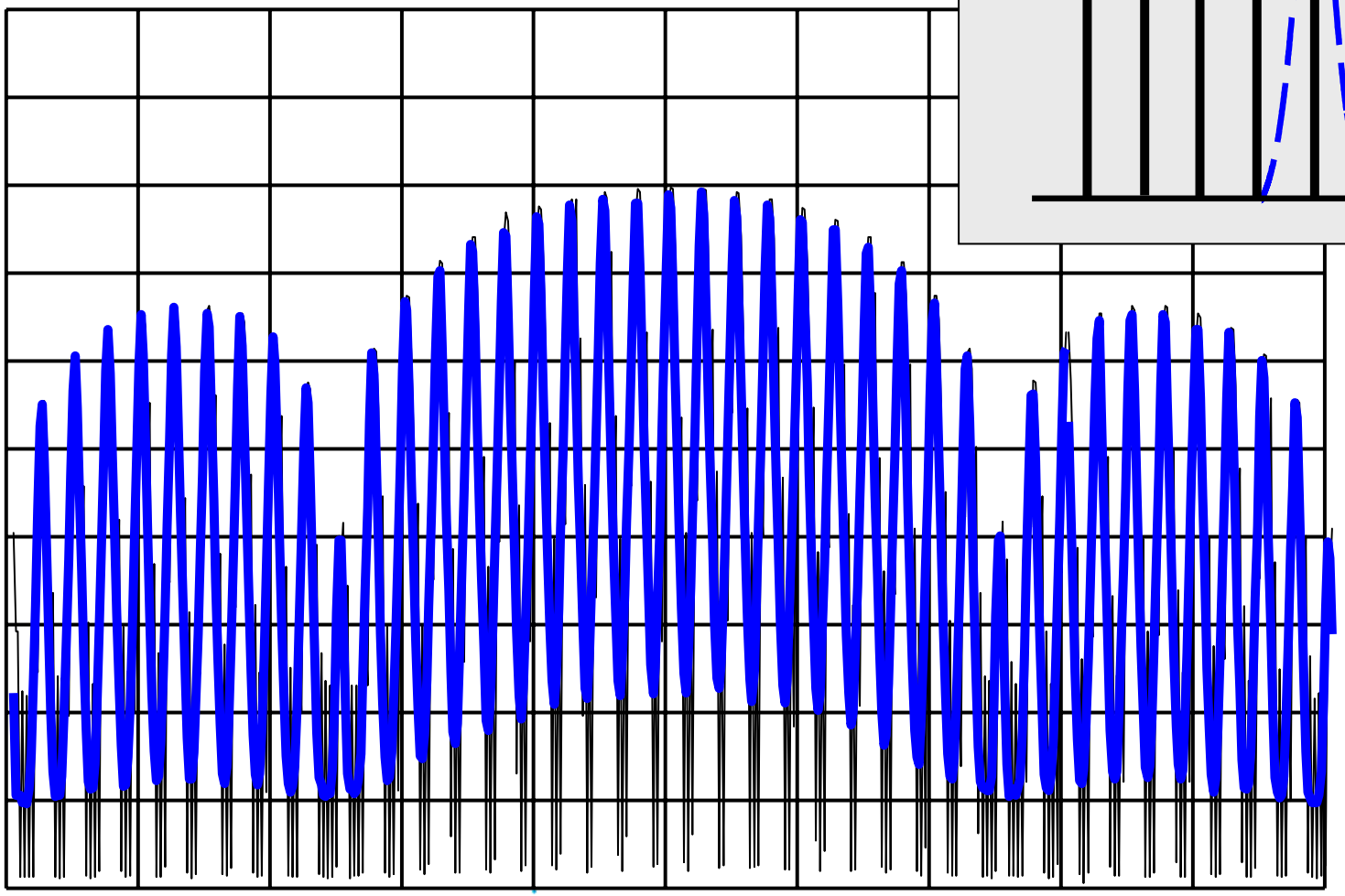
脉冲调制信号频谱



窄带法测脉冲调制信号

Res BW << PRF





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