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Optical-fiber time-transfer & synchronization systems: advantages, physical limitations and practical implementations

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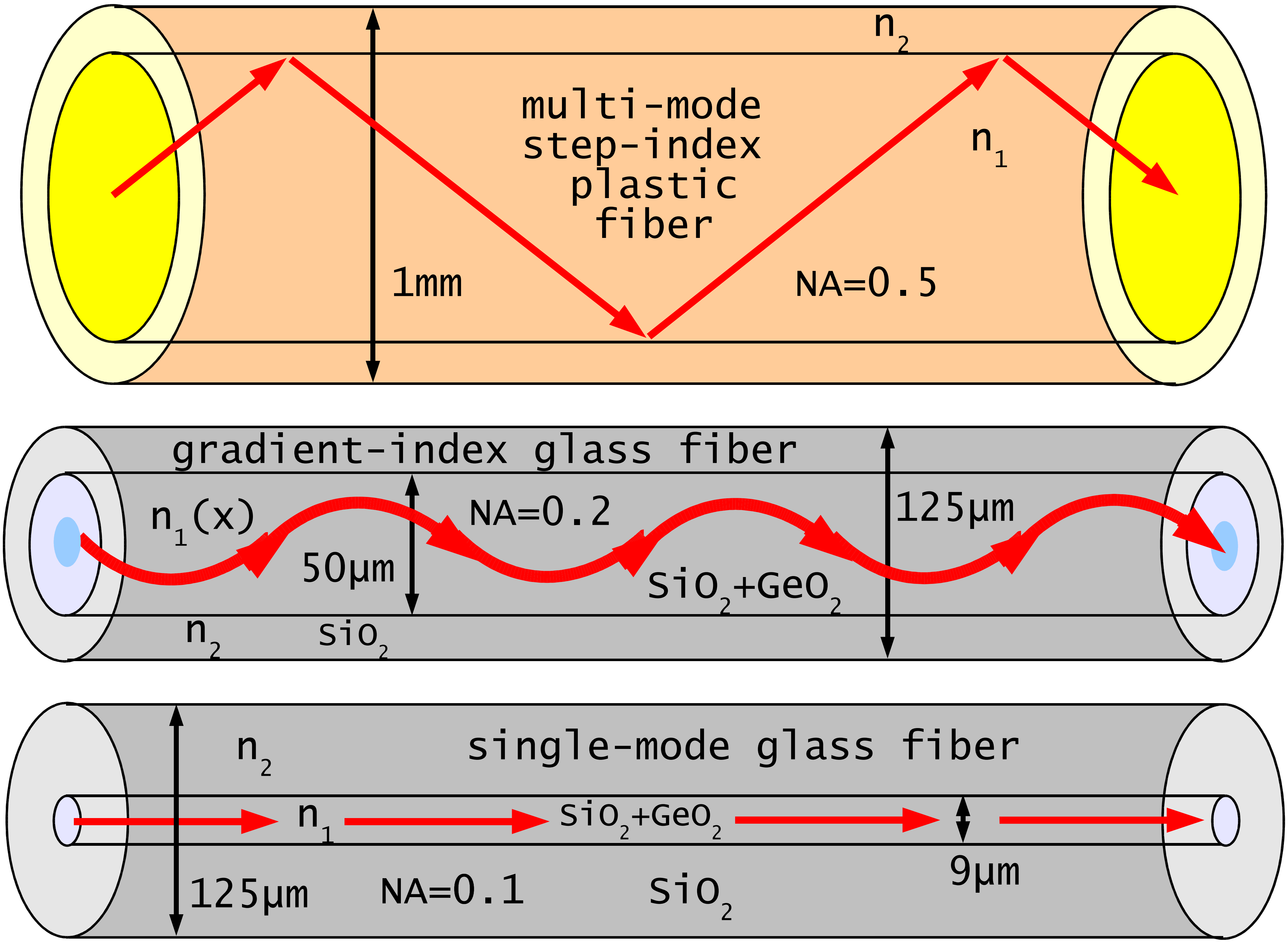
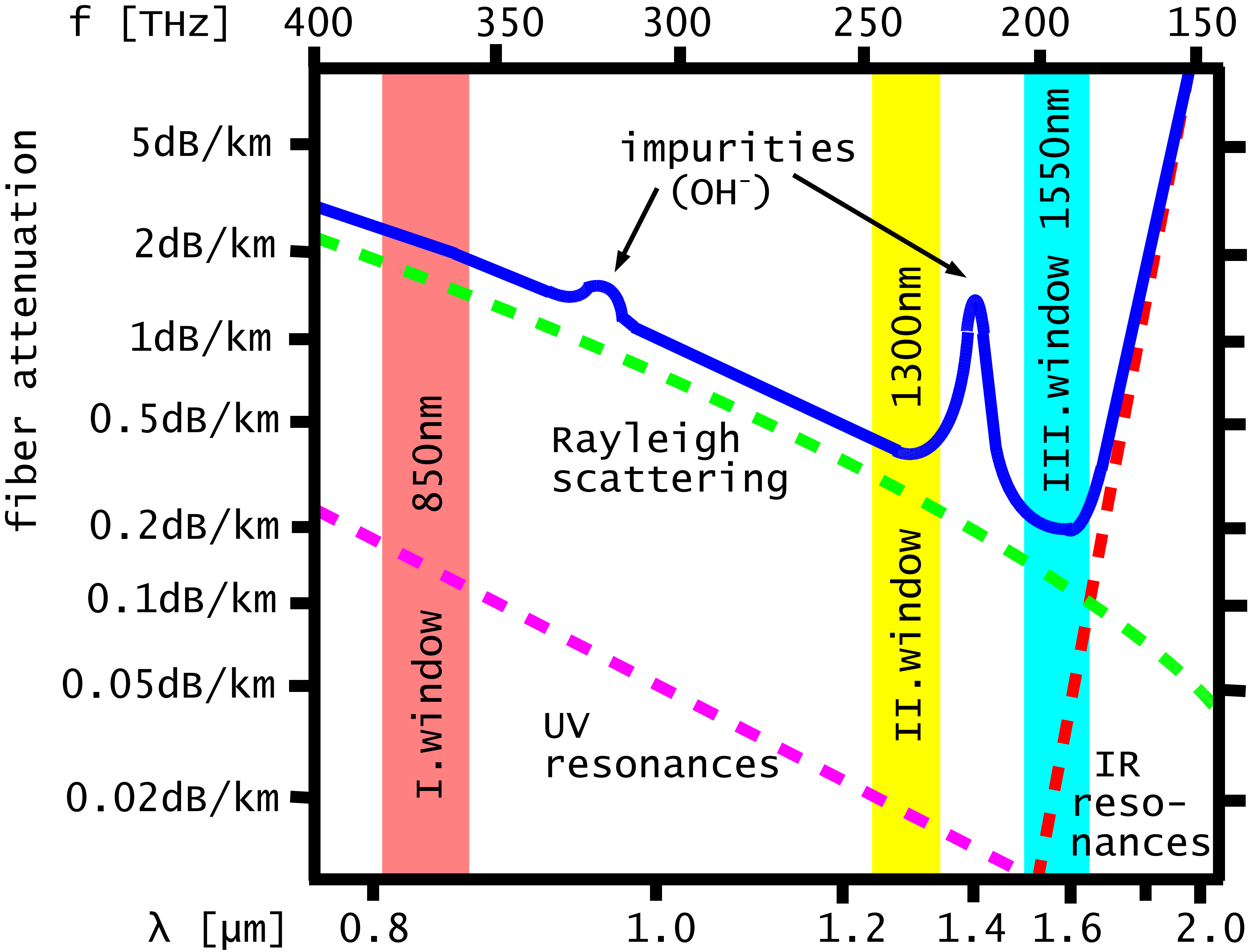
Optical-technology ADVANTAGES:	Optical-technology DRAWBACKS:
very high frequency	fiber dispersion
very large bandwidth	fiber nonlinearities
very low loss	microphonics and sensitivity to vibration
very high peak power	high fiber thermal coefficient
small size optical-fiber cables	difficult optical-signal processing/conversion
low cost optical-fiber hardware	incompatibility with exsisting equipment
electromagnetic immunity	

