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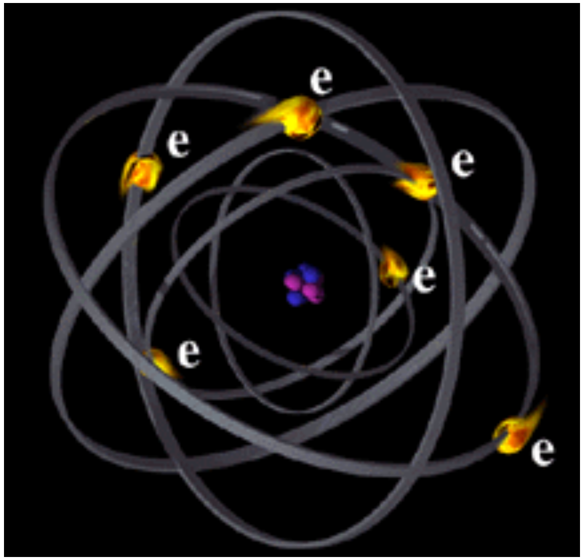
Noise
In
RF Systems

Ralph J. Pasquinelli

What are sources of electrical noise?

Random motion of electrons produces thermal noise
Sometimes referred to as "white noise"



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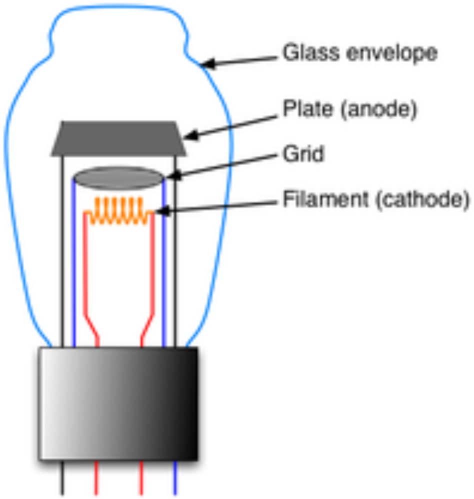
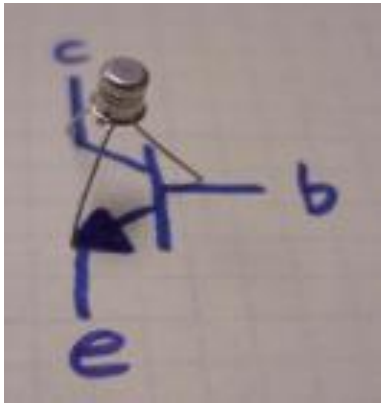
Noise in RF Systems

What are sources of electrical noise?

Vacuum Tube



Transistor



Particle Accelerator

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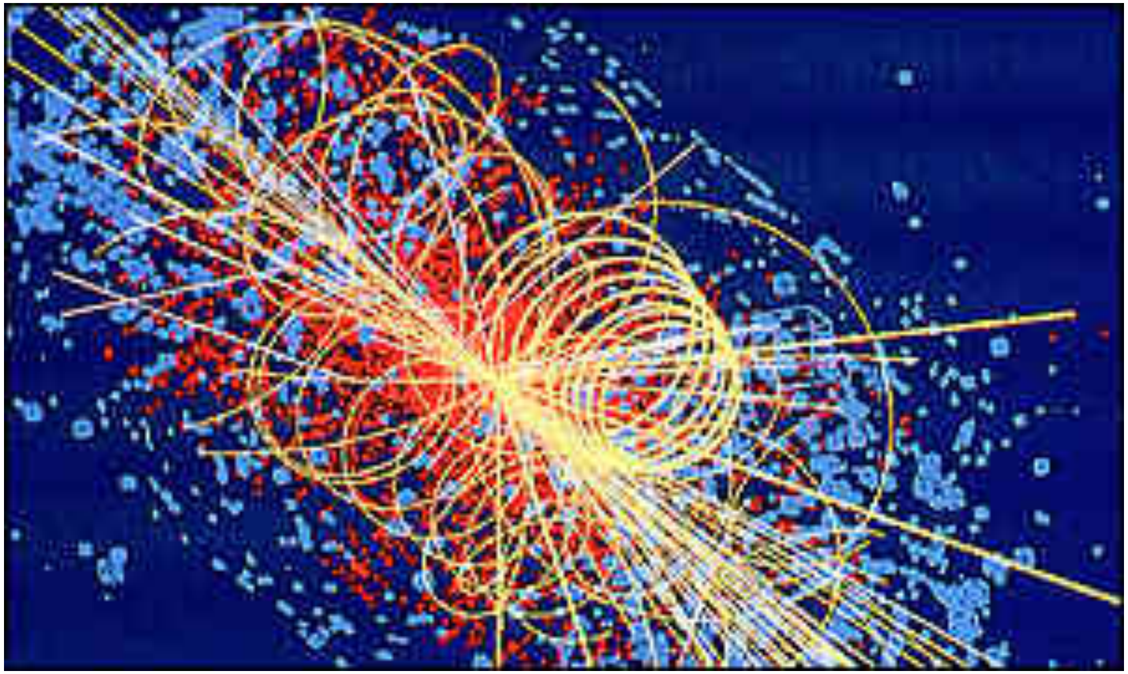
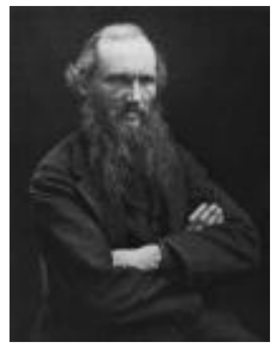
What are sources of electrical noise?

Other undesirable charged particles



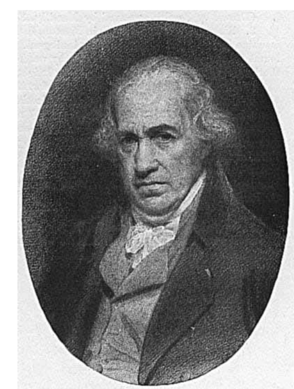
Noise Basics



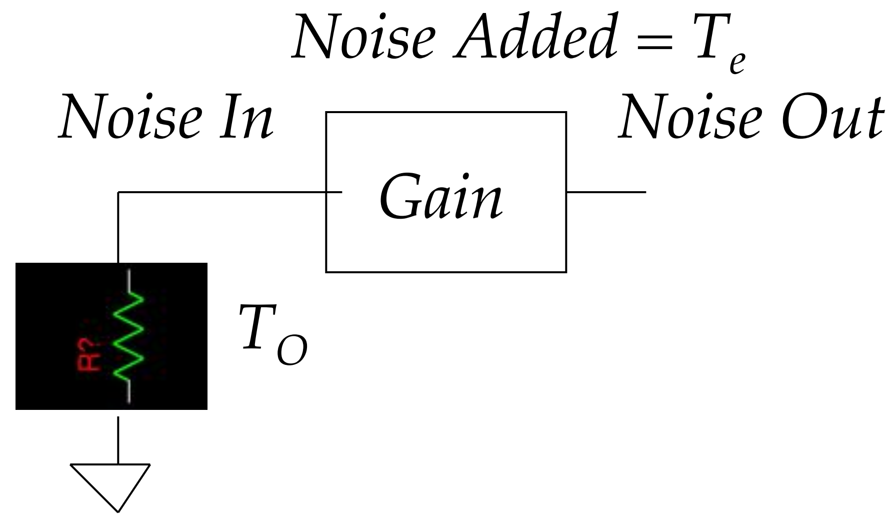
Thermal Noise = kTB

Boltzmann's constant x Temperature x Bandwidth

$$\frac{\text{Watt}\ \cancel{\text{Seconds}}}{\cancel{\text{Degrees K}}} \ x\ \cancel{\text{Degrees K}}\ x\ \frac{1}{\cancel{\text{Seconds}}}$$



Noise Basics



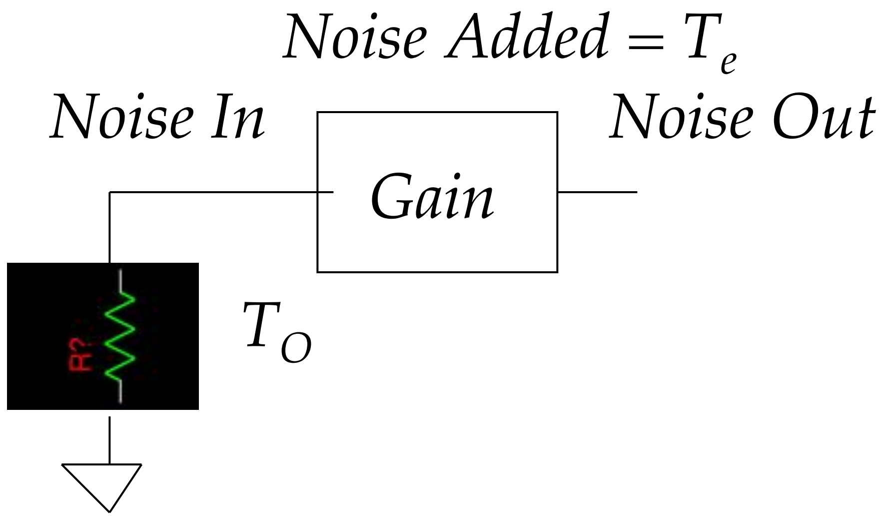
Noise unit is watts

Noise Figure or Noise Factor

$$=NF=\frac{\frac{\text{Signal In}}{\text{Noise In}}}{\frac{\text{Signal Out}}{\text{Noise Out}}}=\frac{(\text{Signal In})(\text{Noise Out})}{(\text{Gain})(\text{Signal In})(\text{Noise In})}=\frac{\text{Noise Out}}{(\text{Gain})(\text{Noise In})}$$

