Arc & Spark Electric

Geometric Method for Independent PAPI Angle Verification

A Two-Reference Laser Level Method

Revision History

Version	Date	Description
1.0	2026-03-06	Initial release
2.0	2026-03-27	Major revision:

Major revision:

- Replaced Two-pole Method with Two-Reference Laser Level Method
- Added laser distance meter and digital clinometer to equipment
- Increased minimum d_2 from 18m to 35m
- Added formal uncertainty budget (Section 9)
- Added detailed error analysis (Section 10)
- Added method comparison (Section 11)
- Added pre-measurement verification procedures (Appendix A)
- Added spatial filtering enhancement (Appendix D)
- Revised figures and worked example

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PART 1: INTRODUCTION

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1. Purpose

This document describes a geometric method for independently verifying the setting angle of a Precision Approach Path Indicator (PAPI) unit. The method uses a laser level, a levelling rod, and a laser distance meter. It does not require access to the PAPI optical assembly or its internal adjustment mechanisms, and is independent of the PAPI's own calibration.

The method is capable of resolving angles to within ±0.05° (3 arcminutes), which corresponds to the tolerance specified in Transport Canada's TP312 5th Edition for PAPI setting angles.

2. Regulatory Basis and Applicable Standards

Transport Canada Advisory Circular AC 300-006, Precision Approach Path Indicator Maintenance and Inspection, Section 6.0, establishes that PAPI setting angles should be verified by an independent method to validate the accuracy of settings completed with the clinometer. This verification is required when the equipment is first put into operation and at regular intervals thereafter. The method described in this document fulfils that requirement.

The following standards are relevant to PAPI angle setting and the tolerances referenced in this document:

TP312 5th Edition – Transport Canada's Standard for Aerodrome Lighting. Table 5.3.16.18 specifies the PAPI setting angle tolerance of ±3 arcminutes from the light centers. Figure B-19 Note (4) specifies that the transition band shall be flat within 3 minutes of arc.

ICAO Annex 14 – Aerodromes, Volume I. Defines PAPI system characteristics and angle specifications.

FAA AC 150/5345-28 – Precision Approach Path Indicator (PAPI) Systems. Provides guidance on PAPI installation, maintenance, and flight inspection.

3. Prior Art

Several methods for independent PAPI angle verification exist in the literature and in current practice. Each uses a different approach to measure the transition angle, with varying levels of precision, cost, and practical accessibility. The following subsections review the principal methods referenced in AC 300-006 and manufacturer documentation.

3.1. Ground Survey Method

AC 300-006 describes a survey method using a theodolite, surveyor's rod, and engineer's square. In this method, the theodolite is placed on or near the PAPI unit cover, and an observer at 16–30m identifies the transition on a surveyor's rod. The theodolite then reads the angle to the marked point on the rod.

While mathematically sound, this method presents several practical challenges:

The method assumes that the surface on which the theodolite is placed is exactly parallel to the PAPI beam. Given the required tolerance of ±3 arcminutes (0.05°), even a minor manufacturing imperfection, surface warping, or debris on the cover could introduce an error exceeding the tolerance. This assumption is not verified by the procedure.

Loading the PAPI unit with a theodolite risks disturbing the very alignment being verified.

A theodolite is an expensive instrument requiring a trained operator.

3.2. Crouse-Hinds (Eaton) Manufacturer Method

Crouse-Hinds FAA Types L-880 And L-881 PAPI Systems Document 2438 (Rev. L) describes a manufacturer's method for independent PAPI angle verification using two stakes at fixed distances of 25 ft and 50 ft from the PAPI unit, with a wooden peepboard drilled with holes at ½-inch intervals to identify the transition. A transit is used to level the stake tops.

This method uses the same underlying trigonometric principle as the method proposed in this document: $\tan(\theta) = (Y - X) / 25$ ft, where $(Y - X)$ is the difference in transition heights between the two stakes. However, it has notable limitations:

- The peepboard quantizes the transition reading to ½-inch (12.7mm) steps. With a baseline of only 25 ft (7.6m), each step corresponds to approximately 0.095°. The manufacturer's own stated tolerance is ±1 inch on the height difference (Document 2438, Note B), corresponding to ±0.19°.

- The short inter-stake distance of 7.6m limits angular resolution.

- A transit is required to level the stakes, adding equipment cost and complexity.

- No validation or repeatability step is included in the procedure.

3.3. Optoelectronic Image Analysis Method

AC 300-006 also references computer image analysis systems, such as equipment manufactured by Argos Ingegneria, as the most accurate method for PAPI angle verification. These systems use a self-levelling optoelectronic sensor to automatically detect the colour transition, achieving accuracy better than 1 arcminute. The ICAO Visual Aids Working Group recognized this class of equipment at meetings in Montréal (February 2009) and Osaka (October 2009).

While the optoelectronic method is the gold standard for accuracy and repeatability, it is typically deployed at major airports. The method described in this document is intended for facilities where optoelectronic equipment is not available.

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PART 2: THE METHOD

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4. Method Overview

The method described in this document addresses the practical limitations of the manual methods above while remaining accessible to airfield electricians. It requires no contact with the PAPI unit, eliminates the need for a theodolite or transit level, mathematically cancels the PAPI mounting height and the distance to the Reference Target, and achieves the required ±0.05° precision using commonly available equipment.

The principle is as follows. A Reference Target is placed in the PAPI beam at distance d_1 from the unit. The operator identifies the white/red transition midpoint on the target surface, and a laser level is set to that exact height. Because the laser projects a horizontal plane, it carries this reference height forward to any distance. A Levelling Rod is then placed at a further distance d_2 from the Reference Target. On the rod, the operator reads two positions: the laser line and the transition midpoint. The vertical difference h between these two readings, combined with the measured distance d_2, gives the PAPI setting angle: $\theta = \arctan(h / d_2)$.

