Circuit and Electromagnetic System Design Notes

Note 54

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Some Thoughts Concerning Extending the Performance of Switched Oscillators

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Abstract

The switched oscillator has limitations associated with size due to frequency and voltage of operation. This paper discusses some techniques for potentially increasing the energy in a pulse by increasing the capacitance (lowering the characteristic impedance) of the energy-storing oscillating transmission line).

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1. Introduction

The switched oscillator [2-5] is an appropriate source for mesoband [6] high-power electromagnetic (HPE) sources. The oscillator is a quarter-wavelength ($\lambda/4$) transmission line driving a high-impedance load (antenna) at one end with a closing switch at the other end. As one increases frequency the oscillator length is decreased. The cross-section dimensions are also decreased due to the $\lambda/4$ requirement. The smaller dimensions lead to smaller stored energy for a given characteristic impedance Z_c of a coaxial transmission line. One is limited by the spacing between inner and outer conductor required for a given charge voltage. Roughly speaking, for a given spacing the capacitance (and hence energy) is proportional to the characteristic dimension ℓ, as ℓ^2. Thus the energy does as f^{-2} where f is the oscillator resonant frequency.

To get the energy back up one can look at decreasing Z_c, while maintaining the electrode spacing. Going away from a simple coaxial geometry to one that can be called "folded" increases the electrode surface area (and hence capacitance) while maintaining the short transit times to the terminals as required.

2. Topological Considerations for Oscillator

The basic switched oscillator is indicated in Fig. 2.1A. It is based on a section of coax of low impedance Z_c (compared to the load impedance (antenna). This is charged to some voltage V_{ch}. It is discharged by a closing switch at the opposite end [5].

Figure 2.1B shows the extension of the switched oscillator to a differential version [3, 4]. This is basically two single-ended versions (of opposite polarities) connected through a single closing switch (thereby avoiding the problem of synchronizing two switches). This doubles the differential voltage to $2V_{ch}$, as well as the impedance initially driven by the switch to $2\,Z_c$.

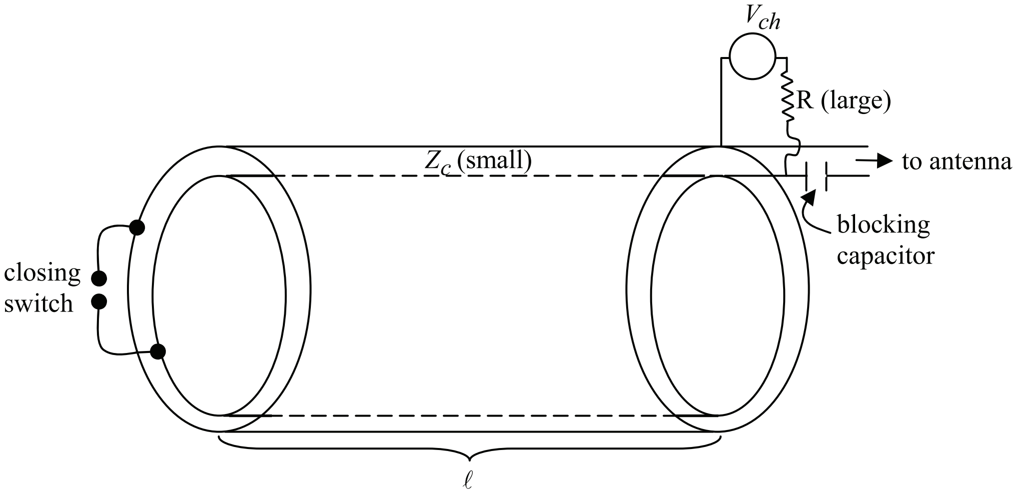
The oscillator frequency is governed by the length ℓ of the coax, which should be λ/4 in the dielectric medium as

$$\begin{aligned}
\ell &= \lambda/4 \ = \text{oscillator length} \\
f &= \frac{\mathrm{v}}{\lambda} \ = \text{oscillator frequency} \\
\mathrm{v} &= c\,\varepsilon_r^{-1/2} \ = \text{wave speed in oscillator} \\
c &= \text{speed of light in vacuum} \\
\varepsilon_r &\equiv \ \equiv \text{relative dielectric constant of oscillator medium}
\end{aligned} \tag{2.1}$$

