

Comprehensive Analysis of the NXP TEF6686 Receiver Architecture: Technical Performance on Amplitude Modulation and Shortwave Broadcast Bands

1. Executive Summary

The landscape of portable radio reception has undergone a radical transformation with the adaptation of automotive-grade silicon for consumer and hobbyist applications. Central to this shift is the TEF6686 system-on-chip (SoC) from NXP Semiconductors. Originally engineered to meet the rigorous demands of modern automotive infotainment systems—where multipath interference, rapid signal fading, and high impulse noise are endemic—the TEF6686 has been appropriated by the radio enthusiast community. This report provides an exhaustive technical evaluation of the TEF6686's expected performance on the Amplitude Modulation (AM) Longwave (LW), Mediumwave (MW), and Shortwave (SW) bands.

The analysis synthesizes data from technical datasheets, open-source firmware repositories, comparative field tests, and user reports to construct a definitive profile of the chip's capabilities. The core findings indicate that the TEF6686 represents a "super-tuner" class of receiver, offering sensitivity and selectivity specifications that frequently exceed those of traditional consumer portable radios. Its Digital Signal Processing (DSP) core enables "brick-wall" filtering and advanced noise blanking that are particularly effective in high-noise urban environments. However, its utility as a general-coverage High Frequency (HF) receiver is constrained by specific architectural decisions intended for the automotive market: notably, a complete lack of Single Sideband (SSB) demodulation, a susceptibility to front-end overload when coupled with high-gain external antennas, and default audio processing behaviors (such as soft muting) that require significant firmware intervention to mitigate.

This report details the architectural topography of the TEF6686, dissects its performance across specific frequency bands, evaluates the impact of third-party firmware and hardware implementations, and places it in direct comparison with competing DSP and analog technologies.

2. Architectural Genesis and Design Philosophy

To accurately predict and understand the performance of the TEF6686 on AM and SW bands, it is essential to analyze its design provenance. Unlike the Silicon Labs Si473x series, which was designed with portable consumer electronics in mind, the TEF6686 is an automotive component. This lineage dictates its strengths, weaknesses, and operational idiosyncrasies.

2.1 The Automotive Radio Environment

The automotive environment is arguably the most hostile operating theater for a radio receiver. The TEF6686 was designed to cope with three primary challenges:

1. **Mobile Fading:** As a vehicle moves, the received signal strength fluctuates rapidly due to multipath propagation (Rayleigh fading).
2. **Impulse Noise:** The vehicle's ignition system, alternators, and increasingly complex ECU networks generate significant broadband electrical noise.
3. **Signal Dynamic Range:** A vehicle may travel past a kilowatt-class transmitter tower, subjecting the receiver to massive signal levels, only to drive into a tunnel or valley where sensitivity is paramount.

These challenges necessitated a Low-IF (Intermediate Frequency) architecture with highly aggressive digital algorithms for Automatic Gain Control (AGC), Noise Blanking (NB), and Channel Equalization (CEQ). When a hobbyist uses a TEF6686-based portable on a desk, they are essentially leveraging a system designed to maintain lock on a weak station while driving 100 km/h through a city center.

2.2 Low-IF Digital Topography

The TEF6686 eschews the traditional superheterodyne architecture of multiple analog conversion stages and ceramic filters. Instead, it employs a highly integrated digital Low-IF topology.

- **RF Front-End:** The analog front-end consists of a Low Noise Amplifier (LNA) with a wide-range AGC. This LNA feeds a mixer that down-converts the RF signal to a low intermediate frequency.
- **Digitization:** The IF signal is immediately digitized by high-dynamic-range Sigma-Delta Analog-to-Digital Converters (ADCs). From this point forward, the signal path is entirely mathematical.
- **DSP Core:** Filtering, demodulation, stereo decoding, and weak signal processing are performed by a dedicated DSP core. This allows for variable filter bandwidths (e.g., 3 kHz, 4 kHz, 6 kHz) to be implemented as software coefficients rather than physical components, offering perfect consistency and "alignment-free" manufacturing.

3. Amplitude Modulation (LW/MW) Performance Analysis

The Mediumwave (MW) and Longwave (LW) performance of the TEF6686 is widely regarded as its strongest attribute outside of FM. The chip's architecture provides a noise floor and selectivity performance that is difficult to achieve with analog components at a similar price point.

