Sensor and Simulation Notes

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Some Planar Geometries for Small Antennas
With Switched Oscillators for THz Mesoband Radiators

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Abstract

Small oscillating antennas present various design challenges. This paper discusses their use with switched oscillators, equally small. The use of planar and multiple-planar geometries, and their combination with lenses and reflectors are considered.

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1. Introduction

In making very small antennas for extremely high frequencies (say THz regime), construction is a big problem. For this reason, planar geometries of conducting films on dielectrics are often used. This constrains our antenna geometries to some degree.

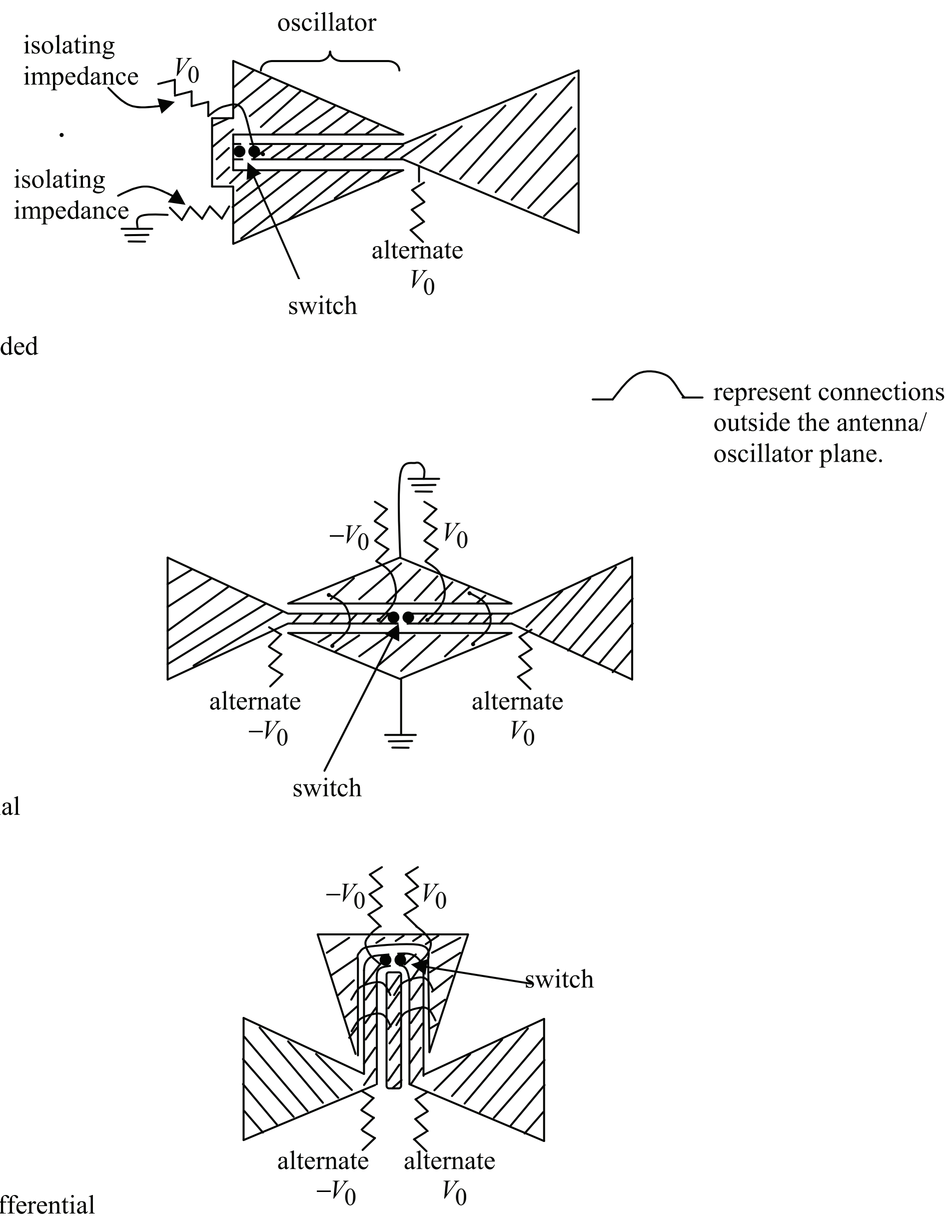
For mesoband radiators (typically damped sinusoids) the switched oscillator has proven to be a useful source [3-5]. In this case a quarter-wave transmission-line switched oscillator of low characteristic impedance is used to drive an antenna of somewhat higher impedance. This increases the voltage transient above that of the charging voltage V_0 of the oscillator. We would like to construct such switched oscillators also in a compatible planar geometry.

