AMPLITUDE AND PHASE IMBALANCE

CALIBRATION FOR RADIO ASTRONOMY RECEIVERS

USING MATLAB SIMULATION

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Abstract

Radio astronomy receivers inherently suffer from **I/Q imbalance** — amplitude (α) and phase (ϕ) mismatches between I and Q channels, corrupting spectral measurements and degrading image rejection.

This work presents a wideband software calibration system for the **21-cm Hydrogen Line at 1420 MHz** using MATLAB. A 5th-order polynomial fitted to 64 noise diode subbands enables real-time correction across 200 MHz bandwidth.

Validated across **four Riyadh seasonal temperatures (0°C – 45°C)**. IRR improvements exceed +40 dB — surpassing the 40 dB target in all conditions.

Introduction & Background

Problem : Dual-channel RF receivers suffer from gain/phase mismatches due to manufacturing variations, temperature changes, and voltage fluctuations.

Impact: In radio astronomy, I/Q imbalance leads to poor spectral quality, image interference, and inaccurate source localization — critical for HI line observations.

Reference Paper: de Souza Melo et al. (FT2025) demonstrated amplitude/phase calibration for X-band direction finding. Online calibration reduced phase error from 4.06° to 0.06°.

Our Extension: Wideband polynomial fitting, temperature-aware modeling, and HI signal simulation with cosmic noise.

System Model & Methodology

1. Distortion Modeling

Simulated 1420 MHz HI signal with hardware I/Q mismatches. Dynamic thermal modeling (0°C–45°C) accounts for non-linear, frequency-dependent imbalances in Riyadh's environment.

2. Calibration Workflow

- Injection: Noise diode signal across 64 subbands.
- Estimation: Statistical estimation of amplitude and phase errors per subband.
- Fitting: 5th-order polynomial regression over 200 MHz bandwidth.
- Correction: Inverse software transformation to maximize Image Rejection Ratio .

3. Key Parameters

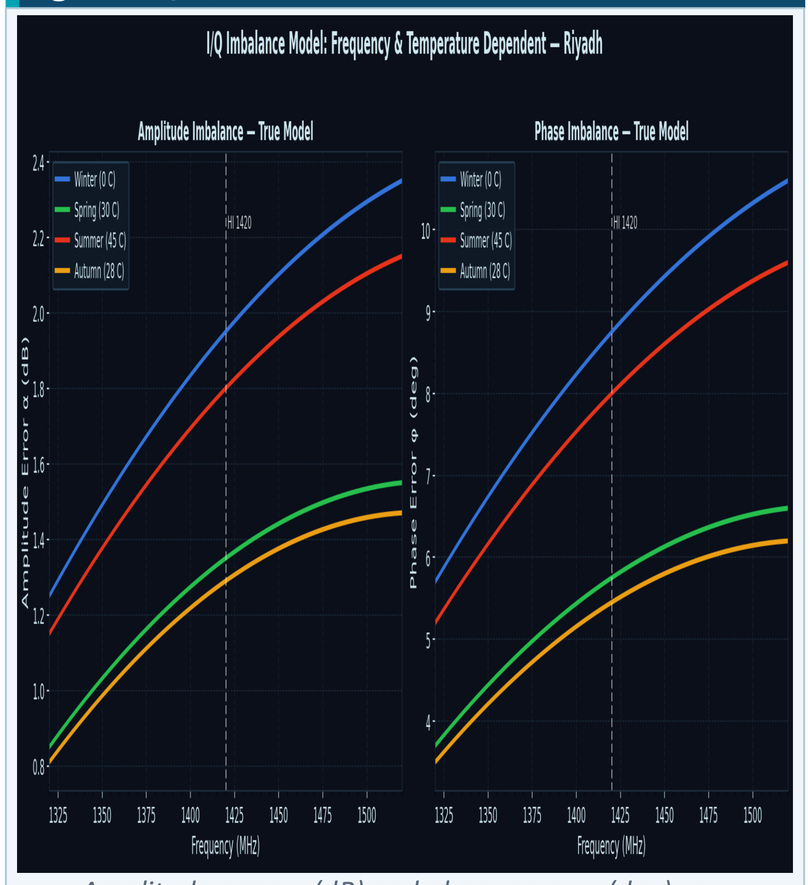
-Frequency: 1420 MHz | BW: 200 MHz
-Target: IRR > 40 dB
-Setup: 5th-order Poly, 64 Subbands

Proposed Solution & Contributions

We developed a reliable, **software–only** calibration system utilizing a 5th-order polynomial fitting algorithm. This approach dynamically estimates and corrects wideband I/Q imbalances in real-time, specifically designed to withstand extreme thermal variations without hardware intervention.

