Arrays of Zig-Zag Antennas Driven by Switched Oscillators

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Abstract

Previous papers have considered zig-zag and similar antennas driven by switched oscillators for THz applications. The present paper considers these elements in an array to increase the directivity and power in the resulting beam.

1 Introduction

Much consideration has been given to switched oscillators driving antennas for THz applications [1–6]. It is difficult to obtain large energies in a narrow (1 ps) pulse. The power can be respectable for a few hundred volts driving an antenna (hundreds of W). What we need is a long THz pulse, such as in [5], for roughly an order of magnitude increase in the energy in the pulse. This is accomplished by a low-characteristic-impedance switched oscillator (perhaps 10 Ω or so) driving a (relatively) high-impedance antenna (hundred Ω or so).

So let us consider such antenna/oscillator combinations as might form a unit cell of an array. Then let us consider how such cells might be wired together to form an array.

2 Unit Cells

We begin with various options for unit cells based on the types of antennas as in Fig. 2.1. Here we see zig-zag, meander and serpentine antennas driven by a switched oscillator. As discussed in [3], these can also take a differential form with two antennas driven by a differential switched oscillator. For further discussion, let us use the zig-zag type, understanding that any of these three types might be used. Here we have illustrated antennas with four "elements", each a half wave long so that the elements all radiate in phase. Of course, we can increase the number of elements, but, as shown in [5], the oscillatory wave dies out after about four elements. (Note that the switch, once triggered, must remain closed during the oscillation, opening only after the oscillation is completed.)

As discussed in [1–3, 5], there is a ground plane approximately $\lambda/4$ (in the dielectric) behind the antenna. The ground plane of the switched oscillator, however, is much closer to the other conductor so as not to radiate, and to raise the oscillator capacitance, and, hence, stored energy. This is indicated as the raised ground planes in Fig. 2.1.

Sticking with the switched oscillators for the moment, Fig. 2.2 shows some alternate cross-section geometries. Fig. 2.2(a) shows the basic or starting geometry with a flat conductor (with rounded edges [2] if possible) over a ground plane. This conductor is wide for high capacitance, but less wide than the length ($\lambda/4$ in the dielectric). Note that the dielectric (relative dielectric constant ϵ_r) can be continued above the top of the conductor to increase the capacitance. Figure 2.2(b) shows the addition of side conductors by bending up the ground plane to increase the capacitance. This can be continued in Fig. 2.2(c) to have the ground surface over the top as well. Note now that the skin resistance is also reduced by having the under and over sides in parallel for the oscillator current.

Now consider some unit-cell geometries as in Fig. 2.3. Here we have both differential (two antennas) and what we might call quad geometry with four antennas with a special differential switched oscillator. We have added a fifth "element" (a zig) to each antenna so as to move the charging leads to the corners of the unit cells. The differential geometry has the charging-lead connections on the same side. (Of course, the lower antenna could also go off to the right.) The quad geometry has four antennas driven by a single quad switched oscillator with four resonant quarter-wave transmission lines with one differential switch (triggered by an fs laser). Note that this has two symmetry planes (perpendicular to the x and y axes). Here we have connected points 1 and 4 to the $+$ and $-$ charging respectively. We could have used points one and two, but the

