Interfacing Digitally-Controlled Microphone Preamplifiers to A/D Converters

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Today's Presentation

- Introduction and Overview of Microphone Specs
- Noise and Gain Structure from XLR to A/D Converter
- Discussion of the Advantages of Digital Control of Microphone Preamplifiers
- Questions

Overview Of Microphone Specifications

- Survey of some popular condenser, dynamic, and ribbon mics
- Compiled “typical” numbers for important parameters relating to preamp design

1 Pa = 94 dB SPL		150 Ohms =	-130.8 dBu unweighted -132.9 dBu A wtd.		200 Ohms	-129.6 dBu unweighted -131.6 dBu A wtd.							
Mfr	Microphone Model	Type	Sensitivity (dBV/Pa)	SNR (dBA re:1Pa)	Output Noise (dBV A)	Output Noise (dBu A)	Mic Noise (dB re: 150 ohms)	Mic Noise Normalized to Sensitivity	Actual Output Z (Ohms)	Self Noise (dB SPL)	Max SPL (dB SPL))	Dynamic Range (dB)	Max Out (dBu)
Shure	KSM42	Condensor	-37	86	-123	-120.8	12.1	-83.8	147	8	139	131	10.22
Shure	KSM44 Omni	Condensor	-37	88	-125	-122.8	10.1	-85.8	50	6	140	134	11.22
Shure	KSM44 Cardioid	Condensor	-31	90	-121	-118.8	14.1	-87.8	50	4	134	130	11.22
Shure	KSM44 Bidirect.	Condensor	-36	86.5	-122.5	-120.3	12.6	-84.3	50	7.5	139	131.5	11.22
Shure	KSM9	Condensor	-51	72	-123	-120.8	12.1	-69.8	150	22	152	130	9.22
Shure	KSM32	Condensor	-36	81	-117	-114.8	18.1	-78.8	150	13	139	126	11.22
Shure	KSM137	Condensor	-37	80	-117	-114.8	18.1	-77.8	150	14	139	125	10.22
Shure	KSM141	Condensor	-37	80	-117	-114.8	18.1	-77.8	150	14	139	125	10.22
Shure	SM27	Condensor	-37	84.5	-121.5	-119.3	13.6	-82.3	140	9.5	138	128.5	9.22
Shure	SM137	Condensor	-41	75	-116	-113.8	19.1	-72.8	150	19	144	125	11.22
Shure	SM86	Condensor	-50	71	-121	-118.8	14.1	-68.8	150	23	147	124	5.22
Shure	SM87A	Condensor	-52.5	70	-122.5	-120.3	12.6	-67.8	100	24	140.5	116.5	-3.78
Shure	SM81	Condensor	-45	78	-123	-120.8	12.1	-75.8	85	16	136	120	-0.78
AT	AE3300	Condensor	-42	75	-117	-114.8	18.1	-72.8	150	19	147	128	13.22
AT	AE5400	Condensor	-40	80	-120	-117.8	15.1	-77.8	150	14	147	133	15.22
AT	AT2010	Condensor	-48	71	-119	-116.8	16.1	-68.8	100	23	136	113	-3.78
AT	AT8033	Condensor	-44	70	-114	-111.8	21.1	-67.8	250	24	137	113	1.22
Audix	VX10	Condensor	-32.4	75	-107.4	-105.2	27.7	-72.8	250	19	138	119	13.82
Audix	SCX25A	Condensor	-31	80	-111	-108.8	24.1	-77.8	200	14	135	121	12.22
Audix	CX-112B	Condensor	-35	79	-114	-111.8	21.1	-76.8	120	15	138	123	11.22
Audix	CX-212B	Condensor	-40	75	-115	-112.8	20.1	-72.8	120	19	133	114	1.22
Sennheiser	MKH8050	Condensor - R	-34	81	-115	-112.8	20.1	-78.8	25	13	142	129	16.22
Sennheiser	MKH8040	Condensor - R	-34	81	-115	-112.8	20.1	-78.8	25	13	142	129	16.22
Sennheiser	MKH8020	Condensor - R	-30	84	-114	-111.8	21.1	-81.8	25	10	138	128	16.22
Sennheiser	MKH800	Condensor - R	-28	84	-112	-109.8	23.1	-81.8	150	10	136	126	16.22
Shure	SM57	Dynamic	-56	76	-132	-129.7	3.2	-73.7	310	18	150	132	2.22
Shure	SM58	Dynamic	-54.5	77.6	-132.1	-129.9	3	-75.4	300	16.4	150	133.6	3.72
AT	AE4100	Dynamic	-55	77.9	-132.9	-130.7	2.2	-75.7	250	16.1	150	133.9	3.22
AT	AE6100	Dynamic	-55	77.9	-132.9	-130.7	2.2	-75.7	250	16.1	150	133.9	3.22
Sennheiser	MD441	Dynamic	-55	78.9	-133.9	-131.6	1.3	-76.6	200	15.1	150	134.9	3.22
Sennheiser	MD421-II	Dynamic	-54	79.9	-133.9	-131.6	1.3	-77.6	200	14.1	150	135.9	4.22
Audix	OM2	Dynamic	-55.4	77.5	-132.9	-130.7	2.2	-75.3	250	16.5	150	133.5	2.82
Audix	OM3	Dynamic	-55.4	77.5	-132.9	-130.7	2.2	-75.3	250	16.5	150	133.5	2.82
Audix	OM7	Dynamic	-62	73.1	-135.1	-132.9	0	-70.9	150	20.9	150	129.1	-3.78
Shure	KSM313	Ribbon	-54.5	78.1	-132.6	-130.3	2.6	-75.8	270	15.9	146	130.1	-0.28
Shure	KSM353	Ribbon	-53.5	79.1	-132.6	-130.3	2.6	-76.8	270	14.9	146	131.1	0.72
AT	AT4080	Ribbon	-39	72	-111	-108.8	24.1	-69.8	100	22	150	128	19.22
AT	AT3081	Ribbon	-42	69	-111	-108.8	24.1	-66.8	100	25	150	125	16.22
Coles	4038	Ribbon	-65	67.1	-132.1	-129.9	3	-64.9	300	26.9	125	98.1	-31.78
Coles	4104	Ribbon	-50	82.1	-132.1	-129.9	3	-79.9	300	11.9	120	108.1	-21.78
AEA	TU4	Ribbon	-51	81.1	-132.1	-129.9	3	-78.9	300	12.9	140	127.1	-2.78
AEA	A440	Ribbon	-33.5	88	-121.5	-119.3	13.6	-85.8	92	6	132.5	126.5	7.22
AEA	R44	Ribbon	-53	79.6	-132.6	-130.3	2.6	-77.3	270	14.4	140	125.6	-4.78

Three Basic Mic Performance Parameters Important to Preamp Design:

- Sensitivity
- Output Noise
- Max Out

Comparison of
- 24 Condensers
- 9 Dynamics
- 9 Ribbons (3 with active preamps)

“Typical” Microphone

Sensitivity (1Pa = 94 dB SPL)

- Condenser: -39 dBV/Pa
- Dynamic: -56 dBV/Pa
- Ribbon: -49 dBV/Pa (no active preamps)

Output Noise

- Condenser: -116 dBu A
- Dynamic: -131 dBu A
- Ribbon: -124 dBu A

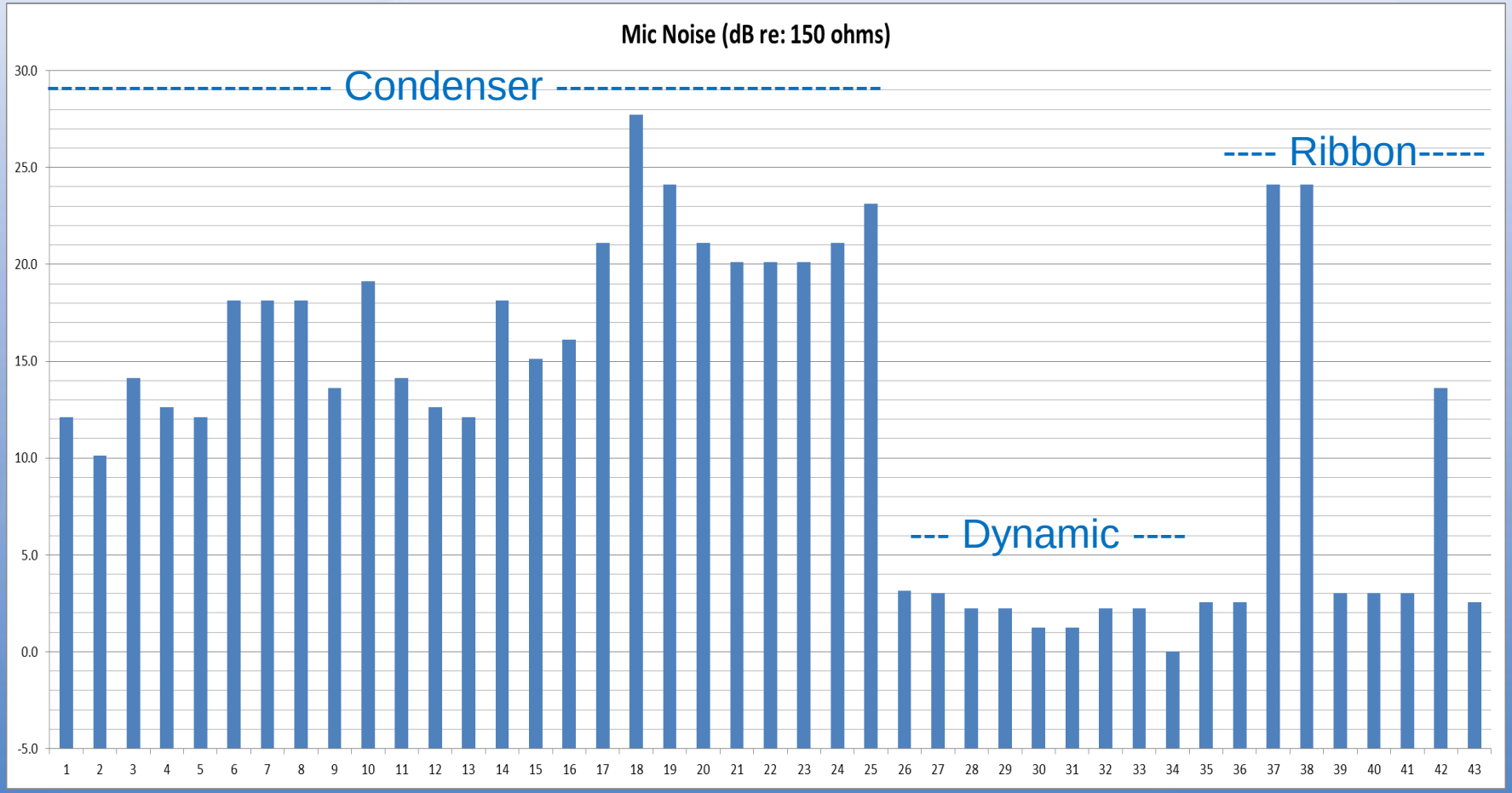
Maximum Output Level

- Condenser: 9.4 dBu
- Dynamic: 3.2 dBu (150dB SPL if no max specified)
- Ribbon: -10 dBu

150 ohms Often Used as Source Impedance for Preamp Specs

How do real mics stack up against the thermal noise of 150 ohm resistor?

- Condensers about 14 to 20 dB worse
  - Dynamics about 3dB worse
    - Ribbons about 3dB worse (with active preamps; 13 to 24 dB worse)

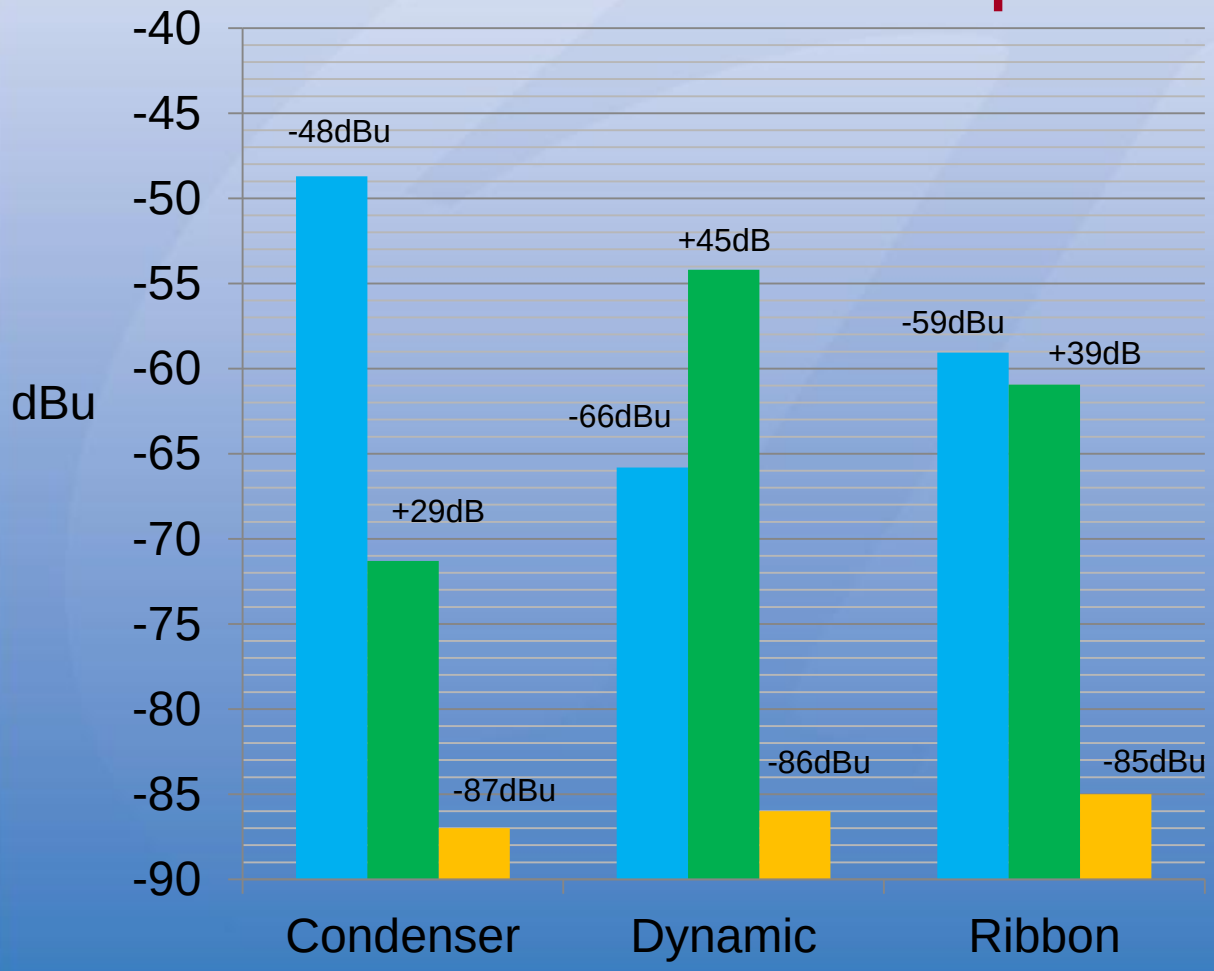


Microphone self noise compared to 150 ohm resistor thermal noise

How does Mic Sensitivity, Mic Self Noise, and Gain effect the final system noise floor?

