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Article

# Research on the Design of an LC VCO in Mobile Digital TV Tuners

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**Abstract:** With the rapid growth of mobile digital television services and the continuing trend toward miniaturization and low power consumption in terminal devices, higher demands are placed on the integration level and performance of radio frequency (RF) tuners. As the core component of the phase-locked loop (PLL) frequency synthesizer within the tuner, the voltage-controlled oscillator (VCO) directly affects receiver sensitivity, signal-to-noise ratio, and overall system stability through its phase noise performance, tuning range, and power consumption. To address the combined requirements of wide frequency coverage, low phase noise, and low power operation, this paper presents a systematic design and optimization study of an LC-based VCO. First, the performance limits that the RF front-end VCO must meet are analyzed based on the system architecture and frequency planning needs of mobile digital TV tuners. Subsequently, utilizing the negative resistance model and phase noise theory, the start-up mechanism, noise sources, and tuning behavior of the LC oscillator are investigated in depth. A differential cross-coupled topology is employed to construct the LC resonant tank. By improving the inductor's quality factor, the variable capacitor structure, and the bias circuitry, phase noise is significantly reduced, and the tuning range is broadened. The design is implemented using standard CMOS technology and evaluated via PSS and Pnoise simulations. The simulation results demonstrate that the proposed LC VCO successfully meets the frequency coverage requirements of mobile digital TV tuners while exhibiting excellent phase noise and power performance, confirming its suitability for practical applications.

**Keywords:** digital television; rf tuner; voltage-controlled oscillator; phase noise; low-power design

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### 1. Introduction

As advancements in digital broadcasting and mobile communication technologies continue to evolve, mobile digital television has emerged as a critical medium for multimedia delivery. Operating within complex propagation environments characterized by severe multipath fading, adjacent-channel interference, and stringent power constraints, mobile digital TV systems demand receiver designs that adhere to rigorous performance standards. At the forefront of these systems, the RF tuner serves as the primary front-end module, directly influencing the sensitivity and selectivity of the overall system. The integration capabilities of CMOS technology have enabled the development of highly compact single-chip tuners, necessitating significant improvements in the performance of key internal components, particularly the voltage-controlled oscillator (VCO). The VCO, embedded within the PLL frequency synthesizer, generates the local oscillator signal, with its phase noise, tuning range, and power consumption playing pivotal roles in determining demodulation quality, band coverage, and battery efficiency [1]. In deep submicron CMOS processes, challenges such as

parasitic effects and the suboptimal quality of passive components further complicate the design of LC VCOs. Despite these challenges, LC VCOs outperform ring oscillators in terms of phase noise, making them more suitable for mobile digital TV applications. However, achieving an optimal balance between tuning range, phase noise, and power consumption remains a significant engineering challenge that requires innovative solutions.

## 2. System Architecture Analysis of Mobile Digital TV Tuners

### 2.1. Overall Tuner Structure

A mobile digital TV tuner is positioned at the forefront of a portable receiver, where it captures and processes broadcast signals received from the antenna. Its primary function is to amplify, filter, and convert incoming RF signals into low-IF signals that are suitable for subsequent demodulation. This process is inherently complex, as the tuner must operate under non-ideal conditions. It is required to isolate the desired channel from surrounding interference, maintain stringent control over internal noise, and simultaneously function within the constraints of limited power availability [2]. Achieving a balance between signal clarity and energy efficiency represents a persistent design challenge in mobile systems. Common architectures employed in these tuners include low-IF and superheterodyne designs. The key components of these systems—such as the matching network, low-noise amplifier, mixer, frequency synthesizer with VCO, IF filter, and automatic gain control—must work in unison to ensure stable and clear signal reception. Each component plays a critical role in optimizing the overall performance of the tuner, making their integration and coordination essential for effective operation.

