Fixed 8x Digital Birding Monocular ��� Concept Optical Design

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Goal

A fixed (non-zoom) 8x-magnification digital camera for birdwatching, built around a 1” sensor, in a camcorder/night-vision-monocular-class form factor rather than a true pocket monocular. “8x” is defined the way birding binoculars define it — true angular magnification relative to the naked eye — not the photographic “focal length ÷ 50mm” convention, which tends to overstate perceived magnification for screen/EVF viewing.

1. Defining “8x” correctly

Binocular magnification is an angular ratio:

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M = (apparent angle of subject through the device) / (true angle of subject to the naked eye)
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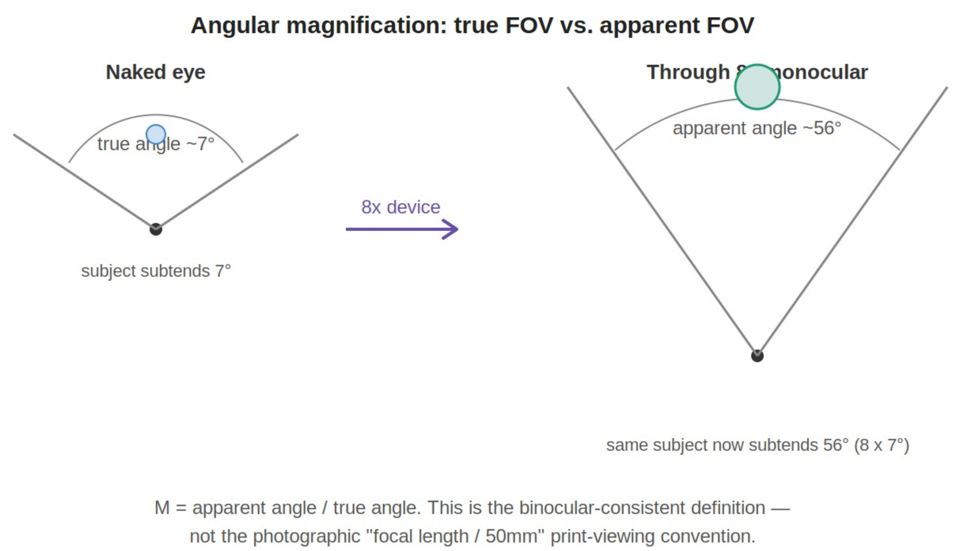
For a real binocular this equals f(objective)/f(eyepiece). The practical spec that follows from this is the **true field of view**: 8x birding binoculars (e.g. 8x42) typically have a true FOV of ~6.5–8°, which expands to a ~55–65° apparent FOV at the eye.

This — not the 50mm print-viewing convention — is the correct target to design the objective lens around.



True FOV vs apparent FOV diagram

2. Deriving the required focal length

Target: capture the same true FOV as a typical 8x42 binocular (~7°) on a 1” sensor (15.86mm diagonal).

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 f = sensor diagonal / (2 × tan(FOV/2))
f = 15.86mm / (2 × tan(3.5°))
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f ≈ 130mm
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Result: ~130mm actual focal length on the 1” sensor. This is meaningfully longer than a naive photographic-zoom-ratio estimate (~74mm) would suggest, and close to what a naive “50mm-baseline” estimate gives (~148mm) — but arrived at for the correct physical reason.

3. Aperture / speed

Matching the light-gathering feel of an 8x42 binocular (42mm objective) at a practical camera f-number:

- Target: **f/3.5–f/4**
- Entrance pupil diameter: 130mm ÷ 3.5–4 ≈ **33–37mm**

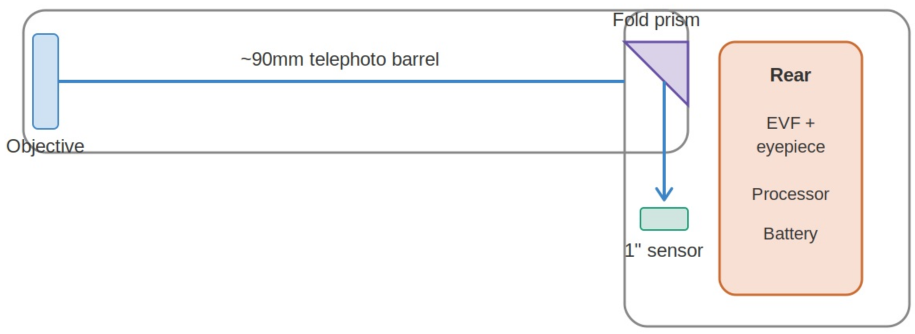
This lands close to real binocular objective sizes — a useful sanity check that the comparison is apples-to-apples.

4. Form factor and optical path

A true monocular tube (~30mm diameter, ~130mm length) is too tight for this focal length without an aggressive multi-bounce catadioptric fold. A **camcorder / NV-monocular-class housing** (~150–230mm long, 60–90mm cross-section) is a much better match:

- **Telephoto lens grouping** (negative rear element behind the positive front group — the standard trick in compact long lenses) compresses the mechanical barrel to roughly **60–75% of the true focal length**, i.e. ~80–95mm of physical barrel before any folding.
- **A single 90° fold** routes that ~85–95mm barrel into an L-shape: roughly 50–55mm from objective to the fold element (using housing depth) + 35–40mm from fold element to sensor (using housing width).
- This frees the entire rear of the housing for the sensor board, image processor, battery, and the EVF module with its own eyepiece optics — matching the layout convention already used by thermal/NV monoculars (objective front, single internal path, OLED microdisplay + eyepiece at the rear).