A key property of this geometry is that the PAPI mounting height and the distance d_1 cancel completely from the calculation. The measured angle depends only on h and d_2. This means the PAPI mounting height does not need to be known, the distance to the Reference Target does not need to be measured, and the method is independent of the PAPI's own reference systems.

5. Equipment Required

1. A Reference Target: any vertical surface (pole on tripod, board, or screen) on which the PAPI transition and laser line can be observed.

2. A 5m levelling rod with millimetre graduations, mounted on a tripod.

3. A laser level with horizontal plane accuracy of ±2mm per 10m or better.

4. A laser distance meter with 50m range.

5. A digital clinometer with accuracy of ±0.1° at plumb

6. A smartphone with camera for photographing rod readings.

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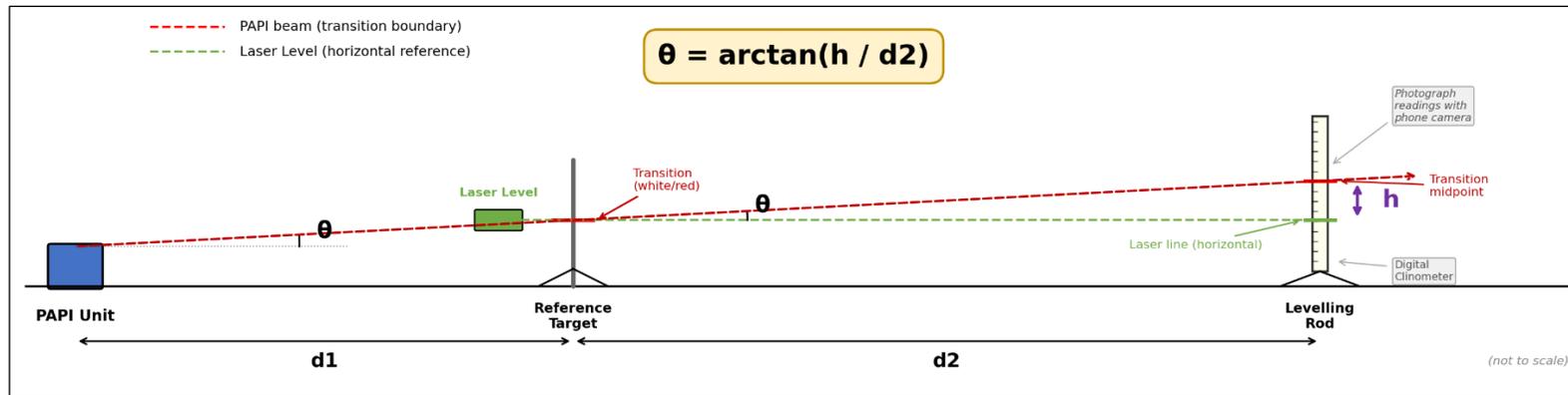
$$\theta = \arctan(h / d2)$$

Figure 1: Side view – Geometric principle of the two-pole laser level method
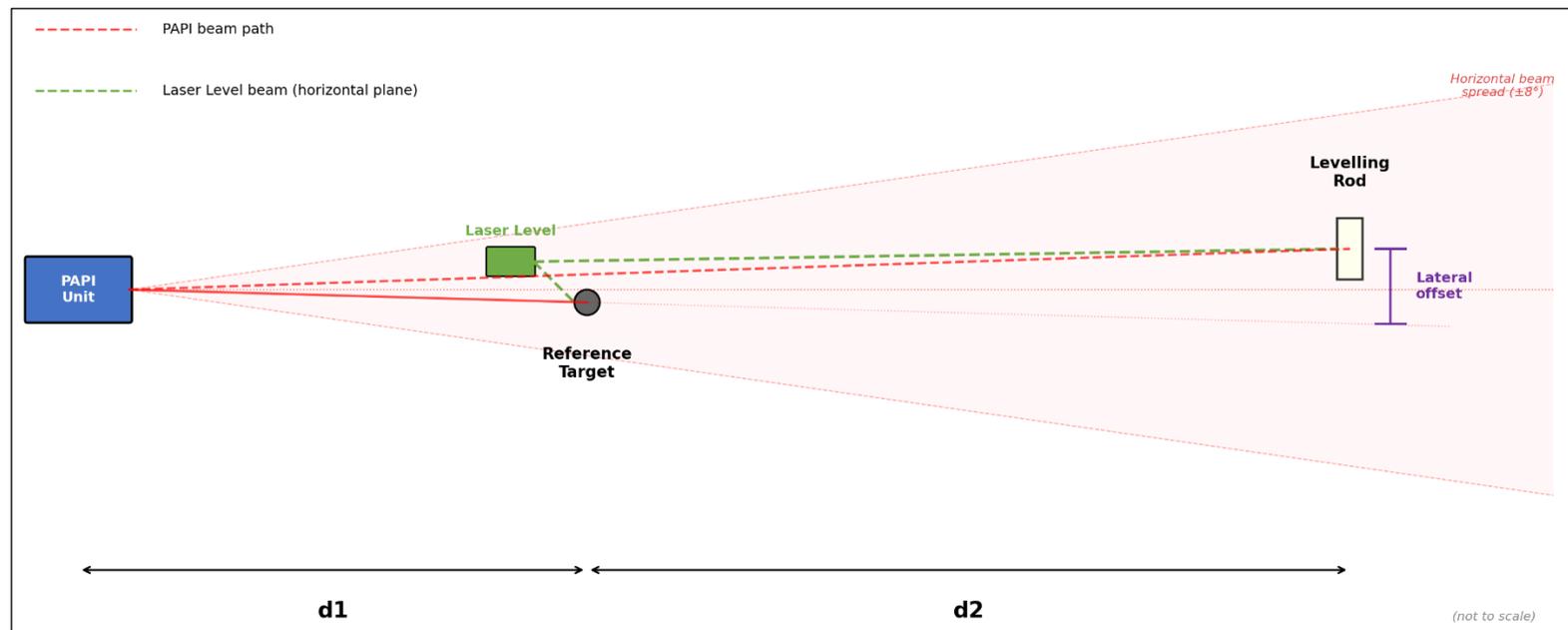
Figure 2: Top view – Field layout showing beam paths and lateral offset

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6. Pre-Measurement Checks

Prior to conducting measurements, verify the following instruments using the procedures described in Appendix A:

Laser Level: Two-peg method (Appendix A.1). The laser must demonstrate an error within the threshold specified in the pass/fail table for the working distance.