To minimize signal loss and enhance power transfer efficiency, the RF signal from the antenna is first routed through an input matching network, as illustrated in Figure 1. This network is designed to optimize the impedance matching between the antenna and the tuner, thereby improving signal strength. Following this, a low-noise amplifier (LNA) amplifies the signal, which is a crucial step as it primarily determines the noise figure of the receiver. An RF filter is then employed to suppress out-of-band interference, ensuring that only the desired signal frequencies are processed. Before the signal is converted to an intermediate frequency by the mixer, a phase-locked loop (PLL)-generated local oscillator provides the necessary frequency for this conversion. At the heart of the synthesizer is the LC voltage-controlled oscillator (VCO), which generates a continuously tunable output with low phase noise. The design of the VCO is particularly critical, as it directly impacts the overall RF performance of the tuner. After down-conversion, the signal undergoes intermediate frequency filtering and automatic gain control (AGC) to stabilize its amplitude before it is subjected to digital processing. This sequence of operations ensures that the tuner delivers a high-quality signal for further stages of the receiver system [3, 4].

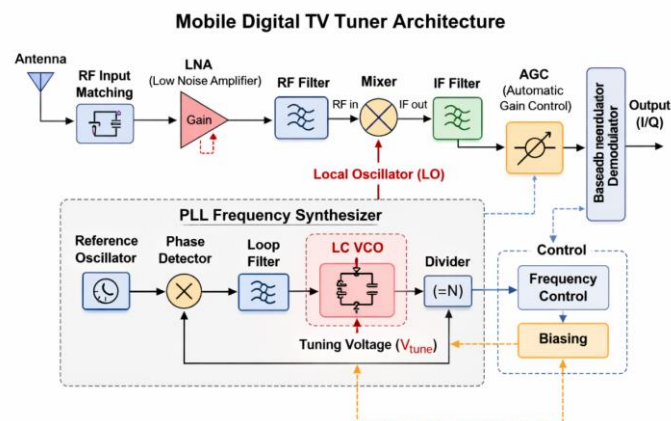


Figure 1. Mobile Digital TV Tuner Architecture

## 2.2. Frequency Synthesizer Structure Analysis

Highly stable, low-phase-noise local oscillators with accurate tuning capabilities form the essential foundation of mobile digital TV tuners. PLL-based frequency synthesizers are widely utilized due to their ability to provide precise frequency control and stability [5, 6]. In practice, integer-N and fractional-N PLLs represent the two primary architectures employed in these systems. Both architectures share fundamental components, including the reference clock, phase detector, charge pump, loop filter, LC VCO, and divider. However, they differ significantly in their approach to frequency division, which ultimately influences resolution and overall performance. An integer-N PLL employs a fixed division ratio, making it straightforward and stable while generating relatively few spurs. However, its frequency resolution is directly tied to the reference frequency. Lowering the reference frequency improves resolution but also reduces loop bandwidth, which can lead to slower locking times and increased phase noise. Fractional-N PLLs address these limitations by employing delta-sigma modulation to dynamically adjust the division ratio. This approach maintains a high reference frequency and broader bandwidth while enabling finer frequency steps. However, this added complexity introduces challenges such as fractional spurs and quantization noise. Regardless of the chosen architecture, the phase noise and tuning behavior of the LC VCO play a critical role in determining the final performance of the synthesizer.

## 2.3. Performance Requirements for the VCO in a Tuner

The LC VCO plays a pivotal role in determining the overall performance of the synthesizer within a mobile digital TV tuner. Whether an integer-N or fractional-N architecture is utilized, its phase noise and tuning characteristics have a direct impact on loop stability, bandwidth, and spectral purity [7]. Even minor fluctuations in tuning gain or noise can disrupt the dynamics of the PLL, leading to potential performance degradation. Mobile reception conditions, characterized by tight channel spacing, frequent switching, and multipath fading, further complicate the design process. To address these challenges, the VCO must exhibit well-regulated tuning sensitivity and provide seamless UHF coverage. Insufficient gain can hinder frequency acquisition, while excessive gain may compromise loop stability. Additionally, low phase noise is essential for reliable demodulation and effective adjacent-channel selectivity. Beyond these performance metrics, the VCO must also meet stringent requirements for power efficiency and robustness. It should demonstrate strong resistance to supply noise, consume minimal power, and deliver an adequate output swing. Achieving a successful design requires balancing these competing demands to ensure stable and optimized performance across all parameters.

