Glossary of Symbols and Acronyms

A	area (m^2); optical absorption
A_b	beam area (mm^2)
A_d	detector area (mm^2)
A_{EP}	entrance pupil area (mm^2)
A_o	illuminated object area (mm^2)
A_p	pixel area (μm^2)
AO	acousto-optic
AOI	angle of incidence (rads)
APD	avalanche photodiode
APS	active-pixel sensor
AR	antireflection
ASE	amplified spontaneous emission
$A\Omega$	étendue (m^2-sr)
B	focused blur diameter (μm); PSD frequency exponent
B_{SA}	focused blur diameter due to spherical aberration (μm)
BFD	back focal distance
BPF	bandpass filter
BPP	beam-parameter product (mm-mrad)
BSDF	bidirectional scatter distribution function
c	speed of light, $\approx 3 \times 10^8$ m/sec
C	wavefront or surface curvature (1/mm)
C_o	wavefront curvature incident on lens (1/mm)
C_i	wavefront curvature exiting lens (1/mm); image contrast
C_{sp}	speckle contrast
C_{well}	charge-well capacitance (pF)
CA	clear aperture
CCD	charge-coupled device
CDS	correlated double sampling
CMOS	complementary metal-oxide semiconductor

CoO	cost of ownership
COTS	commercial off-the-shelf
cps	counts per second
CRT	cathode-ray tube
CTE	charge-transfer efficiency; coefficient of thermal expansion
CTIA	capacitive transimpedance amplifier
CW	continuous wave
d	distance (m)
d_c	coherence length (m)
$d_{c,n}$	coherence length in a medium of index n (m)
d_{FP}	Fabry–Pérot cavity thickness (mm)
dn/dT	change in index with temperature (1/K)
d_p	pixel size (μm)
D	lens diameter or aperture size (mm); fiber diameter (μm)
D_{1/e^2}	beam diameter ($1/e^2$) incident on or exiting from a lens (mm)
$D_b(z)$	beam diameter (mm)
D_{EP}	entrance-pupil diameter (mm)
D_o	waist diameter (mm)
DBR	distributed Bragg reflector
DCR	dark-count rate [e^-/sec or counts per sec (cps)]
DE	directed energy
DFG	difference-frequency generation
DI	direct injection
DLC	diamond-like carbon
DoF	degrees of freedom
DOF	depth of focus (μm)
dpi	dots per inch
DPSS	diode-pumped solid-state
DWDM	dense wavelength-division multiplexing
E	irradiance (W/m^2); Young's modulus (GPa)
E_g	bandgap energy (J or eV)
E_i	electron energy for energy level i (J or eV)
E_o	Gaussian peak irradiance (W/m^2)
E_p	photon energy (J or eV)
EB-CCD	electron-bombarded CCD
EB-CMOS	electron-bombarded CMOS
EFL	effective focal length (mm)
EM	electromagnetic
EM-CCD	electron-multiplying CCD
EOL	end of life

EOM	electro-optic modulator
ESD	energy spectral density
f	focal length (mm); electrical frequency (Hz)
f_d	FPA cutoff frequency (lp/mm)
f_{RO}	relaxation-oscillation frequency (Hz)
f_s	spatial frequency (lp/mm); mirror scan frequency (Hz)
$f/\#$	relative aperture, $\equiv f/D$
F	fluence (J/m^2)
$F(G)$	excess noise factor
F_R	cavity finesse based on power reflectivity R_P
FBG	fiber Bragg grating
FET	field effect transistor
FF	FPA fill factor
FHG	fourth-harmonic generation
FOI	field of illumination (rad)
FOR	field of regard (rad)
FOV	field of view (rad)
FP	Fabry–Pérot
FPA	focal plane array
FPN	fixed-pattern noise
FR	frame rate [Hz or frames per sec (fps)]
FSM	fast-steering mirror
FSR	free spectral range (Hz)
FWHM	full-width at half-maximum
g	laser gain (1/cm)
g_i	laser-cavity stability parameter
G	detector gain; thermo-optic constant (1/K)
GM-APD	Geiger-mode APD
GVD	group-velocity dispersion
h	Planck's constant, $= 6.626 \times 10^{-34}$ J-sec; mirror thickness (mm)
HFOV	half-FOV (rad)
HAZ	heat-affected zone
HPD	hybrid photodetector
HR	high reflectivity
HSF	high spatial frequency
HT	high transmission
HWP	half-wave plate
i	current (A)
i_b	detector background current (A)