Laser Distance Meter: Three-point linearity test (Appendix A.2). The test result must not exceed ±30mm.

Digital Clinometer: 0°/180° reversal check (Appendix A.3). Readings must agree within the manufacturer's stated accuracy (±0.1°).

If any instrument fails its verification check, recalibrate or replace the unit before proceeding.

7. Measurement Procedure

This measurement must be performed at night. The PAPI transition is only clearly visible on the Levelling Rod in darkness.

7.1. Setup

Step 1: Position the Reference Target in front of the PAPI unit under test, at a distance d1 from the PAPI. The recommended distance for d1 is 10 metres, to ensure the beam transition is identifiable. Position approximately in line with the PAPI optical axis by visual alignment from behind the unit.

Step 2: Observe the PAPI beam on the Reference Target. Identify the white/red transition midpoint.

Step 3: Position the Laser Level adjacent to the Reference Target (within 0.5m). Adjust the Laser Level height until the laser line coincides with the transition midpoint on the Reference Target.

Step 4: Position the Levelling Rod at a distance d2 from the Reference Target, further from the PAPI. Minimum d2 is 35 metres; 40 metres or greater is recommended. The Levelling Rod must be within 1.8m of the line extending from the PAPI through the Reference Target.

Step 5: Verify the Levelling Rod is plumb using the digital clinometer.

Step 6: Measure d2 from the Reference Target to the Levelling Rod using the laser distance meter. Record to the nearest millimetre.

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7.2. Measurement

Refer to Figure 3 for a detailed illustration of the readings on the Levelling Rod.

Step 7: On the Levelling Rod, photograph the position of the laser level line using the smartphone camera. Zoom in and record the graduation reading.

Step 8: On the Levelling Rod, photograph the position of the PAPI white/red transition midpoint using the smartphone camera. Zoom in and record the graduation reading.

Step 9: Calculate the vertical distance: h = (transition midpoint reading) − (laser line reading).

Step 10: Calculate the PAPI setting angle: θ = arctan(h / d2).

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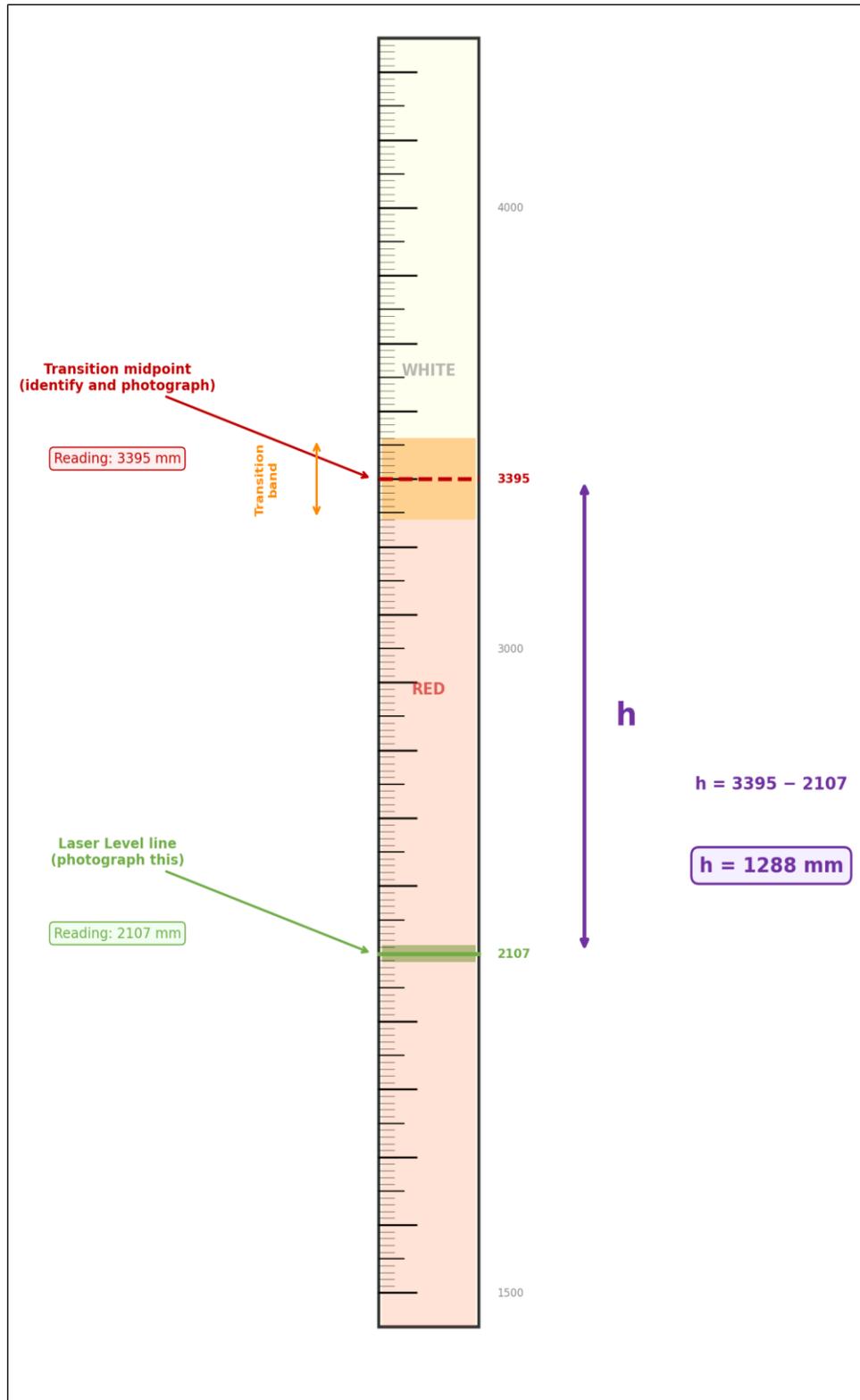airfield.arcandspark.ca