A quick example

Microphone Sensitivity and Noise Example



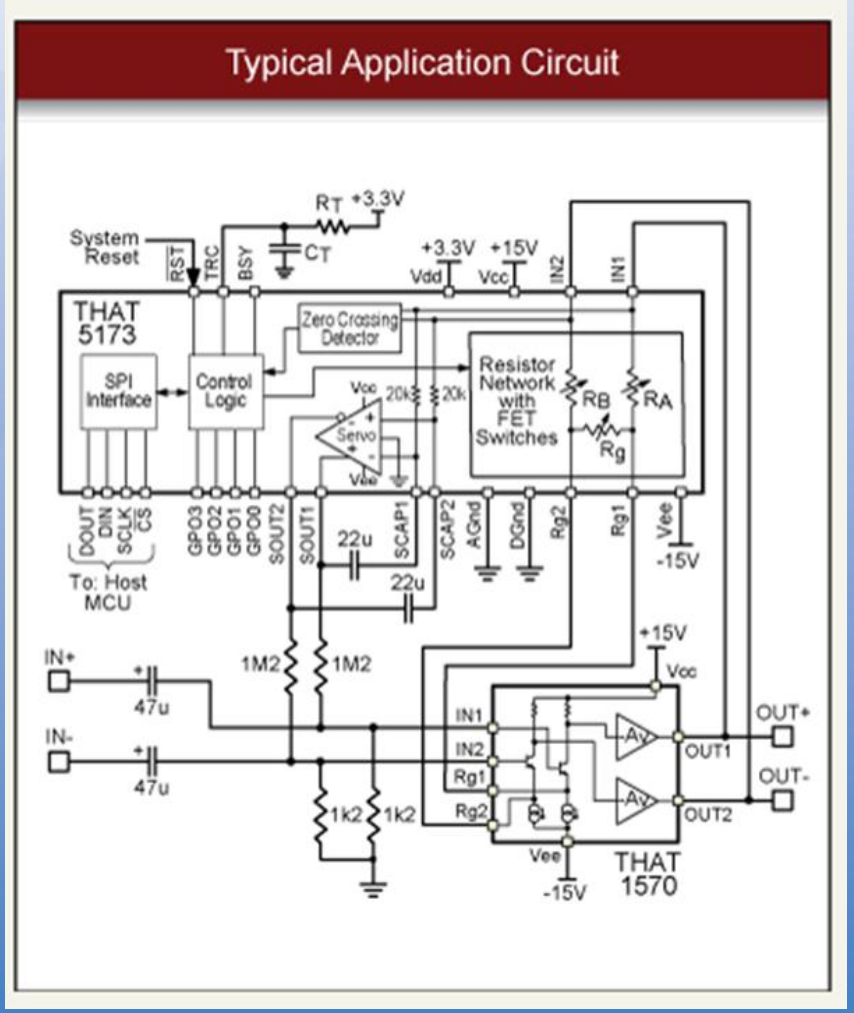
- Mic Output (dBu) at 84 dB SPL [acoustic guitar at 16"]
- Gain required for -20dBu operating level
- Noise Floor after Gain

Preamp/Controller pairs used in today's discussion:

- THAT 1570 Preamp
- THAT 5171 Controller (1dB Steps)

- THAT 1570 Preamp
- THAT 5173 Controller (3 dB Steps)

- THAT 1583 Preamp
- THAT 5173 Controller (3 dB Steps)



Noise and Gain Structure from XLR to A/D Converter

- Aspects of the problem
  - A/D converter dynamic range
  - Widely varying microphone signal and noise levels
  - Accommodating line-level inputs

Typical Pro-Audio A/D Converters

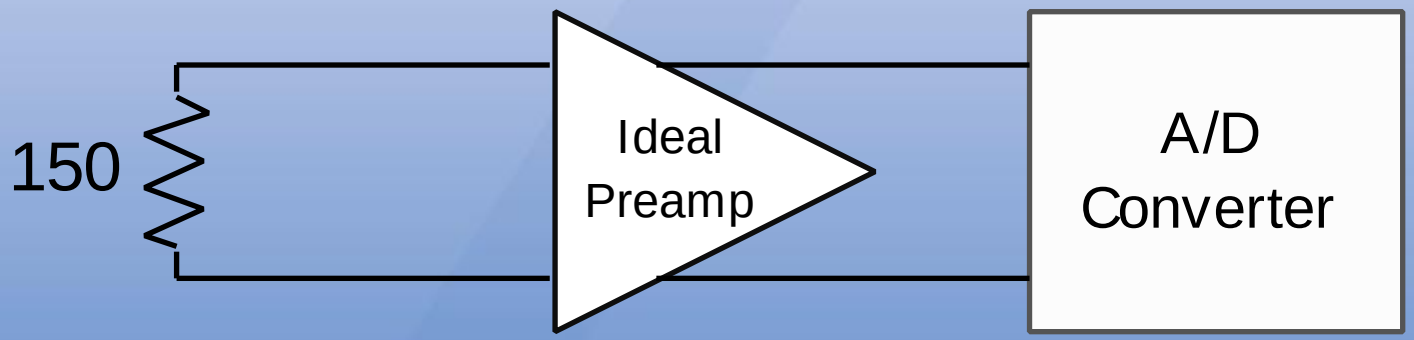
- Differential Input ~ 2 Vrms (+8.2 dBu) FS
- 114 dB Converter -105.8 dBu A-Wtd. Noise
- 120 dB Converter -111.8 dBu A-Wtd. Noise

- All based on typical datasheet specifications (Worst case can be 6 dB noisier)

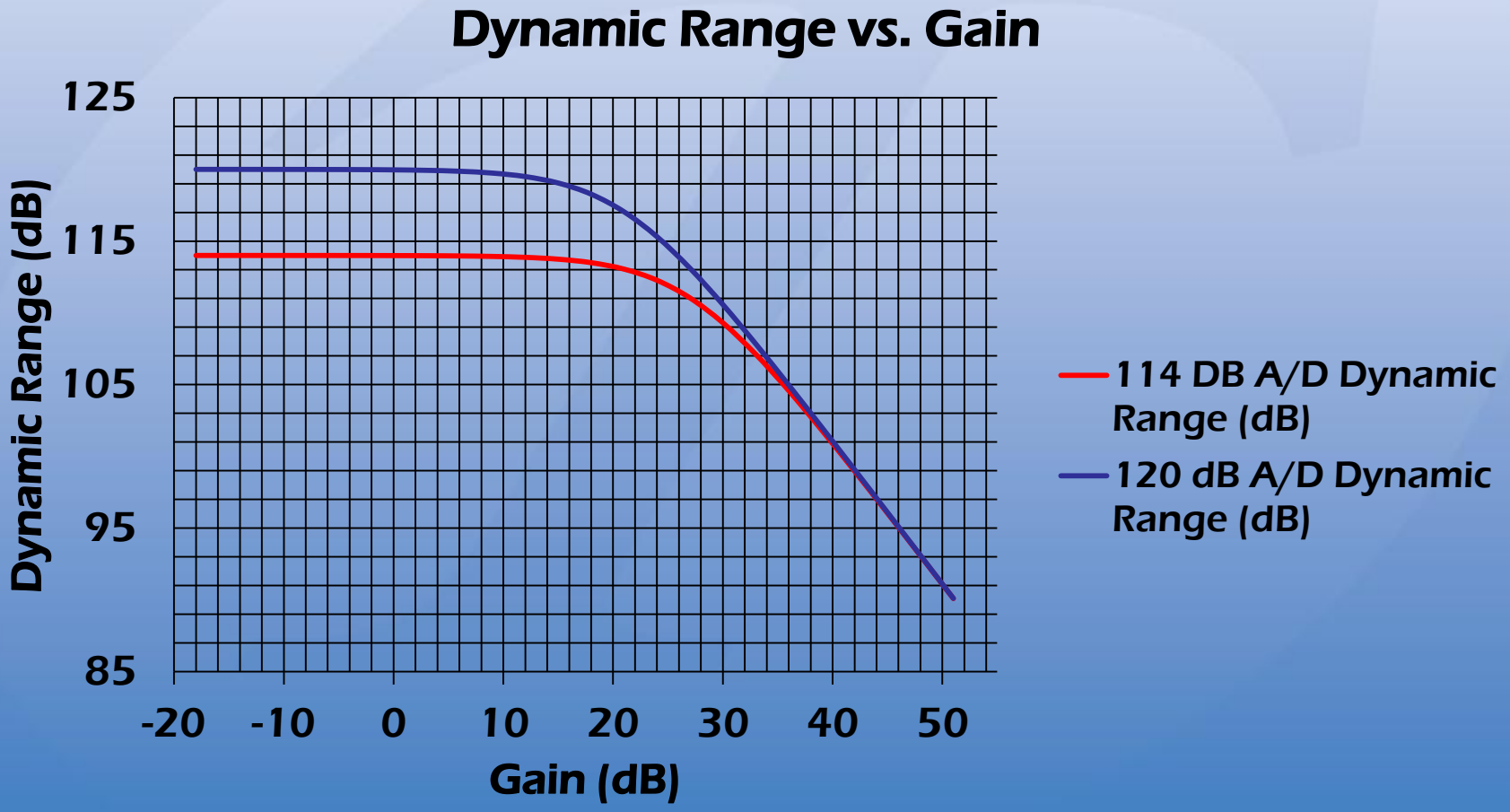
How Quiet is the Source?

- 150-ohm ***thermal noise*** (about as quiet as microphones get – probably quieter)
- 1.58 nV/rtHz = -130.8 dBu (0.223 uVrms) in 20Hz - 20 kHz BW
- -132.9 dBu (.176 uVrms) A Weighted

Ideal Noiseless Preamp with 150-ohm Source



150-ohm Source + Ideal Preamp + A/D Converter Dynamic Range



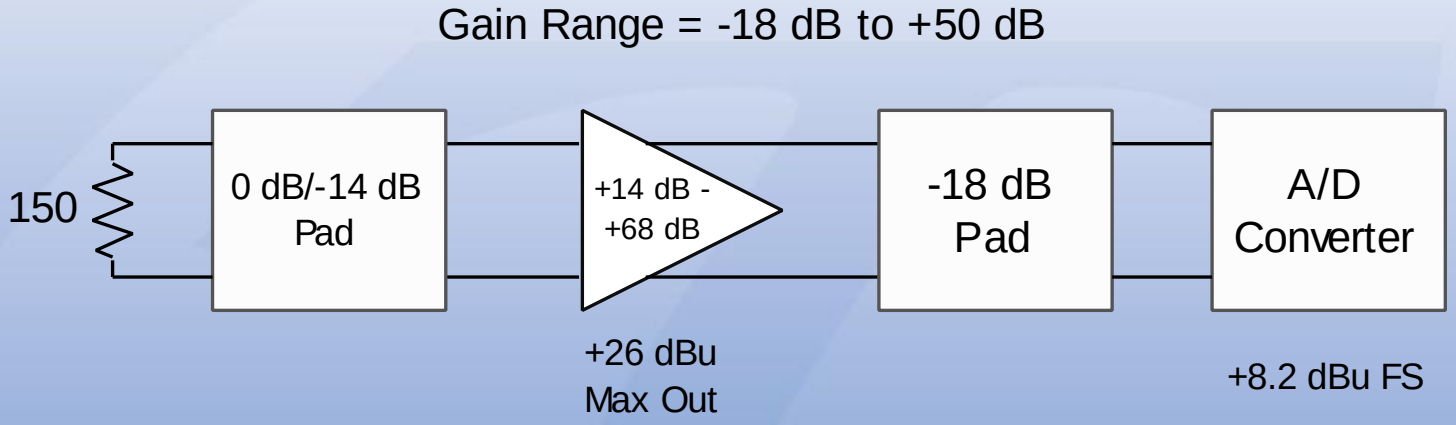
Maximum Signal Levels and Gain

- +10 dBu is not uncommon from condenser microphones
- Some microphones can exceed +20 dBu at maximum dB SPL
- Pro audio line levels can exceed +24 dBu
- Clearly some form of attenuation before the A/D converter is necessary

Gain Structure

- Gain early and attenuation late – a tenet of low-noise design
- Keep high input signals high through as much of the circuitry as possible
- Amplify low input signals as early (and as much) as possible

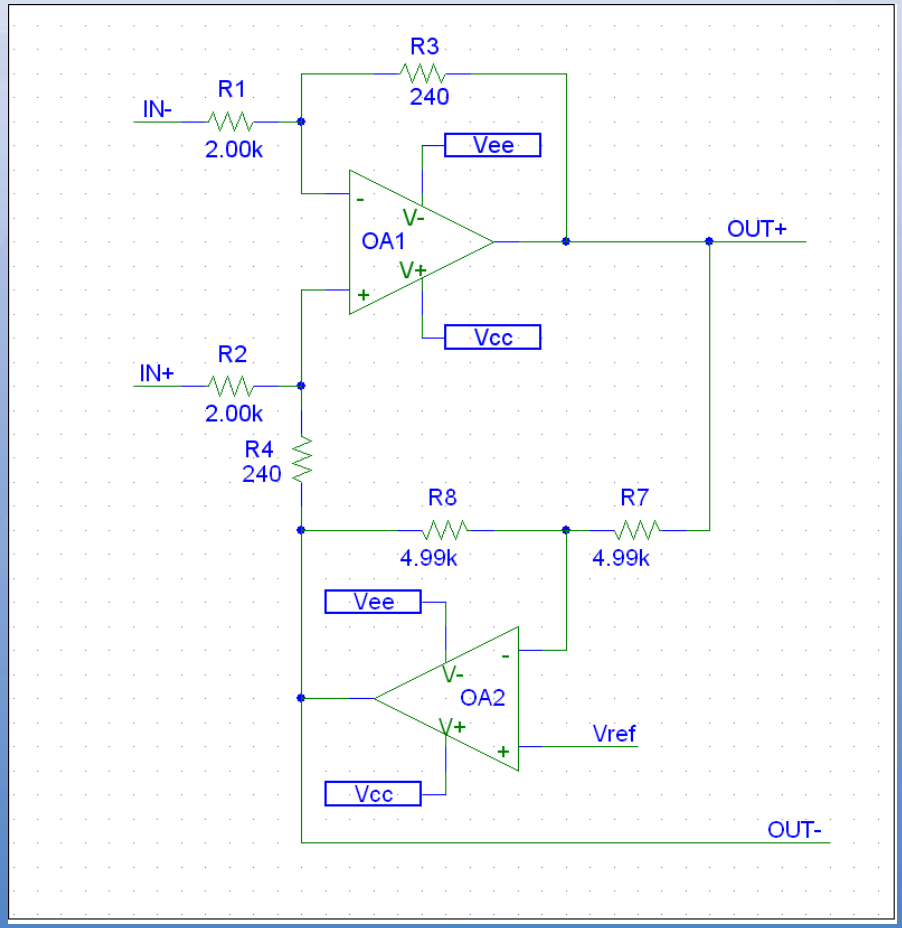
A Gain Structure Example



- Input pad maps maximum input signal to preamp maximum input at minimum gain
- Post-preamp attenuator maps preamp maximum output to A/D converter full scale input
- Passive attenuator before converter can compromise A/D distortion performance at high levels
- Active attenuator A/D driver can be designed for minimal noise degradation and good THD performance