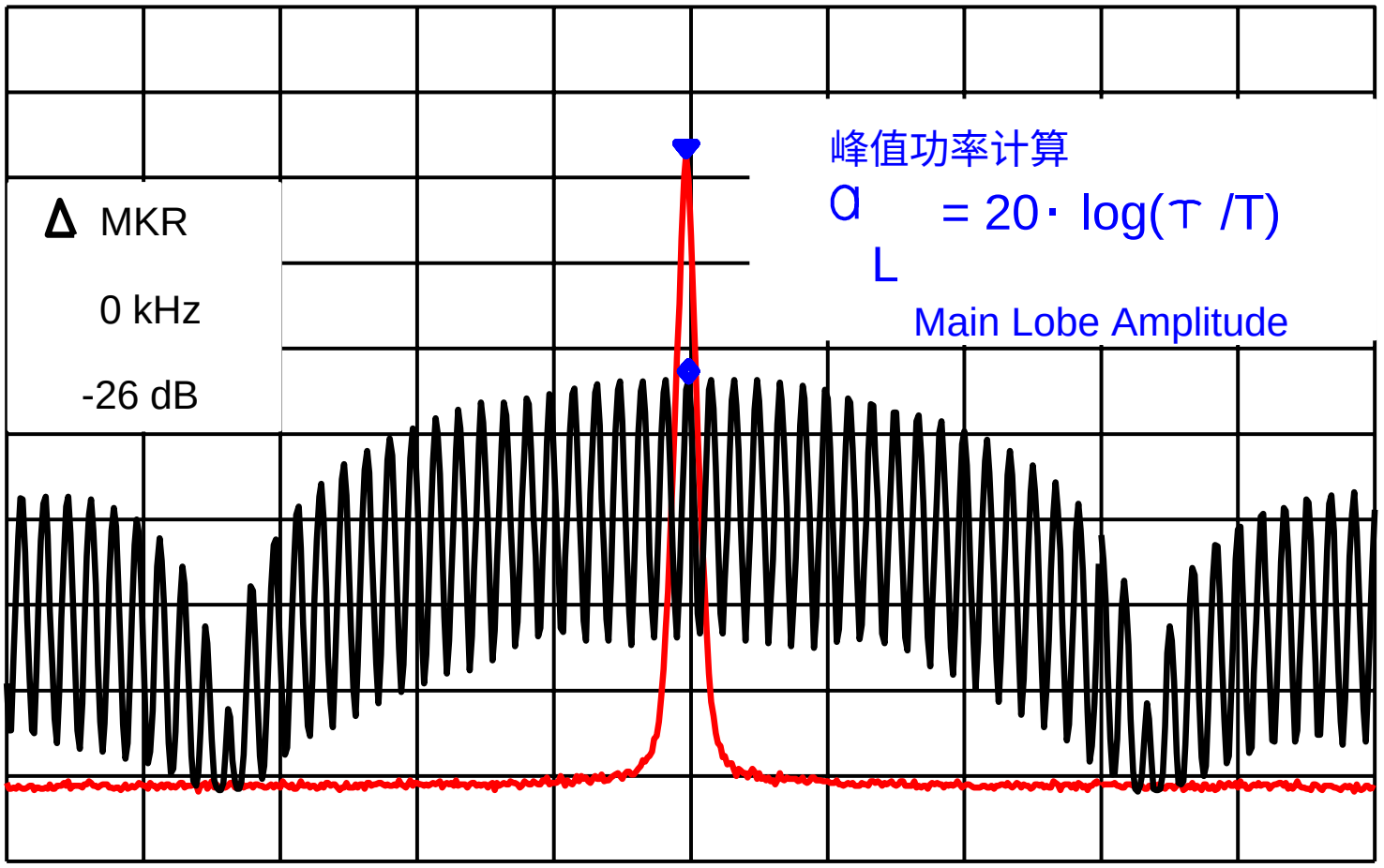
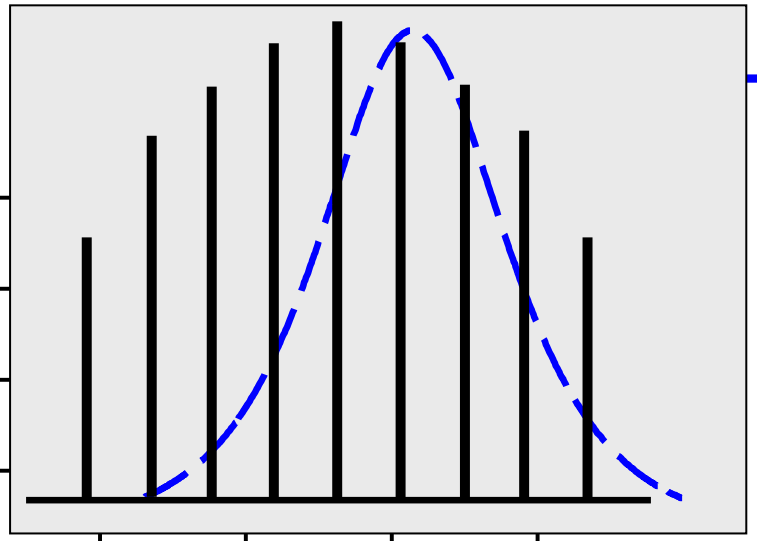
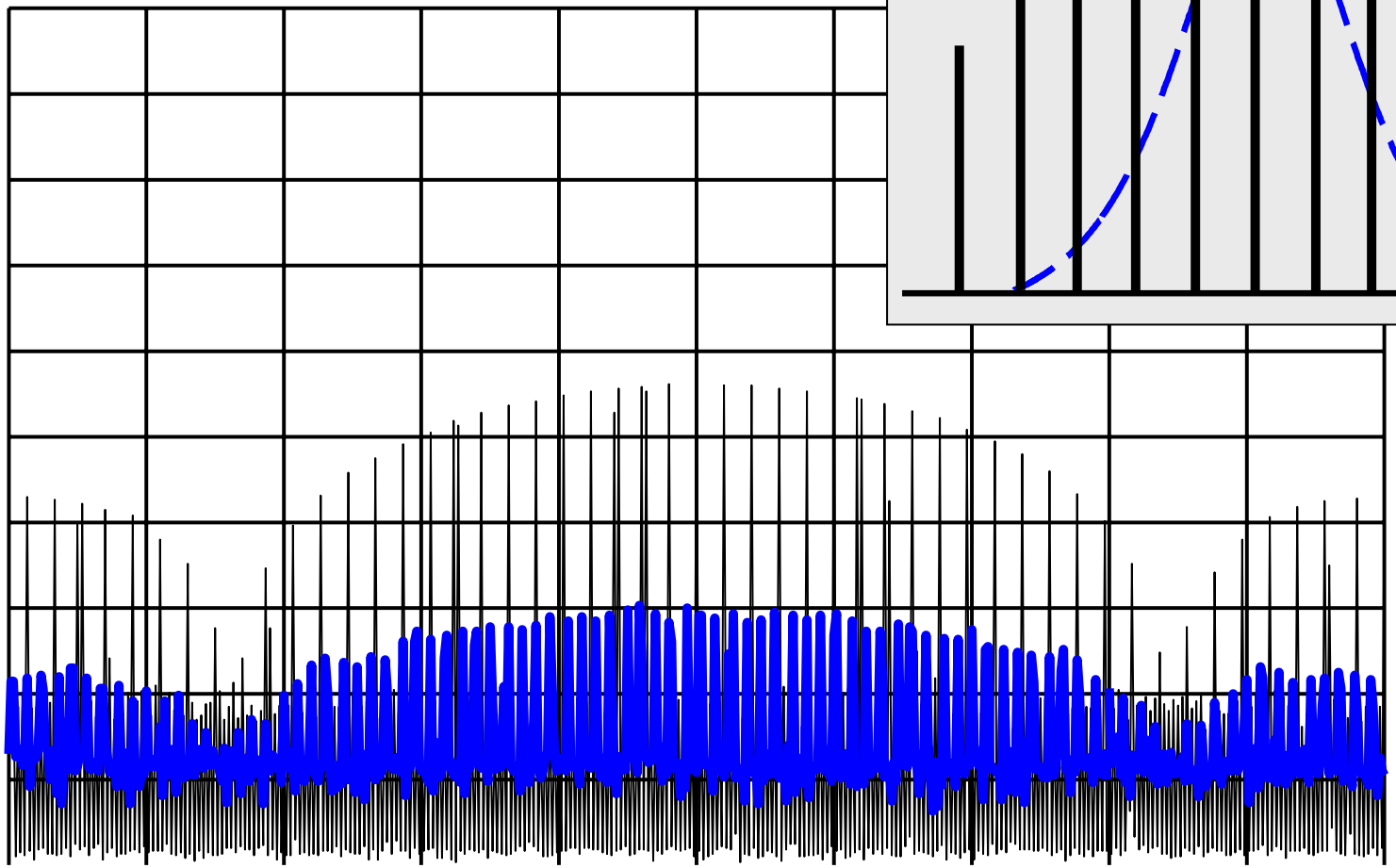
脉冲调制信号峰值功率计算（窄带法）