The Perfect Gain Box adds no noise, so NF=1 or 0 dB

Noise Basics



$$\text{Noise In} = kTB$$

$$\text{Noise Out} = \text{Noise In} * \text{Gain} + \text{Noise Added}$$

$$\begin{aligned}\text{Noise Added} &= \text{Noise Out} - \text{Noise In} * \text{Gain} \\ &= NF * \text{Noise In} * \text{Gain} - \text{Noise In} * \text{Gain} \\ &= (NF - 1) * \text{Noise In} * \text{Gain} \\ &= (NF - 1) * kTBG\end{aligned}$$

Effective Noise Temperature = T_e

Noise generated is temperature dependent

$T_O = 290\ ^O K$ is taken as ambient $= 17^O C = 62.6\ ^O F$

$$NF = \frac{k(T_O + T_e)BG}{kT_O BG} = 1 + T_e/T_O$$

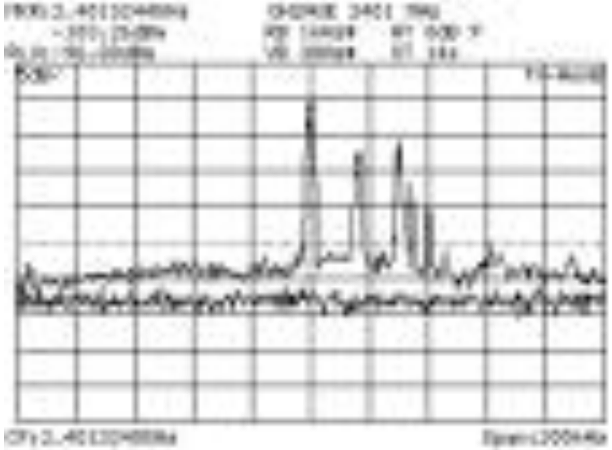
$$T_e = T_O\,(NF\text{-}1)$$

T_e often used in systems where ambient is not 290 ^{O}K

Some examples, radio astronomy, space applications, accelerator physics

Noise Basics

Where is the noise floor?



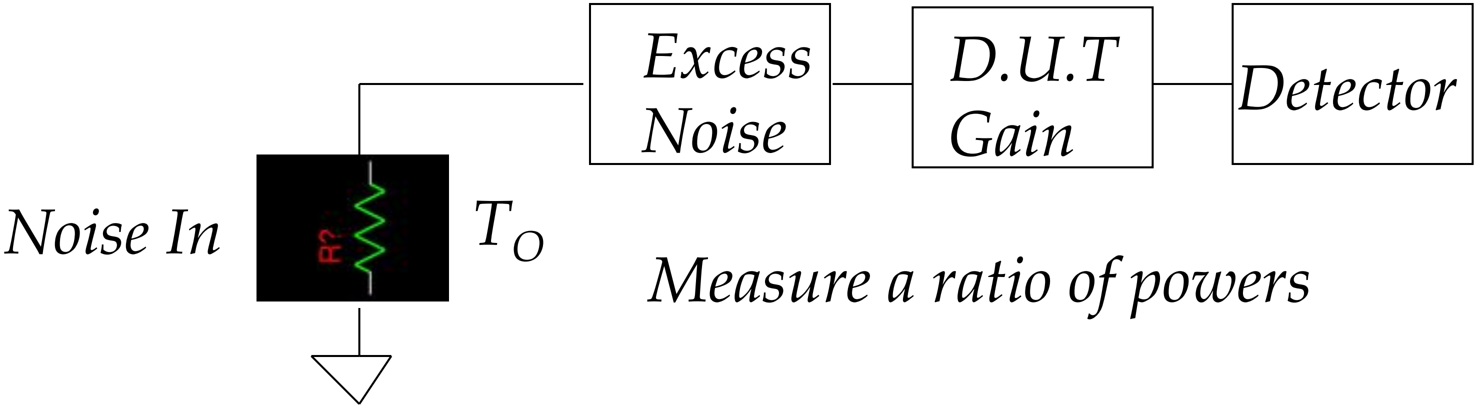
Temperature Dependent
Noise Energy = kT = joules = watt seconds

$=(1.38x10^{-23}\ joules/^{O}K)x(290\ ^{O}K)$
$=4\ x\ 10^{-21}\ joules$
$=4\ x\ 10^{-18}\ milliwatt\ seconds$
$=-174\ dBm\ per\ Hz$

Have a MHz of Bandwidth then add 60 dB for -114 dBm per MHz

Noise Basics

How to Measure Noise Figure



Measure a ratio of powers

excess noise off

D.U.T added Noise
Noise In * Gain

=N1

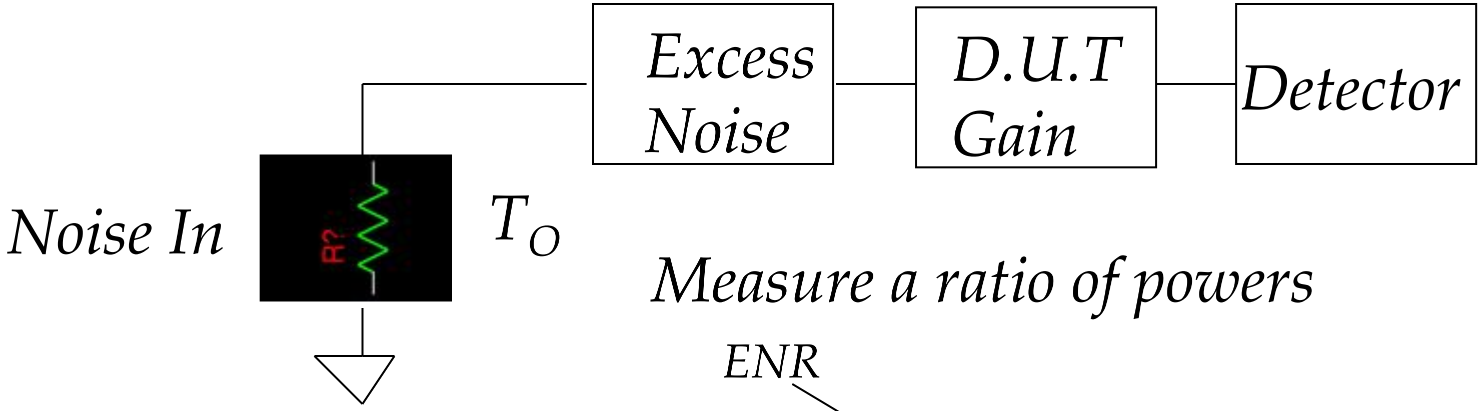
excess noise on

Excess Noise * Gain
D.U.T added Noise
Noise In * Gain

= N2

Noise Basics

How to Measure Noise Figure



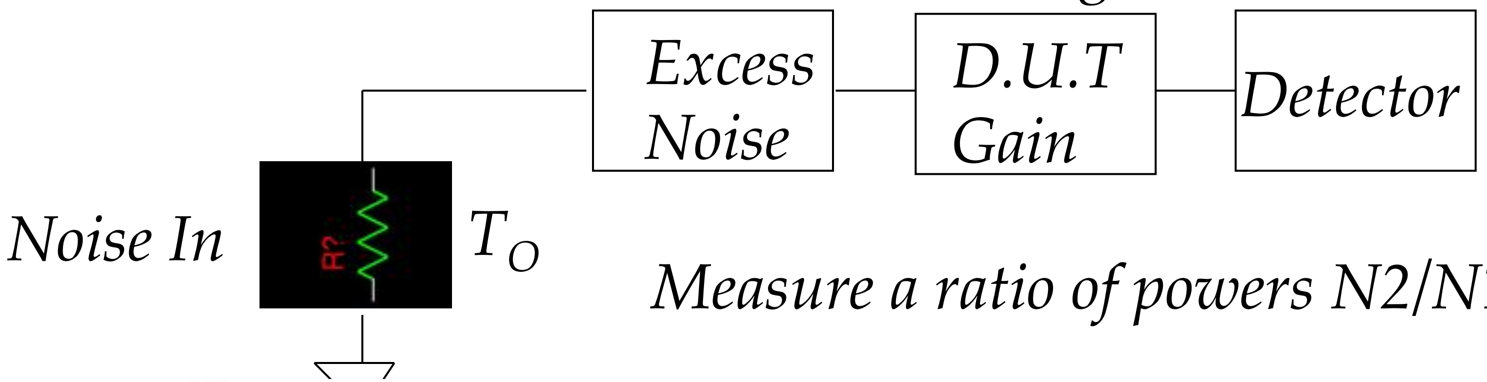
Measure a ratio of powers

ENR

$$Y = N2/N1 = \frac{kT_0BG + k(T_2\text{-}T_0)BG + (NF\text{-}1)kT_0BG}{kT_0BG + (NF\text{-}1)kT_0BG}$$

