International Journal of Scientific Engineering and Science
Volume 3, Issue 8, pp. 42-44, 2019. ISSN (Online): 2456-7361

THD Analysis of Differential Active Balun Topology

Frederick Ray I. Gomez[1,2], John Richard Hizon[1], Maria Theresa De Leon[1]
[1]Microelectronics and Microprocessors Laboratory, University of the Philippines, Diliman, Quezon City, Philippines 1101
[2]New Product Development & Introduction Department, STMicroelectronics, Inc., Calamba City, Laguna, Philippines 4027

Keywords— *Differential active balun; linearity; THD; efficiency, overdrive voltage.*

I. Active Balun Circuit Overview

A balun (balanced-unbalanced) transformer circuit converts signals that are single-ended or unbalanced with respect to ground into signals that are differential or balanced with respect to ground, and vice versa. Shown in Fig. 1 is a simple balun circuit that transforms signal from single-ended input voltage source (Vin) into differential output voltages (V+ and V-) with 180 degrees phase difference.

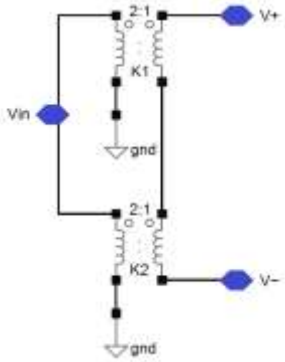

Fig. 1. Simple balun transformer circuit.

Baluns can be classified as either active or passive baluns depending on the devices used. Active baluns, although unidirectional and more complex to implement, are preferred over their passive counterparts because they can produce gain, occupy less chip area, and can operate at higher frequencies [1-2]. One of the active balun topologies is the differential active balun transformer circuit in Fig. 2, composed of 3 transistors namely M1 and M2 for the differential output, and M3 for the tail current. The input signal is applied at the input of one of the differential pair transistors and will ideally split equally between the pair with same amplitude and 180° phase shift. Remarkably, this active balun topology is capable of producing gain.

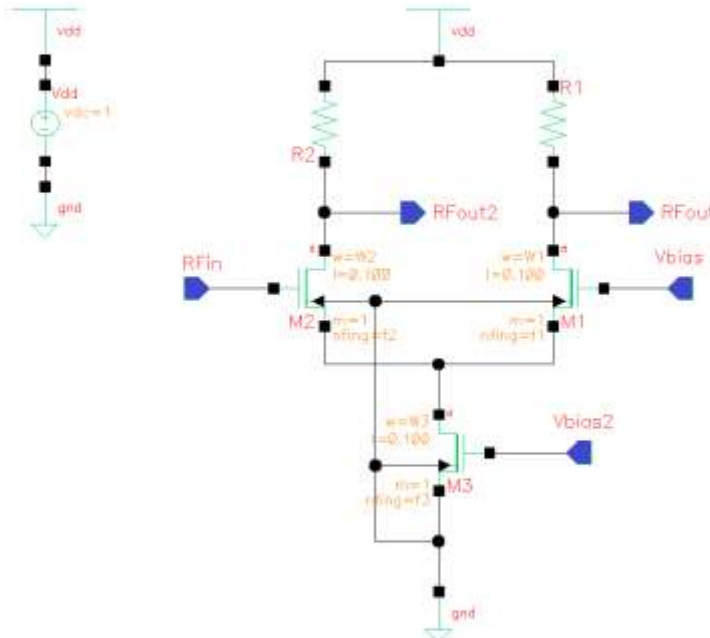

Fig. 2. Schematic diagram of differential active balun topology.

International Journal of Scientific Engineering and Science
Volume 3, Issue 8, pp. 42-44, 2019. ISSN (Online): 2456-7361

II. Total Harmonic Distortion Analysis

An important parameter that should also be considered in the design of active balun is the total harmonic distortion (THD), which is also a linearity parameter. THD is the percentage of the inherent harmonics with respect to the fundamental signal. Ideally, THD is zero, but since this is not really the case for transistors and transistor amplifiers, THD should then be minimized.

Let the total input voltage (Vin) be the sum of direct current (DC) input voltage (V_{IN}) and alternating current AC input voltage (v_{in}), as a function of time (t). AC input voltage could be further expressed as vrfcosωt, where vrf is the peak value of v_{in}.

$$Vin(t) = V_{DC} + V_{AC} = V_{IN} + v_{in} = V_{IN} + vrf\cos\omega t \tag{1}$$

For RFout2 branch which has the port for the input voltage, total drain current (I_{ds}) is expressed as

$$I_{ds2}(t) = \frac{\beta}{2}[V_{GS} - V_t]^2 = \frac{\beta}{2}\{[(V_{IN} + v_{in}) - V_{DS3}] - V_t\}^2 \tag{2}$$

$$I_{ds2}(t) = \frac{\beta}{2}\left[\left({V_{y2}}^2 + \frac{vrf^2}{2}\right) + 2V_{y2}vrf \cdot \cos\omega t + \frac{vrf^2}{2} \cdot \cos 2\omega t\right] \tag{3}$$

$$with\ \ V_{y2} = V_{IN} - V_t - V_{DS3}\ ,v_{in} = \ vrf\cos\omega t\ ,\beta = \mu C_{ox}\frac{W}{L} \tag{4}$$

The drain current or drain-to-source current (I_{ds}) has three terms, as shown in the succeeding expressions.