2. Planar Switched Oscillators and Antennas

Some possible geometries for planar switched oscillators and antennas are indicated in Fig. 2.1. Beginning in Fig. 2.1A we have a single-ended planar switched oscillator. Being in the form of a bow-tie antenna, one of the isosceles-triangular parts is made to contain the switched oscillator. Note that this antenna and oscillator are mounted on a dielectric substrate, with perhaps another layer of dielectric on the other side of the metal. This will lower the resonant frequency, for which one must allow.

Since we need to introduce the “slowly rising high voltage” to the antenna/oscillator, we need to consider where to place the feed. Here the feed is placed near the switch, so that when the switch closes the feed “wire” is effectively shorted to “ground”. This minimizes any loading during the oscillation phase. Some resistance and/or inductance in the lead also helps. The problem may be to feed the high voltage lead through the dielectric (a via) with a location close to the antenna/oscillator conductor. If the impedance (resistance) of the high-voltage feed immediately adjacent to the antenna can be made high enough, then the connection can be made directly to the antenna, with the feed exiting in the same plane as the antenna and oscillator. Similar considerations apply to applying the zero (or ground) potential to the “outside” of the switched oscillator.

In Fig. 2.1B we have a differential version. In this case we have two antenna sections connected to opposite ends of a differential switched oscillator. The outer conductor for the switched oscillator is now in two separate parts which can be electrically connected by vias, (or viae) if desired. Using symmetry these conductors are initially at zero potential with connection to zero potential on the symmetry plane transverse to the antenna (orthogonal to the electric field). Noting that the two antennas are electrically connected by a pair of common triangular conductors, which give a different impedance condition than at the outer ends (open), one will need to adjust the antenna design to bring it into a common resonance condition with the switched oscillator. Furthermore,



A. Single-ended

B. Differential

C. Folded differential

Fig. 2.1 Planar Switched Oscillators and Antennas

noting that the wavelength in the dielectric is shorter than in air, this design (giving a longer antenna in the dielectric) may match better to the exterior air.

If one wishes to avoid the situation of two antenna-source points, one can fold the switched oscillator as in Fig. 2.1C. This brings the launch points of the two antenna halves closer together.

On all the configuration in Fig. 2.1, we generally do not need to radiate both forward and backward from the antenna. As such we can place a reflecting conducting sheet at a quarter wavelength ($\lambda/4$ in the dielectric) behind the antenna. This will raise the Q and send more energy in the forward direction.

Noting that it may be difficult to make electrical connections (vias) out of the antenna/oscillator plane one may wish to avoid these connections as much as possible. This will influence the design of high-voltage and zero potential connections, and perhaps make one avoid some connections between conductors with common potential.

3. Multiplanar Switched Oscillators and Antennas

If we are comfortable using vias for electrical connections through dielectric layers to connect between conductors on opposite sides, new possibilities arise. Here we suggest a few, such as in Fig. 3.1.

Figure 3.1A shows the folded differential oscillator (as in Fig. 2.1C), now with conducting sheets, both above and below. The one below prevents radiation into the lower half space and lowers the characteristic impedance of the switched-oscillator transmission line. The upper one covers only the switched-oscillator portion for further impedance reduction.