## 3. Operating Principle and Theoretical Basis of the LC VCO

In mobile digital TV tuners, the LC VCO serves as the central component of the frequency synthesizer, typically employing a differential cross-coupled topology. The structure, while seemingly straightforward, comprises a bias source, a cross-coupled transistor pair, and an LC resonant tank, each playing a critical role in the system's functionality [5]. The bias network stabilizes the amplitude and influences phase noise by ensuring consistent current flow. The cross-coupled transistor pair introduces negative resistance to counteract losses within the resonator, thereby sustaining oscillation. Meanwhile, the LC tank determines the oscillation frequency by facilitating energy exchange between the inductor and capacitor. In integrated RF designs, on-chip passive components often introduce parasitic losses, necessitating sufficiently high negative resistance to guarantee reliable start-up under varying process, voltage, and temperature conditions. The differential configuration enhances performance by mitigating common-mode noise and reducing susceptibility to supply and substrate interference. To achieve broad frequency coverage without excessive tuning sensitivity, designers incorporate switched capacitor banks for coarse tuning and varactors for fine adjustments. The tank's quality factor and bias current directly impact phase noise, requiring meticulous

optimization to strike a balance between spectral purity and power efficiency, particularly in mobile applications. This careful design approach ensures the LC VCO operates effectively, even under challenging conditions, while maintaining the desired performance metrics for modern digital TV tuners.

#### 4. LC VCO Circuit Design for Mobile Digital TV Tuners

##### 4.1. Specification Definition

An LC VCO may appear to function quietly within the PLL, but in the context of a mobile digital TV tuner, its influence extends to nearly every aspect of the system. When the oscillator performs well, the receiver exhibits responsiveness and stability. Conversely, poor performance from the VCO cannot be fully mitigated by downstream corrections. Key parameters such as spectral purity, demodulation reliability, loop dynamics, and even battery endurance are all directly or indirectly tied to the oscillator's specifications and implementation. Consequently, the specifications for the LC VCO cannot be developed in isolation. They must be derived from the overarching system constraints, including channel planning, required tuning resolution, acceptable phase noise thresholds, switching speed, and the stringent power limitations inherent to portable devices [3].

Fast channel switching is an essential requirement for UHF mobile TV applications. The local oscillator's frequency range shifts depending on whether high-side or low-side injection is employed, necessitating that the VCO covers its operational span seamlessly, without gaps or abrupt nonlinearities. A tuning curve that appears satisfactory on paper but contains discontinuities can result in unstable PLL locking or prolonged acquisition times. In practical applications, these issues manifest as noticeable delays when users switch channels, which is an undesirable outcome for any designer aiming to deliver a smooth user experience [8].

Phase noise represents another critical constraint that demands careful attention. In densely populated spectral environments, excessive phase noise elevates the effective noise floor after mixing, thereby impairing adjacent-channel selectivity and ultimately reducing the accuracy of demodulation. This parameter cannot be treated as an afterthought or optimized at a later stage. Instead, it must influence key design decisions from the outset, including the choice of topology, tank circuit design, bias current levels, and layout strategies. Addressing phase noise early ensures that the system can meet the stringent requirements of modern mobile digital TV tuners.

Power consumption is another factor that cannot be overlooked. Since the VCO operates continuously, its current draw has a direct impact on battery life. Reducing the bias current can conserve energy, but excessive reductions may lead to smaller output swings, degraded phase noise, and unreliable start-up behavior. Conversely, increasing the bias current enhances oscillation stability but reduces efficiency. Each adjustment shifts the balance among these interdependent factors, making it impossible to optimize one parameter in isolation. Designers must navigate this complex trade-off space to achieve a practical balance that meets the system's overall requirements.

