Advanced Photon Source

Basic Linac Microwave

In 2.7 x 10^9 μsec

Part II

Lecture Presented to OPS Group

~~May 24, 2000~~

~~May 31, 2000~~

June 7, 2000

A. Nassiri, RF Group

Outline

Part II:

- **RF Components**
  - **SLED**
  - **Waveguide**
  - **Accelerating Structure**
- **RF Measurements**
  - **Power (forward,reverse)**
  - **SWR**
  - **Coupling**
- **Some Examples**

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RF Components:

- Driver amplifier to power klystron
- Klystron is used to generate high peak power (A small accelerator)
- Need to transport power to the accelerating structure
- Waveguide is used (under vacuum) to propagate and guide electromagnetic fields
- Windows (dielectric material, low loss ceramic) are used to isolate sections of the waveguide
- Termination loads (water loads) are used to provide proper rf match and to absorb wasted power
- Power splitters are used to divide power in different branches of the waveguide run

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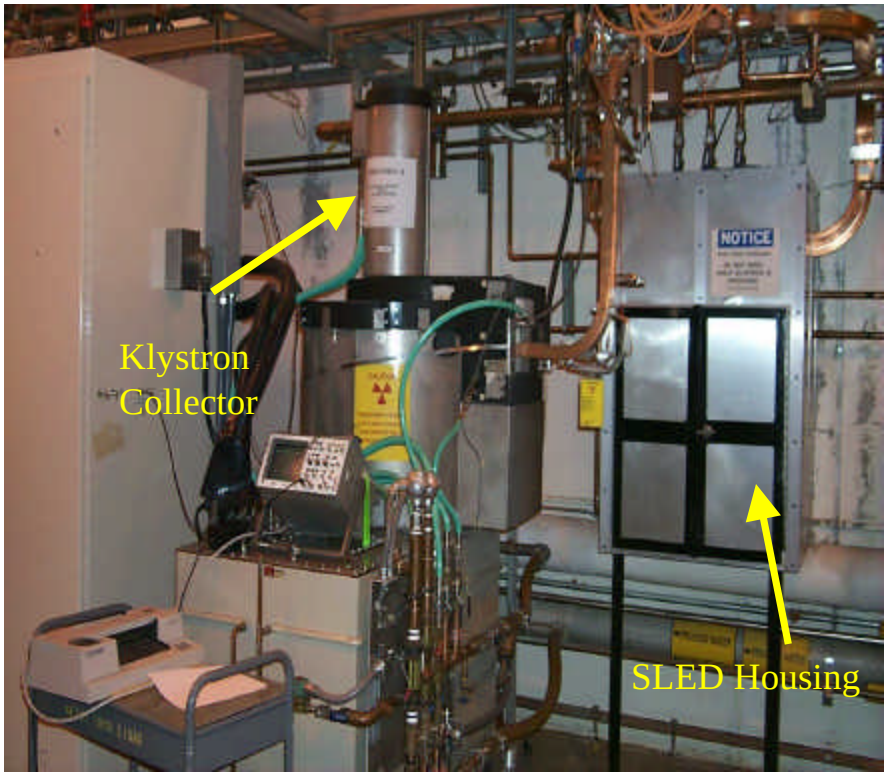

Klystron/SLED Unit

WG Coupler at the output of the klystron

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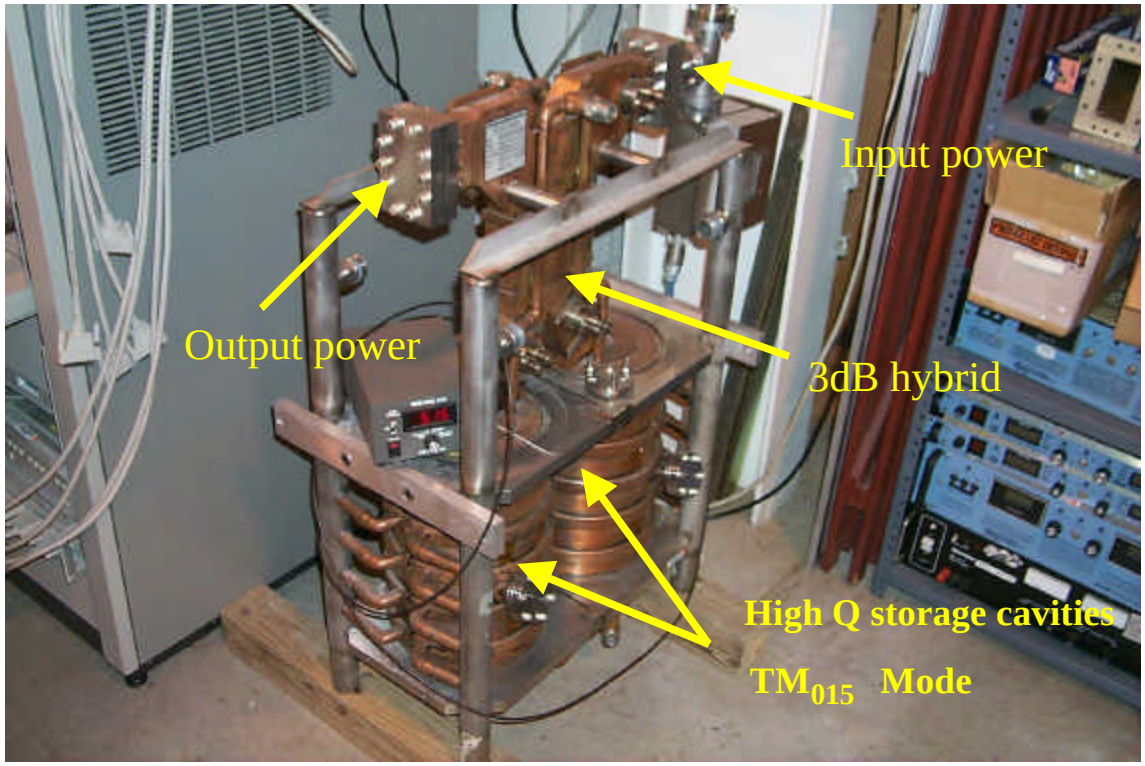

SLED UNIT

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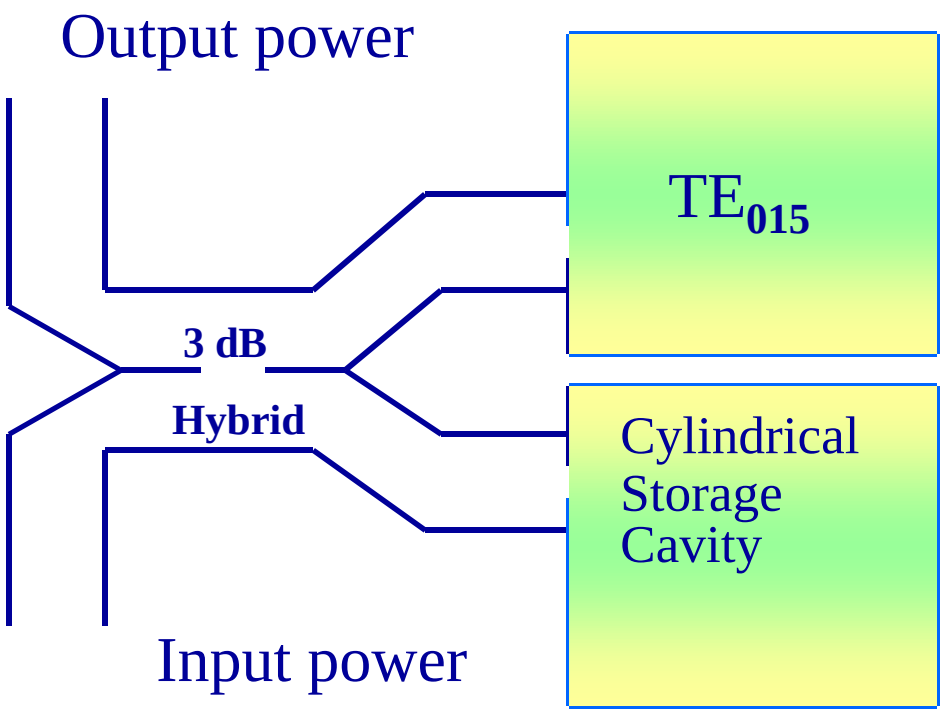

