Circuit and Electromagnetic System Design Notes

Note 65

3 November 2009

# Use of an Etalon as a Microwave Pulse Compressor

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## Abstract

This paper considers a technique for reducing the skin-effect losses in a microwave pulse-compression cavity, based on a waveguide without walls. This is based on the Fabry-Perot interferometer or *etalon*, cut in half to provide a convenient entrance/exit for the microwave power.

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## 1. Introduction

In microwave pulse compression, skin-effect resistance, $R_s$, limits the Q attainable in a resonant cavity. For a length, $\ell$, of waveguide as a resonant cavity, a simple model (not including end effects) gives a gain as [1]

$$G_s = \frac{1}{4\alpha\ell} = \frac{P}{P_0} = \frac{\text{power in cavity (after ringup)}}{\text{power in microwave source}}$$

$$\alpha \equiv \text{attenuation constant } (m^{-1}) \text{ in waveguide} \tag{1.1}$$

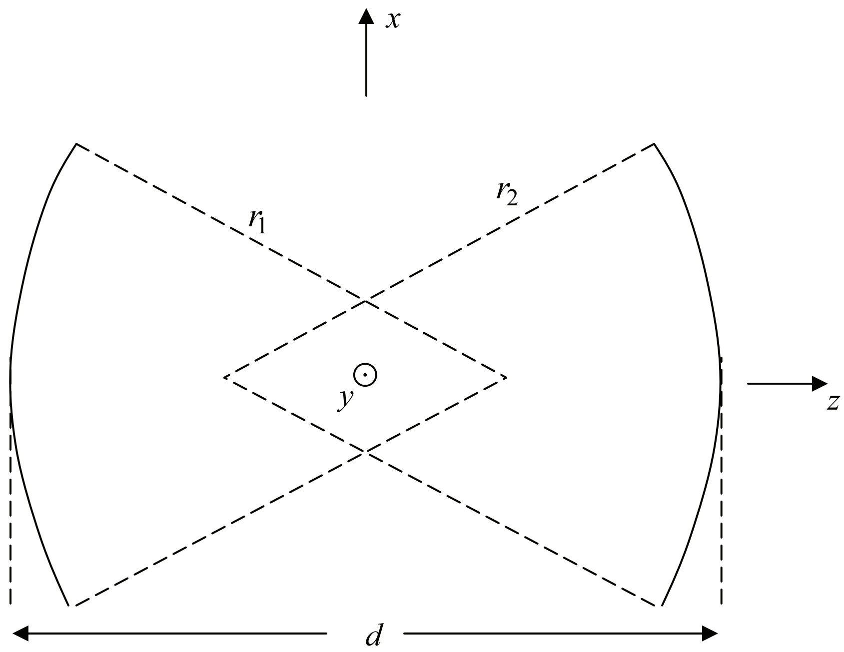
This gives a tradeoff between cavity length (and hence pulse width) and cavity gain [3]. High gain implies short pulse widths. Note that the above does not include the losses at waveguide ends.

To beat this limitation, one can increase the waveguide cross-section dimensions. This leads to an overmoded cavity. One can force only the desired mode to propagate in such a cavity by use of symmetry and techniques which suppress unwanted modes [2]. There is also the $H_{0,1}$ low-loss mode of a circular-cross-section waveguide [4]. In this latter case the special mode has small currents on the waveguide wall to give loss via $R_s$.

Taking the development a step further let us think of a waveguide cavity with no walls. Such is the case of a Fabry-Perot resonator or *etalon* (French, meaning "standard") [7, 8], such as illustrated in Fig. 1.1. This case has been analyzed [5-8] giving a fundamental mode as a Gaussian in the transverse direction as

$$\begin{aligned}
E &= \frac{A\, w_0}{w(z)}\, e^{-\frac{\Psi^2}{w^2(z)}} \\
w(z) &= w_0 \left[1 + \left[\frac{z}{z_0}\right]^2\right]^{1/2} \\
z_0 &= \pi \frac{w_0^2}{\lambda} \\
\Psi &= \left[x^2 + y^2\right]^{1/2} = \text{transverse coordinate}
\end{aligned} \tag{1.2}$$

Since there can be many wavelengths between the mirrors the skin-effect losses are limited to the mirrors. Perhaps this type of resonator can be used to raise the cavity Q.




$r_1$ , $r_2$ are radii of curvature of the two reflectors (or mirrors).