Noise Basics

How to Measure Noise Figure

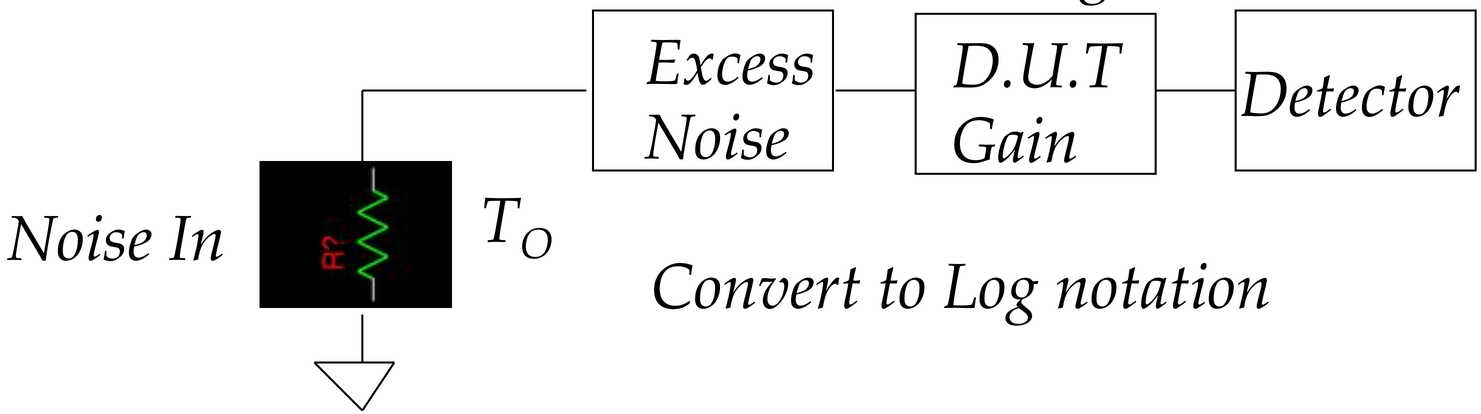


Measure a ratio of powers N2/N1=Y

$$NF = ENR \times \frac{1}{Y - 1}$$

Noise Basics

How to Measure Noise Figure



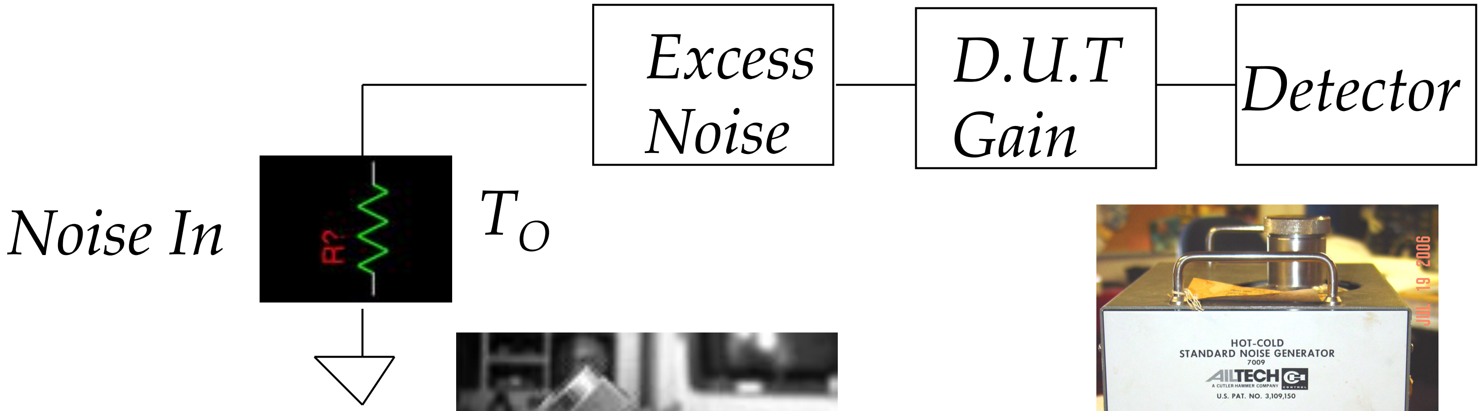
Convert to Log notation

$$NF_{dB} = 10\ Log((T_2 - T_0)/T_0) - 10\ Log(N2/N1 - 1)$$

$$= ENR_{dB} - 10\ Log(N2/N1-1)$$

Noise Basics

How to Measure Noise Figure



Noise Diode

Hot and Cold noise source

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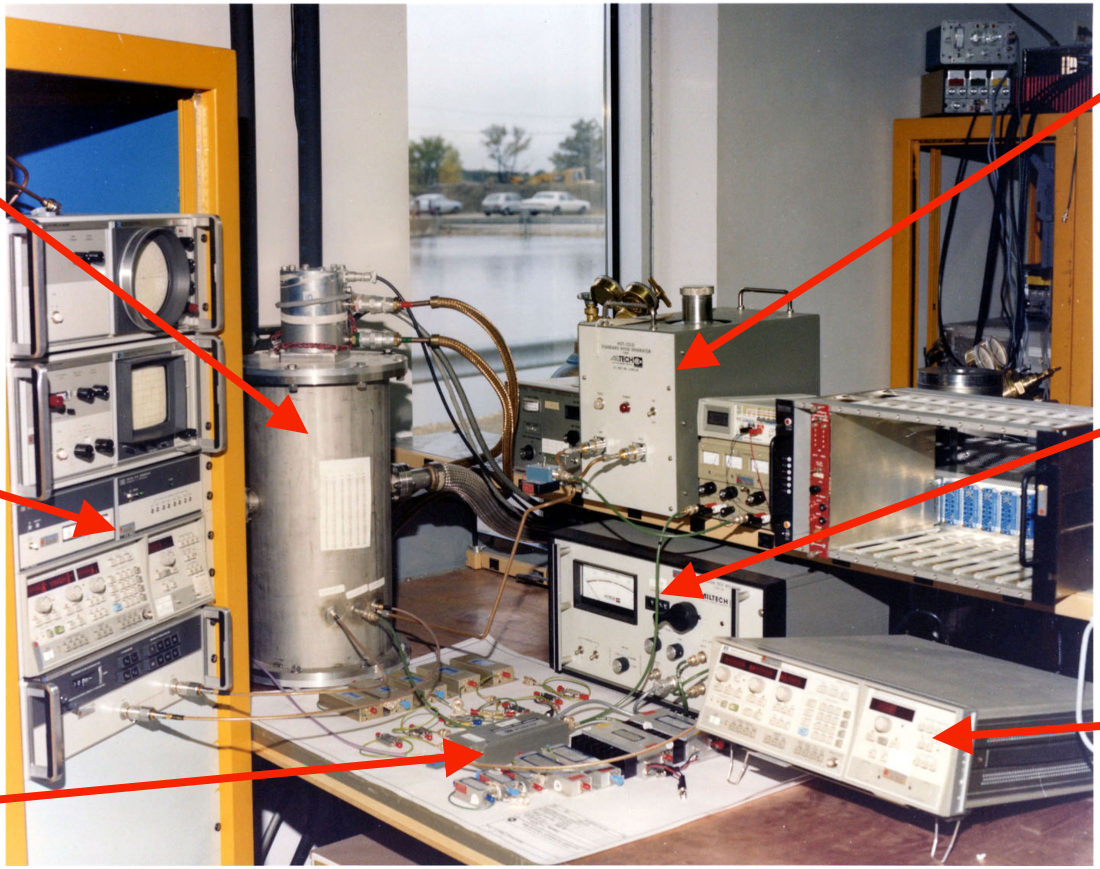
Noise in RF Systems

Noise Figure Test Setup



Cryostat

Network Analyzer

Amplifiers

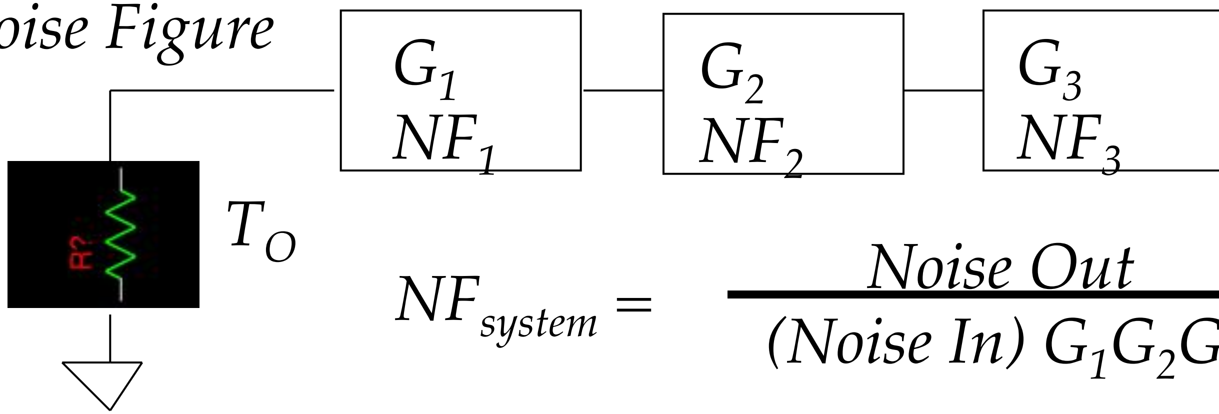
Noise Source

Detector

Local Oscillator

Noise Basics

System Noise Figure



Noise In T_O Noise Out

$$NF_{system} = \frac{\text{Noise Out}}{(\text{Noise In})\, G_1 G_2 G_3}$$

$$NF_{system} = \frac{\cancel{kTBG_1G_2G_3} + (\cancel{NF_1}-1)\,\cancel{kTBG_1G_2G_3}}{\cancel{kTBG_1G_2G_3}} + \frac{(NF_2-1)\cancel{kTBG_2G_3}}{\cancel{k}TBG_1\cancel{G_2}G_3} + \frac{(NF_3-1)\cancel{KTBG_3}}{\cancel{k}TBG_1G_2\cancel{G_3}}$$

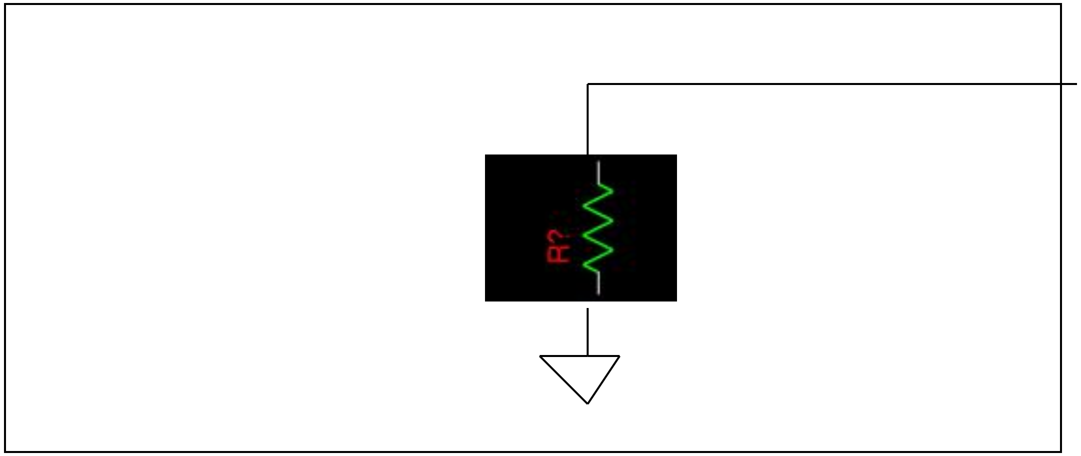
$$NF_{system} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1\, G_2}$$

$$\text{System } T_e = T_{e1} + T_{e2}/G1 + T_{e2}/G1G2$$

Noise in RF Systems

Mount Amplifier
HERE!

