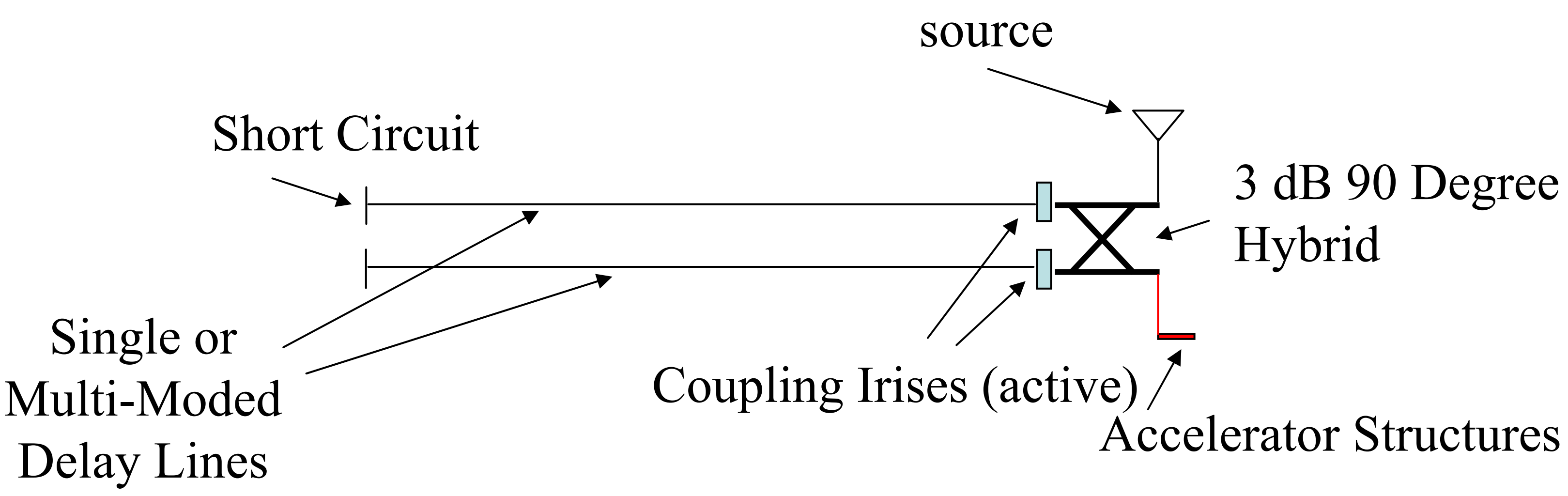
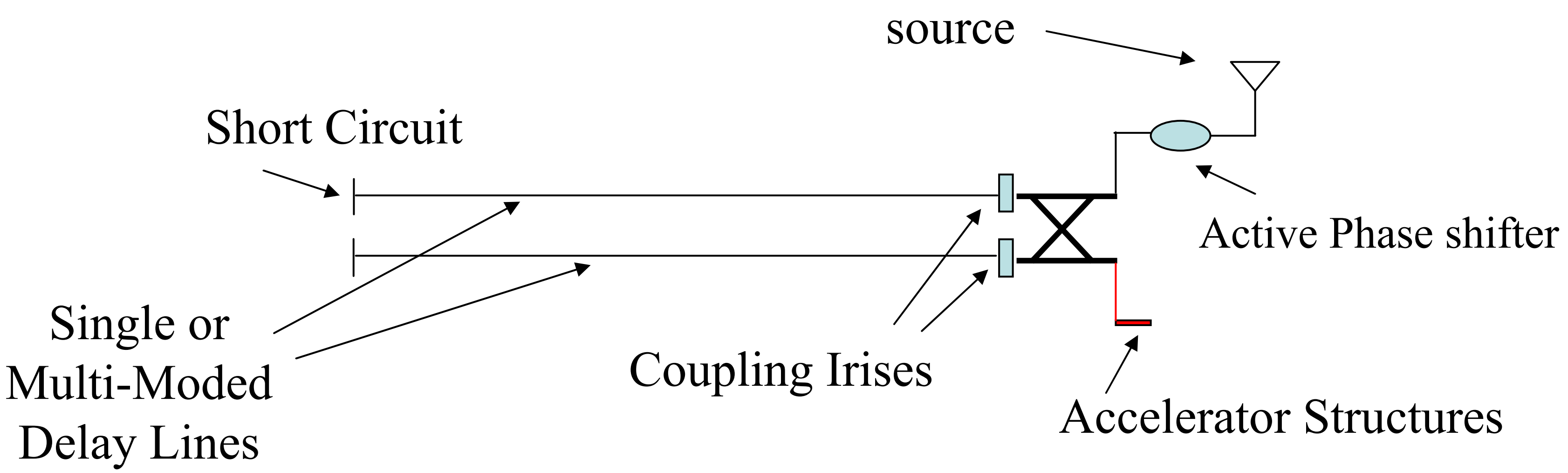
Active Pulse Compression for Oscillator Systems at 30GHz

Sami Tantawi
SLAC



a) Sled-II Pulse compression system with active iris



b) Sled-II Pulse compression system with active phase shifter

Resonant delay line.

$$\underline{\underline{S}} = \begin{pmatrix} -R_0 & -j(1-R_0^2)^{1/2} \\ -j(1-R_0^2)^{1/2} & -R_0 \end{pmatrix}$$