SLED

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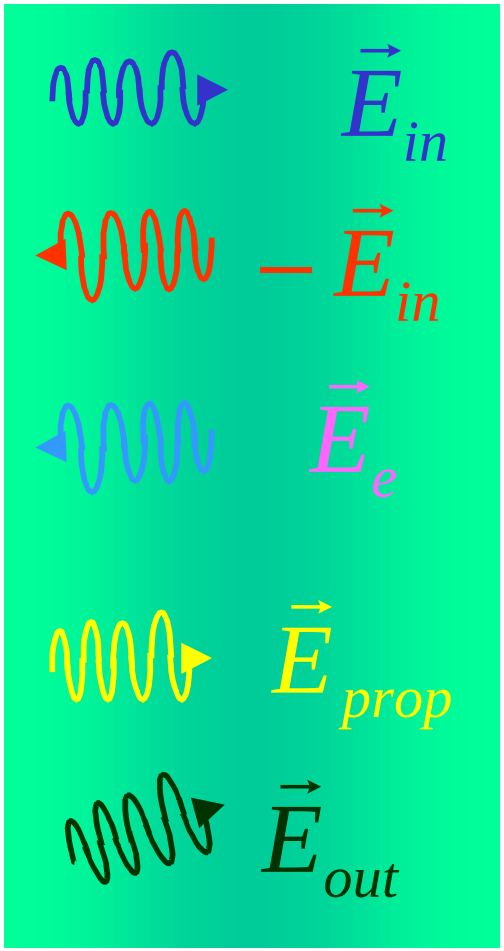
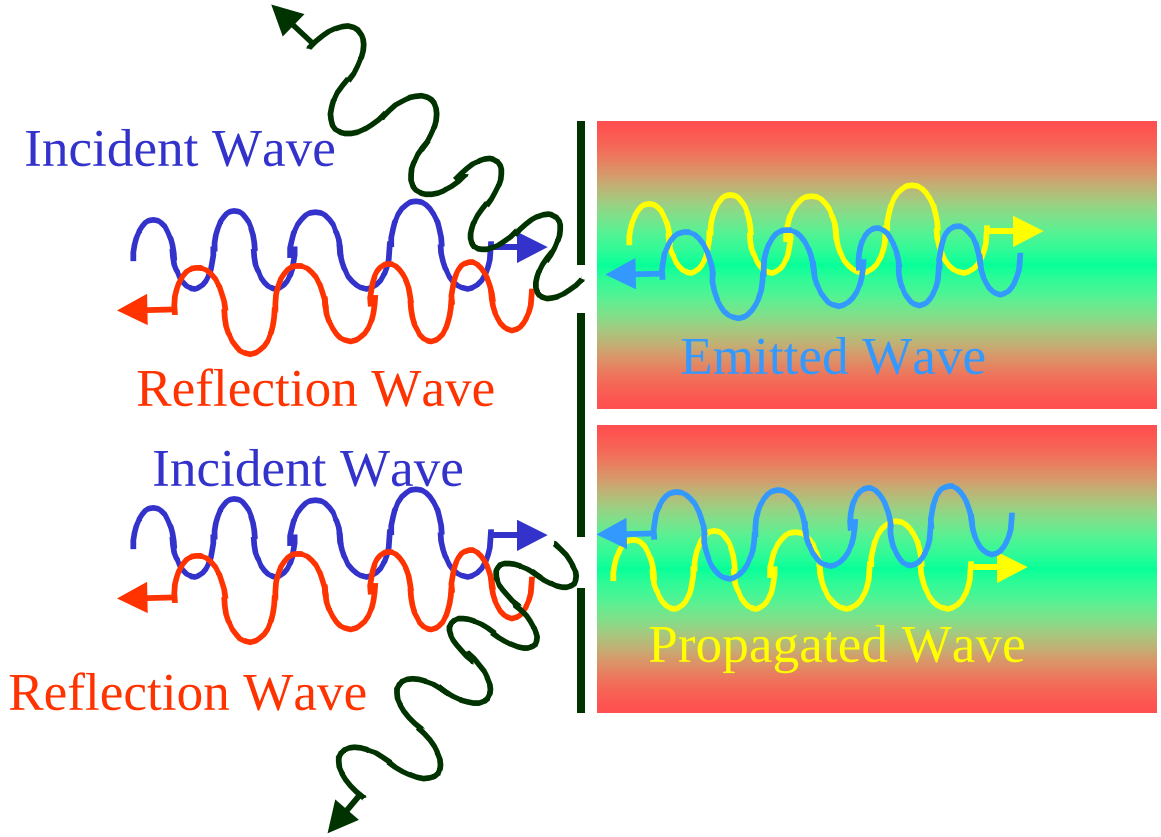
SLED Operation





$$\vec{E}_{out} = \vec{E}_{e} - \vec{E}_{in} \quad \pi\text{-shift} \quad \vec{E}_{out} = \vec{E}_{e} + \vec{E}_{in}$$

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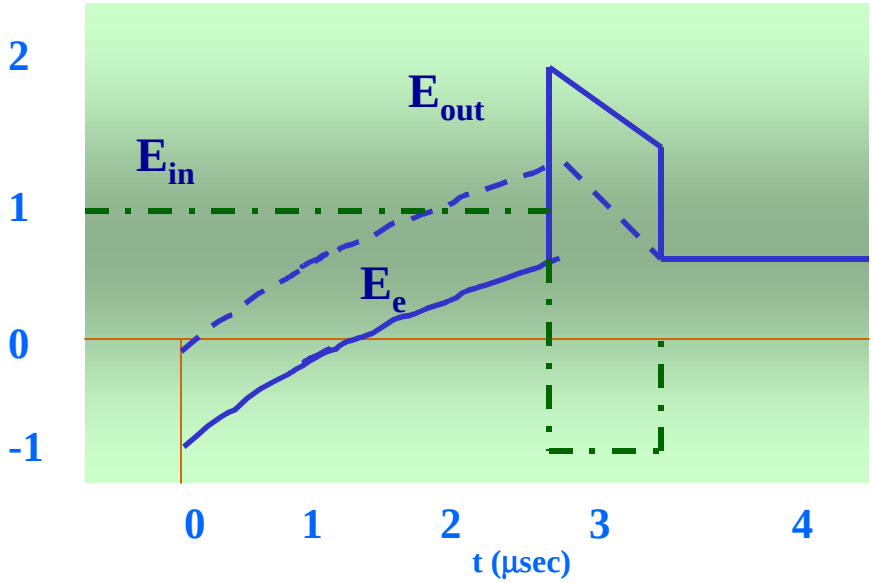
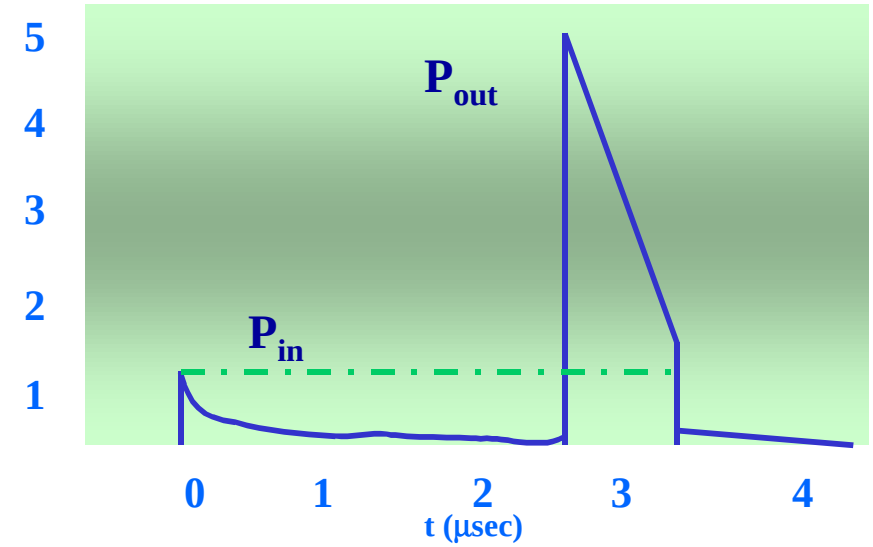
Field