Figure 3: Levelling Rod reading detail

7.3. Height Constraint

The transition on the Levelling Rod must be within the rod's usable height (5m). For the PAPI unit with the largest setting angle (typically 3.5°), the combined distance d1 + d2 must satisfy:

$$(d1 + d2) \times \tan(3.5°) + H_{PAPI} \leq 5.0m$$

With typical PAPI mounting heights of 0.5–1.0m, the maximum practical value of d1 + d2 is approximately 69m. At the minimum d2 of 35m with d1 = 10m, the transition height at 3.5° is approximately 3.55m — well within the rod's range.

The observer must be able to photograph the Levelling Rod graduations at the transition height using a smartphone camera. At d1 = 10m and d2 = 35m, the transition height for the largest setting angle (3.5°) is approximately 3.55m above ground. This is within range of a smartphone camera with zoom from ground level. If the transition height exceeds what can be clearly photographed from ground level, use a step ladder or similar means to elevate the observer

7.4. Alignment Constraint

The Reference Target may be placed at any position in front of the PAPI unit where the white/red transition is clearly visible, typically within ±2° of the PAPI optical axis. Its lateral position does not affect the measurement result.

The Levelling Rod shall be positioned on the line extending from the PAPI through the Reference Target. At d2 = 35m, deviations of up to 1.8m (approximately 3°) introduce an error of less than 0.001°, which is negligible. Visual alignment by sighting from behind the PAPI through the Reference Target is sufficient.

7.5. Repeat for Each PAPI Unit

A standard PAPI system consists of four units, each set to a different angle. Repeat the entire procedure (Sections 6.1 through 6.2) for each unit independently.

7.6. Practical Notes

Wind: The Levelling Rod should be stabilized in windy conditions. A fully extended 5m rod may sway in strong gusts, creating a risk of the rod falling. Brace the rod or take measurements during calm conditions.

Photographic evidence: Retain all photographs of rod readings as part of the measurement record.

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PART 3: TECHNICAL BASIS

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8. Mathematical Proof

8.1. Geometric Model

Consider a PAPI unit emitting its transition beam at angle θ above horizontal from height H above a reference plane. A Reference Target is placed at horizontal distance d1 from the PAPI, and a Levelling Rod is placed at distance d2 from the Reference Target (total distance d1 + d2 from the PAPI).

The height of the white/red transition on the Reference Target is:

$$H_1 = H + d1 \times \tan(\theta)$$

A Laser Level is set at this height. Because the laser projects a horizontal plane, it reads the same height H_1 at any distance.

The height of the transition on the Levelling Rod is:

$$H_2 = H + (d1 + d2) \times \tan(\theta)$$

The measured vertical difference h between the laser line and the transition on the Levelling Rod is:

$$h = H_2 - H_1 = [H + (d1 + d2) \times \tan(\theta)] - [H + d1 \times \tan(\theta)]$$

$$\mathbf{h = d2 \times \tan(\theta)}$$

Therefore:

$$\boldsymbol{\theta = \arctan(h / d2)}$$

The PAPI mounting height H and the distance d1 cancel completely. The measured angle depends only on the height difference h and the inter-pole distance d2.

8.2. Significance of Cancellation

The cancellation of H and d1 is the key property that makes this method practical. It means that:

The exact distance from the PAPI to the Reference Target need not be measured.

The PAPI mounting height need not be known.

The method is independent of the PAPI's own reference systems.

The Laser Level's position (adjacent to the Reference Target) does not affect the result, as the laser simply transports the reference height horizontally.

The Reference Target does not need to be plumb, levelled, or calibrated — it serves only as a visual screen on which the transition midpoint and laser line are matched.

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9. Uncertainty Budget

The following table summarises all identified error sources, their assumed tolerances, verification methods, and contributions to the total measurement uncertainty. Values are calculated for d2 = 35m at θ = 3.5°.

The derivations and justifications for each value in this table are provided in Section 10: Error Analysis.

Error Source	Tolerance	Verification	Δh (mm)	δθ (°)
Transition ID, Reference Target (δt_1)	±5mm	TP312 Fig. B-19 Note (4): Band thickness is 8.7mm at d1=~10m	5	0.008
Transition ID, Levelling Rod (δt_2)	±20mm	TP312 Fig. B-19 Note (4): Band thickness is 39mm at d1+d2=~45m	20	0.033
Laser Level (δlaser)	±1.95mm/10m	Two-peg method	6.8	0.011
		(Appendix A.1)		
Rod graduation (δrod)	±1mm	Factory markings	1	0.002
Rod plumbing (δtilt)	±0.1°	0°/180° reversal (A.3)	0.005	0.000008
Distance d2 (δd2)	±30mm	Three-point linearity (A.2)	—	0.003
Lateral offset	≤ 1.8m	Visual alignment from behind PAPI	—	0.001
Atmospheric refraction	—	N/A (path < 50m)	—	0.0003
Combined (RSS)			**21.7**	**±0.036**

Total method uncertainty: ±0.036° at d2 = 35m, θ = 3.5°. This is within the ±0.05° tolerance specified by TP312 with a margin factor of 1.39×.

