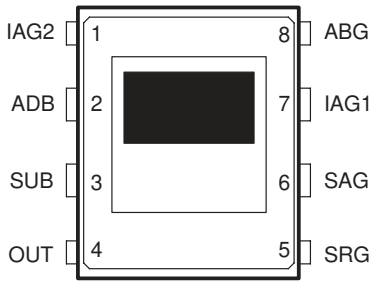
TC255
336- × 244-PIXEL CCD IMAGE SENSOR

SOCS034C – FEBRUARY 1993 – REVISED NOVEMBER 1994

- **Medium-Resolution, Solid-State Image Sensor for Low-Cost B/W TV Applications**
- **324(H) x 243(V) Active Elements in Image-Sensing Area**
- **10-μm Square Pixels**
- **Small Size**
- **Low Cost**
- **Fast Clear Capability**
- **Electronic-Shutter Function From 1/60–1/50000 s**
- **Low Dark Current**
- **Electron-Hole Recombination Antiblooming**
- **Dynamic Range . . . 66 dB Typical**
- **High Sensitivity**
- **High Blue Response**
- **8-Pin Dual-In-Line Ceramic Package**
- **4-mm Image-Area Diagonal**
- **Solid-State Reliability With No Image Burn-In, Residual Imaging, Image Distortion, Image Lag, or Microphonics**

DUAL-IN-LINE PACKAGE
(TOP VIEW)



description

The TC255 is a frame-transfer charge-coupled device (CCD) designed for use in B/W NTSC TV and special-purpose applications where low cost and small size are desired.

The image-sensing area of the TC255 is configured in 243 lines with 336 elements in each line. Twelve elements are provided in each line for dark reference. The blooming-protection feature of the sensor is based on recombining excess charge with charge of opposite polarity in the substrate. This antiblooming is activated by supplying clocking pulses to the antiblooming gate, an integral part of each image-sensing element.

The sensor can be operated in a noninterlace mode as a 324(H) by 243(V) sensor with very low dark current. The device can also be operated in an interlace mode, electronically displacing the image-sensing elements during the charge integration in alternate fields, effectively increasing vertical resolution and minimizing aliasing.

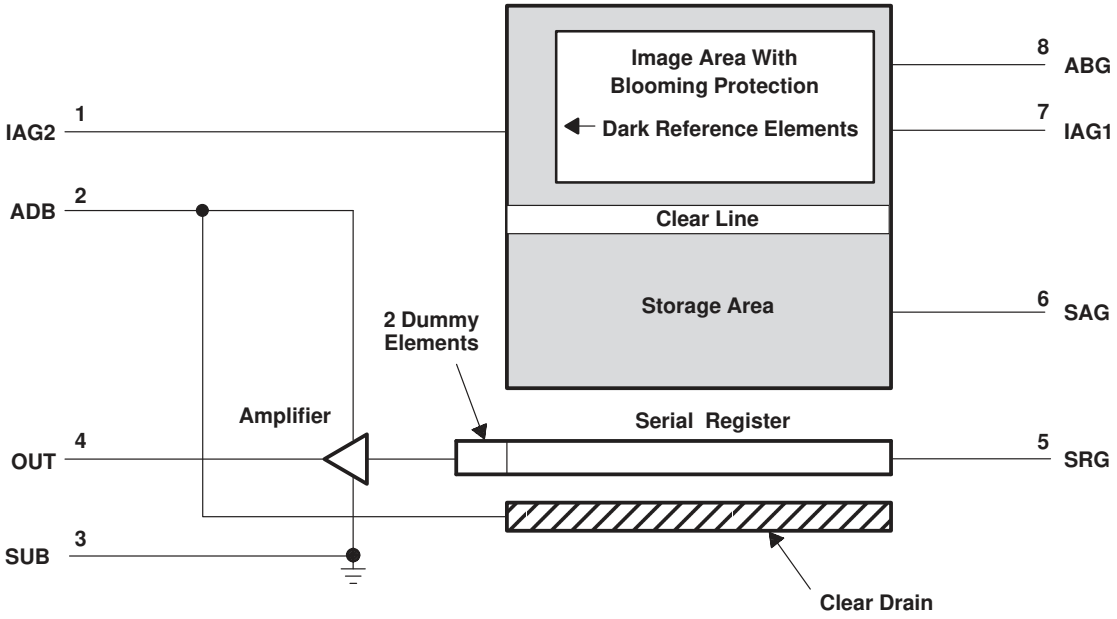
One important aspect of this image sensor is its high-speed image-transfer capability. This capability allows for an electronic-shutter function comparable to interline-transfer and frame-interline-transfer sensors without the loss of sensitivity and resolution inherent in those technologies.

The charge is converted to signal voltage with a 12-μV per-electron conversion factor by a high-performance charge-detection structure with built-in automatic reset and a voltage-reference generator. The signal is buffered by a low-noise two-stage source-follower amplifier to provide high output-drive capability.