$$V_1^- = -R_0 V_1^+ - j(1-R_0^2)^{1/2} V_2^+,$$

$$V_2^- = -j(1-R_0^2)^{1/2} V_1^+ - R_0 V_2^+.$$

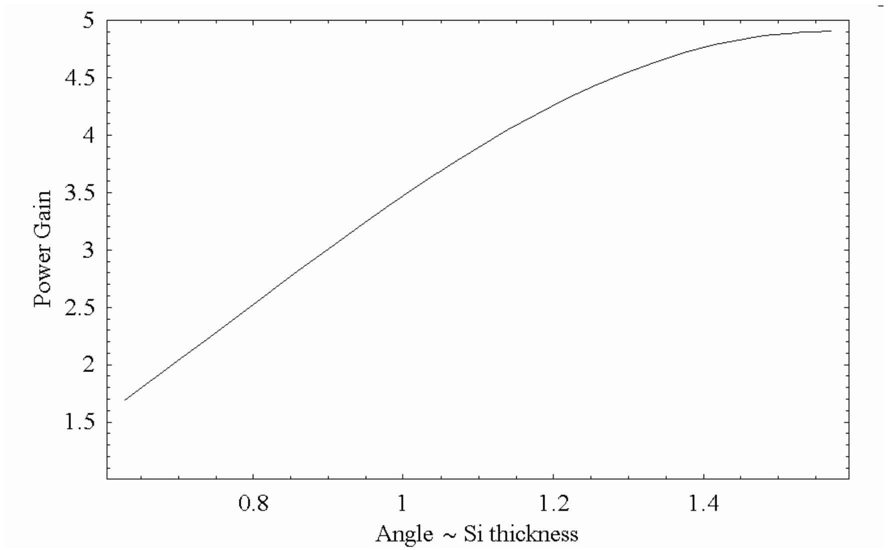
$$V_2^+(t) = V_2^-(t-\tau)e^{-j2\beta l}.$$

Discharging By Active Switching

To discharge the line, one can keep the input signal at a constant level during the time interval $0 \le t < n\tau$ but switching the iris reflection coefficient to zero so that all the energy stored in the line is dumped out. In this case

$$V_{out} = \frac{1-(R_0 p)^n}{1-R_0 p}(1-R_0^2)^{1/2}\, pV_{in}.$$

So, what happens if we do not switch the iris reflection coefficient all the way to zero?



Switching Just Before The Last Time Bin

To reduce the burden on the switch one can indeed utilize the ingenious idea of reversing the phase together with changing the iris reflection coefficient.

$$R_d = \cos\left[\tan^{-1}\left(\frac{1-(R_0 p)^{n-1}}{1-R_0 p}(1-R_0^2)^{1/2} p\right)\right].$$

This new reflection coefficient is greater than zero and the switch need only change the iris between R_0 and R_d.

$$V_{out} = R_d\left[1+\left(\frac{1-(R_0 p)^{n-1}}{1-R_0 p}\right)^2 (1-R_0^2)p^2\right]V_{in}.$$

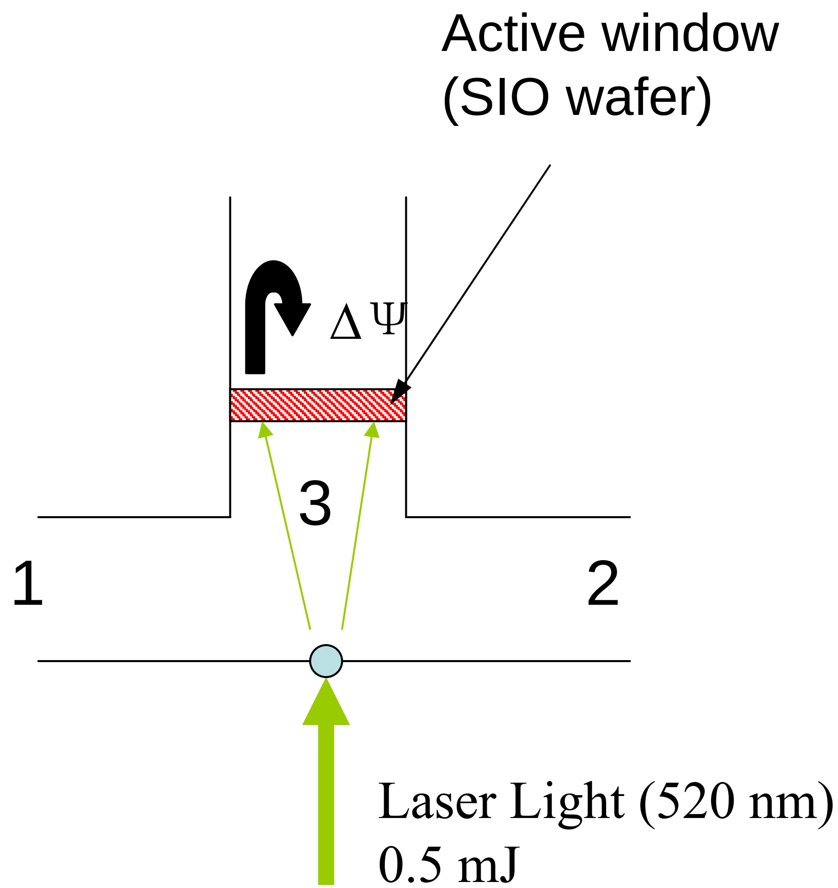
The compressed pulse takes place in the interval $(n-1)\tau \le t < n\tau$. The optimum value of R_0 is such that it fills the system with maximum possible amount of energy in the time interval $(n-1)\tau$ instead of $n\tau$ in the previous case.

