PRACTICAL DESIGN TECHNIQUES FOR SENSOR SIGNAL CONDITIONING

HIGH IMPEDANCE SENSORS

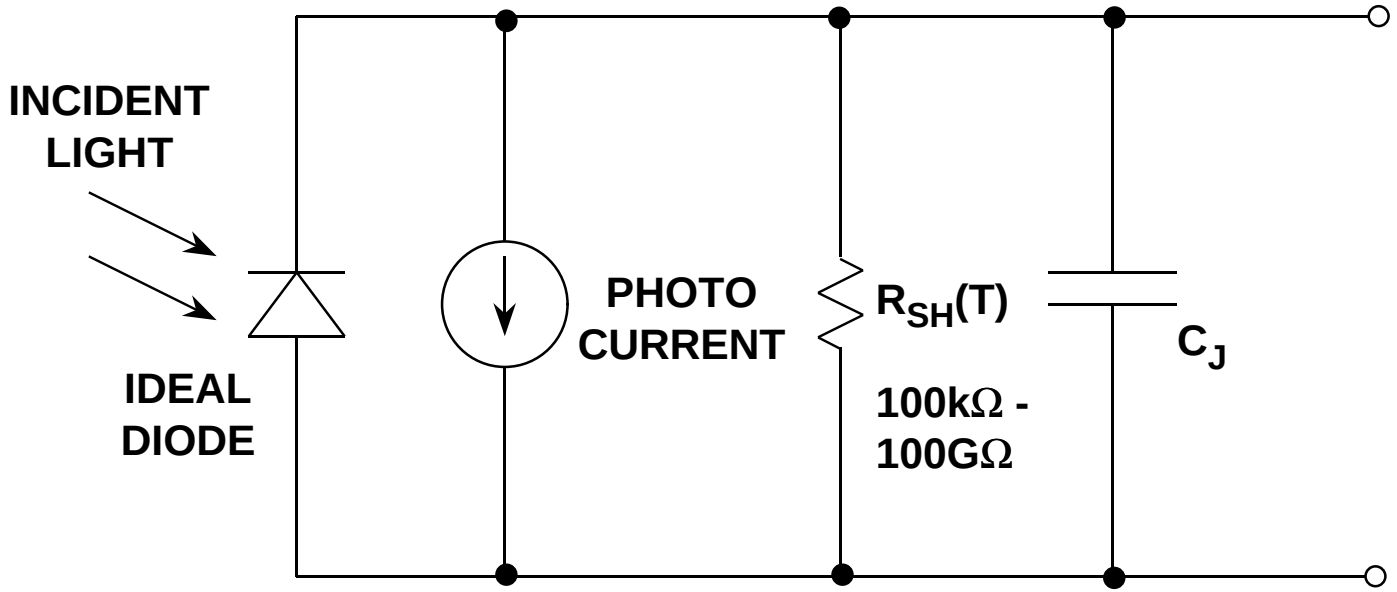
- Photodiode Preamplifiers
- Piezoelectric Sensors
  - Accelerometers
  - Hydrophones
- Humidity Monitors
- pH Monitors
- Chemical Sensors
- Smoke Detectors
- Charge Coupled Devices and

  Contact Image Sensors for Imaging

PHOTODIODE APPLICATIONS

- **Optical: Light Meters, Auto-Focus, Flash Controls**
- **Medical: CAT Scanners (X-Ray Detection), Blood Particle Analyzers**
- **Automotive: Headlight Dimmers, Twilight Detectors**
- **Communications: Fiber Optic Receivers**
- **Industrial: Bar Code Scanners, Position Sensors, Laser Printers**

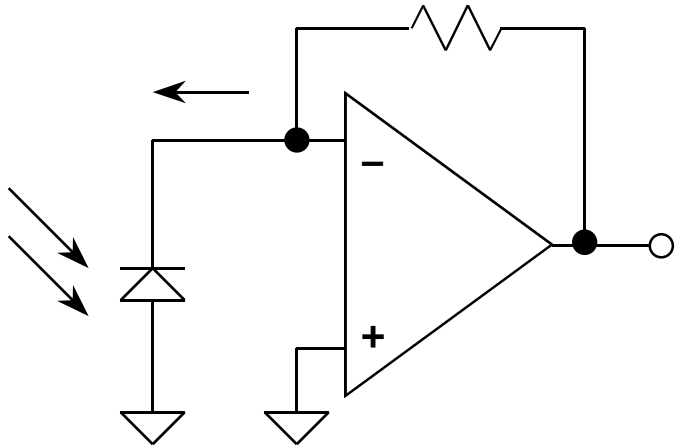
PHOTODIODE EQUIVALENT CIRCUIT

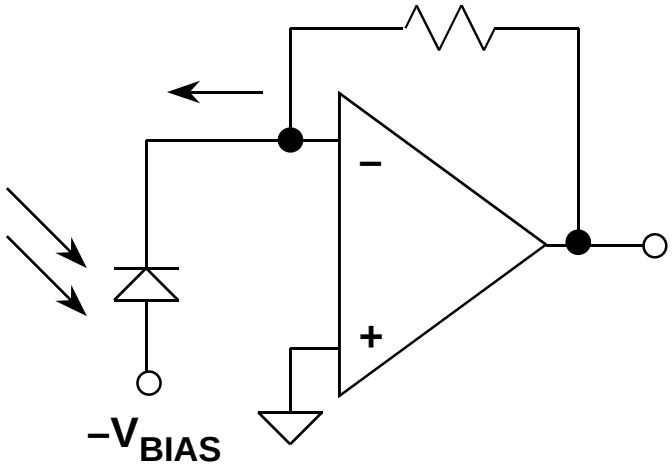


NOTE: R_{SH} HALVES EVERY 10°C TEMPERATURE RISE

a

PHOTODIODE MODES OF OPERATION





PHOTOVOLTAIC

- Zero Bias
- No "Dark" Current
- Linear
- Low Noise (Johnson)
- Precision Applications

PHOTOCONDUCTIVE

- Reverse Bias
- Has "Dark" Current
- Nonlinear
- Higher Noise (Johnson + Shot)
- High Speed Applications

a

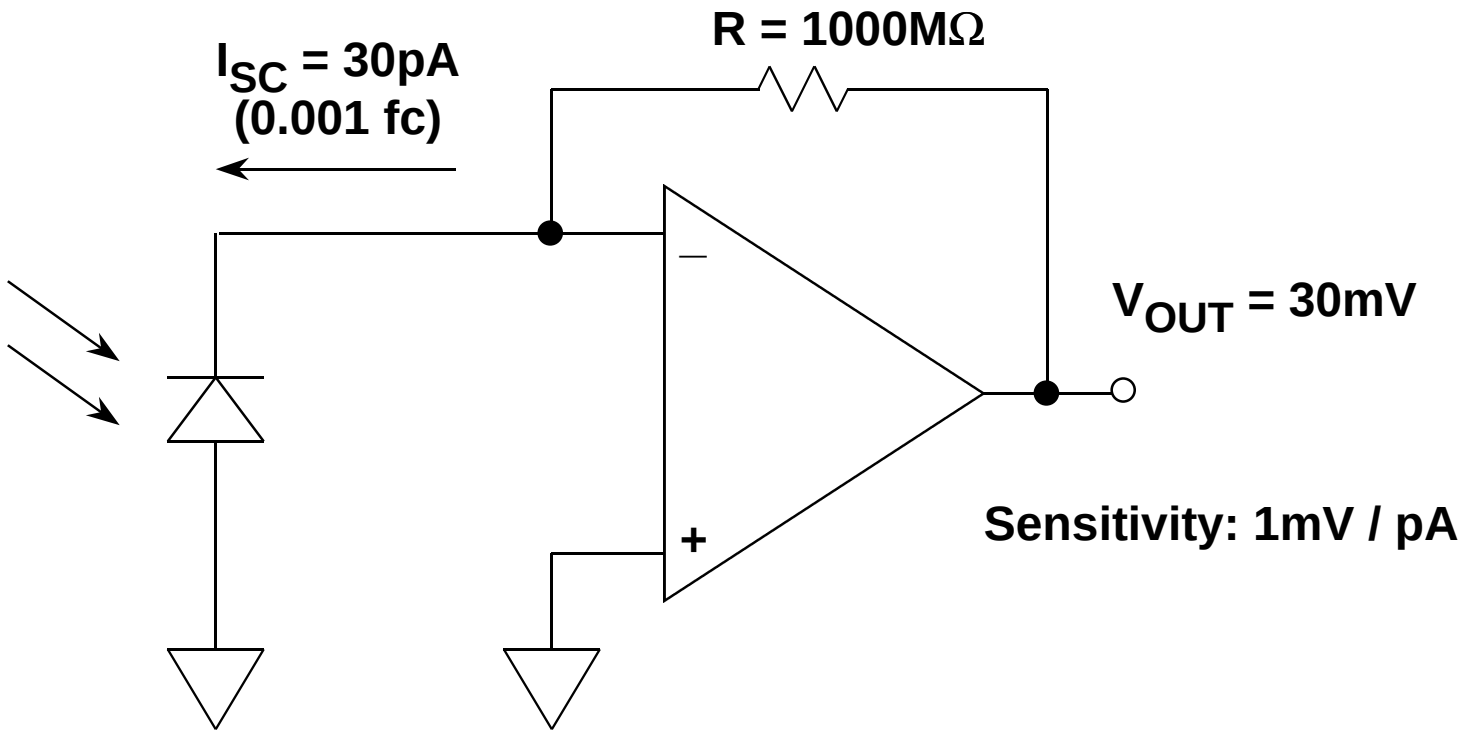
PHOTODIODE SPECIFICATIONS
Silicon Detector Part Number SD-020-12-001

- **Area: 0.2mm^2**
- **Capacitance: 50pF**
- **Shunt Resistance @ 25°C: 1000MΩ**
- **Maximum Linear Output Current: 40µA**
- **Response Time: 12ns**
- **Photosensitivity: 0.03µA / foot candle (fc)**

SHORT CIRCUIT CURRENT VERSUS LIGHT INTENSITY FOR PHOTODIODE (PHOTOVOLTAIC MODE)

ENVIRONMENT	ILLUMINATION (fc)	SHORT CIRCUIT CURRENT
Direct Sunlight	1000	30µA
Overcast Day	100	3µA
Twilight	1	0.03µA
Full Moonlit Night	0.1	3000pA
Clear Night / No Moon	0.001	30pA

CURRENT-TO-VOLTAGE CONVERTER (SIMPLIFIED)



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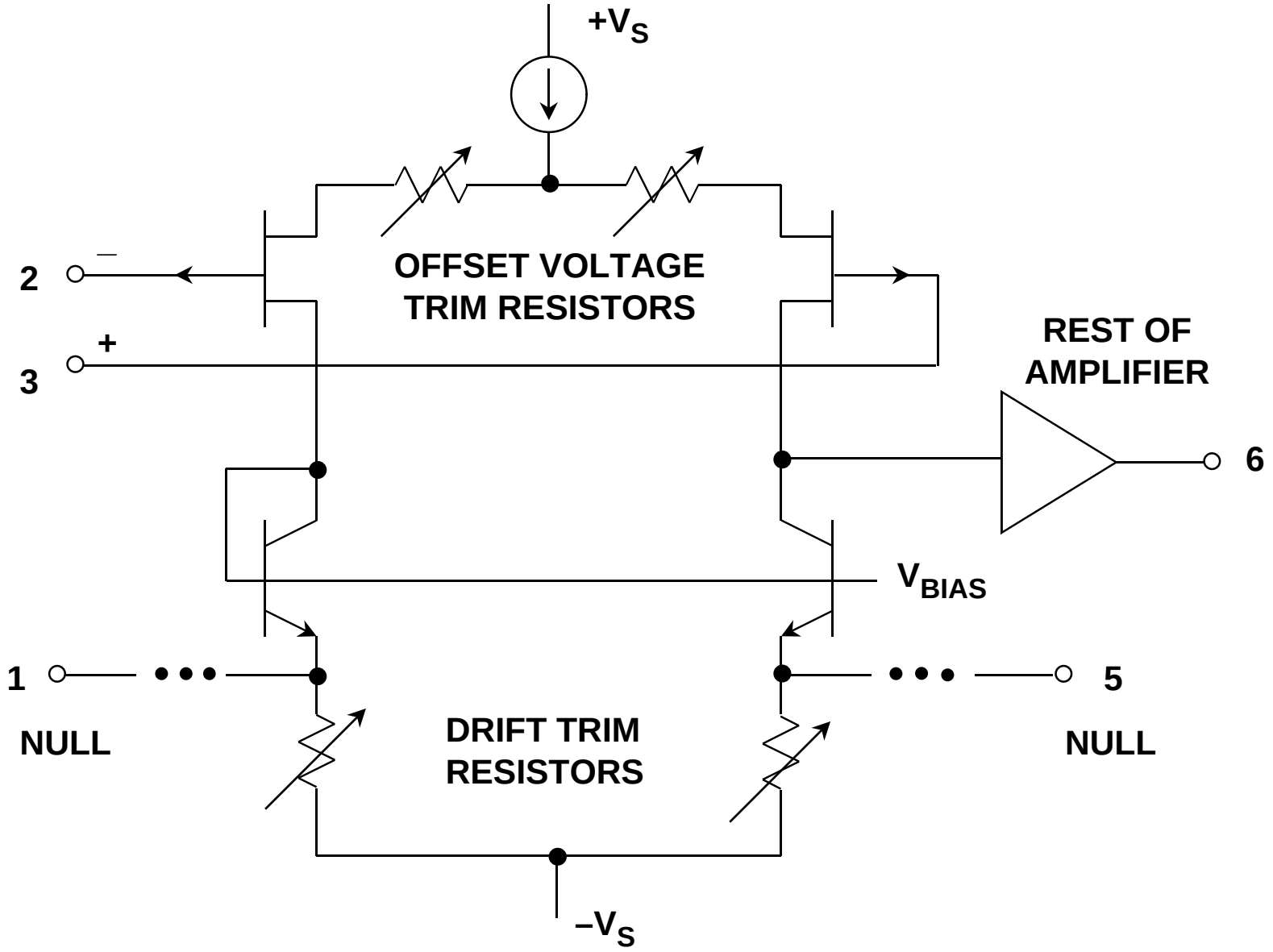
LOW BIAS CURRENT PRECISION BiFET OP AMPS (ELECTROMETER GRADE)

PART #	V_{OS}, MAX*	TC V_{OS}, MAX	I_B, MAX*	0.1Hz TO 10Hz NOISE	PACKAGE
AD549	250µV	5µV/°C	100fA	4µV p-p	TO-99
AD645	250µV	1µV/°C	1.5pA	2µV p-p	TO-99, DIP
AD795	250µV	3µV/°C	1pA	2.5µV p-p	SOIC, DIP