(a) Zig-Zag

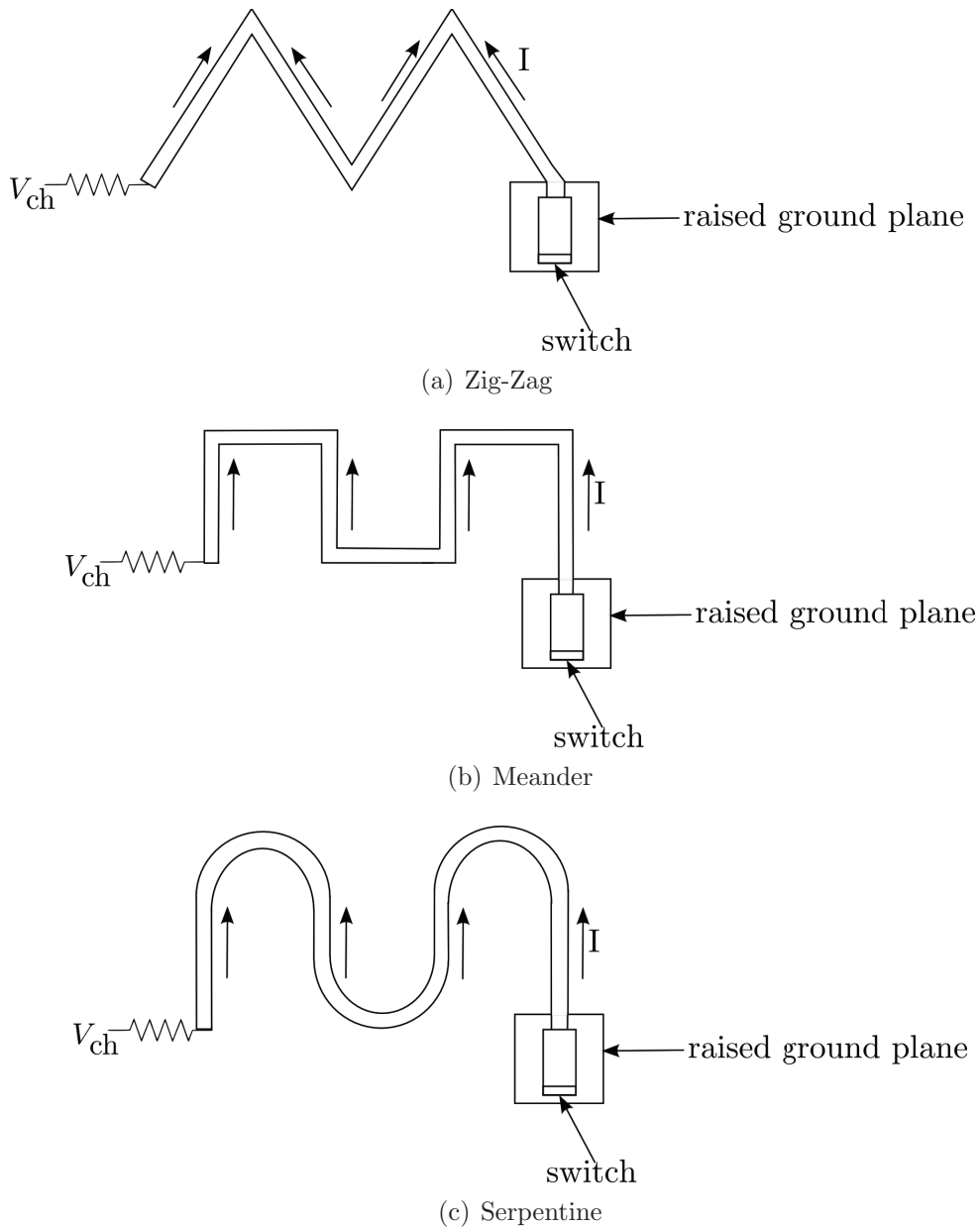
(b) Meander

(c) Serpentine

Figure 2.1: Types of antennas with switched oscillators (ground planes $\approx \lambda/4$ behind antenna elements)

former moves the charging leads farther apart. Note that these configurations have been indicated for vertical polarization, but a 90° rotation would make it horizontal.