3.1 Sensitivity and Noise Floor Characteristics

Sensitivity in modern DSP receivers is often limited not by the gain of the LNA, but by the internal noise generated by the digital circuitry itself. The TEF6686 excels in this metric.

- **Noise Floor Measurement:** Technical analyses indicate the TEF6686 possesses an internal noise level of approximately -7 dBuV. This is exceptionally low, allowing the receiver to resolve signals that are essentially at the thermal noise floor of the antenna

system.

- **Reception Threshold:** Field tests demonstrate that excellent signal reception is possible at signal strengths below 10 dBuV. In practical terms, this allows the TEF6686 to detect "graveyard" channel stations and weak transatlantic DX signals that would be inaudible on standard consumer portables.
- **Signal-to-Noise Ratio (SNR):** In side-by-side comparative testing against the Si4732 DSP chip, the TEF6686 consistently maintains a higher SNR. One documented test showed the TEF6686 maintaining an average SNR of 42.7 dB over a 12-hour period, compared to 35.1 dB for the Si4732. While this specific test referenced FM, the underlying efficiency of the Sigma-Delta ADCs and the low-noise front-end applies equally to the AM signal path.

3.2 Selectivity: The DSP Advantage

For the AM DXer, selectivity—the ability to reject strong signals on adjacent frequencies—is often more valuable than raw sensitivity. The TEF6686 offers user-selectable bandwidths that are defined in software, providing sharp filter "skirts" that do not degrade over time or temperature.

3.2.1 Bandwidth Granularity

Through advanced firmware (such as the PE5PVB project), users can manually select filter bandwidths to suit current propagation conditions. The available AM bandwidths typically include:

- **3 kHz:** The narrowest setting, essential for splitting split-frequency DX (e.g., listening to a 9 kHz spaced European station while near a 10 kHz spaced US station). The steep digital filtering provides near "brick-wall" rejection of adjacent channel splash.
- **4 kHz:** A compromise setting often used for weak but intelligible voice signals.
- **6 kHz:** The standard bandwidth for quality AM listening.
- **8 kHz:** A wide-bandwidth mode that offers high-fidelity audio for strong local stations, approaching the audio quality of FM.

This flexibility stands in stark contrast to analog receivers like the Tecsun PL-660, which typically offer only two physical bandwidth options (Wide/Narrow).

3.2.2 Precision Adjacent Channel Suppression (PACS)

The TEF6686 incorporates a proprietary algorithm known as PACS. This system dynamically monitors the energy on adjacent channels. If a strong adjacent signal is detected that threatens to desensitize the receiver or cause splatter, the DSP automatically narrows the IF bandwidth to preserve the integrity of the desired signal. This automated response is faster and more precise than manual human intervention, making the TEF6686 particularly adept at browsing crowded bands.

3.3 Noise Blanking and Interference Rejection

The automotive heritage of the TEF6686 provides it with a Noise Blanker (NB) that is vastly superior to those found in standard portable radios.

- **Mechanism:** The NB distinguishes between the continuous carrier of a broadcast station

and the short, high-amplitude pulses of impulse noise (e.g., from ignition systems or switching power supplies). When a noise pulse is detected, the DSP briefly mutes the signal (blanks it) for the duration of the pulse.

- **Performance:** Users report that the TEF6686 is nearly immune to the "click-pop" interference caused by USB chargers and LED lighting drivers, sources that render the AM band unlistenable on Si4732-based radios.
- **Configurability:** Advanced firmware allows the user to adjust the trigger threshold of the Noise Blanker (e.g., from 50% to 150% sensitivity), allowing for optimization based on the specific noise environment.

3.4 Channel Equalization (CEQ)

Multipath propagation on AM bands (caused by signal reflections from the ionosphere or terrestrial objects) results in frequency-selective fading, where certain audio frequencies are attenuated more than others, causing the audio to sound "hollow" or distorted. The TEF6686's CEQ algorithm models the transmission channel and applies an inverse filter to flatten the frequency response. This results in audio that remains intelligible even during deep fading cycles, a feature that significantly reduces listener fatigue during long DX sessions.