Fig. 1.1 Etalon with Curved Mirrors

## 2. Half Etalon

For microwave pulse compression we need to concentrate the cavity fields into some port that can be switched from unity reflection to matched-to-output when a switch is closed. The pulse width is then approximately

$$
\begin{aligned}
T &\simeq \frac{2\ell}{c} \\
\ell &= \text{cavity length} \\
&= \text{integer number of half wavelengths} \\
c &= \text{speed of light (medium taken as} \simeq \text{free space)}
\end{aligned}
\tag{2.1}
$$

In the limit of no losses, the $z = 0$ plane can be considered a symmetry plane. We choose $\ell$ such that it is a plane with zero tangential electric field. The modal solutions are unchanged from the case in Fig. 1.1 provided $\ell$ is chosen as in (2.1). Note that this choice makes the beam waist, $w_0$, at the flat reflector (Fig. 2.1). Here we want a small beam waist to be able to match the beam into a waveguide which we can use for feeding in the power and switching it out as in Fig. 2.2.

With the switch open the output port is a half guide wavelength away at an electric-field null, until the switch at $\lambda / 4$ is closed. The input power is at a magnetic-field maximum, before switch closure, with an appropriate iris. The transition section and waveguide lengths are chosen so that the $z = 0$ plane is effectively a short before switch closure, thereby maintaining the reflecting properties of the $z = 0$ plane. The transition to rectangular waveguide has to take the beam waist (radius $w_0$) and reduce it considerably. One might include dielectric lens(es) to better focus the wave into the rectangular waveguide.

Going back to (1.2) we would like to make $w_0$ small so as to better match the resonant mode into the output. However, as $w_0$ approaches a wavelength, $\lambda$, the solution is only approximate. In this case $z_0$ is approaching $\pi$ and the beam waist becomes

$$
w(z) \simeq w_0 \frac{z}{z_0} = \pi \frac{\lambda}{w_0} z \tag{2.2}
$$

away from $z = 0$. This shows that we need

$$
\pi \frac{\lambda}{w_0} < 1 \tag{2.3}
$$

for a not-too-rapidly diverging beam and a limited size of the spherical reflector.

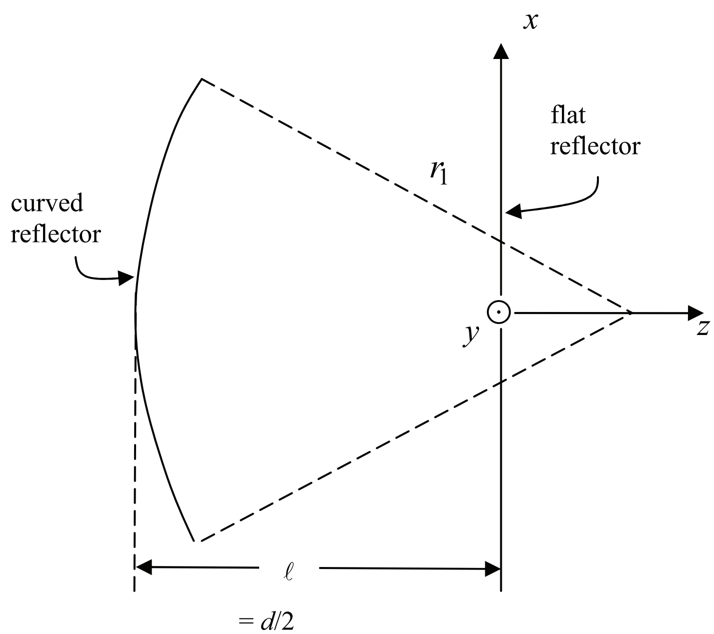



Fig. 2.1  Half Etalon with One Curved and One Flat Mirror.

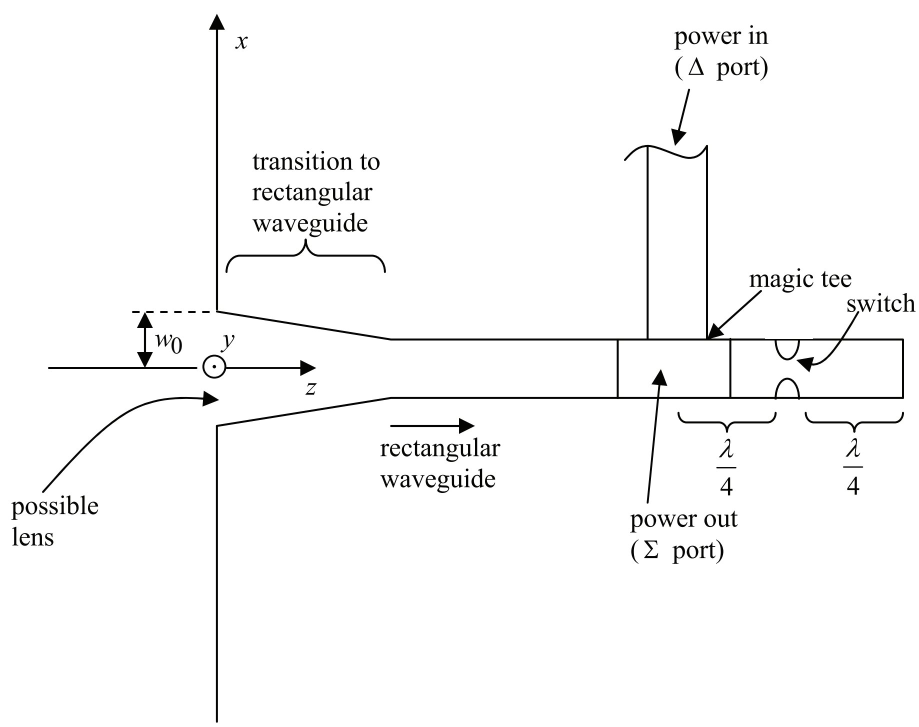



Fig. 2.2  Matching Cavity Mode into Rectangular Waveguide with Magic Tee and Switch.