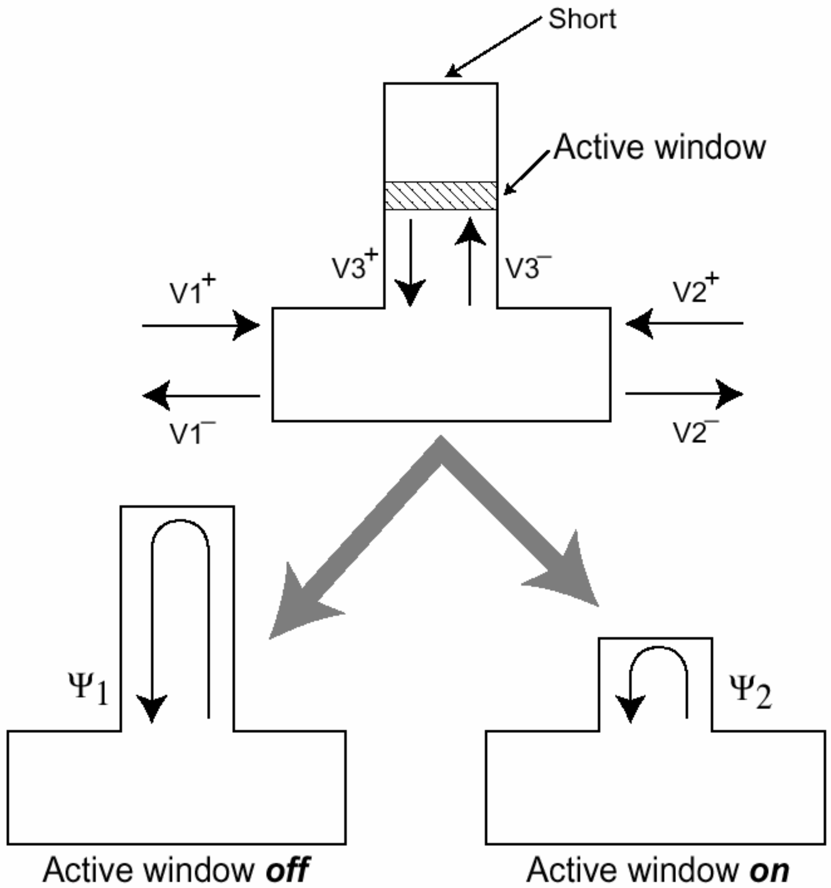
Cr	SLED II		Switching During Charging Time		Discharging After The Last Time Bin.		Discharging Just Before The Last Time Bin		
	η (%)	Opt. R_0	η (%)	Opt. R_0	η (%)	Opt R_0	η (%)	Opt. R_0	R_d
2	78.1	0.5	100	0.707	84.4	0.5	100	0.0	0.707
3	88.7	0.548	98.9	0.631	82.7	0.646	89.6	0.5	0.610
4	86.0	0.607	92.6	0.658	82.1	0.725	87.0	0.646	0.536
5	80.4	0.651	85.1	0.688	81.9	0.775	85.7	0.725	0.483
6	74.6	0.685	78.1	0.714	81.8	0.809	84.9	0.775	0.443
8	64.4	0.733	66.5	0.754	81.6	0.854	84.0	0.835	0.386
10	56.2	0.767	57.7	0.783	81.6	0.882	83.4	0.869	0.346
12	49.9	0.792	50.9	0.805	81.5	0.900	83.1	0.892	0.317
16	40.6	0.828	41.2	0.837	81.5	0.924	82.7	0.920	0.275
24	29.6	0.869	29.8	0.875	81.5	0.949	82.2	0.947	0.225
32	23.3	0.893	23.4	0.897	81.5	0.961	82.0	0.960	0.195
64	12.6	0.936	12.7	0.938	81.5	0.981	81.7	0.980	0.138
128	6.6	0.962	6.6	0.963	81.5	0.990	81.6	0.990	0.099
256	3.4	0.978	3.4	0.979	81.5	0.995	81.5	0.995	0.069

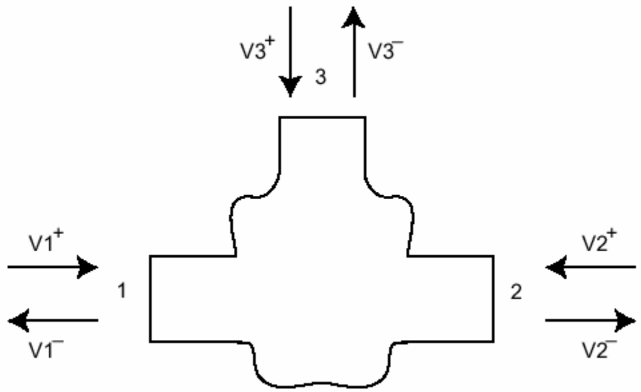
Comparison between different methods of single event switching pulse compression systems.

Design of the Switch Module (Suitable for high frequencies)

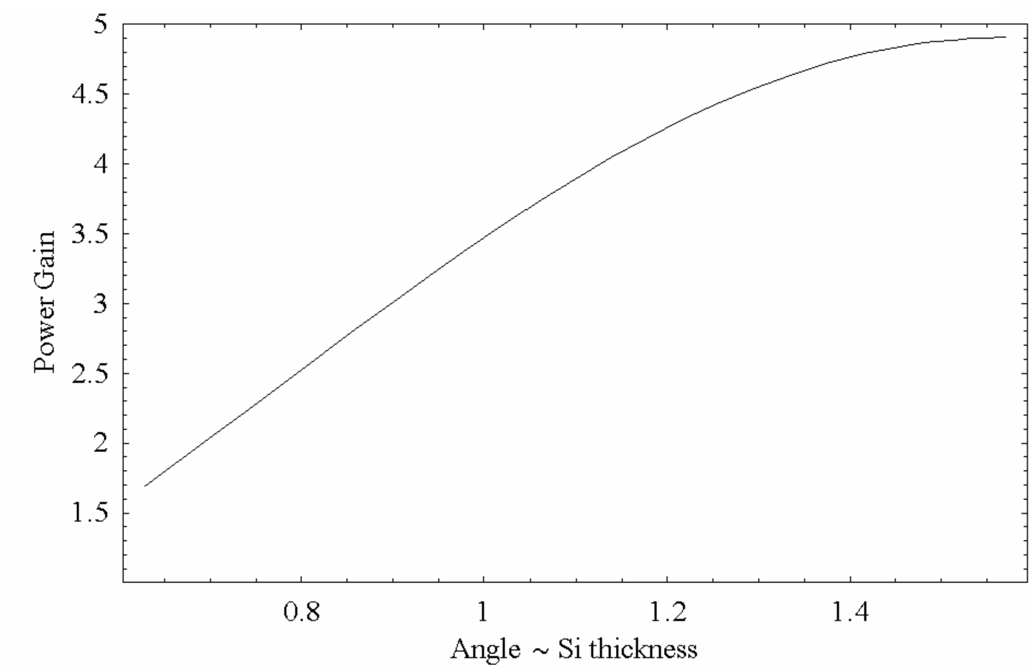
- Switch the S matrix of the two port network by changing the reflection phase in the 3rd arm
- The S matrix of ON state is tuned by the location of the active window.
- OFF state is tuned by the movable short shown.

