CMOS Translinear Loop Based Current Squarer Circuit

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Abstract

This work presents the design and simulation of a CMOS Translinear Loop Based Current Squarer Circuit implemented in eSim. The circuit computes an output current proportional to the square of the input current (Iout proportional to Iin squared) using the Generalized Translinear Principle with six NPN BJT transistors. The circuit is simulated using DC sweep and transient analysis to verify the squaring behavior. The design operates at a 5V supply and demonstrates accurate nonlinear current-mode computation suitable for analog signal processing, RMS detection, and VLSI applications.

Keywords: Current Squarer, Translinear Loop, Current-Mode, BJT, eSim, Analog Signal Processing

I. Introduction

Current-mode analog circuits offer significant advantages over voltage-mode designs in terms of bandwidth, dynamic range, and power consumption at low supply voltages. Among these, the current squarer is a fundamental building block widely used in RMS-to-DC converters, analog multipliers, power detectors, and neuromorphic computing circuits. The squaring function can be elegantly realized using the translinear principle, which exploits the exponential characteristics of BJT junctions in the active region. This project implements and simulates a BJT-based current squarer in eSim based on the work by Chhabra, Aggarwal and Senani (2024), demonstrating the squaring function through DC sweep and transient analysis.

II. Working Principle

The circuit is based on the Generalized Translinear Principle proposed by Seevinck and Wiegerink (1991), which states that in a closed loop of transistors biased in the active region, the product of currents flowing clockwise equals the product of currents flowing counterclockwise. A loop of six NPN BJT transistors (Q1 to Q6, eSim_NPN) is arranged to implement the squaring function. Bias currents I3 = 0.4mA and I1 = I2 = I4 = 0.2mA set the operating point. The input current source U1 (sinusoidal: SINE(0 0.2m 200)) drives the loop and the output current Iout is measured across R1 (1 Meg). Two supply voltages V1 and V2 of 5V each power the circuit. The circuit operates entirely in the current domain with no resistors or capacitors in the core translinear loop, making it compact and suitable for low-voltage VLSI integration.

III. Circuit Diagram

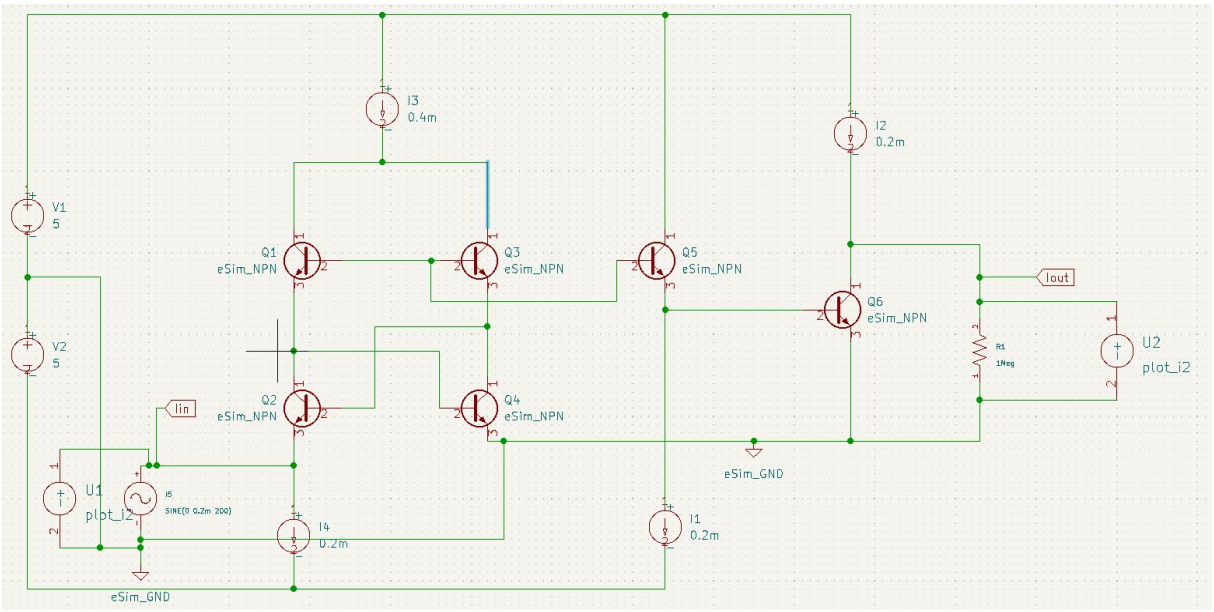

Fig. 1: Translinear Current Squarer Circuit implemented in eSim

IV. Results and Output Waveforms

The circuit was simulated in eSim using Ngspice for two analyses: (1) DC Sweep of the input current from -200uA to +200uA to verify the squaring transfer characteristic, and (2) Transient Analysis with a sinusoidal input current at 200Hz to observe the time-domain squaring behavior.

A. DC Sweep Analysis

The DC sweep was performed by varying the input current from -200uA to +200uA. The output current i(R1) traces a perfect parabolic curve confirming the squaring function Iout proportional to Iin squared. The output is always positive regardless of the sign of the input, ranging from approximately 0uA at Iin = 0 to approximately 200uA at Iin = +/-200uA, which is the expected behavior of a squarer circuit.