Basic Active Attenuator A/D Driver

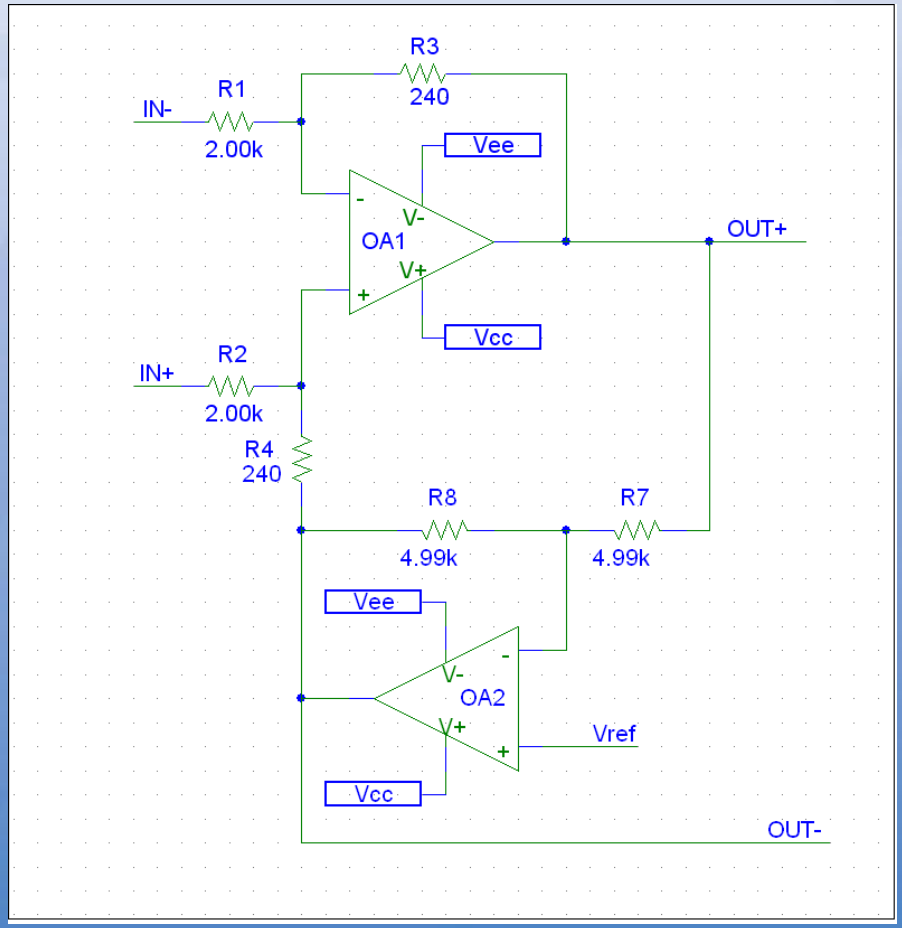
- Gain = R3/R1
- Outputs are biased at Vref
- Low-Z drive to A/D converter
- OA2 doesn't contribute to noise



Basic Active Attenuator A/D Driver

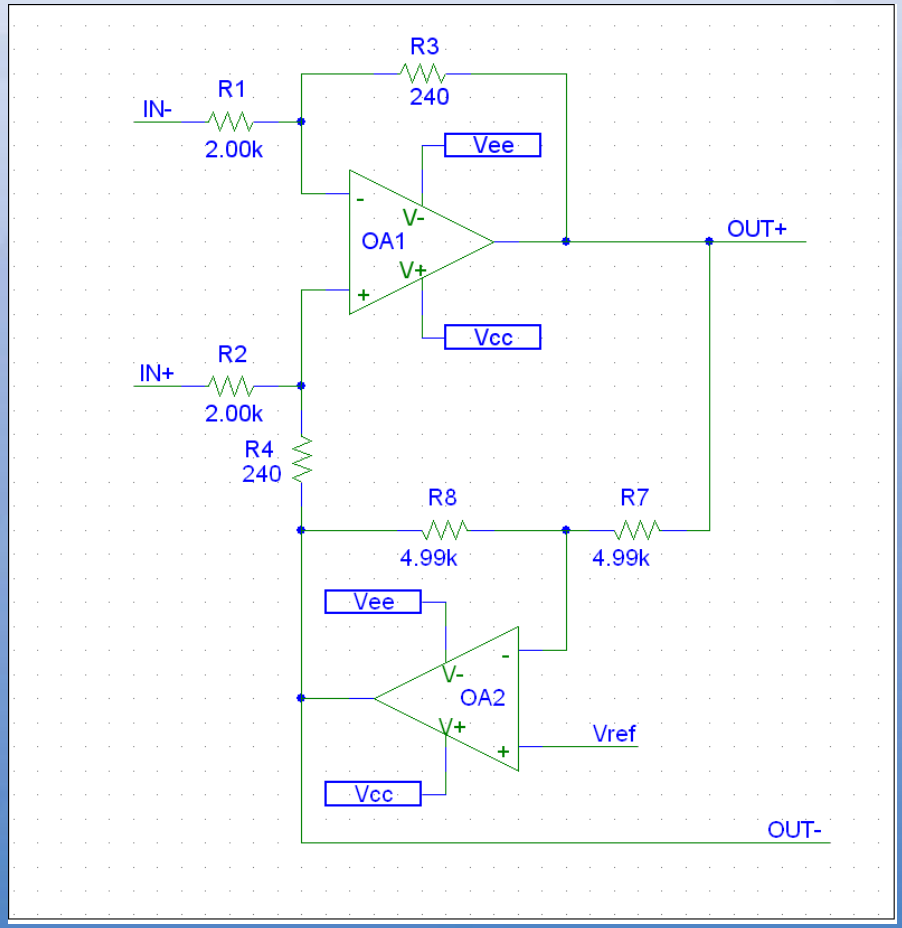
- Noise

- $e_{nout} = NG * \sqrt{(e_{nOA1})^2 + 2(e_{nR1||R3})^2}$
- $Where:$
- $NG = 1 + \frac{R3}{R1}$
- $e_{nOA1} =$ $OA1\ Input\ Noise\ Voltage$
- $e_{nR1||R3} =$ $Thermal\ Noise\ of\ R1||R3$



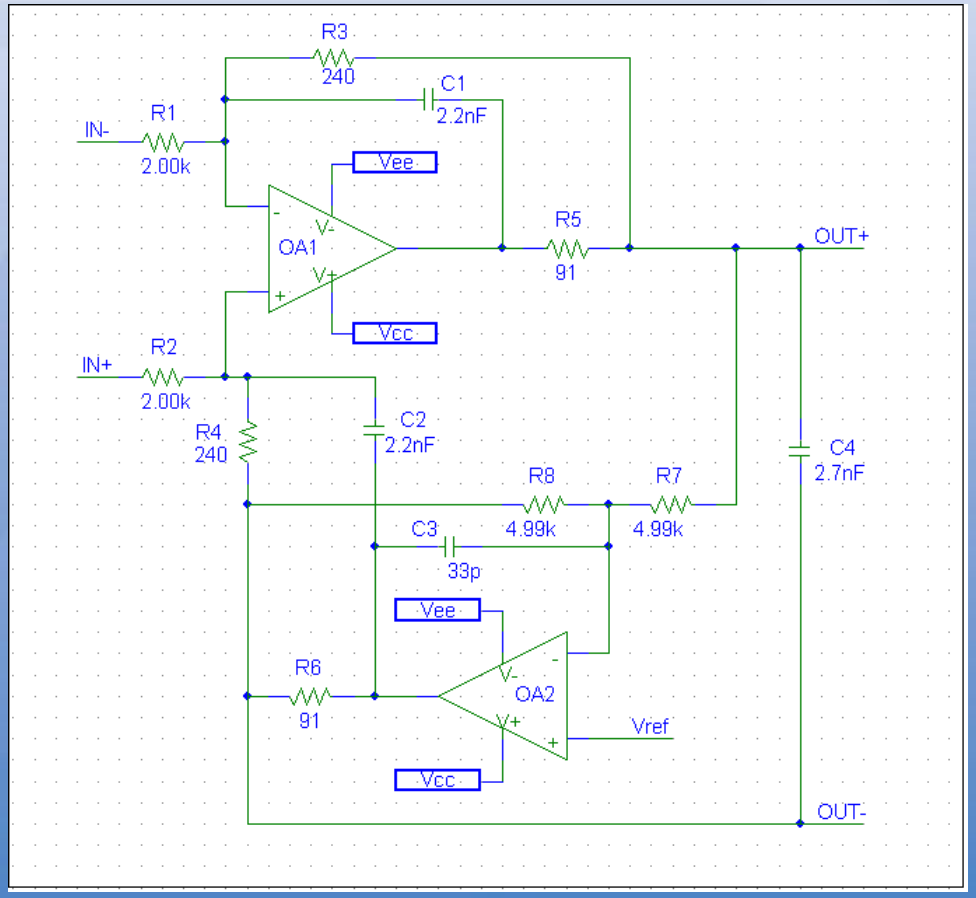
Basic Active Attenuator A/D Driver

- Common-mode range is large
- Can run on +5V
- CMRR controlled by R3/R1 match to R4/R2
- A/D has great CMRR but small CM input range



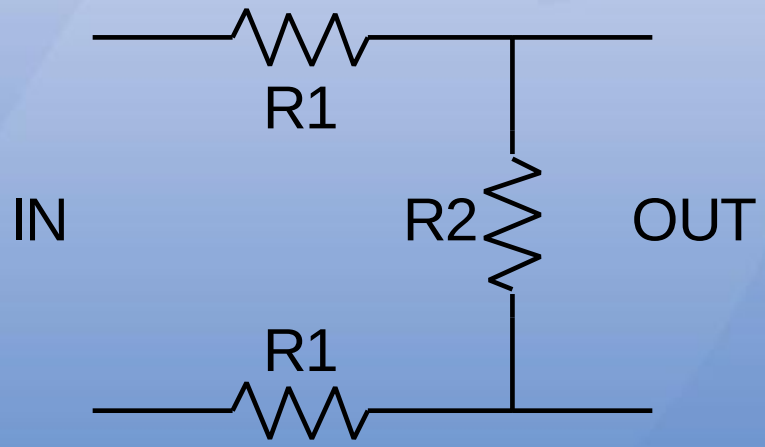
Complete Active Attenuator A/D Driver

- Local HF feedback allows capacitive load
- R5, R6, C4 isolate opamps from A/D input current spikes
- C2 connection preserves HF CMRR



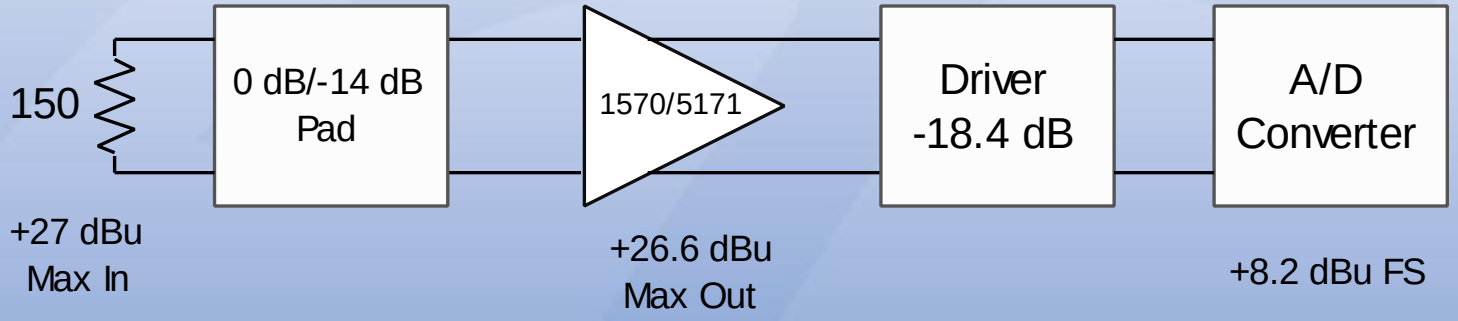
Input Pad

- Start from desired input impedance (Zin) and attenuation (Vout/Vin)
- R2 = Zin*Atten(V/V)
- R1 = (Zin – R2)/2
- Higher Zin means higher noise with pad engaged