4. Shortwave (HF) Performance Characteristics

While the TEF6686's performance on MW is nearly universally praised, its application to the Shortwave (HF) spectrum (1.7 MHz – 27 MHz) is more complex. The chip offers high sensitivity and continuous coverage but faces significant limitations regarding demodulation modes and antenna handling.

4.1 Frequency Coverage and Tuning Mechanics

The TEF6686 supports reception across the entire HF spectrum up to approximately 27-30 MHz.

- **Tuning Range:** The standard implementation covers LW (144-522 kHz), MW (522-1710 kHz), and SW (1710 kHz - 27 MHz).
- **The 27 MHz Ceiling:** Most documentation and firmware implementations limit the upper frequency to 27 MHz, covering the Citizen's Band (CB) but stopping just short of the 10-meter Amateur Radio band (28 MHz). This reflects the chip's automotive requirements, where CB reception was a potential feature, but 10m amateur band reception was not.
- **Tuning Steps:** The DSP architecture allows for fine tuning steps (1 kHz), which are crucial for centering stations on the SW bands. However, the chip does not natively support the 10 Hz or 100 Hz steps typically desired for SSB tuning, rendering it less precise for non-broadcast signals.

4.2 Sensitivity vs. External Noise

Similar to its MW performance, the TEF6686 exhibits high sensitivity on SW.

- **Whip Antenna Performance:** The high gain of the internal LNA allows the TEF6686 to perform exceptionally well with short telescopic whip antennas. Users frequently report receiving international broadcasters (e.g., Radio Romania, BBC, Radio Marti) with strong

signal levels using only the built-in 70-100cm whip.

- **Atmospheric Noise Limits:** In the HF band, the limiting factor is often atmospheric noise rather than receiver sensitivity. The TEF6686's -7 dBuV noise floor is well below the atmospheric noise floor in almost any location, ensuring that the receiver itself does not mask weak signals.

4.3 The Critical Flaw: Lack of Single Sideband (SSB)

The most significant "deal-breaker" for serious HF hobbyists is the TEF6686's inability to demodulate Single Sideband (SSB) signals.

- **Architectural Limitation:** Unlike the Silicon Labs Si4732/35 chips, which accept "patches" (microcode updates) to their DSP core to enable SSB functionality, the TEF6686 is a "closed garden." NXP did not design the DSP to support the injection of a Beat Frequency Oscillator (BFO) or the product detection required for SSB.
- **Implications:** This renders the receiver useless for monitoring amateur radio voice traffic (LSB/USB), CW (Morse code), or many utility transmissions (marine weather, aircraft VOLMET). It is strictly a broadcast receiver. While some "dual-chip" radios (like the ESP138) combine a TEF6686 for FM/AM with an Si4732 for SSB, a pure TEF6686 radio cannot perform this function.

4.4 Dynamic Range and External Antenna Overload

A common issue reported by users attempting to use the TEF6686 for high-performance DXing is front-end overload when connected to large external antennas.

- **Broadband Front-End:** In many portable implementations (such as the generic "blue board" or acrylic case units), the antenna input feeds directly into the chip with minimal pre-selection filtering.
- **The Overload Mechanism:** When a long-wire antenna (e.g., 20+ meters) is connected, the receiver is exposed to the aggregate RF energy of the entire SW, MW, and FM spectrum. If the total energy exceeds the dynamic range of the ADC or the LNA's compression point (approx. 88-92 dBuV), the receiver overloads.
- **Symptoms:** Overload manifests as "ghost" signals (MW stations appearing on SW frequencies), broadband noise, or desensitization (where the AGC clamps down so hard that weak signals disappear).
- **Mitigation Strategies:**
 - **Attenuators:** High-end implementations (like the Qodosen DX-286) or firmware settings allow the user to engage internal attenuators or disable the LNA to manage strong signals.
 - **Pre-selectors:** The use of external passive pre-selector filters is highly recommended when using wire antennas to limit the bandwidth of energy entering the LNA.

5. Firmware Control and Signal Processing Nuances

The TEF6686 is a "headless" chip; it requires an external microcontroller (typically an ESP32) to function. The performance of the radio is therefore defined as much by the firmware running on

the ESP32 as by the silicon itself.