Power



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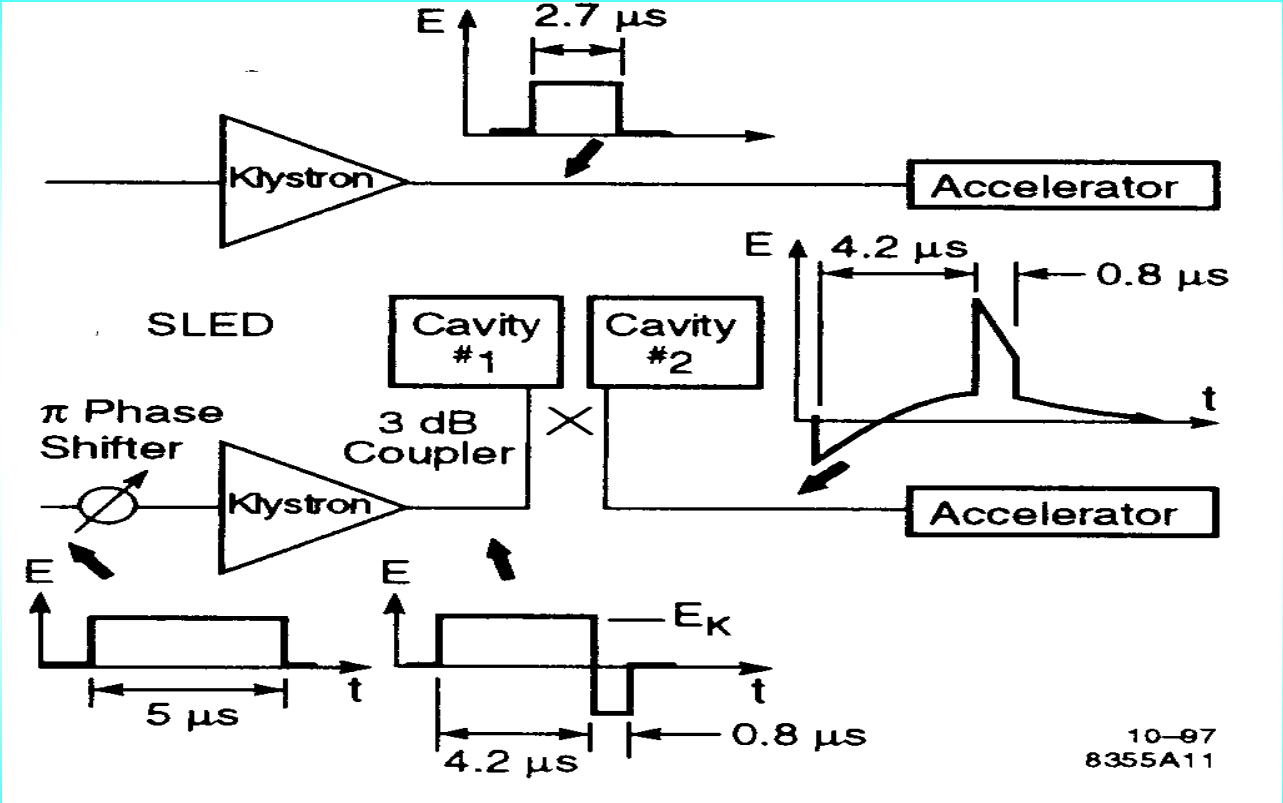
SLED



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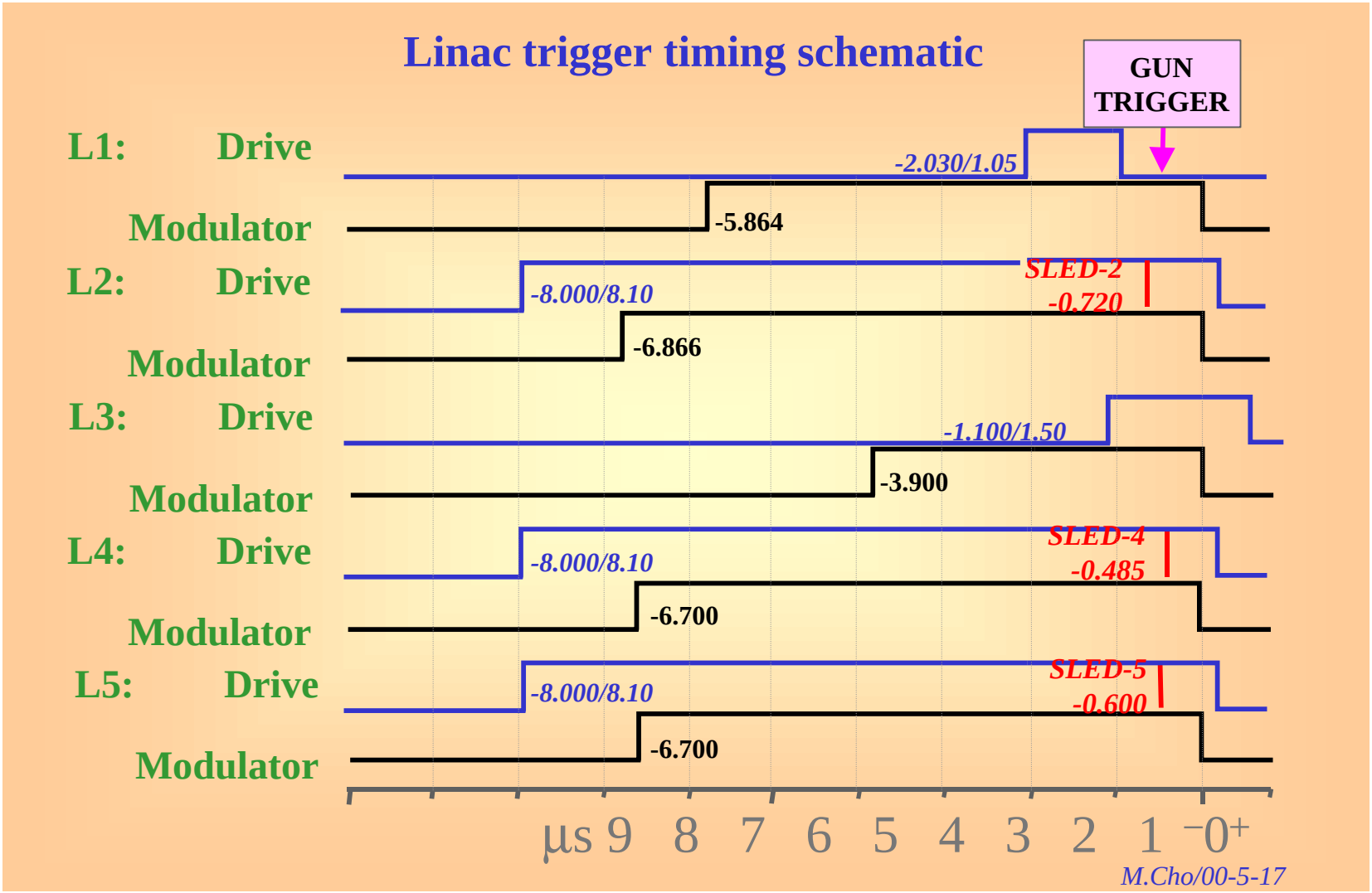

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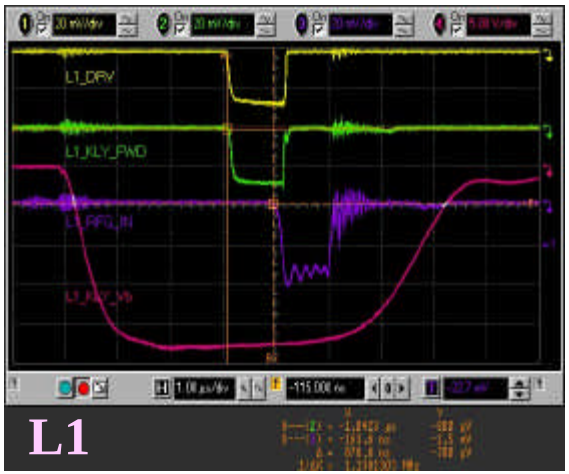
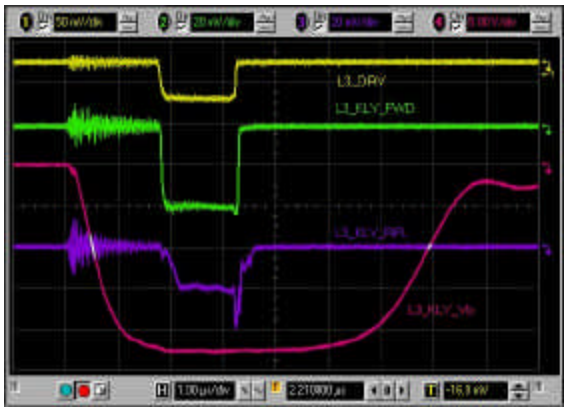
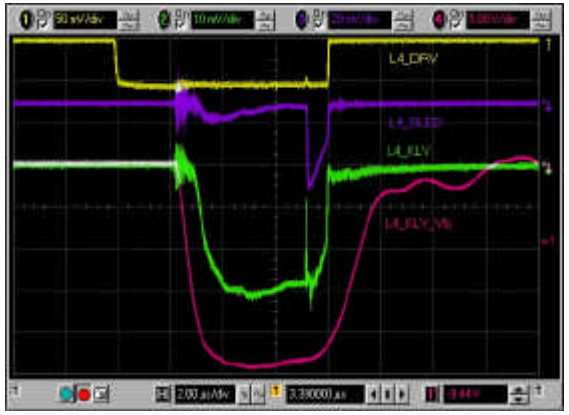