Noise in RF Systems



Look into these boxes
The impedance
looks the same!

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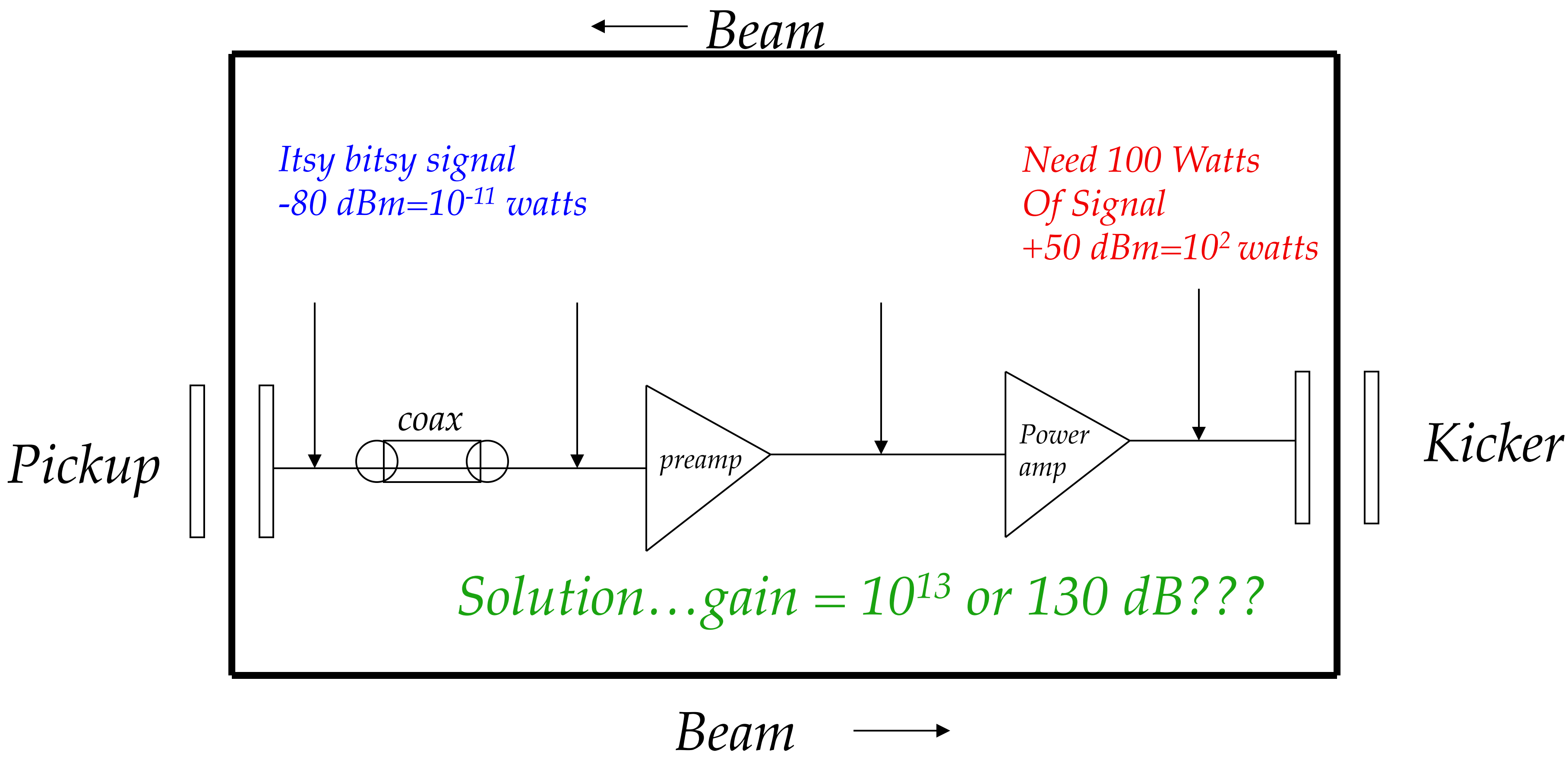
Noise in RF Systems

Typical Stochastic Cooling Feedback System



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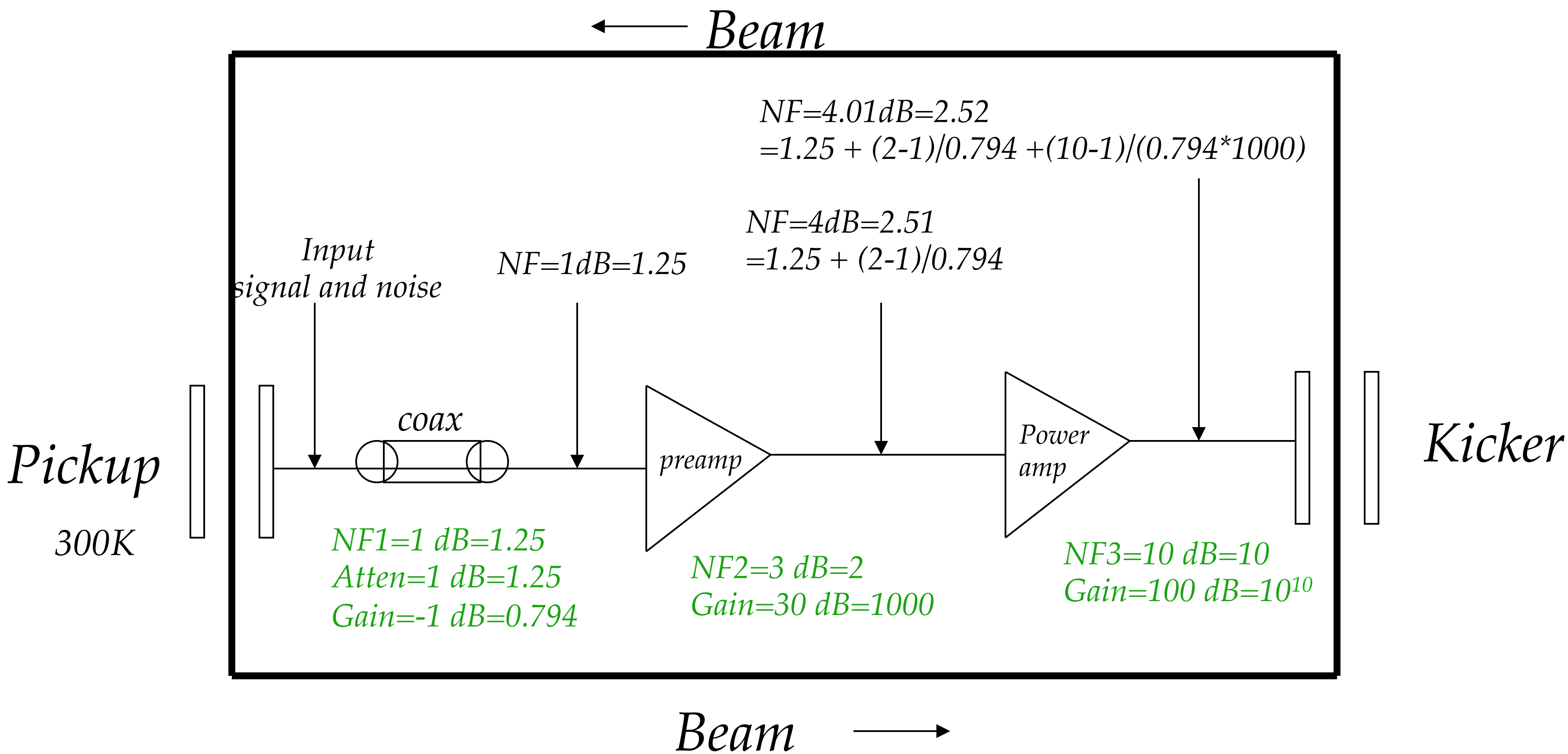
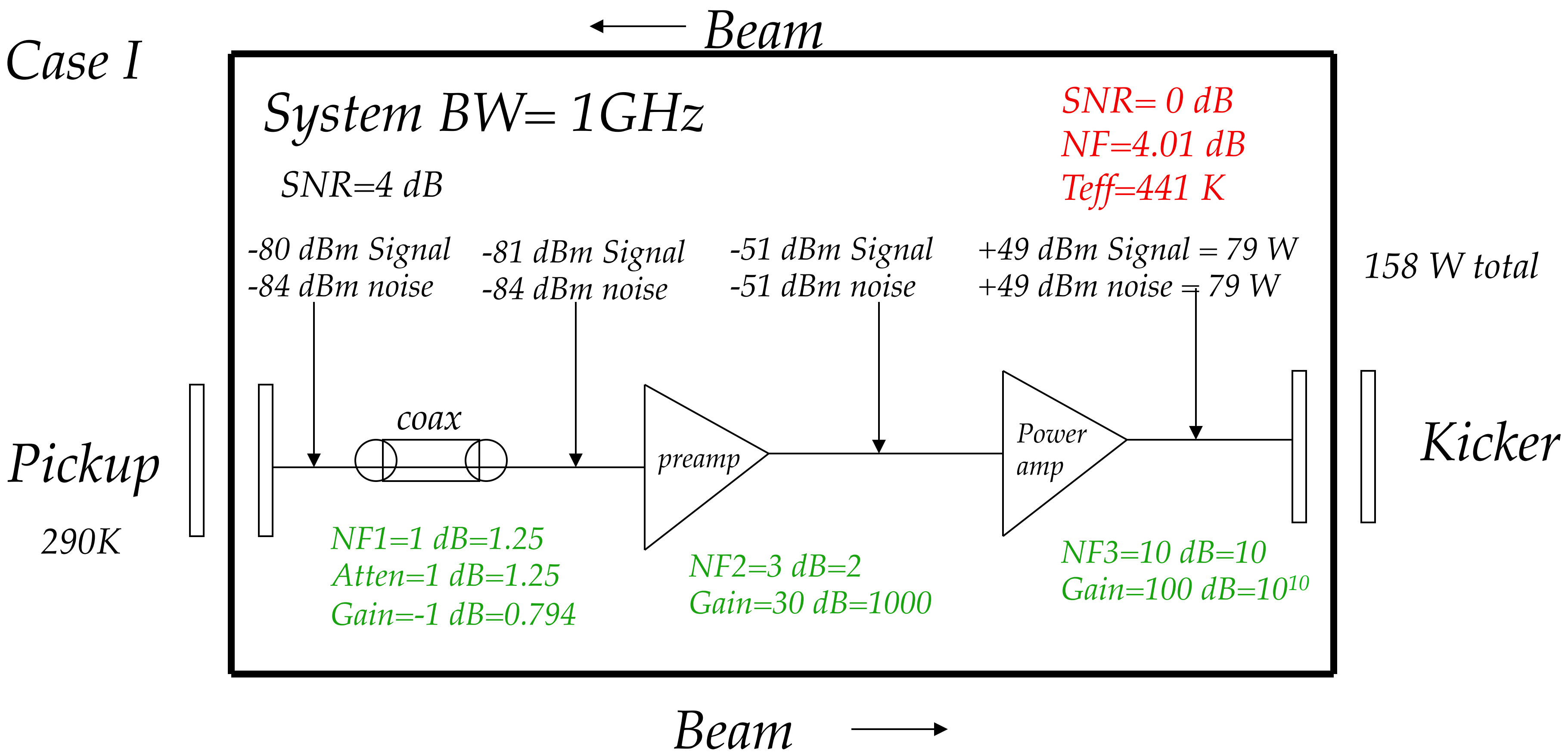
Typical Stochastic Cooling Feedback System