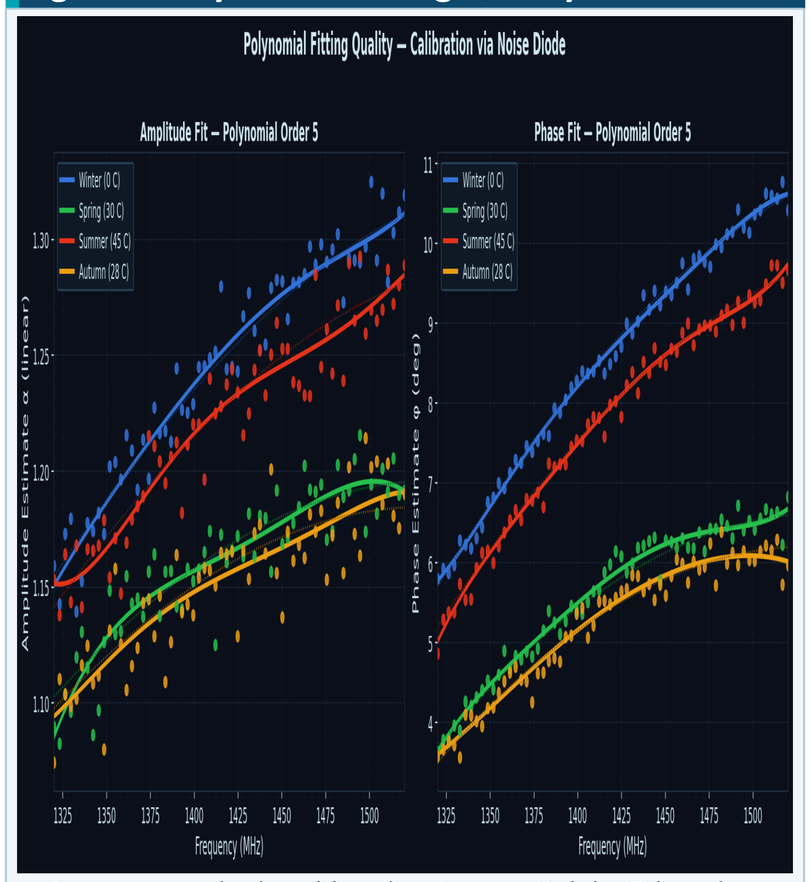
Aspect	Reference Paper	Our Project
Calibration	Per 10 MHz narrowband	**Wideband (200 MHz)**
Frequency	X-band (8.5–9.5 GHz)	**L-band (1420 MHz HI)**
Temperature	Fixed lab temp	**0°–45°C Riyadh seasons**
Test Signal	Single tone	**HI line + cosmic noise**
Application	Satellite DF	**Radio Astronomy**

Fig. 1 — I/Q Imbalance Model



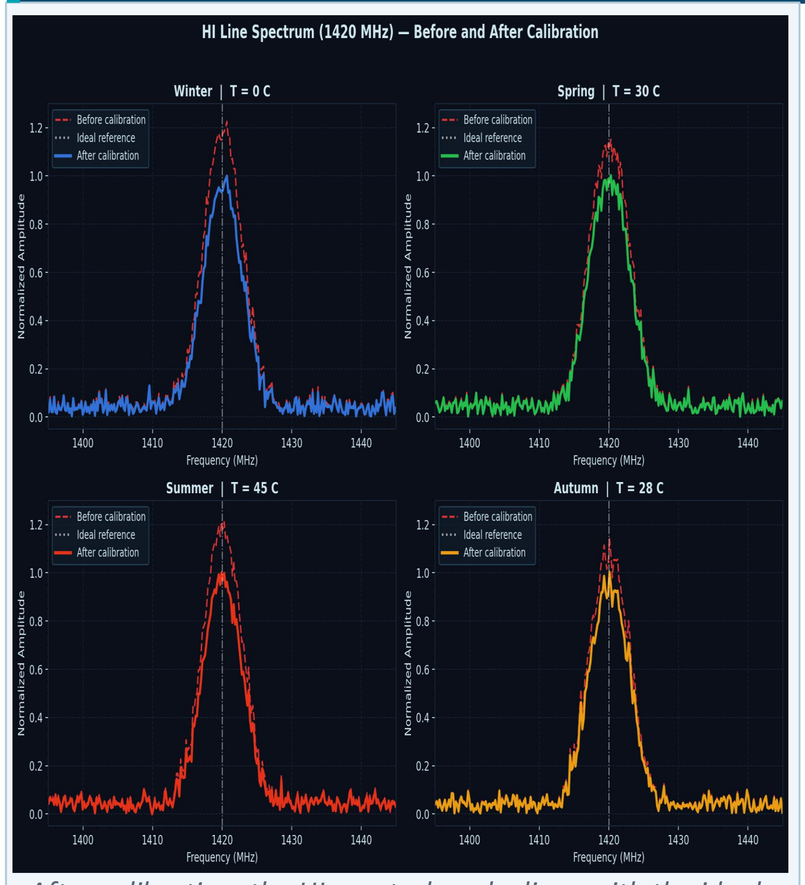
Amplitude error α (dB) and phase error φ (deg) vs. frequency across four Riyadh seasons. Winter (0°C) shows maximum imbalance.