i_d	detector current (A)
i_{dc}	detector dark current (A)
i_s	detector signal current (A)
i_{th}	laser threshold current (A)
I	intensity (W/sr)
IAD	ion-assisted deposition
IBS	ion-beam sputtering
ICCD	intensified CCD
IFOV	instantaneous FOV (μrad)
IR	infrared
IRCM	IR countermeasure
ISO	International Standards Organization
J	rotational moment of inertia (kg-m^2)
k	APD ionization coefficient; thermal conductivity (W/m-K)
K_{SA}	blur size factor due to spherical aberration
K_T	truncation factor
KTP	potassium titanium-oxide phosphate
L	length (m); radiance or brightness (W/m^2-sr)
L_i	image radiance (W/m^2-sr)
L_s	source radiance (W/m^2-sr)
L_λ	spectral radiance or brightness (W/m^2-sr-nm)
LAM	laser additive manufacturing
LCOS	liquid crystal on silicon
LCPG	liquid crystal polarization grating
LDT	laser damage threshold (J/cm^2 or W/cm^2)
LED	light-emitting diode
LIDT	laser-induced damage threshold
LLL	low light level
LMA	large mode area
LM-APD	linear-mode APD
lp	line pair
LWIR	longwave IR
m	integer, 1, 2, 3…; waist magnification w_{02}/w_{01}; mass (kg)
m_i	image modulation; image magnification
m_{lens}	lens object-image magnification
m_p	peak waist magnification w_{02}/w_{01} at 1f:1f conjugates
M	square-root of M^2
M^2	beam quality compared with a diffraction-limited TEM$_{00}$ beam

M_a	afocal telescope magnification
MCP	micro-channel plate
MCT	mercury cadmium telluride
MEMS	micro-electromechanical system
MLM	multiple longitudinal mode
MMF	multimode fiber
MOPA	master-oscillator power amplifier
MPE	maximum permissible exposure; multiphoton excitation
MPN	mode-partition noise
MPPC	multipixel photon counter
MRF	magneto-rheological finishing
MSF	mid-spatial-frequency
MTF	modulation transfer function
MTF_{det}	detector MTF
MTF_{opt}	optical MTF
MTF_{sys}	system MTF
MTTF	mean time-to-failure
MWIR	midwave IR
n	refractive index
n_e	number of electrons
n_f	number of polygon facets
n_p	number of photons
n_s	number of signal electrons
n_w	well depth (e^-)
$n_{\sigma amp}$	number of amplifier noise electrons (e^-)
$n_{\sigma b}$	number of background noise electrons (e^-)
$n_{\sigma dc}$	number of dark-current noise electrons (e^-)
$n_{\sigma FPN}$	number of spatial noise electrons (e^-)
$n_{\sigma read}$	number of read noise electrons (e^-)
$n_{\sigma RIN}$	number of RIN noise electrons (e^-)
$n_{\sigma s}$	number of signal noise electrons (e^-)
$n_{\sigma sp}$	number of speckle noise electrons (e^-)
N	number of longitudinal modes; resolvable spots; detector noise (A or e^-)
N_e	number of electrons per second (e^-/sec)
N_i	number of electrons per unit volume in energy level i ($1/m^3$)
N_p	number of photons per second (#/sec); number of pixels
NBF	narrow-band filter
NEP	noise-equivalent power (W or $W/Hz^{1/2}$)
NEP_{amp}	amplifier-limited NEP (W or $W/Hz^{1/2}$)
NEP_s	signal-limited NEP (W or $W/Hz^{1/2}$)

NEPh	noise-equivalent photons (# of photons)
NIR	near-IR
NPRO	nonplanar ring oscillator
NRE	nonrecurring engineering
NSD	noise spectral density ($A/Hz^{1/2}$)
NUC	non-uniformity correction
NUV	near UV
OCS	optical cross-section (m^2/sr)
OCT	optical coherence tomography
OPA	optical phased array
OPL	optical path length (= *nd*, μm or waves)
OPO	optical parametric oscillator
OPSL	optically pumped semiconductor laser
OXT	optical crosstalk
P	CW output power (W)
P_{avg}	average output power (W)
P_{elec}	electrical power (W)
P_d	probability of detection
P_{fa}	probability of false alarm
P_h	horizontally polarized power
P_{inc}	optical power incident on a lens or surface (W)
P_{peak}	peak output power (W)
P_r	optical power reflected by a lens or surface (W)
P_t	optical power transmitted by a lens or surface (W)
P_{th}	thermal heat load due to lens absorption (W)
P_v	vertically polarized power
PBS	polarizing beamsplitter
PCF	photonic crystal fiber
PDE	photon detection efficiency
PDH	Pound, Drever, and Hall
PER	polarization extinction ratio
PIB	power-in-bucket
PIN	*p-i-n* photodetector
PM	polarization-maintaining
PMT	photomultiplier tube
PRF	pulse repetition frequency (Hz)
PRNU	photo-response non-uniformity
PRR	pixel readout rate (Hz)
PSD	power spectral density (nm^2-m), aka energy spectral density
PV	peak to valley; photovoltaic
PZT	piezoelectric transducer