宽带法测脉冲调制信号

Res BW >> PRF





RBW 30 kHz　　VBW 3 kHz

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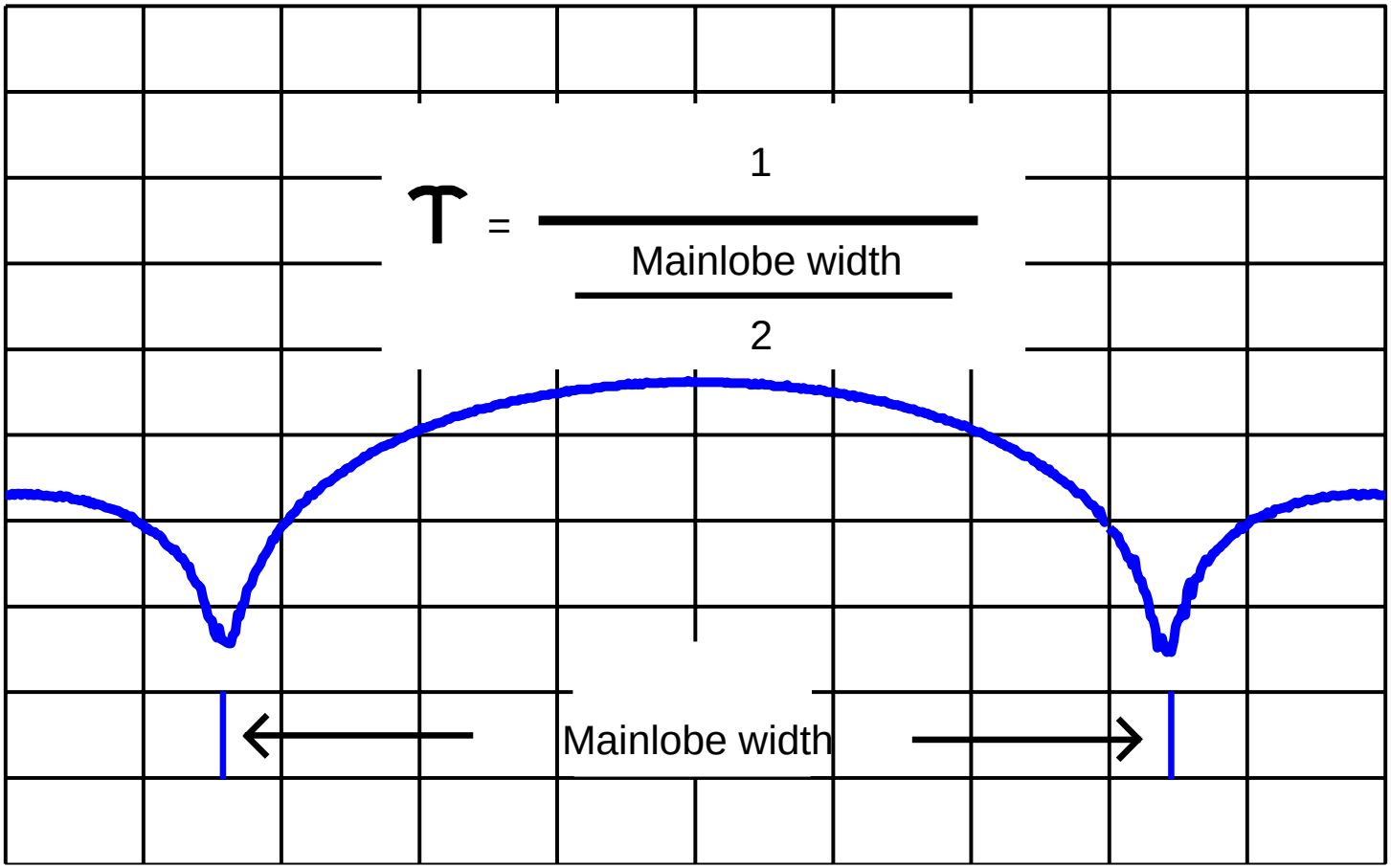
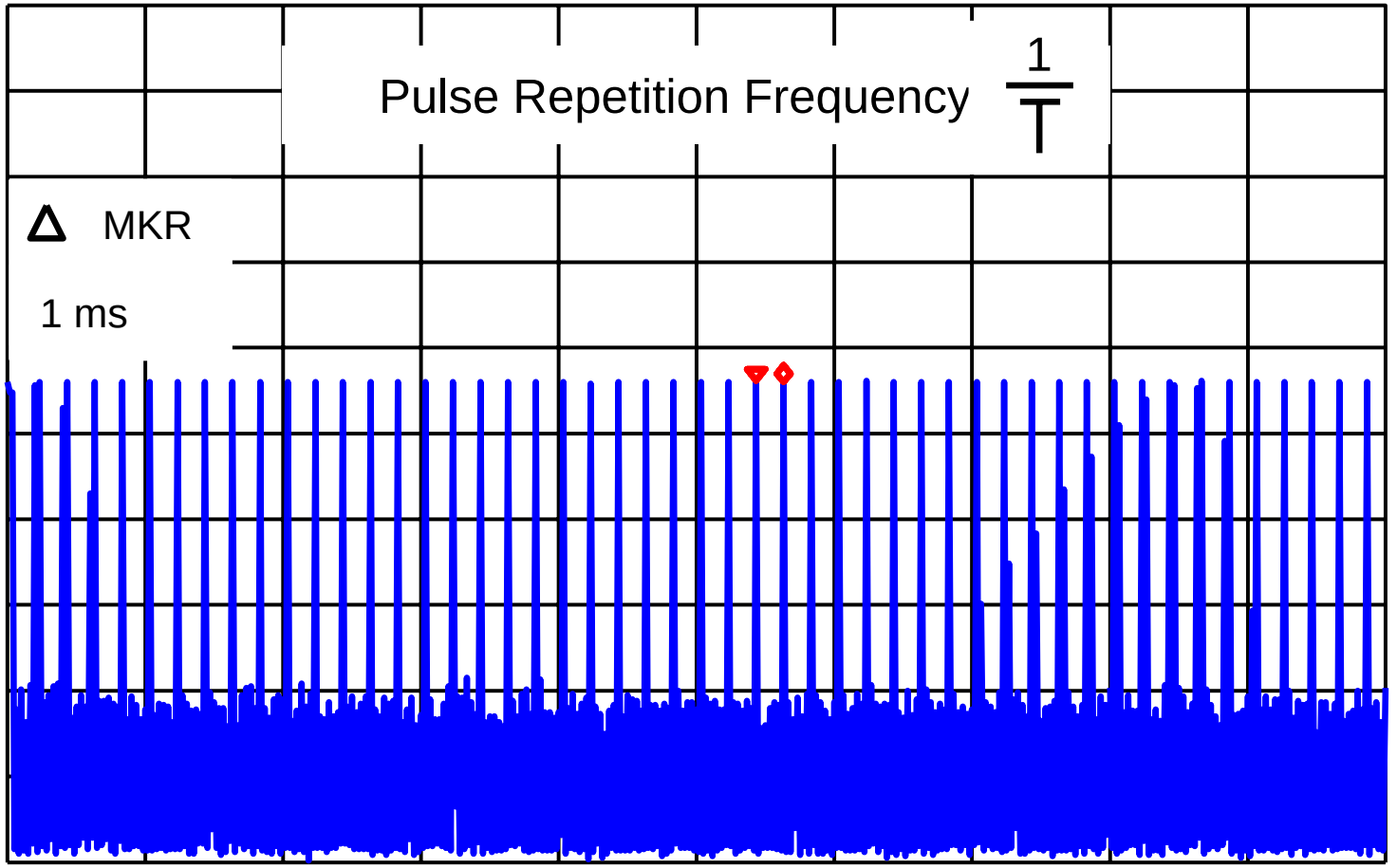
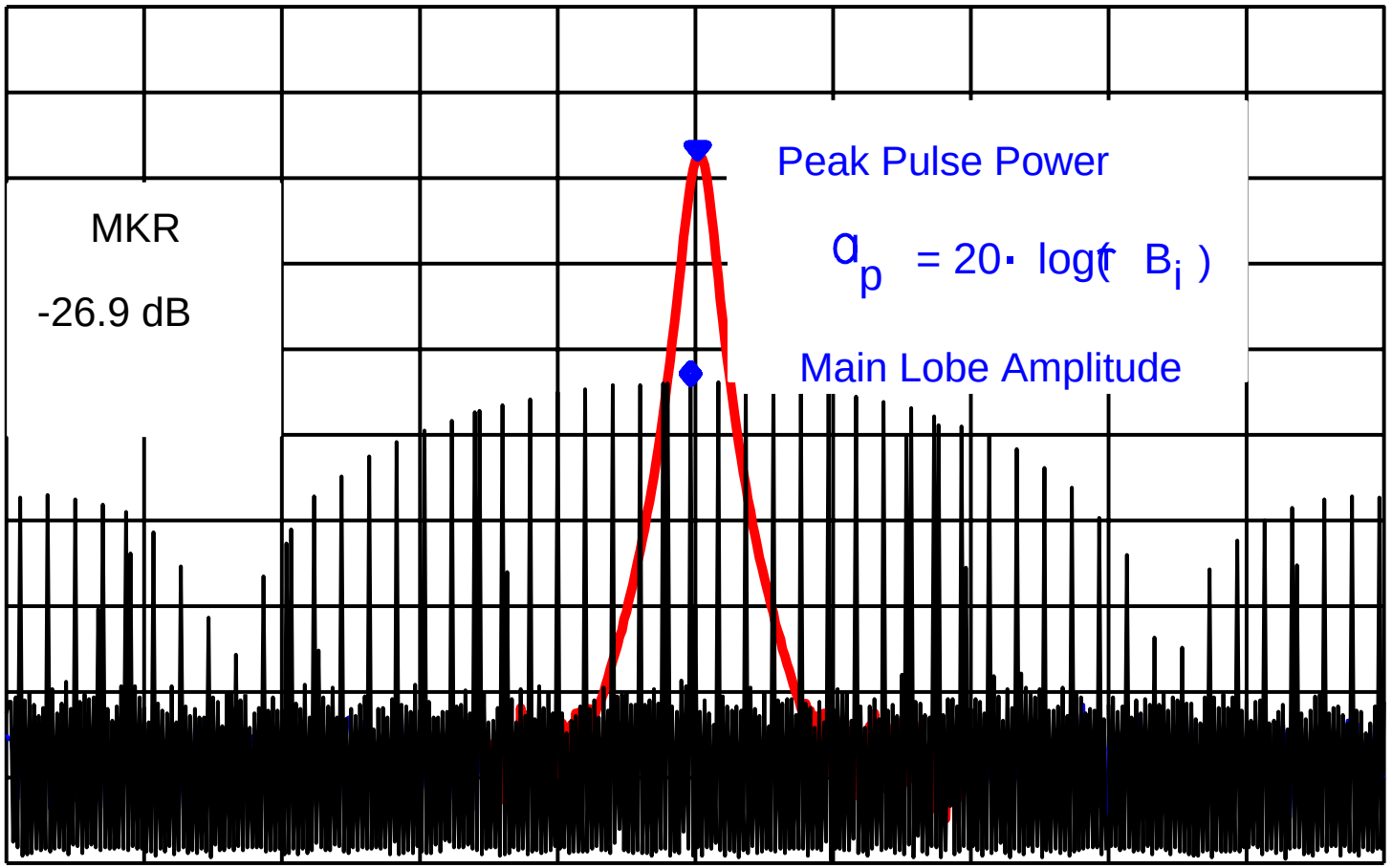
利用 MAX HOLD功能测脉冲宽度