Fig. 2 — Polynomial Fitting Quality



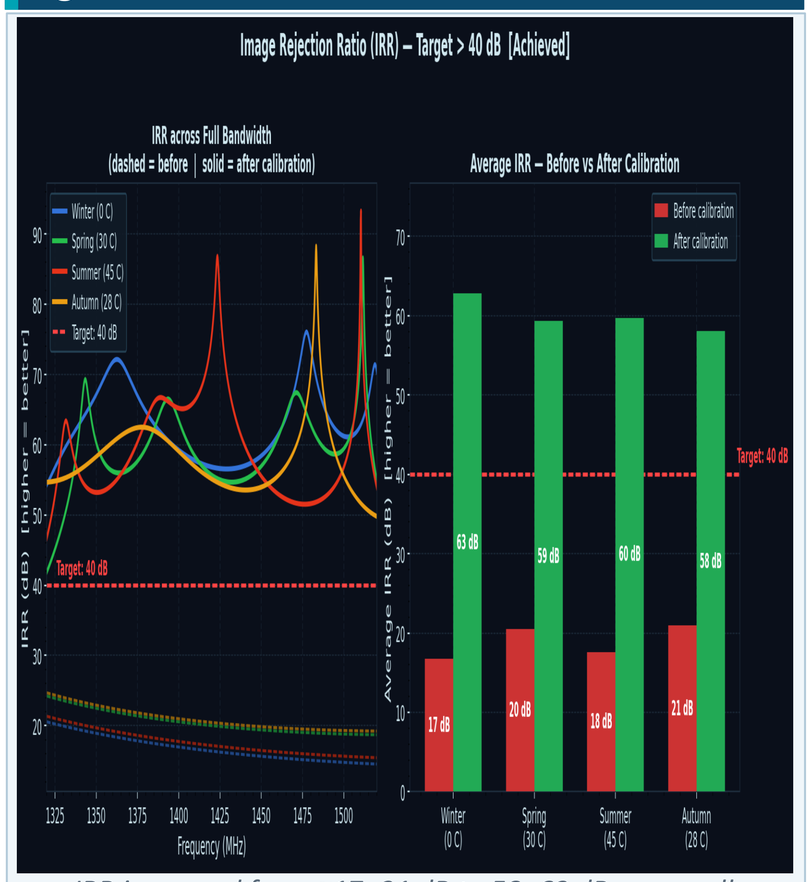
Dots = noise diode subband estimates. Solid = 5th-order polynomial fit. Dotted = true model. Excellent agreement across 200 MHz.

Fig. 3 — HI Spectrum Before & After Calibration



After calibration, the HI spectral peak aligns with the ideal reference across all seasons. Pre-calibration distortion is severe at extreme temperatures.

Fig. 4 — IRR Before vs. After Calibration



IRR improved from ~17–21 dB to 58–63 dB across all seasons — exceeding the 40 dB target. Average gain: +41 dB. Robust across all temperatures.

Results Summary — IRR Performance

Target achieved : Exceeded the 40 dB IRR threshold in all Riyadh seasons.
Peak performance : Maximum calibration gain of +46 dB achieved at 0°C.
Wideband stability : Stable IRR results between 58–63 dB across the full 200 MHz band.
Validation : Accurate spectral alignment with the ideal 1420 MHz HI reference.

Season	Temp (°C)	IRR Before (dB)	IRR After (dB)	Gain (dB)
Winter	0	17.0	**63.0**	+46.0
Spring	30	20.0	**59.0**	+39.0
Summer	45	18.0	**60.0**	+42.0
Autumn	28	21.0	**58.0**	+37.0

Conclusions

✓ 5th-order polynomial calibration achieves >40 dB IRR across the full 200 MHz HI band in all Riyadh seasons.

✓ Average IRR gain: +41 dB — robust from 0°C to 45°C.

✓ Software-only approach — no hardware modifications required.

Reference: de Souza Melo, J. A., Compassi Severo, L., & Coutinho, O. L. (2025). Amplitude and Phase Imbalance Calibration for Space-Based Precision Direction Finding Systems. FT2025, Linköping Electronic Conference Proceedings. DOI: 10.3384/wcc215.1199