*** 25°C SPECIFICATION**

BiFET OP AMP INPUT STAGE



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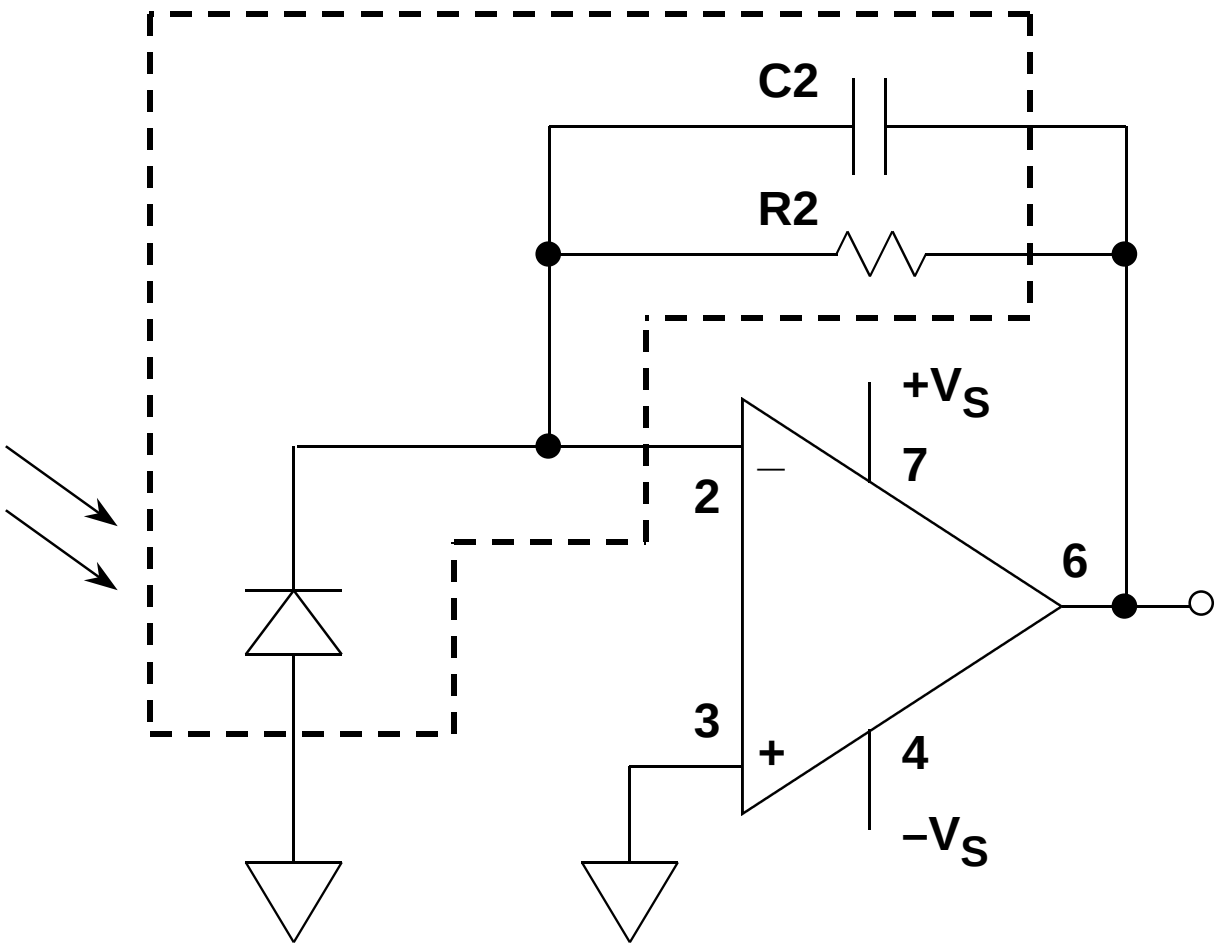
AD795 BiFET OP AMP KEY SPECIFICATIONS

- **Offset Voltage: 250μV Max. @ 25°C (K Grade)**
- **Offset Voltage Drift: 3μV / °C Max (K Grade)**
- **Input Bias Current: 1pA Max @ 25°C (K Grade)**
- **0.1Hz to 10Hz Voltage Noise: 2.5μV p-p**
- **1/f Corner Frequency: 12Hz**
- **Voltage Noise: 10nV / √Hz @ 100Hz**
- **Current Noise: 0.6fA / √Hz @ 100Hz**
- **40mW Power Dissipation @ ±15V**
- **1MHz Gain Bandwidth Product**

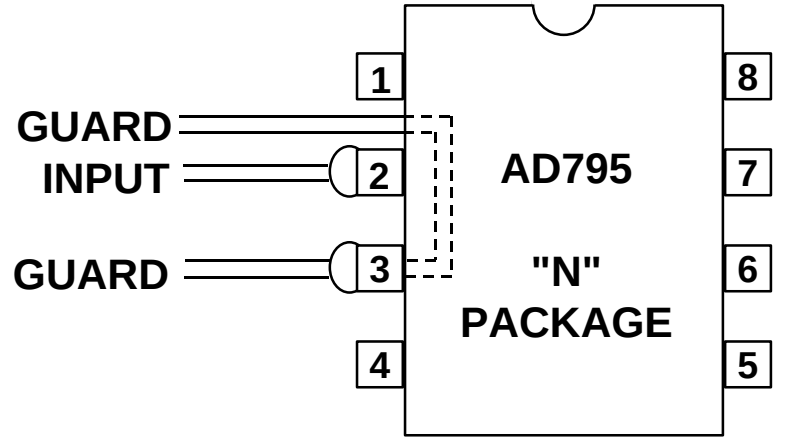
a

LEAKAGE CURRENT PATHS

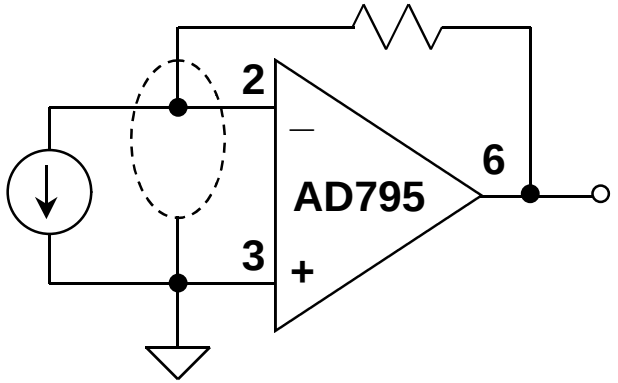


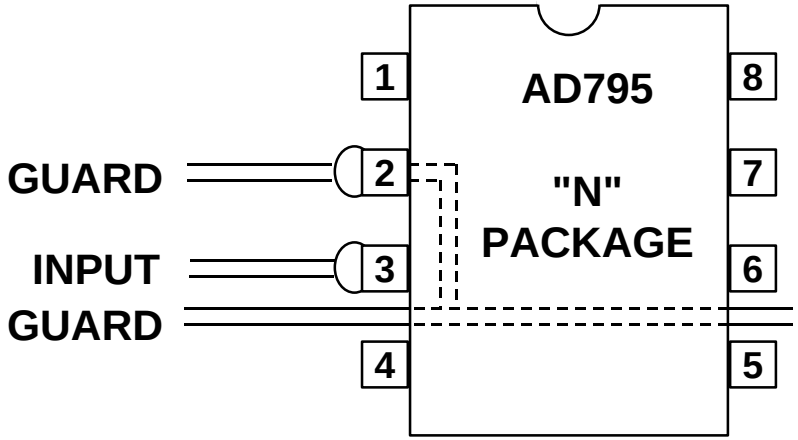
a

PCB LAYOUT FOR GUARDING DIP PACKAGE

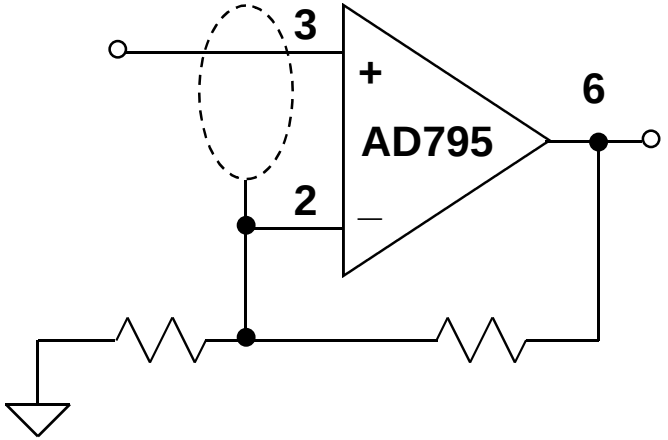


INVERTER





FOLLOWER



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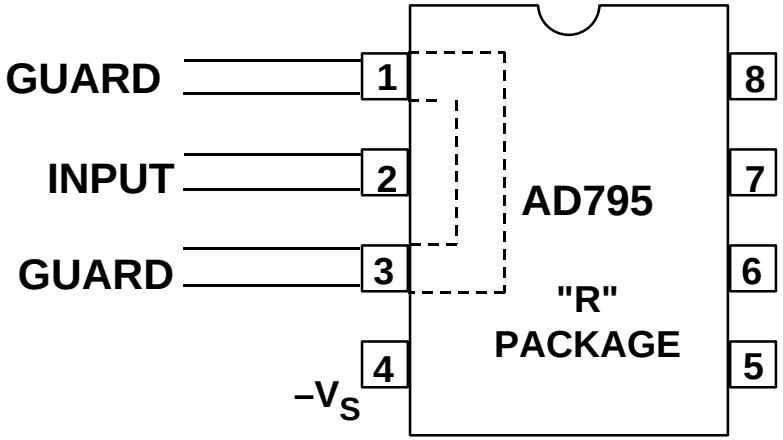
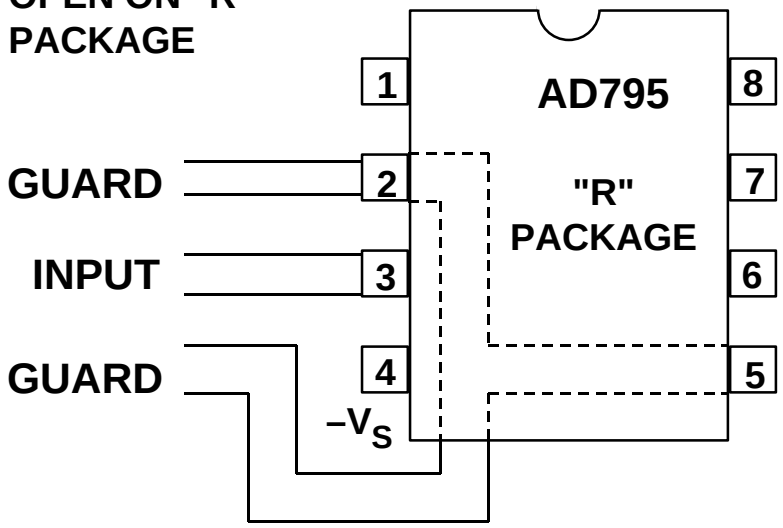
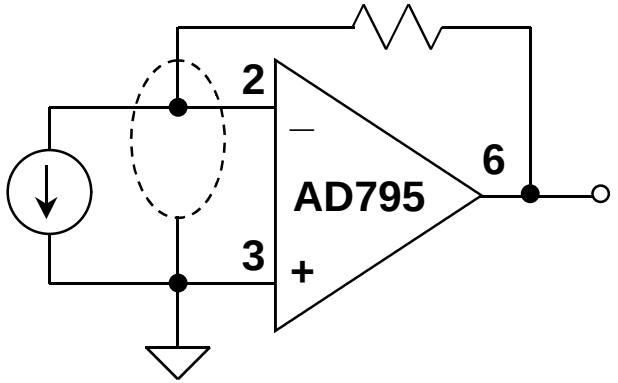
PCB LAYOUT FOR GUARDING SOIC PACKAGE