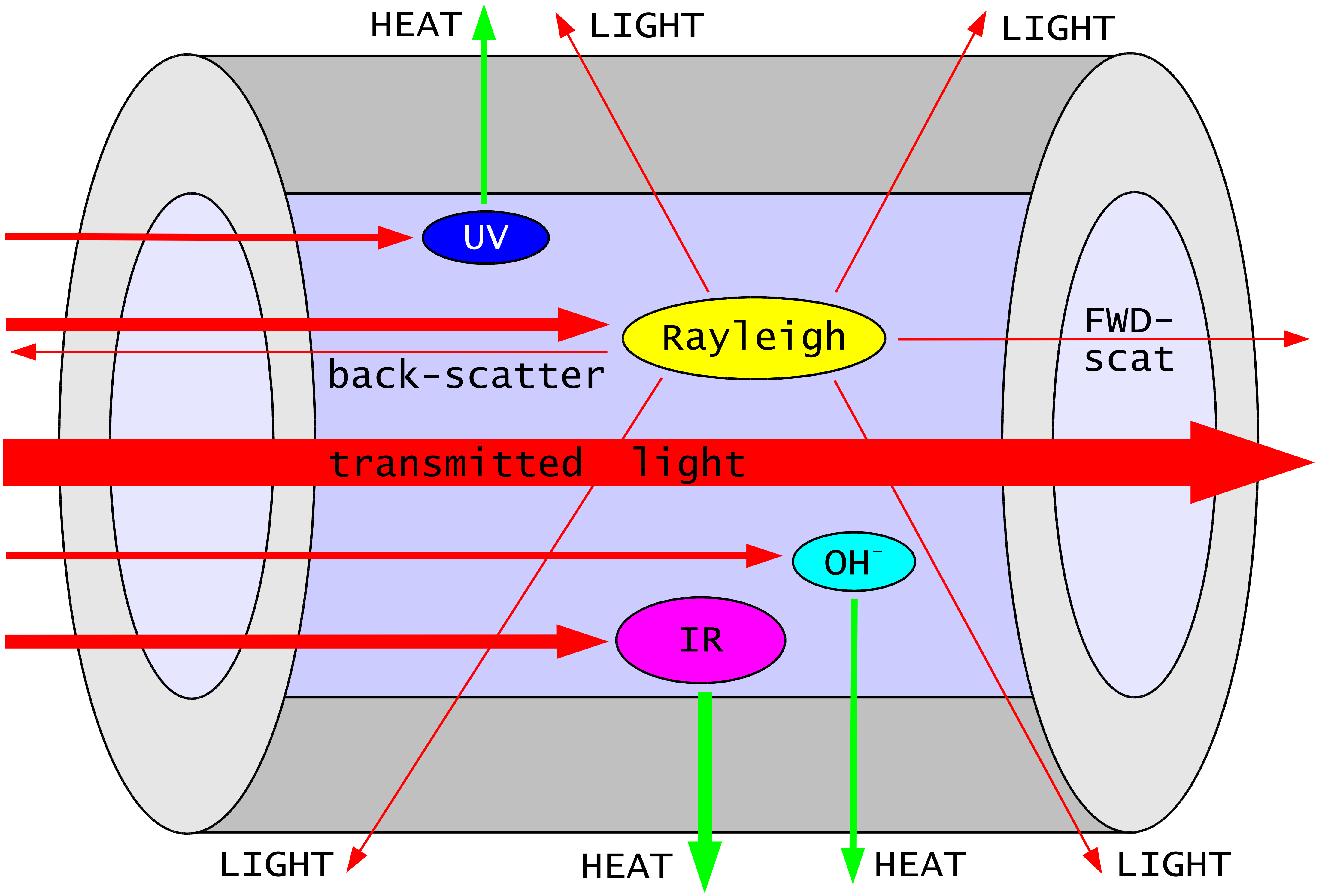
Optical-technology advantages and drawbacks



