Design and Simulation of Gilbert Cell using different types of loads in LTSpice

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***Abstract* - This report delves into the functionality and characteristics of a Gilbert Cell through experimentation with various load types and input signals. The Gilbert cell, a prevalent component in radio frequency (RF) applications, serves as a double-balanced mixer. While resistive loads offer simplicity, robustness, low power consumption, and cost-effectiveness, active loads present advantages such as smaller size, higher dynamic range, improved noise performance, and enhanced interference cancellation. Both load types have been simulated, and crucial insights have been gleaned from these simulations.**

***Keywords* – Gilbert Cell, Mixer, Radio-Frequency, Active – load, Resistive - Load, interference cancellation.**

I. Introduction

Mixers, crucial analog components, are integral to contemporary communication systems. These systems facilitate the transmission of information across diverse mediums like radio waves, fiber optics, and copper wires. To ensure practical antenna sizes and to capitalize on benefits like noise reduction and low power transmission, the transmitted signal undergoes modulation to a higher frequency. This up-conversion process occurs at the transmitter end, where a lower frequency signal is transformed into a higher frequency signal for transmission. Conversely, during the down-conversion process at the receiver, the opposite transformation takes place.

In communication systems, mixers provide the vital purpose of converting frequencies. They can be thought of as simple frequency multipliers. By merging the incoming signal with a local oscillator (LO) signal at a different frequency, mixers carry out the down-conversion. The difference in frequency between the input signal and the down converted signal, or LO signal, is the mixer's output. After being down-converted, the signal is filtered to eliminate undesirable frequencies and boost its amplitude to a level that is useful. Additionally, when signals need to be moved to a different frequency band, mixers are involved in up-conversion and frequency translation procedures.

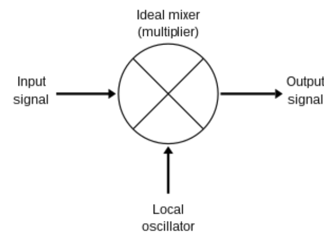

Figure 1 Ideal Mixer

Mixer Definitions:

1) Conversion Gain: This is the ratio (in dB) between the IF signal (usually the difference frequency between the RF and LO signals) and the RF signal.
2) Noise Figure: Noise Figure is the ratio of SNR at the output i.e., IF port to the SNR of input i.e., RF port.
3) Isolation: These parameters define how much signal leakage will occur between pairs of ports. i.e., RF to LO, LO to IF and RF to IF.
4) Linearity: Like other non-resistive networks, a mixer is amplitude-nonlinear above a certain input level resulting in a gain compression characteristic. Above this point the If fails to track the RF input power level

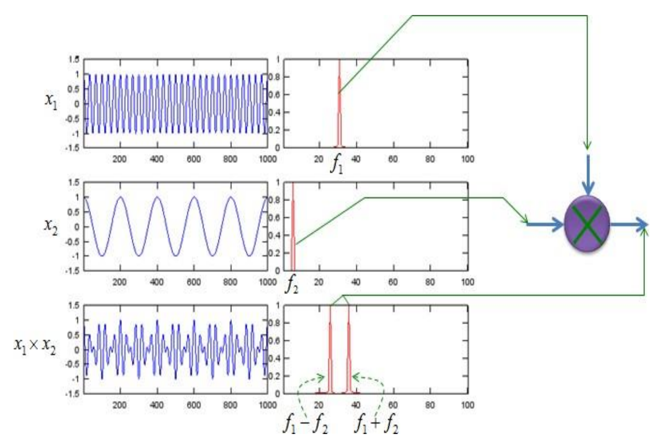

Figure 2 Functioning of a Mixer [1]

In this report, the Gilbert Cell, which is a type of RF mixer has been studied and simulated in different load configurations to bring out a comparative analysis between them.

A. Characteristics of a good mixer:

1) High Linearity – To avoid signal distortion during frequency conversion.
2) Low Noise Figure – To ensure that the SNR of down-converted signal is suitable for demodulation.
3) Wide Bandwidth – To handle a wide range of frequencies.
4) High Isolation – To isolate incoming RF signal and LO signal to avoid any unwanted mixing products.
5) Low Power Consumption – To reduce overall power consumption of the system.

B. Literature Review:

The Gilbert Cell was originally proposed by B. Gilbert. Earlier, diode ring or transistor switching topologies were used to implement mixers which had significant drawbacks such as high noise and distortion. Gilbert proposed a new mixer architecture based on a four-quadrant multiplier, that used a differential pair of transistors as the mixer core [2].