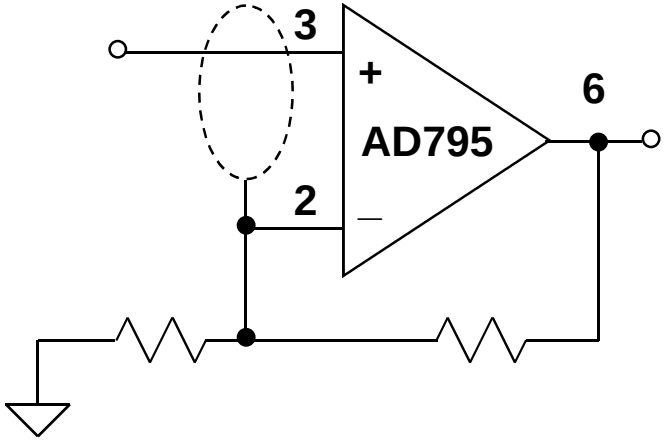
PINS 1, 5, 8 ARE OPEN ON "R" PACKAGE



INVERTER



FOLLOWER



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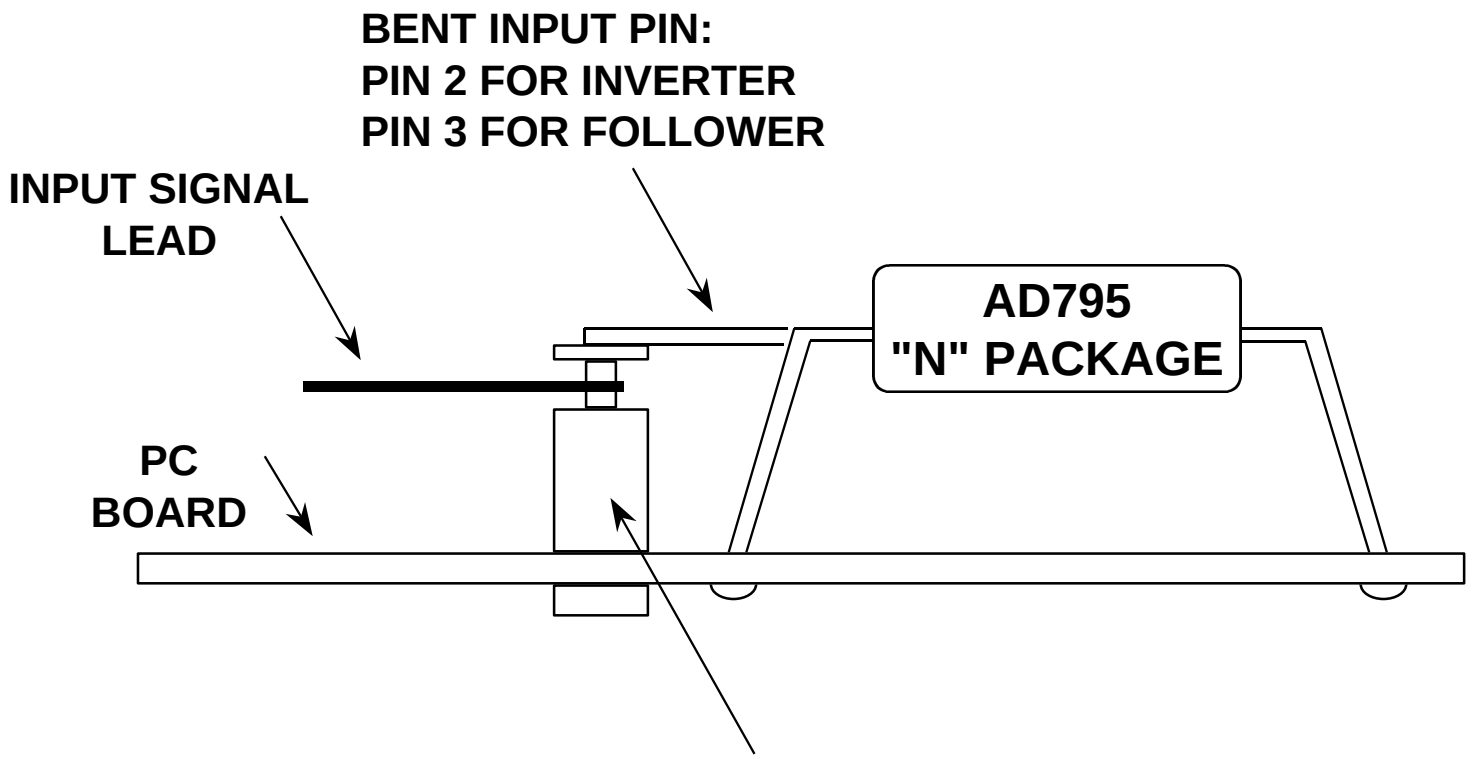
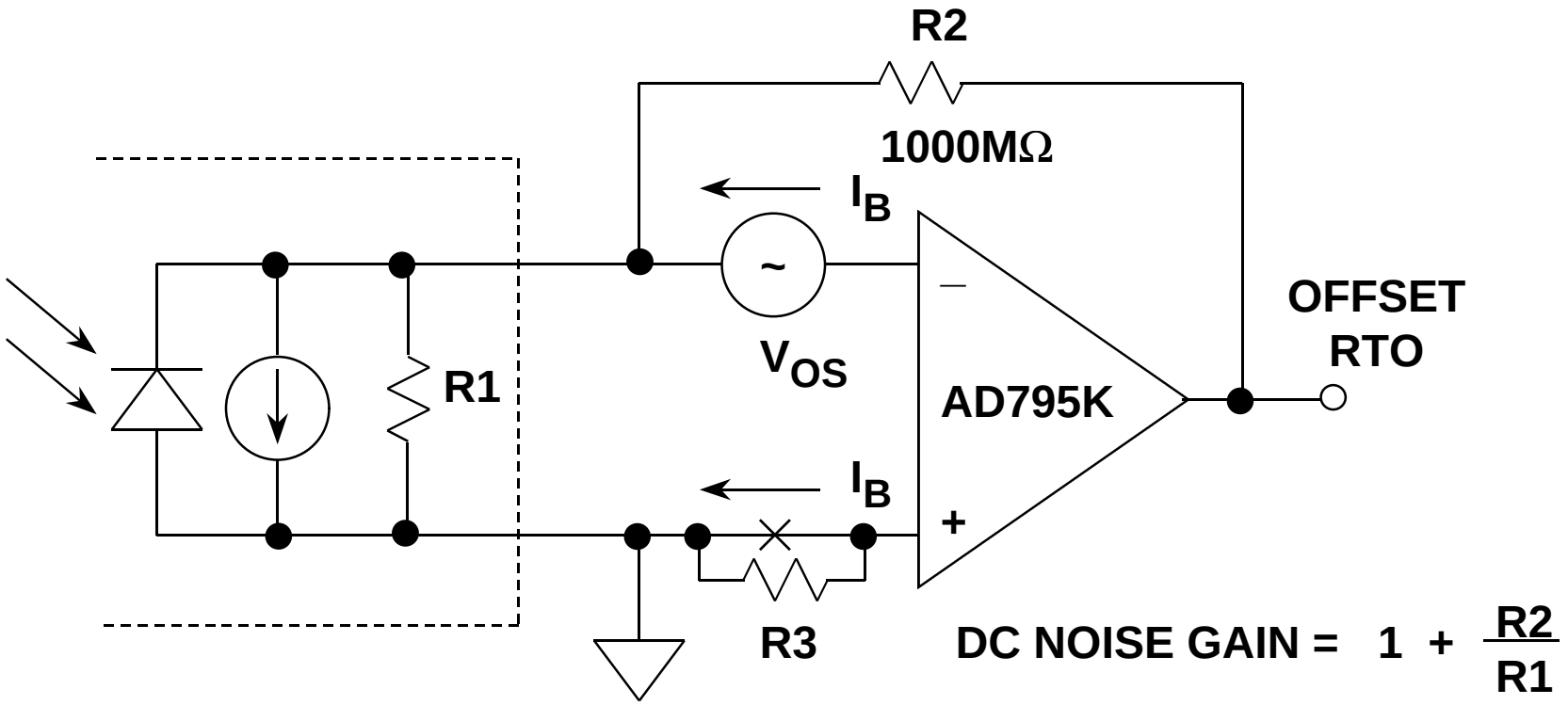
INPUT PIN CONNECTED TO "VIRGIN" TEFLON INSULATED STANDOFF



a

AD795 PREAMPLIFIER DC OFFSET ERRORS



- I_B DOUBLES EVERY 10°C TEMPERATURE RISE
- R1 = 1000MΩ @ 25°C (DIODE SHUNT RESISTANCE)
- R1 HALVES EVERY 10°C TEMPERATURE RISE
- R3 CANCELLATION RESISTOR NOT EFFECTIVE

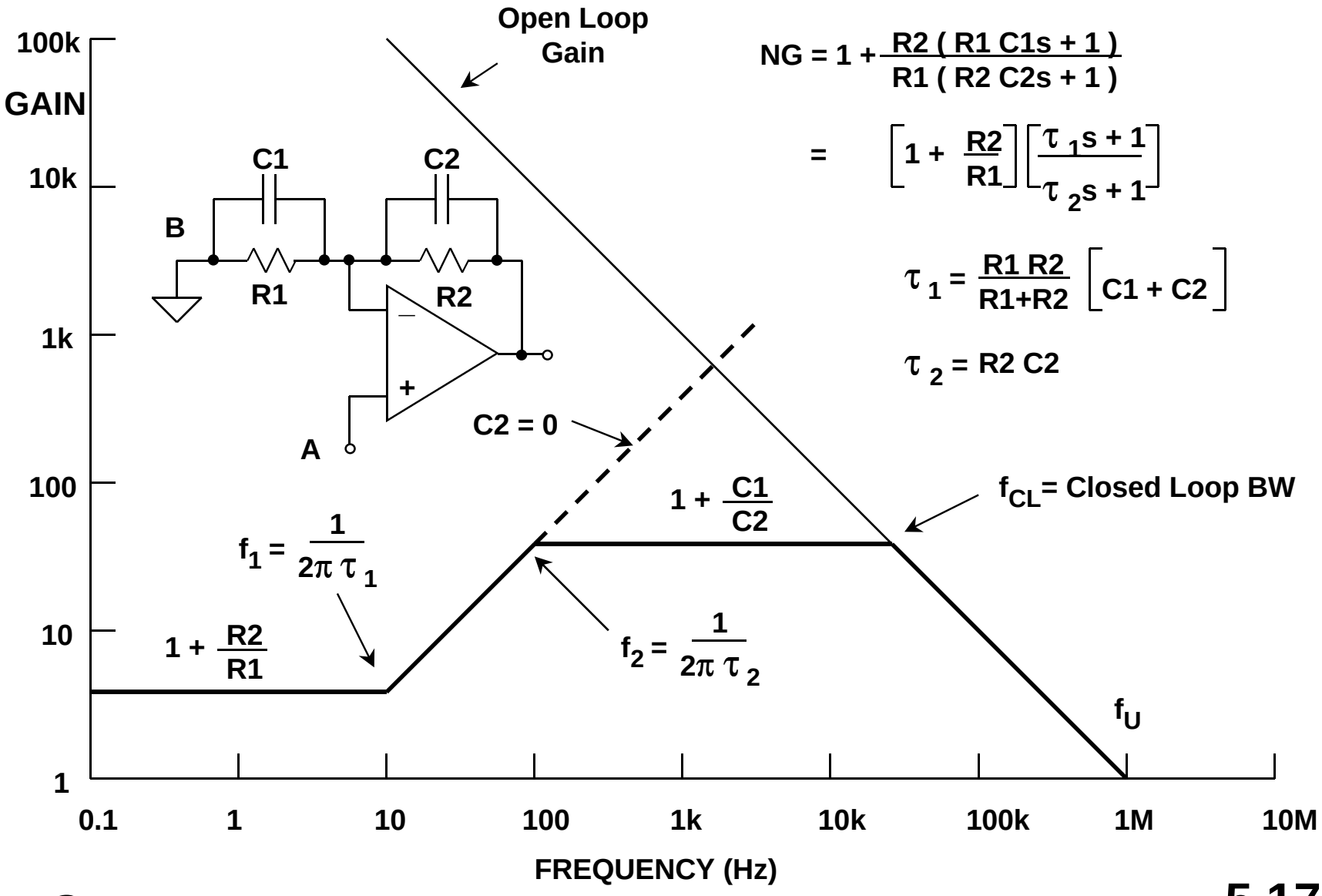
a

AD795K PREAMPLIFIER
TOTAL OUTPUT OFFSET ERROR

	0°C	25°C	50°C	70°C
V_{OS}	0.325mV	0.250mV	0.325mV	0.385mV
Noise Gain	1.1	2	7	24
V_{OS} Error RTO	0.358mV	0.500mV	2.28mV	9.24mV
I_B	0.2pA	1.0pA	6.0pA	24pA
I_B Error RTO	0.2mV	1mV	6.0mV	24mV
Total Error RTO	0.558mV	1.50mV	8.28mV	33.24mV

a

GENERALIZED NOISE GAIN (NG) BODE PLOT



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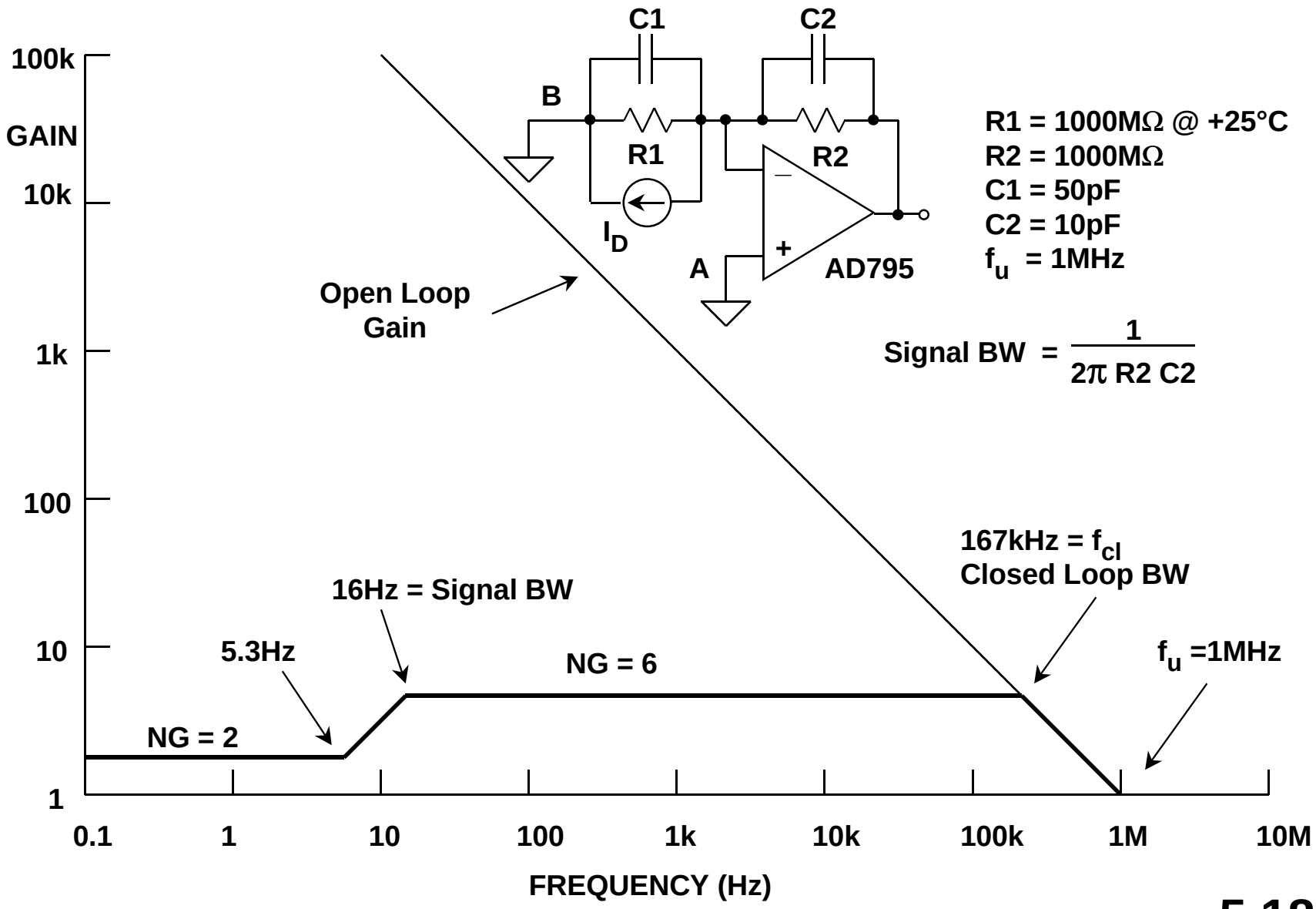
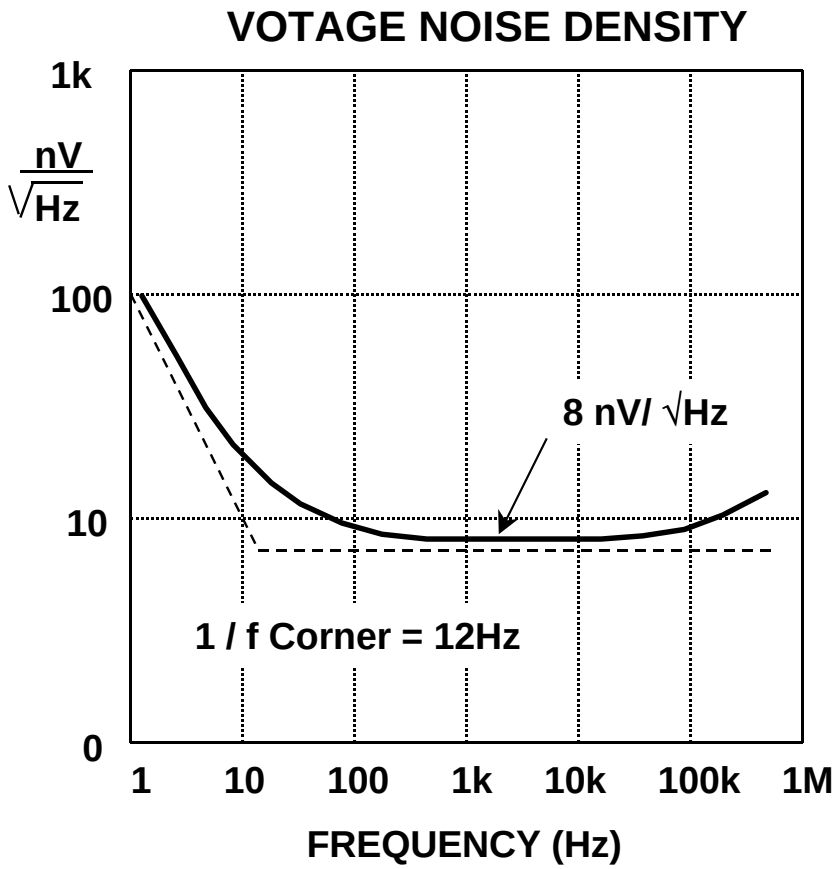
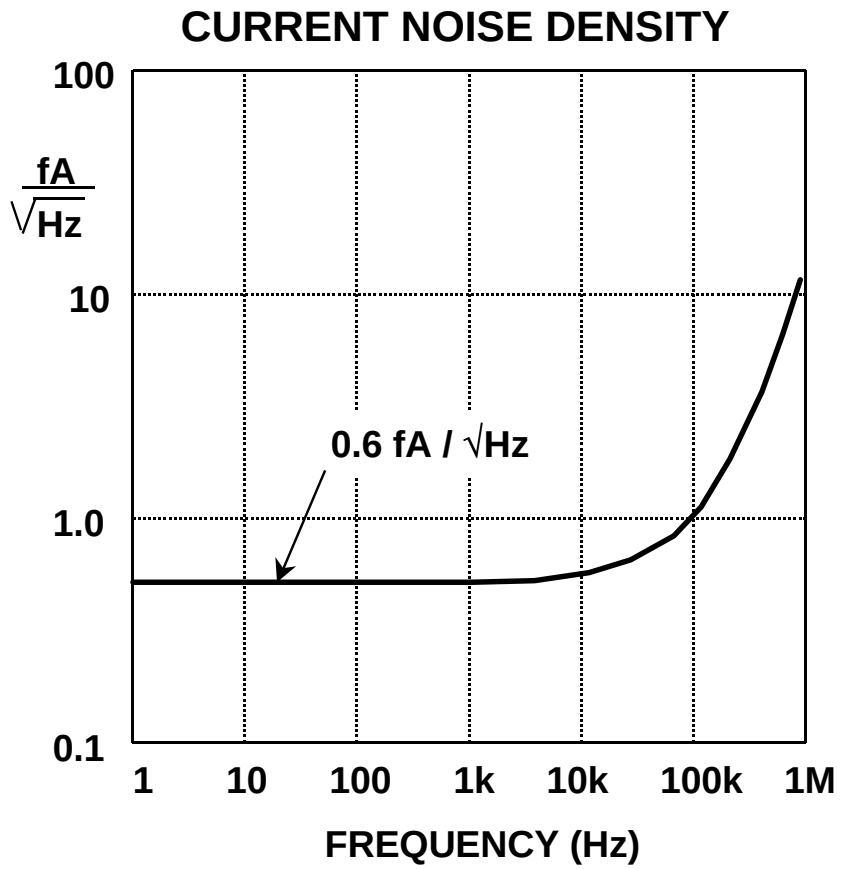
NOISE GAIN OF AD795 PREAMPLIFIER @ 25°C