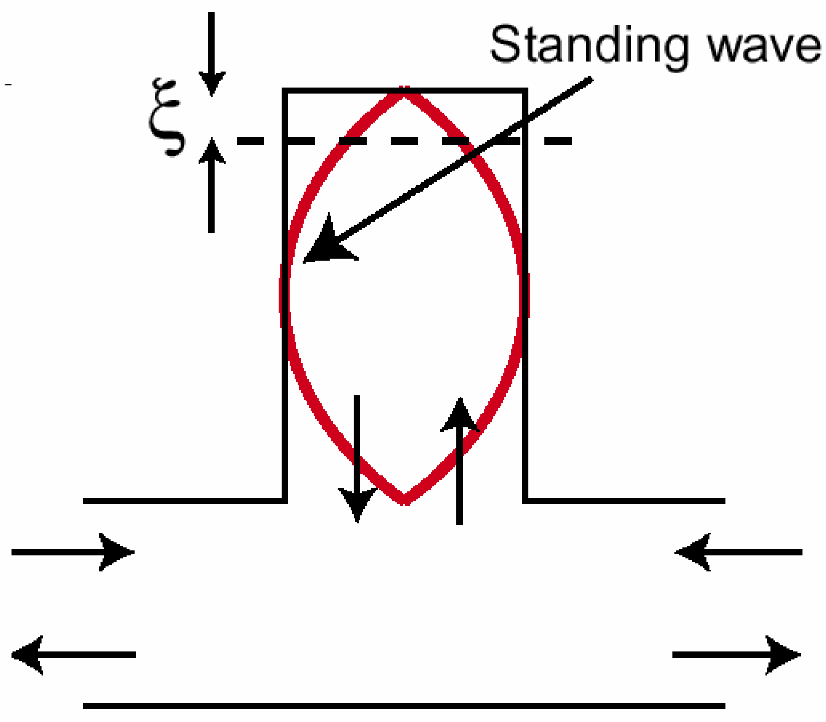






$$\underline{\underline{S}} = \begin{pmatrix} \frac{e^{j\phi} - \cos\theta}{2} & \frac{-e^{j\phi} - \cos\theta}{2} & \frac{\sin\theta}{\sqrt{2}} \\ \frac{-e^{j\phi} - \cos\theta}{2} & \frac{e^{j\phi} - \cos\theta}{2} & \frac{\sin\theta}{\sqrt{2}} \\ \frac{\sin\theta}{\sqrt{2}} & \frac{\sin\theta}{\sqrt{2}} & \cos\theta \end{pmatrix}$$



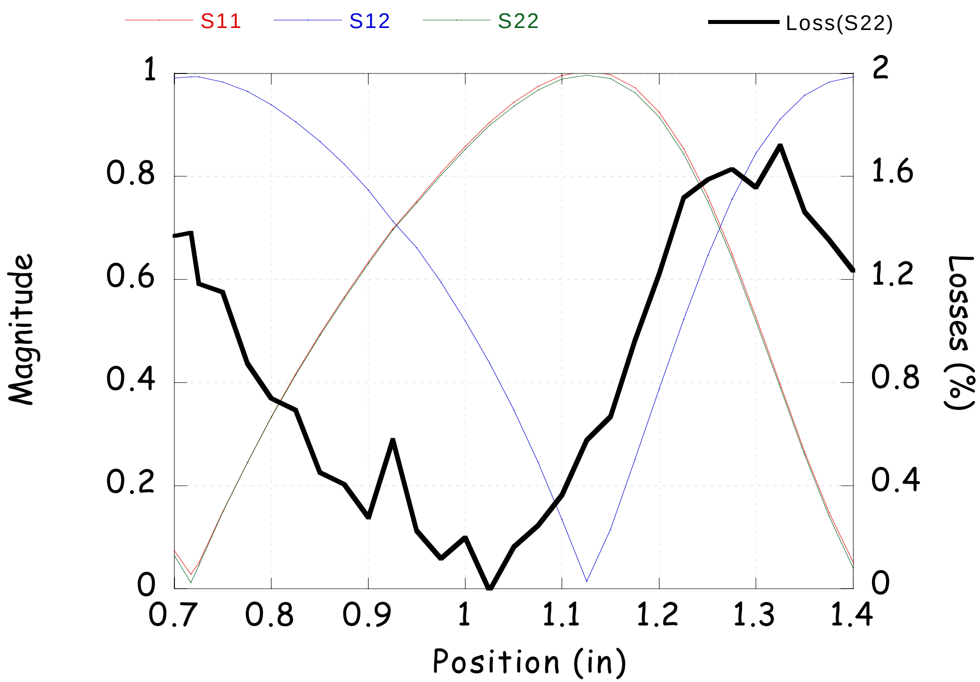


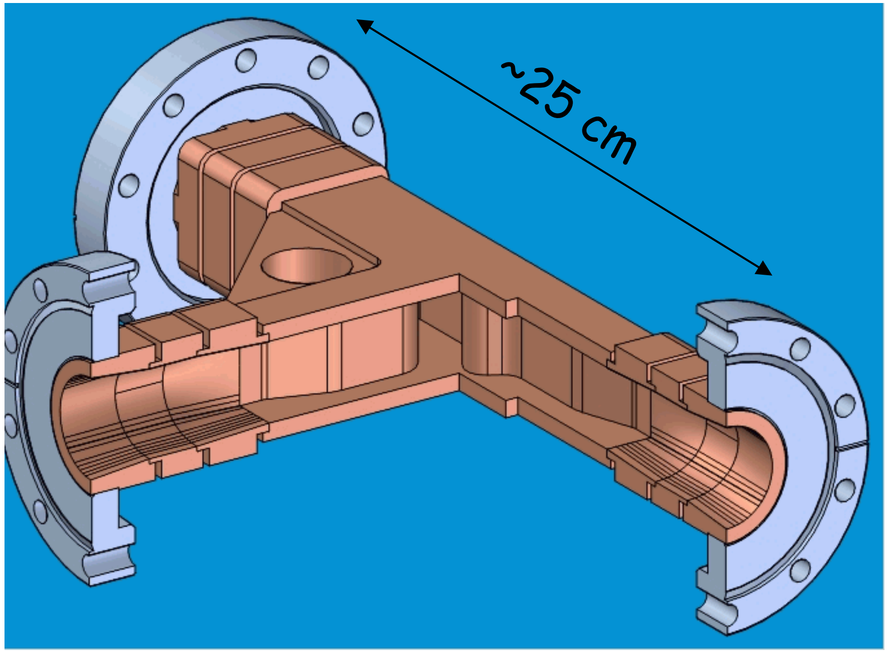
$$|V_3| = 2|V_3^-||\sin \beta_3 \xi|$$

$$E_{max} = 2\sqrt{\frac{1 + 2\cos\theta\cos\zeta + \cos^2\theta}{2\sin^2\theta}}\,|\sin\beta_3\xi|\,\sqrt{\frac{P_{in}Z_g}{AG}}.$$

$$P_l = 4\frac{(1 + 2\cos\theta\cos\zeta + \cos^2\theta)}{2\sin^2\theta}\frac{R_s}{Z_g}\left|V_1{}^+ + V_2{}^+\right|^2.$$