The Gilbert cell has been the subject of in-depth research in the literature, and over time, many changes and advancements have been suggested. The introduction of varactor diodes, which allow for frequency tweaking, and active load resistors, which can enhance the mixer's conversion gain and noise figure, are two modifications that have been suggested in the literature [3]. Additionally, the performance of the mixer may be impacted by the use of various biasing methods and diode types. A modified Gilbert mixer with a configurable active inductor in the LO path was suggested in a recent study. When compared to a conventional Gilbert mixer, the mixer was demonstrated to have better linearity and noise figure, and the active inductor offers frequency tweaking capabilities [4]. An alternative study suggested reorganizing the diode ring structure by substituting a "bridge" form for the conventional ring. It has been demonstrated that the bridge configuration offers better linearity and isolation between the LO and RF signals [5].

Using a folded-cascode amplifier to increase linearity and generate better conversion gain, good linearity, and low power consumption was another improvement suggested by the study. A noise figure of 7.5 dB and a conversion gain of 95 dB were accomplished by the suggested design [6]. [7] presented a high-performance, 60 GHz Gilbert Cell that enhances linearity by using a T-shaped cross-coupled pair. An IIP3 (third-order intercept point) of -3 dBm and a conversion gain of 8.5 dB were attained by the design.

II. GILBERT CELL

A. General Description:

A differential pair of transistors is used as the multiplier in the Gilbert cell, which enables good frequency response, high linearity, low distortion, and low noise. The circuit is set up so that the LO signal and the differential output of the multiplier are combined to create the RF output. This architecture is ideal for usage in communication systems because it permits high gain and good isolation between the RF and LO ports.

Mixers are crucial components in communication systems, available in both passive and active varieties. Passive mixers tend to exhibit higher noise values compared to their active counterparts due to increased conversion losses. Moreover, there are two main categories: double balanced mixers and single balanced mixers. While single balanced mixers are less complex than their double balanced counterparts, they tend to perform poorer in terms of rejecting RF to IF and LO to IF signals. The Gilbert Cell stands out as the most prevalent active, double balanced mixer topology. Its design leverages symmetry to effectively cancel out undesirable RF and LO output signals from the intermediate frequency (IF). This cancellation mechanism helps maintain the purity and integrity of the desired signal, making the Gilbert Cell a preferred choice in various communication applications.

B. Structural and Functional Description:

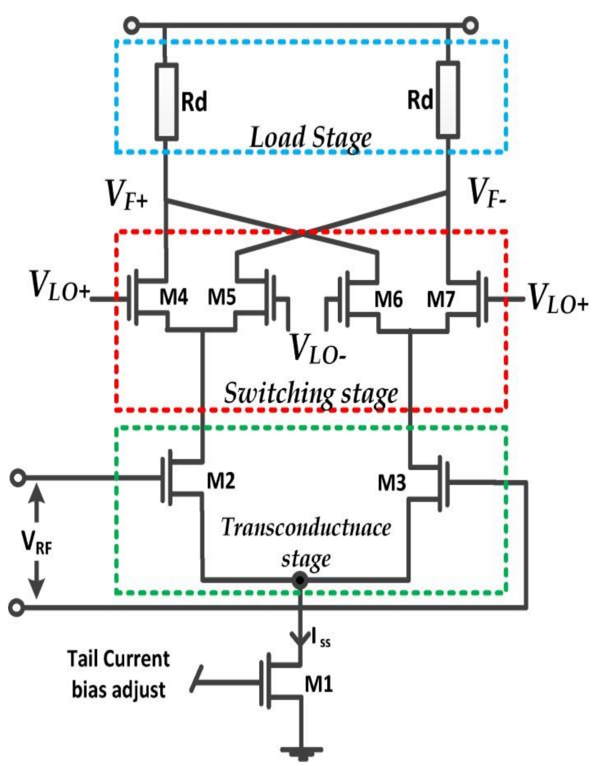

Figure 3 Double Balanced Gilbert Mixer with Field Effect Transistors [8]

In essence, the Gilbert cell mixer consists of two pairs of differential transistors, each of which has a bias current that is regulated by an input signal. The differential pair transistors' base electrodes are driven by the other input signal. There are essentially three primary steps to the overall design:

1. Transconductance stage:

This stage undertakes voltage to current conversion wherein the RF signal applied to transistors M2 and M3 is converted to the RF current.