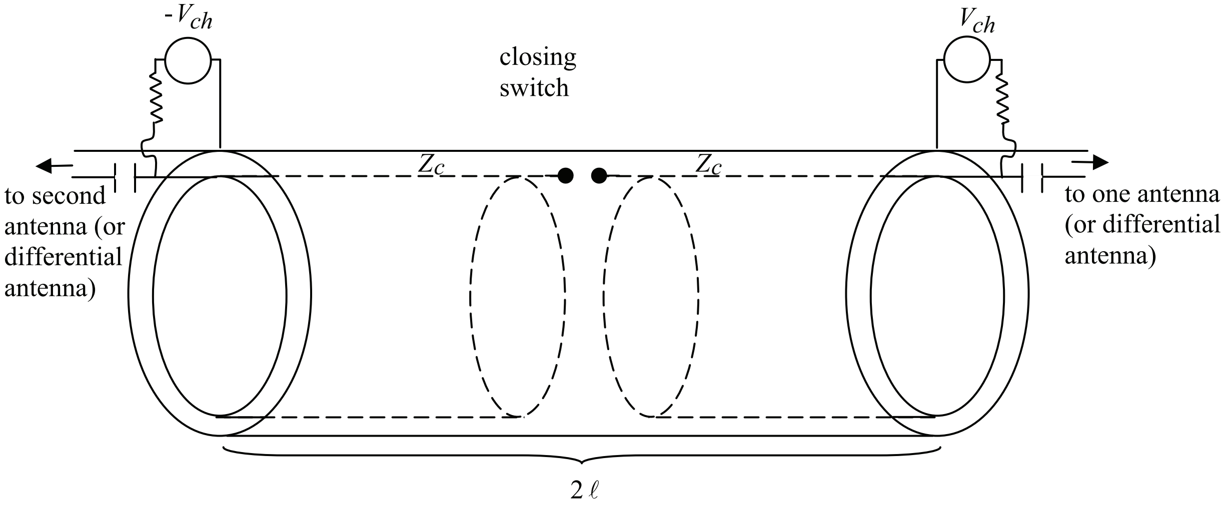
For the differential version the total length is doubled, the stored energy is doubled, the output voltage is doubled, and the Q of the oscillation remains the same (neglecting certain losses).

The design of a switched oscillator for maximum output is faced with various challenges. The spacing between electrodes is limited by electrical breakdown, thereby limiting V_{ch}. However, limiting V_{ch} limits the stored energy as

$$\begin{aligned}
U_{ch} &= \frac{1}{2}\,\mathrm{C}\,V_{ch}^2 \\
\mathrm{C} &= \frac{t_r}{Z_c} = \text{capacitance} \\
t_r &= \frac{\ell}{\mathrm{v}} \equiv \text{transit time through oscillator}
\end{aligned} \tag{2.2}$$



A. Single ended



B. Differential

Fig. 2.1 Basic Switched Oscillator

Here we are placing the equations in the form for a single-ended oscillator. For the differential case one merely doubles the appropriate parameters.