利用 时域功能测脉冲重复周期



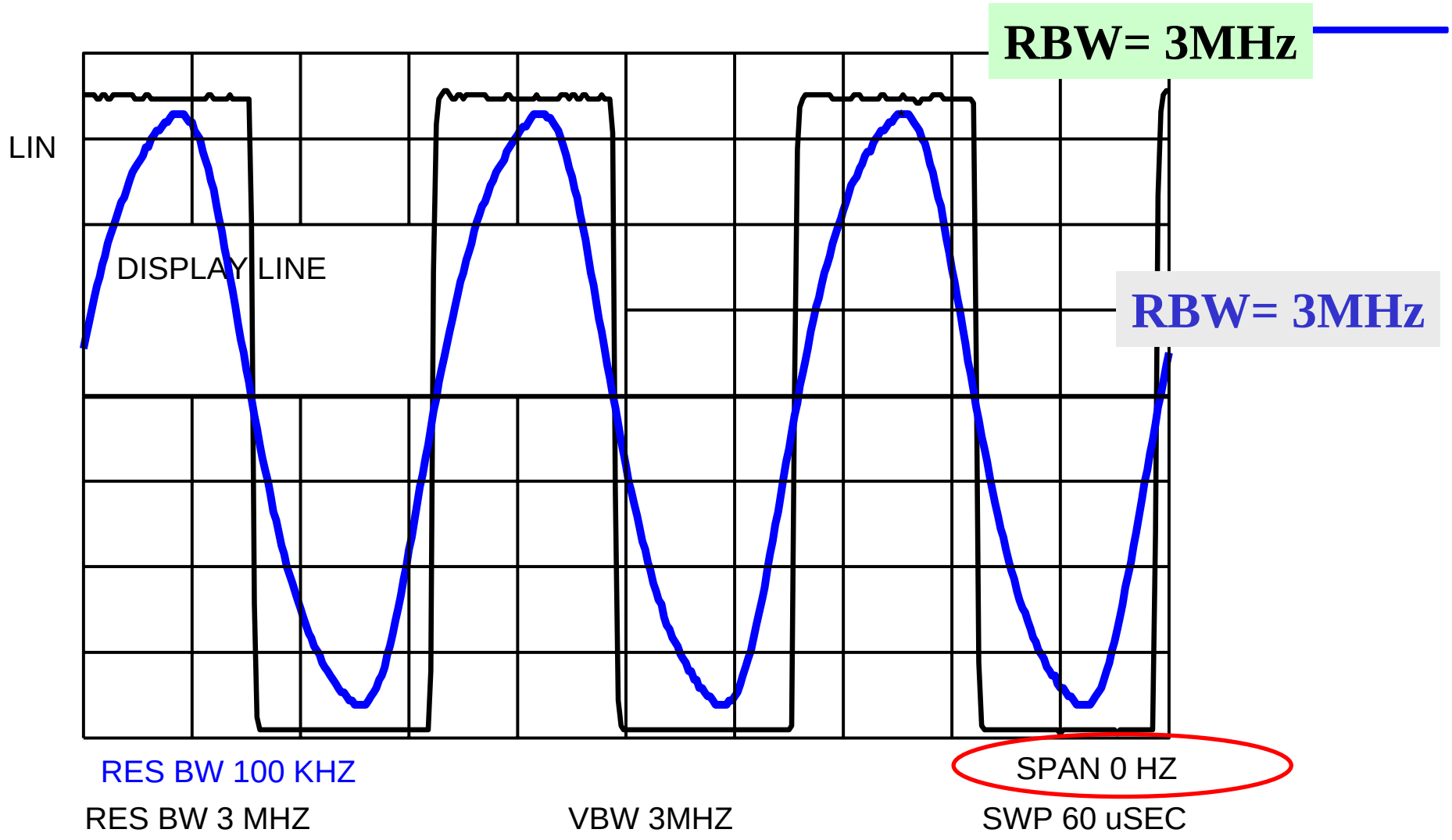
脉冲调制信号峰值功率计算（宽带法）



SPAN 3 MHz

RBW 30 kHz　　VBW 1 MHz　　SWP 50 ms

时域法测脉冲调制信号



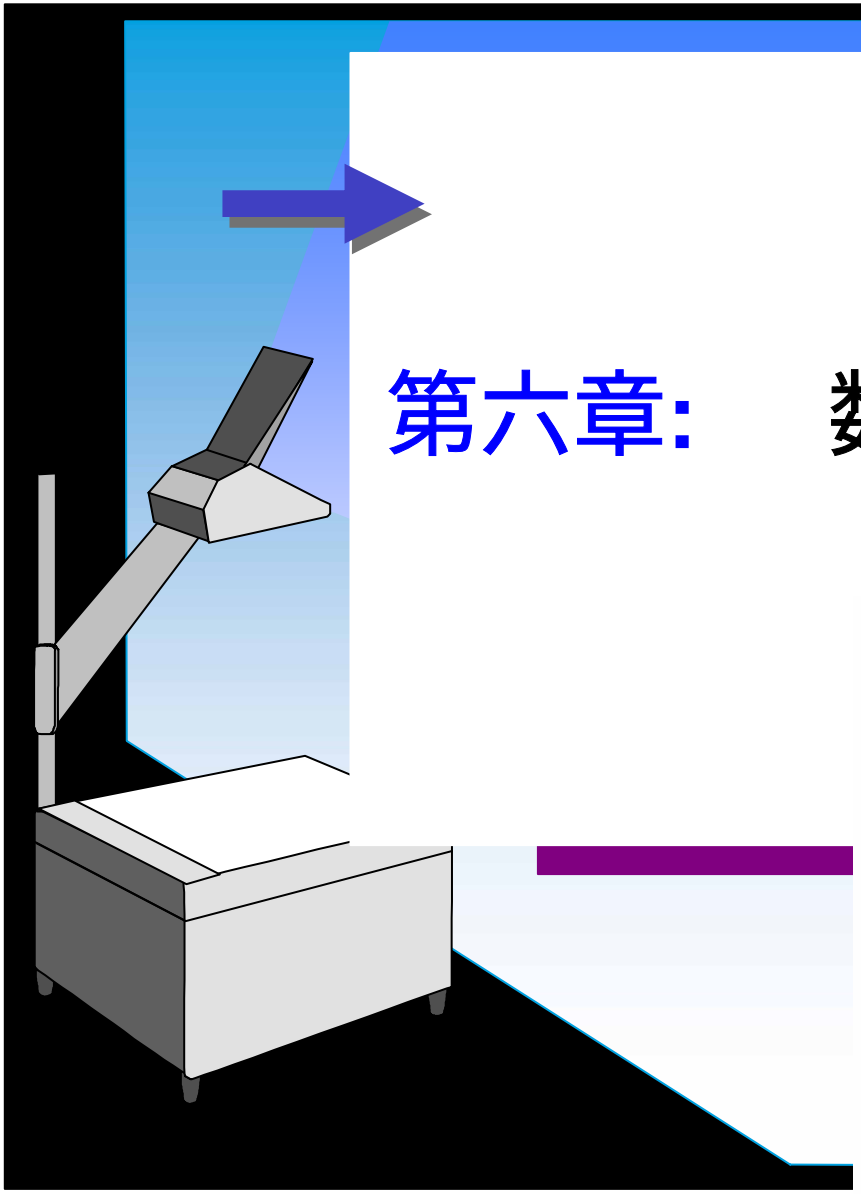
技术小结

⇩ 确定一个模拟AM调制信号需调制信号频率；调制指数等参数，这些参数可在频谱上进行测量；

⇩ 确定一个模拟FM调制信号需调制信号频率；调制指数等参数；这些参数可在频谱上进行测量；

⇩ 确定一个模拟PM调制信号需调制信号频率；调制指数等参数；这些参数可在频谱上进行测量；

⇩ 确定一个模拟脉冲调制信号需调制脉冲宽度；脉冲重复周期等参数；这些参数可在频谱上进行测量；



第六章:　数字调制信号分析

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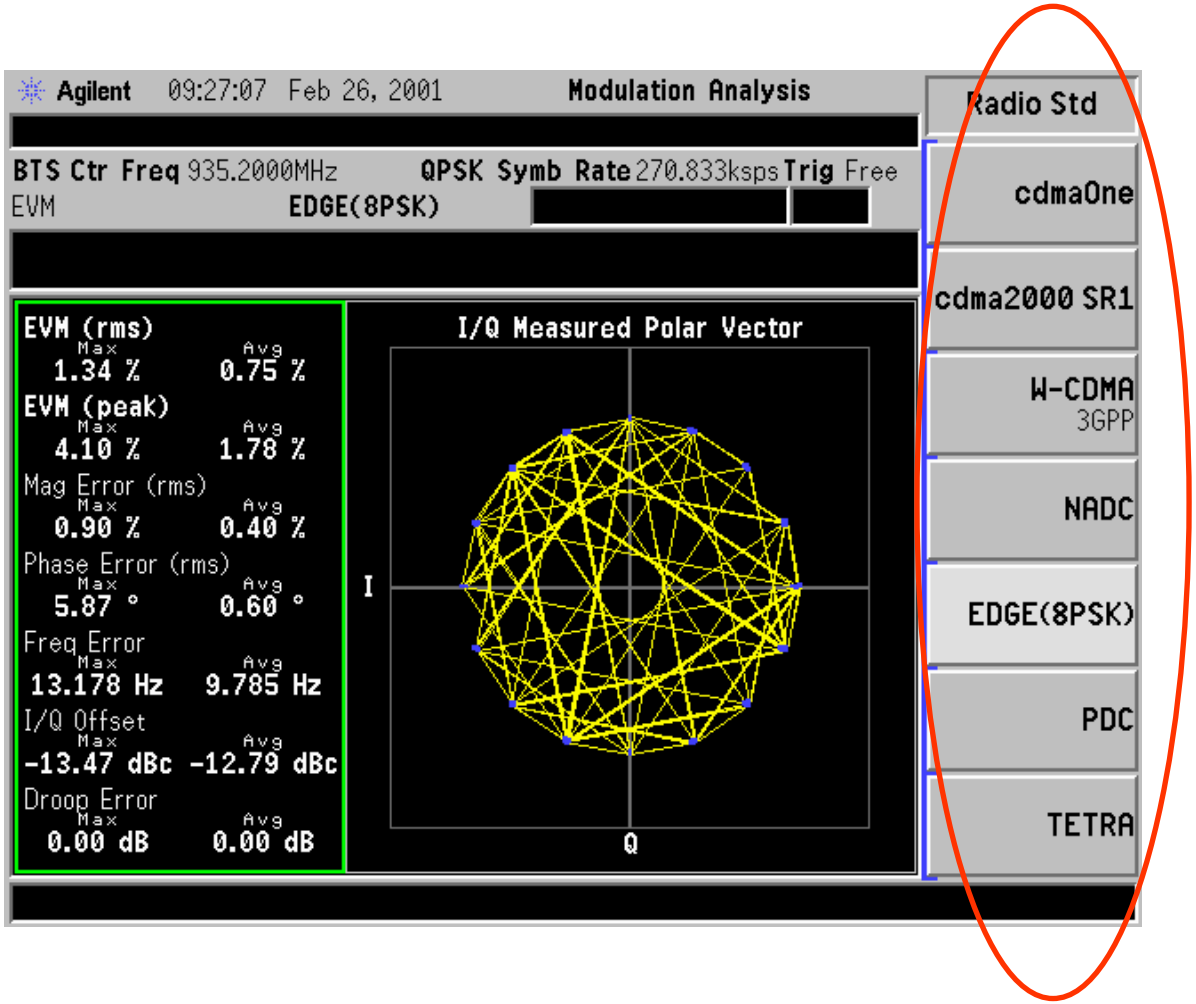