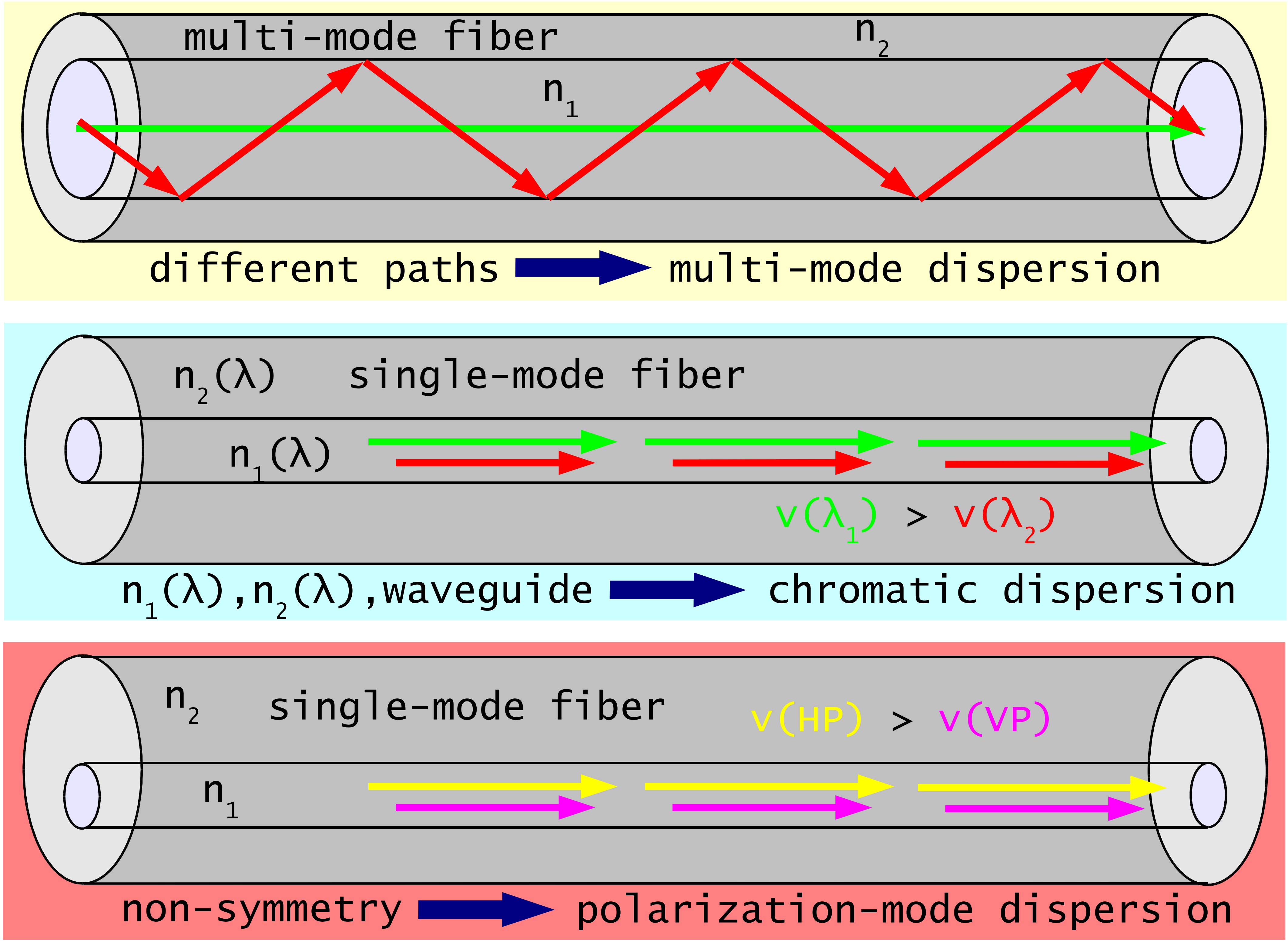
Main types of optical fibers



Single-mode fiber attenuation & telecom windows



Single-mode fiber-attenuation side effects



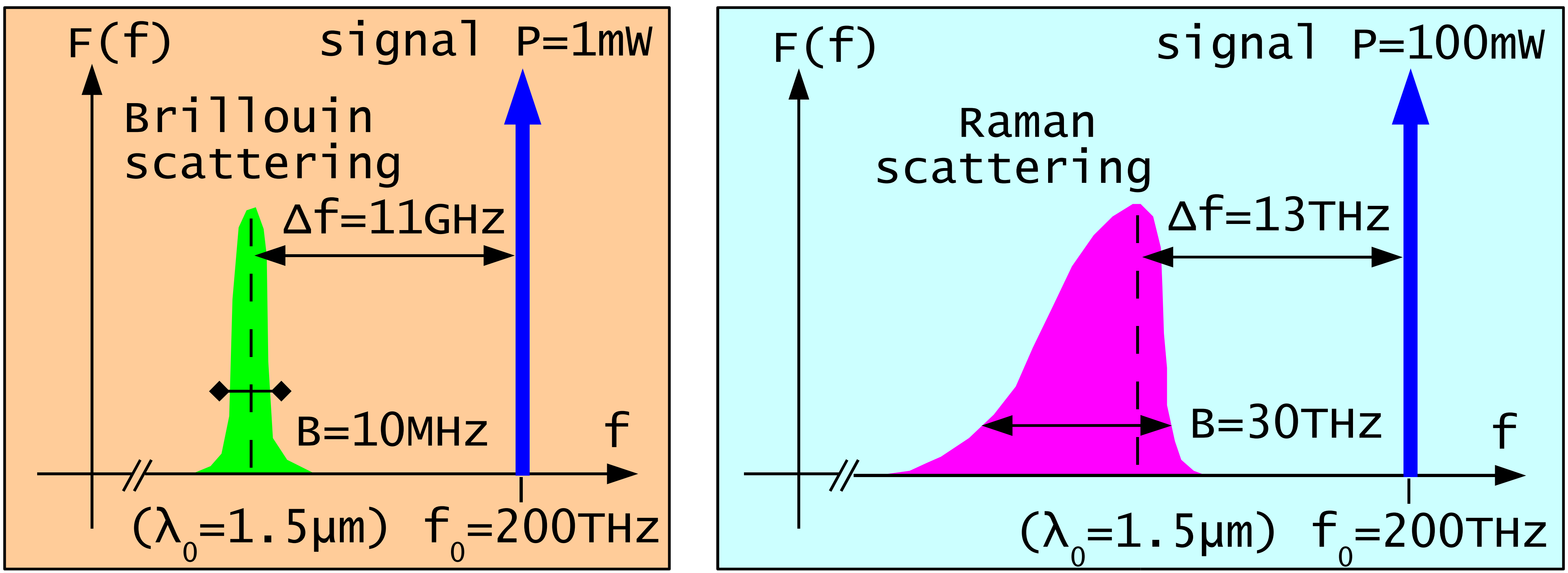
Multi-mode, chromatic and polarization-mode dispersion non-linear refraction index: $n = n_0 + n_2 \cdot S$

SiO_2: $n_0 = 1.46, \quad n_2 = 3.2 \cdot 10^{-20} m^2/W$

(self) phase modulation: $\Delta\phi = \Delta n \cdot k_0 \cdot l$

P=100mW, S=1.43GW/m^2 → $\Delta n = n_2 \cdot S = 4.58 \cdot 10^{-11}$

l=50km, λ_0=1.55µm → $\Delta\phi = \Delta n \cdot (2\pi/\lambda_0) \cdot l = 9.3\, rd$



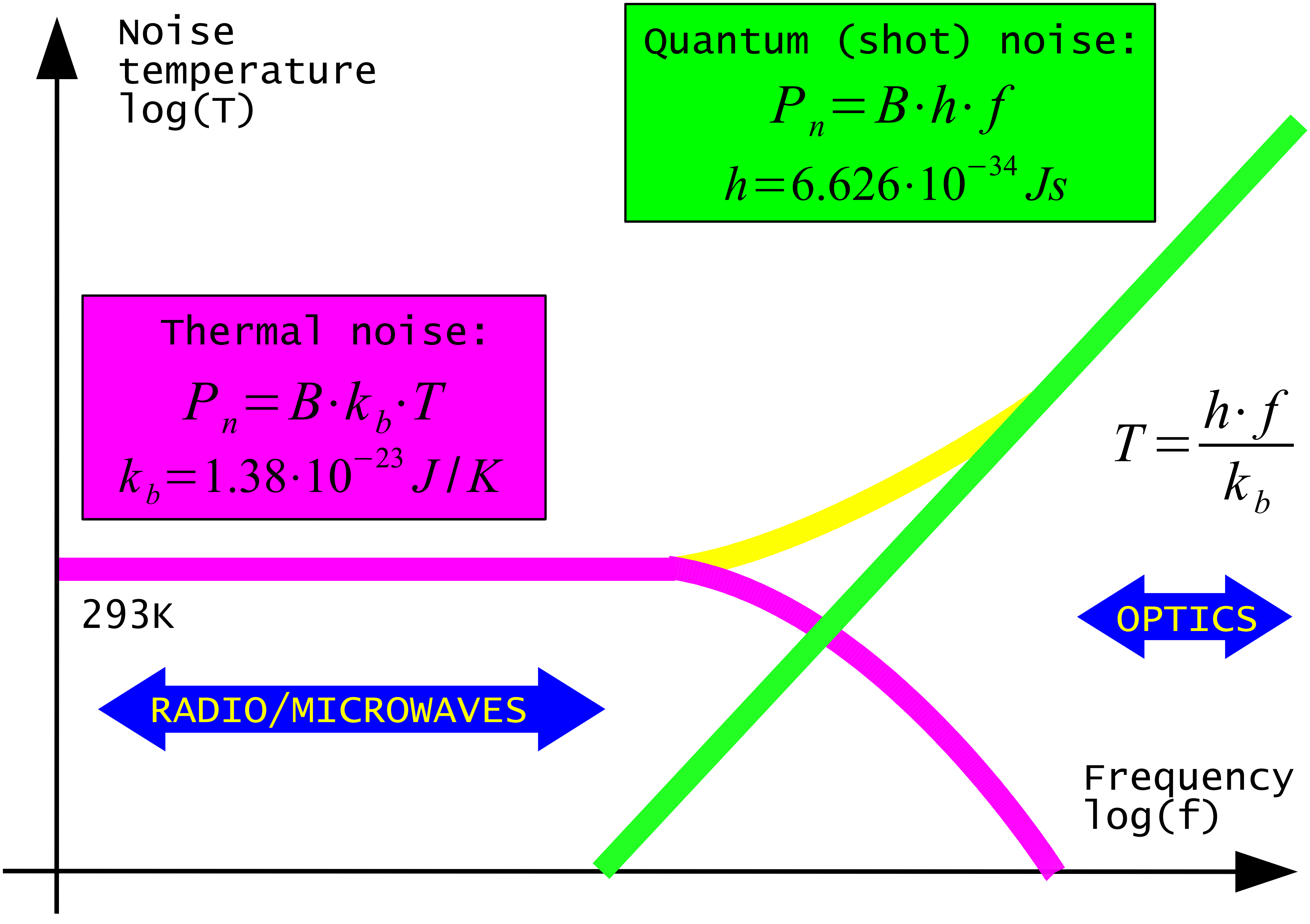
Nonlinearities: non-linear n, Brillouin & Raman