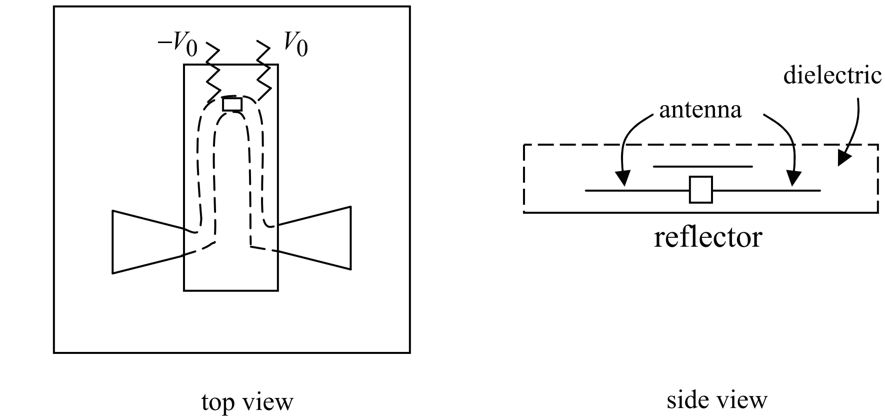
Another variation is shown in Fig. 3.1B. Again there is a reflecting sheet below the oscillator, but it extends outward. A second conducting sheet covers just the switched oscillator (configured as in Fig. 2.1B) to give a low characteristic impedance. The antenna conductors now fold back over the upper conducting sheet to give a half-wave antenna. Now, however, the current maxima are at the outer ends of the antenna with a null at the center (where the two conductors approach each other). The conductors can be about $\lambda/4$ above the conducting sheet to make it act as a reflector (or the antenna conductors can be slanted to keep a resonance condition).

Note that with a reflecting plane the antennas are technically not dipoles, but can be roughly described as quadrupoles. Efficient radiation is maintained by appropriate spacing of the conductors.

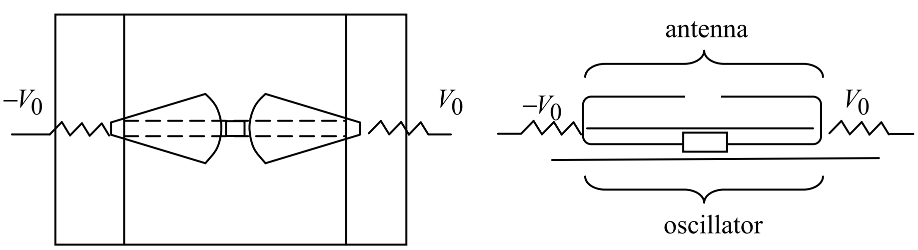
4. Wave Coming Out of Dielectric

With our antenna embedded in (or at least lying on) a dielectric layer, one needs to consider its radiation properties so that the performance can be optimized. Both antenna impedance and directivity are affected.

From an impedance point of view we can raise or lower the antenna impedance depending on our design goals. In particular, the Q of our antenna/oscillator system is influenced by our choice of dielectrics and their geometries. By our choice of Q we can trade between oscillator amplitude and temporal width.



A. Half-wave differential antenna



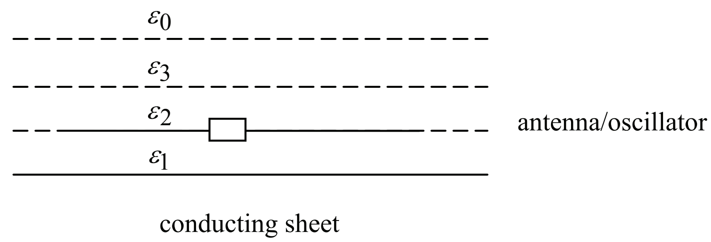
B. Inside-out antenna

Fig. 3.1 Multiplanar Switched Oscillators and Antennas

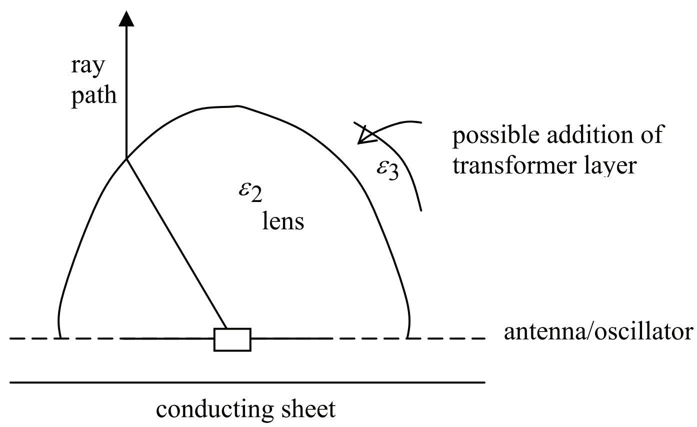
As illustrated in Fig. 4.1A, one might place a dielectric layer with

$$\varepsilon_3 = \left[\varepsilon_2 \, \varepsilon_0\right]^{1/2} \tag{4.1}$$

between the dielectric surrounding the antenna and air. This is an approximate quarter-wave transformer for matching between the two adjacent media. For a plane wave at normal incidence this layer is λ/4 thick, but some allowance can be made for the non-planar nature of the wave incident from the antenna.