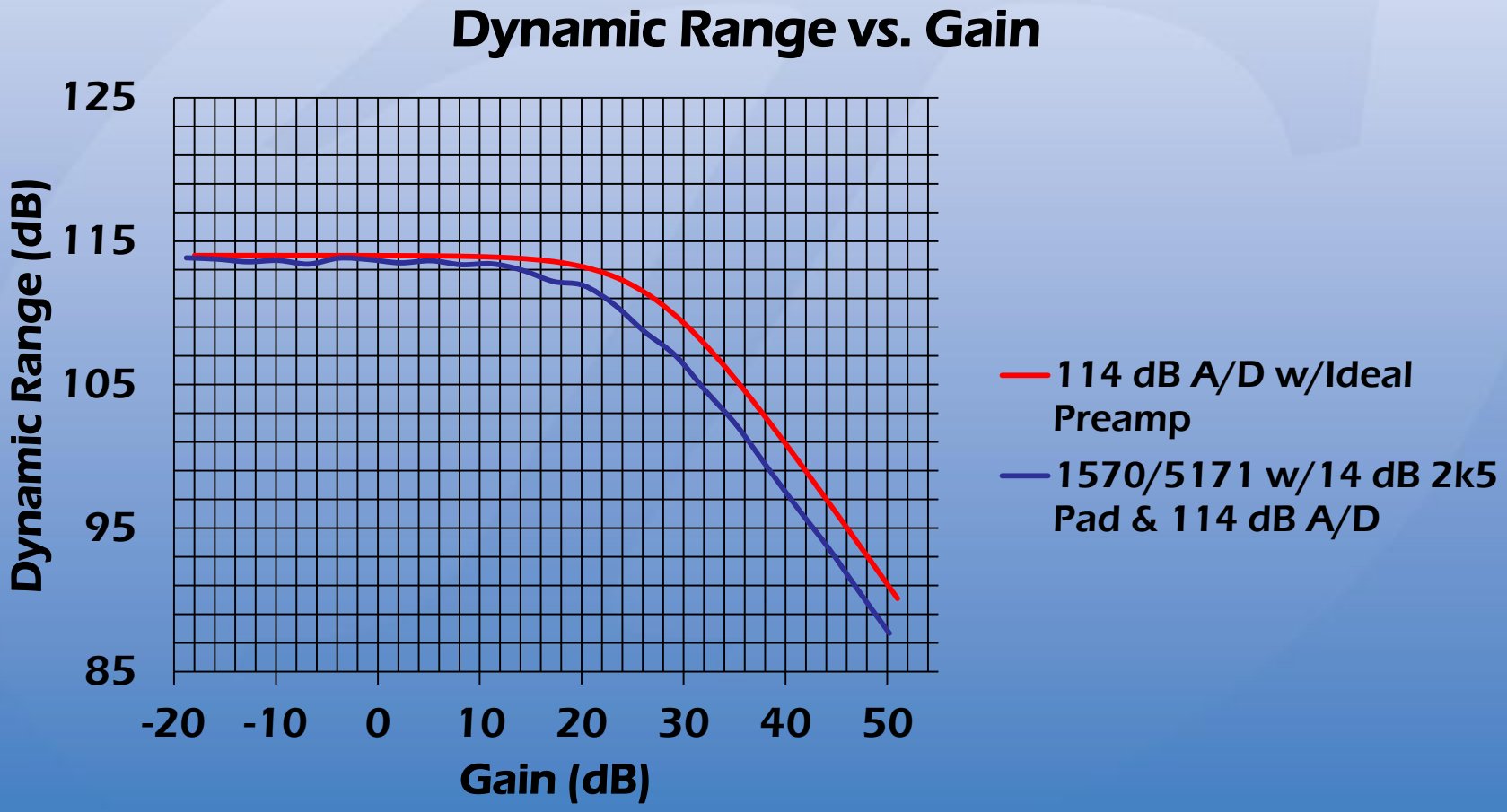
THAT 1570/5171 Example

System Gain Range = -18.8 dB to +50.2 dB

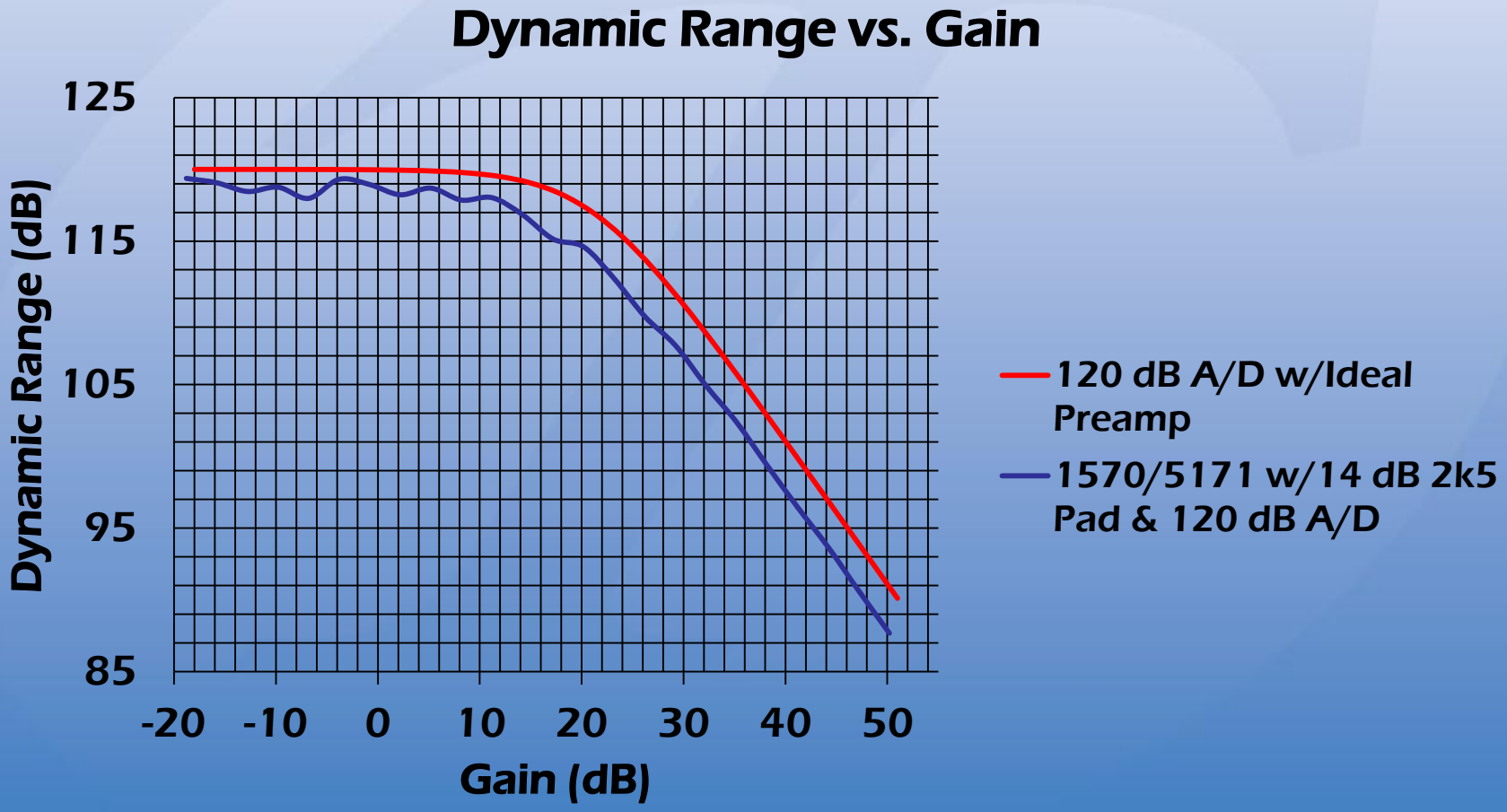


- Switchable 14 dB pad with 2.5 kohm Zin is chosen to allow +27 dBu maximum input level at minimum gain
- THAT 1570/5171 combination provides a 13.6 dB to 68.6 dB preamp gain range in 1-dB steps
- Post-preamp attenuator uses resistor values shown previously along with a 3.5 nV/rtHz opamp

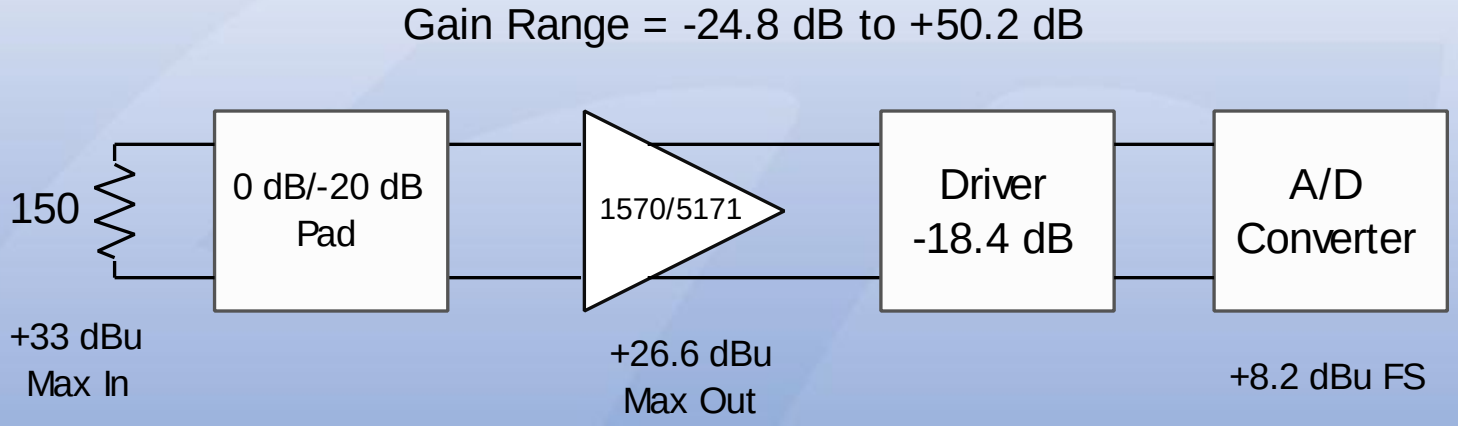
1570/5171 With 114-dB A/D Converter



1570/5171 With 120-dB A/D Converter

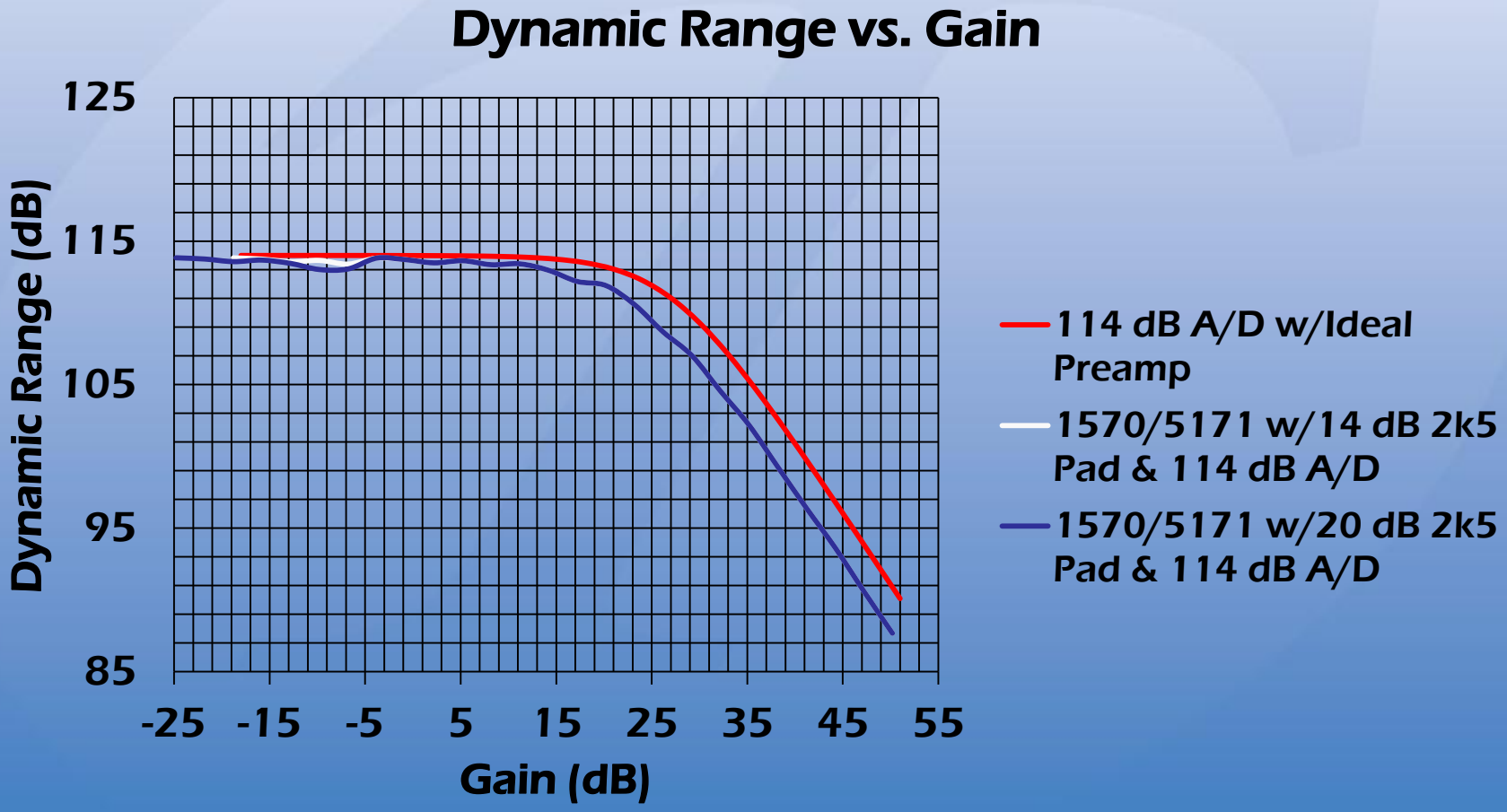


What About a -20 dB Pad?

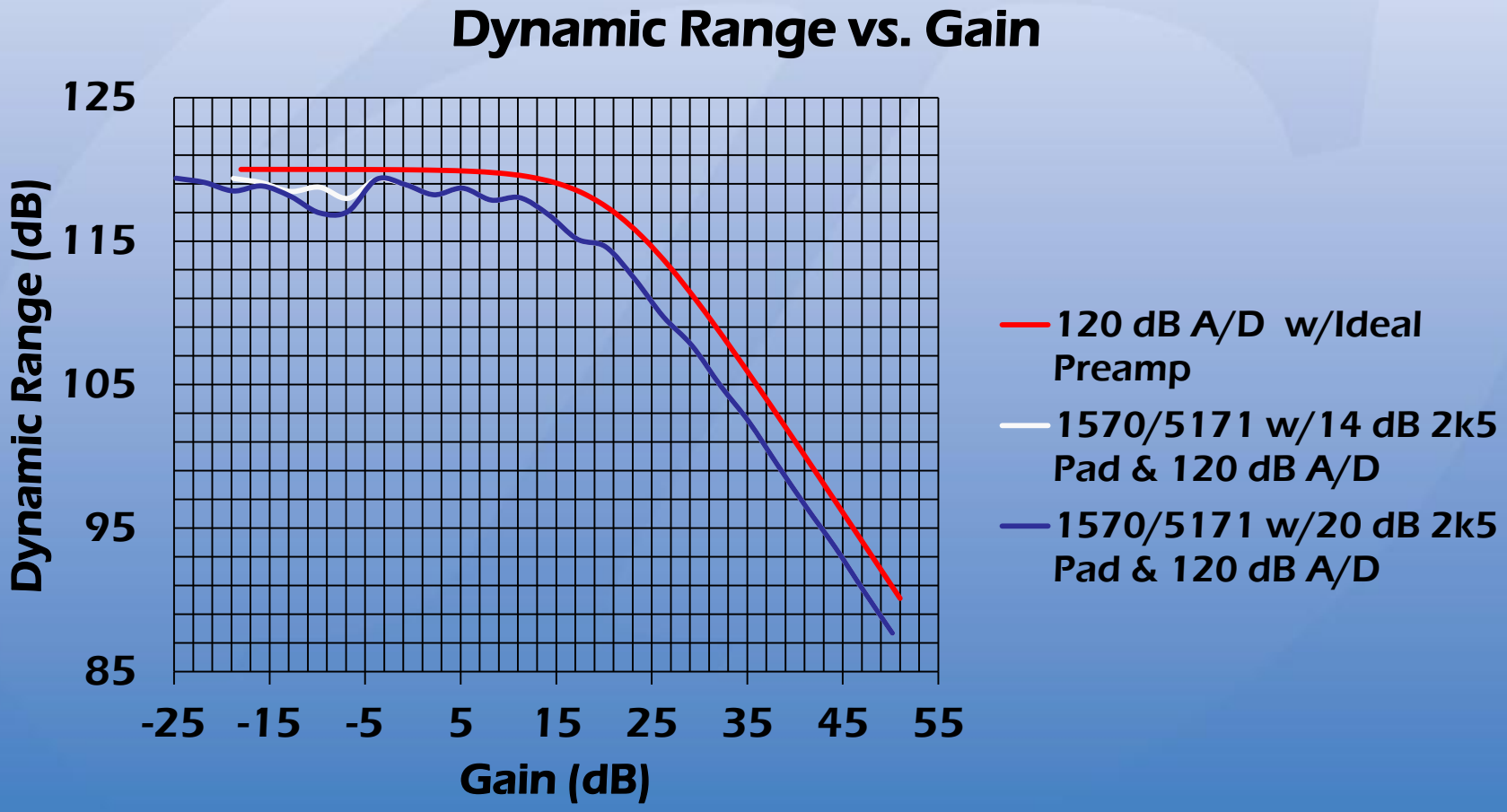


- A more “traditional” -20 dB pad provides 6 dB more gain range and 6 dB higher maximum input (+33 dBu)
- Input impedance is still 2.5 kohm
- While pad is on, preamp gain ranges from13.6 dB to 32.6 dB