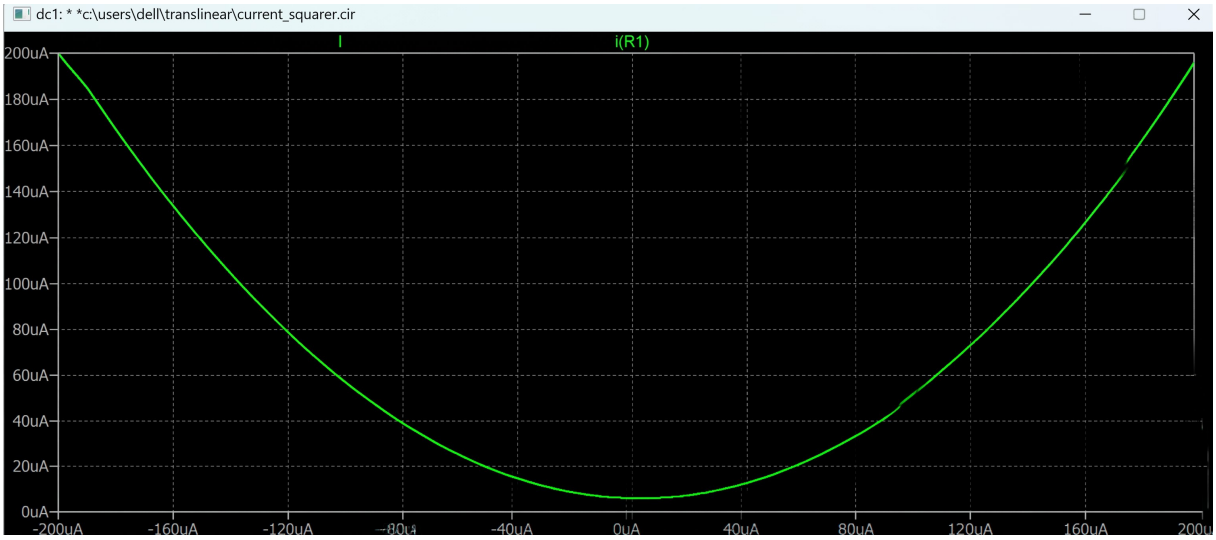

Fig. 2: DC Sweep output showing parabolic squaring characteristic (Iout vs Iin)

B. Transient Analysis

Transient analysis was performed with a sinusoidal input current of amplitude 200uA at 200Hz. The output current i(R1) shown in blue is always positive and oscillates at twice the frequency of the input (green), which is the expected behavior when squaring a sinusoidal signal. The peak output of approximately 200uA corresponds to the maximum squared value of the input current, consistent with the theoretical prediction Iout proportional to Iin squared.

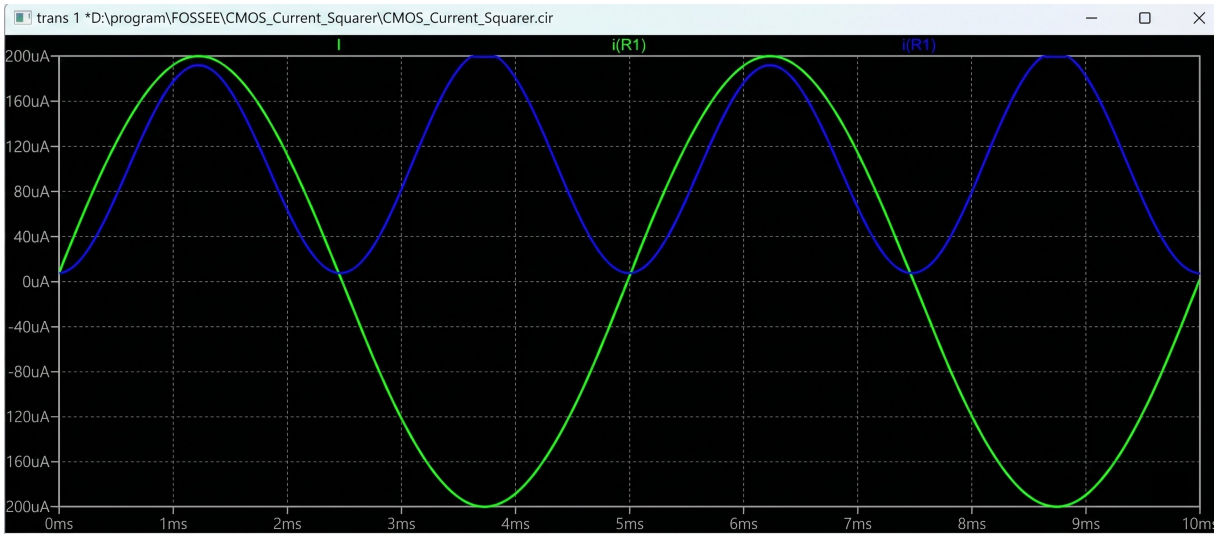

Fig. 3: Transient Analysis — Input current (green) and squared output current (blue)

V. Conclusion

A CMOS Translinear Loop Based Current Squarer Circuit was successfully designed and simulated in eSim using the Generalized Translinear Principle with six NPN BJT transistors. The DC sweep confirmed the parabolic squaring transfer characteristic and the transient analysis verified the time-domain behavior with a 200Hz sinusoidal input. The circuit operates at 5V supply and accurately computes the square of the input current using standard BJT components available in the eSim library. This design contributes a novel current-mode nonlinear circuit to the eSim Research Migration repository, providing an open-source reference for students and researchers in analog VLSI design.

References

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