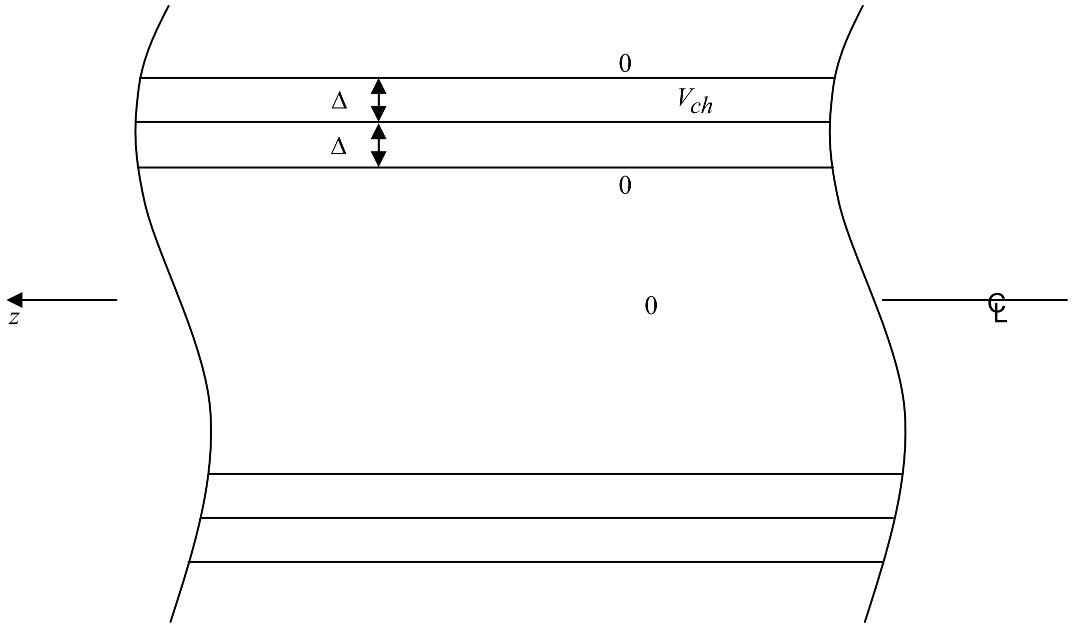
As we have seen, we would like a small Z_c, but this is limited by V_{ch} and the electrode spacing, say about *d*, due to electrical breakdown. As in [5] we could deform the coax, making it fatter in the middle, while still making the cross section small near the switch, and possibly at the connection to the antenna. Being limited by the t_r of the oscillator, this limits not only the length, but also the fatness (no more than $t_r / 2$). The length and fatness are thereby constrained.

So how can we increase the capacitance for given V_{ch} (spacing) and t_r (length)? Basically we can change the topology of the oscillator (as well as the geometry).

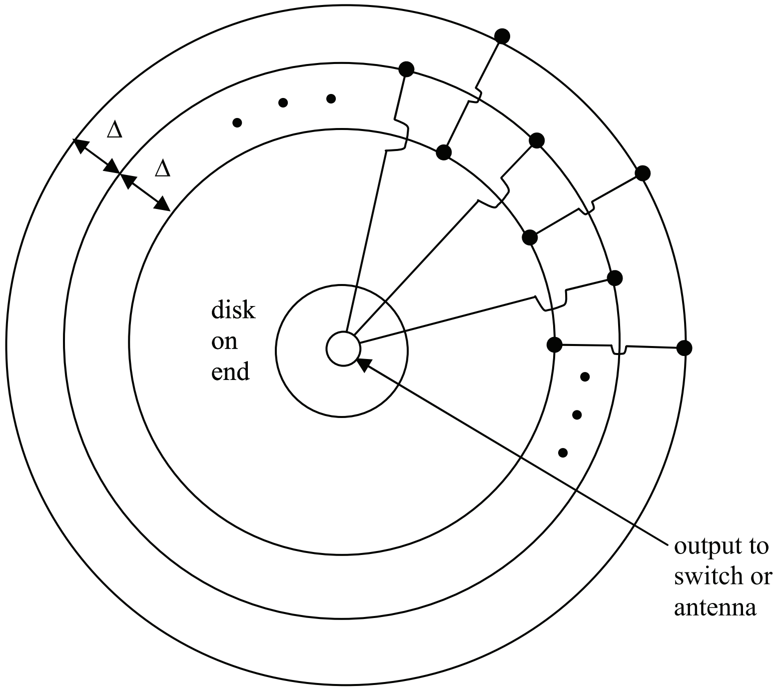
The first technique is illustrated in Fig. 2.2. Basically we have a triaxial structure [1] with inner and outer electrodes as "ground". This doubles up (roughly) the capacitance, cutting the characteristic impedance to Z_c/2. At the ends, the inner and outer conductor need to be electrically connected at many positions around the circumference. The "hot" electrode (cylinder) needs to feed to the output on paths between two disks (or circular cones if preferred). These output connections join together at the center to feed a coaxial output. Various details of the feed recombination can be chosen (e.g., as partially a disk) to optimize the design.