a

VOLTAGE AND CURRENT NOISE OF AD795





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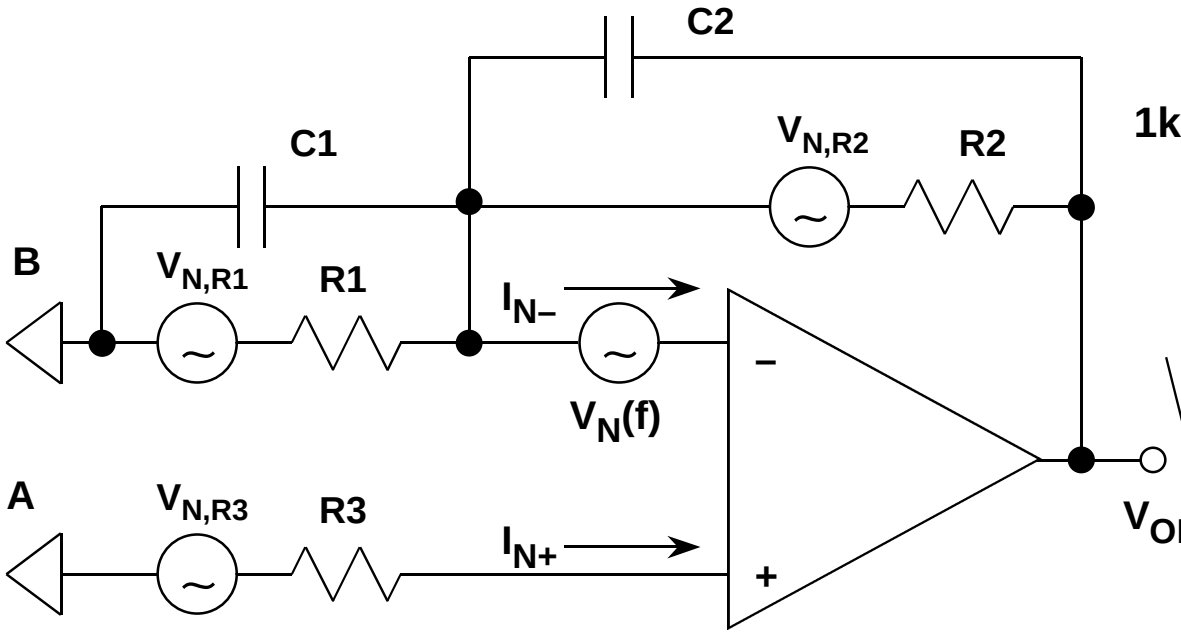
AMPLIFIER NOISE MODEL



1kΩ @ +25°C has 4nV/√Hz Noise

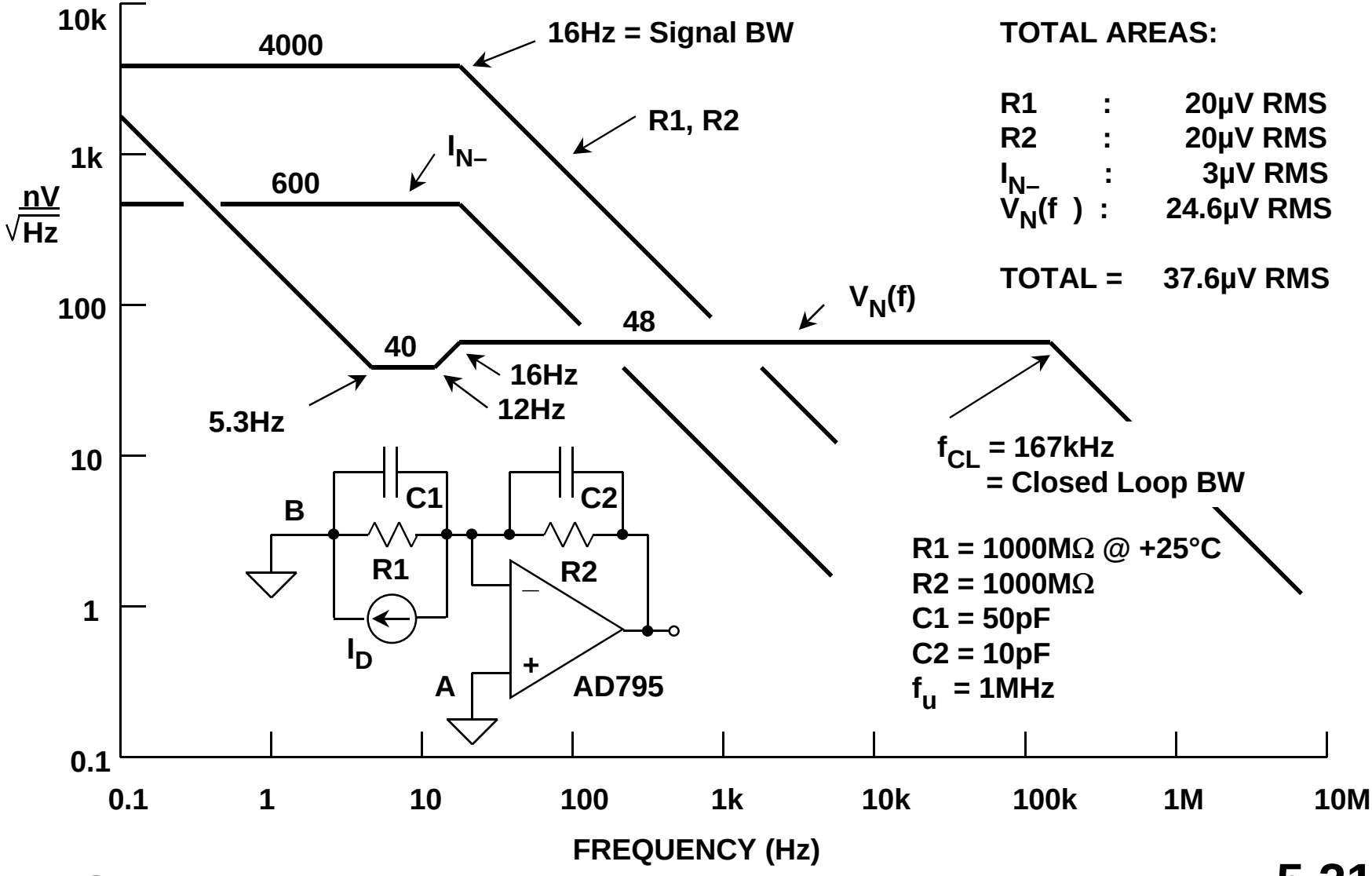
TOTAL NOISE RTO =

$$\sqrt{\int V_1(f)^2 df + \int V_2(f)^2 df + \ldots}$$

NOISE SOURCE	RTO	INTEGRATION BW
$V_N(f)$	$V_N(f)$•Noise Gain	1.57•Closed Loop BW
I_{N+}	I_{N+}•R3• Noise Gain	1.57•Closed Loop BW
I_{N-}	I_{N-}•R2	1.57 •Signal BW
R1	$V_{N,R1}$•(R2/R1)	1.57 •Signal BW
R2	$V_{N,R2}$	1.57 •Signal BW
R3	$V_{N,R3}$ •Noise Gain	1.57•Closed Loop BW

a

OUTPUT VOLTAGE NOISE COMPONENTS
SPECTRAL DENSITIES (nV /√Hz) @ +25°C



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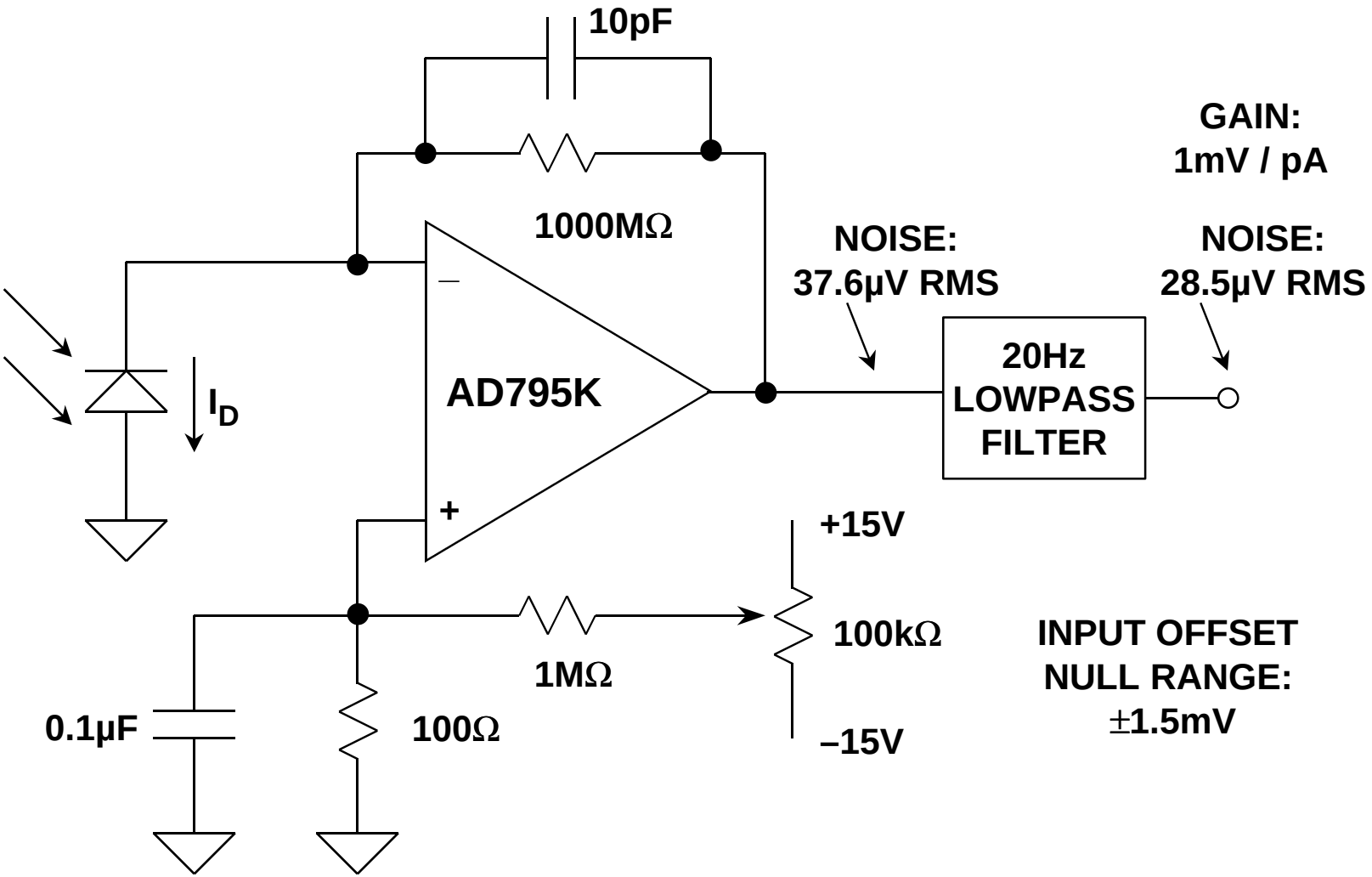
AD795 PHOTODIODE PREAMP WITH OFFSET NULL ADJUSTMENT