ESA 通信信号测试功能选件



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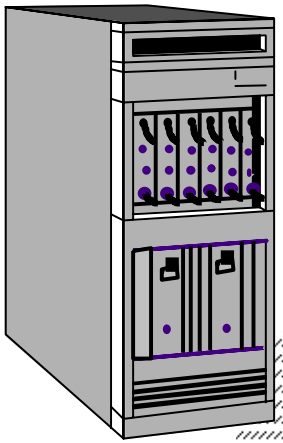
ESA 测试功能的应用

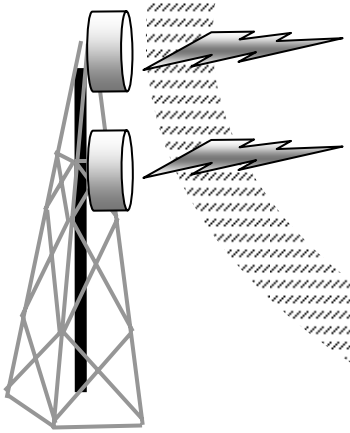
Transmitter Tests

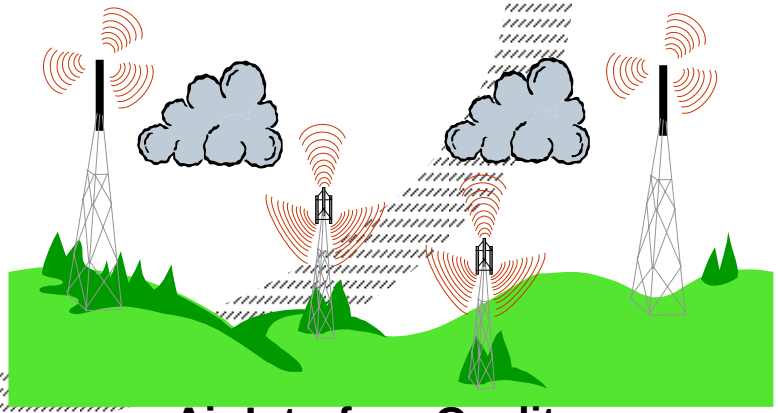
Test against cdmaOne standards with the touch of a button



Cable and Antenna Verification

Measure stimulus response with optional tracking generator





Microwave Link Verification

Operation to 26GHz (optional > 110GHz with external mixing)

