Sensor and Simulation Notes

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More Antennas for the Switched Oscillator

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Abstract

Antennas for mesoband sources present special design problems. Improvements can be made on TEM reflectors to increase radiated fields. Other types of antennas can also be explored for greater efficiency. Specifically, here we consider a special kind of folded horn. Two of these driven by a differential switched oscillator offer interesting possibilities.

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1. Introduction

Switched oscillators are appropriate sources for mesoband (medium band ratio) [4] radiating systems [3, 7, 9, 10]. They use the switching technology appropriate to hyperband radiators [13] such as impulse radiating antennas (IRAs), except that the switches close into a pulse impedance of a few ohms (say 4Ω) instead of the 100 or 200 Ω impedances of the antennas. The switch risetime is limited by the inductance of the arc [8], typically of the order of 1 nH for a 1 mm gap (for hundreds of kV in pressurized hydrogen or transformer oil). The L/R time constant for a 4Ω load is then 250 ps. This makes switched oscillators appropriate for hundreds of MHz. For higher frequencies one can of course increase the pulse impedance of the switched oscillator. However, this makes the pulse impedance closer to the antenna impedance, thereby decreasing the number of cycles (or Q) of the resonance, as well as decreasing the stored energy for a given charge voltage.

The switched oscillator can be built in both single-ended and differential versions. The differential version [7] can be built in such a way that it is basically two back-to-back single-ended oscillators sharing a common switch. As such it can be charged to $\pm V_0$ or $2V_0$ differential with only V_0 potential difference from local "ground". In this symmetrical configuration one can view the L/R time constant of the switch with both 2L for the doubled arc length and 2R for the pulse impedance driven by the switch, leaving the same risetime limitation. However, the voltage and stored energy have been doubled.

Our problem is the design of effective radiating antennas for such frequencies in a limited space. As in Fig. 1.1, let us try to fit our antennas into a volume described by h (height), w (width), and d (depth). We would like the antenna aperture (area hw) to be filled with a wave of approximately uniform phase over the aperture for maximum boresight gain. Some typical numbers might be of the order

$$
\begin{aligned}
f &= 200\ \text{MHz}\ ,\ \lambda = 1.5\ \text{m}\ ,\ \frac{\lambda}{2} = 0.75\ \text{m} \\
h &= 1.5\ \text{m}\ \ \text{(height)} \\
w &= 3\ \text{m}\ \ \text{(width)} \\
d &= 1.5\ \text{m}\ \ \text{(depth)} \\
A &= \text{hw} = 4.5\ \text{m}^2\ \ \text{(aperture area)}
\end{aligned}
\tag{1.1}
$$

For our example the aperture is 1λ by 2λ. While one might like more wavelengths across the aperture, this is a fundamental limitation.

For a uniformly illuminated aperture the directivity is [12]

$$D = \frac{4\pi}{\lambda^2}A \tag{1.2}$$

Which for our example is ≈ 25 (or 14 dB). Of course, the effective aperture is less than the physical aperture due to nonuniform fields in the aperture. For example, a sinusoidal distribution over one dimension (say w) which uniform in the other dimension (say h) gives an aperture efficiency of $8/\pi^2 \approx 0.81$.