A second technique is illustrated in Fig. 2.3. In this case M coaxial cables are connected in parallel for an M-fold increase in oscillator capacitance with an M-fold decrease in Z_c (now the characteristic impedance of one of the cables). To set up the wave from the switch, or to the antenna, we need to propagate a wave between an ending disc (connected to the many cable shields) and the cable center conductors. The wave needs to go directly to the switch or output without having to first propagate to the outer conductor, and then back in toward the center. The switch is centrally located (a single arc), while the connection to the antenna can be via a coax which is somewhat larger.

A third technique is illustrated in Fig. 2.4. In this case we might call this transverse folded. The outer conductor has conducting fins going toward the center. The center (hot) conductor has fins going outward, interleaved with the incoming ones. This essentially increases the surface area (and hence capacitance) of the conductors for a given conductor spacing (limited by electrical breakdown). Now at the output the outer conductor can be shrunk while the inner conductor is enlarged to make the transit times from different parts of the capacitive structure to the output more uniform. At the switch end we need a low-inductance connection to the switch on the center line.



A. Incremental length



B. Connection at ends

Fig. 2.2 Triaxial Switched Oscillator

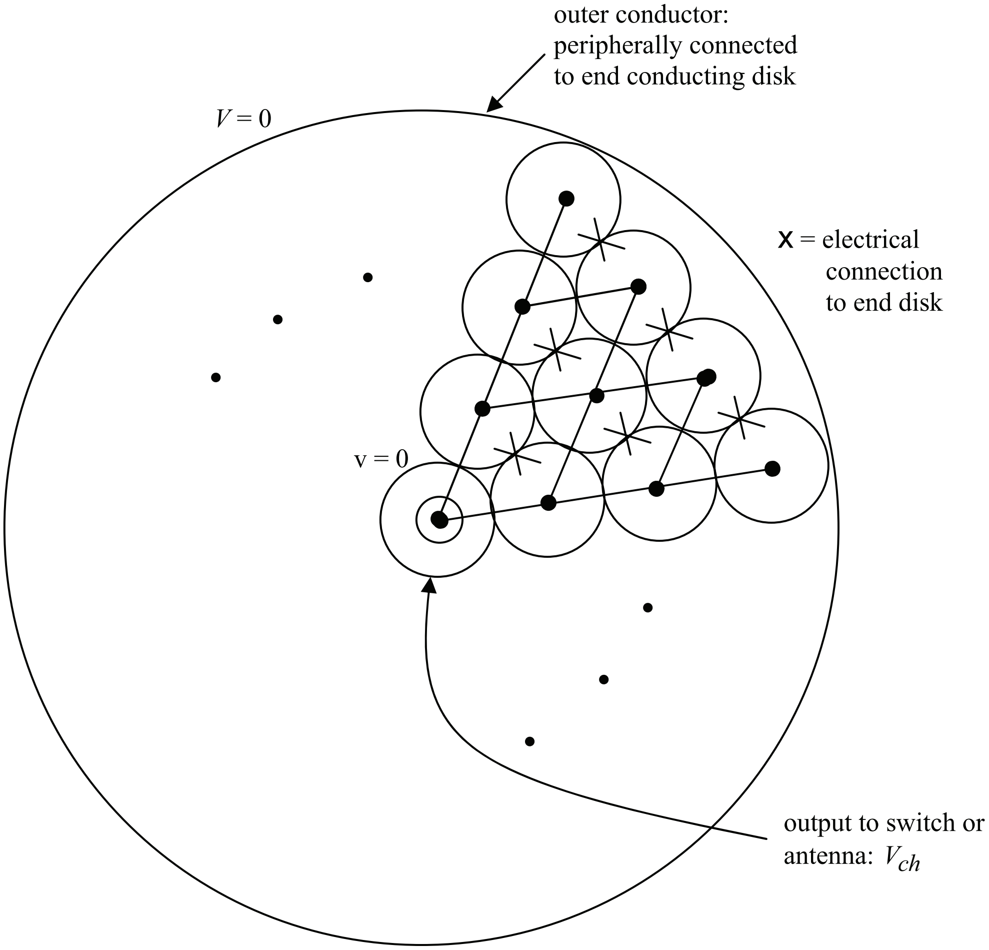
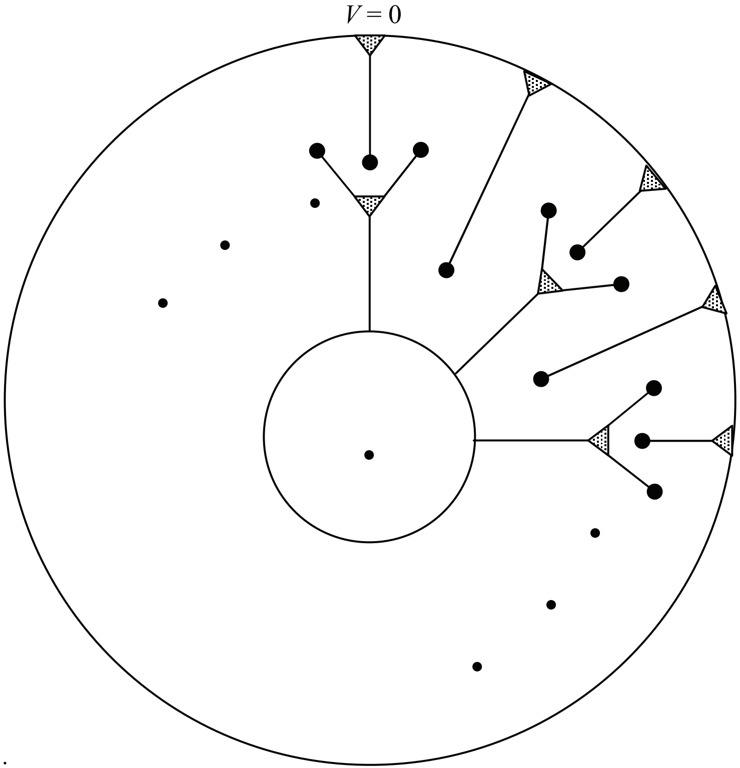
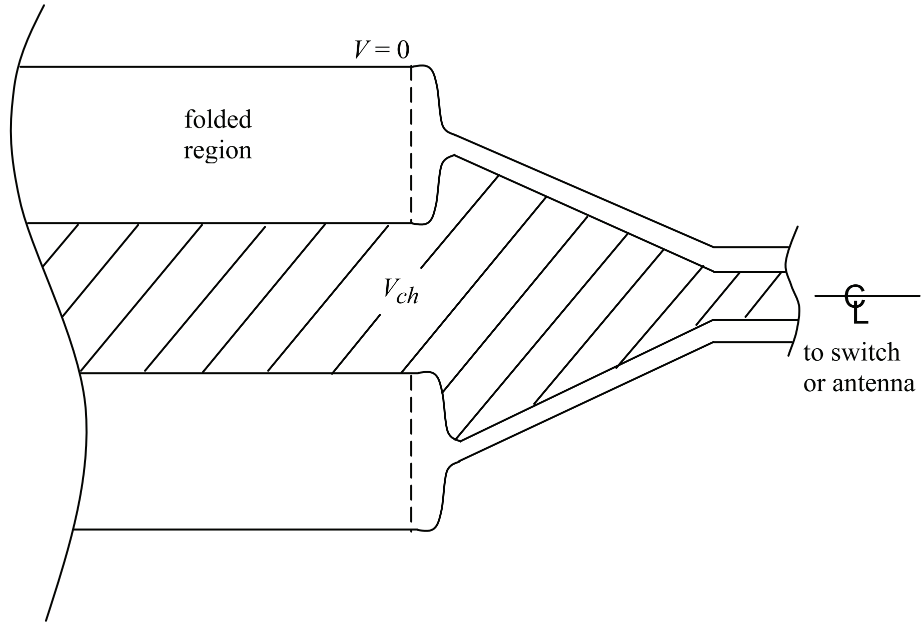