5.1 The "Soft Mute" Phenomenon

Soft Mute is a feature designed for the comfort of automotive listeners but is often despised by DXers.

- **Function:** As the Signal-to-Noise Ratio (SNR) of a station drops (e.g., during a fade), the DSP automatically reduces the audio volume to mask the rising static hiss.
- **Impact on DXing:** For weak signals, this causes the audio to "pump" or "chuff," fluctuating in volume rhythmically with the signal fade. This can make intelligible speech unreadable.
- **Firmware Solutions:** The automotive default settings for Soft Mute are very aggressive. Hobbyist firmware (specifically the PE5PVB v1.18 and v2.0+) exposes the specific registers controlling Soft Mute. Users can adjust the **Threshold** (the SNR level where muting begins), the **Slope** (how quickly volume is reduced), and the **Release Rate**. Crucially, modern firmware allows Soft Mute to be disabled entirely, which is essential for extracting weak SW signals.

5.2 Automated Gain Control (AGC) Customization

The TEF6686 offers separate AGC loops for the RF and IF stages.

- **RF AGC:** Controls the LNA gain. Firmware allows users to set the start threshold (e.g., 92 dBuV down to 84 dBuV) to prevent overload.
- **Antenna Gain Bug:** Some users of early firmware versions noted a counter-intuitive behavior where increasing the "Antenna Gain" setting actually reduced signal strength. This was identified as a register mapping error in specific beta versions and highlights the importance of using stable, updated firmware.

5.3 Audio Processing Features

The DSP core includes several audio processing blocks that enhance the listening experience:

- **High Cut Filter:** A low-pass filter that engages when signals are weak to reduce high-frequency hiss. The corner frequency is adjustable (e.g., 1.5 kHz to 7 kHz).
- **De-emphasis:** Selectable between 50us and 75us to match regional broadcast standards (Europe/Asia vs. Americas).
- **Stereo High Blend:** While primarily for FM, the stereo separation logic can be manipulated in firmware to improve the perceived SNR of weak signals by blending channels.

6. Hardware Implementations and Build Quality

It is critical to distinguish between the TEF6686 *chip* and the various *radios* that use it. The implementation of the RF PCB, shielding, and power supply plays a massive role in realized performance.

6.1 The "DIY" / Open-Source Market (Blue Board/Silver Box)

The most common and affordable TEF6686 radios are the "DIY" units found on AliExpress/eBay, often referred to by their case material or board color.

- **Characteristics:** These units typically use the PE5PVB firmware. They feature a raw ESP32 module, a generic IPS display, and the TEF6686 module soldered onto a carrier board.
- **Performance:** These units offer the raw performance of the chip but often suffer from "digital noise" (whining or buzzing) caused by poor isolation between the ESP32's Wi-Fi/Bluetooth radio and the TEF6686's antenna input. They often lack input filtering, making them highly susceptible to overload on long wire antennas.

6.2 The Commercial Standard: Qodosen DX-286 / SR-286

The Qodosen DX-286 represents a professional, commercial implementation of the TEF6686.

- **Optimization:** Unlike the DIY boards, the Qodosen features a custom-designed RF front-end with better impedance matching for telescopic whips.
- **Performance:** Reviews consistently rank the Qodosen DX-286 as superior to the DIY versions on SW and MW. It is less prone to overload and has better noise shielding. It utilizes a dedicated amplifier for the speaker (e.g., TPA6211A1), providing cleaner audio.
- **Firmware:** While it runs a proprietary fork of the firmware, it is highly optimized for the specific hardware, eliminating bugs like the antenna gain issue.

6.3 Desktop and "HamGeek" Variants

Larger "desktop" style units (often branded as HamGeek) include larger batteries (4000-5000mAh) and larger speaker cavities.

- **Audio:** The larger cavity provides better bass response, leveraging the wide 8 kHz bandwidth of the TEF6686 for near-FM quality on strong AM stations.
- **Power:** These units handle the power-hungry nature of the TEF6686/ESP32 combination (which can draw significant current compared to simple DSP radios) by including massive battery packs.

7. Comparative Performance Analysis

To contextualize the TEF6686, it must be compared against its primary competitors in the portable market.