	pulse broadening @ l = 10km	
multi-mode dispersion	step-index	Δt = 500ns
	gradient-index	Δt = 5-50ns
chromatic dispersion $\Delta\lambda$ = 1nm	G.652 @ λ=1.3µm	$\Delta t \approx$ 20ps
	G.652 @ λ=1.55µm	$\Delta t \approx$ 170ps
PMD	G.652 old	$\Delta t \approx$ 10ps
	G.652 new	$\Delta t \approx$ 300fs

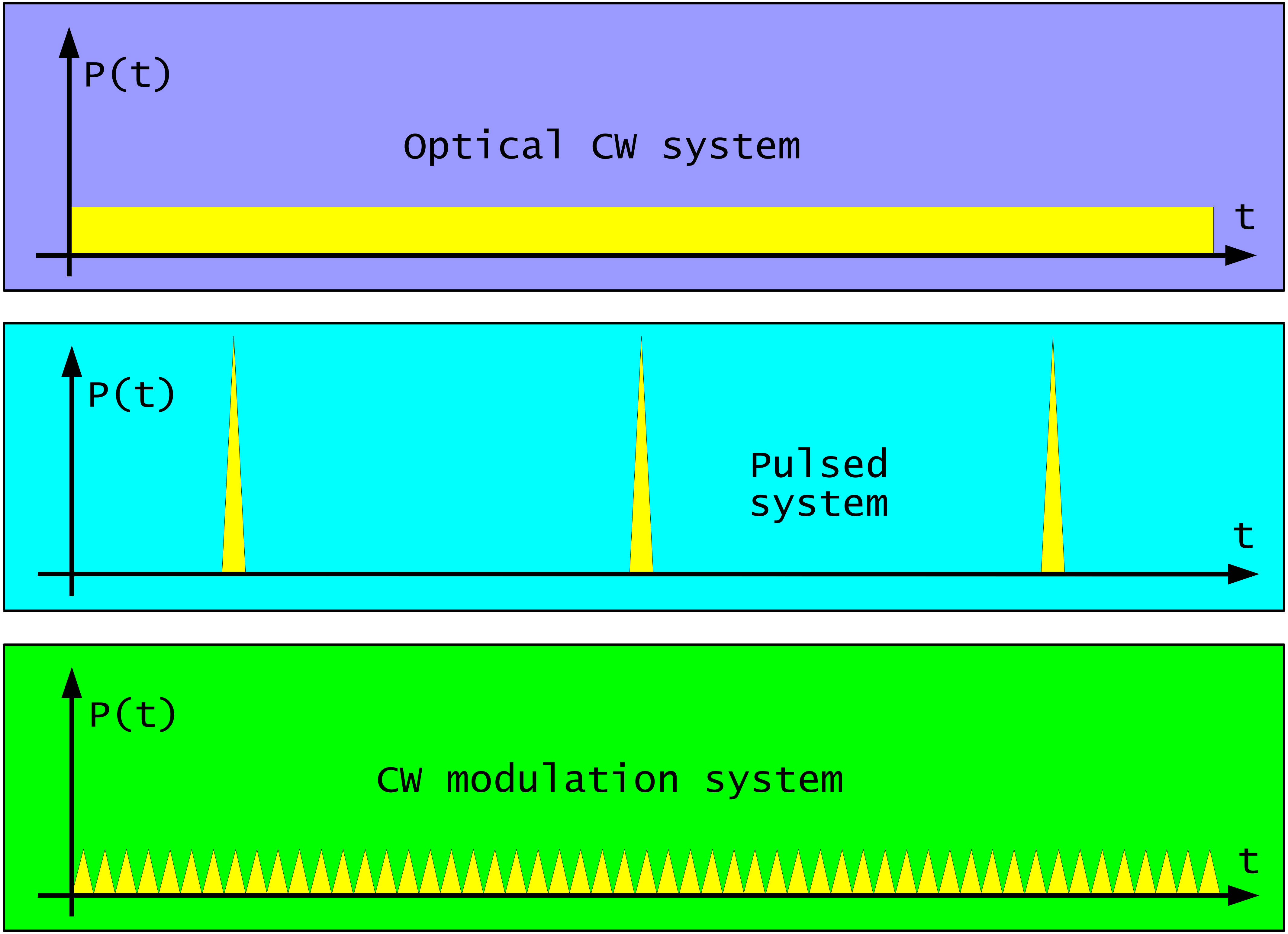
$P_{MAX} \approx$ 100mW (Raman and/or non-linear n)

$P_{MAX} \approx$ 1mW (Brillouin in narrowband systems)

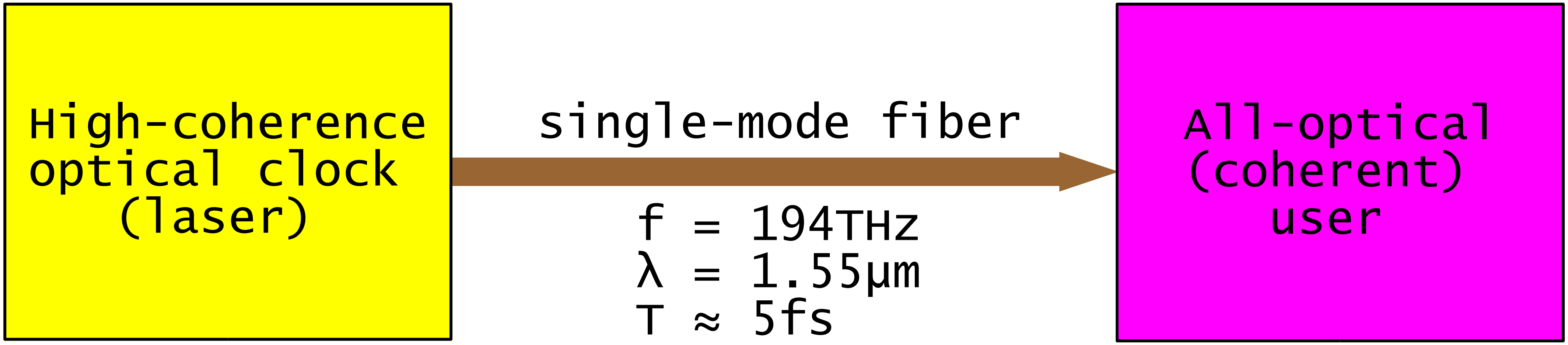
Comparison of limitations of optical fibers