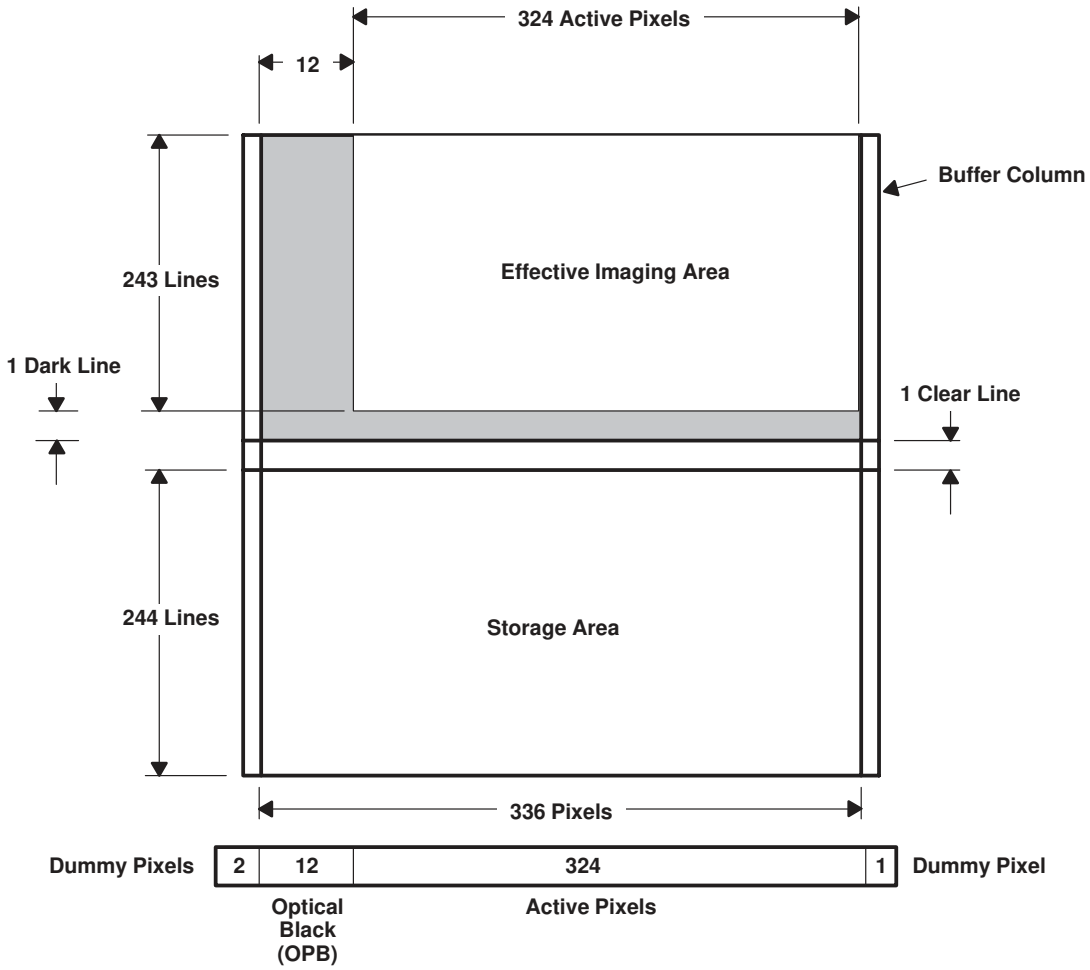
The TC255 is built using TI-proprietary virtual-phase technology, which provides devices with high blue response, low dark signal, good uniformity, and single-phase clocking. The TC255 is characterized for operation from –10°C to 45°C.

This device contains circuits to protect its inputs and outputs against damage due to high static voltages or electrostatic fields. These circuits have been qualified to protect this device against electrostatic discharges (ESD) of up to 2 kV according to MIL-STD-883C, Method 3015; however, it is advised that precautions be taken to avoid application of any voltage higher than maximum-rated voltages to these high-impedance circuits. During storage or handling, the device leads should be shorted together or the device should be placed in conductive foam. In a circuit, unused inputs should always be connected to an appropriated logic voltage level, preferably either V_{CC} or ground. Specific guidelines for handling devices of this type are contained in the publication *Guidelines for Handling Electrostatic-Discharge-Sensitive (ESDS) Devices and Assemblies* available from Texas Instruments.

functional block diagram



sensor topology diagram



Terminal Functions

TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
ABG	8	I	Antiblooming gate
ADB	2	I	Supply voltage for amplifier-drain bias
SUB	3		Substrate
IAG1	7	I	Image-area gate 1
IAG2	1	I	Image-area gate 2
OUT	4	O	Output
SAG	6	I	Storage-area gate
SRG	5	I	Serial-register gate

detailed description

The TC255 consists of five basic functional blocks: 1) the image-sensing area, 2) the clear line, 3) the storage area, 4) the serial register, and 5) the charge-detection node and output amplifier.

image-sensing area

Cross sections with potential-well diagrams and top views of image-sensing and storage-area elements are shown in Figure 1 and Figure 2. As light enters the silicon in the image-sensing area, free electrons are generated and collected in the potential wells of the sensing elements. During this time, the antiblooming gate is activated by the application of a burst of pulses every horizontal blanking interval. This prevents blooming caused by the spilling of charge from overexposed elements into neighboring elements. To generate the dark reference that is necessary in subsequent video-processing circuits for restoration of the video black level there are 12 columns of elements on the left edge of the image-sensing area that are shielded from light. There is also one column of elements on the right side of the image-sensing area and one line between the image-sensing area and the image-clearing line.