Note that in Fig. 2.3 we have indicated the charging leads on the forward ($+z$) side of the ground plane, perhaps $\lambda/4$ away from it, like the antennas. One could cut holes in the ground plane to pass the charging leads to the back side, but this might increase the complexity.
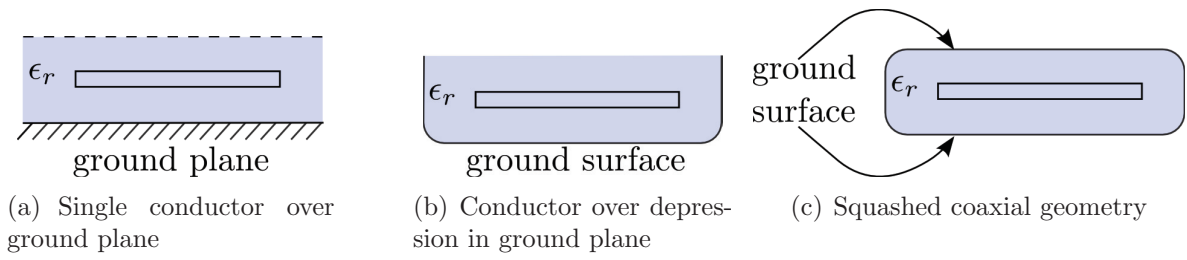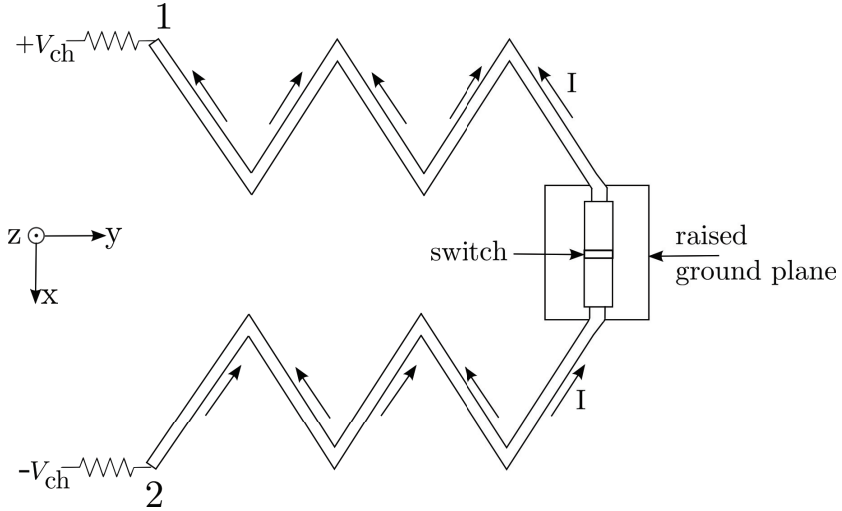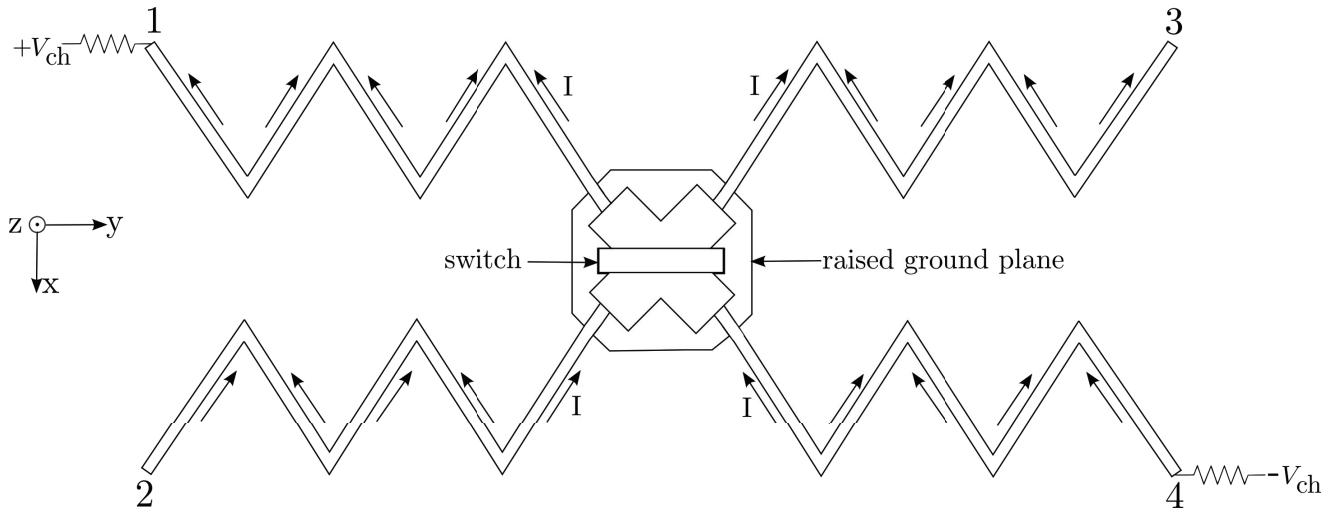
(a) Single conductor over ground plane