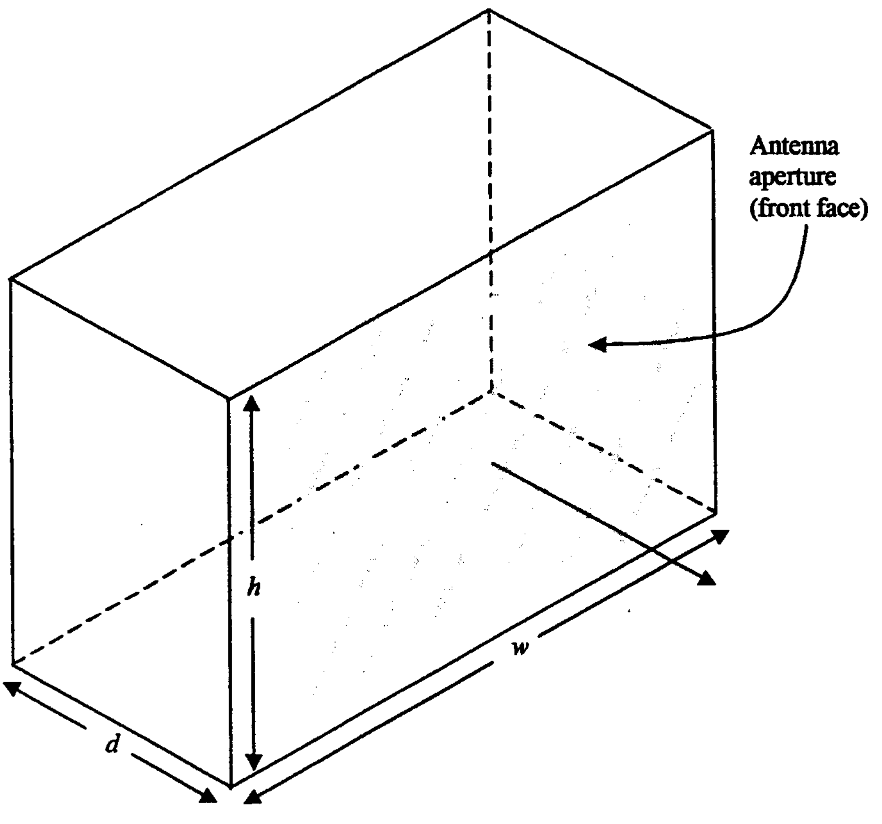


Fig. 1.1. Antenna Volume

2. Modification of Reflector-IRA-Like Antenna

Reflector IRAs have been developed to have a nearly flat dispersionless response over a hyperband of frequencies (band ratio greater than a decade). For mesoband (or hypoband) systems such ideal characteristics are not necessary. Such purity can be sacrificed in the interest of greater radiation efficiency.

In [2] I describe a reflector IRA type of antenna for the switched oscillator. In this case the feed arms are needed as a conical transmission line to effectively get the long-wavelength fields to the reflector. However, the resistive terminations are not needed for this purpose; they absorb energy. Replacing the terminating resistors by extensions of the conducting feed arms all the way to (and connected to) the reflector may be beneficial, by giving larger currents reaching to and reflecting from the reflector.

There are also modifications which can be made to the reflector to increase efficiency. In [1, 5] it is shown that certain portions of the reflector can be removed (those portions with small fields or even reversed polarization) for increased efficiency. Other portions can be extended to better fill the rectangular aperture (Fig. 1.1). One can also replace portions of the reflector by a uniconducting surface (wires or conducting strips) to convert fields in undesirable directions to more useful reflected fields [4, 6]. While these conductors may introduce resonances, this may not be important for appropriate mesoband applications.

So there are various improvements one may incorporate in TEM fed reflectors for increased mesoband efficiency.

3. Fielded-Horn Antenna

Consider a quite different kind of antenna. It is basically a sophisticated type of horn. Compared to the previous section, the intent here is to make all the energy go in the desired direction toward the target. Let us first consider the single-ended version for simplicity.

Figure 3.1 shows two views of such an antenna. The switched oscillator feeds a waveguide through a coax-to-waveguide transition. The region near the switched oscillator can take various shapes, such as a rectangular waveguide with a closure at $\simeq \lambda/4$ behind the transition. The wave propagates out on an H-plane sectoral waveguide (constant height), expanding out to the full antenna width w. The height of the sectoral guide needs to be less than $\lambda/2$, perhaps significantly less. The sectoral waveguide is bent upward and back in the reverse direction where it becomes a rectangular waveguide of constant width w. The bend is *not* of a generalized cylindrical shape, but has the bend axis bent in the shape of a *parabola*. This converts the circular wave front in the H-plane sectoral waveguide to a planar wave front in the rectangular guide. For this purpose the phase center of the sectoral-guide wave should be at the focus of this parabola. Note that, as the wave propagates around the bend, the plate spacing needs to be less than $\lambda/2$ to avoid overmoding, and detailed shaping needs to be considered to avoid reflections.