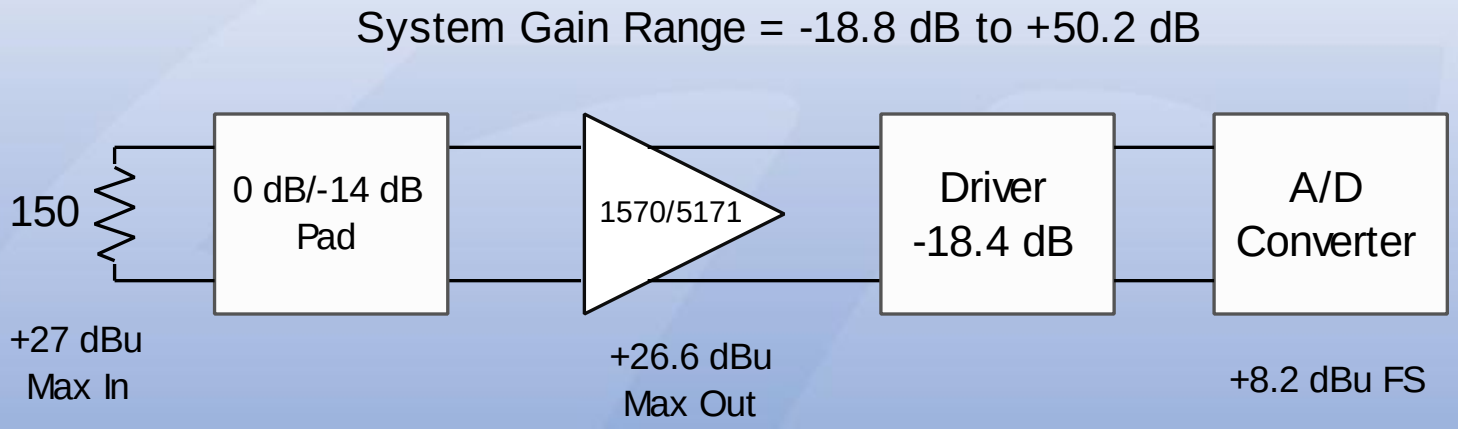
1570/5171 With 114-dB A/D Converter



1570/5171 With 120-dB A/D Converter

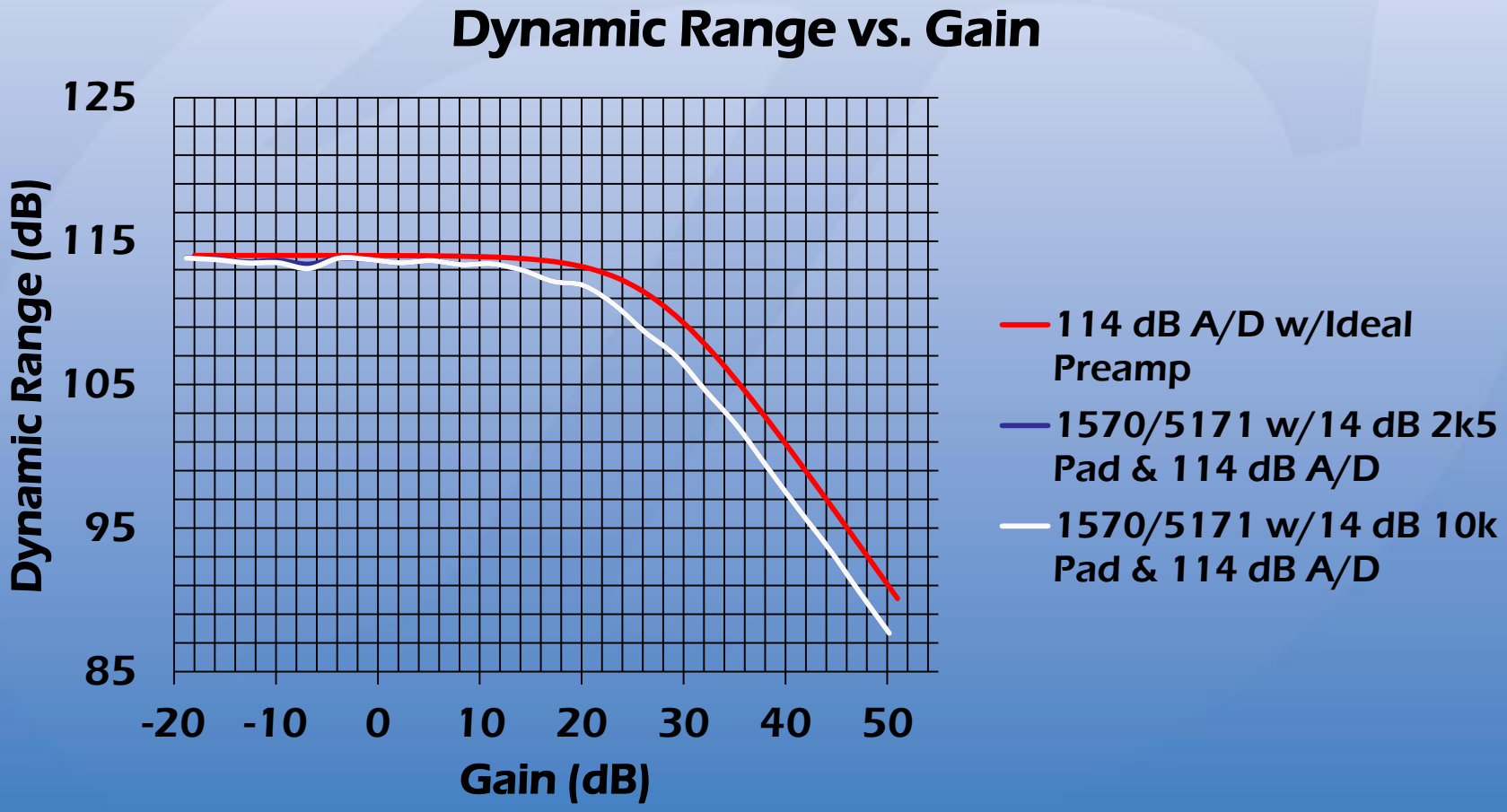


What If We Use a 10k Zin Pad?

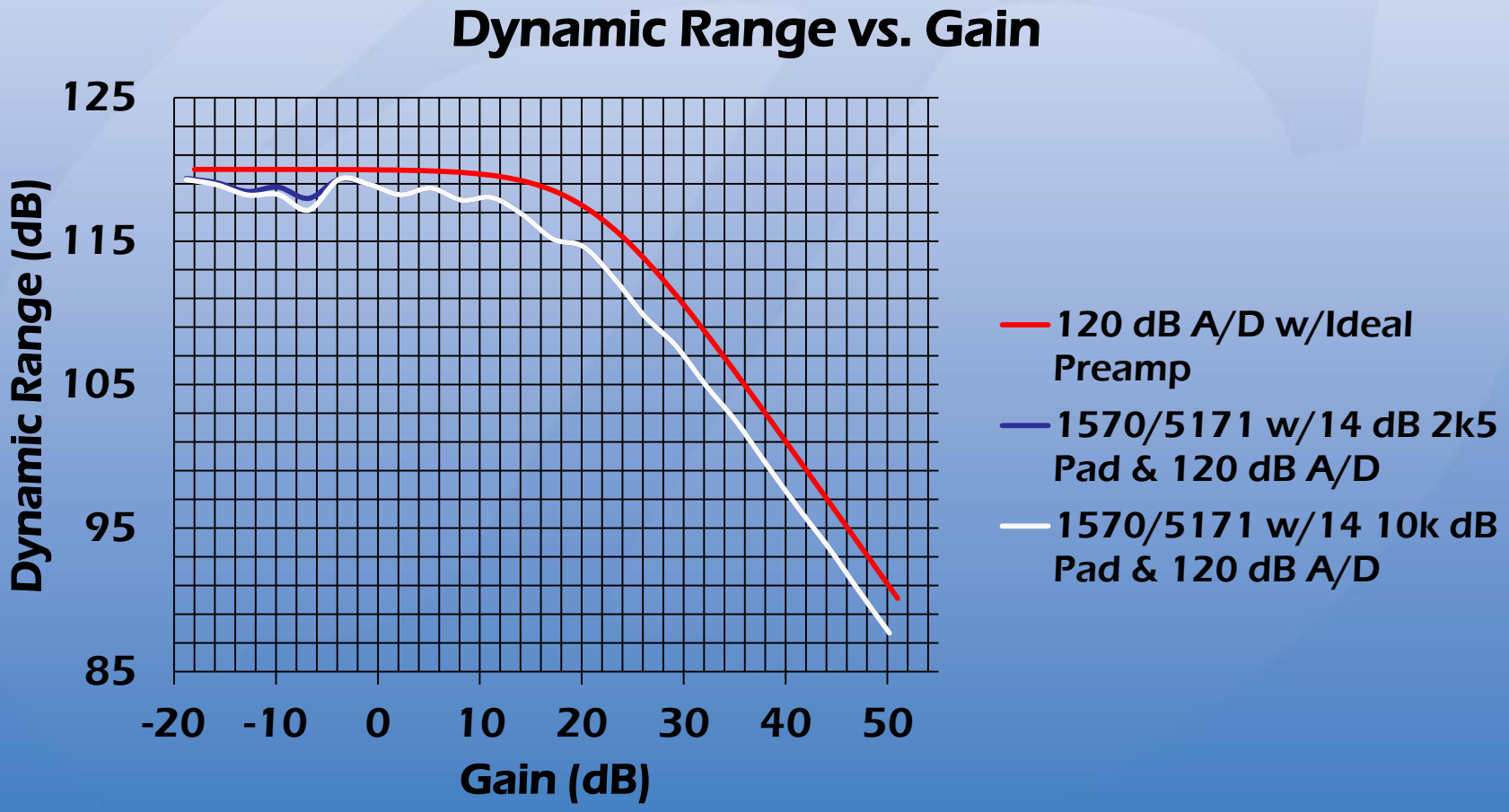


- Back to the -14 dB pad
- Zin = 10k
- Pad now presents about a 1.6 kohm source impedance to the preamp

