The continued increase in data rates and routing density in modern electronic systems has intensified the challenges associated with maintaining signal integrity in high-frequency interconnects. Conventional planar transmission lines, such as microstrip structures, increasingly experience electromagnetic coupling, radiation loss, and dispersion as operating frequencies extend into the multi-gigahertz regime. In densely routed environments, crosstalk between adjacent conductors becomes a primary limitation to bandwidth scalability and compact layout design. This thesis investigates Surface Spoof Plasmon Polariton (SSPP) interconnects as an alternative high-frequency transmission architecture and presents the systematic design, optimization, and validation of an SSPP-based interconnect specifically engineered to improve crosstalk performance relative to standard RF interconnects.

SSPP structures support slow-wave electromagnetic modes confined along periodically corrugated metallic surfaces. Unlike conventional transmission lines, the electromagnetic fields associated with SSPP modes are tightly localized near the engineered surface geometry. This strong field confinement reduces modal overlap between neighboring interconnects and directly mitigates interline coupling. Leveraging this confinement mechanism, this work develops a broadband impedance-matched SSPP interconnect designed for high-frequency signal transmission in dense routing environments.

A comprehensive simulation-based parametric study is conducted to understand the influence of key geometric and structural parameters on interconnect performance. The impact of taper transitions is first examined to evaluate the trade-offs between impedance matching and isolation. Gradual mode-conversion tapers are shown to influence reflection characteristics and the efficiency of coupling suppression. Next, variations in groove geometry—including depth, periodicity, and related structural features—are analyzed to assess their effects on dispersion behavior, modal confinement, and interconnect coupling. Adjustments to groove parameters modify the slow-wave characteristics of the SSPP mode and alter the spatial decay of the electromagnetic fields, thereby influencing crosstalk performance. The role of interconnect separation distance is also systematically investigated, confirming the expected dependence of coupling on spacing and providing design guidance for dense layout implementations.

The optimized SSPP interconnect is benchmarked against a conventional microstrip reference line fabricated under identical conditions. Frequency-domain comparisons demonstrate consistent improvements in crosstalk suppression while maintaining comparable impedance matching and insertion loss characteristics. The enhanced isolation observed in the SSPP structure is attributed to its engineered electromagnetic confinement rather than solely geometric spacing.

To evaluate scalability, multilayer interconnect configurations are analyzed to assess vertical and lateral coupling in stacked routing environments. The SSPP architecture maintains improved isolation characteristics compared to conventional transmission lines, indicating suitability for compact multilayer systems. In addition to steady-state frequency-domain analysis, time-domain signal integrity tests are performed to evaluate transient behavior and coupled noise during pulse excitation. The SSPP interconnect exhibits reduced coupled signal distortion and improved transient performance, confirming its applicability to high-speed digital signaling environments.

Experimental validation is conducted using fabricated prototypes and vector network analyzer measurements to characterize scattering parameters. Measured insertion loss, reflection, and crosstalk trends align with simulation predictions, demonstrating the practical feasibility of the proposed design. Minor deviations between simulated and measured responses are attributed to fabrication tolerances and material parameter variations, but the overall improvement in isolation performance is preserved.

This thesis establishes a structured design methodology for SSPP interconnects with a specific emphasis on crosstalk mitigation in dense, high-frequency routing applications. By systematically examining taper transitions, groove geometry, separation distance, multilayer configurations, and time-domain performance, this work demonstrates that SSPP-based transmission lines provide an effective and scalable alternative to conventional planar interconnects. The results confirm that engineered surface plasmon structures offer a promising solution for next-generation electronic systems requiring compact layouts, broadband operation, and enhanced electromagnetic isolation.