Real-world conditions introduce additional challenges, such as temperature variations, supply voltage fluctuations, and process changes. If the start-up margin and gain stability are insufficient, a design that performs well under nominal simulation conditions may fail at process, voltage, and temperature (PVT) corners. Robustness is not merely an optional enhancement but a fundamental requirement of the core specification. The final architectural approach is shaped by these interconnected constraints. A differential cross-coupled LC topology is often preferred due to its ability to provide strong negative resistance for reliable oscillation and its superior rejection of common-mode noise. To achieve broad frequency coverage with controllable tuning sensitivity, a segmented capacitor array and high-quality inductors are typically employed [9, 10]. The bias point is meticulously adjusted to strike a practical balance among start-up reliability, noise performance, and power consumption, rather than focusing solely on maximizing

amplitude or minimizing current. Output isolation techniques are also incorporated to maintain signal integrity without unnecessarily increasing load or current draw. The ultimate goal is not merely to design an oscillator with impressive datasheet specifications but to ensure that the LC VCO integrates seamlessly with the PLL and the broader tuner architecture. In a mobile digital TV system, the design transitions from theoretical adequacy to practical reliability only when tuning smoothness, phase noise, efficiency, and stability are harmonized effectively.

#### 4.2. Circuit Design

The process of circuit design becomes highly tangible once the specifications are firmly established. At this stage, every component, including the size of transistors, the selection of inductors, and the determination of bias currents, must demonstrate its compatibility and effectiveness within the phase-locked loop (PLL) system it will integrate with. The LC voltage-controlled oscillator (VCO) must align seamlessly with the loop bandwidth, divider configurations, and lock-time requirements to ensure optimal performance. These practical constraints significantly influence the overall design methodology, necessitating a meticulous and systematic approach to achieve the desired outcomes. The interplay between these parameters is critical, as even minor deviations can lead to suboptimal performance or system instability. Therefore, the design process demands a rigorous evaluation of each component's role and its contribution to the overall system's functionality.

For this reason, the design is fundamentally rooted in a differential cross-coupled LC topology. This configuration is not chosen for its popularity but for its proven ability to deliver superior spectral purity and predictable operational characteristics. The differential structure is particularly advantageous as it inherently mitigates common-mode disturbances, thereby enhancing the system's robustness against external noise. Furthermore, the cross-coupled transistor pair generates the negative resistance required to counteract the losses within the LC tank circuit, ensuring sustained oscillation. This approach is further reinforced by its capacity to maintain stability and reliability under varying operational conditions. The emphasis on spectral purity and predictable behavior is crucial, as these factors directly impact the performance of the PLL. By adhering to this foundational design principle, the circuit achieves a balance between theoretical ideals and practical constraints, ensuring that it meets the stringent requirements of modern electronic systems.

### 5. Performance Comparison and Results Analysis

We took a step back and evaluated the proposed LC VCO from a system-level perspective rather than solely focusing on its schematic design before making any decisions. While an independent oscillator may appear impressive in theoretical analysis, its true value lies in its performance when integrated into a complete synthesizer and compared to other established designs. This comparison was deliberate, encompassing frequency coverage, phase noise performance, power consumption, and the overall figure of merit simultaneously with prior works. Such a holistic approach ensures that the design is not only theoretically sound but also practically viable for real-world applications [11].

Initially, we examined the frequency range. The VCO demonstrated continuous tuning capabilities from approximately 1.05 GHz to 1.35 GHz, with a center frequency of 1.20 GHz, as determined through periodic steady-state (PSS) simulations. This corresponds to a tuning range of about 25%. Notably, the tuning curve is smooth, devoid of abrupt jumps or irregular slopes, which is critical for predictable PLL dynamics. A wide tuning range alone is insufficient; it must also exhibit manageable behavior. In this case, the smooth tuning characteristics facilitate stable loop design and align well with the requirements for local oscillators in mobile digital TV receivers. Phase noise was analyzed independently using Pnoise analysis, focusing on key frequency offsets that significantly impact adjacent-channel performance. Table 1 provides a summary of the detailed results, offering a comprehensive understanding of the oscillator's real-world performance. These

results are not mere simulation artifacts but rather indicators of the design's ability to maintain high spectral purity in a crowded UHF environment. The simulations reveal that the proposed LC VCO exceeds its nominal objectives, delivering balanced performance across tuning range, noise, and power efficiency—attributes essential for mobile digital TV tuners to function effectively in practical scenarios [12].