A. Quarter-wave transformer



B. Dielectric lens

Fig. 4.1 Transitioning from Antenna to Air

While considering dielectrics between the antenna and air (approximately free space), we can use such dielectrics for another advantage. Such dielectrics can be shaped in the form of a lens for focusing the beam (increasing the gain) on a distant position. As in Fig. 4.1B an appropriate shape might approximate a prolate sphere [1]. One might, in addition, have a coating layer at an intermediate permittivity acting as a transformer to free space. Of course, this introduces manufacturing problems. However, this lens can be made much larger than the antenna dimensions. One may also need to consider the possibility of dielectric losses which may limit the allowable propagation distances through the (lossy?) dielectric.

5. Use with Reflectors for Focusing the Wave

Having propagated the wave out from the antenna into air, we need to decide what to do with this wave. For many applications one wants a narrow antenna beam for high gain in a particular direction. (One may also wish a pencil beam for communication security.) At THz frequencies a paraboloidal reflector with even modest diameter, D, has a near field extending out a distance $2D^2 / \lambda$, which can be quite large.

The basic configuration is given in Fig. 5.1A. Our oscillator/antenna launches a wave toward the reflector. This wave is centered on the focal point of a paraboloidal reflector, allowing for the presence of any dielectrics around the antenna and a reflecting surface behind the antenna.

While we are discussing this type of antenna, we can note that multiple reflectors are possible to form the beam. A common example is the Cassegrain configuration.

While the emphasis here is on oscillatory waveforms, other waveforms are possible. For example, Fig. 5.1B shows a configuration as an impulse radiating antenna (IRA). Noting the planar nature of the connection to the switch (no switched oscillator now), one can have a dielectric lens for this application [2] which reforms a spherical wave from an effective focal point behind the switch. This new spherical wave is fed into a paraboloidal reflector on a TEM waveguiding structure (conical feed arms, typically four) with terminations at the reflector.

6. Concluding Remarks

Optimizing THz antennas presents some significant challenges. For damped sinusoidal waveforms switched-oscillator sources are appropriate. The miniature construction details can pose difficulties. While conducting sheets on a single dielectric substrate are possible, they have disadvantages. Multiple conducting sheets with possible multiple dielectrics allow for increased performance. Combining these with lens and reflectors can lead to even greater performance.

References

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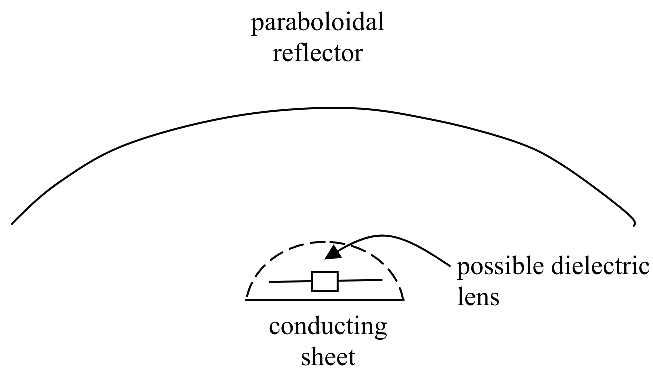
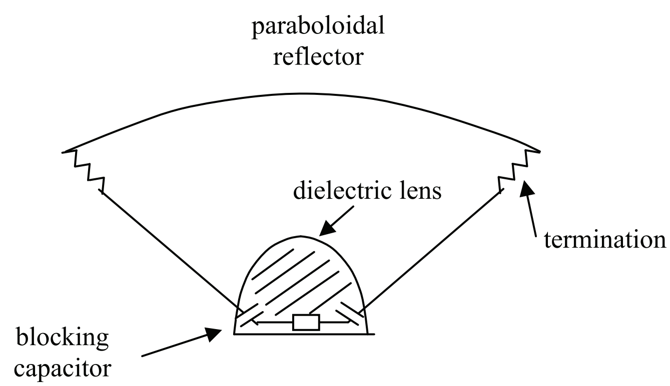


A. Oscillatory source with reflector



B. Impulse-radiating antenna (IRA)

Fig. 5.1 Combination with Paraboloidal Reflector