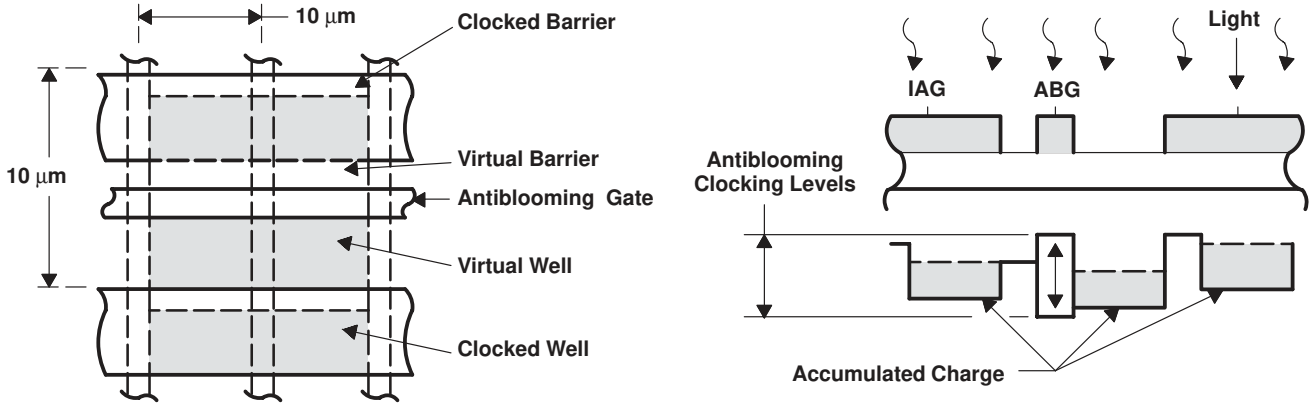


Figure 1. Charge-Accumulation Process

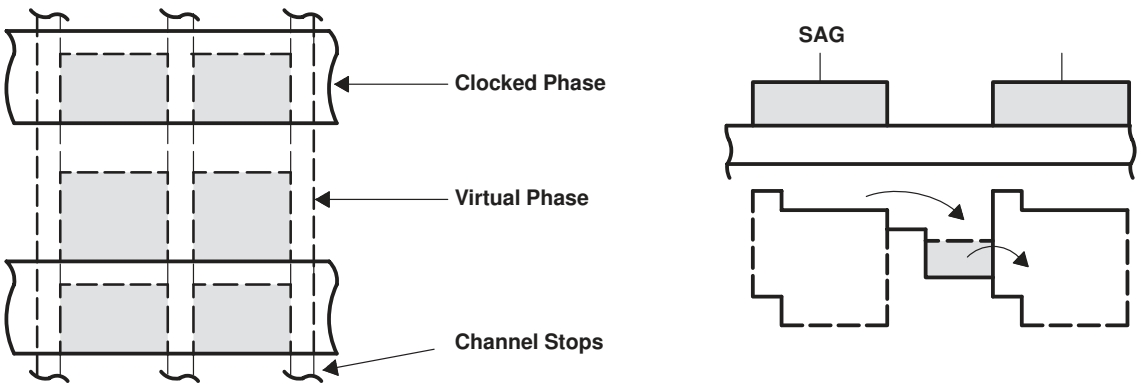


Figure 2. Charge-Transfer Process

image-clear line

During start-up or electronic-shutter operations, it is necessary to clear the image area of charge without transferring it to the storage area. In such situations, the two image-area gates are clocked 244 times without clocking the storage-area gate. The charge in the image area is then cleared through the image-clear line.

storage area

After exposure, the image-area charge packets are transferred through the image-clear line to the storage area. The stored charge is then transferred line by line into the serial register for readout. Figure 3 illustrates the timing to 1) transfer the image to the storage area and 2) to transfer each line from the storage area to the serial register.

serial register

After each line is clocked into the serial register, it is read out pixel by pixel. Figure 3 illustrates the serial-register clock sequence.

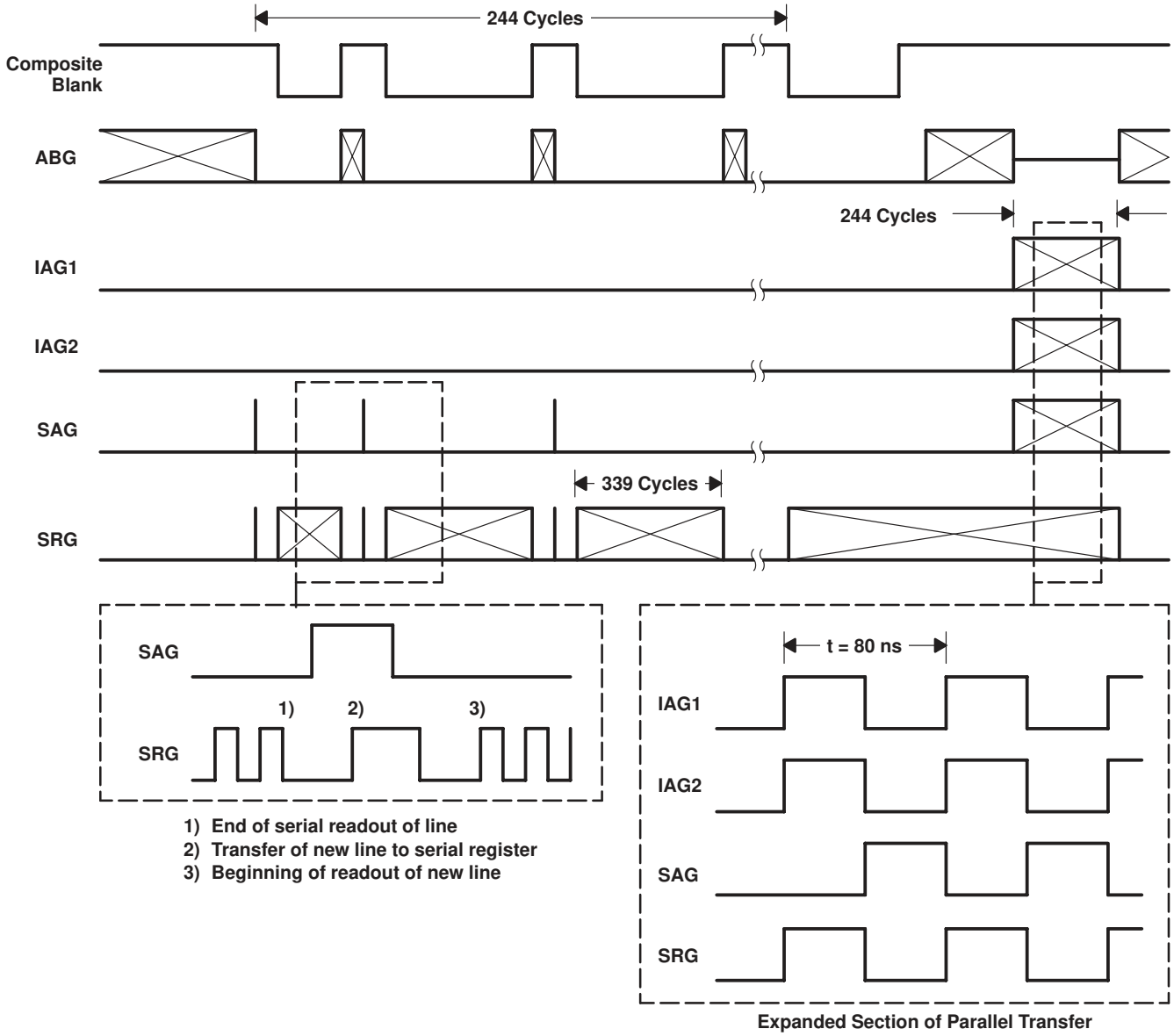


Figure 3. Timing Diagram

charge-detection node and output amplifier

The buffer amplifier converts charge into a video signal. Figure 4 shows the circuit diagram of the charge-detection node and output amplifier. As charge is transferred into the detection node, the potential of this node changes in proportion to the amount of signal received. This change is sensed by an MOS transistor and, after proper buffering, the signal is supplied to the output terminal of the image sensor. After the potential change is sensed, the node is reset to a reference voltage supplied by an on-chip reference generator. The reset is accomplished by a reset gate that is connected internally to the serial register. The detection node and buffer amplifier are located a short distance away from the edge of the storage area; therefore, two dummy cells are used to span this distance.