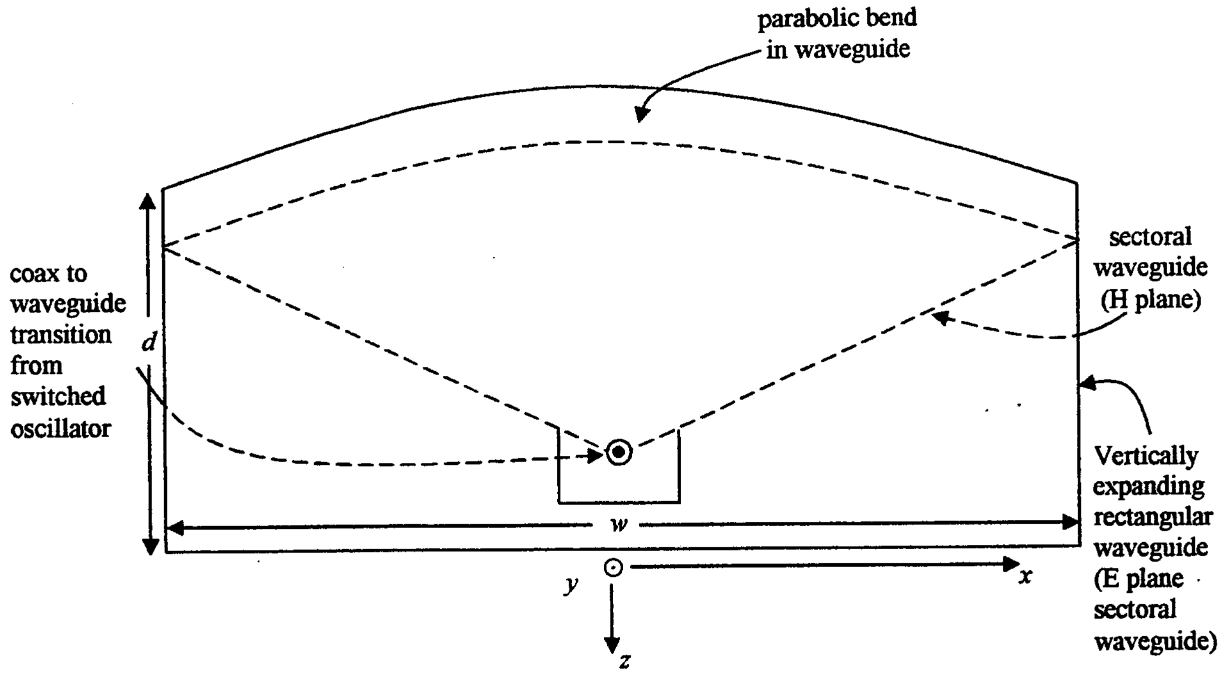
So far, this type of antenna has some similarity to a double-layer pillbox antenna [11]. In that case parallel plates without the side closure of the sector guide are used and the spreading of the wave is allowed over almost π (180°) instead of the narrower angular width of the sectoral waveguide.

The rectangular waveguide expands from a small height at the back to a large horn opening at the front. This can also be considered as an E-plane sectoral waveguide/horn. Let us make this opening $h/2$ (or $\simeq$ 0.75 m), half the height of the antenna volume in Fig. 1.1. With a length of approximately d (say 1.5 m) we can have a differential length of