Thermal and quantum noise as function of frequency



Optical timing systems



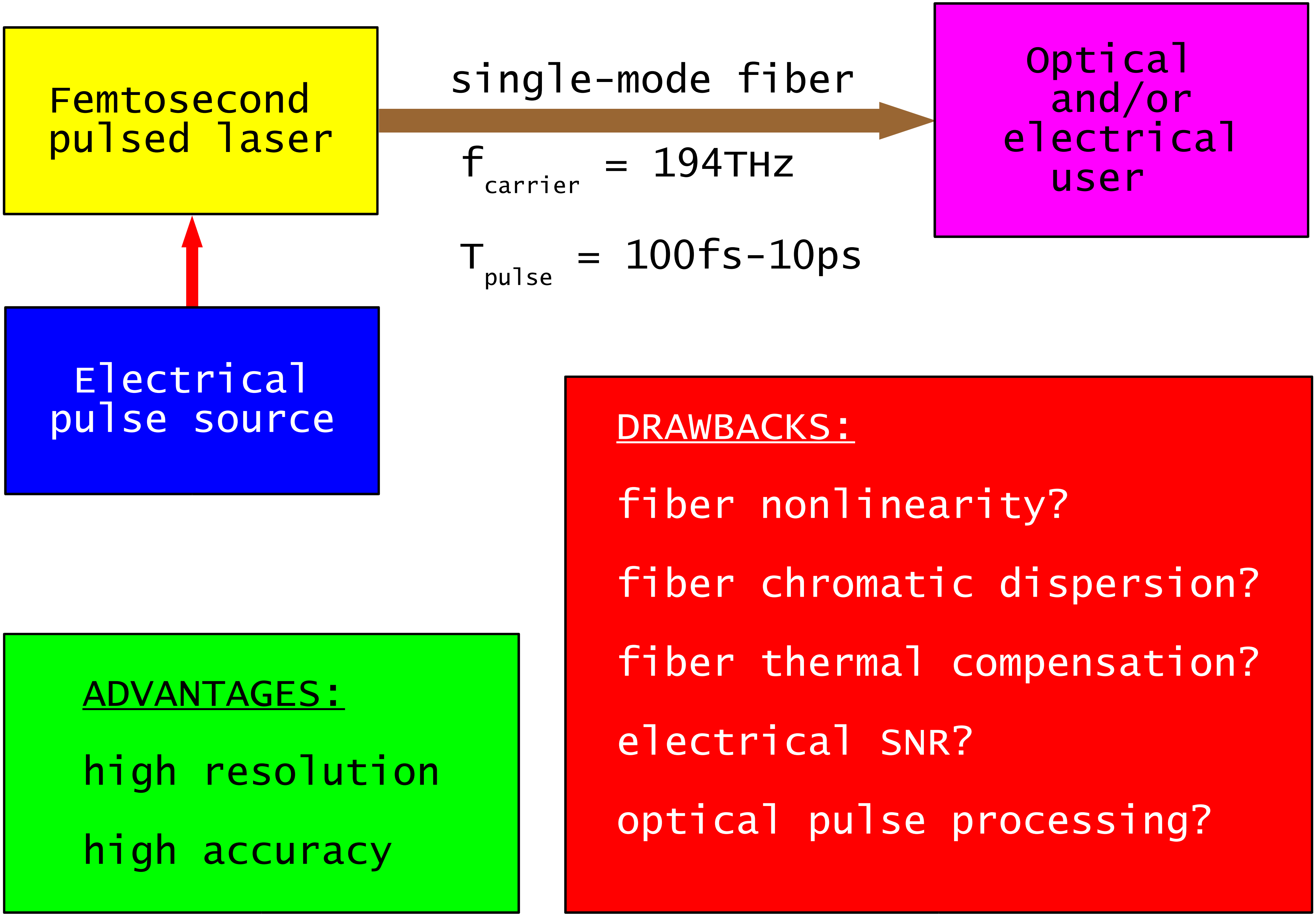
ADVANTAGES:

- highest resolution
- highest accuracy

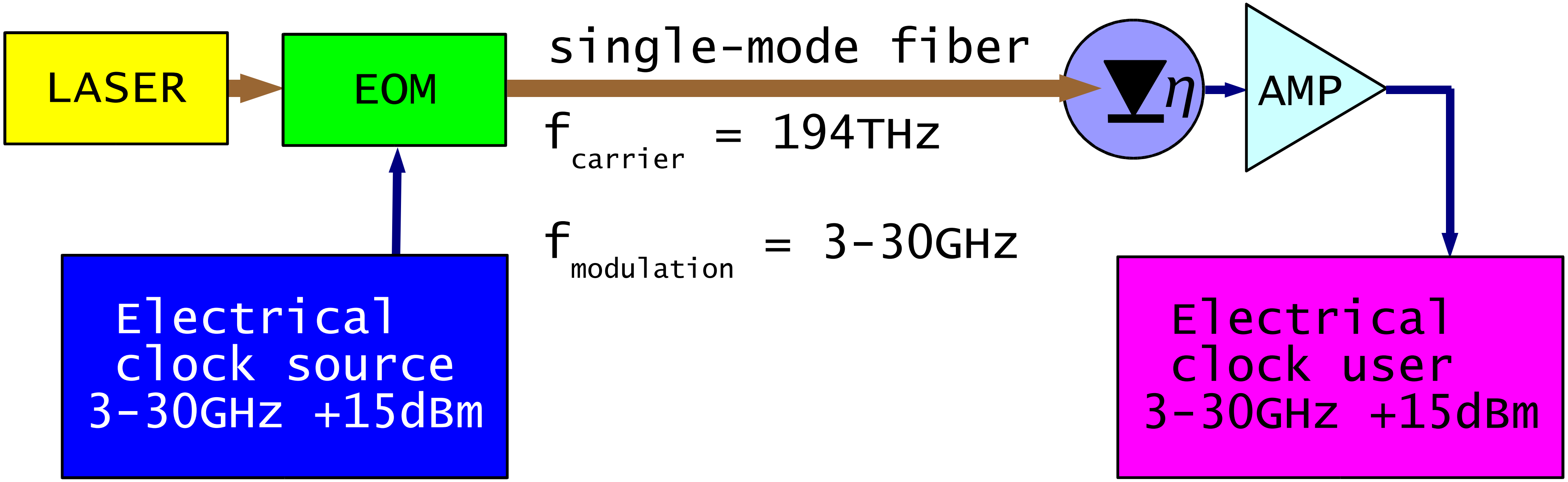
DRAWBACKS:

- 5fs timing ambiguity?
- interferometric noise?
- Brillouin scattering?
- PMD effects?
- user-equipment availability?