2. Switching Stage:

The switching stage consists of the 4 cross- coupled transistors that are together known as the mixer core as it performs the multiplication of the RF and LO signals. This stage is composed of two parts that complement each other. The Transistors M4 and M7 form a multiplication function of the linear signal current RF from M2 and M3 with local oscillator signal applied across M4 and M7. The switch between transistors M4 and M6 provides the inverted RF current signal towards the load connected with M4. Similarly, the RF current signal from transistors M5 and M7 is received by the load connected with transistor M7.

3. Load Stage:

At the load stage, the current is transformed back to the voltage to give the differential output IF signal. Here, Rd can be a passive or active load.

A current sink is connected with the transconductance stage so as to maintain a stable bias point of operation for the mixer. The bias current is approximately 1 mA to 10 mA in general implementations. The observable symmetry in the circuit of Gilbert Cell enables the balance as well as the rejection of individual LO and RF signals at the output.

4. Gilbert Cell Configurations:

The Gilbert Cell can be used in majorly two configurations:

Gilbert cell mixer: The RF input can be a linear signal while the LO signal is a square wave. Furthermore, there is no requirement for a pre-distortion circuitry. The switching LO signal multiplies the overall RF signal by either +1 or -1. While multiplication with -1 adds a 180-degree phase shift, multiplication with +1 transmits the RF signal directly to the output without causing any changes. In this case, the LO signal needs to give a faster switching time rather than excellent linearity. But the operation needs to be linearized by the RF input. The switching design, which has low power consumption but poor linearity and strong harmonic distortion, is mostly employed in digital communication.

Analogue Gilbert Cell Mixer: The analogue Gilbert Cell mixer employs a mixer configuration to linearly multiply input signals, reducing harmonic distortion and improving linearity for analog transmission. Despite its increased electricity usage due to continuous transistor biasing, it remains indispensable in modulation, demodulation, and frequency conversion tasks across communication applications. Its ability to ensure accurate signal reproduction solidifies its role in maintaining fidelity in analog transmissions, making it a cornerstone technology in the field.

III. SPICE SIMULATION

Spice Simulation has been carried out for a double – balanced gilbert Cell to analyze its behavior in response to different signals and under different configurations using the LTSpice Tool provided by Analog Devices. Combining the results of the simulation with the theoretical concepts would help in deriving important results regarding the same.

A. Resistive Load Configuration:

Spice Simulation Code:

```
*For Resistive Load For Gilbert Cell Mixer

*C:\Users\success\Desktop\ACIC\Project\Special_Assig
nment_21BEC006\gilbert_cell.asc

M1 N003 N006 N004 N004 NMOS l=0.18u w=6u
M2 N002 N007 N004 N004 NMOS l=0.18u w=6u
M3 N004 N009 N008 N008 NMOS l=0.18u w=6u
M4 N003 N007 N005 N005 NMOS l=0.18u w=6u
M5 N005 N010 N008 N008 NMOS l=0.18u w=6u
M6 N002 N006 N005 N005 NMOS l=0.18u w=6u

R1 N001 N003 300 tol=1 pwr=0.1
R2 N001 N002 300

V1 N001 0 1.8
V2 N006 N007 PULSE(0 1.8 0 10p 10p 0.03n 0.1n)

I1 N008 0 100m
V3 N010 N009 SINE(0 1 1.1g) AC 1

.model NMOS NMOS
.model PMOS PMOS

.lib D:\LTSpice\lib\lib\cmp\standard.mos
.tran 0 10n 0 10p

.lib mosfet_018.lib
.options plotwinsize = 0
;ac dec 100 1 10g

.backanno
.end
```

TABLE I
SIMULATION PARAMETERS FOR SWITCHING MODE

SIMULATION PARAMETERS	
W/L Ratio	6 µm / 0.18 µm
LO SIGNAL	Square Wave: Amplitude = 1.8 Volt, Duty Cycle = 30%
RF SIGNAL	Sinusoidal: Frequency = 1.1 GHz, Amplitude = 1 Volt
POWER SUPPLY	1.8 Volts
BIAS CURRENT	100 mA

Simulation Waveforms:

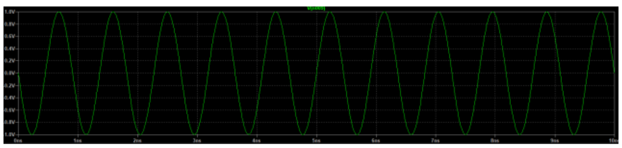

Figure 4; Input RF Signal.