Air Interface Quality

Identify low level interference with optional digital RBW's and preamplifier

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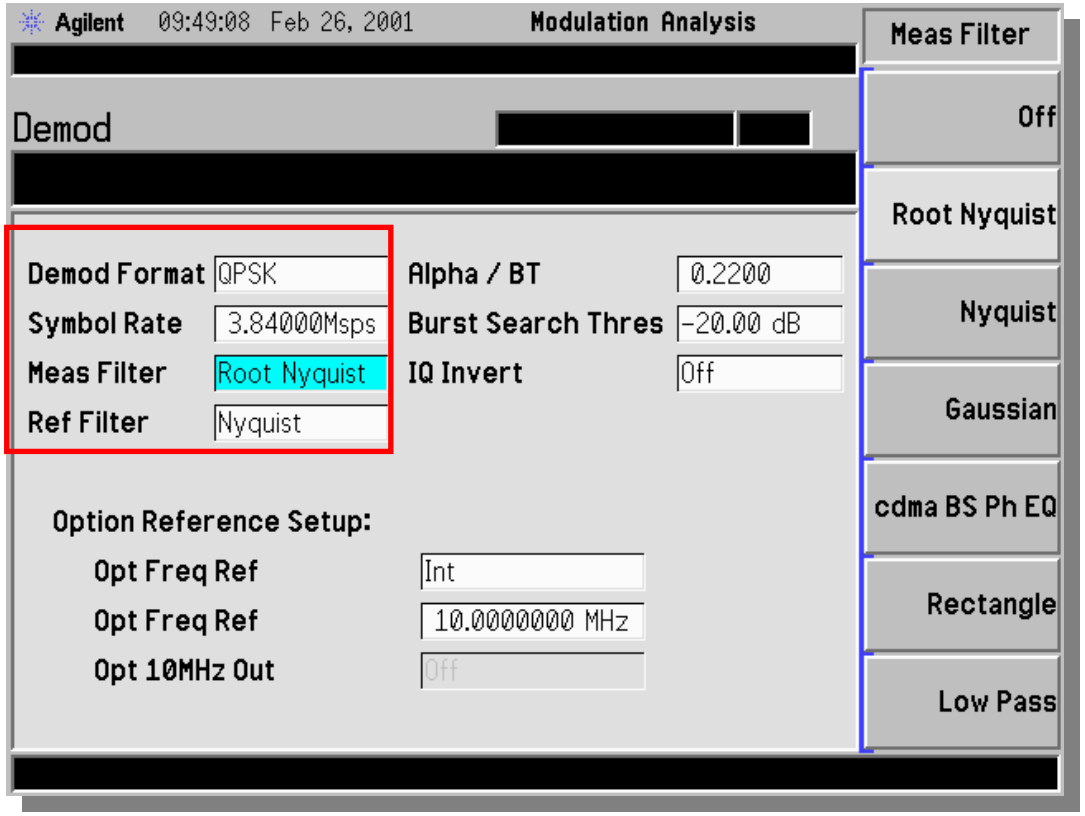
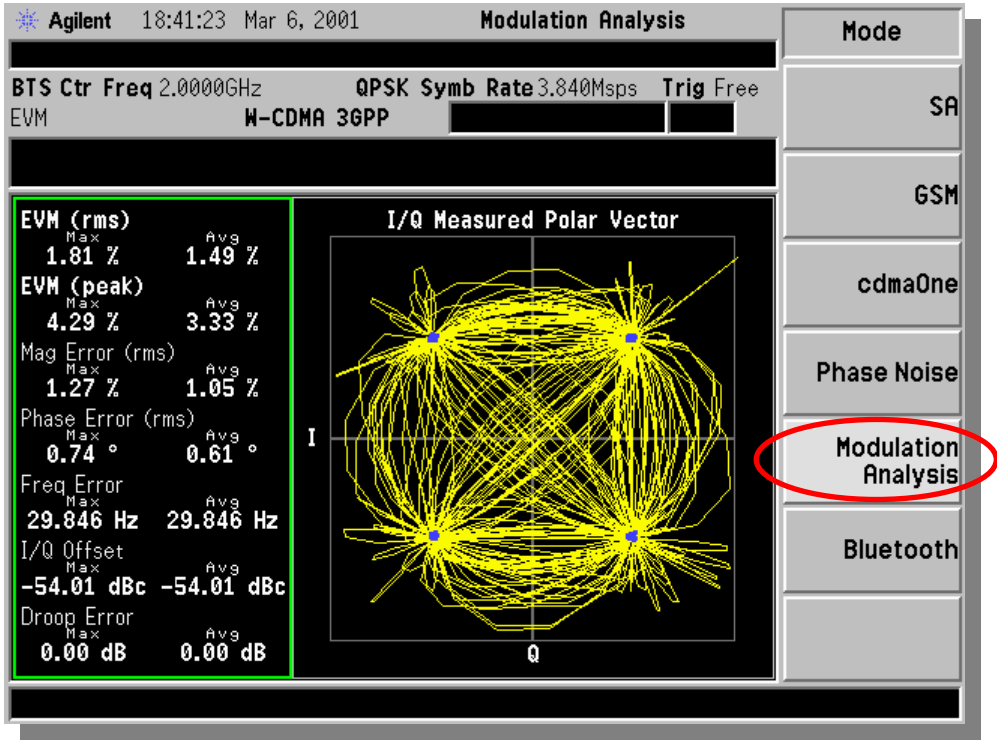
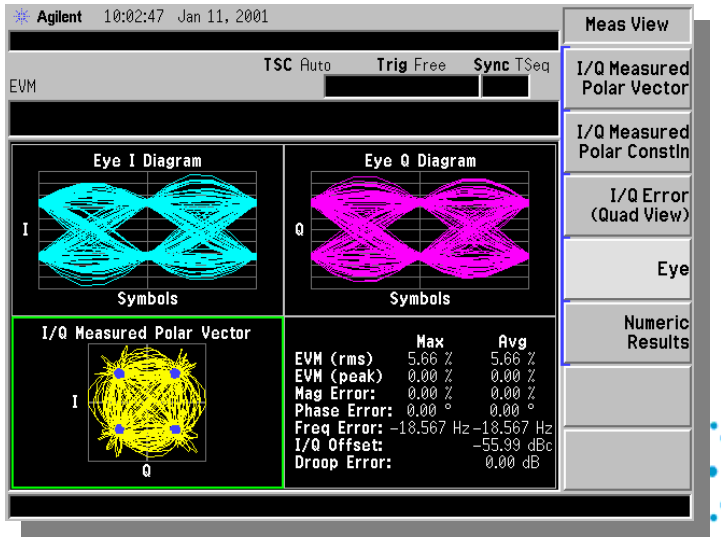
数字调制信号测试（Option B74+229）







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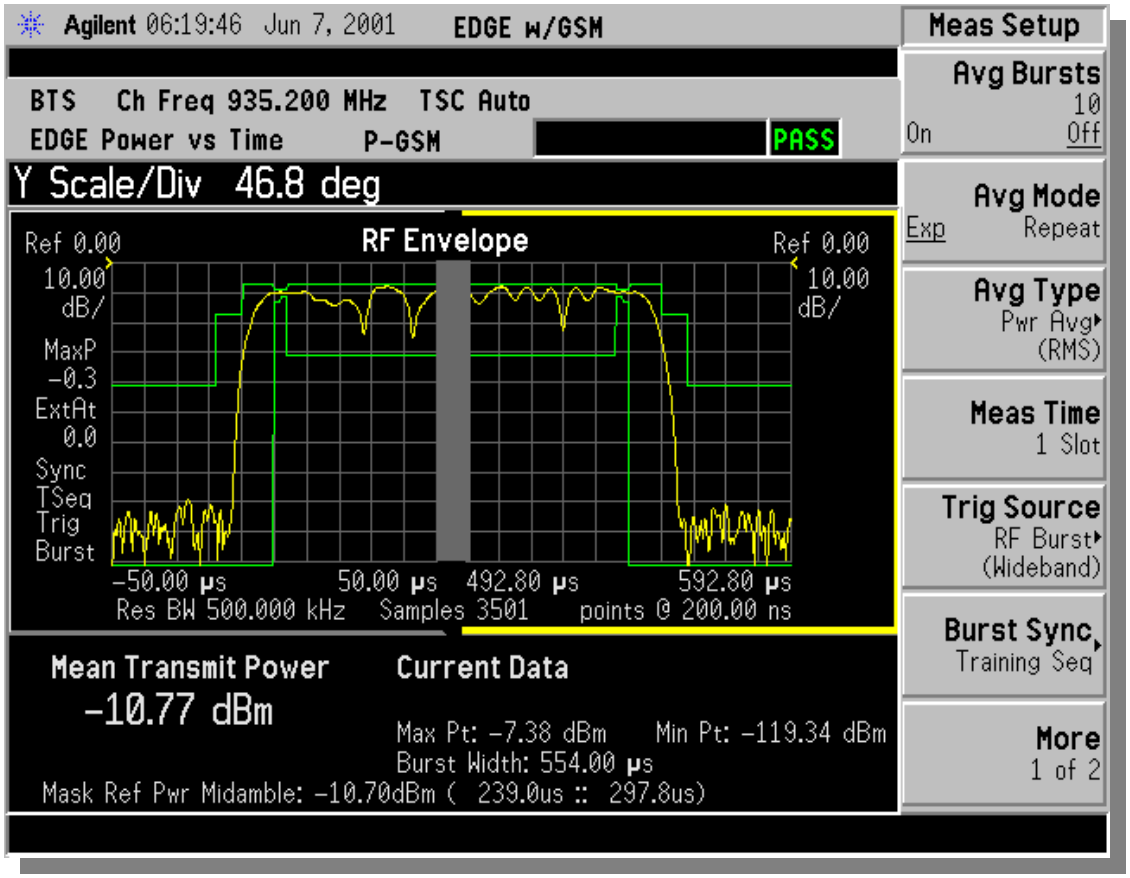
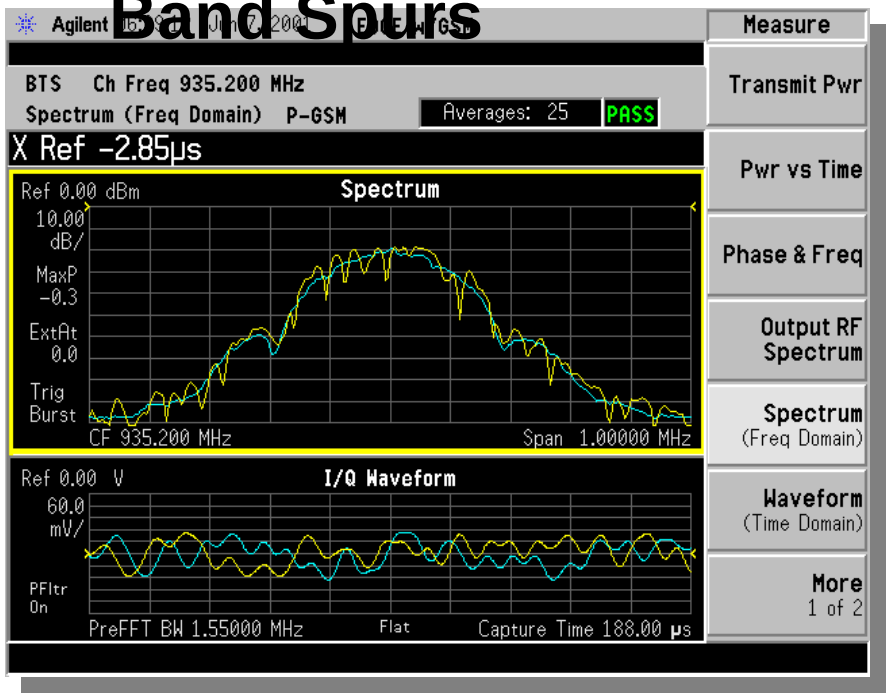
GSM/GPRS 信号测试（Option B74+BAH）