L1

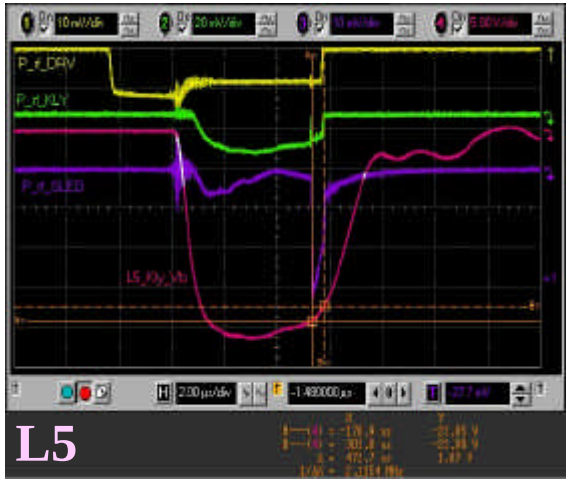
L2



L3



L4



L5

Drive power

Klystron output power

SLED output power

Klystron beam voltage

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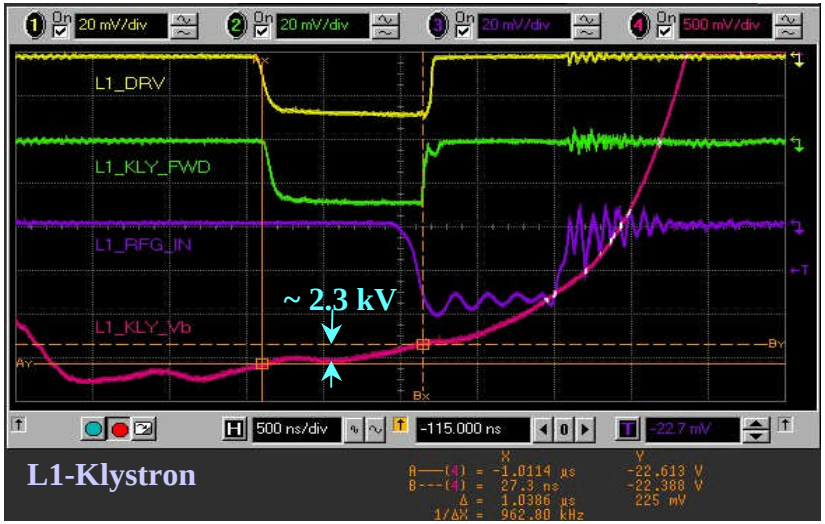

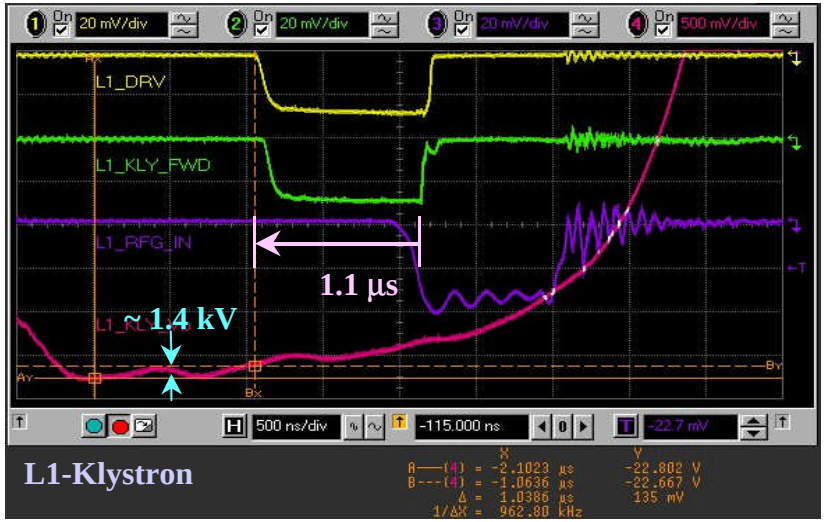

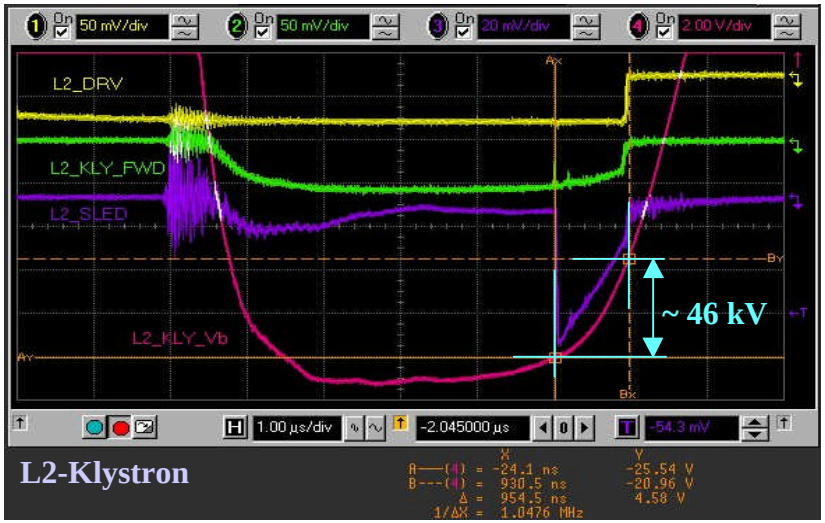

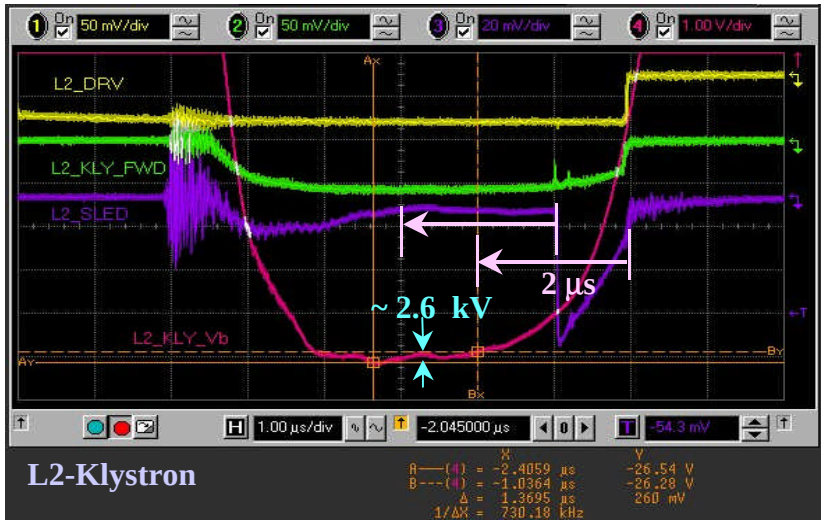

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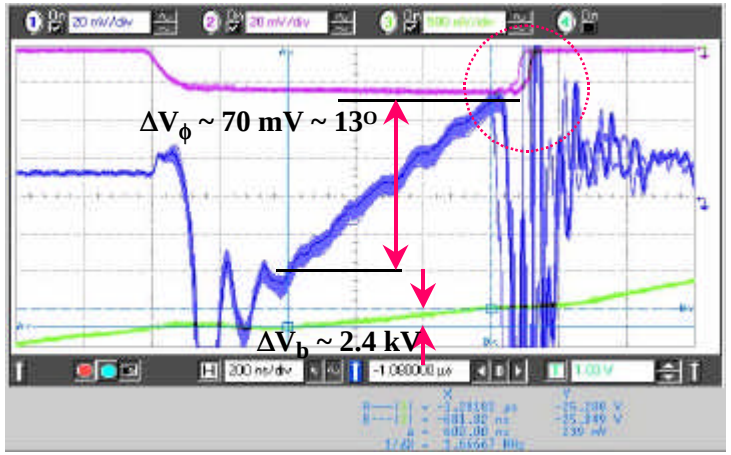
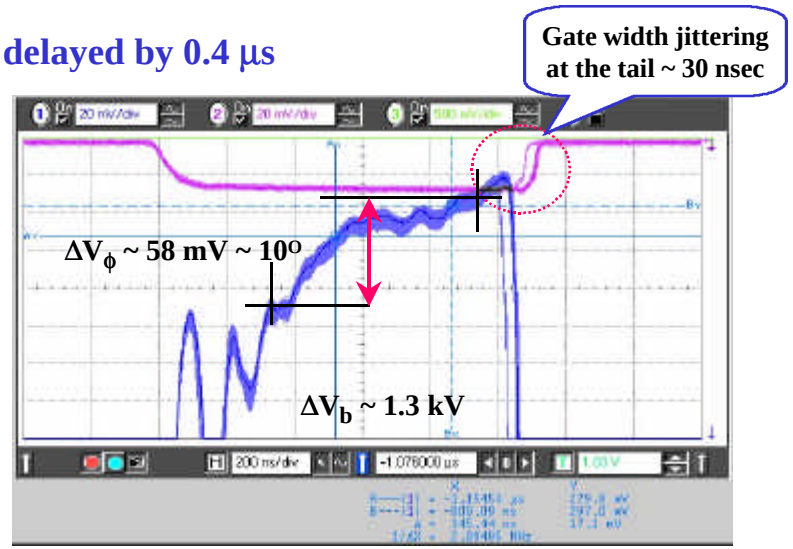
- Effect on Klystron output phase : Modulator trig delayed by 0.4 μs