Optical CW system



Pulsed system



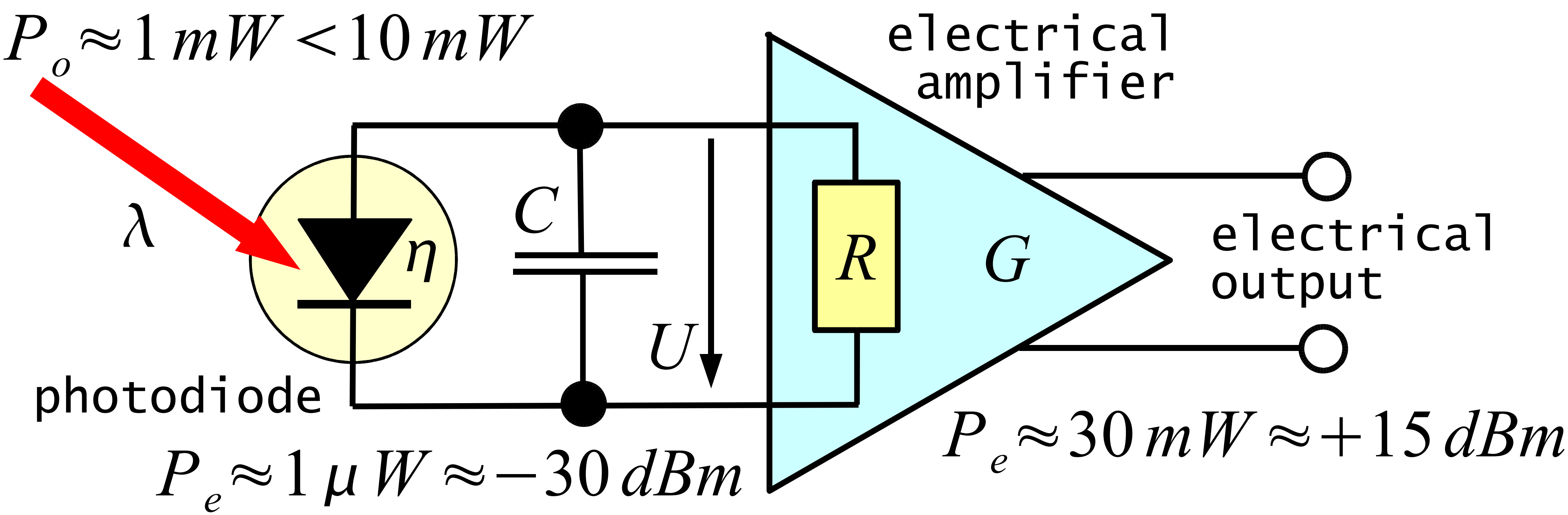
ADVANTAGES:

- simple temperature compensation
- standard electrical interfaces
- standard hi-rel telecom components

DRAWBACKS:

- high photodetector electrical noise: jitter 1-10ps
- low timing resolution?