(b) Conductor over depression in ground plane

(c) Squashed coaxial geometry

Figure 2.2: Cross sections of switched oscillators

(a) Differential geometry

(b) Quad geometry

Figure 2.3: Unit cells

3 Aggregation of Unit Cells into Arrays

The previous unit cells can be repeated in two dimensions to form an array as in Fig. 3.1. Here we have arranged the coordinates so that x corresponds to rows (at x_n) and y corresponds to column (at y_n) of a matrix. So a unit cell centered at $x = x_n, y = y_n$, can be labeled as the (n,m) cell of the array. As before we also have the four corners for connections. Then our N×M array has cell centers at

$$
\begin{aligned}
n &= 1, ..., N \text{ (rows)} \\
m &= 1, ..., M \text{ (columns)}
\end{aligned}
\tag{3.1}
$$

Figure 3.2 shows one way to feed the array be placing $+V_{\text{ch}}$ on the left, and $-V_{\text{ch}}$ on the right of the whole array, feeding each row as indicated. In Fig. 3.2(a) we merely electrically connect the antenna ends together across top and bottom. The antennas and switched oscillators form two continuous conducting paths, one across the top, and one across the bottom of the row of unit cells. This should allow rapid charging of the switched oscillators. However, for high pulse-repetition rates one might be concerned about potential oscillations in each array row during the charging cycle. Figure 3.2(b) shows an alternate design with resistive connections from each charging bus to the appropriate connection points on the unit cells.
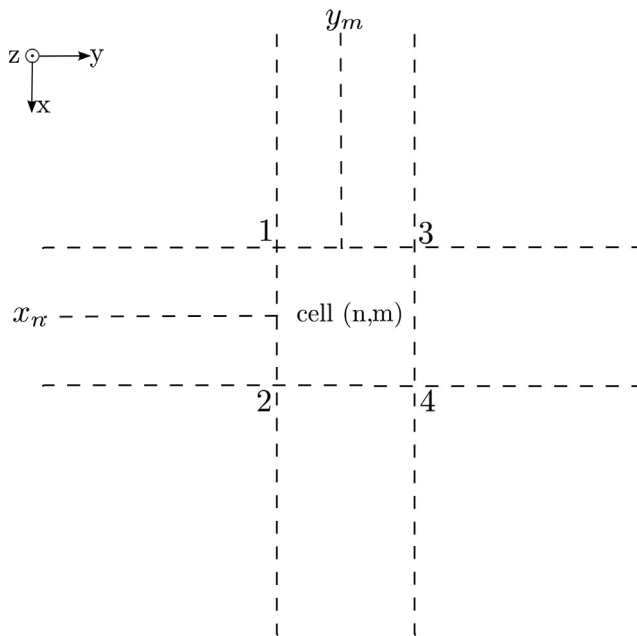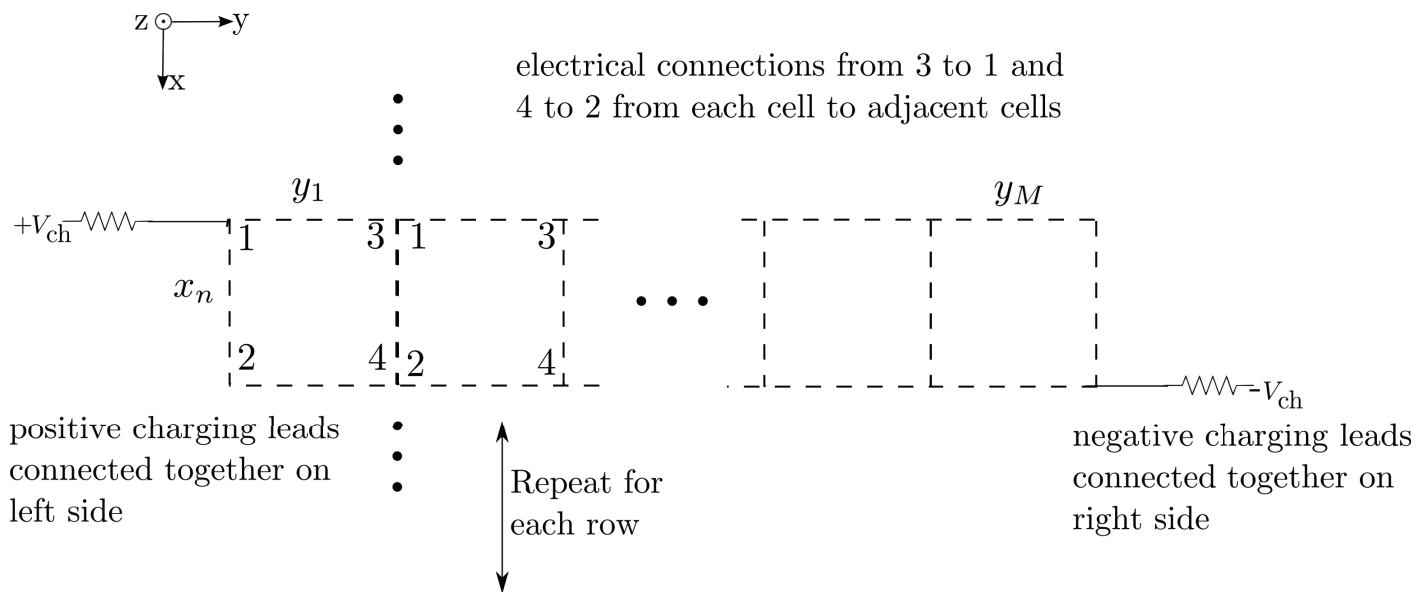

Figure 3.1: Array Coordinates

Figure 3.3 shows a feeding scheme where the feeding buses are organized along columns. Now the cells in the adjacent columns are not connected to each other and room is allowed for the vertical (x directed) charging buses. Two such buses (one + and one −) need to fit between adjacent columns.