1570/5171 With 114-dB A/D Converter

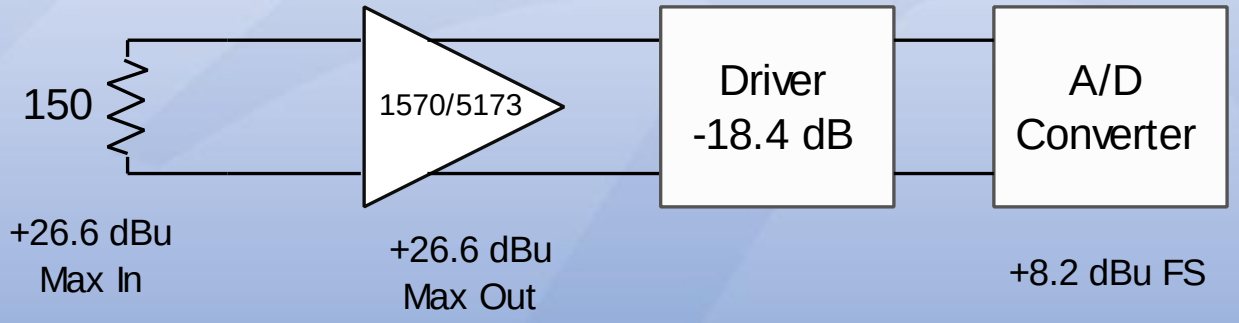


1570/5171 With 120-dB A/D Converter



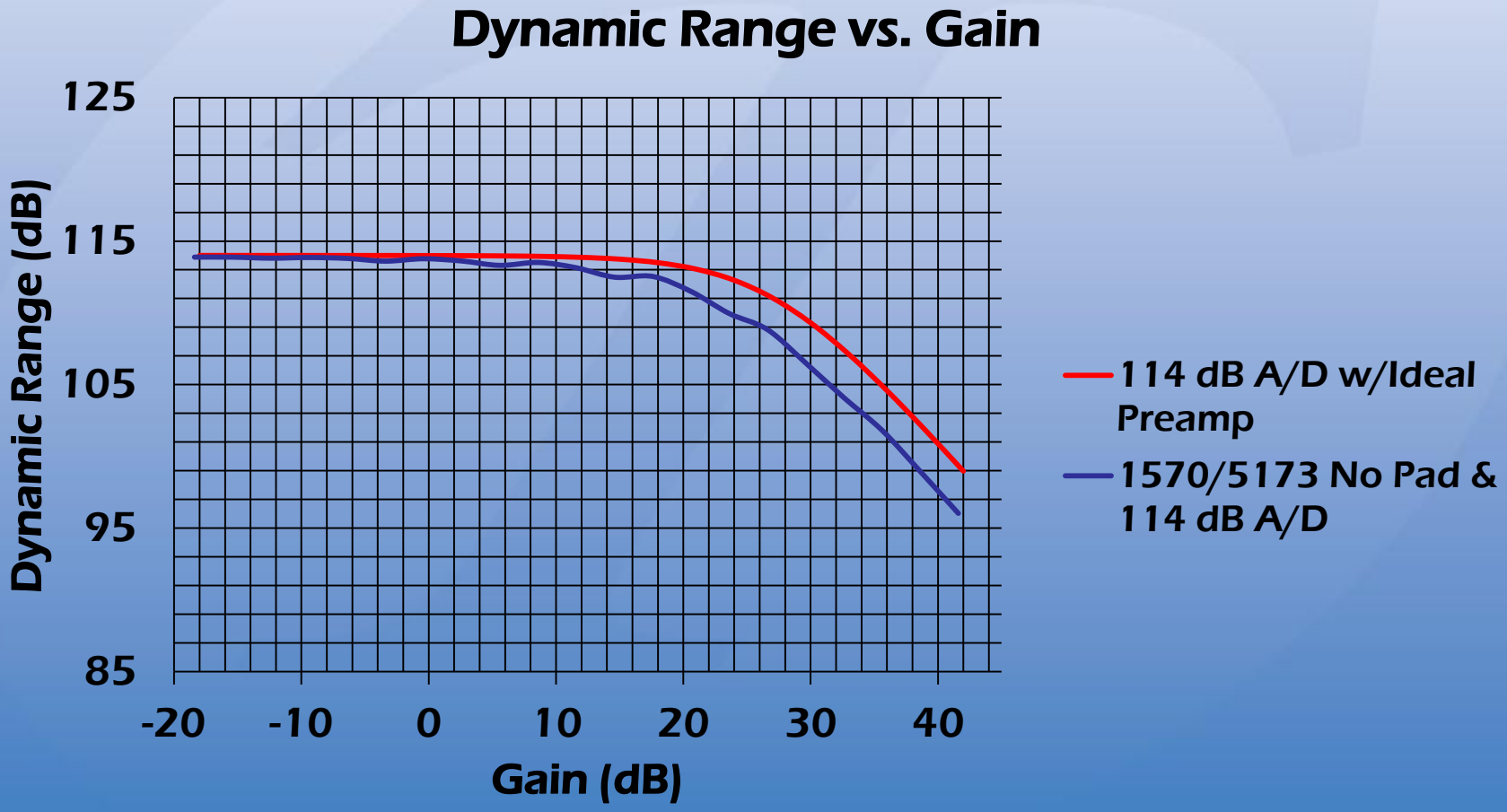
THAT 1570/5173 No-Pad Example

System Gain Range = -18.4 dB to +41.6 dB

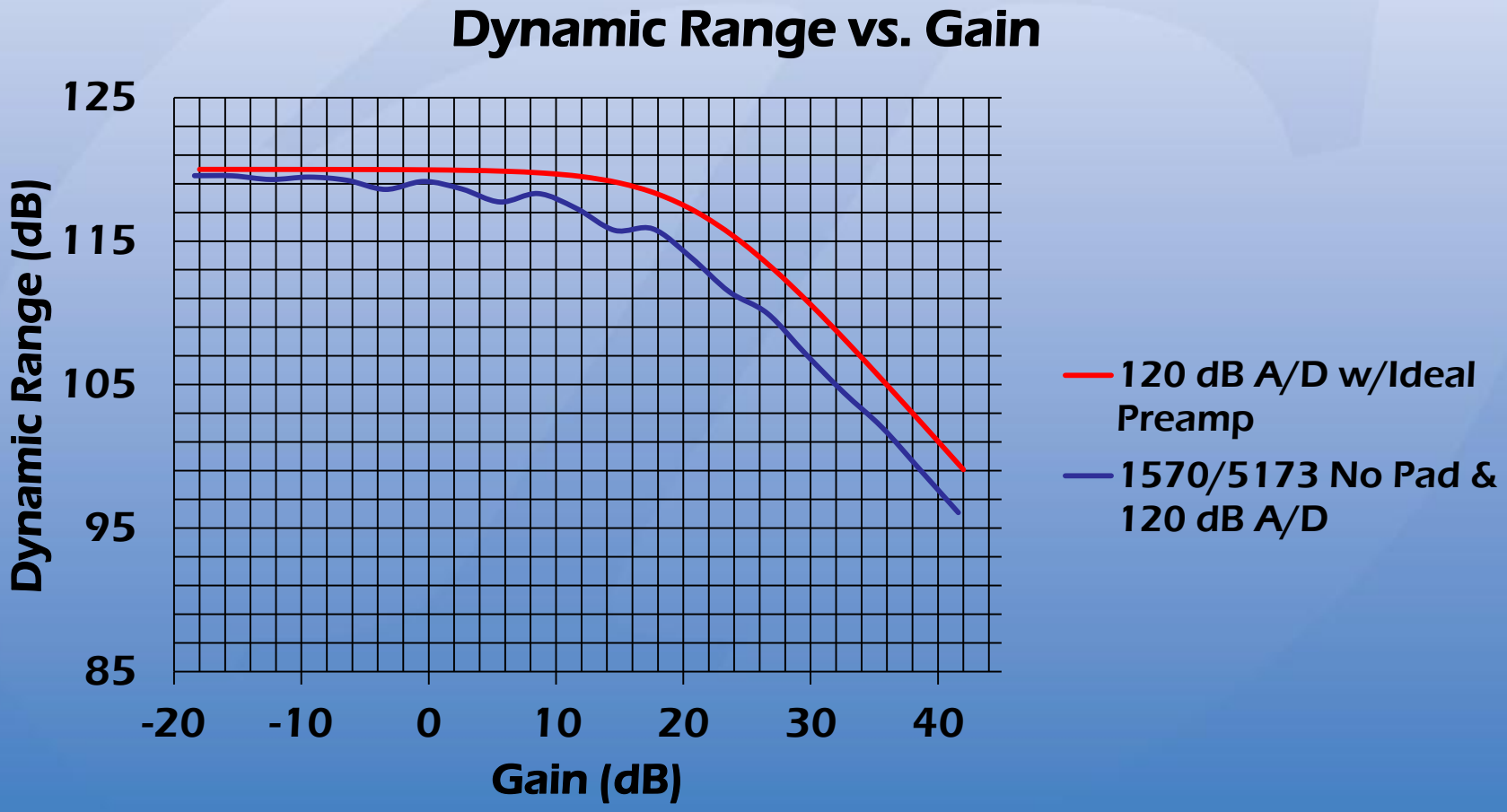


- THAT 1570/5173 combination provides a 0 dB to 60 dB preamp gain range in 3-dB steps
- Max input level is +26.6 dBu
- Overall system gain ranges from -18.4 dB to +41.6 dB

1570/5173 With 114-dB A/D Converter

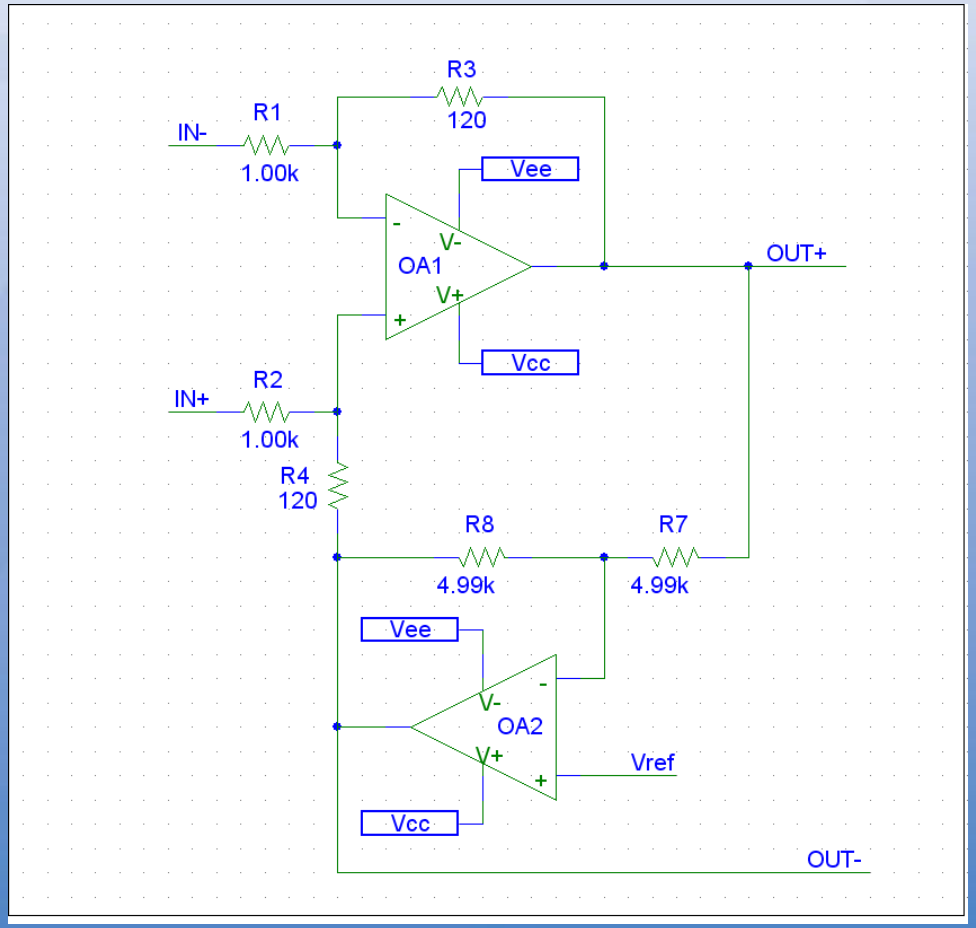


1570/5173 With 120-dB A/D Converter

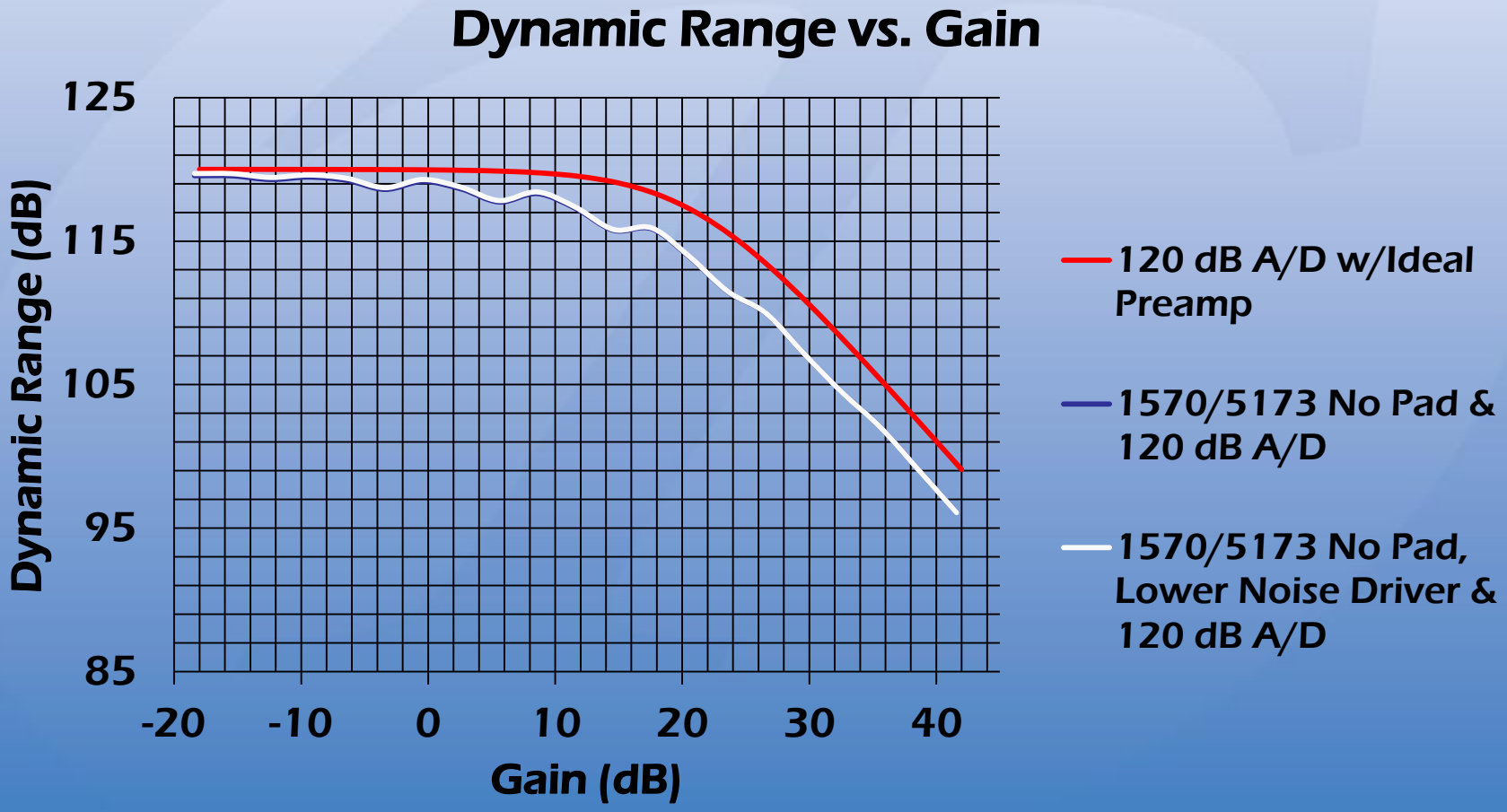


Quieter Active Attenuator A/D Driver

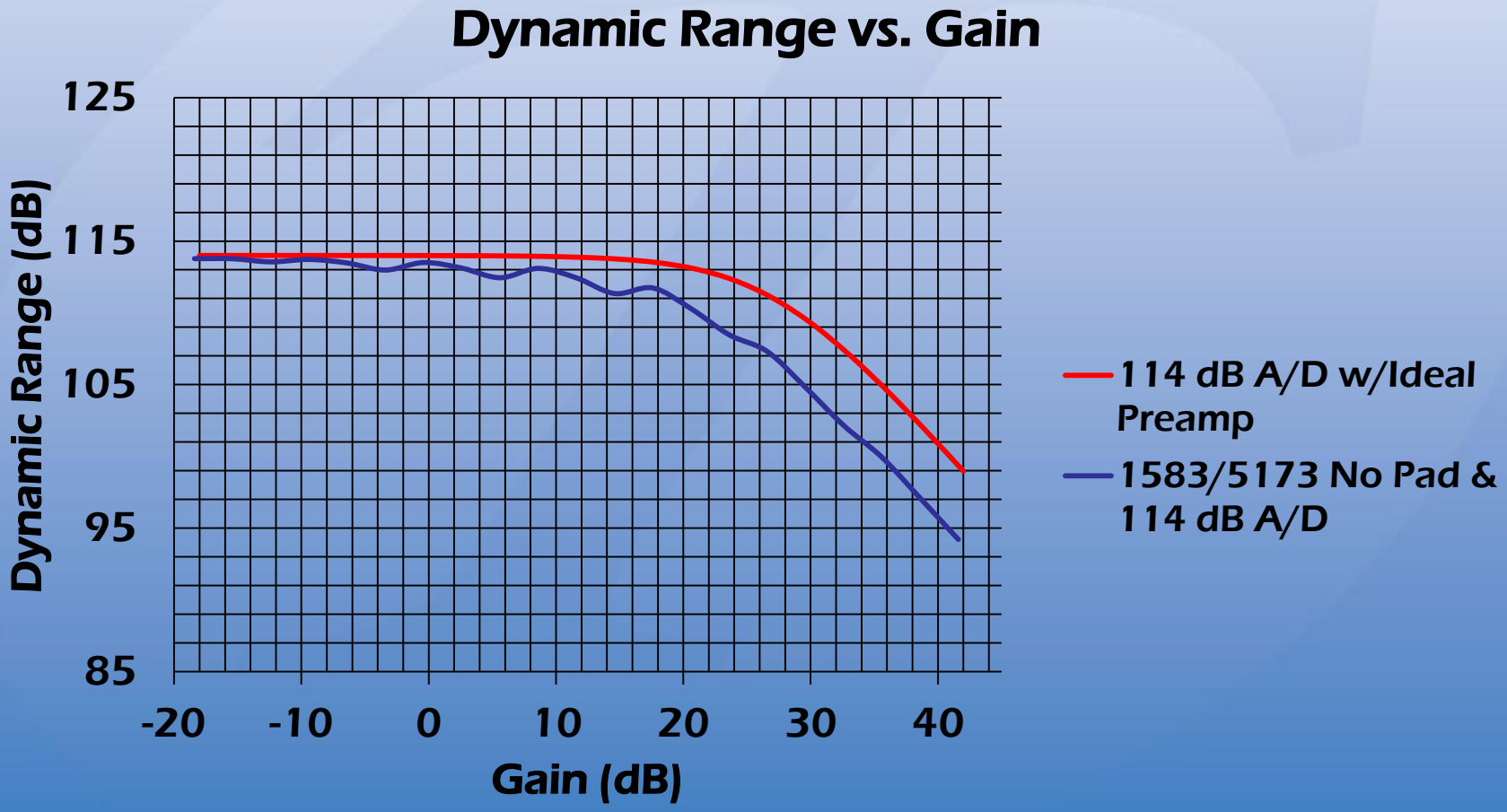
- R1, R2, R3, R4 scaled down by a factor of 2
- Opamp EIN reduced from 3.5 nV/rtHz to 2.5 nV/rtHz
- All else unchanged



1570/5173 With 120-dB A/D Converter and Lower Noise Driver



1583/5173 With 114-dB A/D Converter



Conclusions

- Take gain early and attenuation late as much as possible
- Use all of the available headroom and high voltage supplies up front if possible
- If an input pad is necessary, use the minimum attenuation possible to meet the maximum input requirement
- Don’t neglect the A/D’s noise contribution (or the D/A’s, which was not included today)

Advantages of Using Digitally-Controlled Microphone Preamplifiers

Controlling the Preamp Gain from the Master Processor

- Automation/Recall
- Remote hardware location
- The ability to interactively link the complete system gain map under one “master” control
  - Input Gain,
  - the internal processor levels
  - and the final “mix” level