If a PAPI unit's transition band exceeds the thickness predicted by TP312 Figure B-19 Note (4), the unit may be non-compliant. This is a reportable finding independent of the angle measurement.

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10. Error Analysis

10.1. Error Propagation

From θ = arctan(h/d2), the total angular uncertainty is:

$$\delta\theta \approx \sqrt{[\,(\delta h / d2)^2 + (\tan(\theta) \times \delta d2 / d2)^2\,]}\ \ \text{(radians)}$$

For small angles (h/d2 << 1), the first term dominates.

10.2. Transition Identification Error

The transition identification error is the dominant contributor to the measurement uncertainty. Per TP312 Figure B-19 Note (4), the transition band of a compliant PAPI unit is flat within 3 arcminutes (0.05°). The physical thickness of this band at distance D from the PAPI is:

$$\text{Band thickness} = D \times \tan(0.05°)$$

At the Reference Target (D = 10m), the band thickness is 8.7mm. At the Levelling Rod (D = 45m), the band thickness is 39mm. The observer identifies the midpoint of this band by visual inspection, aided by mm graduations and a phone camera photograph.

The assumed identification uncertainty of ±5mm at the Reference Target and ±20mm at the Levelling Rod represents midpoint identification within approximately half the respective band thickness. These are conservative estimates.

At the Reference Target: $\delta\theta_1$ = 5mm / 35,000mm = 0.000143 rad = 0.008°. At the Levelling Rod: $\delta\theta_2$ = 20mm / 35,000mm = 0.000571 rad = 0.033°.

10.3. Laser Level Error

The laser level accuracy is specified as ±1.95mm at 10m. At the Levelling Rod distance of approximately 35m from the Laser Level, the error scales linearly to ±6.8mm. This is verified in the field by the two-peg method (Appendix A.1).

At d2 = 35m: δθ = 6.8mm / 35,000mm = 0.000194 rad = 0.011°.

10.4. Distance Measurement Error

The laser distance meter has a manufacturer's specification of ±2mm. At d2 = 35m and θ = 3.5°:

$$\tan(3.5°) \times 0.002 / 35 = 0.00003°$$

Even with the three-point linearity test threshold of ±30mm, the contribution is only 0.003°. Distance measurement error is negligible in this method.

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10.5.　　Rod Plumbing Error

A tilt of α from vertical causes a vertical displacement of:

$$\delta h_{tilt} \approx H \times (1 - \cos α)$$

With the digital clinometer verified to ±0.1°, at a mark height of 3.55m:

$$\delta h_{tilt} \approx 3550 \times (1 - \cos 0.1°) = 0.005mm$$

This contributes less than 0.001° to the angle measurement. Note that the Reference Target does not require plumbing, as its tilt introduces no error (the laser is adjusted to visually match the transition midpoint on the target surface).

At d2 = 35m: δθ = arctan(0.005mm / 35,000mm) = 0.000008° <0.000001

10.6.　　Lateral Offset Error

The Reference Target's lateral position does not affect the measurement. The laser level is set to the transition height at whatever position the Reference Target occupies, and this height is valid for any point at distance d1 from the PAPI. Since d1 cancels from the main formula, the Reference Target's exact position — on-axis or off-axis — does not affect the calculated angle.

The only offset that matters is the Levelling Rod's deviation from the line extending from the PAPI through the Reference Target. If the Rod is offset by angle α from this line (measured at the Reference Target), the effective PAPI-to-Rod distance is:

$$D\_rod = \sqrt{(d1^2 + d2^2 + 2 \cdot d1 \cdot d2 \cdot \cos(α))}$$

The effective baseline becomes d2' = D_rod − d1, which is slightly shorter than the measured d2. The total angular error is:

$$\delta θ = \arctan(d2' \times \tan(θ) / d2) - θ$$

This analysis reintroduces d1, which normally cancels from the method. However, with d1 estimated at 10m ±1m, the sensitivity is negligible: at α = 3°, varying d1 from 9m to 11m changes the error by only 0.00009°.

Representative values at d2 = 35m, θ = 3.5°:

α	Levelling Rod offset (m)	δθ
1°	0.6	−0.0001°
2°	1.2	−0.0005°
3°	1.8	−0.0010°
5°	3.1	−0.0030°

The laser level error contribution (Section 9.3) is unaffected by lateral offset, as it is based on the measured distance d2 from the laser to the Rod, which remains the same regardless of offset.