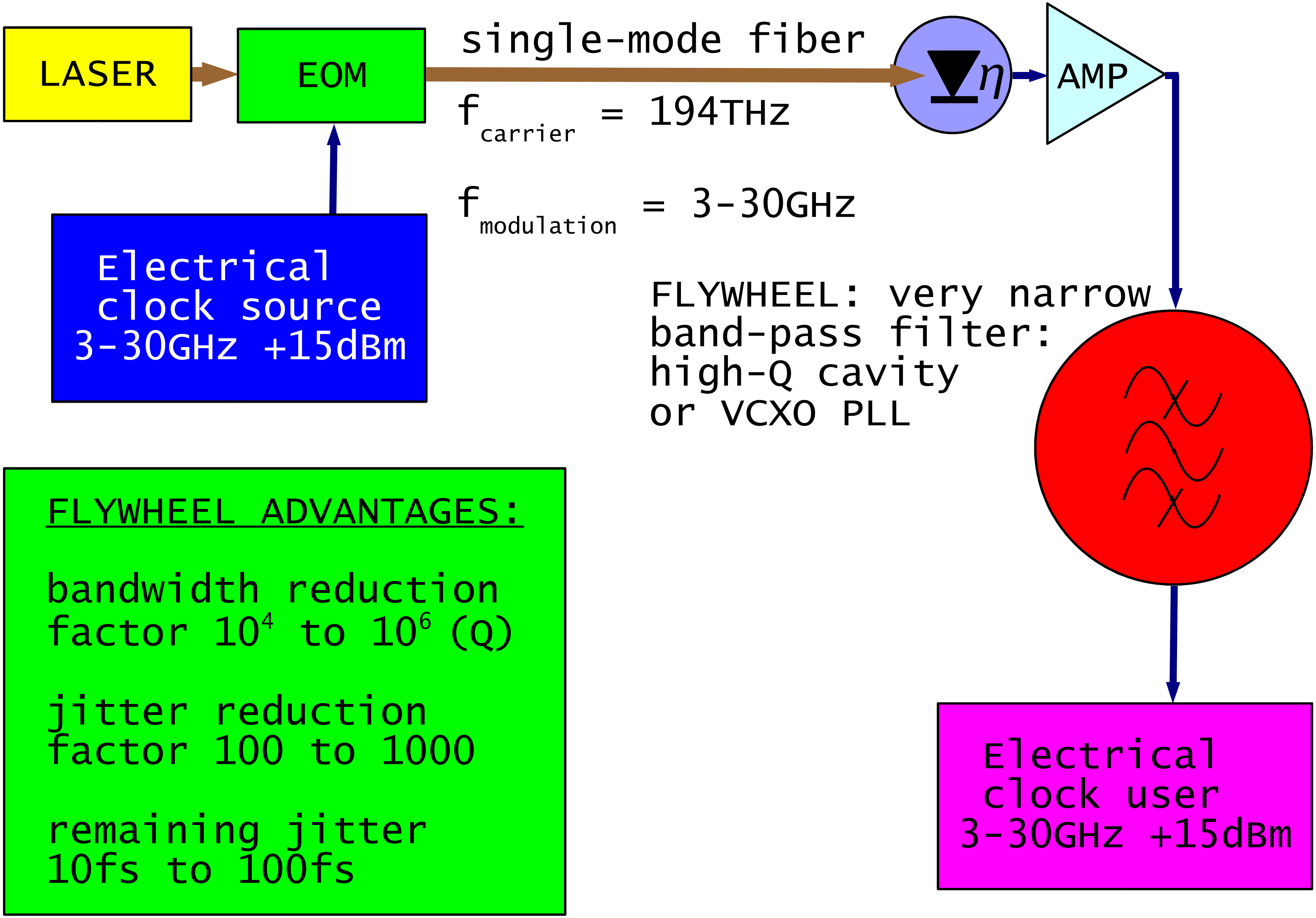
CW modulation system



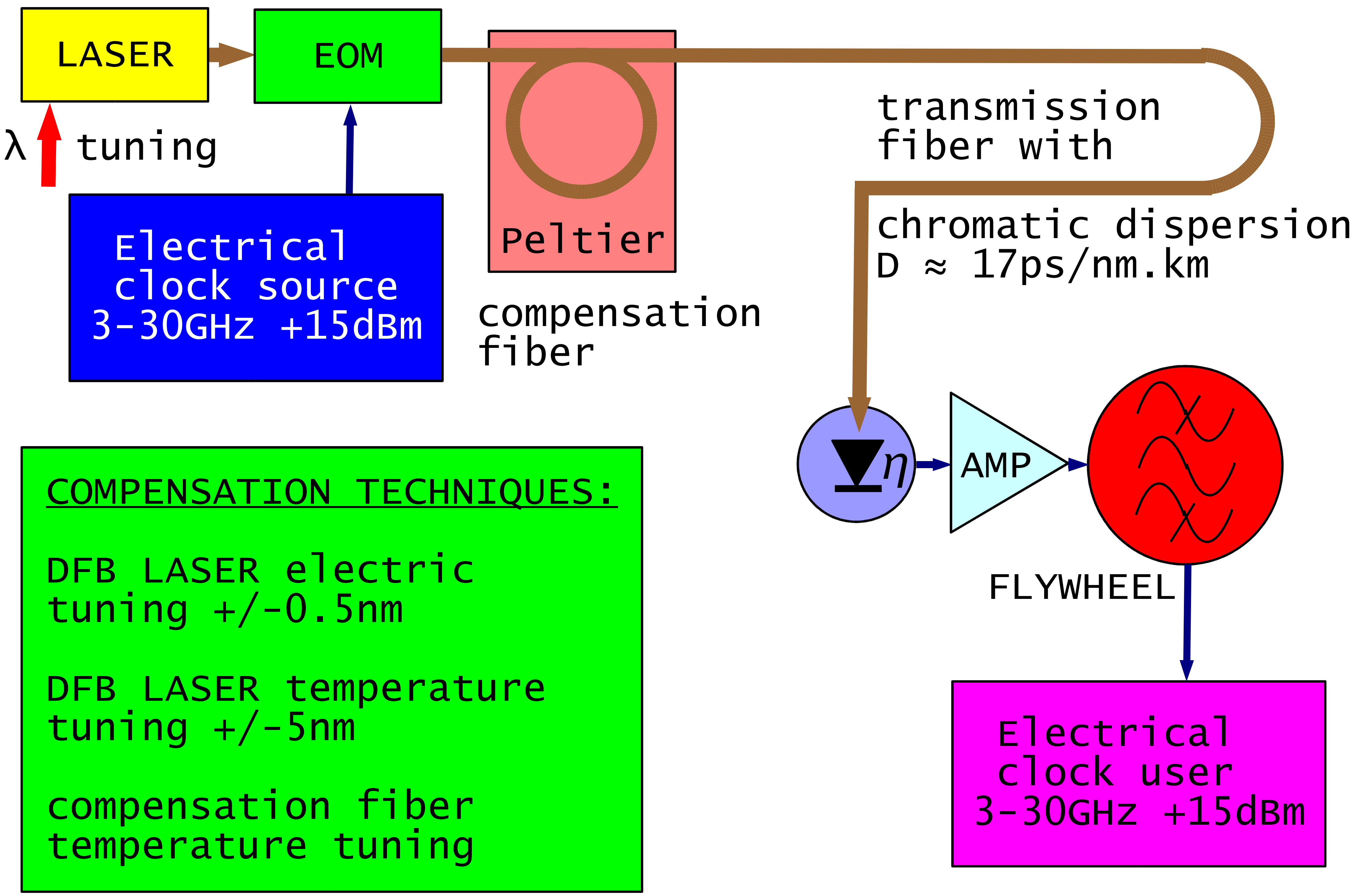
$$U_{neff} = \sqrt{P_n \cdot R} \qquad P_n = B \cdot k_b \cdot T \qquad B = \frac{1}{2\pi \cdot R \cdot C}$$

$$U_{neff} = \sqrt{\frac{k_b \cdot T}{2\pi \cdot C}} = 25.7\,\mu V_{eff}$$ @ C=1pF, T=300K