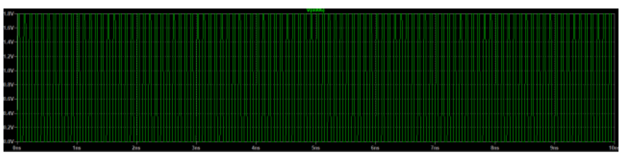

Figure 5: Input LO Signal.

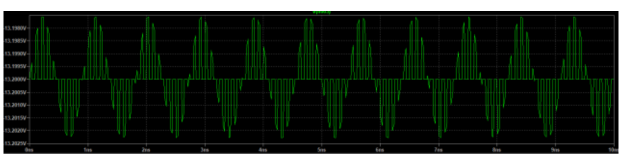

Figure 6: Output IF Signal.

TABLE II
SIMULATION PARAMETERS FOR ANALOGUE MODE

SIMULATION PARAMETERS	
W/L RATIO	6 µm / 0.18 µm
LO SIGNAL	Sinusoidal: Frequency = 100 kHz, Amplitude = 1.8 Volt
RF SIGNAL	Sinusoidal: Frequency = 1.1 kHz, Amplitude = 1.8 Volt
POWER SUPPLY	1.8 Volts
BIAS CURRENT	100 mA

Simulation Waveforms:

Figure 7: Input IF Signal.

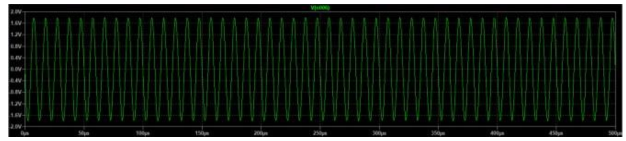

Figure 8: Input LO Signal.

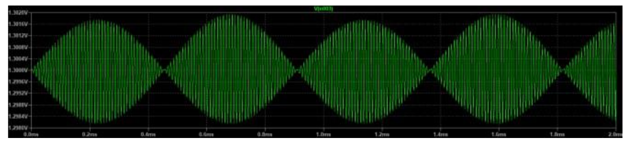

Figure 9: Output IF Signal.

B. *Active Load Configuration:*

Spice Simulation Code:

```
*For Active Load For Gilbert Cell Mixer

*C:\Users\success\Desktop\ACIC\Project\Special_Assi
gnment_21BEC006\gilbert_cell_pl.asc

M1 N002 N006 N004 N004 NMOS l=0.18u w=6u
M2 N003 N007 N004 N004 NMOS l=0.18u w=6u
M3 N004 N009 N008 N008 NMOS l=0.18u w=6u
M4 N002 N007 N005 N005 NMOS l=0.18u w=6u
M5 N005 N010 N008 N008 NMOS l=0.18u w=6u
M6 N003 N006 N005 N005 NMOS l=0.18u w=6u

V1 N001 0 1.8
V2 N006 N007 PULSE(0 1.8 0 1p 1p 3p 10p)

I1 N008 0 100m
V3 N010 N009 SINE(0 1.8 1.1k) AC 1

M7 N001 N001 N003 N003 NMOS l=0.18u w=6u
M8 N001 N001 N002 N002 NMOS l=0.18u w=6u

.model NMOS NMOS
.model PMOS PMOS

.lib D:\LTSpice\lib\lib\cmp\standard.mos

.tran 0 2n 0 10p
.lib mosfet_018.lib
.options plotwinsize = 0
;ac dec 100 1 10g
.backanno
```

TABLE III
SIMULATION PARAMETERS FOR SWITCHING MODE

SIMULATION PARAMETERS	
W/LRATIO	6 µm / 0.18 µm
LO SIGNAL	Square Wave: Amplitude = 1.8 Volt, Duty Cycle = 30%
RF SIGNAL	Sinusoidal: Frequency = 1.1 GHz, Amplitude = 1 Volt
POWER SUPPLY	1.8 Volts
BIAS CURRENT	100 mA

Simulation Waveforms:

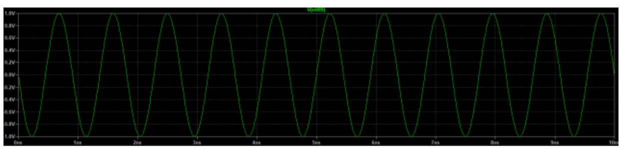

Figure 10: Input IF Signal.