5

(a) Continuous electrical connection cell to cell on n$^{\text{th}}$ row
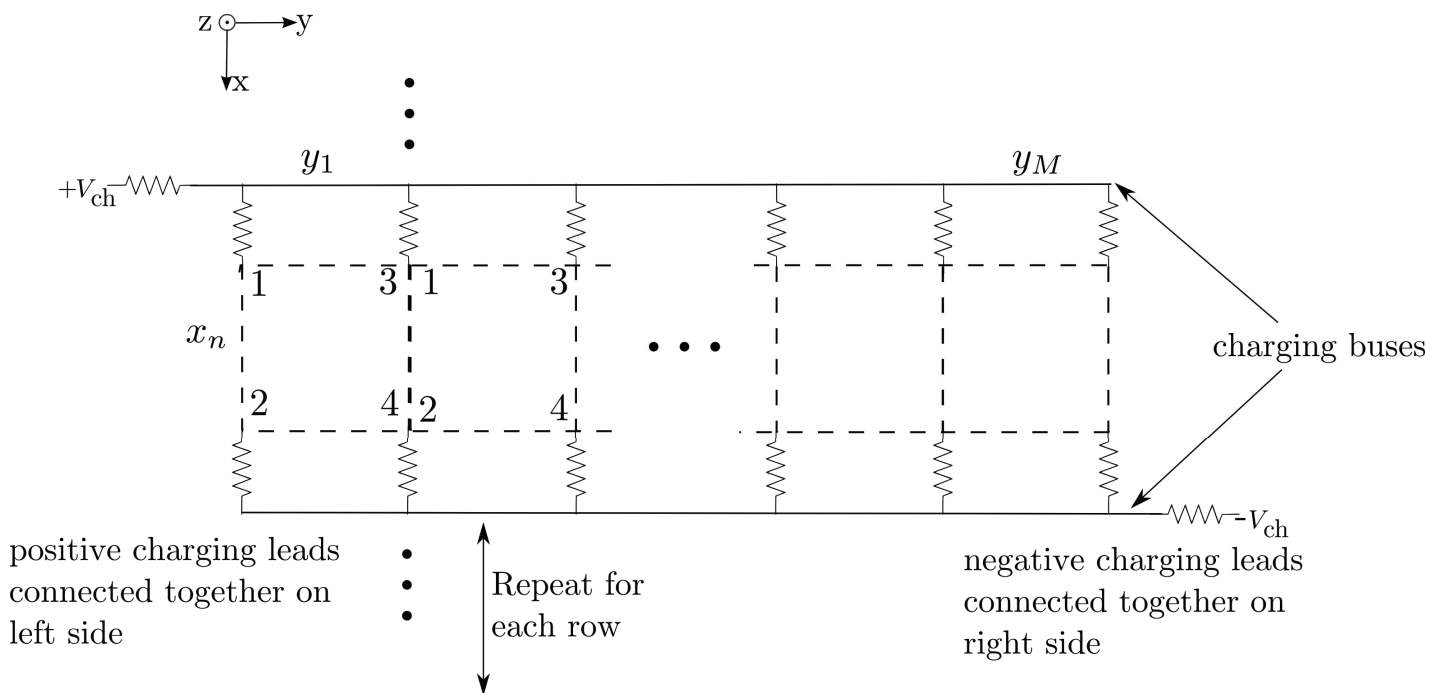
(b) Resistive isolation at each cell on n$^{\text{th}}$ row

