Fan-In Capacitance

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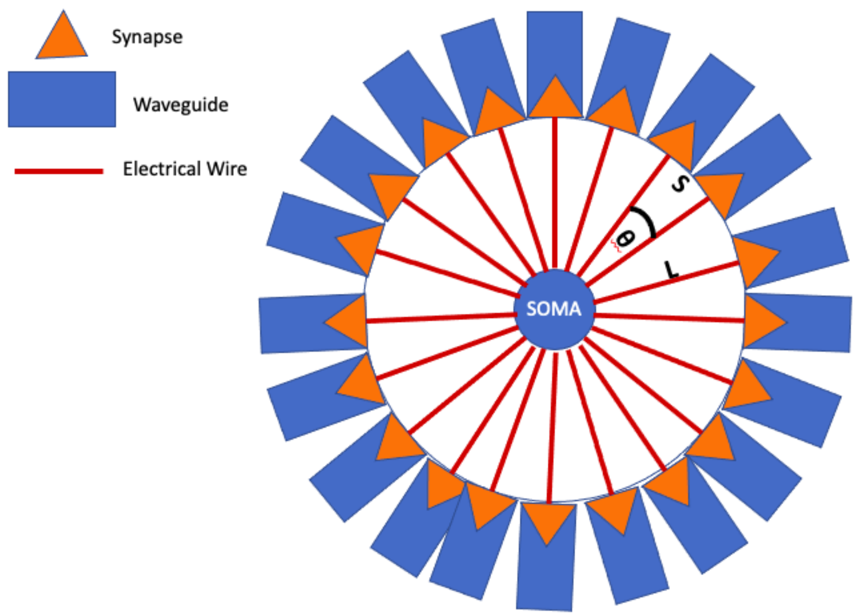
January 2021



Let's assume that the minimal wiring configuration is given in the figure. There are also assumptions that the soma will be much smaller in area than that needed for wiring and that the number of synapses is large. S is the distance between the centers of two waveguides - let's call it $1\mu m$. θ is the angular distance between waveguides. We get our first fan-in (N) dependent parameter:

$$\theta = \frac{2\pi}{N} \tag{1}$$

Lastly, L is the length of the wires. Miller says wire capacitance is about $200aF/\mu m$ - we'll call this capacitance/length c. The total capacitance (C_{total}) of the wiring must then be:

$$C_{total} = NLc \tag{2}$$

L is defined by the geometry to be:

$$L = \frac{S}{\theta} = \frac{SN}{2\pi} \tag{3}$$

So,

$$C_{total} = \frac{N^2 Sc}{2\pi} \tag{4}$$

If the neuron's ever going to fire, you need to build up some voltage (V) on all of this capacitance, which will be set by the threshold voltage of whatever transistor technology you're using. This gives an expression for the amount of energy you're going to need per spike.

$$E = \frac{N^2 ScV^2}{4\pi} \tag{5}$$

For $N = 1000$, $c = 200aF/\mu m$, $S = 1\mu m$, and $V = 1V$, you get $E = 16pJ$. For comparison, you'd expect communication to cost 1pJ for unit transmitter efficiency. This charging energy could also be reduced a couple orders of magnitude by using lower threshold transistors, say $200mV$. If you push to $N = 10^4$, this charging energy would be comparable to the communication energy if your transmitter was 1% efficient.

We also get an estimate (of questionable accuracy) of wiring area that may or may not be useful later:

$$A_{wiring} = \pi L^2 = \frac{N^2 S^2}{4\pi} \tag{6}$$

With our numbers, we get $A_{wiring} = 80,000\mu m^2$.

Of course, all of this could be repeated with multiple layers of detectors. Everything's reduced by a factor of the number of layers (N_L):

$$C_{total} = \frac{N_{tot}^2 Sc}{2\pi N_L} \tag{7}$$

$$E = \frac{N_{tot}^2 ScV^2}{4\pi N_L} \tag{8}$$

$$A_{wiring} = \pi L^2 = \frac{N_{tot}^2 S^2}{4\pi N_L} \tag{9}$$

The total capacitance also gives you an idea for the maximum amount of current that you'd like a synapse to be able to produce. Let's say you want a single synapse that's capable of charging up all that capacitance. It'll need to provide a current of:

$$I = C_{total} V f = \frac{N_{tot}^2 S c V f}{2\pi N_L} \tag{10}$$

If you want $N = 1000$ and $f = 10MHz$ (and $N_L = 1$), you're going to need synapses capable of outputting $300\mu A$ if a single synapse is going to switch the neuron. $N = 10,000$ gives an outrageous (right?) $30mA$. So maybe this equation is a nice look at the trade-offs between current, fan-in, and frequency.