Typical Stochastic Cooling Feedback System



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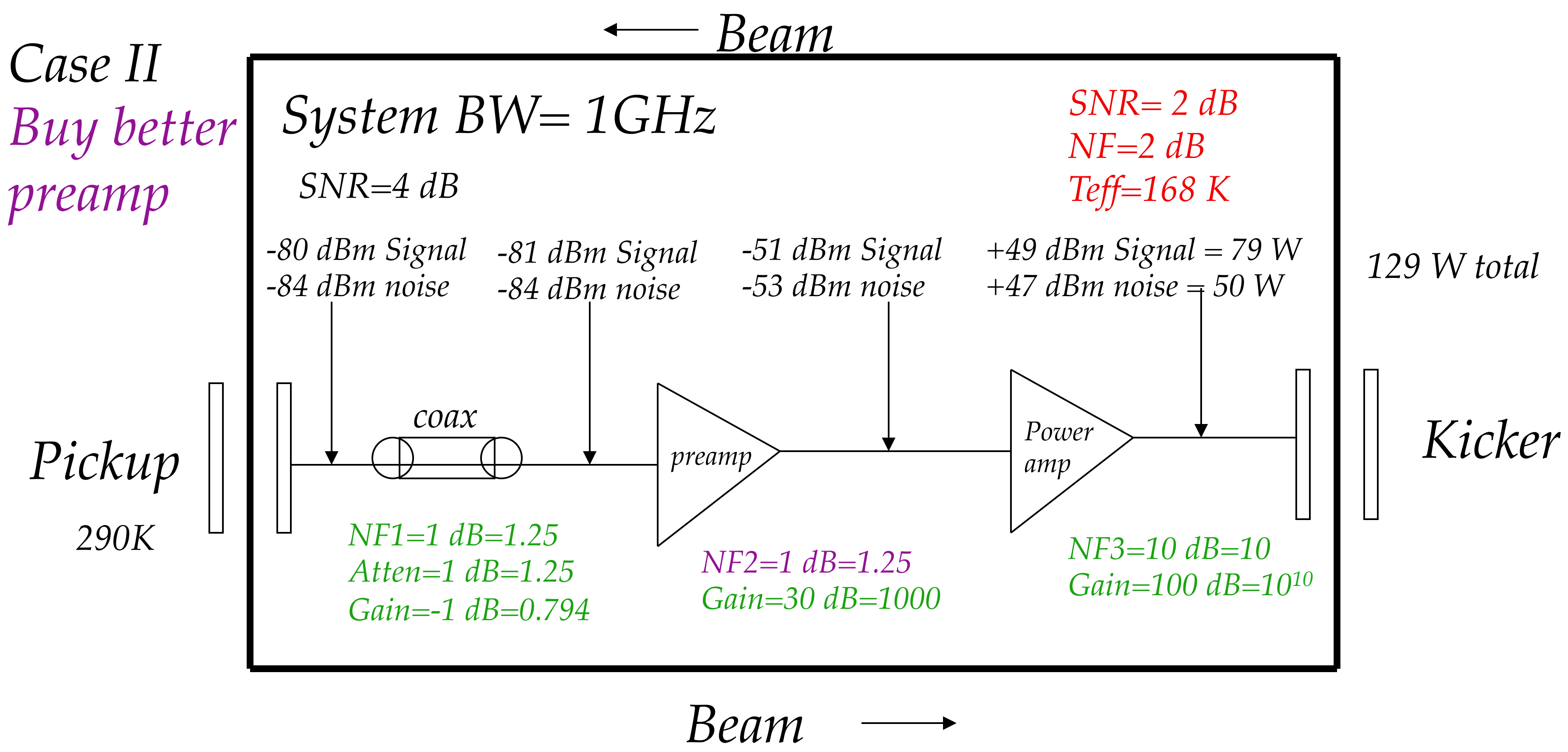
Noise in RF Systems

Typical Stochastic Cooling Feedback System

Case II

Buy better preamp



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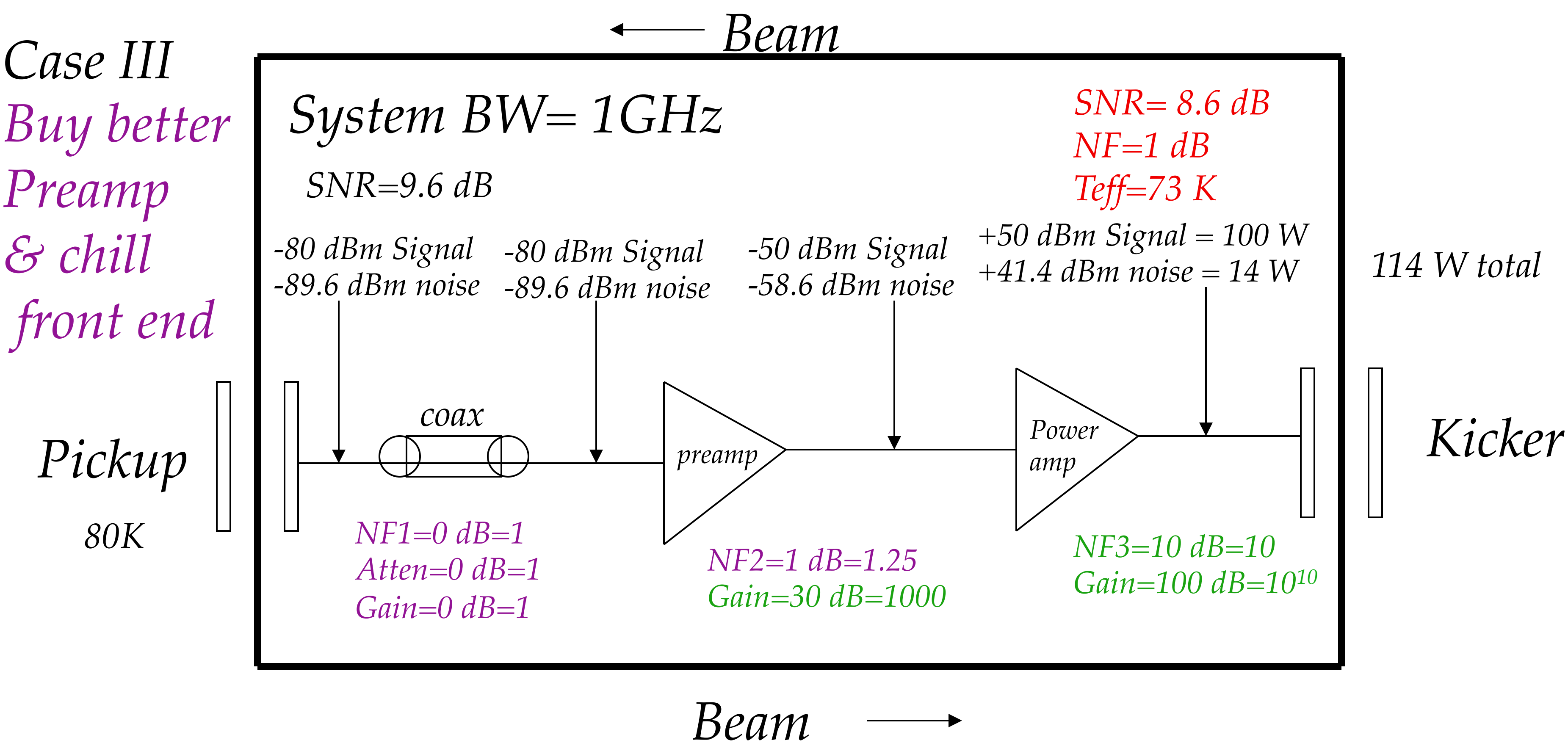
Typical Stochastic Cooling Feedback System