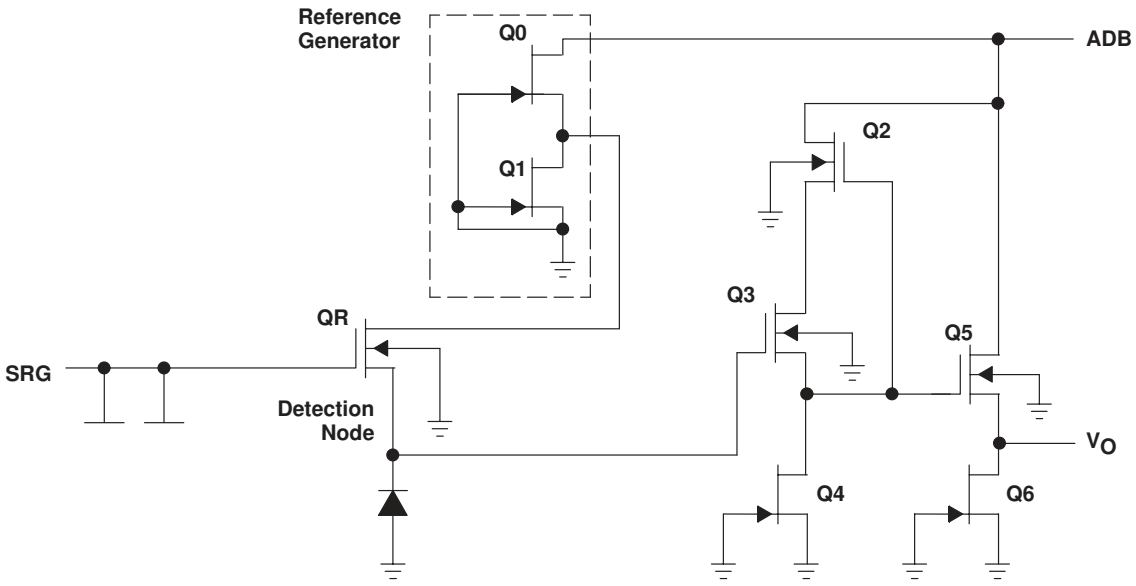


Figure 4. Output Amplifier and Charge-Detection Node

spurious nonuniformity specification

The spurious nonuniformity specification of the TC255 is based on several sensor characteristics:

- Amplitude of the nonuniform pixel
- Polarity of the nonuniform pixel
  - Black
  - White
- Column amplitude

The CCD sensor is characterized in both an illuminated condition and a dark condition. In the dark condition, the nonuniformity is specified in terms of absolute amplitude as shown in Figure 5. In the illuminated condition, the nonuniformity is specified as a percentage of the total illumination as shown in Figure 6.

The specification for the TC255 is as follows:

WHITE SPOT (DARK)	WHITE SPOT (ILLUMINATED)	COLUMN (DARK)	COLUMN (ILLUMINATED)	BLACK SPOT (ILLUMINATED)	WHITE/BLACK† PAIR
x < 15 mV	x < 15%	x < 0.5 mV	x < 1 mV	x < 15%	x < 9mV

† A white/black pair nonuniformity is no more than 2 pixels even for integration times of 1/60 second.

The conditions under which this specification is defined are as follows:

1. The integration time is 1/60 second except for illuminated white spots, illuminated black spots and white/black pair nonuniformities; in these three cases the integration time is 1/240 second.
2. The temperature is 45°C.
3. The CCD video-output signal is 60 mV ± 10 mV.

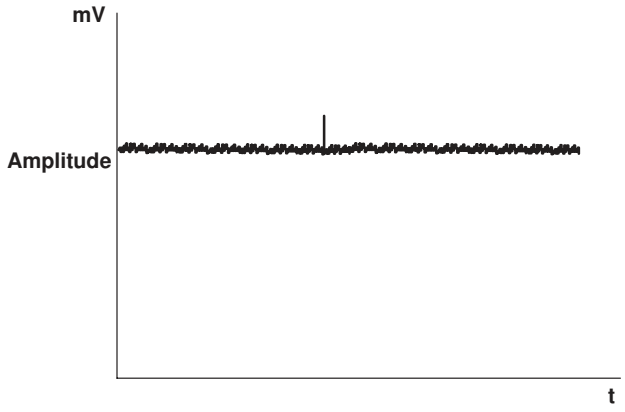


Figure 5. Pixel Nonuniformity, Dark Condition

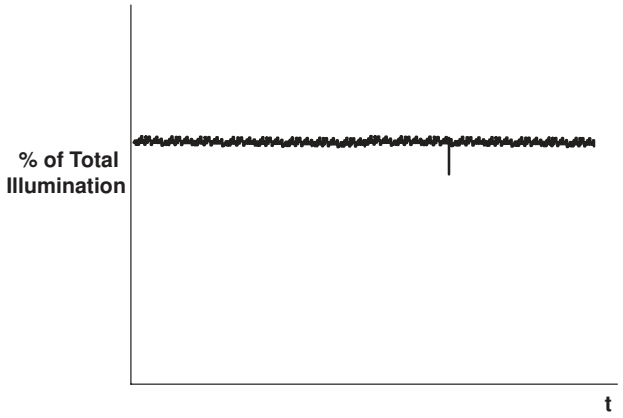


Figure 6. Pixel Nonuniformity, Illuminated Condition

absolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Supply voltage range for ADB (see Note 1) . . . . . 0 V to 15 V
Input voltage range for ABG, IAG1, IAG2, SAG, SRG . . . . . –15 V to 15 V
Operating free-air temperature range, T_A . . . . . –10°C to 45°C
Storage temperature range . . . . . –30°C to 85°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltages are with respect to the substrate terminal.

recommended operating conditions

			MIN	NOM	MAX	UNIT
Supply voltage, ADB			11	12	13	V
Substrate bias voltage				0		V
Input voltage, V_I	IAG1, IAG2	High	1.5	2	2.5	V
		Low	–10.5	–10	–9.5	
	SAG	High	1.5	2	2.5	
		Low	–10.5	–10	–9.5	
	SRG	High	1.5	2	2.5	
		Low	–10.5	–10	–9.5	
	ABG	High	3.5	4	4.5	
		Intermediate		–2.5‡		
		Low	–8	–7	–6	
Clock frequency, f_{clock}	ABG			6.25	12.5	MHz
	IAG1, IAG2				25	
	SAG				12.5	
	SRG			6.25	12.5	
Capacitive load	OUT				6	pF
Operating free-air temperature, T_A			–10		45	°C