$$I_{ds}(t) = I_0 + I_1\cos\omega t + I_2\cos 2\omega t \tag{5}$$

The terms are given as

$$I_{0f2} = \frac{\beta}{2}\left[(V_{IN} - V_t - V_{DS3})^2 + \frac{vrf^2}{2}\right] = I_{DC} \rightarrow \quad \text{DC term} \tag{6}$$

$$I_{1f2} = \frac{\beta}{2}[2vrf(V_{IN} - V_t - V_{DS3})] \rightarrow \quad \text{Amplitude of 1st harmonic} \tag{7}$$

$$I_{2f2} = \frac{\beta}{2}\left(\frac{vrf^2}{2}\right) \rightarrow \quad \text{Amplitude of 2nd harmonic} \tag{8}$$

Total harmonic distortion of RFout2 could be calculated as

$$THD_2 = \frac{vrf}{4(V_{IN} - V_{DS3} - V_t)} = \frac{vrf}{4(V_{GS2} - V_t)} = \frac{vrf}{4V_{OV}} = \frac{vrf}{8}\frac{g_{m2}}{I_{DS2}} \tag{9}$$

It can be observed that minimizing the overdrive voltage (V_{OV}) of transistor M2 would result to higher THD. Furthermore, increasing the efficiency in terms of gmoverId would also result to higher THD. With this, there is a limit in the efficacy of optimizing V_{OV} and gmoverId in minimizing the total harmonic distortion.

Now for the RFout1 branch, total drain current is expressed as

$$I_{ds1}(t) = \frac{\beta}{2}[V_{GS} - V_t]^2 = \frac{\beta}{2}[(V_{BIAS} - V_{DS3}) - V_t]^2 \tag{10}$$

Substituting V_{DS3} in terms of V_{IN} and with $V_{GS} - V_t > 0$, expression for total drain current becomes

$$I_{ds1}(t) = \frac{\beta}{2}\{[V_{BIAS} - (V_{IN} - V_t)] - V_t\}^2 = \frac{\beta}{2}[V_{BIAS} - (V_{IN} + v_{in})]^2 \tag{11}$$

$$I_{ds1}(t) = \frac{\beta}{2}\left[\left({V_{y1}}^2 + \frac{vrf^2}{2}\right) - 2V_{y1}vrf \cdot \cos\omega t + \frac{vrf^2}{2} \cdot \cos 2\omega t\right] \tag{12}$$

$$with\ \ V_{y1} = V_{BIAS} - V_{IN}\ \ \ and\ \ \ v_{in} = \ vrf\cos\omega t \tag{13}$$

The drain current has three terms, given as

$$I_{0f1} = \frac{\beta}{2}\left[(V_{BIAS} - V_{IN})^2 + \frac{vrf^2}{2}\right] = I_{DC} \rightarrow \quad \text{DC term} \tag{14}$$

$$I_{1f1} = \frac{\beta}{2}[2vrf(V_{IN} - V_{BIAS})] \rightarrow \quad \text{Amplitude of 1st harmonic} \tag{15}$$

$$I_{2f1} = \frac{\beta}{2}\left(\frac{vrf^2}{2}\right) \rightarrow \quad \text{Amplitude of 2nd harmonic} \tag{16}$$

Total harmonic distortion of the RFout1 could now be generated as

$$THD_1 = \frac{vrf}{4(V_{DS3} + V_t - V_{BIAS})} = \frac{vrf}{4[V_t - (V_{BIAS} - V_{DS3})]} \tag{17}$$

$$THD_1 = \frac{vrf}{-4(V_{GS1} - V_t)} = -\frac{vrf}{4V_{OV}} = -\frac{vrf}{8}\frac{g_{m1}}{I_{DS1}} \tag{18}$$

Minimizing the overdrive voltage (V_{OV}) of transistor M1 would result to higher THD. In addition, increasing the efficacy in terms of gmoverId would also result to higher THD. With this, there is a limit in the effectiveness of optimizing V_{OV} and gmoverId to minimize the signal distortion.

Acknowledgment

The authors would like to thank the Department of Science and Technology (DOST), DOST-PCASTRD, DOST-ERDT, and the Microelectronics and Microprocessors Laboratory (Microlab) of the University of the Philippines for the great support. Author F.R. Gomez would also like to express appreciation and gratitude to the STMicroelectronics Calamba New Product Development & Introduction (NPD-I) team and the Management Team.

References

[1] K. Jung, W.R. Eisenstadt, R.M. Fox, A.W. Ogden, and J. Yoon, “Broadband active balun using combined cascode-cascade configuration,” IEEE Transactions on Microwave Theory and Techniques, vol. 56, issue 8, pp. 1790-1796, Aug. 2008.
[2] F.R. Gomez, M.T. De Leon, and C.R. Roque, Active balun circuits for WiMAX receiver front-end, TENCON 2010 – IEEE Region 10 Conference, pp. 1156-1161, November 2010.
[3] P.R. Gray, P.J. Hurst, S.H. Lewis, and R.J. Meyer, Analysis and Design of Analog Integrated Circuits, 4th ed., New York: John Wiley & Sons, Inc., 2001.
[4] W. Sansen, “Distortion in elementary transistor circuits,” IEEE Transactions on Circuits and Systems–II: Analog and Digital Signal Processing, vol. 46, no. 3, pp. 315-325, March 1999.
[5] B. Razavi, Design of Analog CMOS Integrated Circuits, New York: McGraw-Hill, 2001.
[6] F.R. Gomez, J.R. Hizon, and M.T. De Leon, Differential active balun design for WiMAX applications, Journal of Engineering Research and Reports, vol. 4, no. 4, pp. 1-8, April 2019.
[7] J.R. Hizon and E. Rodriguez-Villegas, “Design tradeoffs in a triode transconductor for low voltage zero-IF channel select filters,” 52nd IEEE International Midwest Symposium on Circuits and Systems, September 2009.
[8] Cadence Design Systems, Inc. Custom IC / analog / RF design – circuit design. https://www.cadence.com/content/cadence-www/global/en_US/home/tools/custom-ic-analog-rf-design/circuit-design.html