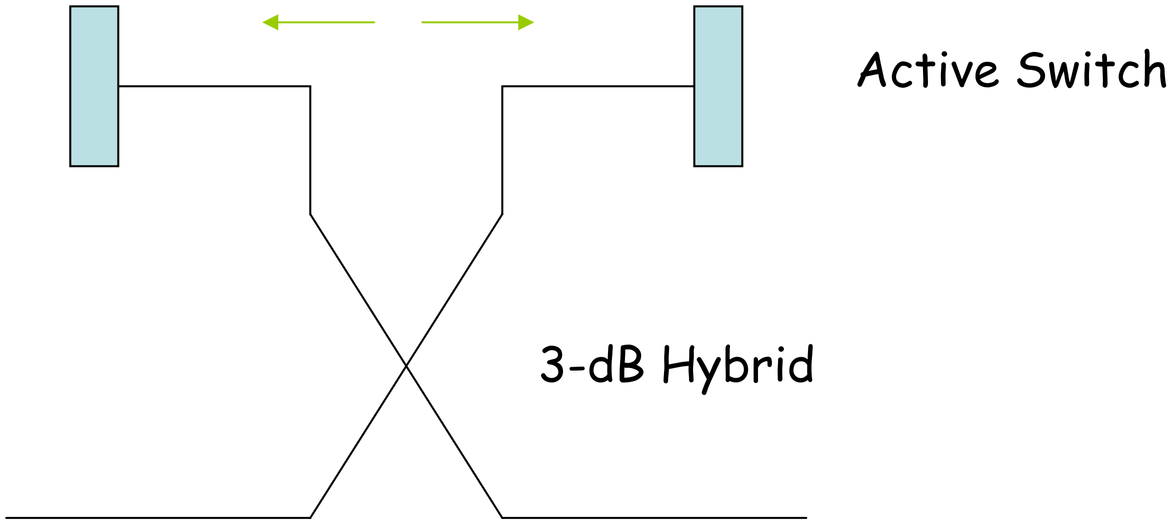
TE_{01} Mode Tee (Variable Iris)





- The Tee body is planer rectangular guide operating in the TE_{20}
- We Taper from Circular to Rectangular with a special taper which generate the TE_{01} mode