‡ Adjustment is required for optimum performance.

electrical characteristics over recommended operating range of supply voltage, T_A = –10°C to 45°C

PARAMETER		MIN	TYP	MAX	UNIT
Dynamic range (see Note 2)	Antiblooming disabled (see Note 3)		66		dB
Charge conversion factor		11	12	13	μV/e
Charge-transfer efficiency (see Note 4)			0.9995	0.99999	
Signal-response delay time, τ (see Note 5)			20		ns
Gamma (see Note 6)		0.97	0.98	0.99	
Output resistance			350		Ω
Noise equivalent signal without correlated double sampling			62		electrons
Noise-equivalent signal with correlated double sampling (see Note 7)			31		electrons
Rejection ratio	ADB (see Note 8)	13	15	18	dB
	SRG (see Note 9)		50		
	ABG (see Note 10)		40		
Supply current			5	10	mA
Input capacitance, C_i	IAG 1, 2		1000		pF
	SRG		22		
	ABG		850		
	SAG		2000		

NOTES: 2. Dynamic range is –20 times the logarithm of the mean-noise signal divided by saturation output signal.
3. For this test, the antiblooming gate must be biased at the intermediate level.
4. Charge-transfer efficiency is one minus the charge loss per transfer in the output register. The test is performed in the dark using an electrical input signal.
5. Signal-response delay time is the time between the falling edge of the SRG pulse and the output signal valid state.
6. Gamma (γ) is the value of the exponent in the equation below for two points on the linear portion of the transfer function curve (this value represents points near saturation).

$$\left(\frac{\text{Exposure (2)}}{\text{Exposure (1)}}\right)^{\gamma} = \left(\frac{\text{Output signal (2)}}{\text{Output signal (1)}}\right)$$

7. A triple-level serial gate clock is necessary to implement correlated double sampling.
8. ADB rejection ratio is –20 times the logarithm of the ac amplitude at the output divided by the ac amplitude at ADB. See Figure 11 for measured ADB rejection ratio as a function of frequency.
9. SRG rejection ratio is –20 times the logarithm of the ac amplitude at the output divided by the ac amplitude at SRG.
10. ABG rejection ratio is –20 times the logarithm of the ac amplitude at the output divided by the ac amplitude at ABG.

optical characteristics, T_A = 40°C, integration time = 16.67 ms (unless otherwise noted)

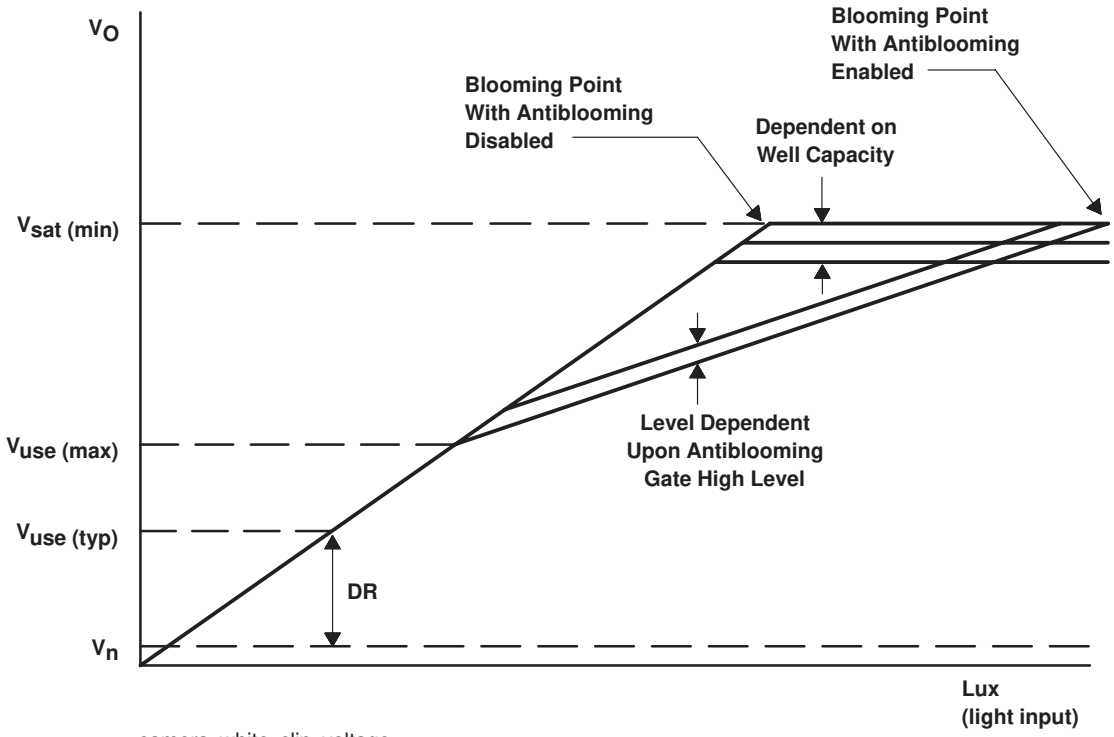
PARAMETER		MIN	TYP	MAX	UNIT
Sensitivity	No IR filter		350		mV/lx
	With IR filter		45		
Saturation signal, V_{sat} (see Note 11)	Antiblooming disabled, Interlace off	600	750		mV
Maximum usable signal, V_{use}	Antiblooming enabled	200	250		mV
Blooming overload ratio (see Note 12)		100	200		
Image-area well capacity		50000	62500		electrons
Smear (see Notes 13 and 14)			0.00012		
Dark current	Interlace disabled, T_A = 21°C		0.20		nA/cm^2
Dark signal			200		μV
Pixel uniformity	Output signal = 60 mV ± 10 mV		15		mV
Column uniformity	Output signal = 60 mV ± 10 mV		0.5		mV
Shading			15		%
Electronic-shutter capability		1/15000	1/60		s

NOTES: 11. Saturation is the condition in which further increase in exposure does not lead to further increase in output signal.
12. Blooming is the condition in which charge is induced in an element by light incident on another element. Blooming overload ratio is the ratio of blooming exposure to saturation exposure.
13. Smear is a measure of the error introduced by transferring charge through an illuminated pixel in shutterless operation. It is equivalent to the ratio of the single-pixel transfer time to the exposure time using an illuminated section that is 1/10 of the image-area vertical height with recommended clock frequencies.
14. The exposure time is 16.67 ms, the fast-dump clocking rate during vertical transfer is 12.5 MHz, and the illuminated section is 1/10 of the height of the image section.