q	electron charge, $= 1.602 \times 10^{-19}$ C/e$^-$; lens shape factor
Q	heat load (W)
Q_c	cavity quality
Q_p	pulse energy (J)
Q_{store}	cavity photon-energy storage (J)
QCL	quantum-cascade laser
QCW	quasi-continuous wave
QE	quantum efficiency
QWP	quarter-wave plate
r	radial coordinate (m)
R	average power reflectivity; diffraction ripple; range (m)
$R(z)$	Gaussian wavefront radius of curvature (mm)
R_f	Fresnel surface reflectivity
R_g	responsivity after including detector gain G (A/W)
R_i	wavefront radius of curvature exiting lens (mm)
R_o	wavefront radius of curvature incident on lens (mm); detector responsivity (A/W)
R_p	reflectance of p-polarized light
R_{pi}	power reflectivity of surface i
R_s	reflectance of s-polarized light
R_t	thermal resistance (K/W)
RHS	right-hand side
RIN	relative intensity noise (1/Hz or dB/Hz)
RMS	root mean square
ROI	region-of-interest
ROIC	readout integrated circuit
RPM	revolutions per minute
RSS	root sum square
s	incoherent source size (mm)
s_o	object distance (mm)
s_i	image distance (mm)
sCMOS	scientific-grade CMOS
S	Strehl ratio; mirror width (mm); detector signal (A or e$^-$)
SA	spherical aberration
SAM	saturable-absorber mirror
SESAM	semiconductor saturable-absorber mirror
SFE	surface figure error (μm or waves)
SFG	sum-frequency generation
SHG	second-harmonic generation
SiPM	silicon photomultiplier
SLM	single longitudinal mode

SMF	single-mode fiber
SNR	signal-to-noise ratio
SPAD	single-photon avalanche detector
SPCM	single-photon counting module
SPDT	single-point diamond turning
SRS	stimulated Raman scattering
STED	stimulated emission depletion
SWaP	size, weight, and power
SWIR	shortwave IR
t	time (sec)
t_f	time of flight (sec)
t_{int}	detector integration time (sec)
t_s	scan time (sec)
T	truncation ratio; optical transmittance; temperature (K); torque (N-m)
T_{atm}	atmospheric transmission
T_{ext}	external transmission
T_{int}	internal transmission
T_{opt}	optical transmission
T_p	pulse period (sec)
T_{PIB}	transmitted power-in-bucket
T_{trunc}	optical transmission after truncation losses
TCK	transfer clock
TDL	times diffraction limited
TEA	transversely excited atmospheric
TEC	thermoelectric cooler
TEM_{pq}	transverse electro-magnetic mode with integer number of nodes p and q
THG	third-harmonic generation
TIA	transimpedance amplifier
TIR	total internal reflection
TIS	total integrated scatter
ToF	time of flight (sec)
ULE	ultralow expansion
USP	ultrashort pulse
UV	ultraviolet
v	scan velocity (m/sec)
v_g	group velocity (m/sec)
V	volume (cm^3)
V_b	bias voltage (V)

V_{br}	breakdown voltage (V)
VAC	volts of alternating current
VCSEL	vertical-cavity surface-emitting laser
VECSEL	vertical-external-cavity surface-emitting laser
VIS	visible
VPR	pixel reset voltage
VUV	vacuum UV
$w(z)$	Gaussian $1/e^2$ beam radius (mm)
w_o	Gaussian $1/e^2$ waist radius (mm)
w_{01}	Gaussian $1/e^2$ object-waist radius (mm)
w_{02}	Gaussian $1/e^2$ image-waist radius (mm)
w_{oM}	laser waist radius for an embedded beam with quality M^2 (mm)
WD	working distance
WFE	wavefront error (μm or waves)
WP	wall plug
x	transverse coordinate (m)
x_p	pixel pitch (μm)
y	transverse coordinate (m)
y_{MSF}	surface error (nm)
z	axial (or longitudinal) propagation axis (m)
z_1	object waist-to-lens distance (mm)
z_2	lens-to-image waist distance (mm)
z_{FF}	far-field distance (m)
z_R	Rayleigh range (m)
z_{R1}	Rayleigh range of the object waist (m)
z_{R2}	Rayleigh range of the image waist (m)
α	angular acceleration (rad/sec^2)
α_{int}	internal loss (1/cm)
α_m	mirror loss (1/cm)
$\alpha_m(\lambda)$	material attenuation coefficient (1/cm)
α_t	coefficient of thermal expansion (1/K)
β_{SA}	angular blur size due to spherical aberration (μrad)
δ	mirror dynamic deflection (μm)
δ_{RMS}	RMS surface finish (Å or nm)
δ_T	mirror thermal distortion (μm)