<before adjust>



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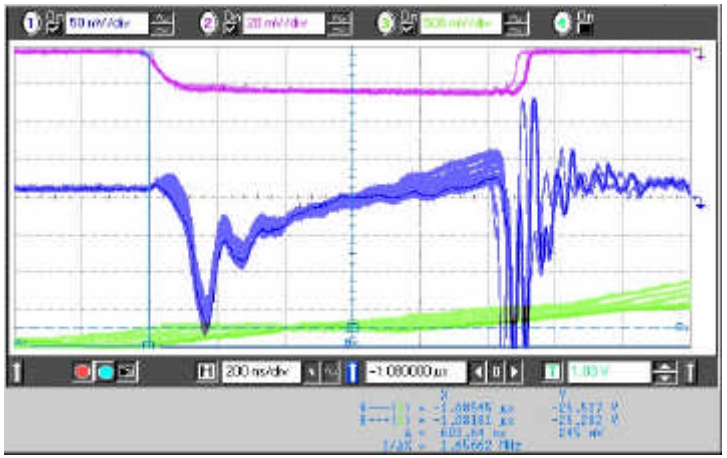

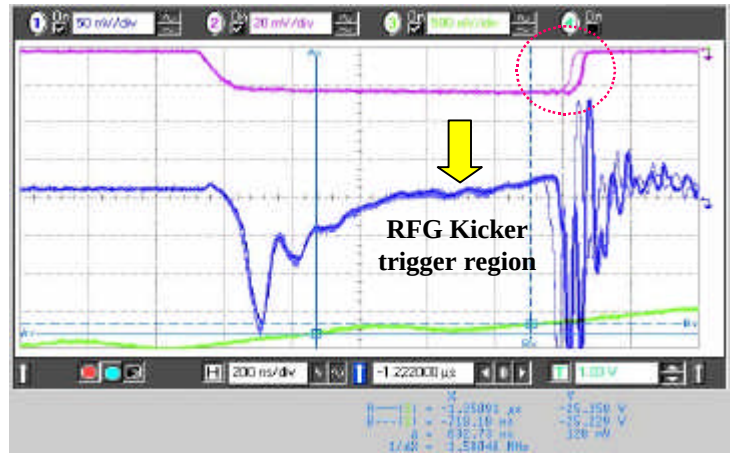

* L1 Klystron beam voltage (V_b) set at -270 kV (was -254 kV)

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$$P_{in} = P_{out} + P_c + \frac{dU_c}{dt}$$

$$P_{in} = k \; E_{in}^{2}$$

$$P_{out} = k \; (E_e + \Gamma E_{in})^2$$

Coupling Coeff. $b = \dfrac{P_e}{P_{c(diss)}}$

$$P_c = \frac{k E_e^{2}}{b}$$

$$U_c = \frac{Q_0}{w} P_c = \frac{Q_0}{w} \frac{k E_e^{2}}{b}$$

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$$\frac{dU_e}{dt} = \frac{2kQ_0}{wb} E_e \frac{dE_e}{dt}$$

At $t = 0, U_c = 0$

$\therefore E_e = 0$

To account for p phase shift, set $\Gamma = -1$

$$E^2{}_{in} = (E_e - E_{in})^2 + \frac{1}{b} E_e{}^2 + \frac{2Q_0}{wb} E_e \frac{dE_e}{dt}$$

$$E^2{}_{in} = E_e{}^2 + E_{in}^2 - 2E_e E_{in} + \frac{1}{b} E_e{}^2 + \frac{2Q_0}{wb} E_e \frac{dE_e}{dt}$$

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$$E_{in}{}^2 = E_e{}^2 + E_{in}^2 - 2E_e E_{in} + \frac{1}{b}E_e{}^2 + \frac{2Q_0}{wb}E_e\frac{dE_e}{dt}$$

$$0 = E_e{}^2 - 2E_e E_{in} + \frac{1}{b}E_e{}^2 + \frac{2Q_0}{wb}E_e\frac{dE_e}{dt}$$

$$0 = 1 - 2\frac{E_{in}}{E_e} + \frac{1}{b} + \frac{2Q_0}{wb}\frac{1}{E_e}\frac{dE_e}{dt}$$

$$0 = E_e(1+\frac{1}{b}) - 2E_e + \frac{2Q_0}{wb}\frac{dE_e}{dt}$$

$$\frac{dE_e}{dt} + \frac{w}{2Q_L}E_e = \frac{wb}{Q_0}E_{in}, \quad Q_L = \frac{Q_0}{1+b}$$

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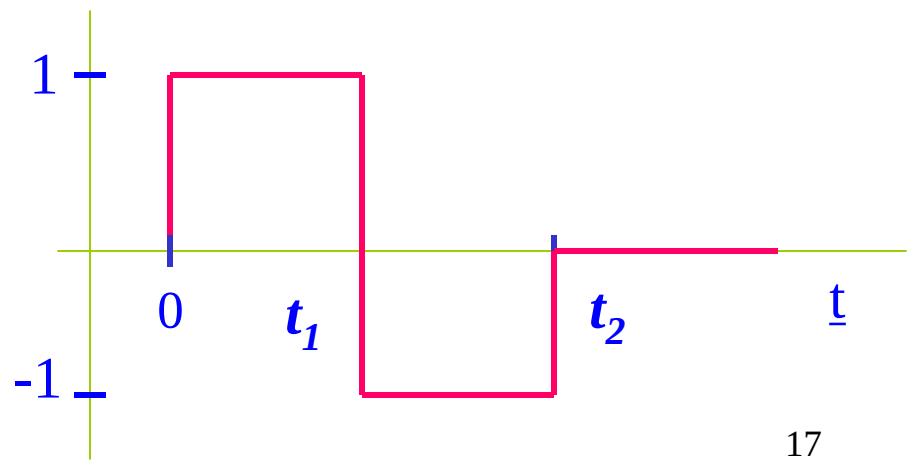
Defining $T_c = \dfrac{2Q_L}{w}$ and $a = \dfrac{2b}{1+b}$:

$$T_c \frac{dE_e}{dt} + E_e = aE_{in}$$

Input to the SLED is a constant amplitude pulse with phase reversal towards the end.

$$E_{in} = \begin{cases} 1, & 0 \le t \prec t_1 \\ -1, & t_1 \le t \prec t_2 \\ 0, & t_2 \prec t \end{cases}$$



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$$E_{\max} = E_{out}(t = t_1) = a\,(1 - e^{-\frac{t_1}{T_c}}) + 1$$

Typical numbers :

$$a = \frac{2b}{1+b} = \frac{10}{6} = 1.66$$

$$Q_L = \frac{Q_0}{1+b} = \frac{10^5}{6} \Rightarrow Q_L = 16667$$

$t_2 \approx 3.5\,m\,\text{sec}$, Klystron Pulse Width $T_c = 1.86\,m\,\text{sec}$, $T_f = 0.82\,m\,\text{sec}$