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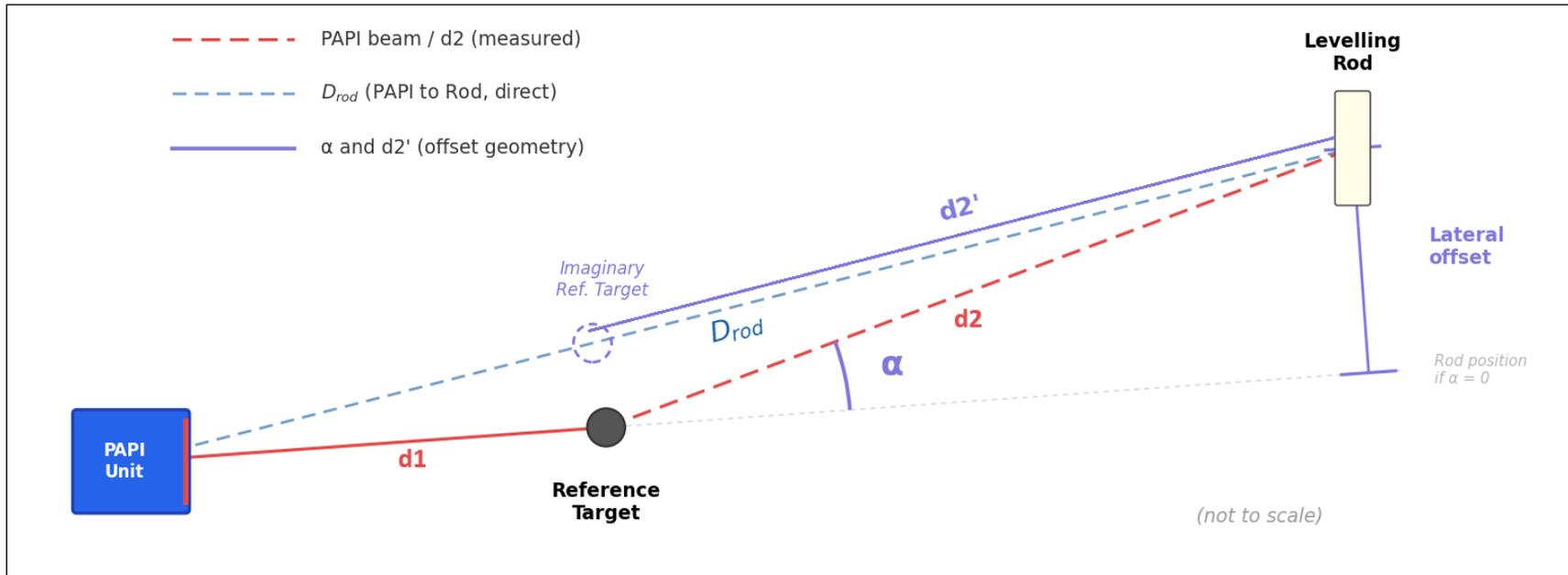
Figure 4: Top View – Lateral Offset Geometry

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10.7.   Atmospheric Refraction

Over the short distances involved in this method (total path length under 50m), atmospheric refraction causes a height error of:

$$\delta h = (1-k) \times d^2 / (2R) = 0.87 \times 2500 / (2 \times 6{,}371{,}000) = 0.17mm$$

At d2 = 35m: $\delta\theta$ = 0.17mm / 35,000mm = 0.000005 rad < 0.001°.

This contributes less than 0.001° to the angle measurement. No correction is required.

10.8.   Combined Uncertainty Statement

The combined standard uncertainty of the method, calculated by root-sum-square of all individual contributions, is ±0.036° at d2 = 35m with θ = 3.5°. This is within the ±0.05° (3 arcminute) tolerance specified by TP312 5th Edition, Table 5.3.16.18, with a margin factor of 1.39.

The uncertainty improves with increasing d2:

d2 (m)	δθ (°)	Margin to ±0.05°	Transition height at 3.5°
35	±0.036	1.39×	3.55m
40	±0.032	1.56×	3.86m
45	±0.029	1.72×	4.17m
50	±0.026	1.92×	4.47m

Note: Transition heights assume d_1 = ~10m and H_PAPI = 0.8m. Actual heights will vary with site conditions but remain well within the 5m rod range at all listed distances.

11.   Method Comparison

The following table compares the proposed method with existing methods referenced in AC 300-006 and manufacturer documentation.

Attribute	This Method	Ground Survey	Crouse-Hinds	Optoelectronic
Achievable precision	±0.036°	±0.05° (claimed)*	~±0.19°**	< ±0.017°
Equipment cost	<$1,000	>$2,500	~$200	>$50,000
Personnel required	1-2	2	1-2	1
Contact with PAPI	No	Yes	No	No
Parallelism assumption	No	Yes (critical)*	No	No
Calibration traceability	Field-verified	Certificate	None	Factory calibrated
Specialist training	No	Yes (surveyor)	No	Yes (operator)
Risk to PAPI alignment	None	Yes (loading)	None	None

* Ground Survey method assumes the surface on which the theodolite is placed is exactly parallel to the PAPI beam. At ±3 arcminute tolerance, this assumption is unverified and may introduce error exceeding the tolerance due to manufacturing imperfections, surface warping, or debris.

**Crouse-Hinds Document 2438 (Rev. L), Note B, specifies a tolerance of ±1 inch on the height difference over a 25 ft baseline, corresponding to ±0.19°.

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12. Practical Constraints Summary

Parameter	Constraint
d1 (PAPI to Reference Target)	≥ 10m (far-field beam pattern)
d2 (Reference Target to Levelling Rod)	≥ 35m minimum; 40m+ recommended
d1 + d2 (total distance)	≤ ~69m (5m rod height at 3.5°)
Lateral offset	≤ 1.8m from PAPI-to-Reference Target line
Laser Level accuracy	≤ ±2mm per 10m
Transition identification	±5mm at Reference Target; ±20mm at Levelling Rod
Rod plumbing	Digital clinometer, ±0.1°
Target precision	±0.05° (3 arcminutes) per TP312
Method uncertainty (d2 = 35m)	±0.036° (margin: 1.39×)

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APPENDICES

Appendix A: Pre-Measurement Verification Procedures

A.1 Two-Peg Method for Laser Level Verification

The two-peg method is a standard technique for detecting and quantifying tilt error in a laser level. It is self-referencing and works regardless of the ground slope between the two measurement points.

TWO-PEG METHOD FOR LASER LEVEL VERIFICATION

STEP 1: Laser Level at midpoint

Any tilt error affects both readings equally → $a_1 - b_1$ = true height difference

(ground slope does not affect the result)

Laser Level
(midpoint)

a_1 b_1

Pole A   Pole B

equal   *equal*

STEP 2: Laser Level near Pole A

a_2 is nearly error-free (short distance) → b_2 carries full tilt error

Laser Level
(near Pole A)

a_2 b_2

Pole A   Pole B

short

Laser error = $(a_2 - b_2) - (a_1 - b_1)$

Figure 5: Two-peg method for laser level verification

Procedure

Step 1: Place two poles (A and B) at a distance apart equal to or greater than the maximum working distance for the PAPI measurement.