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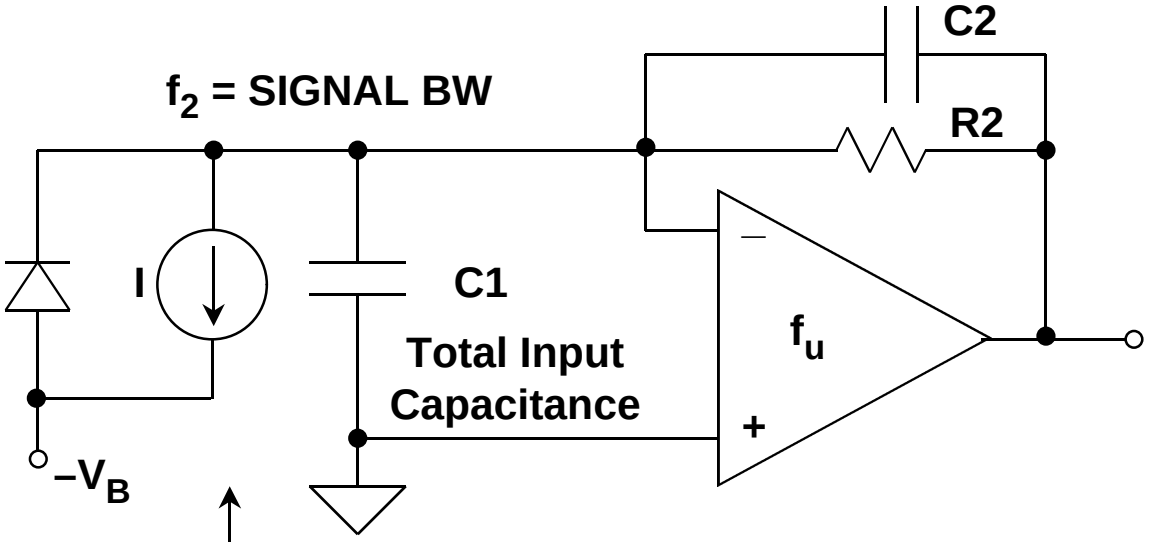
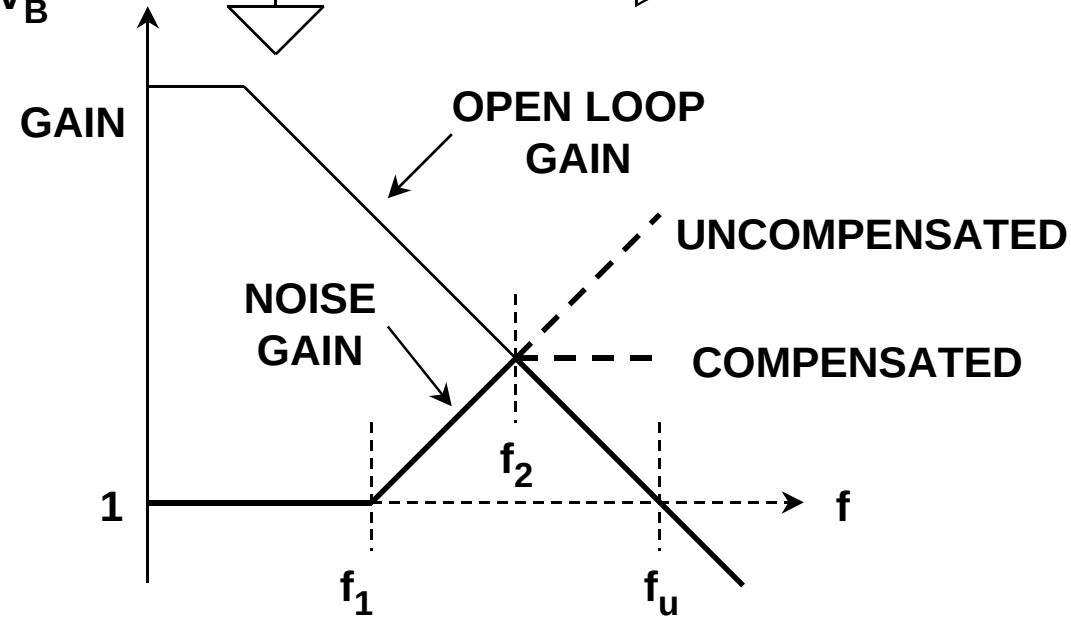
AD795 PHOTODIODE CIRCUIT PERFORMANCE SUMMARY

- **Output Offset Error (0°C to +70°C) : 33mV**
- **Output Sensitivity: 1mV / pA**
- **Output Photosensitivity: 30V / foot-candle**
- **Total Output Noise @ +25°C : 28.5µV RMS**
- **Total Noise RTI @ +25°C : 44fA RMS, or 26.4pA p-p**
- **Range with R2 = 1000MΩ : 0.001 to 0.33 foot-candles**
- **Bandwidth: 16Hz**

COMPENSATING FOR INPUT CAPACITANCE IN A CURRENT-TO-VOLTAGE CONVERTER





f_u = OP AMP UNITY GAIN BW PRODUCT

$$f_1 = \frac{1}{2\pi\ R2\ C1}$$

$$f_2 = \frac{1}{2\pi\ R2\ C2}$$

$$f_2 = \sqrt{f_1 \bullet f_u}$$

$$C2 = \sqrt{\frac{C1}{2\pi\ R2\ f_u}}$$

FOR 45° PHASE MARGIN

$$f_2 = \sqrt{\frac{f_u}{2\pi\ R2\ C1}}$$

a

FET-INPUT OP AMP COMPARISON TABLE FOR WIDE BANDWIDTH PHOTODIODE PREAMPS

	Unity GBW Product fu (MHz)	Input Capacitance C_{IN} (pF)	f_u/C_{IN} (MHz/pF)	Input Bias Current I_B (pA)	Voltage Noise @ 10kHz (nV/√Hz)
AD823	16	1.8	8.9	3	16
AD843	34	6	5.7	600	19
AD744	13	5.5	2.4	100	16
AD845	16	8	2	500	18
OP42	10	6	1.6	100	12
AD745*	20	20	1	250	2.9
AD795	1	1	1	1	8
AD820	1.9	2.8	0.7	2	13
AD743	4.5	20	0.2	250	2.9

***Stable for Noise Gains ≥ 5, Usually the Case, Since High Frequency Noise Gain = 1 + C1/C2, and C1 Usually ≥ 4C2**

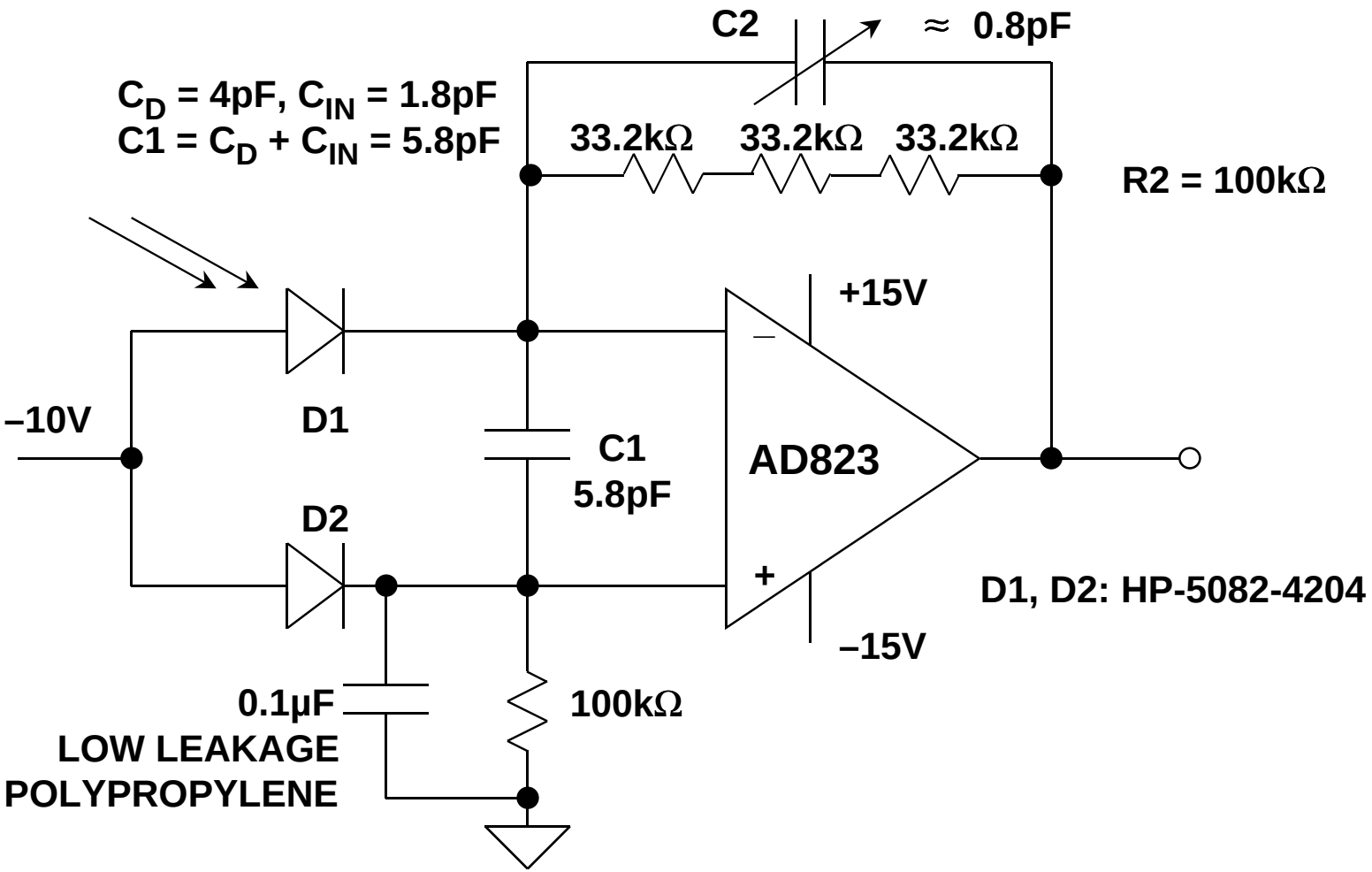
a

HP 5082-4204 PHOTODIODE

- **Sensitivity: 350μA @ 1mW, 900nm**
- **Maximum Linear Output Current: 100μA**
- **Area: 0.002cm^2 (0.2mm^2)**
- **Capacitance: 4pF @ 10V Reverse Bias**
- **Shunt Resistance: $10^{11}\Omega$**
- **Risetime: 10ns**
- **Dark Current: 600pA @ 10V Reverse Bias**

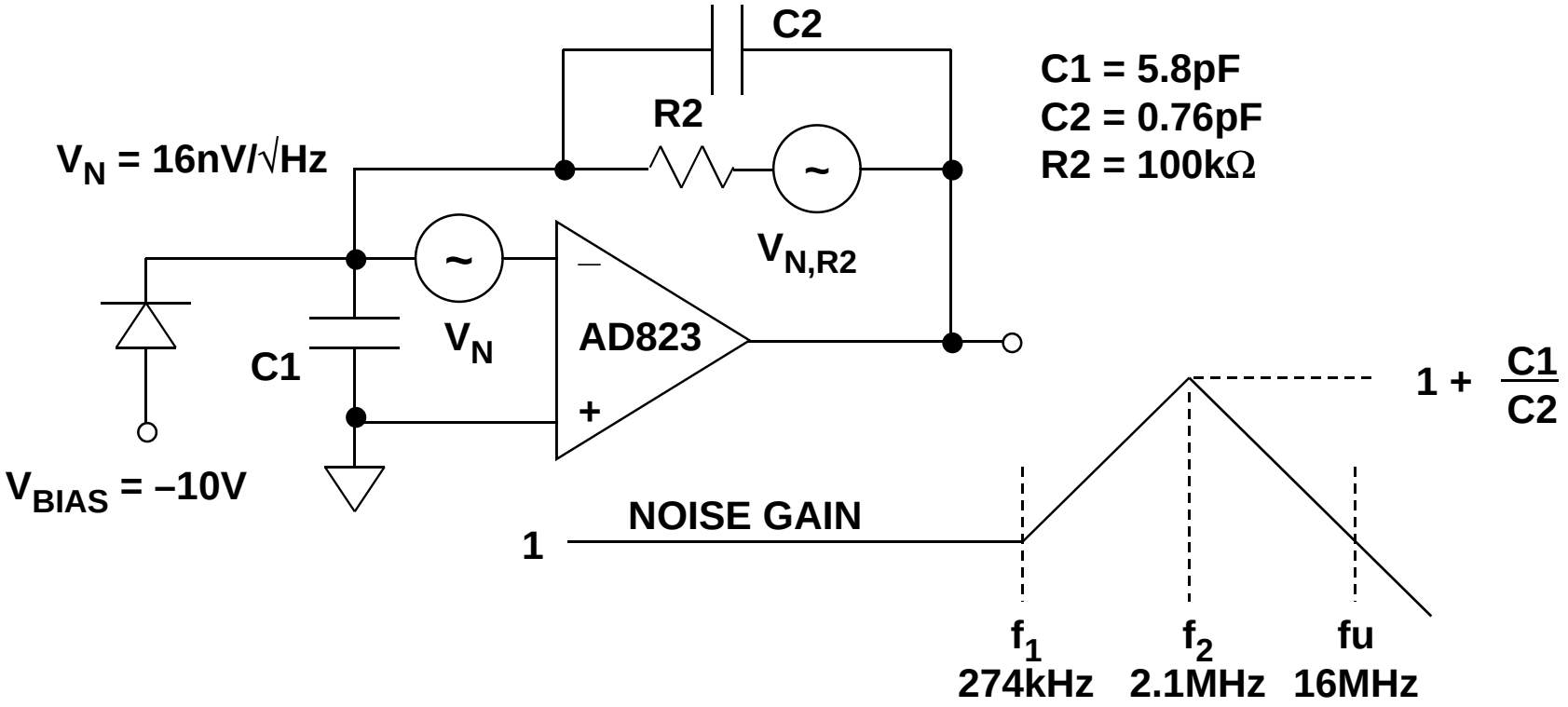
a

2MHz BANDWIDTH PHOTODIODE PREAMP WITH DARK CURRENT COMPENSATION



a

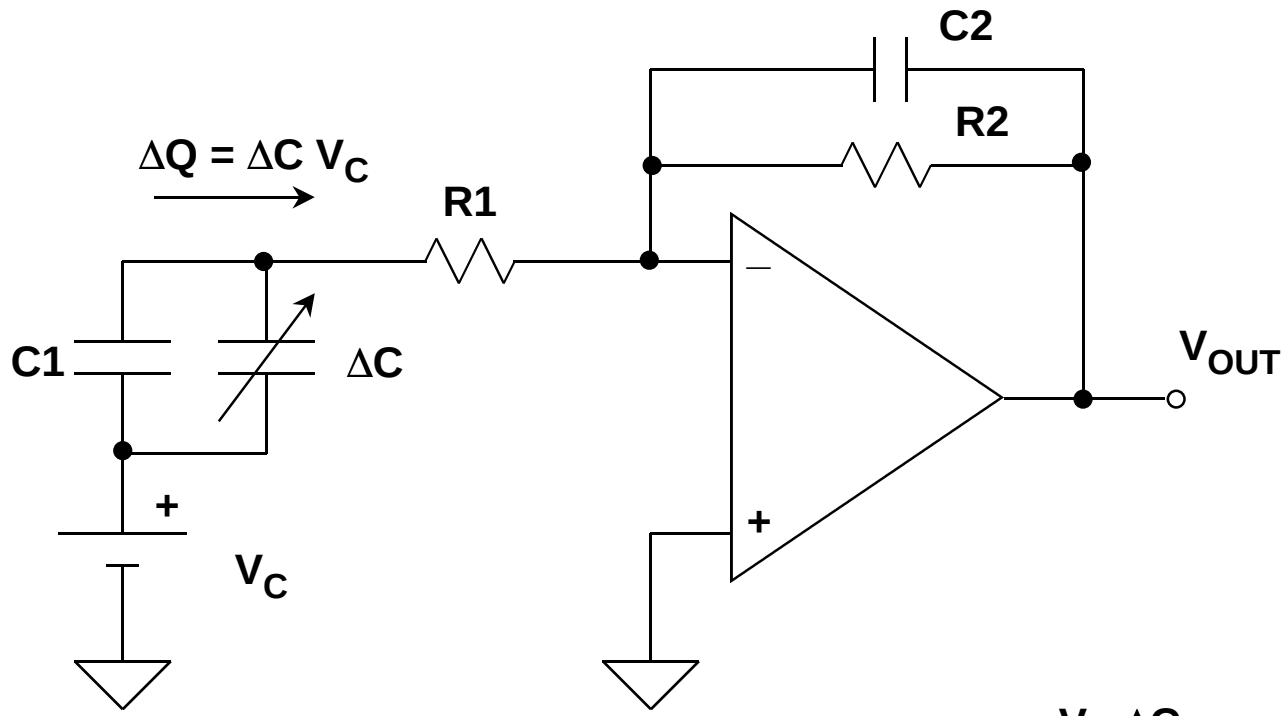
EQUIVALENT CIRCUIT FOR OUTPUT NOISE ANALYSIS



