



# Zen of Analog Circuit Design - Part I

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## Zen of Analog Circuit Design

For two years from 2011 till 2013, I taught a course titled **Analog Design for all** which covered concepts starting with MOS transistor behavior and progressed till the design of two stage amplifiers. The course introduced concepts in a manner that led the student to the **synthesis** of new circuits, not merely their **analysis**. But I still felt that there was a more intuitive way to introduce Analog Circuit Design, one that would bring out the beauty of the subject so that the student could 'stop and smell the roses'. The quest to find that way is what led me to the **Zen of Analog Circuit Design**.

But why a 'Zen of Analog'...?

Because the foundational concepts in Analog closely mirror human relationships! The purpose of this book is to take a simplified and intuitive path to unlock some profound secrets of Analog Design – a path similar to Zen. The protagonist of this book is Ang-Lao, a traveling monk who brings his insights into the Analog world to solve the challenges faced by human civilization.

The book addresses a problem statement that much of Analog Circuit Design tries to solve - how do you realize an **ideal buffer**? It starts with the simple concepts of voltage sources and current sources. From the I-V curve of the MOS transistor, we see how it behaves much like a **Voltage controlled current source** (VCCS). The inherent challenge in getting even a simple two-transistor circuit to work is the conflict arising from having two such current source-like elements in series. The **digital inverter** is shown to be one such circuit that can function like an **analog amplifier**, albeit over a narrow range of input voltage. The effect of **loading** on such a circuit is illustrated graphically and is shown as an added challenge in getting it to work in an analog manner.

Having understood the complications involved, we see how through the strikingly simple but immensely powerful concept of **feedback**, one of the two transistors can be modified subtly to make it behave like a voltage source. In that process, we realize our first approximation to an ideal analog buffer. We then see how manifestations of the same concept leads us to the synthesis of a whole bunch of two transistor circuits - **source followers**, common source amplifiers with **gm-load** and with **diode-connected load**. The concepts used in synthesis of such elegant circuits are also extended to the analysis of much more complex circuits, for example, a **Voltage to Current (V2I) conversion** circuit.

Throughout the quest to realize our ideal buffer, the narrative switches between concepts of electronics and the story of Aman-Ra, an engineer from Medieval Egypt. Struggling with a relationship burdened by several factors causing stress, his guiding light dawns in the form of Ang-Lao, a wandering monk who teaches him the secret to a happy relationship.

For some, this book will signal the end of the fear of Analog. For others, it will be the start of a love story with a new subject. For some others, it is hoped, this book will trigger a quiet moment of reflection into

one's relationships.

After all, is not the intent of all Education that it should better one's life?

## Concepts covered

- o I-V characteristics of Voltage & Current sources
- o Ideal & non-ideal sources
- o Controlled sources
- o Active and passive elements
- o I-V characteristics of a MOSFET in saturation
- o MOS transistor as a Voltage controlled current source
- o Digital inverter as Analog amplifier
- o Operating/ Bias point
- o Common source (CS) amplifier
- o Effect of loading on a CS amplifier
- o Feedback
- o How can you make a MOSFET behave like a voltage source?
- o Synthesis of a CS amplifier with diode-connected load
- o Analysis of a V2I circuit including an introduction to current mirror
- o Synthesis of CS amplifier with gm-load
- o Synthesis of source follower circuit

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