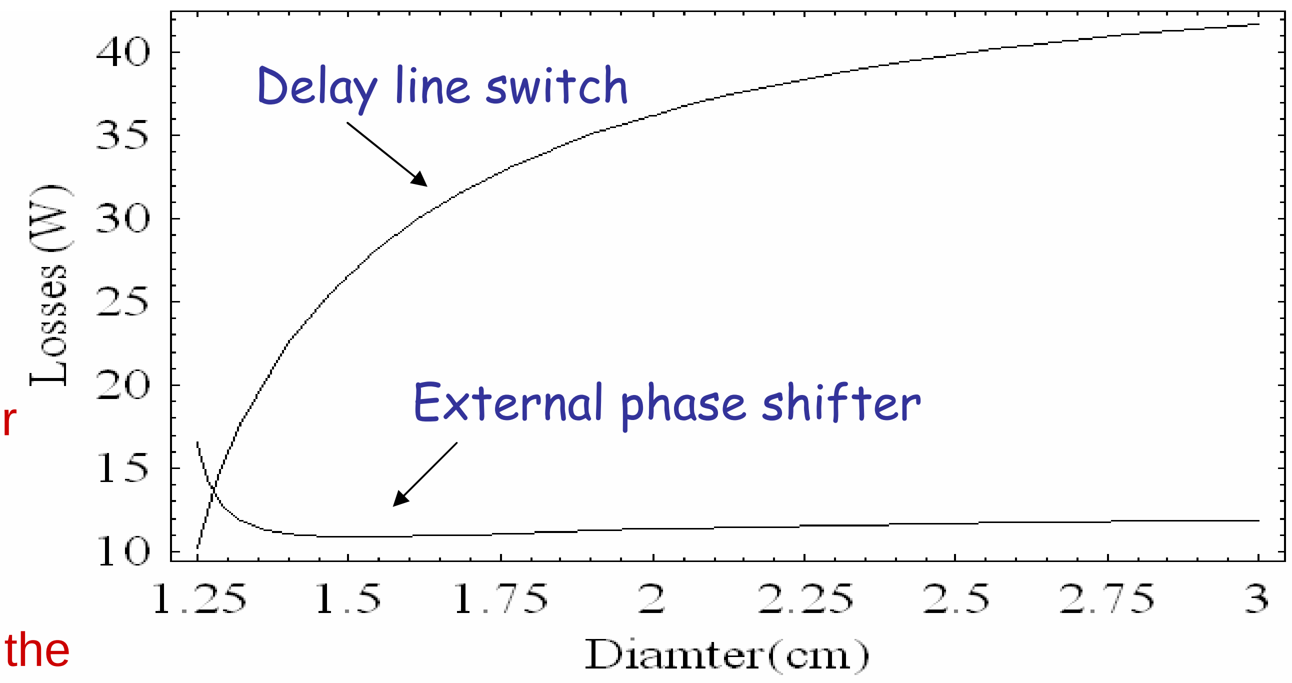
Pi Phase Shifter

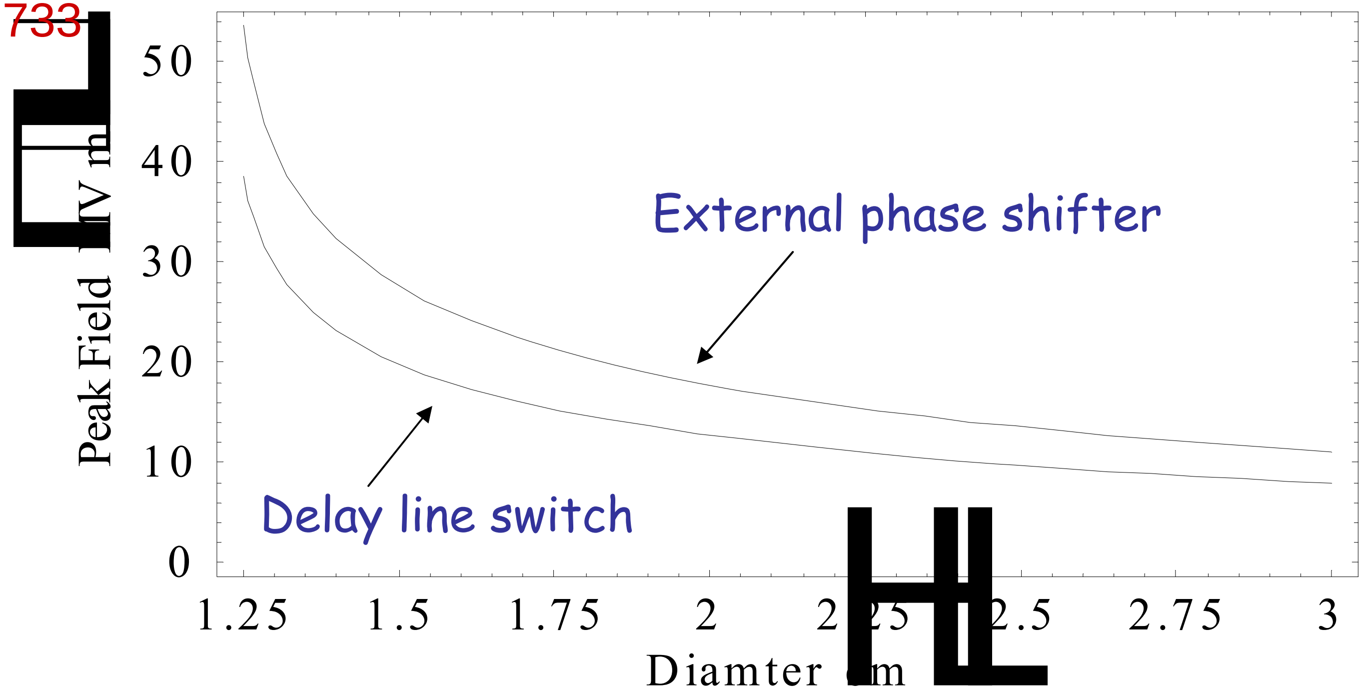


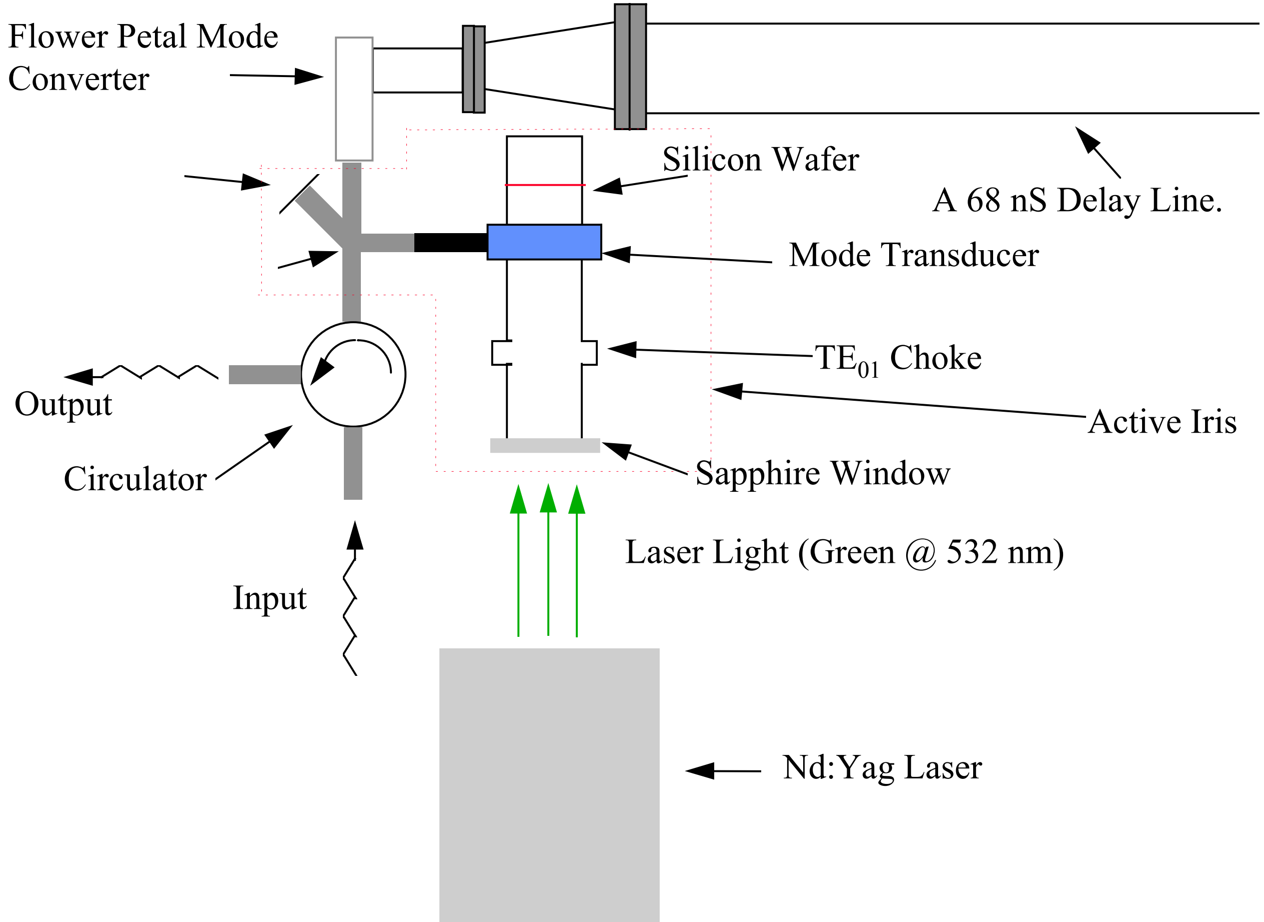
The switch has to change the phase by Pi. The thickness of the of the Si wafer is ~ 730 micron