**Table 1.** Key Simulation Results of the LC VCO

Metric	Simulated Result	Design Target
Center frequency	1.20 GHz	~1.2 GHz
Tuning range	1.05–1.35 GHz	≥ 20% coverage
Phase noise @ 100 kHz offset	–95 dBc/Hz	≤ –90 dBc/Hz
Phase noise @ 1 MHz offset	–112 dBc/Hz	≤ –100 dBc/Hz
DC power consumption	8.6 mW	≤ 10 mW
Differential output swing	0.85 V <sub>pp</sub>	≥ 0.6 V <sub>pp</sub>

The simulated phase noise stabilizes at approximately –112 dBc/Hz when the carrier frequency is offset by 1 MHz. This value not only meets the original design target but also surpasses it significantly. This outcome validates the design process, which emphasized the importance of constructing a high-Q resonant tank and carefully shaping the bias current. By minimizing noise contributions from active devices, the energy exchange within the tank remains clean and efficient. Furthermore, setting the bias current at an optimal level—neither overly aggressive nor excessively conservative—enables the oscillator to achieve a stable amplitude without introducing additional noise into the spectrum. Importantly, this performance is achieved without incurring excessive power consumption. The design maintains a DC power consumption below 8.6 mW, comfortably within the limits expected for battery-powered receivers. This balance between spectral purity and power efficiency is crucial for portable applications. The oscillator consistently delivers reliable performance across its entire operating range, as evidenced by its robust output swing and comprehensive tuning coverage.

The design ensures smooth frequency control, dependable mixer operation, and efficient current usage. Collectively, these attributes provide a more holistic narrative than any single performance metric could convey. To further contextualize the design's performance, we evaluated its figure of merit (FoM), which combines phase noise and power consumption into a single metric for cross-comparison. As shown in Table 2, the proposed LC VCO demonstrates competitiveness with contemporary designs, indicating that its performance enhancements are structurally significant rather than incremental. This achievement is attributed to multiple factors, including an improved resonant tank, smoother and more predictable tuning behavior, and a bias strategy that minimizes extraneous noise within the oscillation core. These refinements collectively enable the oscillator to maintain the desired tuning range and output swing while keeping phase noise under control and power consumption low. This balance ultimately enhances the FoM, making the design well-suited for practical applications.

**Table 2.** Performance Comparison with Representative LC VCO Designs

Parameter	This Work	Reference A	Reference B
Process	0.18 μm CMOS	0.18 μm CMOS	0.13 μm CMOS
Center frequency (GHz)	1.20	1.10	1.30
Phase noise @ 1 MHz (dBc/Hz)	–112	–105	–108
Power (mW)	8.6	12.0	10.5
FoM (dBc/Hz)	–182	–176	–179

When evaluating the overall results, it is not merely the low phase noise or modest power consumption that stands out but also the synergy between these two aspects. With a Figure of Merit of –182 dBc/Hz, the proposed LC VCO surpasses several comparable designs, as summarized in Tables 3 and 4. This improvement is not the result of a single

breakthrough but rather a culmination of incremental advancements, such as a more refined resonant tank, smoother tuning characteristics, and a biasing approach that effectively suppresses noise in the oscillation core. In practical terms, the oscillator achieves the necessary tuning range and output swing without excessive current consumption. The phase noise remains well-controlled, while DC power usage is kept within acceptable limits. This balance is what ultimately drives the improvement in the FoM. From a system-level perspective, the benefits are evident. Reduced phase noise after frequency conversion enhances adjacent-channel tolerance, which is critical in dense UHF environments. Simultaneously, low power consumption extends battery life, a key consideration for portable receivers. By addressing these factors collectively rather than in isolation, the design achieves a harmonious balance between efficiency and spectral performance [12]. In essence, the LC VCO avoids extremes, instead striking a stable equilibrium that makes it an ideal candidate for mobile digital TV tuner systems requiring simultaneous stability, noise performance, and energy efficiency.