timing requirements

			MIN	NOM	MAX	UNIT
t_r	Rise time	ABG	10	40		ns
		IAG1, 2 (fast clear)	10	10		
		IAG1, 2 (image transfer)	10	20		
		SAG	10	20		
		SRG	10	40		
t_f	Fall time	ABG	10	40		ns
		IAG1, 2 (fast clear)	10	10		
		IAG1, 2 (image transfer)	10	20		
		SAG	10	20		
		SRG	10	40		

PARAMETER MEASUREMENT INFORMATION



$$\text{DR (dynamic range)} = \frac{\text{camera white clip voltage}}{V_n}$$

V_n = noise floor voltage
$V_{sat\ (min)}$ = minimum saturation voltage
$V_{use\ (max)}$ = maximum usable voltage
$V_{use\ (typ)}$ = typical user voltage (camera white clip)

NOTES: A. $V_{use\ (typ)}$ is defined as the voltage determined to equal the camera white clip. This voltage must be less than $V_{use\ (max)}$.
B. A system trade-off is necessary to determine the system light sensitivity versus the signal/noise ratio. By lowering the $V_{use\ (typ)}$, the light sensitivity of the camera is increased; however, this sacrifices the signal/noise ratio of the camera.

Figure 7. V_{sat}, V_{use} Relationship

PARAMETER MEASUREMENT INFORMATION

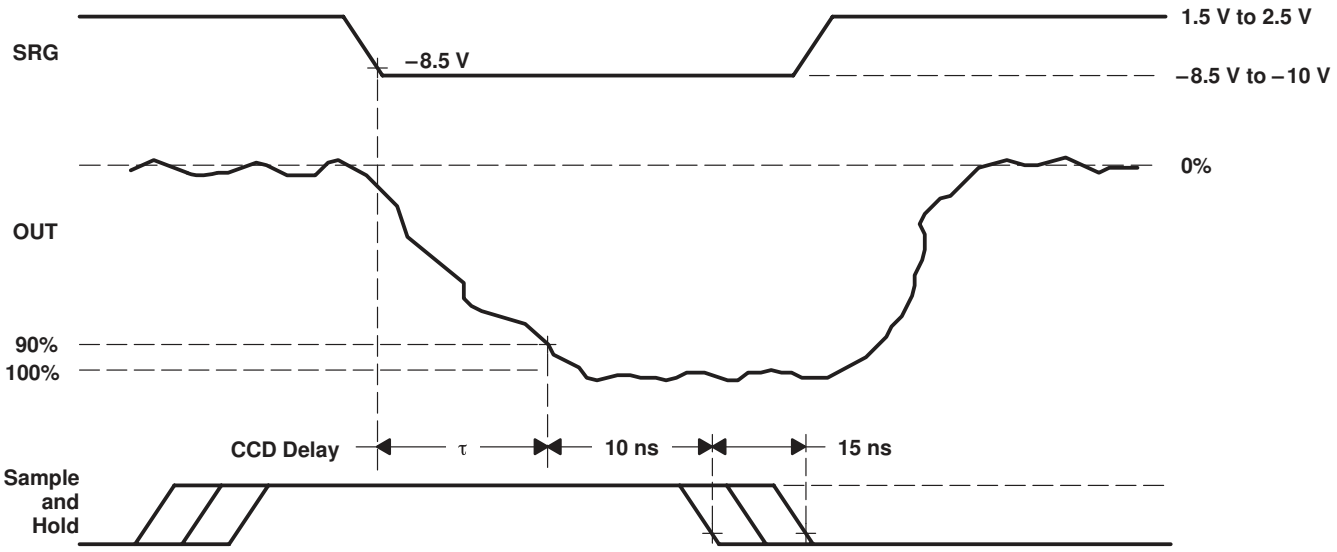


Figure 8. SRG and CCD Output Waveforms

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TYPICAL CHARACTERISTICS

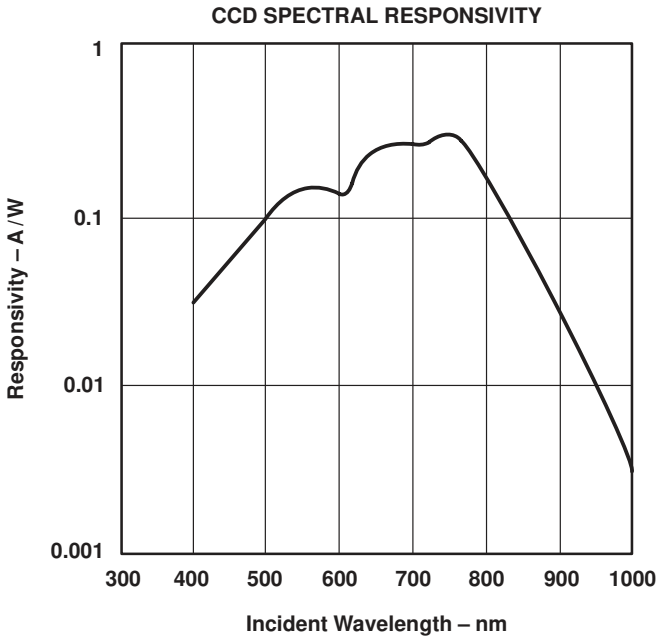


Figure 9

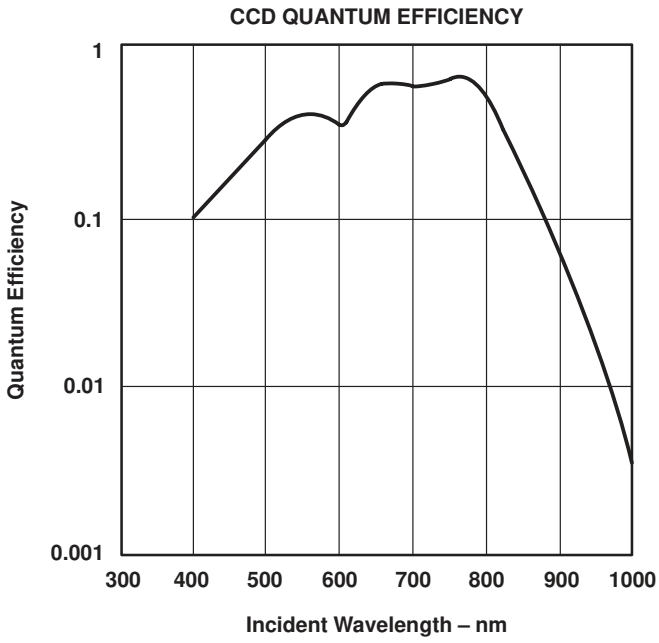


Figure 10

TYPICAL CHARACTERISTICS

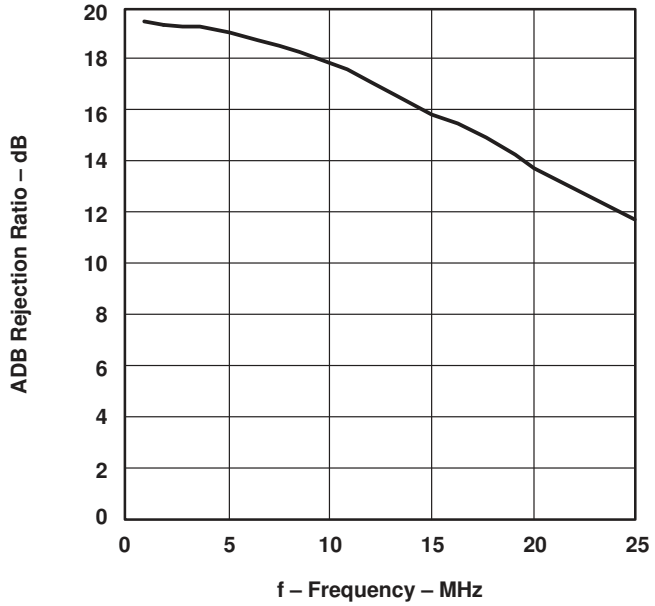


Figure 11. Measured ADB Rejection Ratio as a Function of Frequency

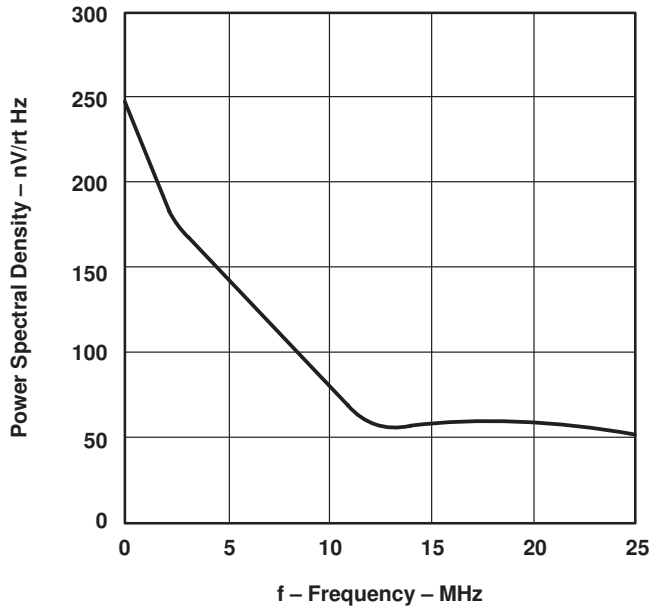
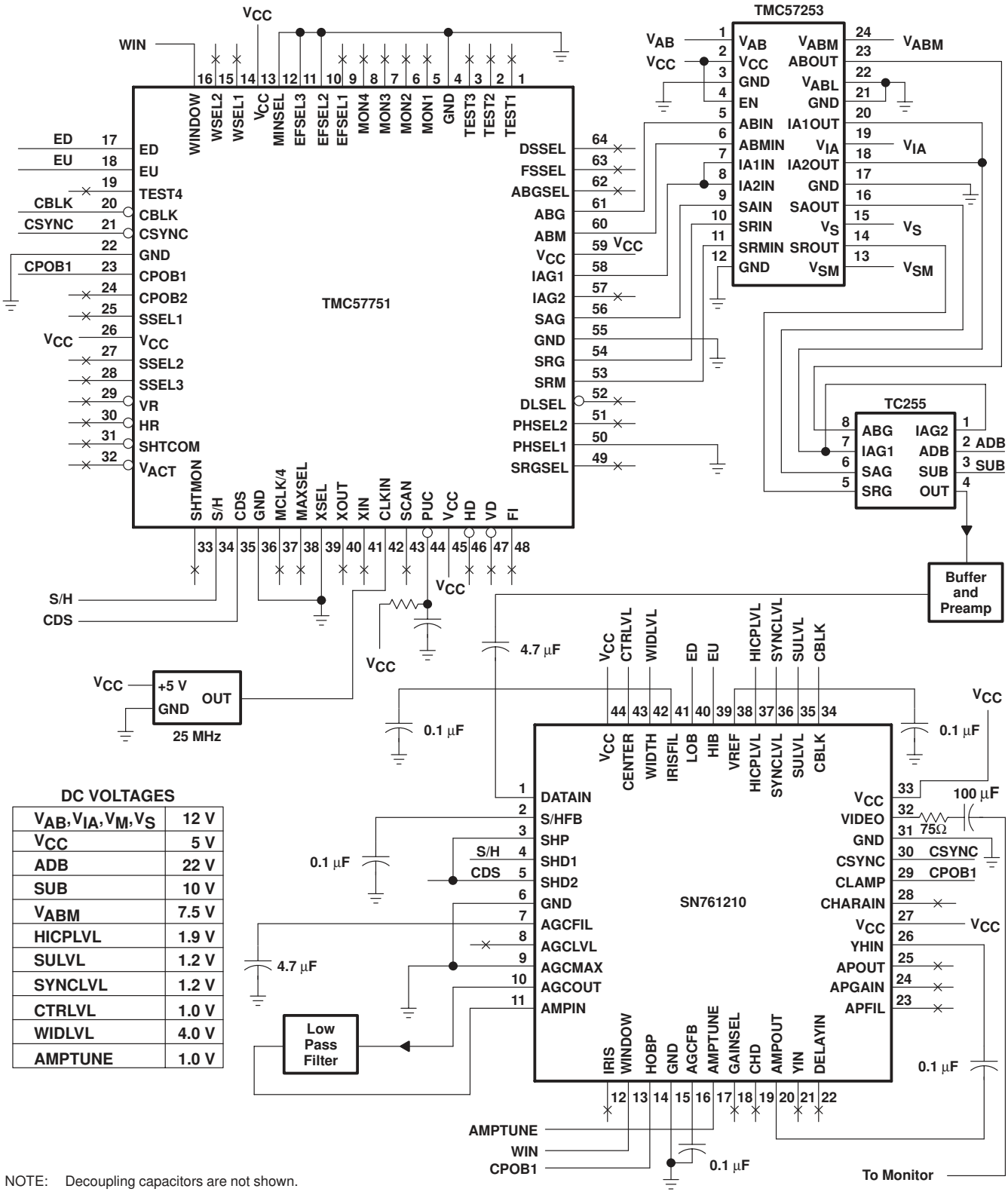