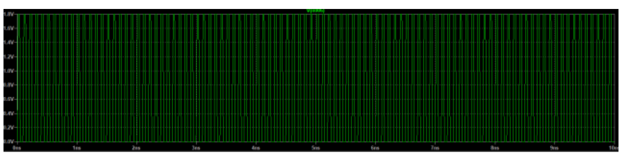

Figure 11: Input LO Signal.

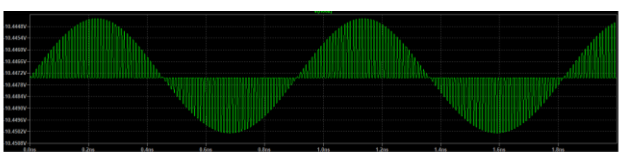

Figure 12: Output IF Signal.

TABLE IV
SIMULATION PARAMETERS FOR ANALOGUE MODE

SIMULATION PARAMETERS	
W/L RATIO	6 µm / 0.18 µm
LO SIGNAL	Sinusoidal: Frequency = 100 kHz, Amplitude = 1.8 Volt
RF SIGNAL	Sinusoidal: Frequency = 1.1 kHz, Amplitude = 1.8 Volt
POWER SUPPLY	1.8 Volts
BIAS CURRENT	100 mA

Simulation Waveforms:

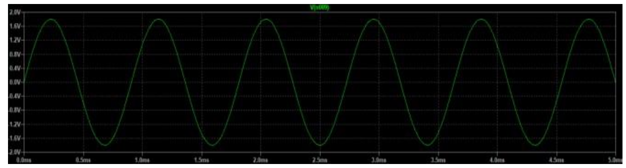

Figure 13: Input IF Signal.

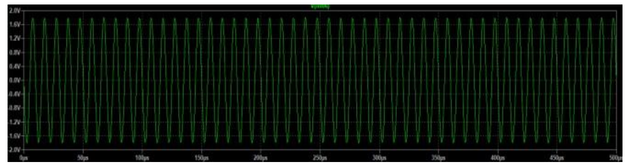

Figure 14: Input LO Signal.

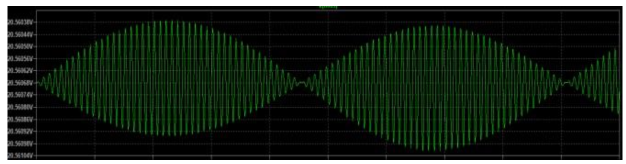

Figure 15: Output IF Signal.

C. Comparison Table:

Based on the theoretical concepts as well as the practical observations from the Spice simulations, following comparison table is derived that elaborates the advantages as well as limitations of both resistive and active load Gilbert Cell.

TABLE V
ATTRIBUTE COMPARISON OF GILBERT CELL FOR DIFFERENT LOADS

COMPARISON TABLE		
PROPERTY	**Resistive Load**	**Active Load**
DYNAMIC RANGE	**LOW**	**HIGH**
NOISE PERFORMANCE	**POOR**	**BETTER**
SELECTIVITY	**LOW**	**HIGH**
DESIGN COMPLEXITY	**LOW**	**HIGH**
POWER CONSUMPTION	**LOW**	**HIGH**
ROBUSTNESS	**HIGH**	**LOW**
COST	**LOW**	**HIGH**
SPACE	**LARGE**	**SMALL**

IV. CONCLUSION

This research presents the design and simulation of a Gilbert Cell under various load scenarios. In addition to its primary use as a frequency mixer, the Gilbert Cell has applications in the fields of key analog devices such as Variable Gain Amplifier, Four Quadrant Analog Multiplier, Automatic Gain Control Circuits, Phase Detector, etc. In order to highlight the advantages and disadvantages of the active and resistive load Gilbert Cells, the developed mixer has been simulated for both switching and analogue modes. The corresponding findings have also been calculated.

Although the active load inverter has a smaller design, its construction also makes the circuit more complex. It is advantageous, therefore, if the application calls for a greater dynamic range and improved noise performance. In comparison to normal designs, which call for a basing current of between 1 and 10 mA, the simulated design for the specified aspect ratio (combined active and resistive load) requires a large amount of current (~100 mA), which is not necessary. The aspect ratio and other circuit characteristics can be changed to reduce the biasing current.

Future research can focus on putting the changes mentioned in the study into practice, like using varactor diodes to maximize conversion gain and Schottky diodes in the mixer's RF channel to gauge how much the linearity has improved over a typical diode. Furthermore, various biasing strategies can be experimented with to enhance the mixer's overall performance.

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