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$$ What's the Cost $$

Power costs $100 per watt for this system

Case I: Warm pickup and 3 dB NF preamp
79 watts signal + 79 watts noise = 158 watts
Did not meet 100 watt signal minimum so must add 26% more total power for 200 Watts

Preamp cost……………….$500
Power cost……………$20,000
Subtotal………………$20,500

$$ What's the Cost $$

Power costs $100 per watt for this system

Case II: Warm pickup and 1 dB NF preamp

79 watts signal + 50 watts noise = 129 watts

Did not meet 100 watt signal minimum so must add 26% more total power for 162 Watts

Preamp cost.................$2000

Power cost...............$16,200

Subtotal..................$18,200

$$ What's the Cost $$

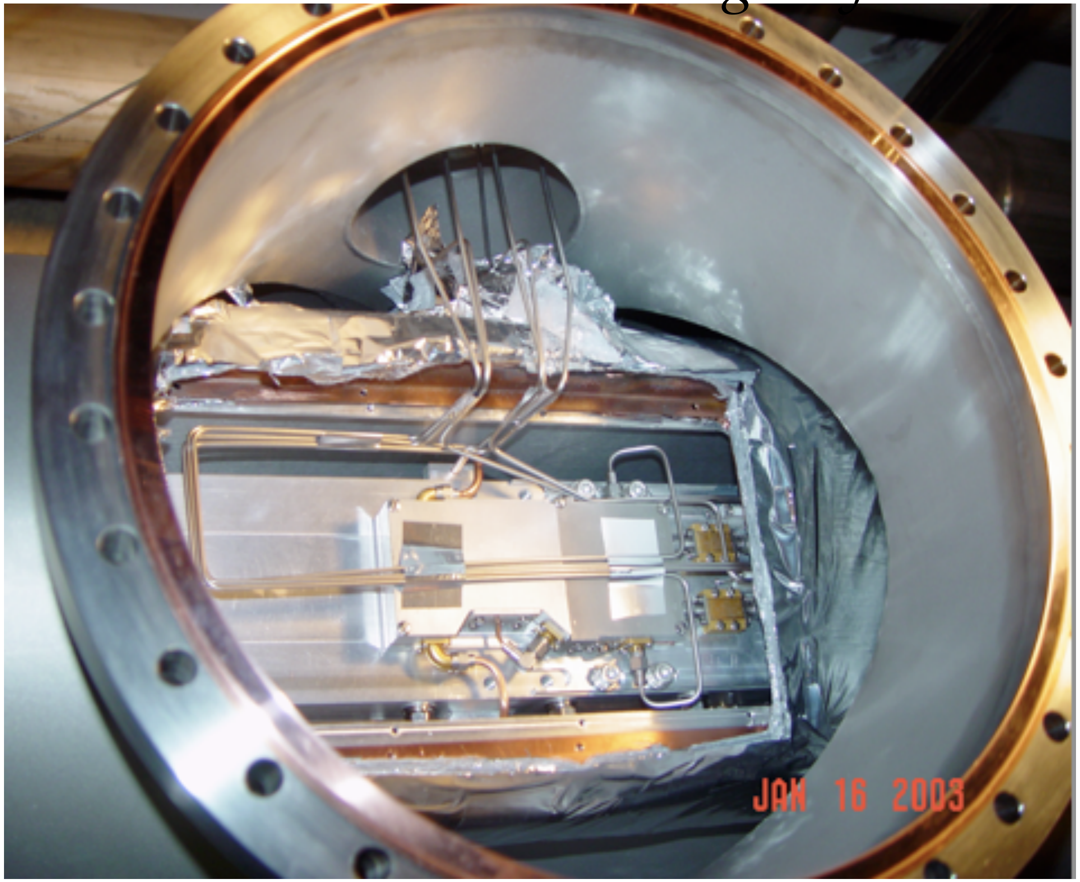
Power costs $100 per watt for this system

Case III: Cold pickup and 1 dB NF preamp
100 watts signal + 14 watts noise = 114 watts

Cryogenics …………..$50,000
Preamp cost…………….$2000
Power cost……………$11,400

Subtotal………………$63,400

Debuncher Stochastic Cooling Cryo Preamp



What if?

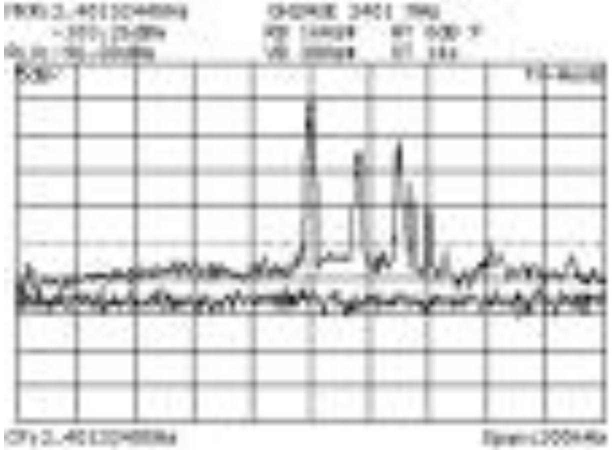
Ferrite Saturation?

Power Handling?

Tight fit?
No room
For
More Kickers

Noise Basics

Where is the noise floor?



Temperature Dependent

Noise Energy = kT = joules = watt seconds

$=(1.38 \times 10^{-23}$ *joules/K*$) \times (290$ *K*$)$

$=4 \times 10^{-21}$ *joules*

$=4 \times 10^{-18}$ *milliwatt seconds*

=-174 dBm per Hz

Have a MHz of Bandwidth then add 60 dB for -114 dBm per MHz

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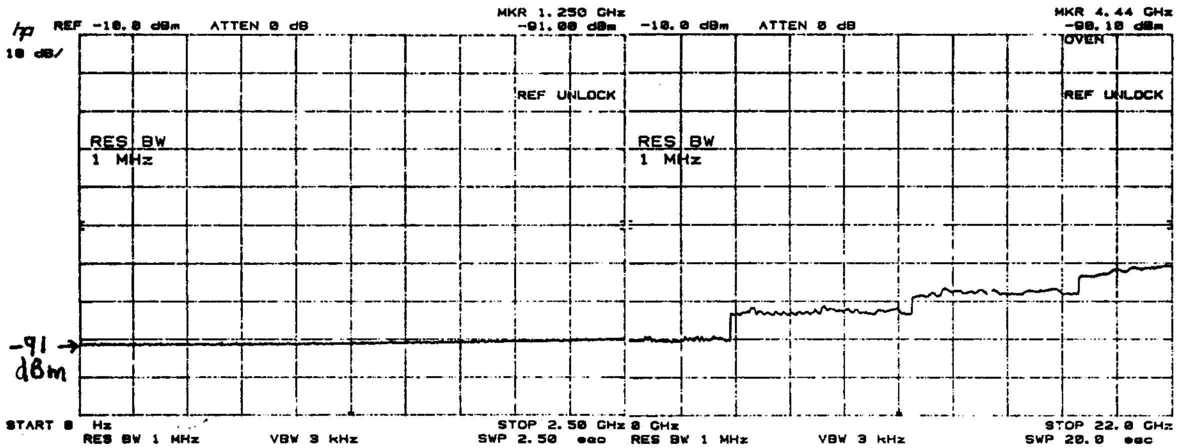
Noise Performance of Swept Frequency Spectrum Analyzer



With a Resolution Bandwidth of 1 MHz noise floor = -91 dBm
Some 23 dB worse than ideal