- Transmitter Power
- Power vs Time
- Phase and Freq.
- ORFS
- Band Spurs





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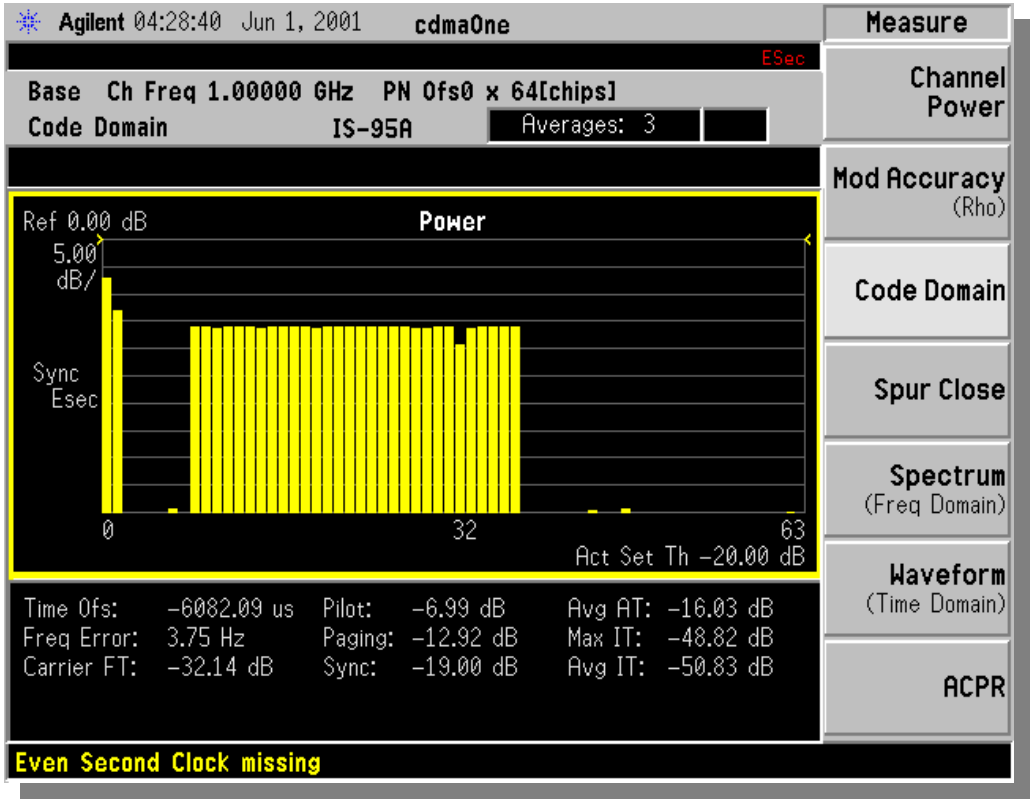
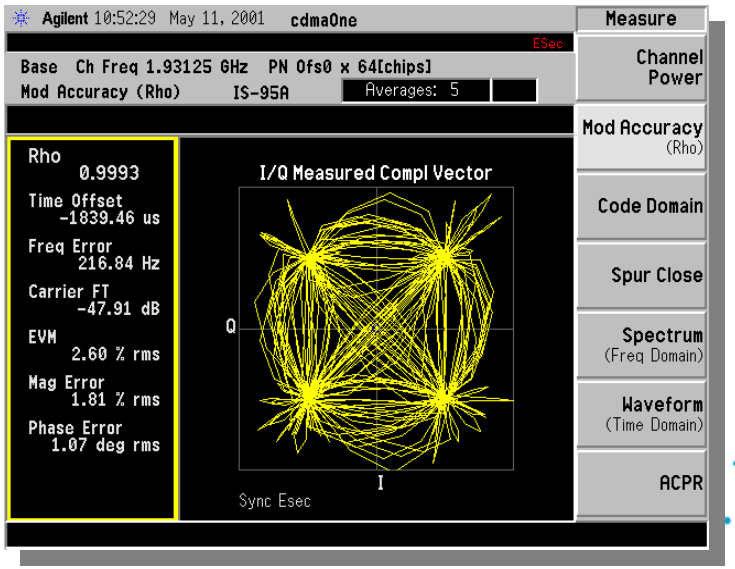
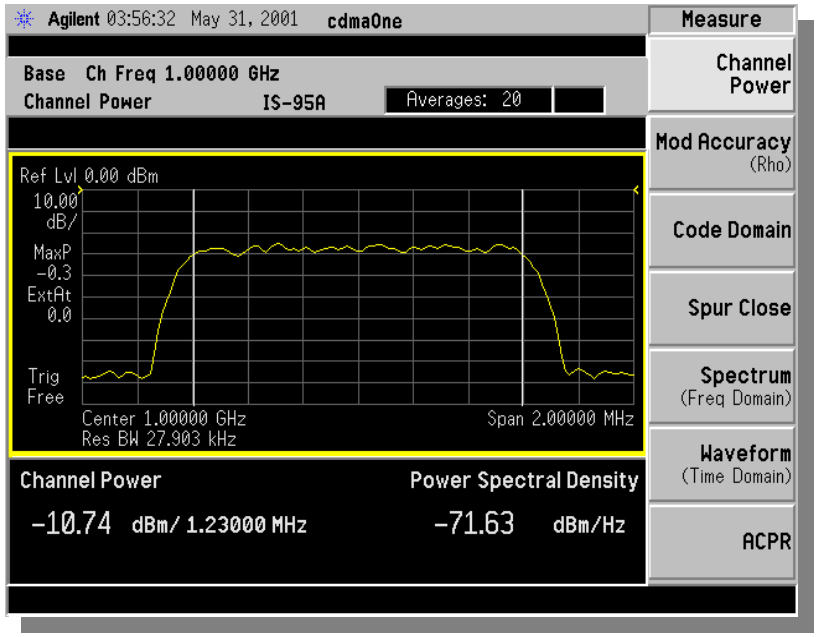
CDMAone 信号测试（Option B74+BAC）