Table 1: TEF6686 vs. Si4732 (The "Mini" Chip)

Feature	TEF6686 (Automotive DSP)	Si4732 (Consumer DSP)
Sensitivity	Superior (-7 dBuV noise floor)	Good (-98 dBm lock threshold)
Selectivity	Excellent (Sharp "brick wall" filters)	Good
Noise Handling	Superior (Advanced Impulse Blanking)	Moderate
SSB Capability	None	Yes (via patch)
Overload	Moderate (Requires attenuation for long wires)	High Susceptibility (Easily desensitized)

Feature	TEF6686 (Automotive DSP)	Si4732 (Consumer DSP)
Power Use	High (Requires large battery)	Low
Bandwidth	Adjustable (3, 4, 6, 8 kHz)	Adjustable (via filters)

Analysis: The TEF6686 is the superior receiver for broadcast listening (FM/AM/SW) due to its lower noise floor and better filtering. The Si4732 is the only choice for users needing SSB.

Table 2: TEF6686 vs. Tecsun PL-660 (Analog Superhet)

Feature	TEF6686 (DSP)	Tecsun PL-660 (Analog)
Audio Quality	Crisp, can be harsh/digital	Warm, natural analog sound
Fading Handling	CEQ (Channel Equalization)	Sync Detection (Synchronous AM)
Tuning Experience	Discrete steps, fast lock	Smooth analog feel
SSB	No	Yes (Excellent)
Air Band	No (Limited to 108 MHz FM)	Yes (118-137 MHz AM)

Analysis: The PL-660 remains the choice for traditionalists who value Sync Detection and SSB. The TEF6686 wins on raw sensitivity and the ability to separate tightly spaced stations with its DSP filters.

8. Conclusion and Strategic Recommendations

The expected performance of the TEF6686 chip on AM and SW broadcast bands is characterized by **exceptional sensitivity** and **precision selectivity**, hampered only by its **automotive-centric limitations**.

On the AM (MW/LW) bands, the TEF6686 is a powerhouse. It outperforms many dedicated portable receivers costing twice as much. Its ability to dig weak signals out of the noise floor, combined with effective noise blanking, makes it a premier choice for Mediumwave DXing in urban environments.

On the Shortwave (SW) bands, the TEF6686 provides a high-fidelity broadcast listening experience. It is capable of hearing any station the atmosphere will support. However, it requires a knowledgeable user. To extract maximum performance, the user must:

1. **Use Optimized Firmware:** Running firmware that allows for the disablement of "Soft Mute" is non-negotiable for serious listening.
2. **Manage Signal Levels:** When using external wire antennas, users must be prepared to use the internal attenuators or external pre-selectors to prevent front-end overload.
3. **Accept Limitations:** The user must accept that this is a broadcast-only receiver. The lack of SSB is a hardware reality that no firmware update can fix.

In summary, the TEF6686 is not a "do-it-all" radio chip. It is a specialist tool that, when applied to its intended domain of broadcast reception, offers performance that redefines the price-to-performance ratio of the portable radio market.

9. Appendix: Technical Data Reference

9.1 Key Operational Specifications

Parameter	Specification	Notes
Frequency Range	144 kHz - 27 MHz	Continuous AM coverage
Internal Noise Floor	-7 dBuV	
Sensitivity	< 10 dBuV	For intelligible reception
AM Filter Bandwidths	3, 4, 6, 8 kHz	Firmware selectable
LNA Gain Control	+15 dB to -25 dB	Variable via registers
ADC Dynamic Range	~100 dB	Sigma-Delta Architecture
Max Input Signal	~92 dBuV	Before compression/overload

9.2 Firmware Menu Parameters (PE5PVB)

Menu Item	Function	Recommended Setting for DX
Soft Mute	Attenuates audio on weak signals	OFF
High Cut	Low-pass filter for noise	3 kHz - 5 kHz
RF AGC	Controls LNA gain	Auto or Manual for Ext Ant
Bandwidth	IF Filter Width	3 kHz (Crowded) / 6 kHz (Clear)
De-emphasis	Audio EQ curve	50us (EU) / 75us (US)

The integration of these parameters allows the TEF6686 to be fine-tuned from a generic car tuner into a precision instrument for long-distance reception.

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