Approaching this from a different direction, consider a microwave horn as in Fig. 2.3. In this case the situation is much like that in Fig. 2.2 without the flat plane extending from the horn mouth. So we can refer back to (2.3) to see how large the horn aperture should be in wavelengths. To launch an approximate spherical wave one can use the phase center of the horn [9]. Of course, one can combine a lens with the horn, say at the horn aperture to give a narrower beam consistent with the previous.

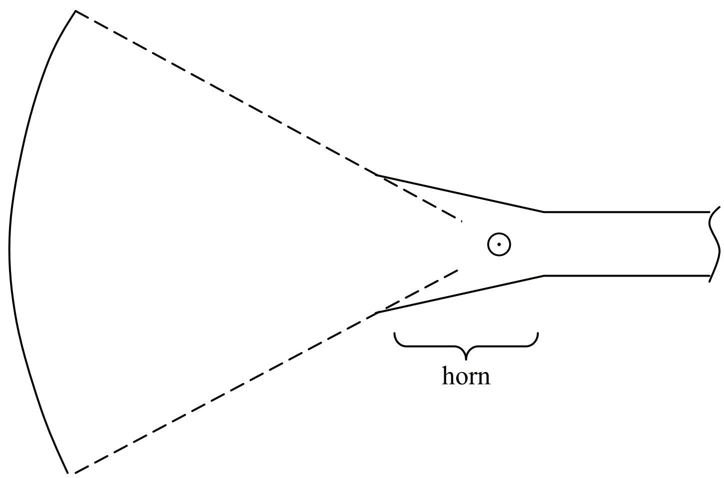



Fig. 2.3 Horn Feeding Spherical Reflector Feeding Back into Horn

## 3. Skin-Effect Losses on Reflector

Having removed the skin-effect losses from the waveguide walls (by removing these walls), there are still losses associated with the remaining conductors. One can estimate the power loss on the large approximately spherical reflector as

$$P_r = \frac{1}{2} R_s \int_{\text{reflector}} J_s^2 \, dS \tag{3.1}$$

The fields and surface currents behave as $z^{-1}$ giving

$$J_s = Y_0 \frac{V_0}{z} \; , \quad Y_0 = Z_0^{-1} = \text{wave admittance} \tag{3.2}$$

Over a beam of radius, $\Psi_r$, proportional to $z$ as

$$\Psi_r = bz \qquad (z \text{ dimensionless}) \tag{3.3}$$

This gives a simple estimate (approximating the reflector as flat) as

$$\begin{aligned} P_r &= \frac{R_s}{2} \int_0^{\Psi_r} \int_0^{2\pi} \Psi J_s^2 \, d\phi \, d\Psi \\ &\simeq R_s \pi \int_0^{\Psi_r} \Psi \left[ Y_0 \frac{V_0}{z} \right]^2 d\Psi \\ &\simeq R_s \pi \int_0^{\Psi_r} \Psi \left[ Y_0 \frac{bV_0}{\Psi_r} \right]^2 d\Psi \\ &= \frac{\pi}{2} R_s Y_0^2 b^2 V_0^2 \end{aligned} \tag{3.4}$$

which is independent of beam radius. So the beam radius and rate of increase with $z$ (as in (2.2)) approximately do not affect the loss. While $R_s$ increases as the square root of frequency, the number of wavelengths in a length, $\ell$ (as in Fig. 2.1), is proportional to frequency, giving an increase of Q proportional to the square root of frequency.

There are still the waveguide losses in the input/output transition (Fig. 2.2) to be included. Of course as frequency increases this waveguide can be made shorter. There is also the power leaking out of the beam to be included.

A previous note [2] considered an overmoded waveguide as a means of reducing the skin-effect losses in the waveguide walls. The present result (3.4) also applies in that case for the ends of the waveguide cavity. These losses are approximately independent of the waveguide cross-section dimensions.

## 4. Concluding Remarks

The basic scheme here is the elimination of the waveguide walls, so as to remove a major source of skin effect losses. This introduces other problems which need careful consideration. In particular, the means of launching the wave into the resonant cavity and receiving it toward the load needs detailed design consideration if a high system Q is to be attained. In particular a sufficiently large (multi wavelength) horn aperture is needed to have a reasonable beam radius at the reflector.

References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