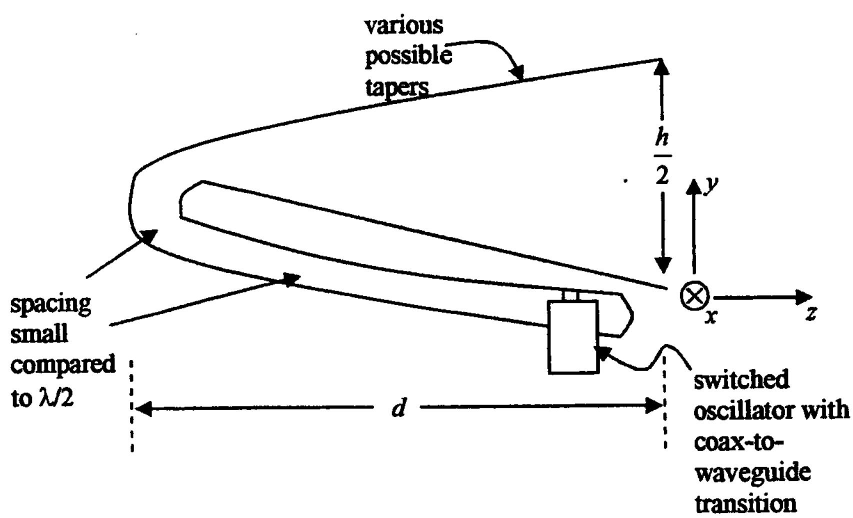
$$\Delta\ell = \left[d^2 + \left[\frac{h}{4}\right]^2\right]^{1/2} - d \simeq \frac{h^2}{32d} \simeq 4.7\ cm \tag{3.1}$$

Between the paths along the center and edges, which is quite small compared to $\lambda/4$ ($\simeq$ 0.375 m). So the phase will be nearly constant across the horn aperture, as desired. The field is approximately uniform in the vertical direction, and a half cycle of a sine function in the horizontal direction, going to zero on both sides.

The region near the switched oscillator needs some attention so as efficiently to get the power from the switched oscillator into the waveguide. This involves the coax-to-waveguide transition and the geometry behind the oscillator to adjust the impedance at the oscillator dominant frequency. As indicated in Fig. 3.2A. There might be a