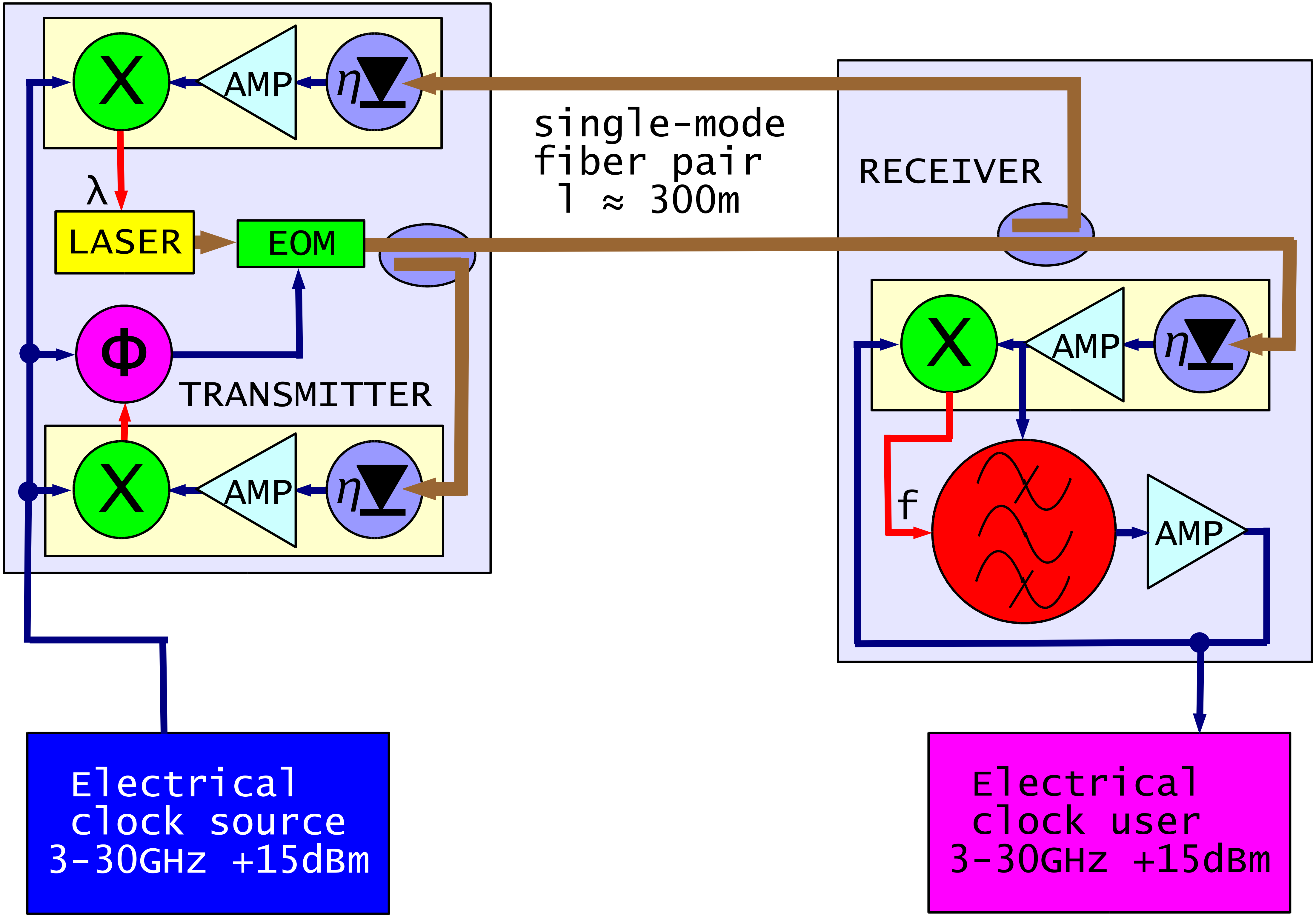
Photodiode electrical noise



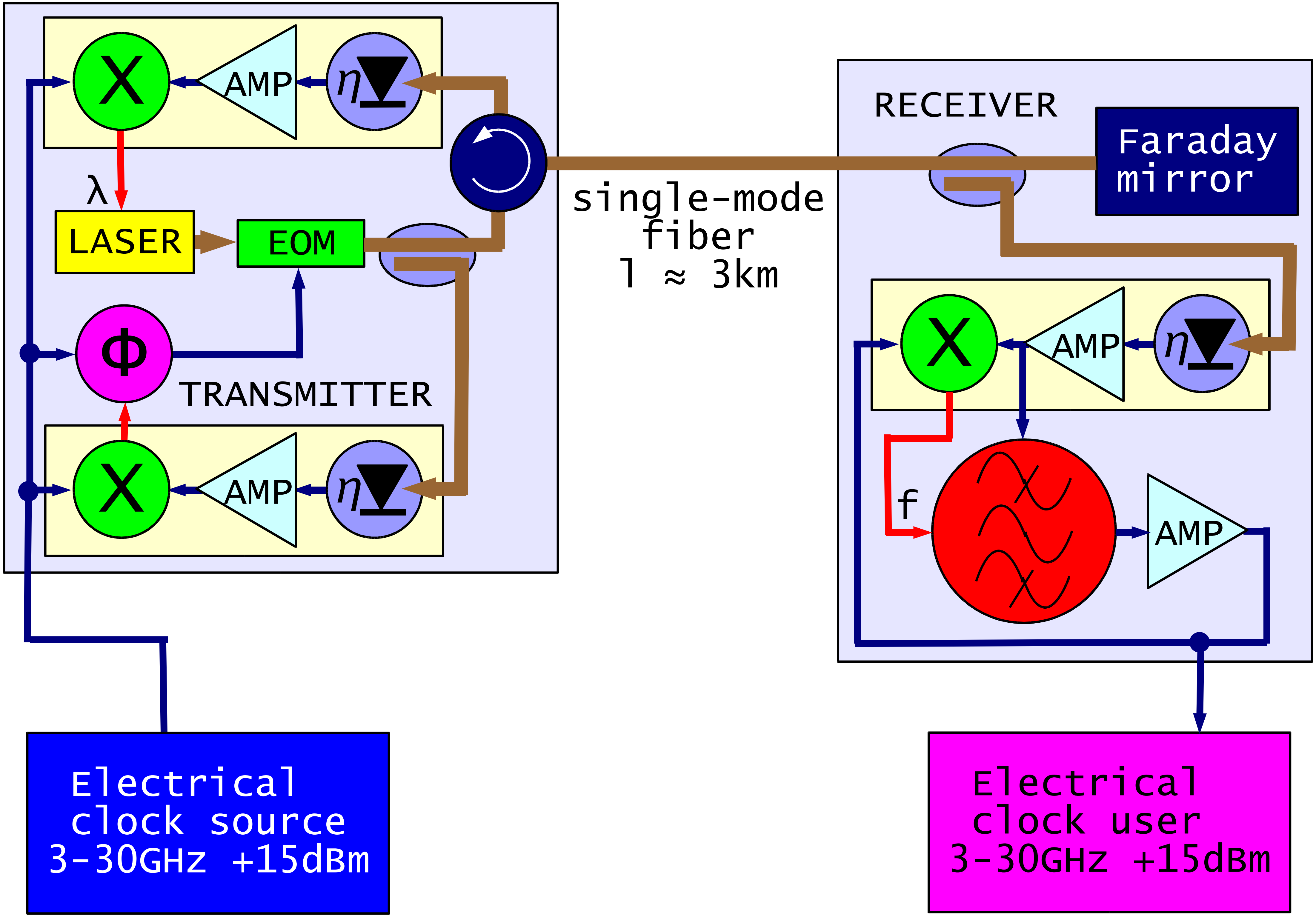
CW modulation system with flywheel



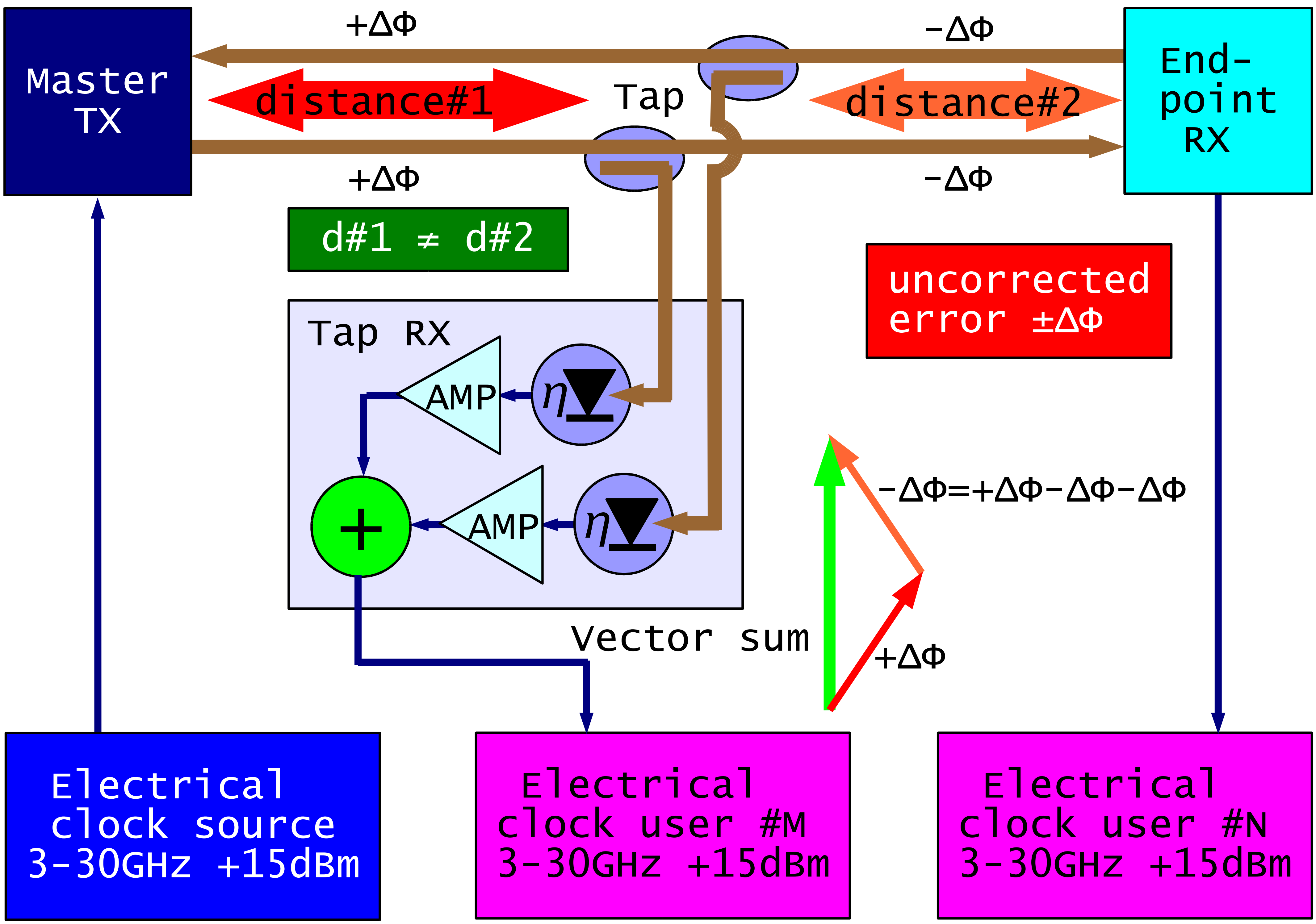
Delay-variation compensation techniques



CW modulation system with temperature compensation



CW modulation system with PMD compensation



Multi-point chain clock distribution

OPTICAL FIBER:

long-term, temperature & PMD characterization

connector performance

ferrite components: isolators, circulators & Faraday mirrors

FLYWHEEL TECHNOLOGY:

ceramic materials for dielectric resonators

VCXO characterization

low-noise frequency multipliers and dividers

LASER TECHNOLOGY:

high-speed electronic wavelength tuning

low-coherence sources

direct laser modulation

safety & reliability

USER REQUIREMENTS:

optical input & output?

pulsed input & output?

integration with other equipment?

diagnostics?

Future-developement action list