Fig. 2.3 Cable Bundle as Oscillator



A. Cross section



B. Input/output

Fig. 2.4 Transversely Folded Transmission Line

3. Symmetry Considerations for Oscillator

The role of symmetry is to reduce unwanted oscillations. This is related to the problem of equalizing the transit times on the various paths from switch to output. Looking at the various diagrams in Section 2, we find rotation symmetry. Figure 2.1 shows the $C_{\infty a}$ symmetry [7] of a body of revolution, the switch being placed on the center line. This avoids the problem of waves (oscillations) running around the perimeter instead of from end to end. Figure 2.2 has $C_{\infty a}$ symmetry in the main oscillator section and portions of the end feed to/from the switch and antenna. With the interleaved connections from the ends to switch and output we have N-fold rotation symmetry C_{Na}. Each $2\pi / N$ section has small transverse distances, thereby not supporting oscillations until a much higher frequency than the principal oscillation.

Going on to more elaborate cases, Fig. 2.3 shows a set of coaxes packed in C_{6a} symmetry (hexagonal). While we have gained more capacitance, the symmetry is a smaller N than previous examples.

In Figure 2.4 we are back to C_N where N can be large. This minimizes distances in a transverse (ϕ) direction. However, now we have to consider the distances from inner to outer conductor through a labarynthian path between the interleaved conductors. This can lead to undesirable transverse resonances. This can be partly aleviated by the technique in Figure 2.4B, in which the transit times to the output from various parts of the cross section are more equalized.

4. Concluding Remarks

Our design considerations are based on a tradeoff between charge voltage and capacitance limited by the transit time (based on oscillator frequency). The techniques discussed in this paper allow for larger oscillator capacitance within the constraints.

An important consideration is the dielectric medium. High-pressure hydrogen gas has been used, but other media are possible. One possibility at lower voltages (and lower pressures) might involve a trombone configuration, for example with an oil dielectric. This would allow a variable oscillator frequency. This also depends on the ease of implementing the various techniques discussed in this paper.

References

1. C. E. Baum, “A Technique for the Distribution of Signal Inputs to Loops”, Sensor and Simulation Note 23, July 1966.

2. C. E. Baum, “Antennas for the Switched-Oscillator Source”, Sensor and Simulation Note 455, March 2001.

3. C. E. Baum, “Differential Switched Oscillators and Associated Antennas”, Sensor and Simulation Note 457, June 2001.

4. C. E. Baum, “Differential Switched Oscillators and Associated Antennas, Part 2”, Sensor and Simulation Note 484, November 2003.

5. C. E. Baum, “Switched Oscillators”, Circuit and Electromagnetic System Design Note 45, September 2000.

6. C. E. Baum, “The Dispatcher: A New Mesoband High-Power Radiator”, 4 pp. in Proc. URSI General Assembly, Maastricht, Netherlands, 2002.

7. C. E. Baum and H. N. Kritikos, “Symmetry in Electromagnetics”, ch. 1, pp. 1-90, in C. E. Baum and H. N. Kritikos (eds.) *Electromagnetic Symmetry*, Taylor & Francis, 1995.