Silicon Wafer Thickness for delay line switch ~ 153 microns

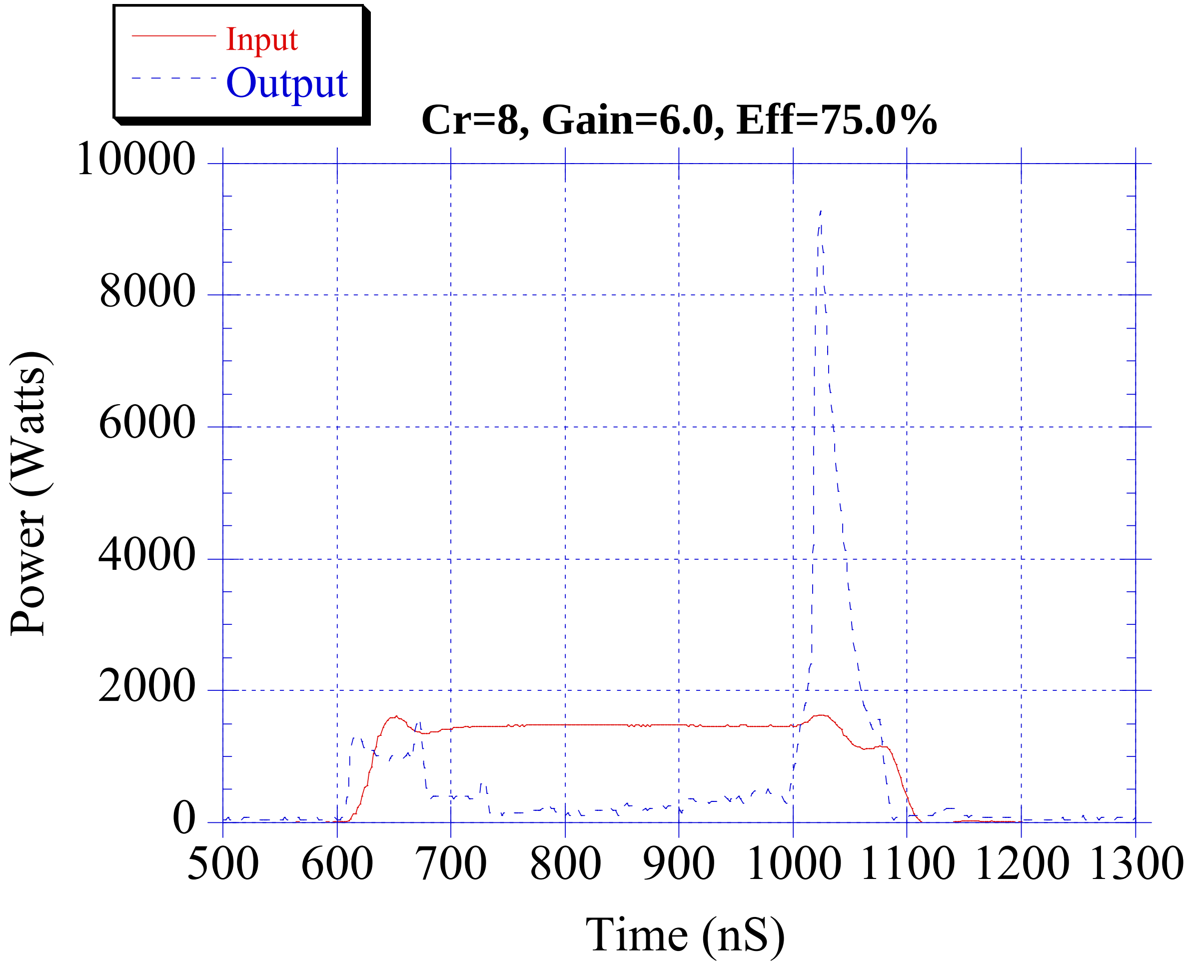
Silicon wafer thickness for the external phase shifter ~ 733 microns