## 6. Conclusion

This study addressed the practical challenge of designing an LC voltage-controlled oscillator (VCO) tailored for mobile digital TV tuners, operating within stringent real-world constraints. Beginning with system-level requirements such as frequency planning, phase noise thresholds, and power consumption limits, the design employed a differential cross-coupled topology with segmented tuning to achieve broad frequency coverage and robust control. By optimizing the resonator quality factor and fine-tuning the biasing conditions, the design successfully minimized phase noise while maintaining low power consumption. Simulation results confirm that the proposed VCO meets the specified targets for tuning range, phase noise performance, and energy efficiency without necessitating significant trade-offs. This work underscores the importance of a balanced, system-driven design approach for achieving reliable and effective RF front-end integration in mobile applications. Future research could explore further enhancements in resonator design, advanced tuning mechanisms, or integration with emerging technologies to push the boundaries of performance and efficiency in similar systems.

## References

1. D. Balodi, A. Verma, and A. G. Paravastu, "Ultra-wideband Quadrature LC-VCO using Capacitor-Bank and backgate topology with on-chip spirally stacked inductor in 0.13  $\mu\text{m}$  RF-CMOS process covering S-C bands," *Microelectronics Journal*, vol. 99, p. 104727, 2020.
2. M. F. Siddiqui, M. K. Maheshwari, M. Raza, and A. R. Masud, "Design and Optimization of an Ultra-Low-Power Cross-Coupled LC VCO with a DFF Frequency Divider for 2.4 GHz RF Receivers Using 65 nm CMOS Technology," *Journal of Low Power Electronics and Applications*, vol. 13, no. 4, p. 54, 2023.
3. M. Tiebout, "Low-power low-phase-noise differentially tuned quadrature VCO design in standard CMOS," *IEEE Journal of Solid-State Circuits*, vol. 36, no. 7, pp. 1018-1024, 2001.
4. Z. Zhang, H. Djahanshahi, C. Gu, M. Patel, and L. Chen, "Single-event effects characterization of LC-VCO PLLs in a 28-nm CMOS technology," *IEEE Transactions on Nuclear Science*, vol. 67, no. 9, pp. 2042-2050, 2020.
5. J. Jiang, "Design of a Highly Linear RF Front-End, a Low-Spur Fractional-N Frequency Synthesizer and a High-Speed, Low-Power Data Converter", Doctoral dissertation, 2021.
6. B. Sadhu and R. Harjani, "Capacitor bank design for wide tuning range LC VCOs: 850MHz-7.1 GHz (157%)," in *Proceedings of 2010 IEEE International Symposium on Circuits and Systems*, pp. 1975-1978, May 2010.
7. B. Jafari and S. Sheikhaei, "Phase noise reduction in a CMOS LC cross coupled oscillator using a novel tail current noise second harmonic filtering technique," *Microelectronics Journal*, vol. 65, pp. 21-30, 2017.
8. R. F. I. C. Plenary, "Plenary Schedule Sunday, 5 June 2011 5:40 PM Baltimore Convention Center–Level 400, Ballroom III-IV."
9. T. Tan, X. Li, Y. Li, and P. Ke, "A 7–9 GHz fast-startup low phase noise CMOS LC VCO using Gm-booster technique and circuit asymmetries for multi-mode radar transmitter," *Microelectronics Journal*, vol. 157, p. 106586, 2025.
10. D. Su and B. Taddiken, "TV Tuner/RFID," in "2007 IEEE International Solid-State Circuits Conference. Digest of Technical Papers", pp. 204-205, Feb. 2007.
11. Y. Sun, C. J. Jeong, S. K. Han, and S. G. Lee, "CMOS on-chip active RF tracking filter for digital TV tuner ICs," *Electronics Letters*, vol. 47, no. 6, pp. 407-409, 2011.

12. K. Kwon, "A 40 M–1000 MHz 77.2-dB spurious free dynamic range CMOS RF variable gain amplifier for digital TV tuner ICs," *International Journal of Circuit Theory and Applications*, vol. 43, no. 7, pp. 875-886, 2015.

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