Step 2: Set the laser level at the midpoint between A and B.

Step 3: Read and record the laser height on Pole A (reading a_1) and Pole B (reading b_1). These readings are measured from the ground at each pole to the laser line.

Step 4: Move the laser level to within 1–2 metres of Pole A.

Step 5: Read and record the laser height on Pole A (reading a_2) and Pole B (reading b_2).

Calculation

The laser error over the full distance is:

$$error = (a_2 - b_2) - (a_1 - b_1)$$

This works because in Step 2, any laser tilt affects both readings equally (equal distances), so $a_1 - b_1$ represents the true height difference. In Step 4, the reading on the nearby pole (A) is essentially error-free, but the far reading (B) carries the full tilt error. The difference between the two setups isolates the laser error.

Ground elevation at A and B does not affect the result, as it appears identically in both measurement sets and cancels.

Pass/Fail Threshold

The maximum allowable two-peg error depends on ~d2 (the distance from the Laser Level to the Levelling Rod). The following values correspond to a maximum laser contribution of ±0.01° to the final angle measurement:

d2 (m)	Maximum allowable error (mm)
35	±6.1
40	±7.0
45	±7.9
50	±8.7

If the error exceeds the threshold, the laser level must be recalibrated or replaced before proceeding with PAPI measurements.

A.2 Three-Point Linearity Test for Laser Distance Meter

This test verifies that the laser distance meter is functioning correctly by checking internal consistency across three collinear points.
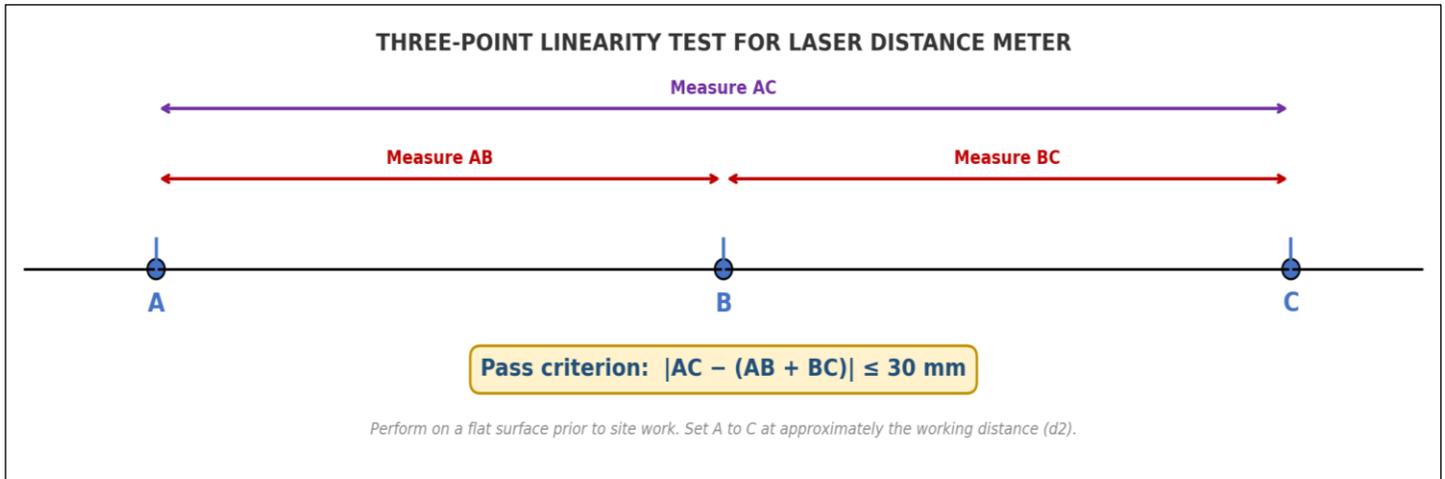

Figure 6: Three-point linearity test for laser distance meter

Procedure

Place three marks (A, B, C) in a straight line on a flat surface, with A to C set at approximately the working distance (d2). Measure AB, BC, and AC with the laser distance meter.

Pass/Fail Criterion

$$|AC - (AB + BC)| \leq 30mm$$

At d2 = 35m and θ = 3.5°, a 30mm distance error contributes less than 0.003° to the measured angle.

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A.3 Digital Clinometer 0°/180° Reversal Check

Procedure

Step 1: Place the digital clinometer on a stable surface.

Step 2: Record the reading.

Step 3: Rotate the clinometer 180° on the same surface.

Step 4: Record the reading.

Pass/Fail Criterion

The two readings should be equal and opposite. The difference must not exceed the manufacturer's stated accuracy (±0.1° for most models). If the clinometer supports self-calibration, perform it before the check.

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Appendix B: Sample Data Recording Sheet

PAPI Unit Identification: _____   Airport: _____   Date: _____

Measurement

Parameter	Value
d1 (PAPI to Reference Target)	_____ m
d2 (Reference Target to Levelling Rod)	_____ m
Laser line reading on Levelling Rod	_____ mm
Transition midpoint reading on Levelling Rod	_____ mm
h = transition − laser	_____ mm
Calculated θ = arctan(h / d2)	_____ °

Photographs attached: YES / NO

Measured by: _____   Signature: _____

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Appendix C: Worked Example

C.1 Given

A PAPI unit has a nominal setting angle of 3.00°. The following measurement is taken:

$d1$ = 11.200m

$d2$ = 37.250m

Laser line reading on Levelling Rod: 1856mm

Transition midpoint reading on Levelling Rod: 3812mm

C.2 Calculation

h = 3812 − 1856 = 1956mm = 1.956m

θ = arctan(1.956 / 37.250) = arctan(0.05250) = 3.007°

The measured angle of 3.007° is within ±0.05° of the nominal 3.00° setting. The PAPI unit passes the angle verification.

