

# Standing Wave Oscillators for Global Clock Distribution

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**Abstract**—The clock signal of modern computer processors consumes a large portion of overall chip power. By modeling global clock network wires as transmission lines and manipulating their dimensions, the global clock signal can be transformed into a standing-wave oscillator that conserves energy and reduces skew. This paper explains the lossy transmission line model and explores the effects of matching impedances and altering line capacitances, and concludes with preliminary results and the direction of future research.

**Keywords**—clock signal, global clock distribution, resonant frequency, salphasic clock, transmission lines

## I. INTRODUCTION

Traditionally, because the electrical length of most clocks is significantly larger than the sub-millimeter lengths of typical global clock wires, the lumped wire model has been used to model them. But as clock speeds increase and die sizes do not shrink [1], electrical lengths of global clock wires are approaching those wires' lengths.

All results shown were derived using HSPICE.

## II. THEORY

### A. Transmission Lines

Strictly speaking, no electrical connection can be perfectly modeled using the lumped wire model. No conductive medium is perfectly conductive. When wires are modeled as an instantaneous, lossless connection, it is because their applied signal frequencies are slow enough, and their losses are small enough, to not affect circuit performance. For such “lumped” connections, we assume that at any given moment, the potential at each and every point on the wire is identical. But when we have a signal that changes very rapidly, or a wire with significant series resistance, or a wire that's running parallel with another one – the distributed model is no longer accurate enough. Lossy transmission lines are used to realistically simulate what happens to the signal as it travels through the imperfect medium.

A lossy transmission line has four components: a series resistance and inductance (to model wire loss and self-inductance, respectively) and a parallel capacitance and conductance (to model parasitics due to nearby materials).

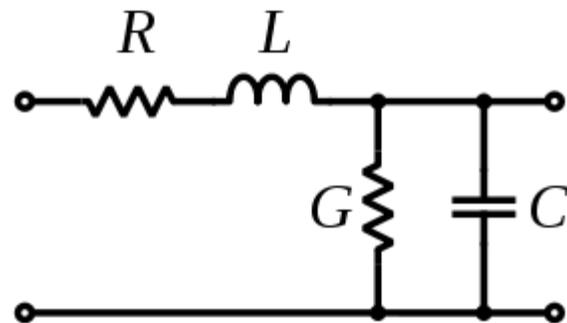


Fig. 1 Lossy transmission line

By modeling electrical connections as near-infinite series connections of lossy transmission lines, we can closely approximate a true connection.

Transmission line component parameters are expressed per-unit-length, and together make up the *primary line constants*  $R$ ,  $L$ ,  $G$ , and  $C$ . From the primary line constants, we can derive other important characteristics. One of these characteristics, the propagation constant, describes the attenuation and phase shift of a signal travelling through a transmission line [2]:

$$\begin{aligned}\gamma &= \sqrt{ZY} \\ Z &= R + i\omega L \\ Y &= G + i\omega C \quad [3]\end{aligned}$$

The imaginary part of the propagation constant is known as the phase constant, and can be approximated as

$$\beta = \omega\sqrt{LC}$$

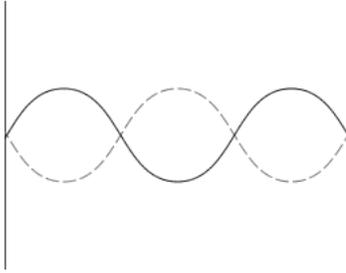
for small  $R$  and  $G$ . [4]

Armed with this information, we can determine the phase shift along a wire for a signal of known frequency, and thus the points along the wire that will have the largest amplitude.

### B. Standing Waves

A standing wave is the sum of two waves of equal amplitude and frequency that are travelling in opposite

directions.



A unique property of standing waves is that they have identical phase at each point along the wire; the two travelling waves combine to form one stationary wave.

By taking into account of the impedance mismatch between the transmission lines and their sink impedances (branches) – that is,  $Z_L \gg Z_S$  – we can assume a large coefficient of reflection  $\rho$ ,

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

If we make the phase shift of each binary tree branch a multiple of  $\pi$  radians, then we will have signals of closely-matched amplitude at each sink. If we know that the source signal is an antinode, then each branch will also be an antinode of the standing wave.

Because the standing wave is the sum of the incident wave and its reflections, a higher potential is formed; the wave reflections have been used constructively rather than ignored. We are also taking advantage of the idea that the reflected signal will reflect yet again at its source, in a process that will repeat several times, each time adding to the amplitude of the wave.

### III. METHODS

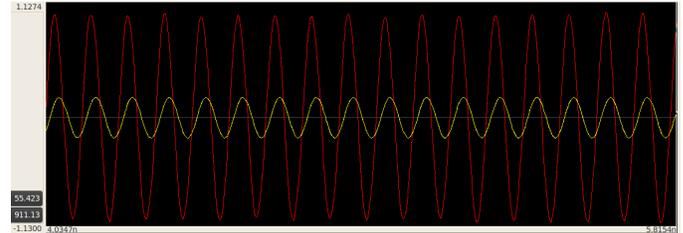
Rarely is the phase shift of a global clock wire coincidentally a multiple of  $\pi$ ; we must manipulate the primary line constants to achieve this. To avoid wirelength manipulation, its per-unit inductance and capacitance can be manipulated. Wire inductance is inversely proportional to its width. Wire capacitance can be increased by running dummy wires parallel alongside it.

Alternatively, we can leave the per-unit-length parameters alone and increase a wire's length by snaking it. By making the wire longer, we increase its impedance, and therefore its phase shift. Typically we need more phase shift, not less, because at 10GHz with standard impedances the signal's electrical length approaches a millimeter; thus, wires do not need to be shorter than their minimum path.

Simulations were performed with HSpice, and run on a three-branch binary clock tree. The root of the tree was 64x

the minimum width of 65nm; its children were both 32x minimum width, and the children of those each 16x minimum width. Primary line constants were derived using ASU's PTM tool [5]. Line capacitances were altered to produce ideal phase shifts, using hard value changes as opposed to an E&M simulator and parallel dummy wires.

### IV. RESULTS



To calculate power savings, the current draw of the sinks with a unit voltage *without* impedance matching was measured. Next, impedances were matched and a source voltage that created a standing wave of the same unit voltage as the previous circuit was multiplied by its current draw. Power savings of 73% were observed.

### V. IMPLICATIONS AND FUTURE WORK

Standing-wave oscillator clock distribution was first explored in 1996 [6] for a 100MHz sine wave, with a 12.7-m RG58/U cable. Now that clock speeds are in the multiple-gigahertz range, it is possible to scale this down to global clocks near the millimeter scale. While large power savings have been observed, methods need to be developed to adjust a line's primary line constants without adverse side effects. Non-unity  $\rho$  must also be accounted for with buffers, as suggested by O'Mahony [7]. With methods to handle those things, salphasic clocks show promise for low-power applications.

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