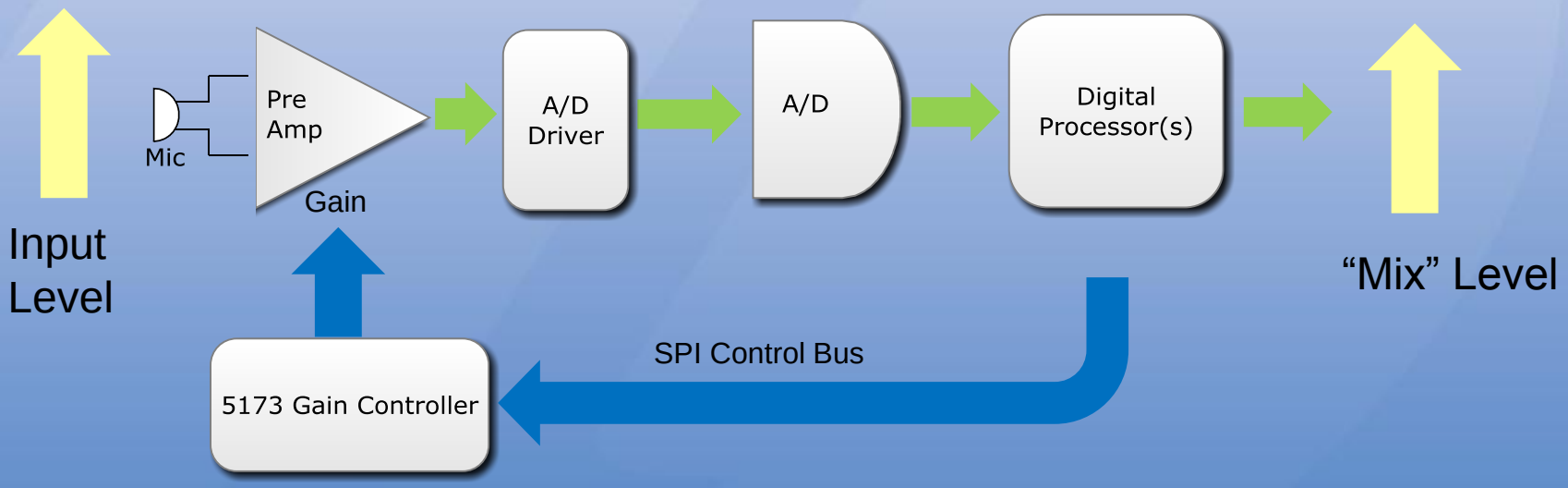
→ Maximize system SNR by working more with full scale “headroom” rather than absolute level (top down instead of bottom up)

Some of the variables that determine the optimum required preamp gain:

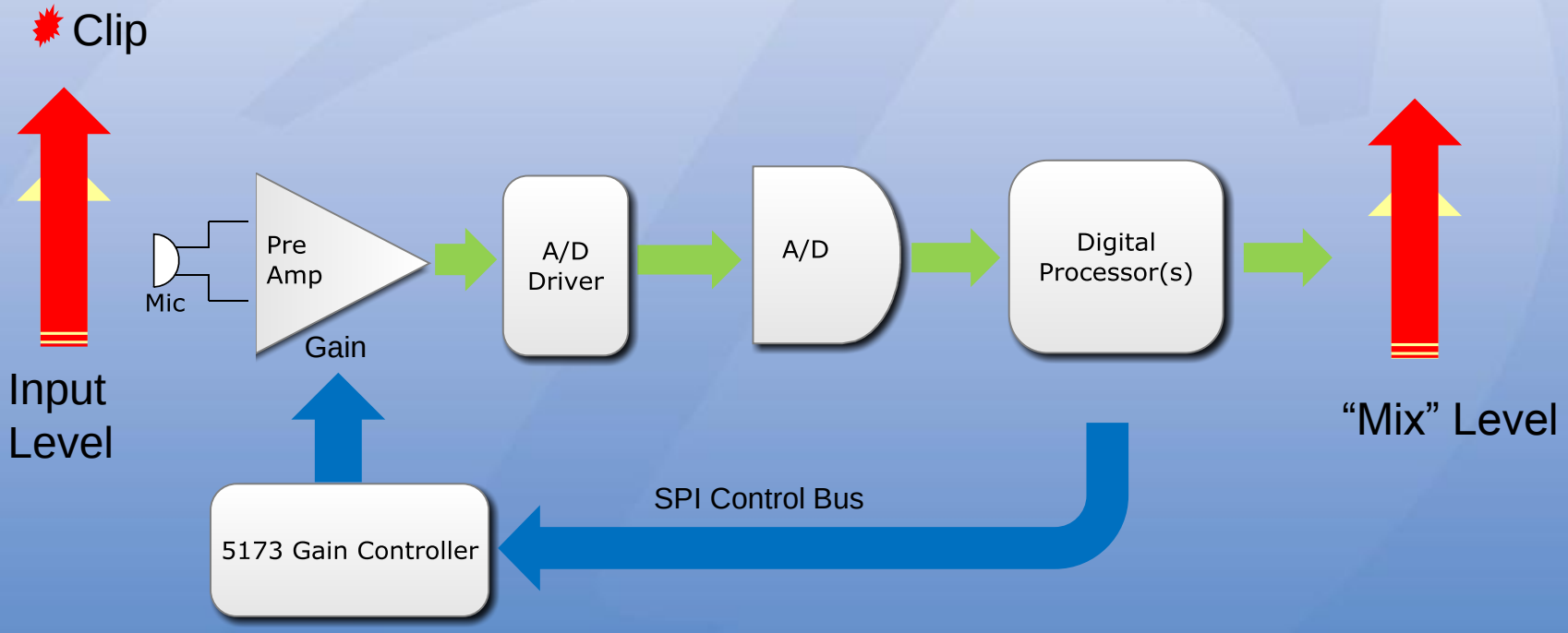
- Source SPL
- Microphone sensitivity
- Microphone placement
- Source Dynamics

By matching the preamp and A/D dynamic range, the final SNR depends on headroom requirements

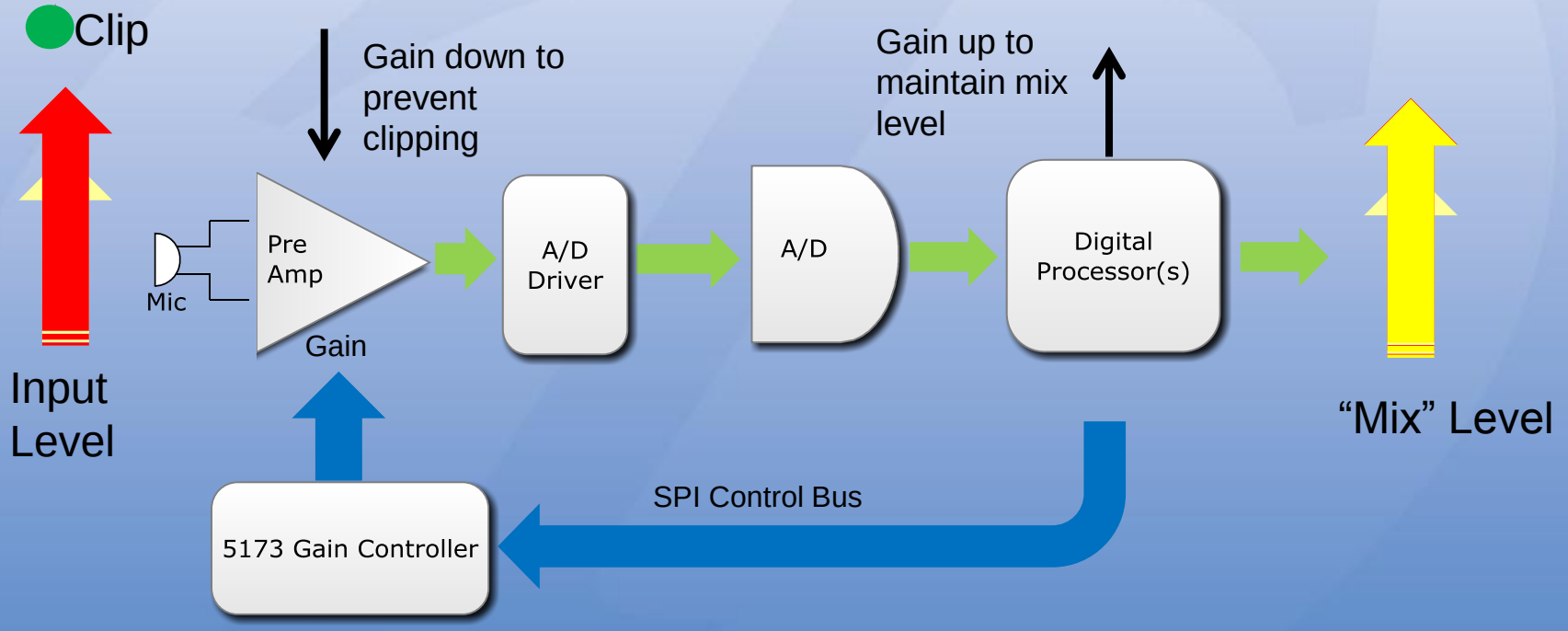
Digitally-Controlled Microphone Preamplifier System Block Diagram



Digitally-Controlled Microphone Preamplifier System Block Diagram



Digitally-Controlled Microphone Preamplifier System Block Diagram



Coupled level controls

- Allows operating level adjustments without changing the final mix level
- Possible to turn the Trim knob into a Headroom knob (a twist on the classic **MORE** control)
- Opens up the possibilities for automatic headroom adjustments under computer control
  - Remember, Gain Early, Attenuation Late

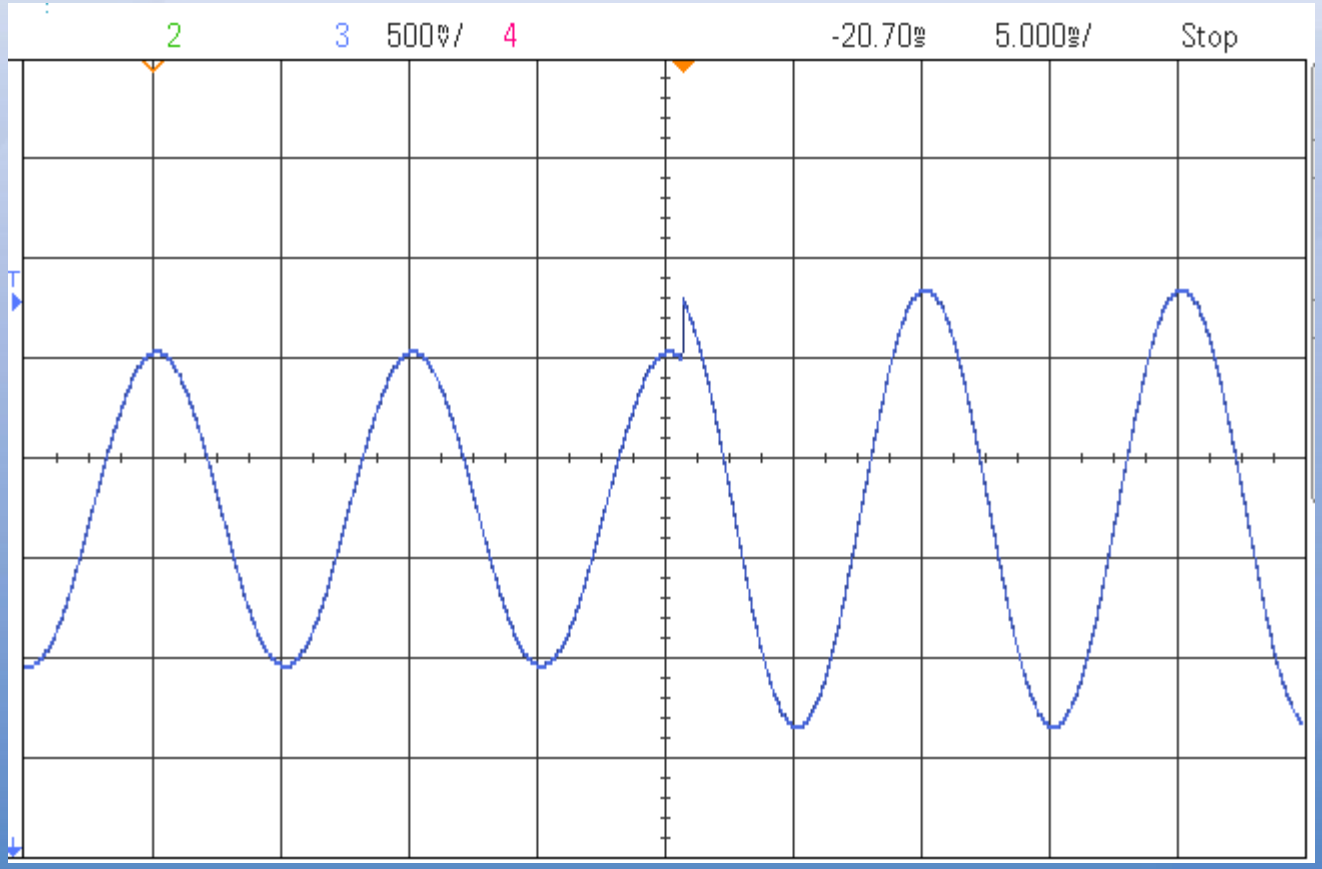
➢ On-the-fly preamp gain adjustments

Incremental gain changes completed during signal zero crossings helps eliminate any “zipper” noise

- Use the processor to generate a sequential gain ramp and synchronize each change with a zero crossing
- Listening tests with different ramp speeds:
  - ➢3dB steps (5173), mostly ok
  - ➢1dB steps very smooth