- V_N RTO NOISE $\approx V_N\left[1 + \frac{C1}{C2}\right]\sqrt{1.57\, f_2}$ = 250µV RMS
- $V_{N,R2}$ RTO NOISE $\approx \sqrt{4kTR2 \bullet 1.57 f_2}$ = 73µV RMS
- TOTAL RTO NOISE $= \sqrt{250^2 + 73^2}$ = 260µV RMS
- DYNAMIC RANGE $= 20 \log\left[\frac{10V}{260\mu V}\right]$ = 92dB

a

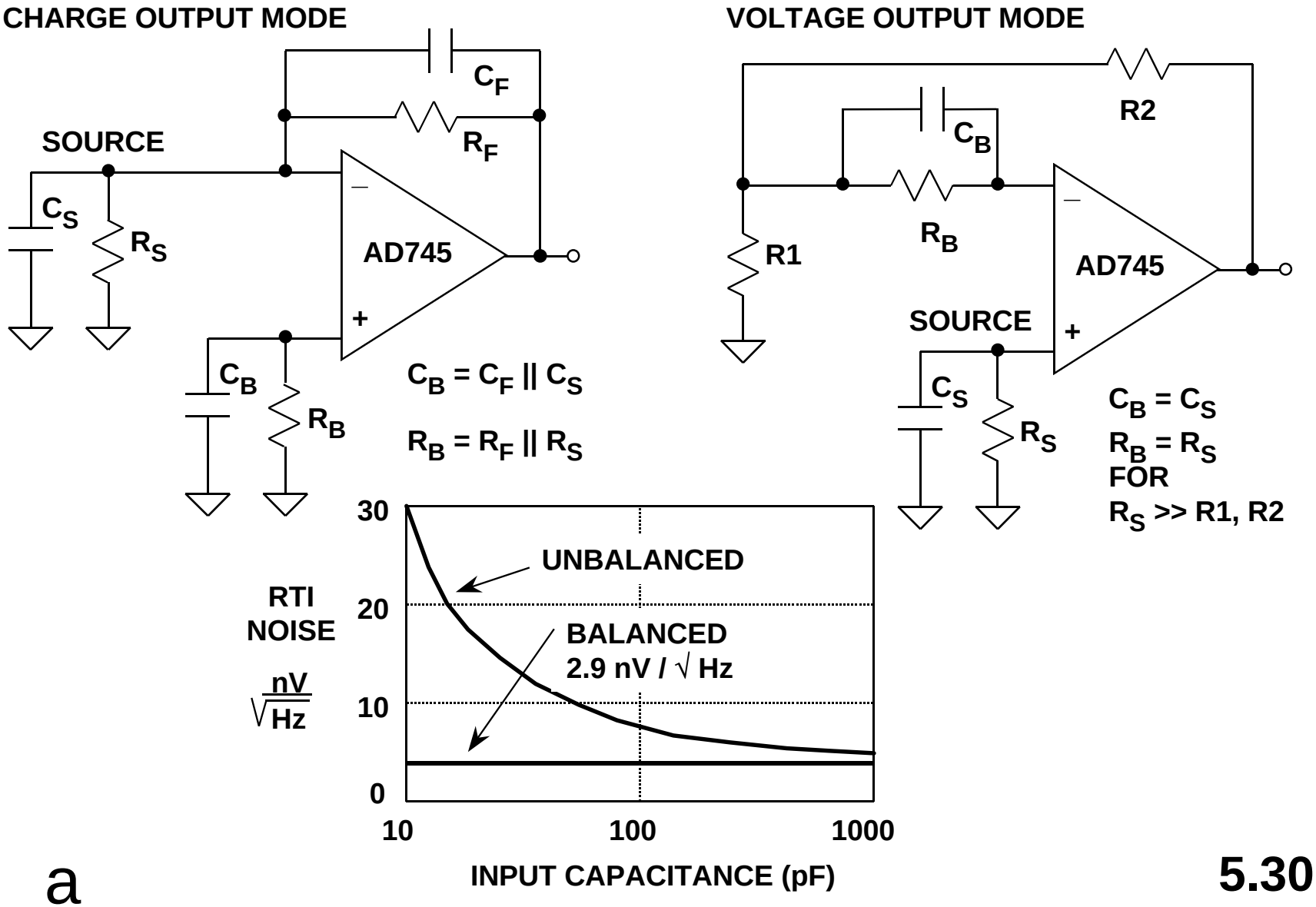
CHARGE AMPLIFIER FOR CAPACITIVE SENSOR



- **FOR CAPACITIVE SENSORS:** $\Delta V_{OUT} = \dfrac{-V_C\,\Delta C}{C2}$
- **FOR CHARGE-EMITTING SENSORS:** $\Delta V_{OUT} = \dfrac{-\Delta Q}{C2}$
- **UPPER CUTOFF FREQUENCY** = $f_2 = \dfrac{1}{2\pi\, R2\, C2}$
- **LOWER CUTOFF FREQUENCY** = $f_1 = \dfrac{1}{2\pi\, R1\, C1}$

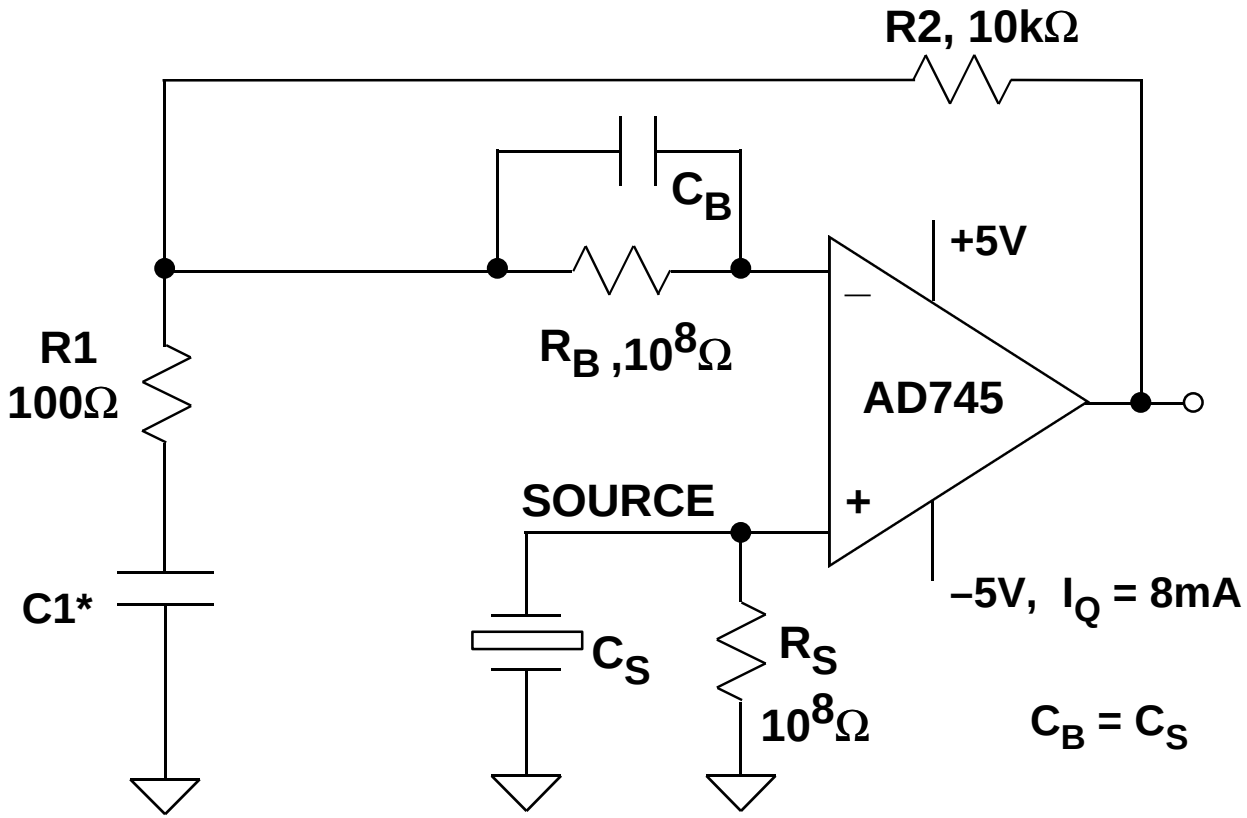
a

BALANCING SOURCE IMPEDANCES MINIMIZES EFFECTS OF BIAS CURRENTS AND REDUCES INPUT NOISE



a

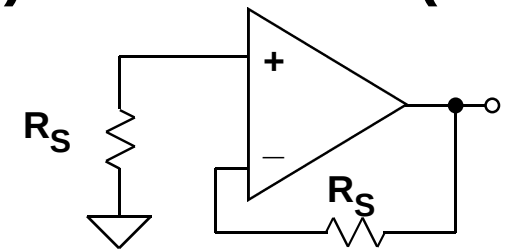
GAIN OF 100 PIEZOELECTRIC SENSOR AMPLIFIER

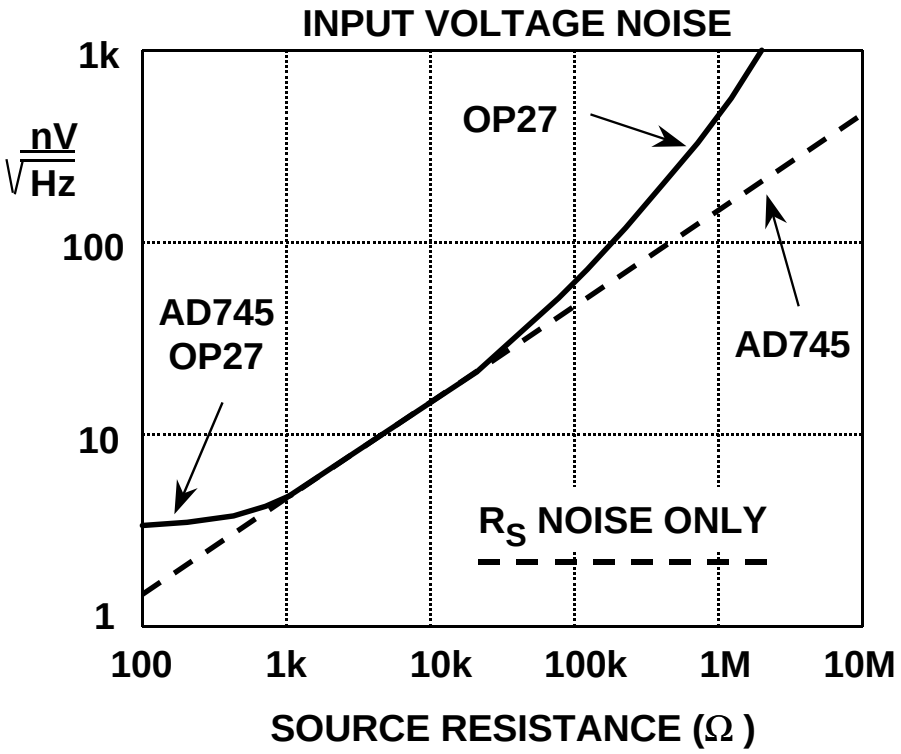


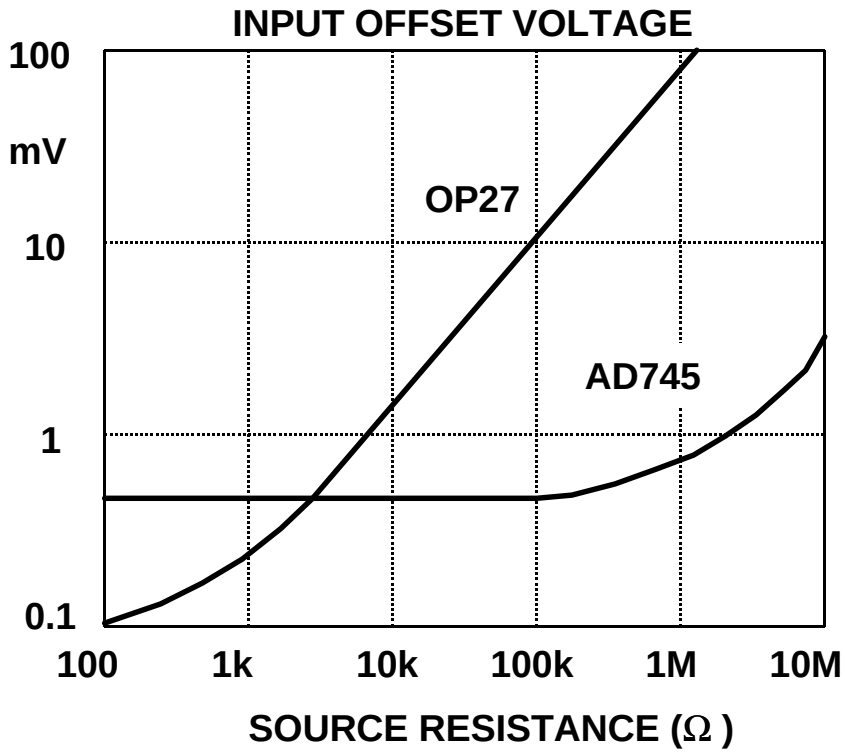
- ±5V Power Supplies Reduce I_B for 0°C to +85°C Operation, P_D = 80mW
- C1 Allows –55°C to +125°C Operation