Single-fold optical layout — camcorder-class housing (~190mm)



One 90-degree bend routes the barrel into the housing depth, freeing the rear for electronics and the eyepiece

Single-fold optical layout diagram

5. Fold element: prism, not mirror

A right-angle **prism** is preferred over an open first-surface mirror:

Consideration	Prism	Mirror
Alignment stability	Fold angle fixed in the glass itself	Depends on a separate mechanical mount; can shift under shock/vibration/thermal cycling
Reflecting surface	Total internal reflection (~100%, no coating needed at 45° in BK7-type glass, since incidence exceeds the critical angle)	Requires a metal/dielectric coating (90–99% reflective), exposed and subject to degradation unless rear-surface (which adds ghosting)
Chromatic penalty	None (behaves as a parallel plate — small back-focus shift only)	None
Image erection	Not needed here — sensor/EVF pipeline can flip/rotate the image in software, so only the simplest single right-angle prism is required (no Porro/roof geometry needed)	N/A
Weight/cost	~100g in BK7 at this aperture (~35mm), higher cost	~15–20g, lower cost

Given this is a handheld outdoor field instrument, the prism's durability advantage outweighs its weight/cost penalty — consistent with why prisms are standard in binoculars, riflescopes, and monoculars generally.

6. Bill of materials — lens module

Scope: front element through the prism, up to the sensor interface. Excludes sensor, EVF, and camera electronics. Conceptual BOM for a ~130mm f/3.6 fixed telephoto; final element curvatures/counts require lens-design software (e.g. Zemax, CODE V) to finalize.

#	Item	Qty	Material / spec	Function
1	Front protective window	1	BK7 or sapphire, flat, AR-coated both sides	Weather/scratch barrier
2	Front group — ED element	1	Low-dispersion glass (e.g. FPL-53 type)	Chromatic aberration control at 130mm FL
3	Front group — mating element	1	Standard crown glass, cemented to #2	Achromatic doublet with the ED element
4	Aspherical corrector element	1	Molded glass or hybrid glass/polymer replica	Spherical aberration/coma control at f/3.6
5	Rear (telephoto) group — negative element	1	Standard flint glass	Compresses mechanical barrel below true focal length
6	Rear group — corrector element	1	Standard/high-index glass, cemented or air-spaced to #5	Field curvature / residual aberration correction
7	Fold prism	1	BK7 or N-SF-series (higher index → smaller prism), ~35mm leg, right-angle	90° fold via TIR; no coating on fold face
8	IR-cut / hot-mirror filter	1	Dielectric-coated or absorptive glass	Blocks near-IR ahead of the Bayer sensor
9	Aperture stop	1	Fixed metal stop (laser-cut/etched)	Sets f/3.5–4 (fixed aperture, no iris)
10	Fixed front lens barrel	1	Anodized aluminum or glass-filled polymer	Houses elements 1–4, threaded for window/hood
11	Focus mechanism	1	Manual helicoid, or stepper/voice-coil AF	Moves rear group (or full assembly) for focus

			unit	
12	Element retaining rings/spacers	~6–8	Aluminum or engineered plastic	Precision axial element positioning
13	Prism mount bracket	1	Machined aluminum, bonded with UV-cure optical adhesive	Holds prism at fixed 45° through shock/vibration
14	Internal baffles / flocking	Several	Matte-black anodized aluminum or flocked paper	Stray-light control (extra internal surfaces from the fold)
15	O-ring seals	3–4	Nitrile or fluorocarbon rubber	Weatherproofing; nitrogen/argon purge typical
16	Rear barrel / prism housing	1	Anodized aluminum	Structural shell around prism, interfaces to sensor mount
17	Sensor mount flange	1	Machined aluminum, precision-shimmed	Sets exact back-focus distance and squareness
18	Lens hood (optional)	1	Rubber or polymer, bayonet/screw-on	Flare control
19	Fasteners/adhesives	Various	Stainless screws, optical cement, thread-lock	Assembly

Optical element count: 6 glass elements in 5 groups + prism + IR-cut filter + protective window = 9 optical components — a conventional formula for a compact fixed telephoto at this speed.

Estimated per-unit optical-component cost at moderate volume (tens of thousands of units): roughly **$60–150**, though this is a loose planning estimate, not a quote — actual cost depends heavily on tolerances, coatings, and supplier volume commitments.

7. Open design questions

- **Manual helicoid vs. motorized AF** — birding users expect instant manual-focus response similar to a binocular focus wheel; AF hunting on fast-moving birds is a known complaint on existing digital birding optics. This is a UX decision as much as an engineering one.
- **Prism mount design** deserves particular attention — a bonded-only mount risks adhesive creep under repeated shock; bonded + mechanically backed is the safer approach.