- Channel Power
- Rho
- Code domain
- Spurs
- Freq. and Time
- ACPR





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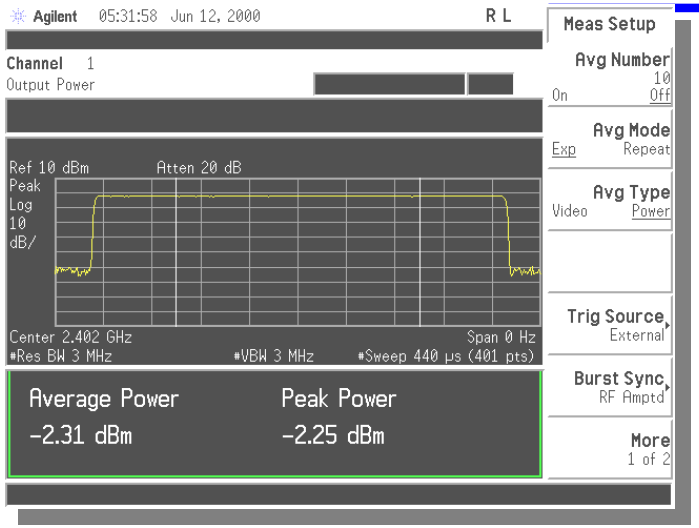
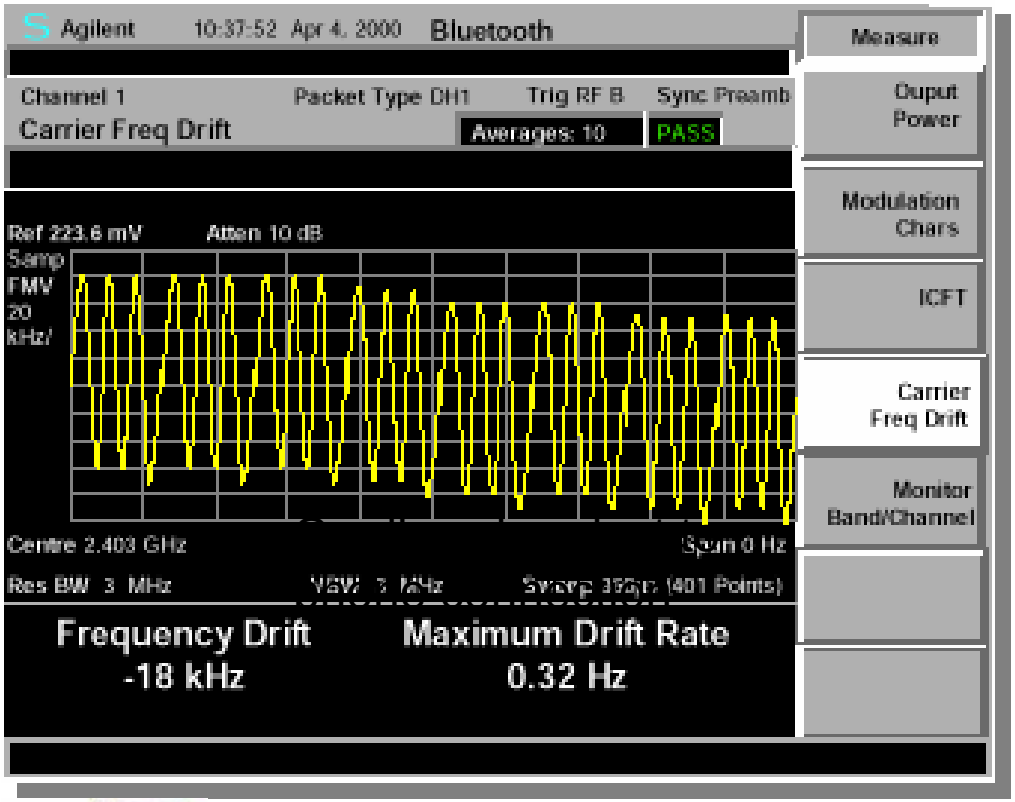
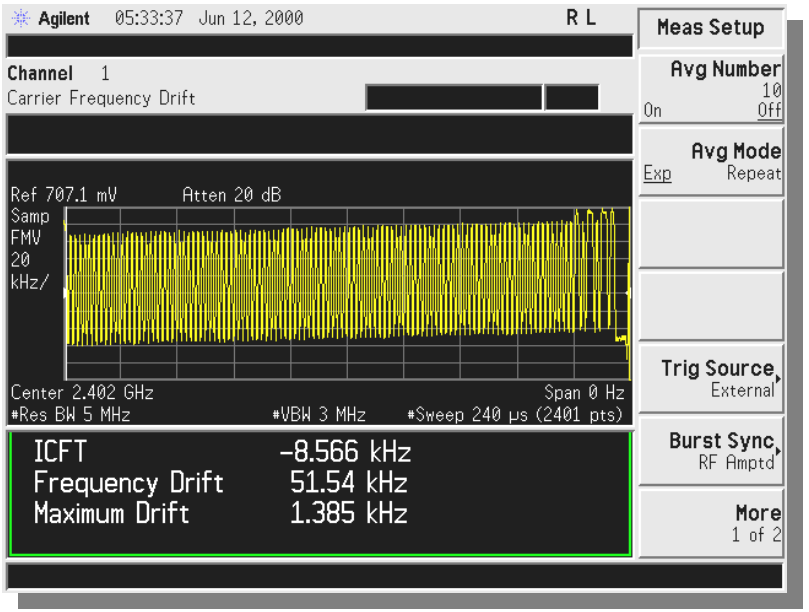
Bluetooth 信号测试（Option 304）







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技术小结

⇩ 分析数字调制信号的调制质量，需对信号进行解调后然后合成标准信号，进行对比得到误差测试结果。

射 频 和 天 线 设 计 培 训 课 程 推 荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

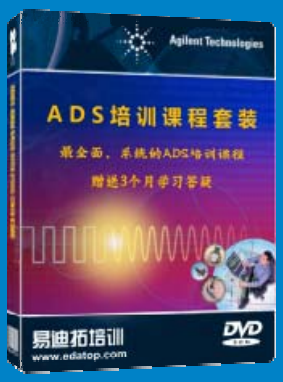
易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

射频工程师养成培训课程套装

该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共 30 门视频培训课程和 3 本图书教材；旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求…

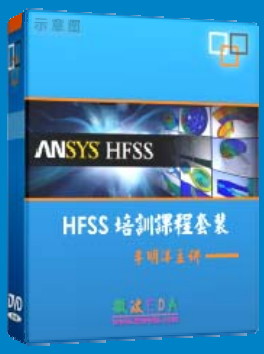
课程网址：http://www.edatop.com/peixun/rfe/110.html

ADS 学习培训课程套装



该套装是迄今国内最全面、最权威的 ADS 培训教程，共包含 10 门 ADS 学习培训课程。课程是由具有多年 ADS 使用经验的微波射频与通信系统设计领域资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了 ADS 在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用 ADS，迅速提升个人技术能力，把 ADS 真正应用到实际研发工作中去，成为 ADS 设计专家...

课程网址： http://www.edatop.com/peixun/ads/13.html



HFSS 学习培训课程套装

该套课程套装包含了本站全部 HFSS 培训课程，是迄今国内最全面、最专业的 HFSS 培训教程套装，可以帮助您从零开始，全面深入学习 HFSS 的各项功能和在多个方面的工程应用。购买套装，更可超值赠送 3 个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的 HFSS 学习更加轻松顺畅…

课程网址：http://www.edatop.com/peixun/hfss/11.html

CST 学习培训课程套装

该培训套装由易迪拓培训联合微波 EDA 网共同推出，是最全面、系统、专业的 CST 微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您从零开始，全面系统地学习 CST 微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送 3 个月免费学习答疑…

课程网址：http://www.edatop.com/peixun/cst/24.html

HFSS 天线设计培训课程套装

套装包含 6 门视频课程和 1 本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了 HFSS 天线设计的全过程。是国内最全面、最专业的 HFSS 天线设计课程，可以帮助您快速学习掌握如何使用 HFSS 设计天线，让天线设计不再难…

课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…

详情浏览：http://www.edatop.com/peixun/antenna/116.html

我们的课程优势：

※ 成立于 2004 年，10 多年丰富的行业经验，

※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

联系我们：

※ 易迪拓培训官网：http://www.edatop.com

※ 微波 EDA 网：http://www.mweda.com

※ 官方淘宝店：http://shop36920890.taobao.com