Figure 12. Noise Power Spectral Density

APPLICATION INFORMATION



DC VOLTAGES

V_{AB}, V_{IA}, V_M, V_S	12 V
V_{CC}	5 V
ADB	22 V
SUB	10 V
V_{ABM}	7.5 V
HICPLVL	1.9 V
SULVL	1.2 V
SYNCLVL	1.2 V
CTRLVL	1.0 V
WIDLVL	4.0 V
AMPTUNE	1.0 V

NOTE: Decoupling capacitors are not shown.

Figure 13. Typical Application Circuit

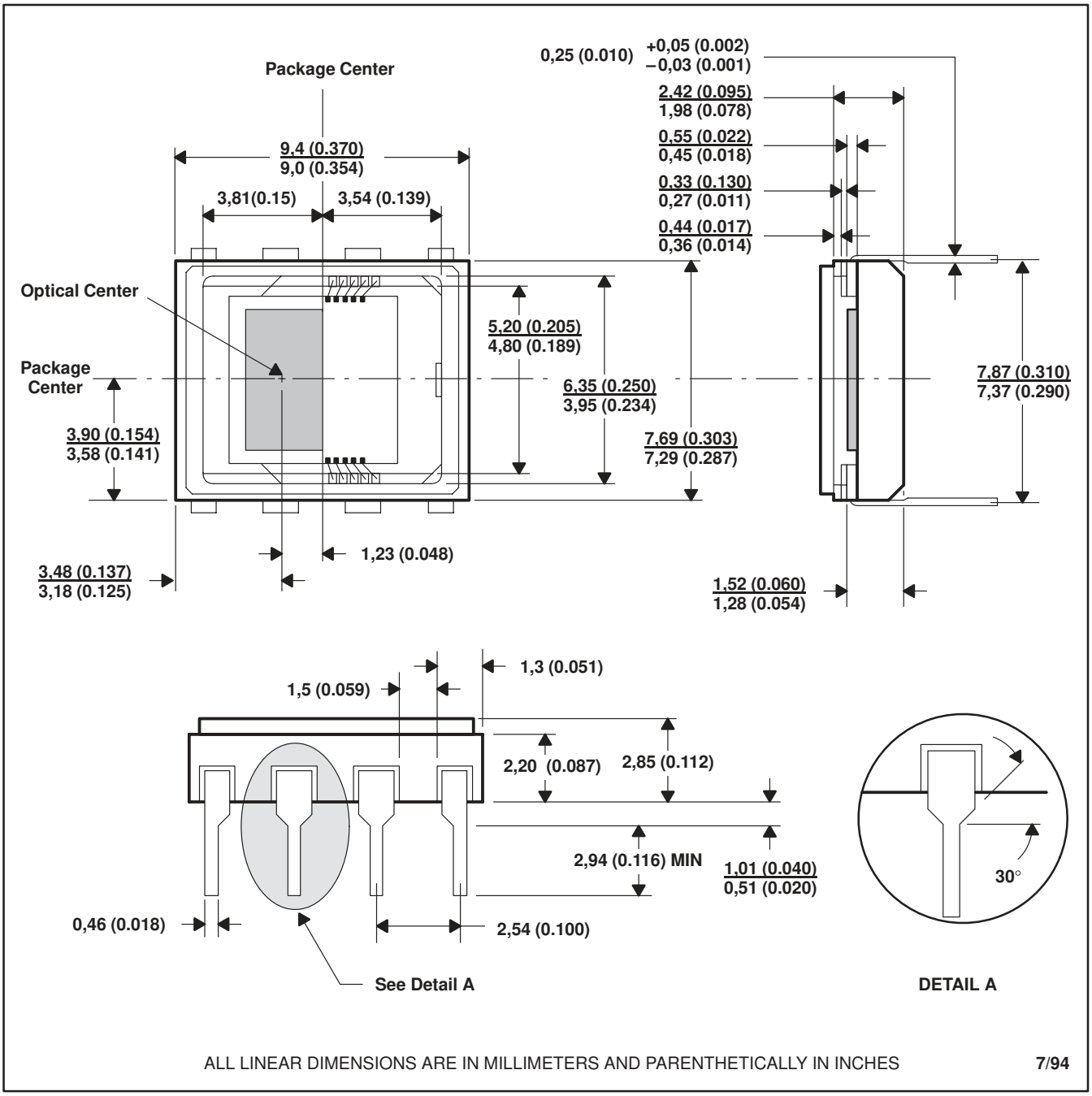
APPLICATION INFORMATION

SUPPORT CIRCUITS			
DEVICE	**PACKAGE**	**APPLICATION**	**FUNCTION**
TMC57751LQFP	64-pin flat pack	Timing generator	EIA-170 timing and CCD control signals
TMC57253HSOP	24-pin small outline package	Driver	Driver for ABG, IAG1, IAG2, SAG, and SRG
SN761210FR	44-pin flat pack	Video processor	SYNC, BLANK, AGC, IRIS, CLAMP, S/H, CDS, and WINDOW

Figure 13. Typical Application Circuit (continued)

MECHANICAL DATA

The package for the TC255 consists of a ceramic base, a glass window, and an 8-lead frame. The glass window is sealed to the package by an epoxy adhesive. The package leads are configured in a dual-in-line organization and fit into mounting holes with 2,54 mm (0.1 inch) center-to-center spacings.



NOTES: A. Single dimensions are nominal except where noted.
B. The center of the package and the center of the image area are not coincident.
C. The glass is 0.65 ± 0.05 mm thick and has an index of refraction of 1.53.
D. The distance from the top of the glass to the die is 1.47 ± 0.14 mm.
E. Maximum rotation of sensor within package is ± 1°.

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