C.3 Note

Observe that $d1$ does not appear in the calculation. Different values of $d1$ will produce different laser line and transition readings on the Levelling Rod, but the difference h remains the same, yielding the same calculated angle.

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Appendix D: Enhanced Transition Identification Using Spatial Filtering

D.1. Purpose

In the base method (Section 6), the dominant source of measurement uncertainty is the identification of the transition midpoint on the Levelling Rod (δt_2 = ±20mm). This appendix describes an optional enhancement that reduces δt_2 to ±5mm by placing an apertured screen at the Reference Target position. The improvement allows shorter working distances while maintaining or exceeding the precision of the base method.

If conditions in the field make the enhanced method impractical (e.g., insufficient light on the rod, inability to position the screen), the operator shall revert to the base method in Section 6.

D.2. Principle

A compliant PAPI transition band occupies 3 arcminutes of vertical angle (TP312 Figure B-19 Note 4). At d_1 = 10m, this corresponds to a physical band height of 8.7mm. At the Levelling Rod, the same angular range produces a wider gradient that is difficult to interpret visually.

A horizontal aperture of height s, positioned at the transition midpoint on a screen at distance d_1, passes only the light within that vertical slice. The light that passes through projects forward and illuminates a bounded strip on the Levelling Rod with defined upper and lower edges against a dark background. The observer identifies both edges on the rod graduations and averages them to determine the strip centre. This centre corresponds to the transition height at the Levelling Rod.

The screen does not need to be plumb or levelled. The aperture is positioned by visually matching it to the transition on the screen surface, so any tilt of the screen is self-correcting.

D.3 Aperture Height

For an aperture height of 5mm, at d_1 = 10m, the projected strip height on the Levelling Rod is:

strip height = 5 × (d_1 + d_2) / d_1

At d_2 = 15m: 12.5mm. At d_2 = 18m: 14.0mm.

A 5mm aperture is selected as a practical starting point that balances light throughput against spatial filtering. Operators should verify that the projected strip is clearly visible and that the edges can be reliably identified on the rod graduations before relying on the enhanced uncertainty figures in Section D.6.

D.4 Additional Equipment

In addition to the equipment listed in Section 4: An opaque screen (cardboard, plywood, or similar) of sufficient size to block the PAPI beam, with a pre-cut horizontal aperture of 5mm height.

D.5 Procedure

Centreline establishment:

Step D1: Before placing the screen, establish the PAPI optical axis on the ground. From behind the PAPI unit, sight along the centreline and mark the ground at two points using a chalk line, string line, or a laser pointer projected forward. All subsequent equipment shall be placed on or within 0.5m of this line.

Screen setup:

Step D2: Position the screen at distance d_1 (≥ 10m) from the PAPI, on the centreline.

Step D3: Position the aperture at the transition midpoint.

Step D4: Position the Laser Level adjacent to the screen. Adjust the Laser Level height until the laser line coincides with the centre of the aperture.

Rod setup:

Step D5: Position the Levelling Rod at distance d_2 from the screen, on the centreline. Minimum d_2 is 15 metres; 18 metres or greater is recommended.

Step D6: Verify the Levelling Rod is plumb using the digital clinometer.

Step D7: Measure d_2 from the screen to the Levelling Rod using the laser distance meter.

Measurement:

Step D8: On the Levelling Rod, photograph the upper and lower edges of the illuminated strip. Record the graduation reading at each edge. Calculate the strip centre as the average of the two readings.

Step D9: Photograph the laser level line on the Levelling Rod. Record the graduation reading.

Step D10: Calculate the vertical distance: h = (strip centre reading) − (laser line reading).

Step D11: Calculate the PAPI setting angle: $\theta = \arctan(h / d_2)$.

Repeat:

Step D12: Repeat the entire procedure (Steps D2 through D11) for each PAPI unit. The aperture must be repositioned for each unit, as each unit has a different setting angle and therefore a different transition height on the screen.

Photographic evidence:

Retain all photographs of strip edges and laser line readings as part of the measurement record.

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D.6 Revised Uncertainty Budget

Values calculated for d_1 = 10m, θ = 3.5°, aperture height = 5mm.

Error Source	Tolerance	δh (mm)	δθ at d_2 = 15m	δθ at d_2 = 18m	δθ at d_2 = 35m
Transition ID, screen ($δt_1$)	±5mm	5	0.019°	0.016°	0.008°
Transition ID, rod strip centre ($δt_2$)	±5mm	5	0.019°	0.016°	0.008°
Laser Level (δlaser)	±1.95mm/10m	2.9 / 3.5 / 6.8	0.011°	0.011°	0.011°
Rod graduation (δrod)	±1mm	1	0.004°	0.003°	0.002°
Rod plumbing (δtilt)	±0.1°	0.005	<0.0001°	<0.0001°	<0.0001°
Distance d_2 ($δd_2$)	±30mm	—	0.004°	0.003°	0.003°
Lateral offset	≤ 0.5m	—	0.001°	0.001°	0.001°
Combined (RSS)			**±0.029°**	**±0.025°**	**±0.016°**

D.7 Summary

Parameter	Base Method (Section 6)	Enhanced Method (this appendix)
d_2 minimum	35m	15m
d_2 recommended	40m+	18m+
Rod height at 3.5° ($d_1 + d_2$)	3.55m (at 45m)	1.71m (at 28m)
δθ	±0.036°	±0.025°
Margin to ±0.05°	1.39×	2.0×
Additional equipment	None	Apertured screen