$t_1 = 2.68\,m\,\text{sec}$

$E_{\max} \approx 2.3$

$P \propto E_{\max}^2 \approx 5.3$

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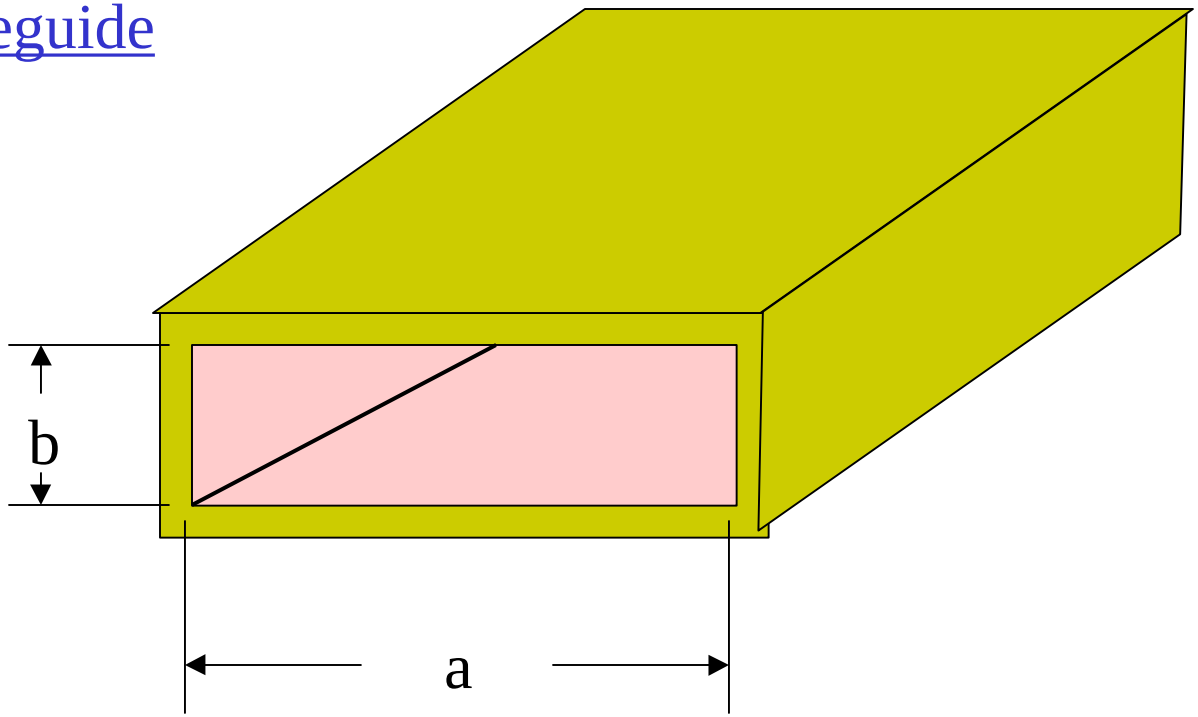
Rectangular Waveguide

Cut-off frequency:

$$f_c = \frac{c}{2a}$$



For S-band:

$$a = 8\ cm$$

$$f_c = \frac{3\times10^{10}\ cm/\sec}{16\,cm} = 1.875\ GHz$$

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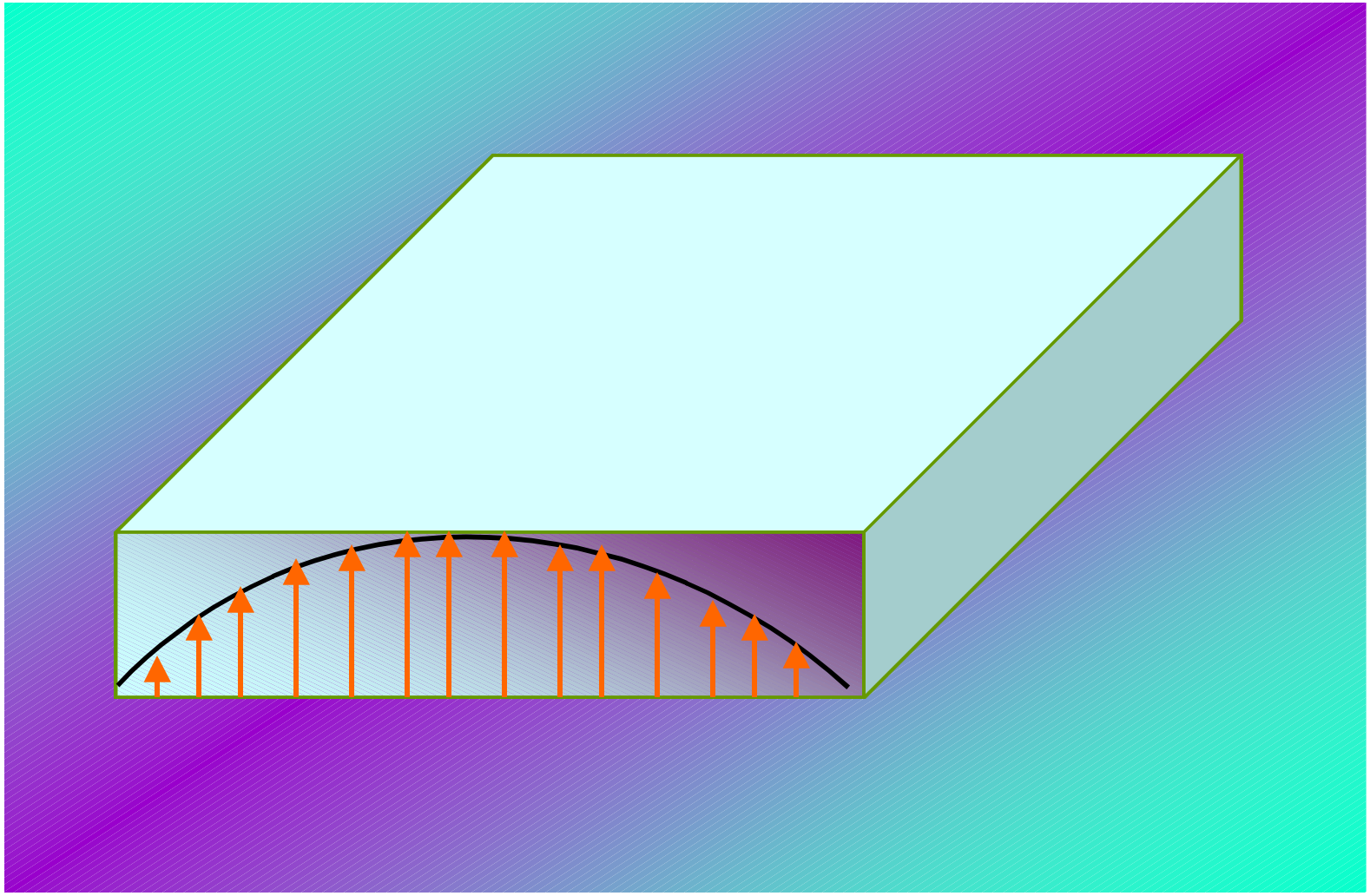

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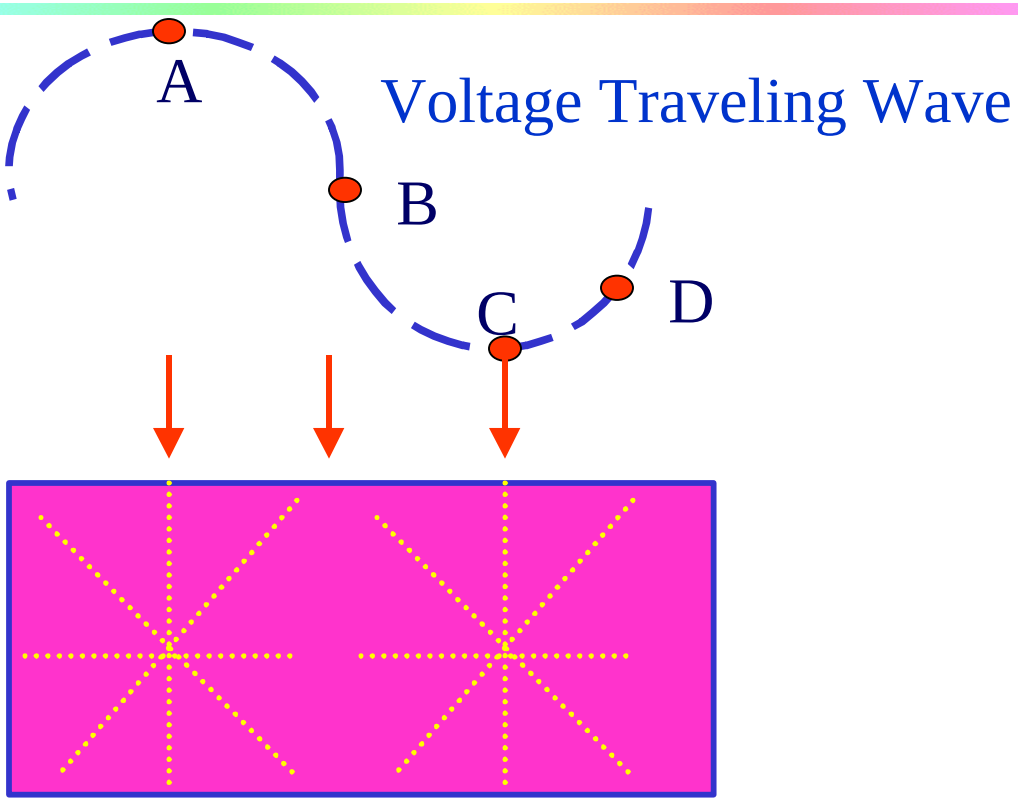
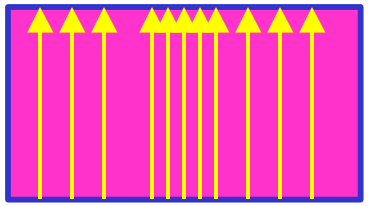
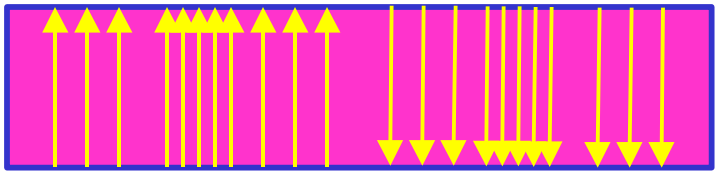