a

EFFECTS OF SOURCE RESISTANCE ON NOISE AND OFFSET VOLTAGE FOR OP27(BIPOLAR) AND AD745 (BiFET) OP AMPS

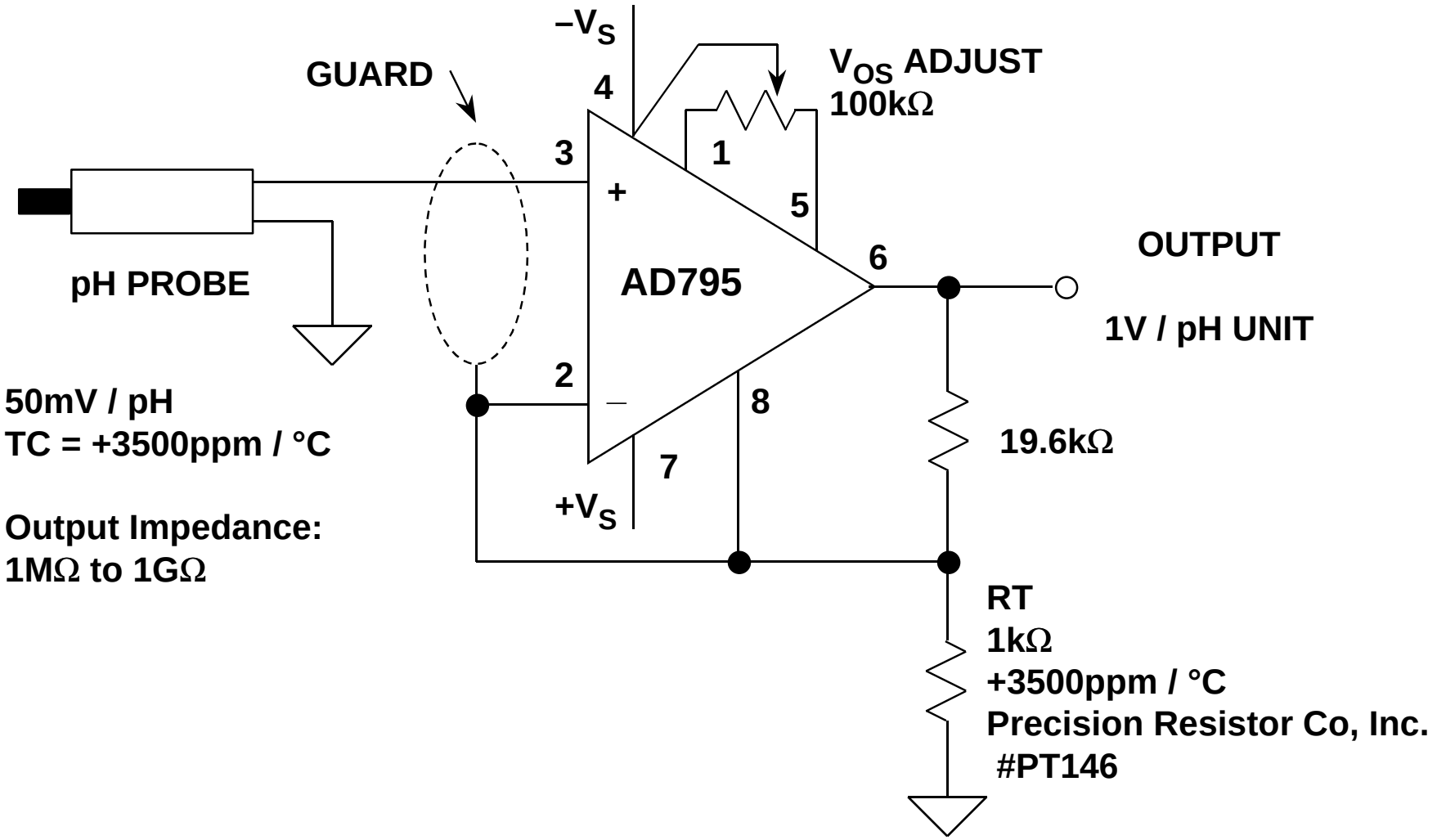






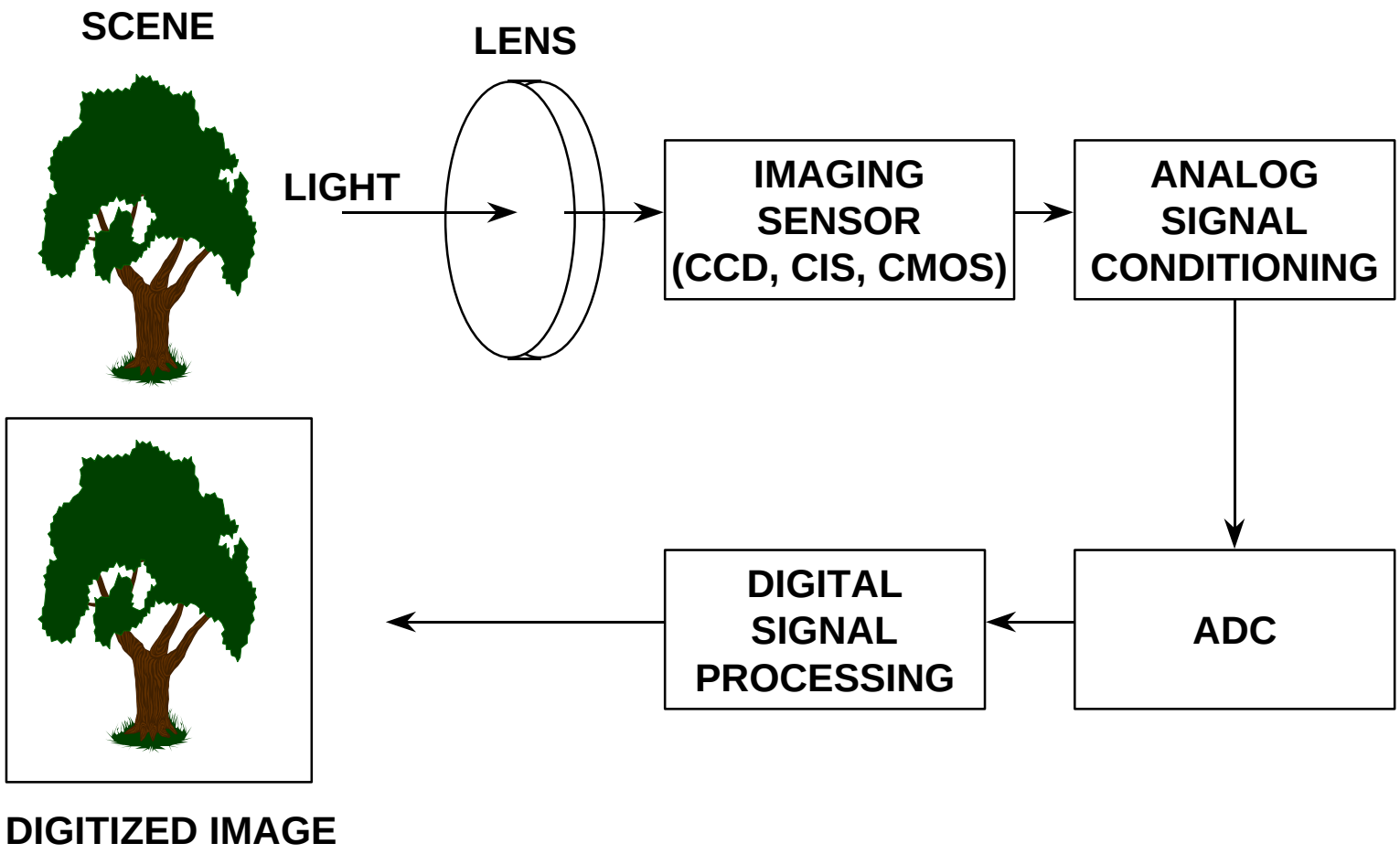
a

A pH PROBE BUFFER AMPLIFIER WITH A GAIN OF 20 USING THE AD795 PRECISION BiFET OP AMP



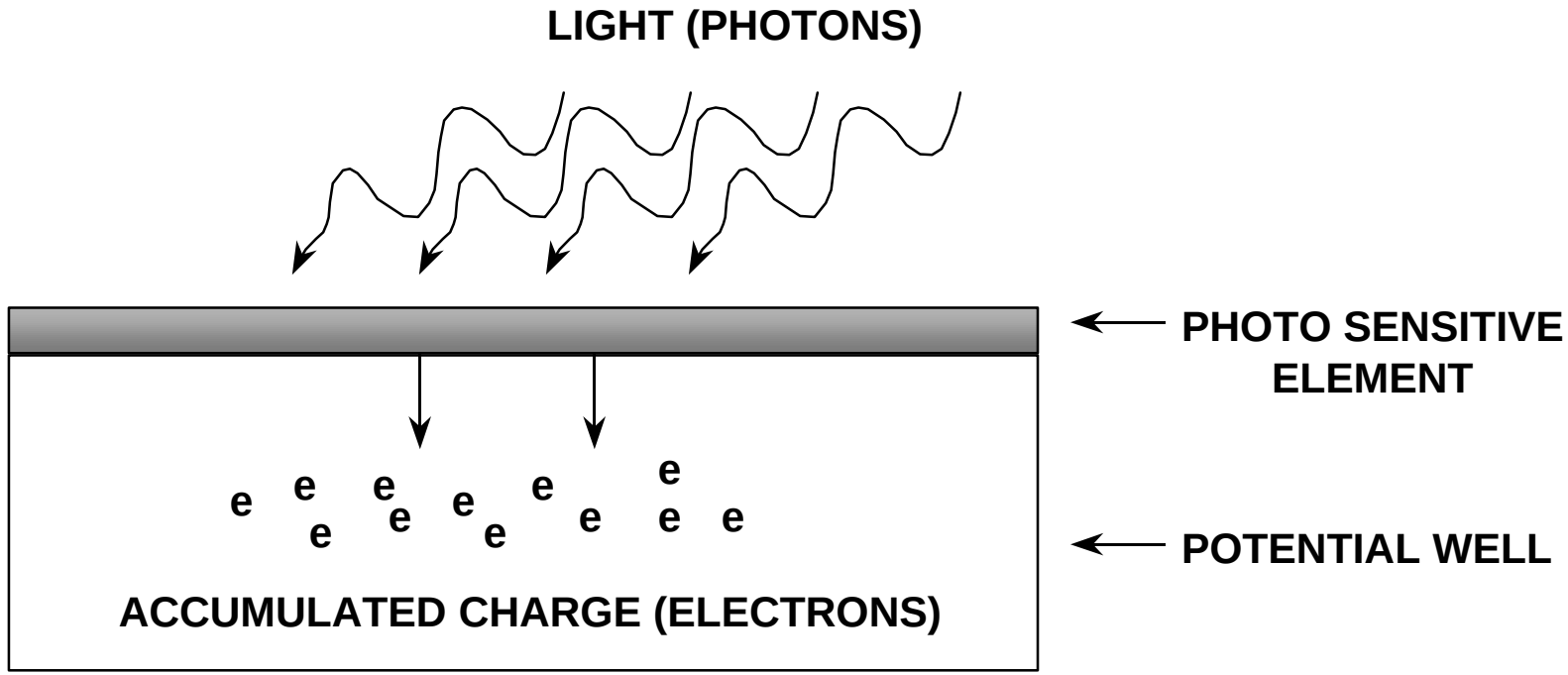
a

GENERIC IMAGING SYSTEM FOR SCANNERS OR DIGITAL CAMERAS



a

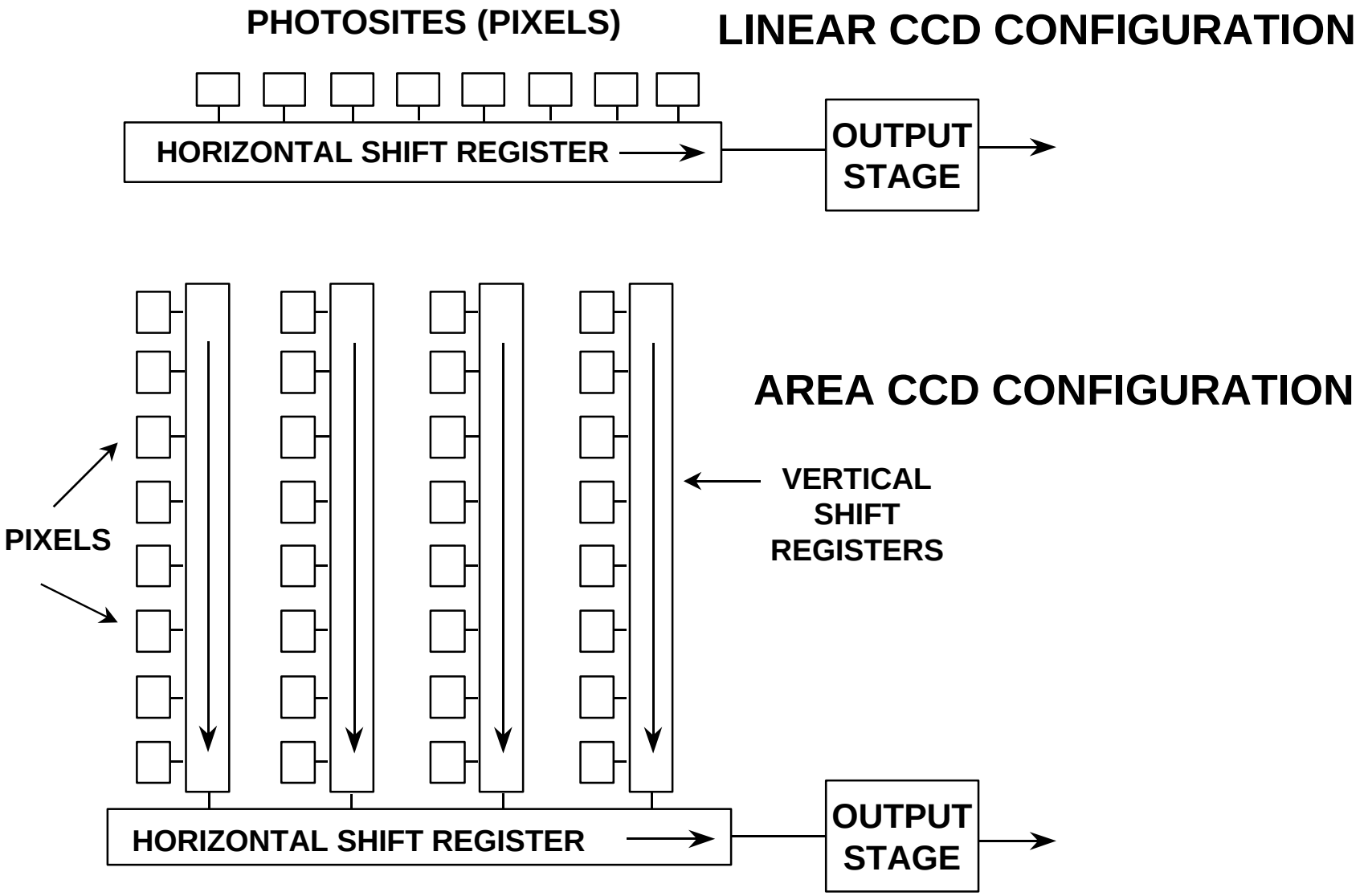
LIGHT SENSING ELEMENT



ONE PHOTOSITE OR "PIXEL"

a

LINEAR AND AREA CCD ARRAYS



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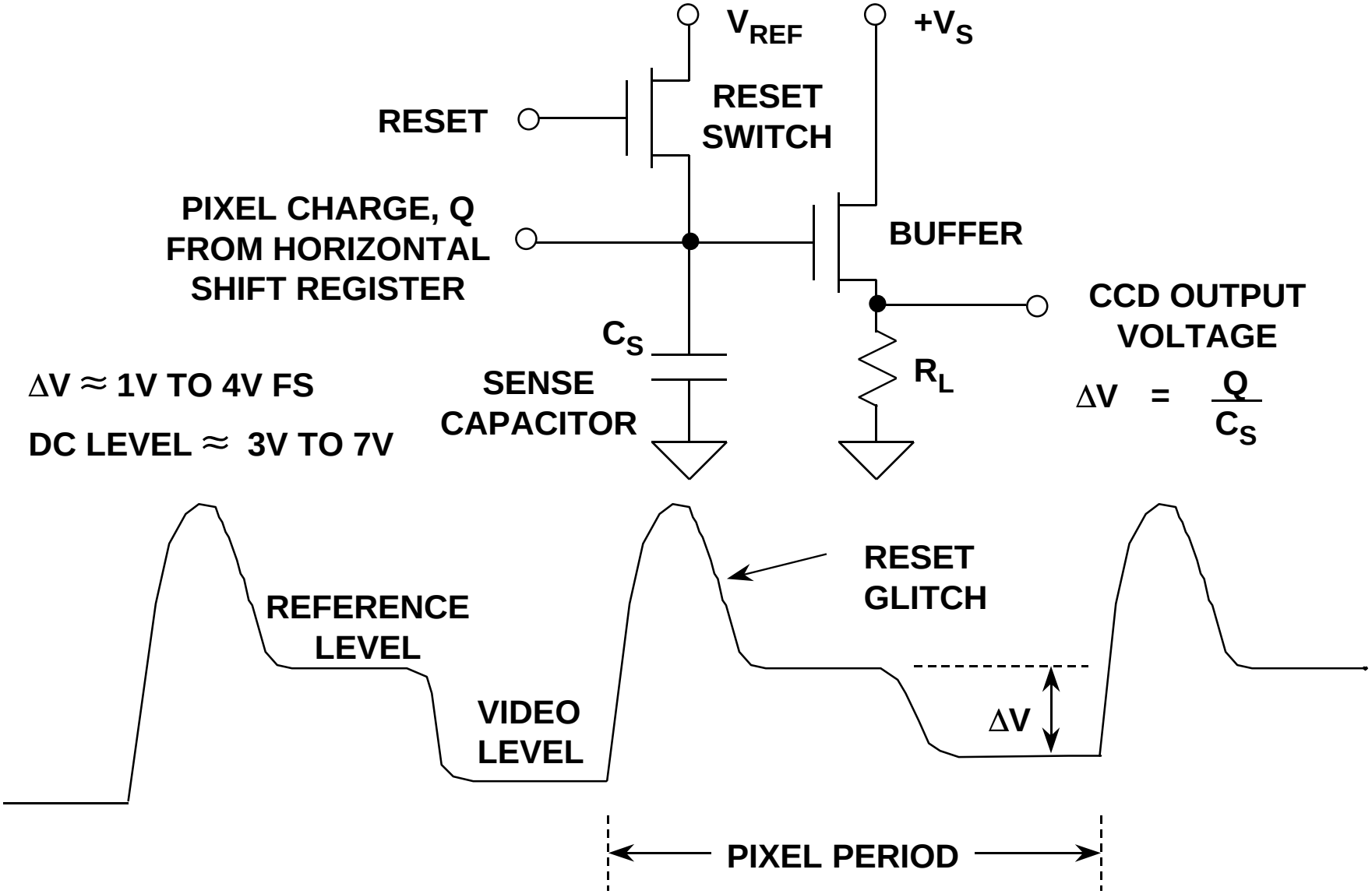
OUTPUT STAGE AND WAVEFORMS