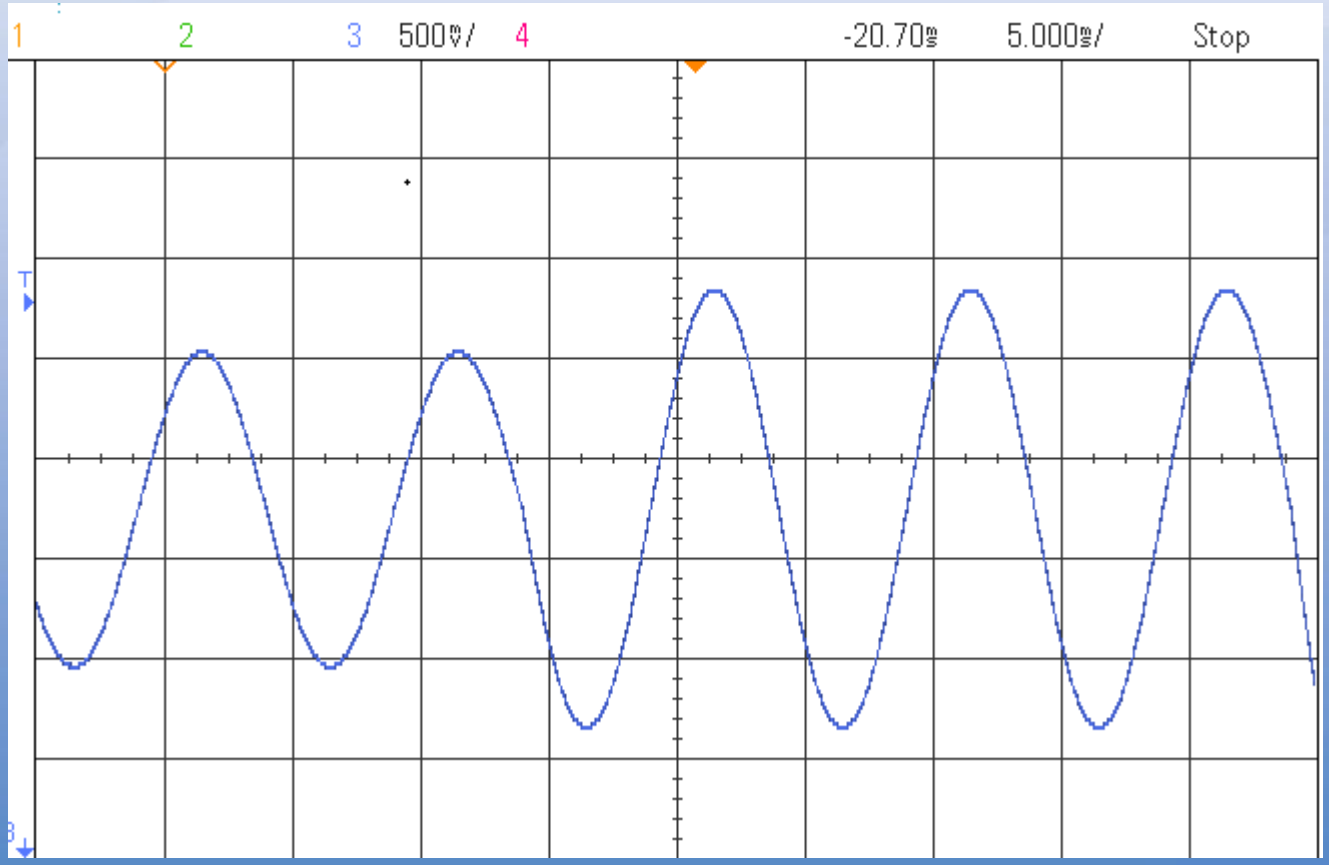
ZCD Example

+3dB Gain Change ZCD Disabled



ZCD Example

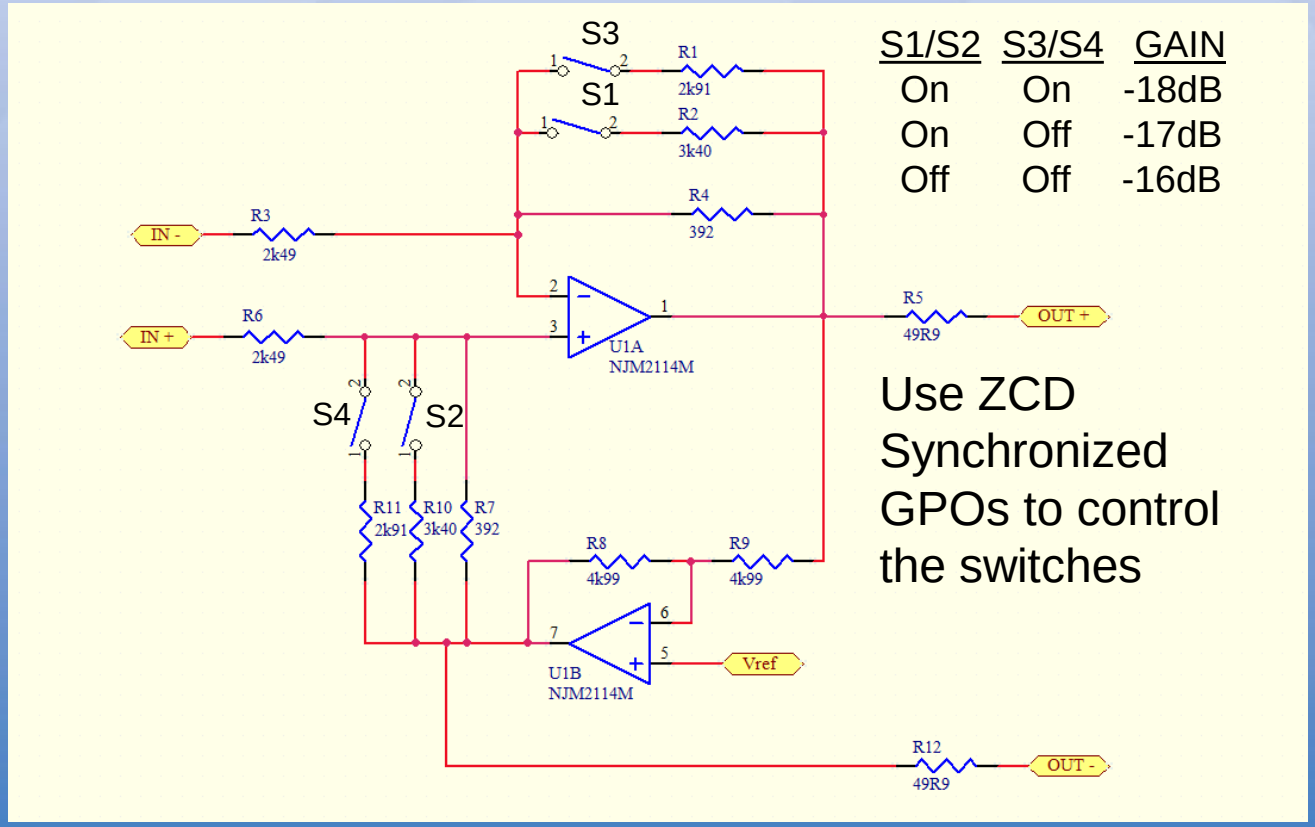
+3dB Gain Change ZCD Enabled



Adding 1dB Steps the A/D Driver

The basic A/D driver circuit

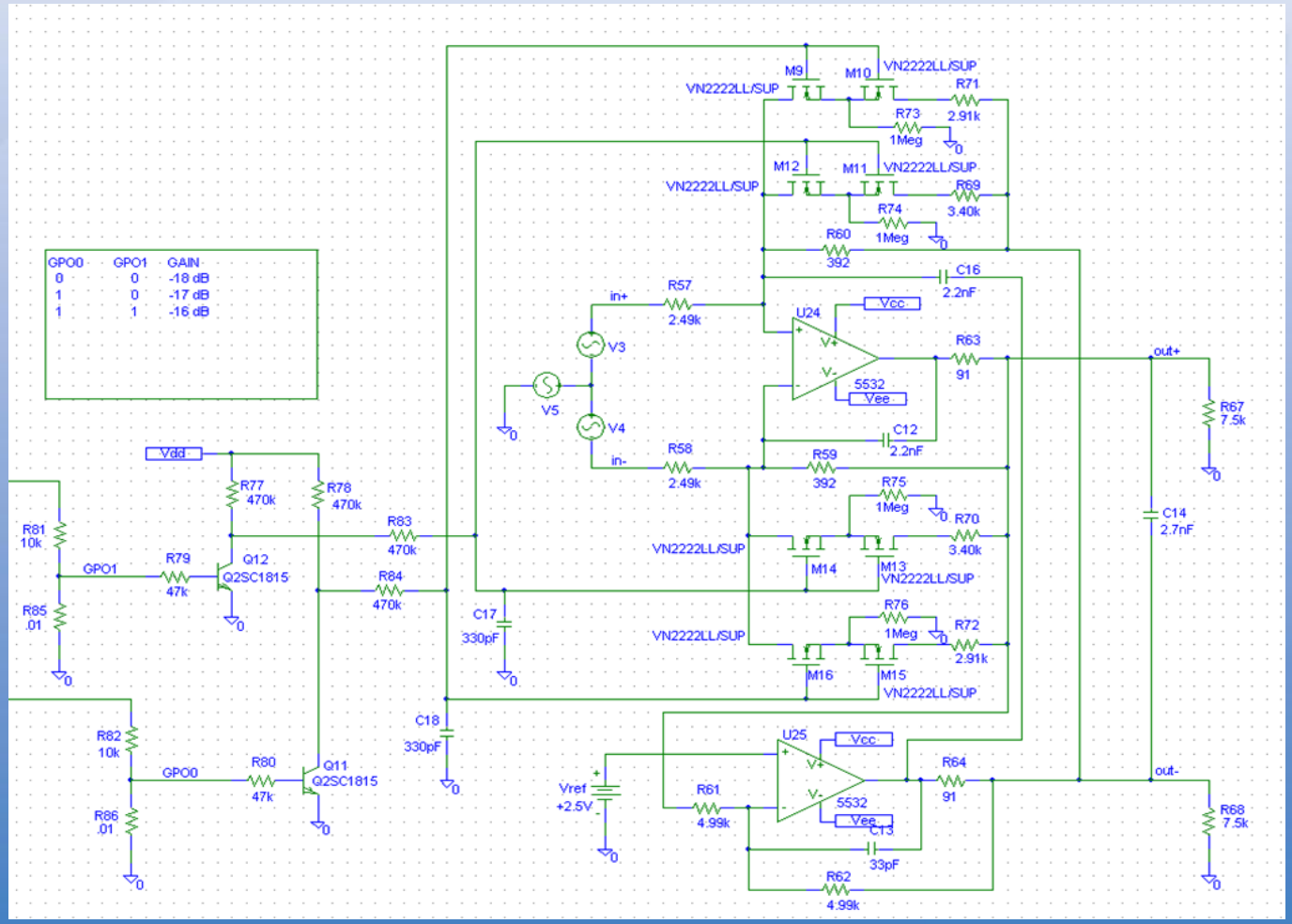
Add 4 switches and 4 resistors



S1/S2	S3/S4	GAIN
On	On	-18dB
On	Off	-17dB
Off	Off	-16dB

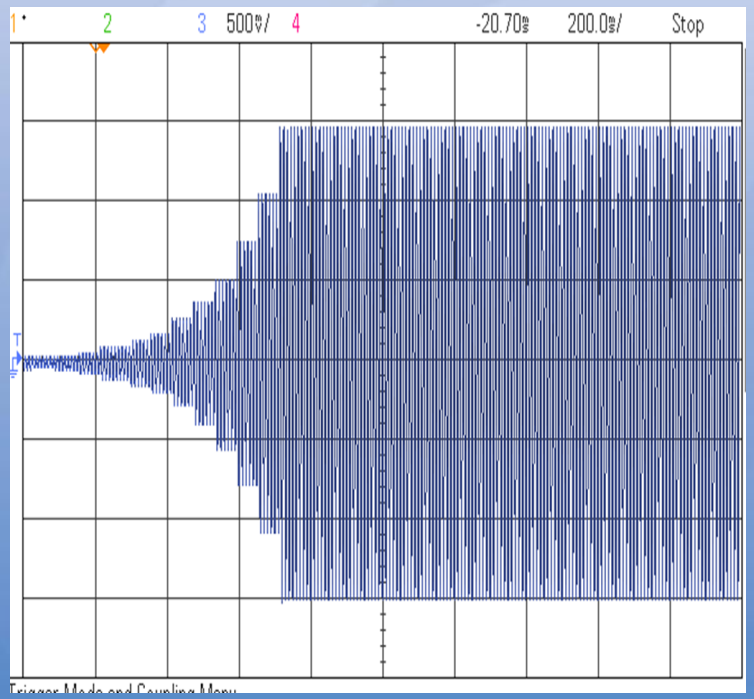
Use ZCD Synchronized GPOs to control the switches

Lab Test Circuit

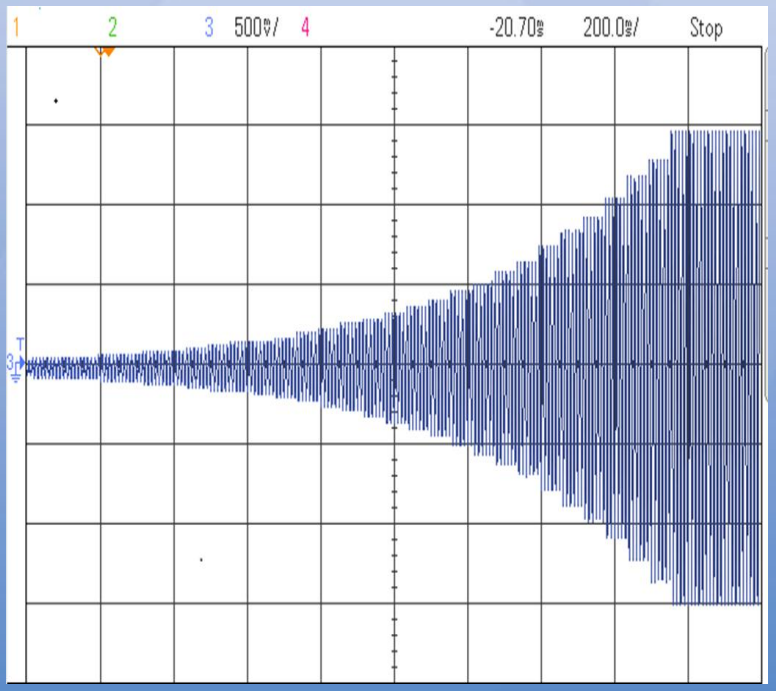


Scope shots form the test circuit

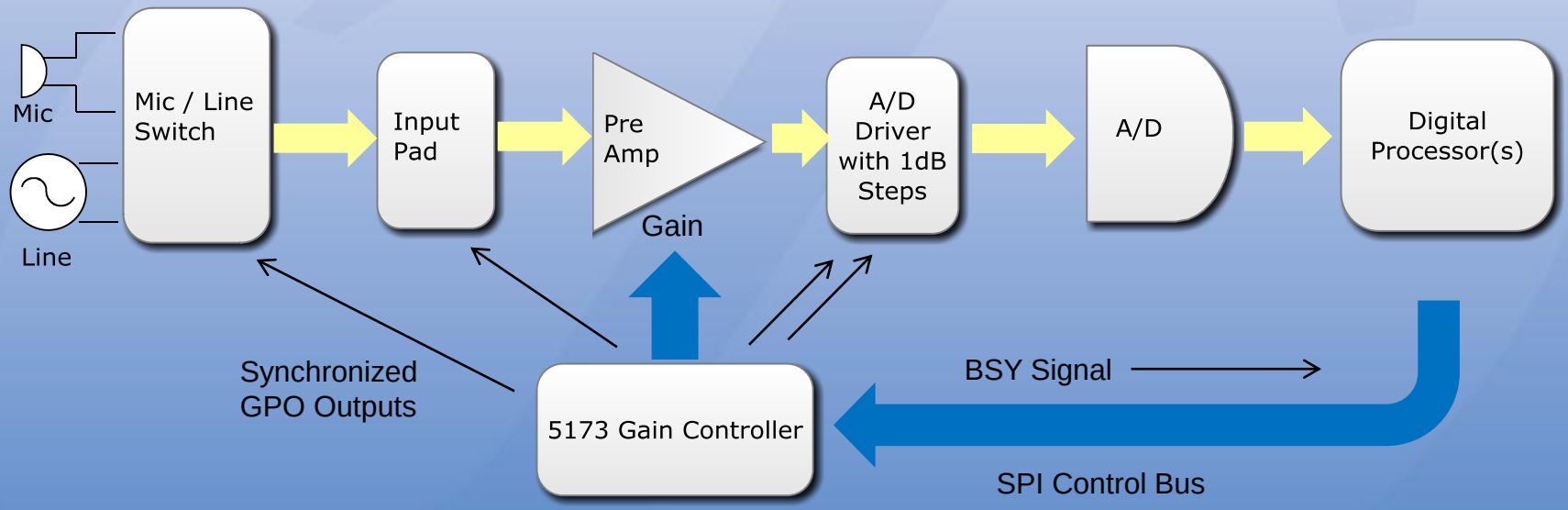
- 3dB Steps



- 1dB Steps



Digitally-Controlled Microphone Preamplifier System Block Diagram with Synchronized GPO Control



Questions?