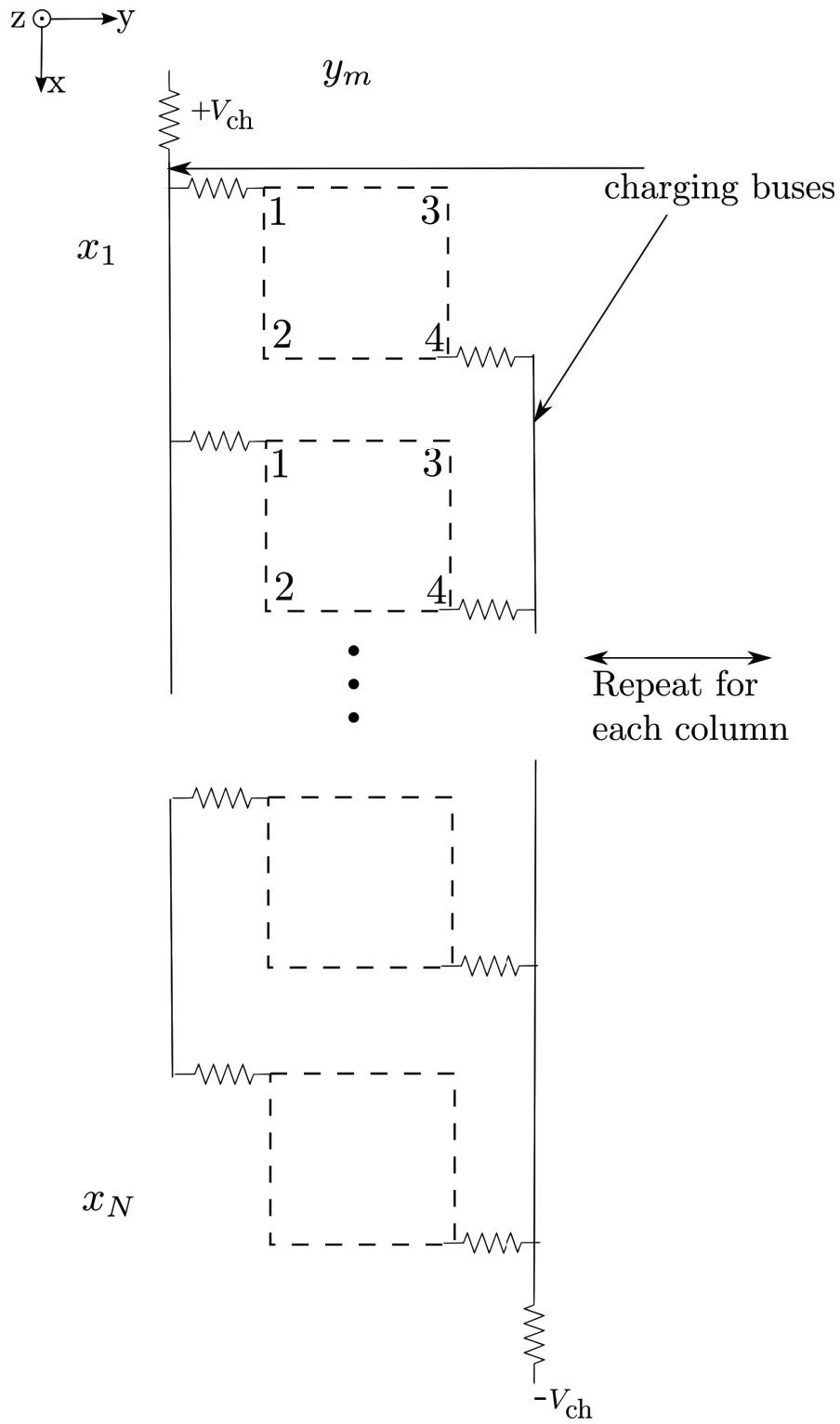Figure 3.2: Row power feed for typical array row

Figure 3.3: Column power feed for typical array column

4 Concluding Remarks

This paper has illustrated numerous forms of array unit cells involving zigzag and similar antennas driven by switched oscillators. These are then aggregated together in N×M arrays with coordinates in matrix form. The DC charging voltage (+ and − for differential can then be fed to the unit cells in various ways.

Clearly there is a complex problem in physically constructing such arrays. Which cell design and which DC feeding scheme one chooses will be strongly influenced by such considerations.

Here we have not yet considered where to place the fs laser with the beam splitting and focusing system to trigger all the unit cells. Should this be off to the side in front of the array (so as not to block the array radiation), or should it be behind the array with holes to feed the fs pulse through the ground plane to the semiconductor switches? Do we also want a scanning beam from the array? This would considerably increase the complexity.

This paper has shown various concepts for maximizing THz energy launching. Each of the element designs and array designs needs detailed (computer) calculations for optimization.

References

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[5] M.E. Shaik, C. E. Baum and C. G. Christodoulou, "Integrated Switched Oscillator and Zig-Zag Antenna with Photoconductive Semiconductor Switch as a Terahertz (THz) Pulse Transmitter." Sensor and Simulation Note 541, July 2009.

[6] C. E. Baum, "Use of Symettry for Measuring the Spread of Switching Times for Extremely-High-Frequency Radiating Oscilllatory Sources." Switching Note 34, May 2008.