End View

Top View



Side View

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Guide Wavelength:

$$l_g = \frac{l}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

Using $f_c = 1.875\ GHz$,

$$l_g = \frac{10.5\ cm}{\sqrt{1-\left(\frac{1.875\ GHz}{2.856\ GHz}\right)^2}} = 18.5\ cm$$

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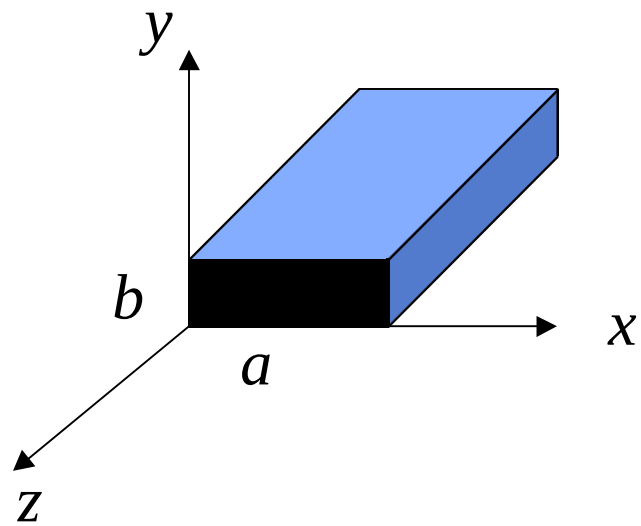
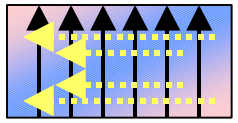
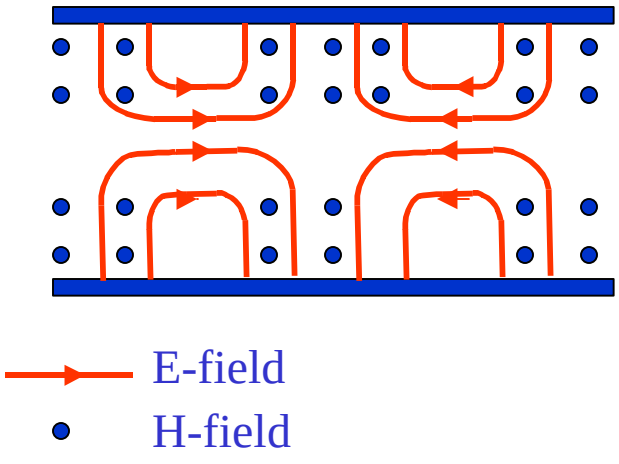
Waveguide Propagation Modes



TE - Transverse Electric Field



TM - Transverse Magnetic Field



$$k = \frac{w}{n} = 2p\,\frac{f}{n} = \frac{2p}{l}$$

$$k_0 = \frac{2p}{l_0},\ k_c = \frac{2p}{l_c}$$

$$b = \left(k_0^{\,2} - k_c^{\,2}\right)^{1/2}$$

$$b \equiv real \Rightarrow propagatin\,g \ \bmod e$$

$$b \equiv imaginary \Rightarrow evanescent \ \bmod e$$

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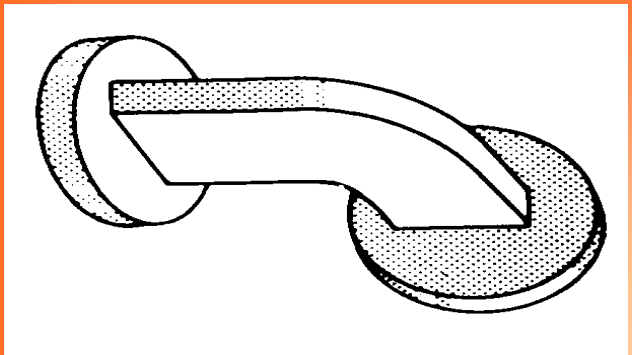
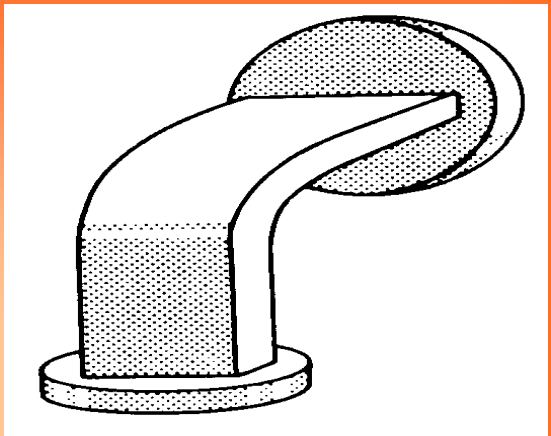
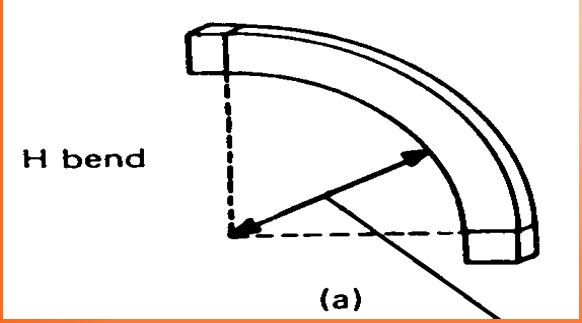
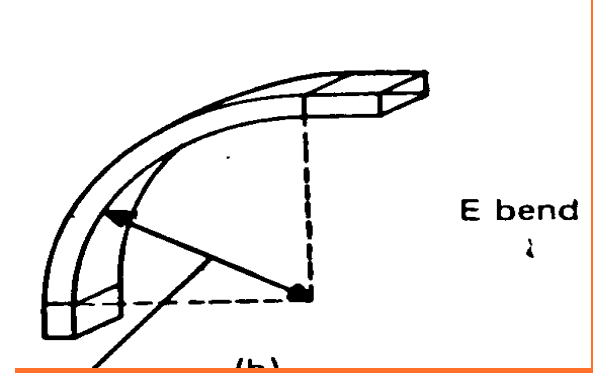
RF Components:









Radius must be at least $2\lambda_g$

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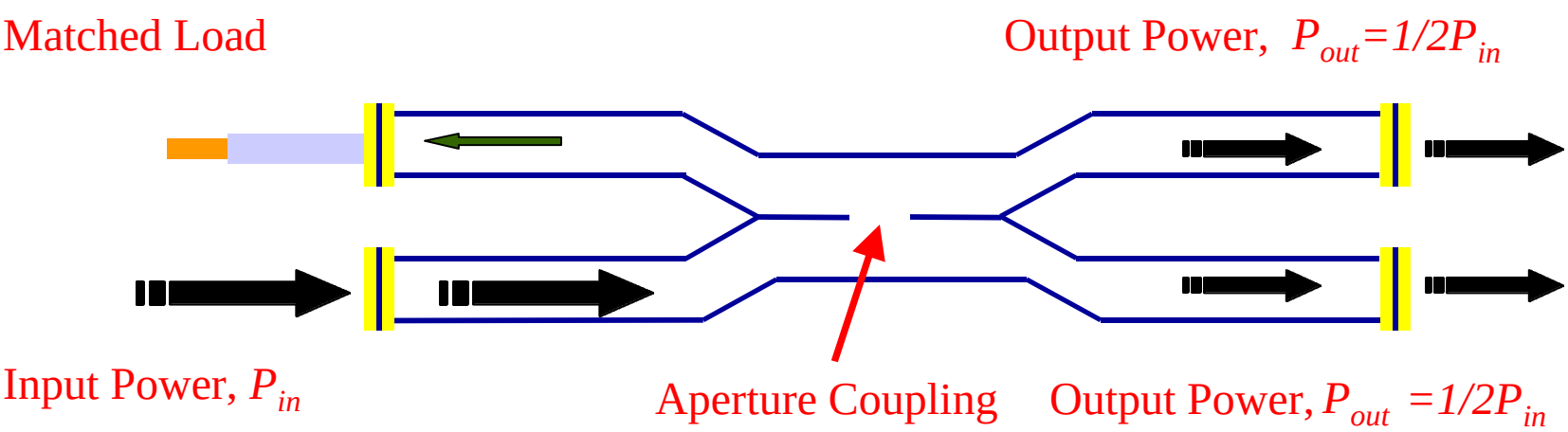
RF Components:

- Power dividers are 4-port hybrids of various coupling (I. E. a 3-dB hybrid splits the input power in half)



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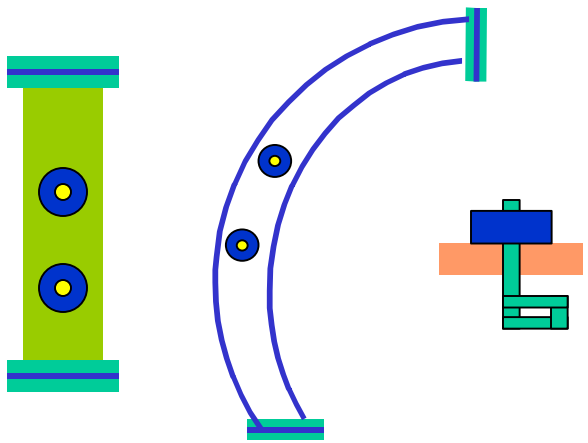
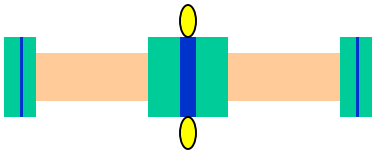
RF Components:

Couplers



Window



Load

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$$10 \log \frac{P_1}{P_2} dB$$

$$20 \log \frac{V_1}{V_2} dB$$

$$10 \log \frac{P_1}{1\,mW} dBm$$

1 mW	**0 dBm**
1 W	**30 dBm**
100 W	**50 dBm**
1 kW	**60 dBm**

Power:	
10 dB	10
20 dB	100
30 dB	1000
40 dB	10,000
Voltage:	
10 dB	3
20 dB	10
30 dB	31
40 dB	100

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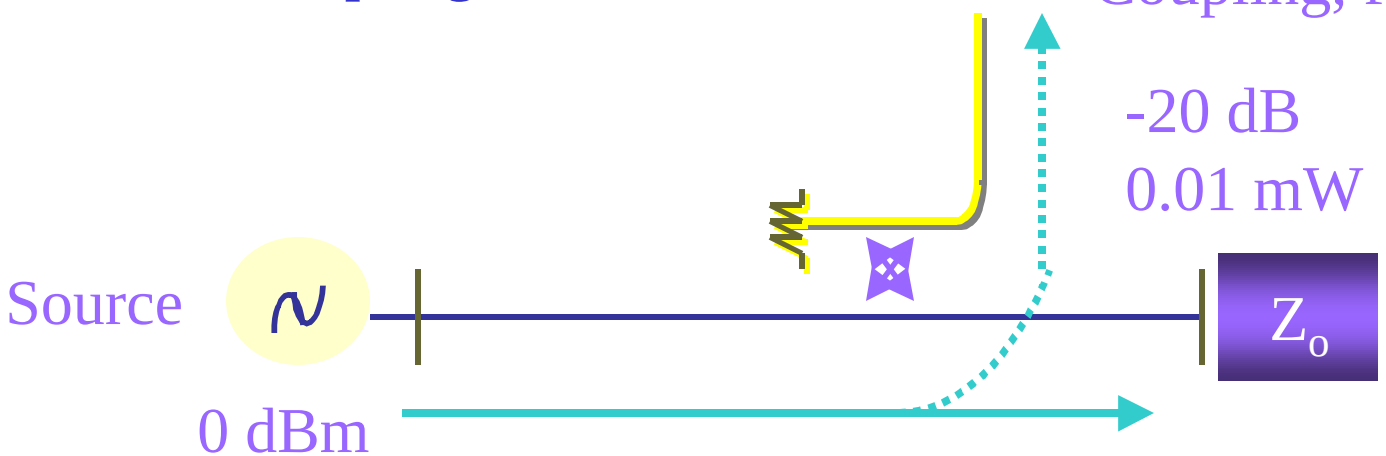
Forward Coupling



$$\text{Coupling Factor (dB)} = -10\log\frac{P_{forward}}{P_{incident}}$$

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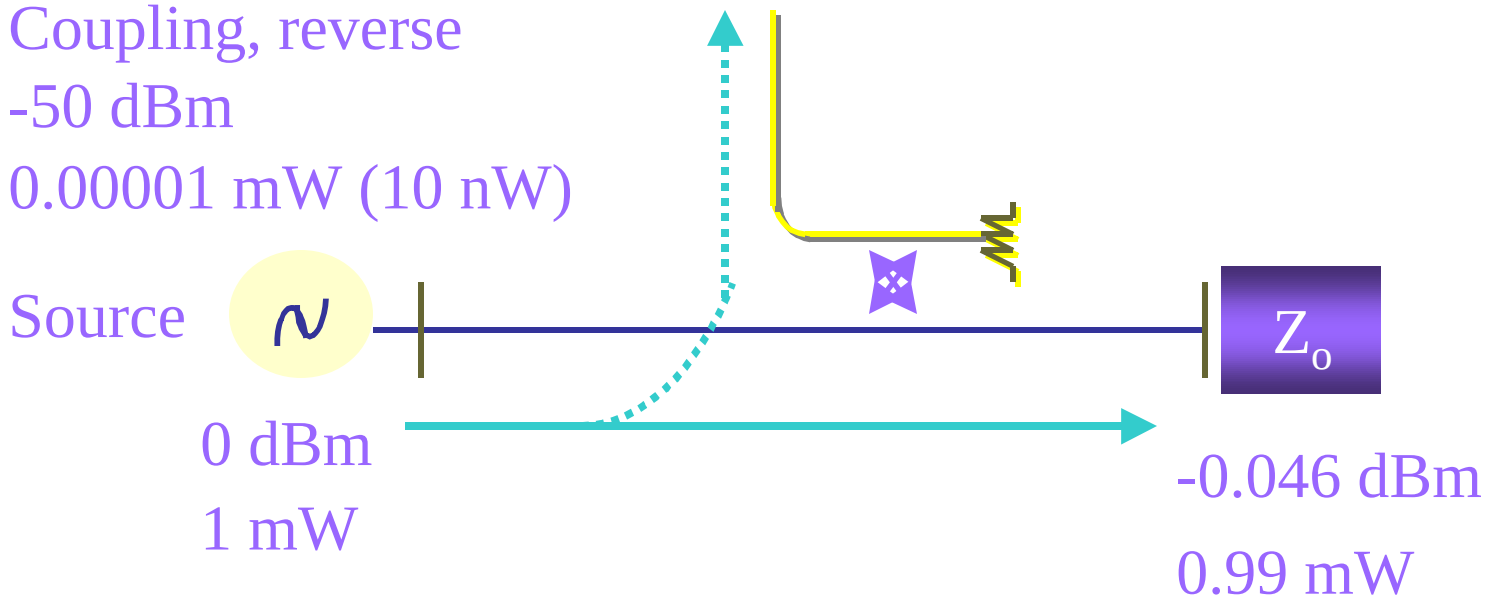
Directional Coupler Isolation



Isolation Factor (dB) = $-10\log\frac{P_{reverse}}{P_{incident}}$

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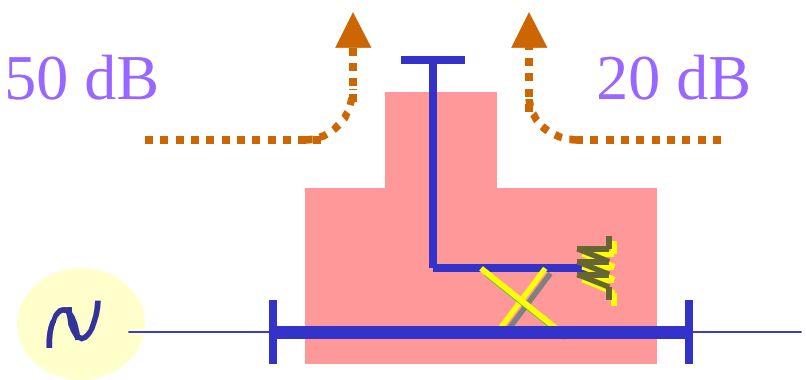
Directional Coupler Directivity

$$\text{Directivity} = \frac{\text{Coupling Factor}_{(\text{fwd})} \times \text{Loss}_{(\text{througharm})}}{\text{Isolation}_{(\text{reverse})}}$$

$$\text{Directivity (dB)} = \text{Isolation(dB)} - \text{Coupling Factor(db)} - \text{Loss (dB)}$$



Directivity = 50 dB - 20 dB = 30 dB