Δd	surface figure error (SFE) or irregularity (μm or waves)
Δf	electrical bandwidth (Hz)
ΔL	change in cavity length (μm)
ΔL_t	change in cavity length due to thermal expansion (μm)
ΔQ	gain bandwidth (J)
ΔR	range resolution (m)
Δt_p	pulse width (sec)
ΔT	temperature change (C or K)
Δv	velocity variation (m/sec)
Δx	distance between spatial features (mm)
Δy	change in beam-pointing location (μm)
Δz_{ast}	axial astigmatism (μm)
$\Delta\phi$	phase difference (rad)
$\Delta\lambda$	emission linewidth (μm or nm)
$\Delta\lambda_g$	gain bandwidth (μm or nm)
$\Delta\nu$	emission linewidth (Hz)
$\Delta\nu_a$	axial mode spacing (Hz)
$\Delta\nu_g$	gain bandwidth (Hz)
$\Delta\nu_L$	frequency shift or broadening due to change in cavity length (Hz)
$\Delta\nu_{MLM}$	multi-longitudinal-mode emission linewidth (Hz)
$\Delta\nu_R$	laser or etalon cold-cavity transmission bandwidth (Hz)
$\Delta\nu_{SLM}$	single-longitudinal-mode cold-cavity linewidth (Hz)
$\Delta\nu_{ST}$	Schawlow–Townes single-longitudinal-mode emission linewidth (Hz)
$\Delta\theta$	mirror misalignment angle or change in beam pointing angle (μrad)
$\Delta\theta_d$	diffraction angle
$\Delta\theta_m$	change in mirror mechanical pointing angle
$\Delta\omega$	linewidth (rad/sec)
$\Delta\omega_a$	axial mode spacing (rad/sec)
ε	obscuration ratio
Φ	optical power collected by an optical system (W)
Φ_L	refractive or reflective power of a lens or mirror (1/m)
γ_{obs}	obscuration loss
η	polygon geometric efficiency factor
η_{GM}	Geiger-mode avalanche efficiency
η_s	slope efficiency (W/A)
η_{QE}	quantum efficiency – also see QE
η_{WP}	wall-plug efficiency (%)

λ	wavelength (μm or nm)
λ_o	center wavelength (μm or nm)
ν	optical frequency (= c/λ, Hz)
ν_m	axial mode frequency (Hz)
ν_p	pump optical frequency (Hz)
ν_{pqm}	transverse mode frequency (Hz)
θ	angular coordinate or angular scan range (rad)
θ_{01}	far-field half-divergence angle incident on lens (rad)
θ_{02}	far-field half-divergence angle exiting lens (rad)
θ_d	diffraction angle (rad)
θ_{DL}	diffraction-limited full-divergence angle (rad)
θ_o	far-field half-divergence angle (rad)
θ_s	scatter angle (rad)
θ_{slow}	slow-axis full-divergence angle (rad)
$\dot{\theta}$	angular velocity (rad/sec)
$\ddot{\theta}$	angular acceleration (rad/sec^2)
ρ	power reflectivity; mass density (kg/m^3)
σ_{amp}	amplifier noise (A)
σ_{APD}	APD-detector signal noise (A)
σ_b	detector background noise (A)
σ_{dc}	detector dark-current noise (A)
σ_{FPN}	detector spatial noise (A)
σ_n	detector noise current (A)
σ_o	second-moment beam radius (mm)
σ_P	standard deviation of output power (W)
σ_{read}	detector read noise (A)
σ_{RIN}	detected RIN noise (A)
σ_s	detector signal noise (A)
σ_{sp}	detected speckle noise (A)
τ_c	coherence time (sec)
τ_p	photon lifetime or energy storage time (sec)
ω	optical frequency (= $2\pi\nu$, rad/sec)
Ω	modulation frequency (rad/sec); solid angle (sr)
$\Omega_{f/\#}$	solid angle of lens focusing cone (sr)
Ω_{IFOV}	solid angle of pixel IFOV (sr)

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Keith J. Kasunic has more than 30 years of experience developing optical, electro-optical, infrared, and laser systems. He holds a Ph.D. in Optical Sciences from the University of Arizona, an M.S. in Mechanical Engineering from Stanford University, and a B.S. in Mechanical Engineering from MIT. He has worked for or been a consultant to a number of organizations, including Lockheed Martin, Ball Aerospace, Sandia National Labs, and Nortel Networks; he is currently the Technical Director of Optical Systems Group, LLC. He is also the author of two textbooks [*Optical Systems Engineering* (McGraw-Hill, 2011) and *Optomechanical Systems Engineering* (John Wiley, 2015)], an Instructor for SPIE, an Affiliate Instructor with Georgia Tech's SENSIAC, and an Instructor for the Optical Engineering Certificate Program at Univ. of California – Irvine.