

Pushing the Limits of Established Sensor Technologies

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Summary:

Regulatory tightening and increasingly demanding applications are driving sensor and measurement systems toward performance levels that were not anticipated in the original designs. Rather than pursuing new sensing technologies, a structured engineering approach can unlock substantial performance gains in existing systems, often with minimal hardware changes. This paper presents two industrial examples that illustrate the gains obtained through systematic modelling of measurement uncertainty, identification of dominant error contributors, and targeted mitigations.

Keywords: FTIR, Gas Chromatograph, Emission Monitoring, Established Technologies

Methodology

A complete error budget decomposes total uncertainty into individual contributors (noise, drift, cross-sensitivity, thermal effects, etc.), ranking them to reveal high-leverage "knobs." Targeted engineering effort on dominant contributors achieves required performance improvement efficiently.

Notably, this systematic approach yields substantial gains without novel sensing technologies.

CEMS for Waste Incineration

ABB ACF5000 is a multi-component FTIR-based analyser certified for Continuous Emission Monitoring (CEMS) of combustion plants [1].

Best Available Techniques Conclusions (BATc) under Directive 2010/75/EU establish emission limit values based on industry best practices. The updated 2019 BATc for waste incineration introduced significantly tighter limits for several components. For example, HCl and NH₃ limits were reduced substantially compared to the previously certified ranges [2].

Meeting these new limits required a rigorous analysis of measurement uncertainty as defined by DIN EN15267-3 [3]. The standard imposes two seemingly independent requirements: noise must be $\leq 2\%$ of measurement range, and cross-interference between specified gas pairs must be $\leq 0.5\%$ for relevant pairs, with the sum of all relevant cross-interferences $< 4\%$ of range.

A critical statistical insight emerged during error budget analysis: when the noise limit is narrowly satisfied at 2%, measurement uncertainty is too high to reliably quantify cross-interference between gas pairs. In this regime, the sum of all relevant cross-interference cannot be verified to stay below the 4% requirement. This revealed the true requirement: achieve noise at approximately 1% of measurement range, creating sufficient statistical margin to measure and control cross-interference accurately.

Error budget analysis then identified the dominant physical contributors to excess noise and cross-interference: ambient temperature fluctuations inside the analyser cabinet, which degraded signal stability at very low concentration ranges, and insufficient heating in sample handling components for reactive gases such as HCl and NH₃, causing adsorption losses before the gas cell.

Targeted interventions addressed precisely these contributors: the cabinet cooling was mandated as air-conditioned only, and the heated sample probe design was changed to one providing a higher and more stable wall temperature. Gas cell optics were also updated, and processor capacity was increased to support parallel spectral evaluation models. The test infrastructure itself was recognized as a contributor; improved gas supply control and automation eliminated test-set-up-induced artifacts.

The resulting product, the ACF5000 LCS achieved a measurement performance improvement of up to factor 10 relative to the previous

platform, delivering successful certification for emission monitoring in 2026 with certified ranges [4][5] shown in Table 1. Those are the lowest certified ranges of any CEMS available.

Table 1, certified measurement range in mg/m^3

Component	Standard ACF5000	ACF5000 LCS
CO	0–75	0–15
NO	0–150	0–50
NO ₂	0–80	0–60
SO ₂	0–75	0–7.5
HCl	0–15	0–3
HF	0–3	0–1.35
NH ₃	0–5	0–3

Chromatography of trace gases using a Thermal Conductivity Detector (TCD)

An upcoming variant of ABB GCPro Series Gas Chromatograph [6] includes an advanced TCD designed to achieve ultra-low detection limits (~ 0.3 ppm) for trace gas analysis. Development employed systematic multi-physics modelling to understand and control the complete error chain.

Detailed simulations (combining thermal dynamics, fluid mechanics, heat transfer, and electronics noise) revealed the dominant uncertainty contributors. Critically, baseline noise at peak frequency (~ 0.1 Hz) was identified as the repeatability limiter; Figure 1 depicts the main elements influencing the noise. Three key physical knobs emerged: thermal wall temperature stability within the detector chamber (requiring ± 50 μK control), baseline electronics noise across frequency band of interest (from A/D converter, signal conditioning, and thermal fluctuations), and detector geometry and gas flow patterns affecting heat transfer uniformity.

Three coordinated improvements emerged: miniaturized multi-plate geometry via diffusion bonding; advanced electronics (8-9 $\times$ lower noise spectral density); optimized signal processing. Thermal stability required precision heater control and shielding.

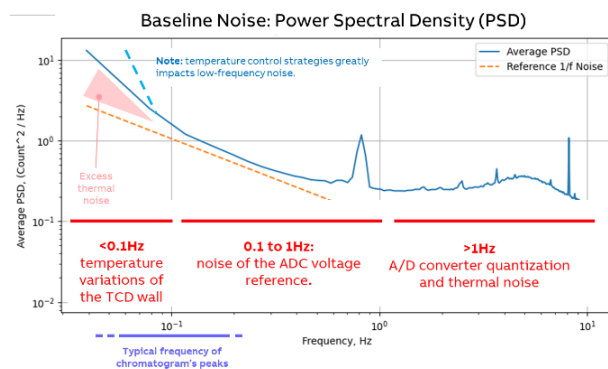


Figure 1. TCD noise model with main contributors

These coordinated physical improvements delivered a 6 $\times$ enhancement in peak repeatability for low-ppm analytes compared to the previous TCD detector, translating to detection limits of 0.3 ppm with 0.05 ppm standard deviation. Signal processing algorithms alone contributed a 2 $\times$ improvement in repeatability, demonstrating the importance of systematic optimization across the measurement and processing chain.

Both examples share a common pattern. In the ACF5000 case, the critical step was understanding that the normative noise requirement was not the true requirement: achieving 2% noise makes the cross-interference specification statistically unachievable. Recognizing this hidden constraint unlocked the path forward. In the GCPro TCD case, multiphysics simulation exposed that thermal wall stability at the sub-millikelvin level was the binding constraint, not electronics or geometry alone. In both cases, the performance breakthrough came not from incremental trial-and-error tuning, but from first building a sufficiently complete model of the error chain to know which knobs mattered.

Conclusions

Both examples demonstrate that systematic error modelling, grounded in physics-based understanding of the complete measurement chain, is a powerful and efficient route to extending the performance envelope of established sensor technologies.

The common thread across both is this: identify the dominant error contributors early through rigorous modelling, then apply focused engineering only to those high-leverage knobs. This approach can deliver up to factors 6-10 improvement without fundamentally new sensing principles. The methodology applies broadly across established sensor technologies, systematically transforming performance limitations into opportunities for significant improvement without costly redesigns.

References

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