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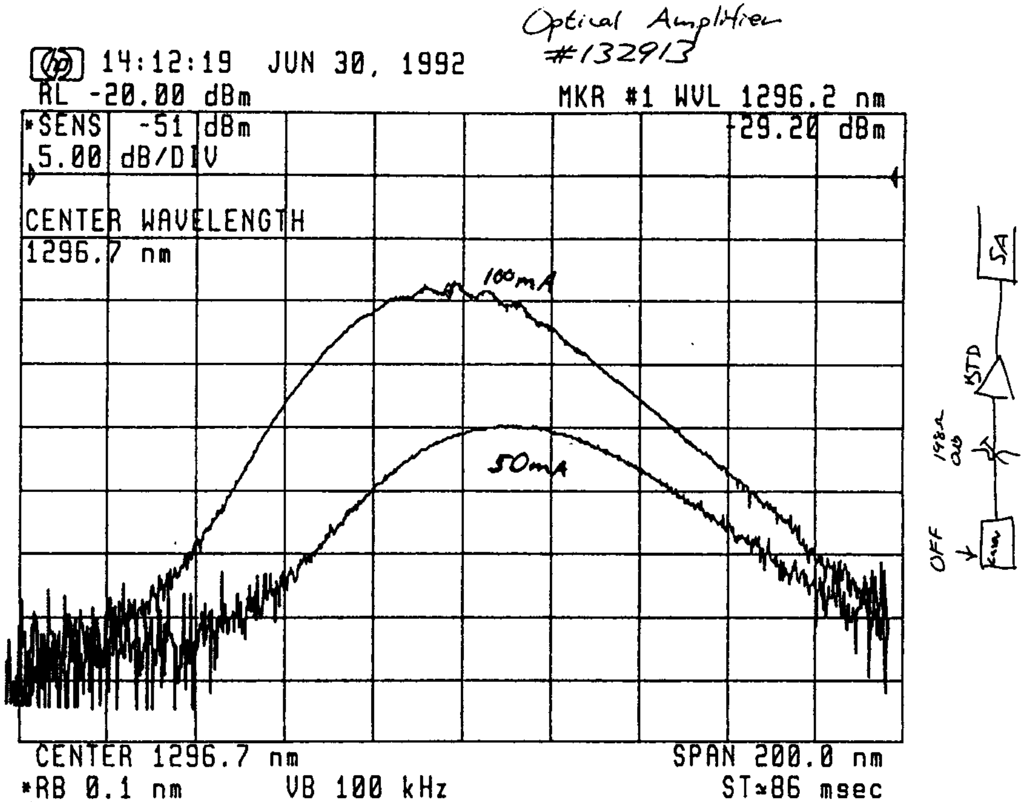
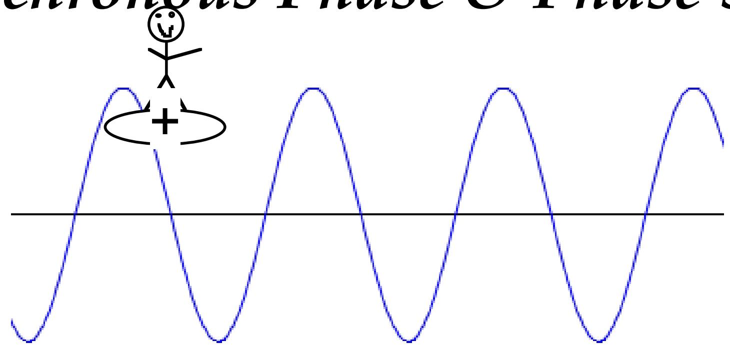
Optical Amplifier Noise Performance



Synchronous Phase & Phase Stability



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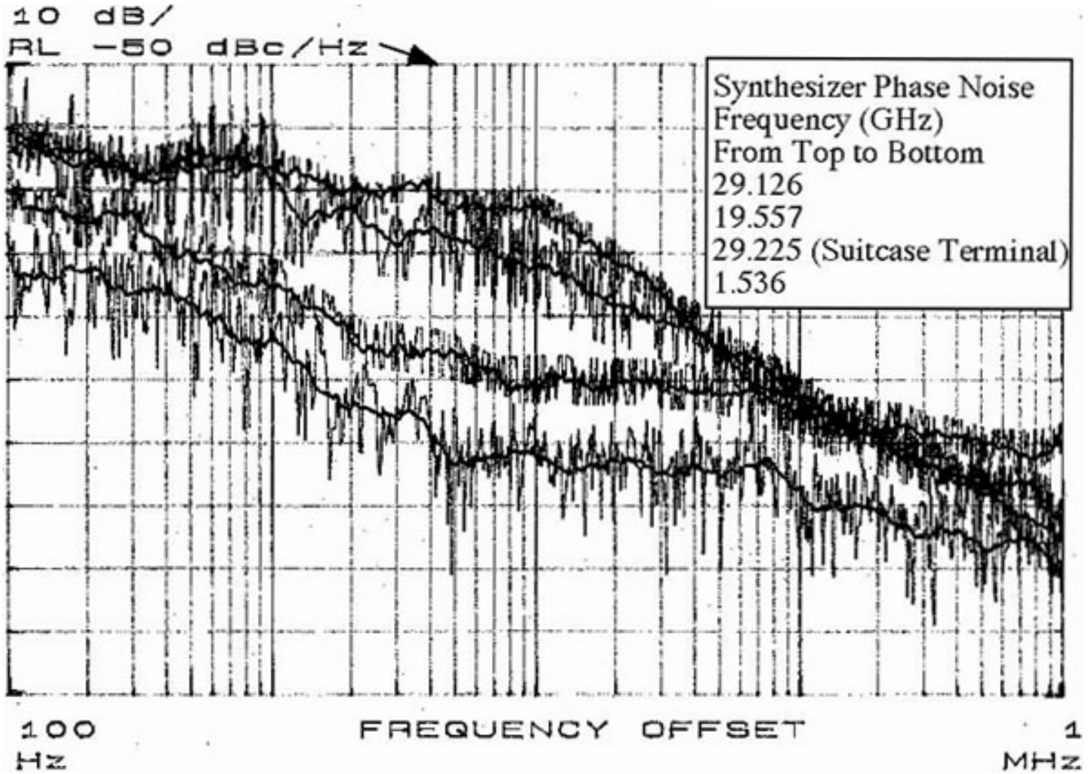
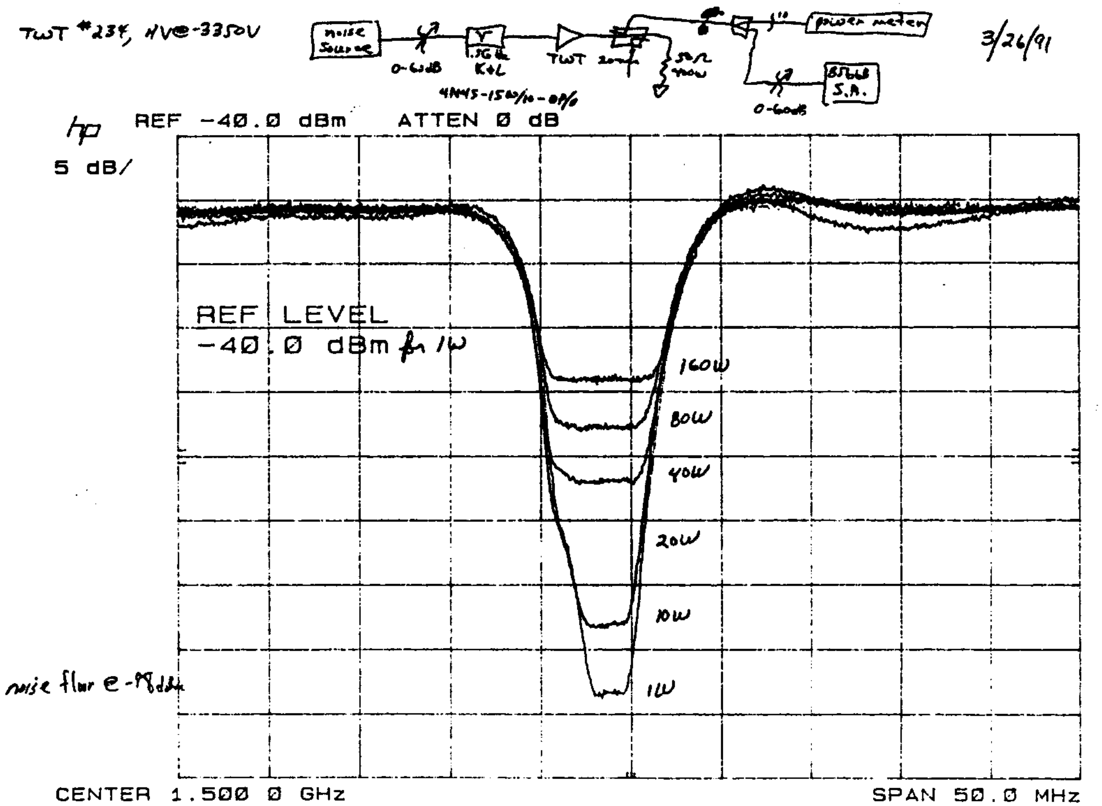
Plot of Phase Noise vs Frequency



Intermodulation Noise in a Power Amplifier



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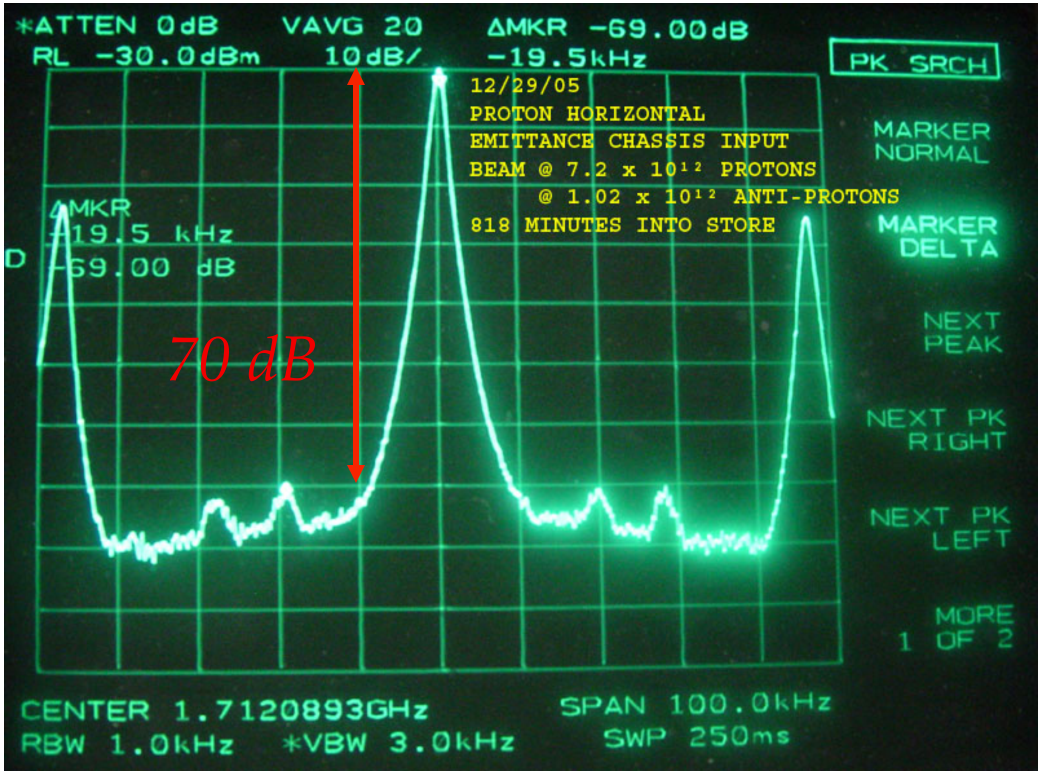
Coherent Beam Signal Noise
Tevatron Schottky Signal