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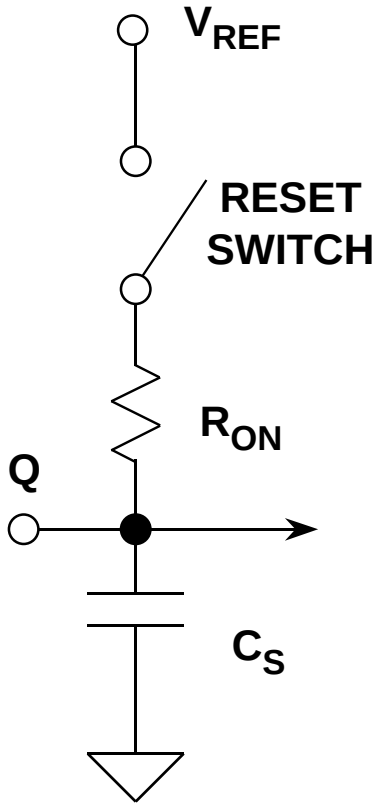
kT/C NOISE



$$\text{THERMAL NOISE} = \sqrt{4kT \cdot BW \cdot R_{ON}}$$

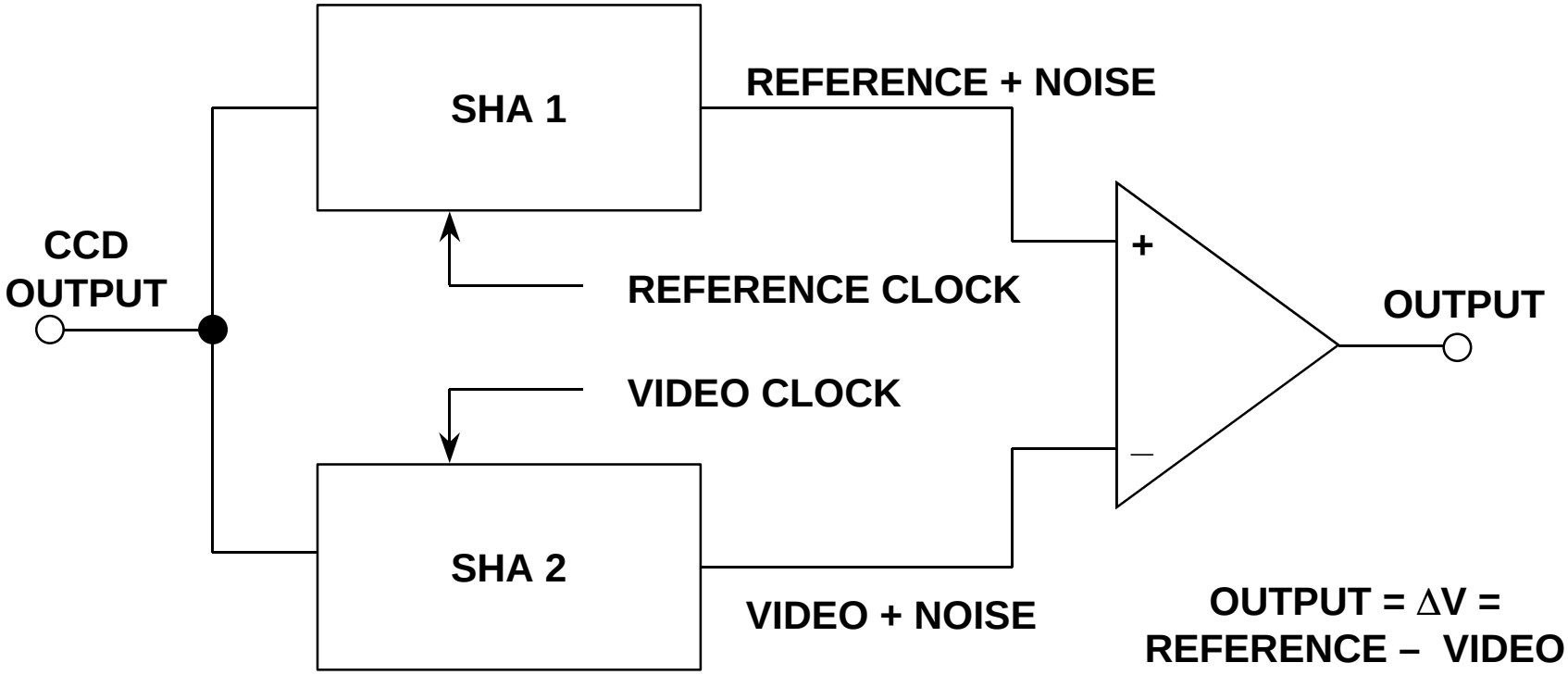
$$\text{NOISE BW} = \frac{\pi}{2}\left[\frac{1}{2\pi R_{ON}C_S}\right] = \frac{1}{4 R_{ON}C_S}$$

$$\text{THERMAL NOISE} = \sqrt{\frac{kT}{C_S}}$$

SAME VALUE PRESENT DURING REFERENCE AND VIDEO LEVELS WHILE RESET SWITCH IS OPEN

a

CORRELATED DOUBLE SAMPLING (CDS)



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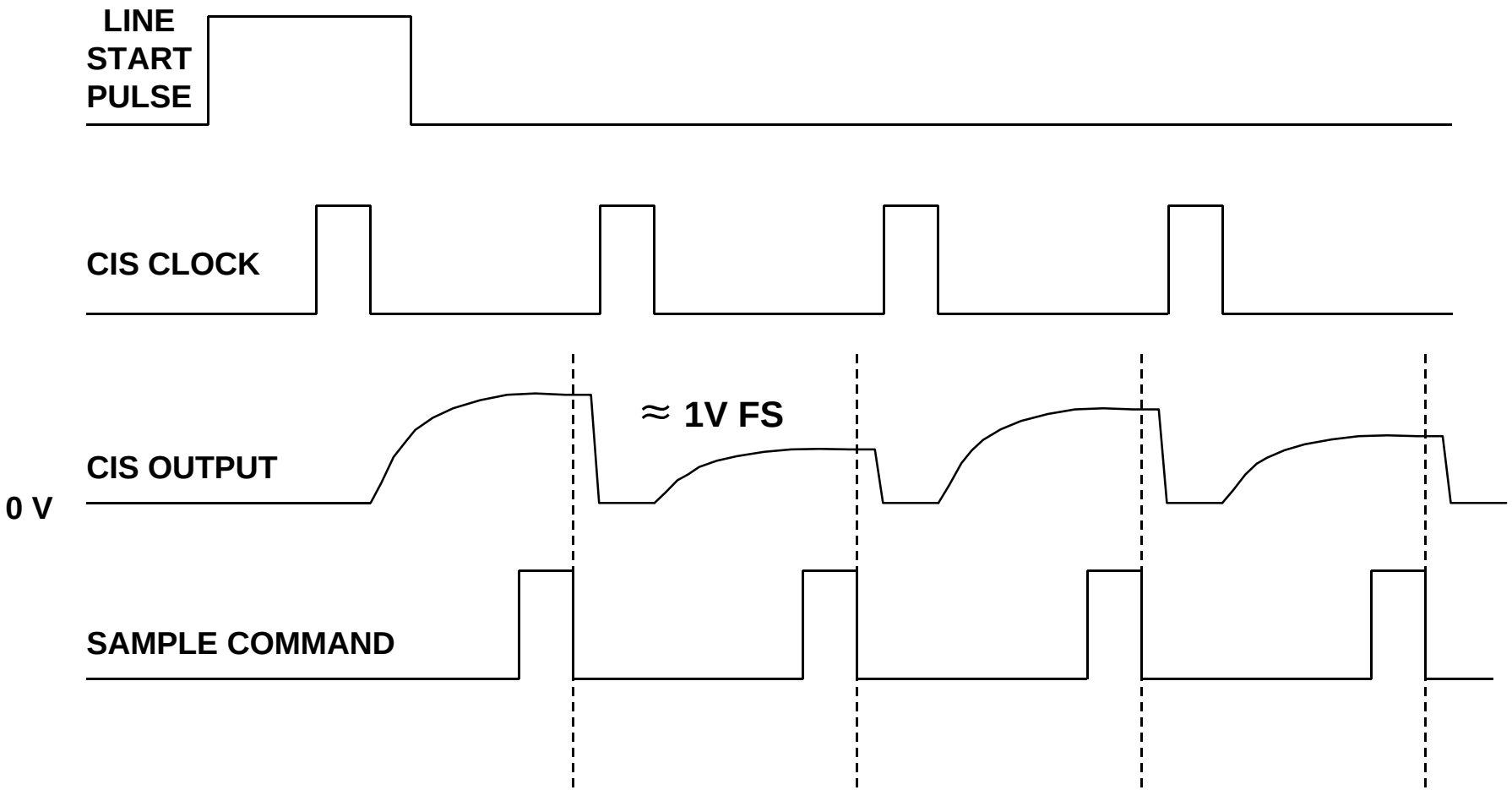
CONTACT IMAGE SENSOR (CIS) WAVEFORMS



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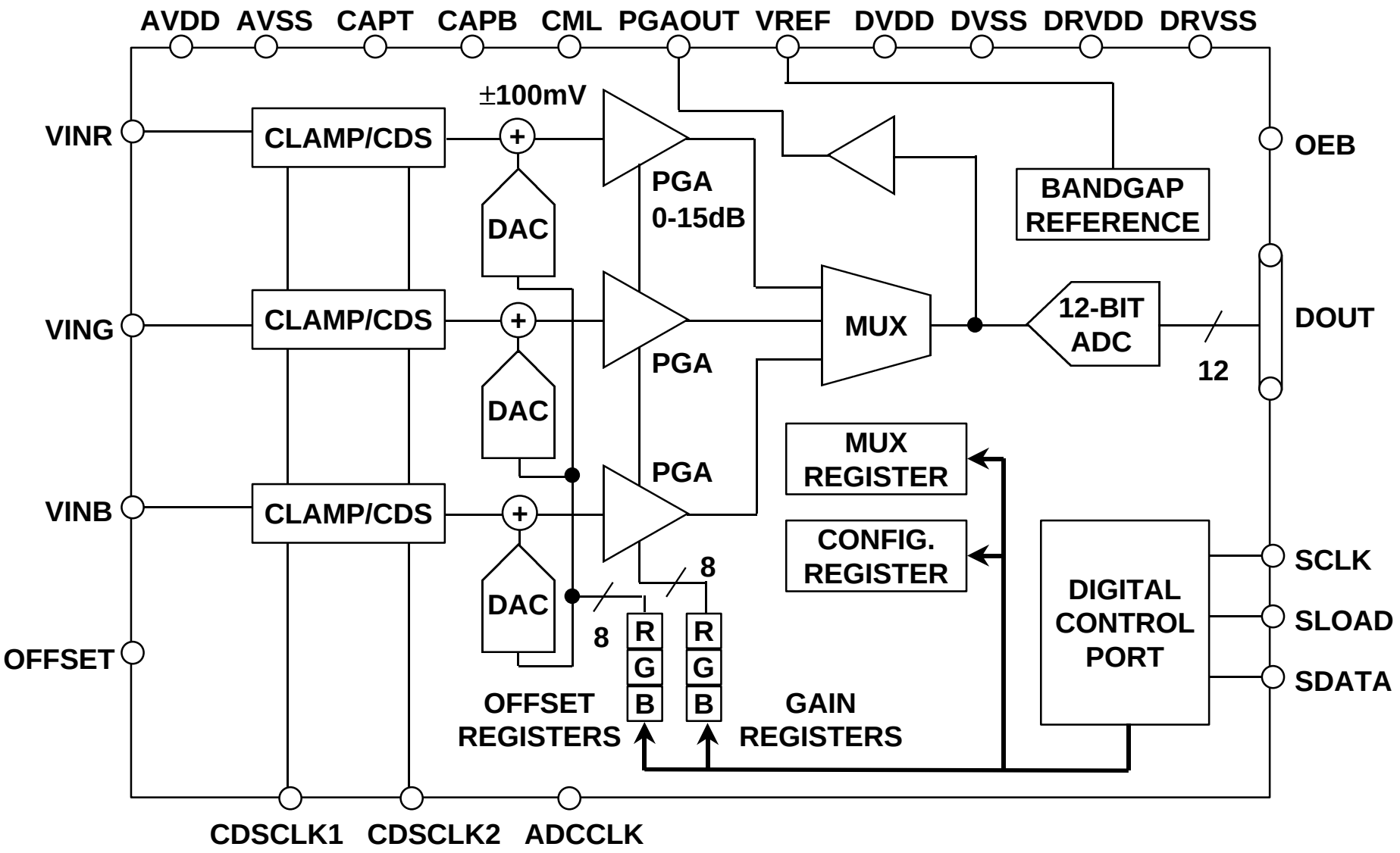
AD9816 ANALOG FRONT END CCD/CIS PROCESSOR



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AD9816 KEY SPECIFICATIONS

- **Complete 12-Bit 6MSPS CCD/CIS Signal Processor**
- **3-Channel or 1-Channel Operation**
- **On-Chip Correlated Double Sampling (CDS)**
- **8-Bit Programmable Gain and 8-Bit Offset Adjustment**
- **Internal Voltage Reference**
- **Good Linearity: DNL = ±0.4LSB Typical, INL = ±1.5 LSB Typical**
- **Low Output Noise: 0.5 LSB RMS**
- **Coarse Offset Removal for CIS Applications**
- **3-Wire Serial Interface**
- **Single +5V Supply, 420mW Power Dissipation**
- **44-Lead MQFP Package**

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