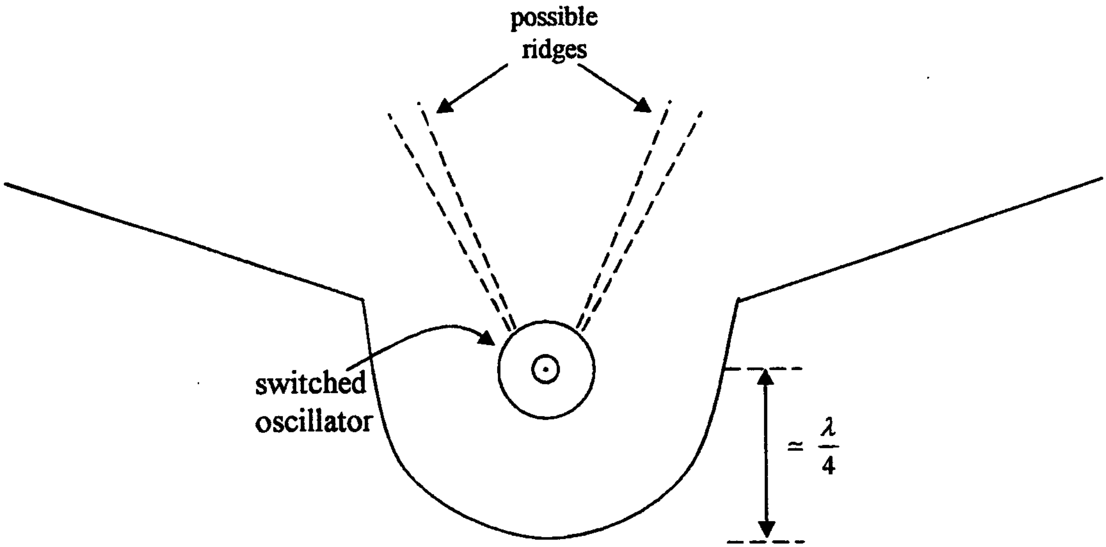


A. Top View

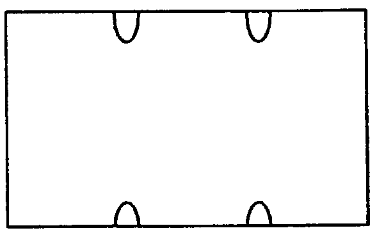


B. Side view (cross section)

Fig. 3.1 Single-Ended Switched-Oscillator-Driven Folded-Horn Antenna



A. Top View: oscillator to waveguide transition



B. Cross section of waveguide with four possible ridges

Fig. 3.2 Geometry Near Switched Oscillator waveguide short roughly $\lambda/4$ behind the transition. This can take various shapes (to be optimized). The waveguide near the transition needs to be wide enough to propagate the basic mode (an H or TE mode). For a simple rectangular guide the width needs to be $> \lambda/2$. One can make the width smaller by use of ridged waveguide. Figure 3.2B shows a case of four ridges (or two double ridges). This helps maintain the field more uniform across the waveguide and in the connecting sectoral waveguide. As one proceeds along the sectoral waveguide the ridges can be gradually diminished to nothing. Such ridges would also need to be blended into the coax-to-waveguide transition.

Now we can take two of the folded horns and arrange them as in Fig. 3.3 with the two sectoral waveguides adjacent to each other. Then we use a differential switched oscillator as discussed in [7], now driving two waveguides instead of two half reflectors. By so doing the antenna aperture height of h is filled, and the oscillator voltage and stored energy are doubled. Furthermore, where the two horns are connected at the antenna aperture the waves from the two horns match avoiding the otherwise discontinuity there, i.e., giving less reflection at the antenna aperture.

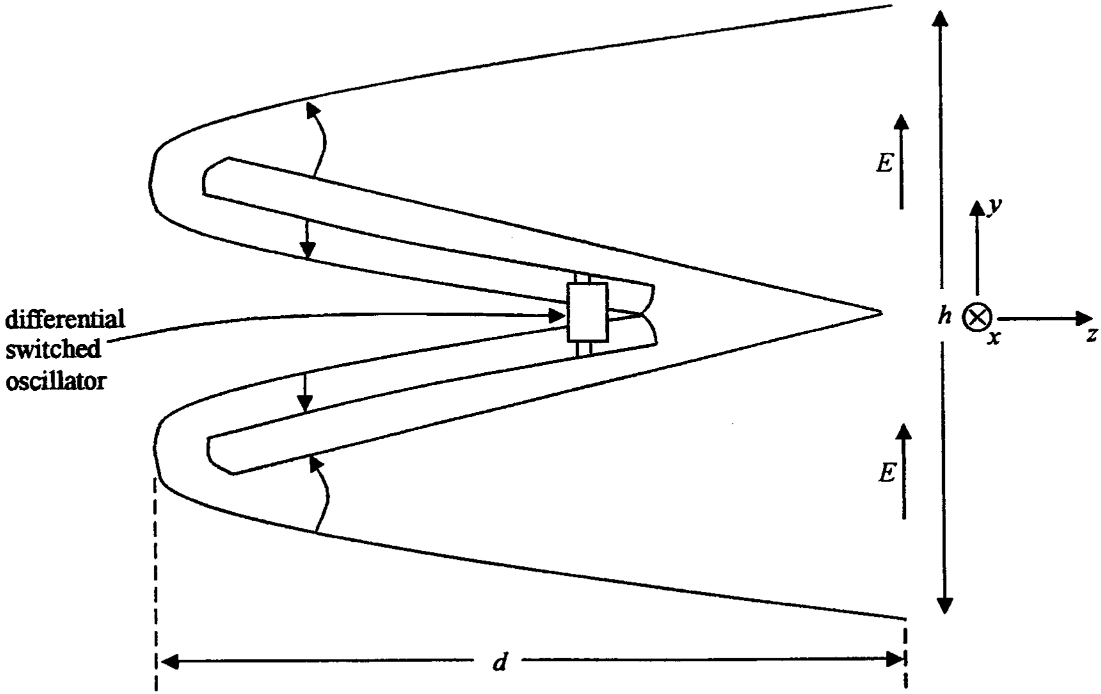


Fig. 3.3 Double Folded Horn Driven by Differential Switched Oscillator (Side View, Cross Section)

4. Concluding Remarks

As we can see, there are various possible antennas which can be used with the switched oscillator. Some will be more efficient than others depending on frequency and antenna aperture. Here we have discussed a double folded-horn design appropriate for use with a differential switched oscillator. While this is an interesting and potentially useful conceptual design, much more detailed analysis and/or experimental work is needed to optimize the design.

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