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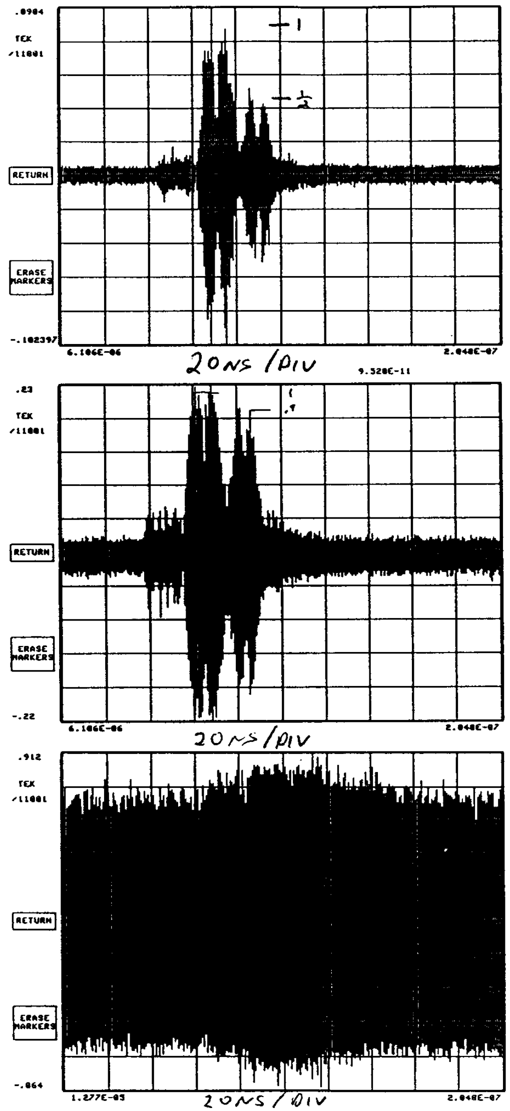

Tevatron Schottky Time Domain Signals

After pickup

After pre-amplifier

After power amplifier

Peak Power
Levels can
Saturate the system
But not be
Obvious in the
Frequency Domain

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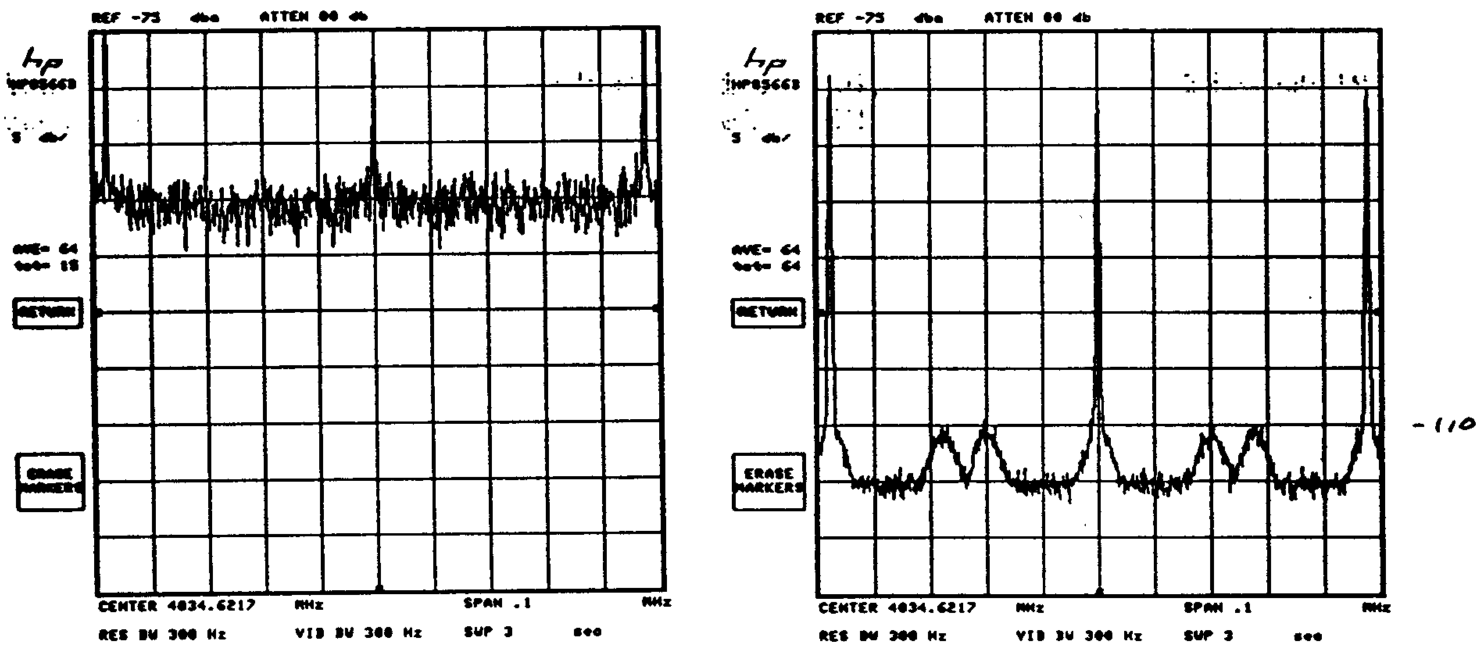
Effects by gating on Tevatron Schottky Signal



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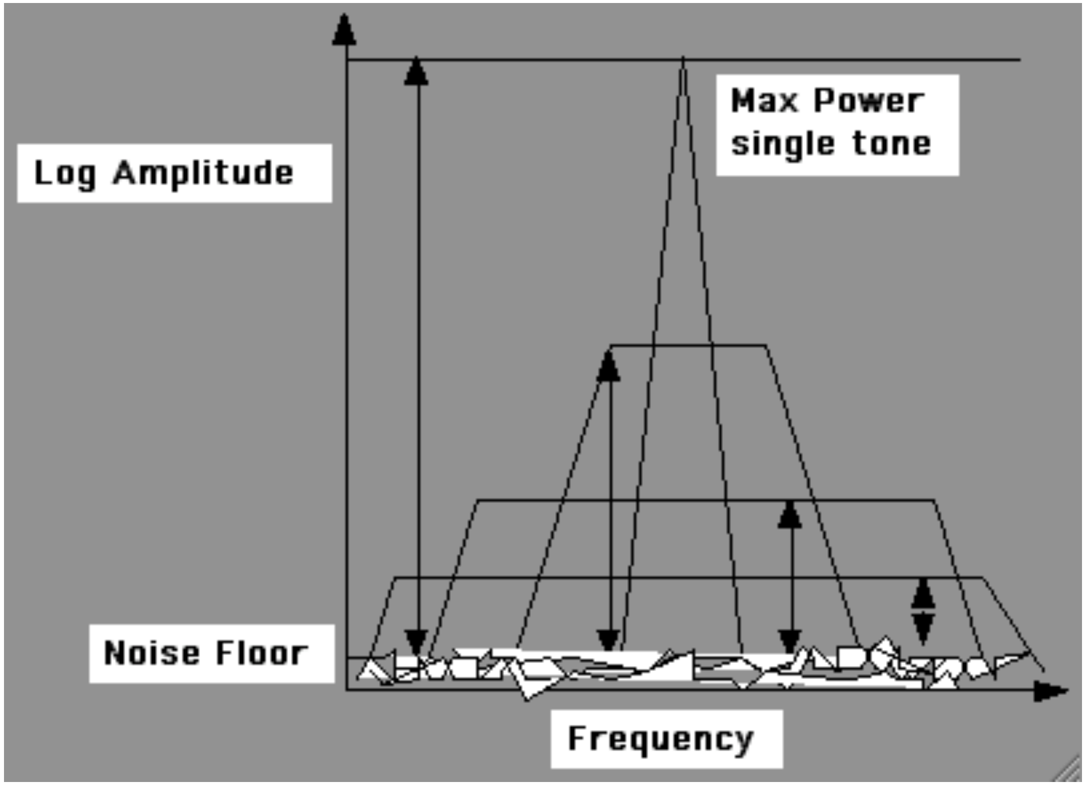
Dynamic Range = Max operable power/Noise floor power



Total Power
Is the
Integral across
Full bandwidth

Digital Connection

How many bits?

Digital is base two, so every Bit is 2 x voltage or 6 dB

Take required dynamic range dB and
Divide by 6 dB for number of bits!

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