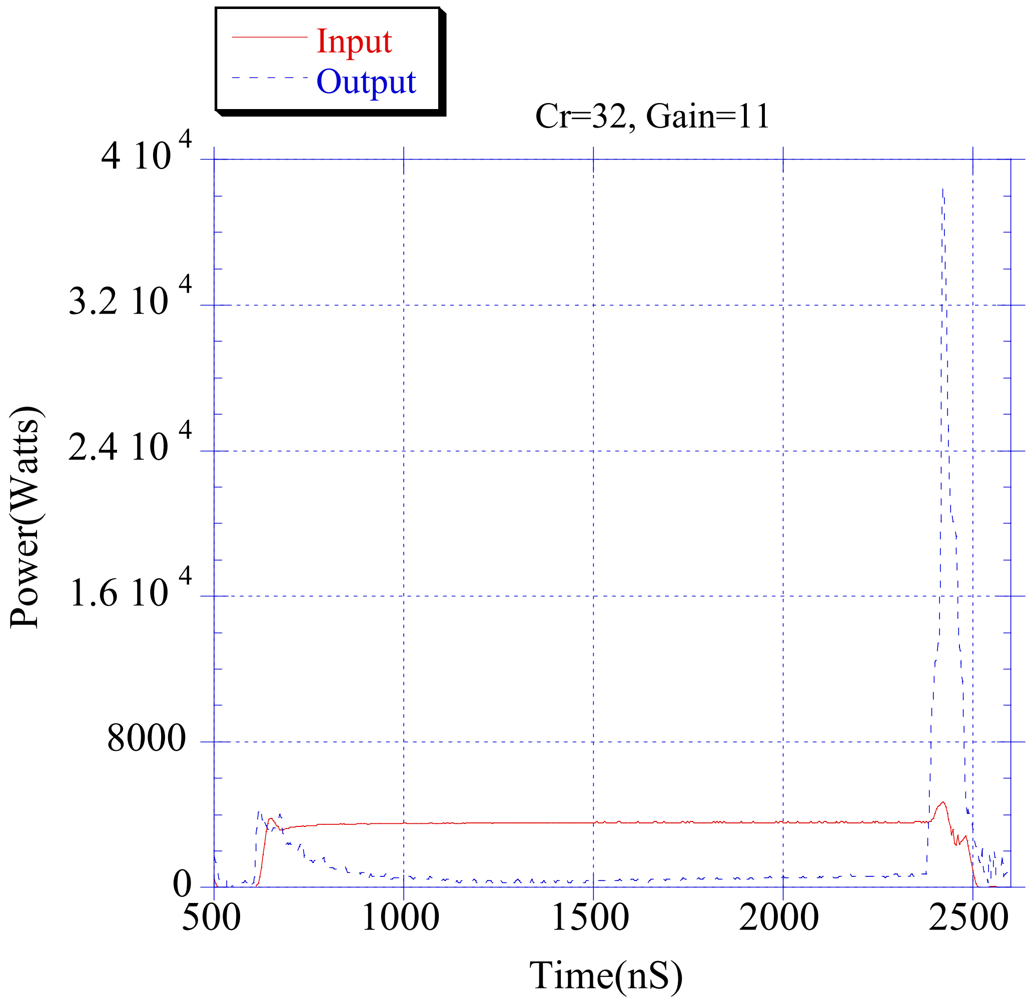




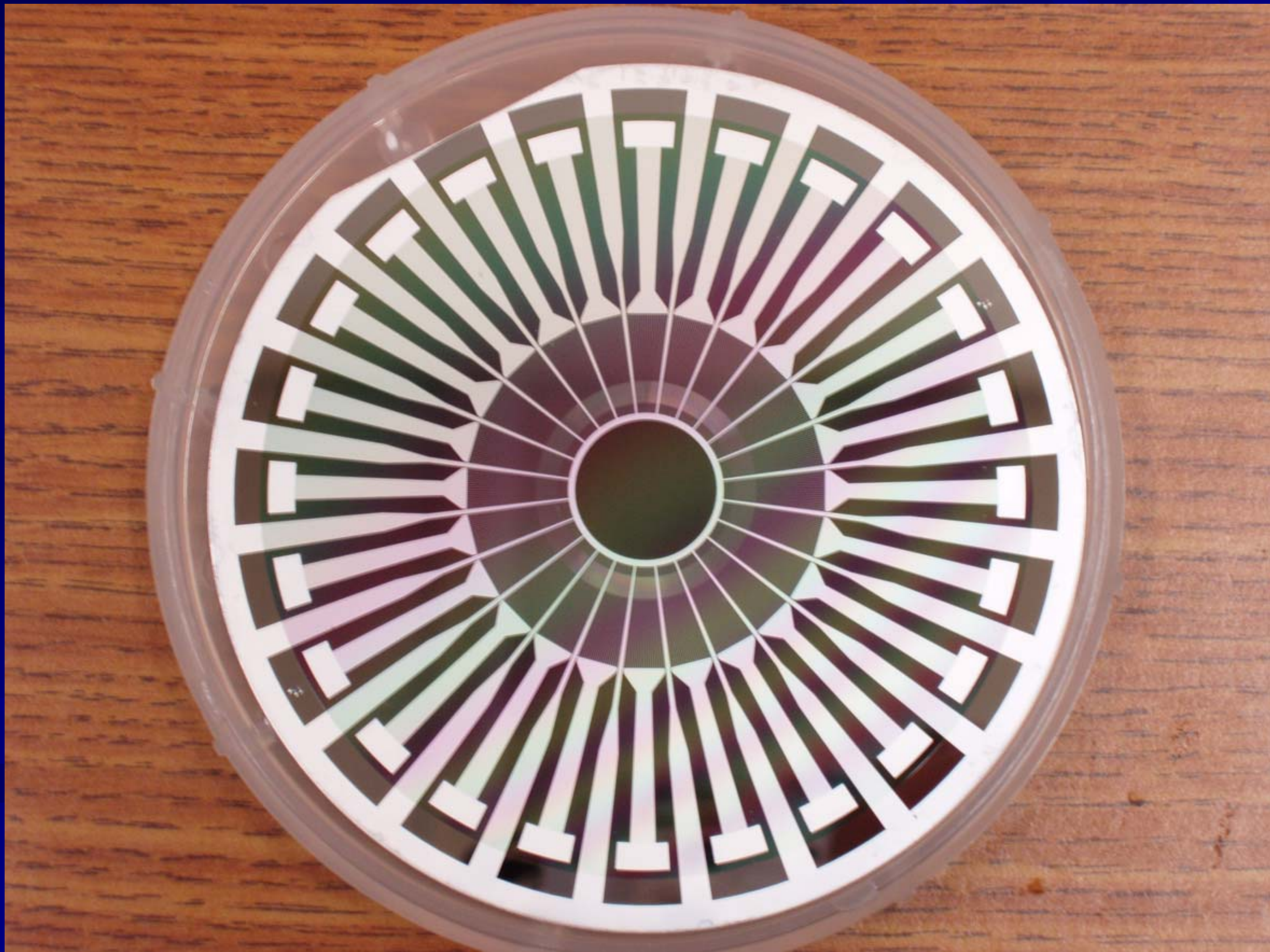


Flower Petal Mode Converter
Silicon Wafer
A 68 nS Delay Line.
Mode Transducer
TE_{01} Choke
Active Iris
Output
Circulator
Sapphire Window
Laser Light (Green @ 532 nm)
Input
Nd:Yag Laser


Input
Output
Cr=8, Gain=6.0, Eff=75.0%
10000
8000
6000
4000
2000
0
500
600
700
800
900
1000
1100
1200
1300
Power (Watts)
Time (nS)

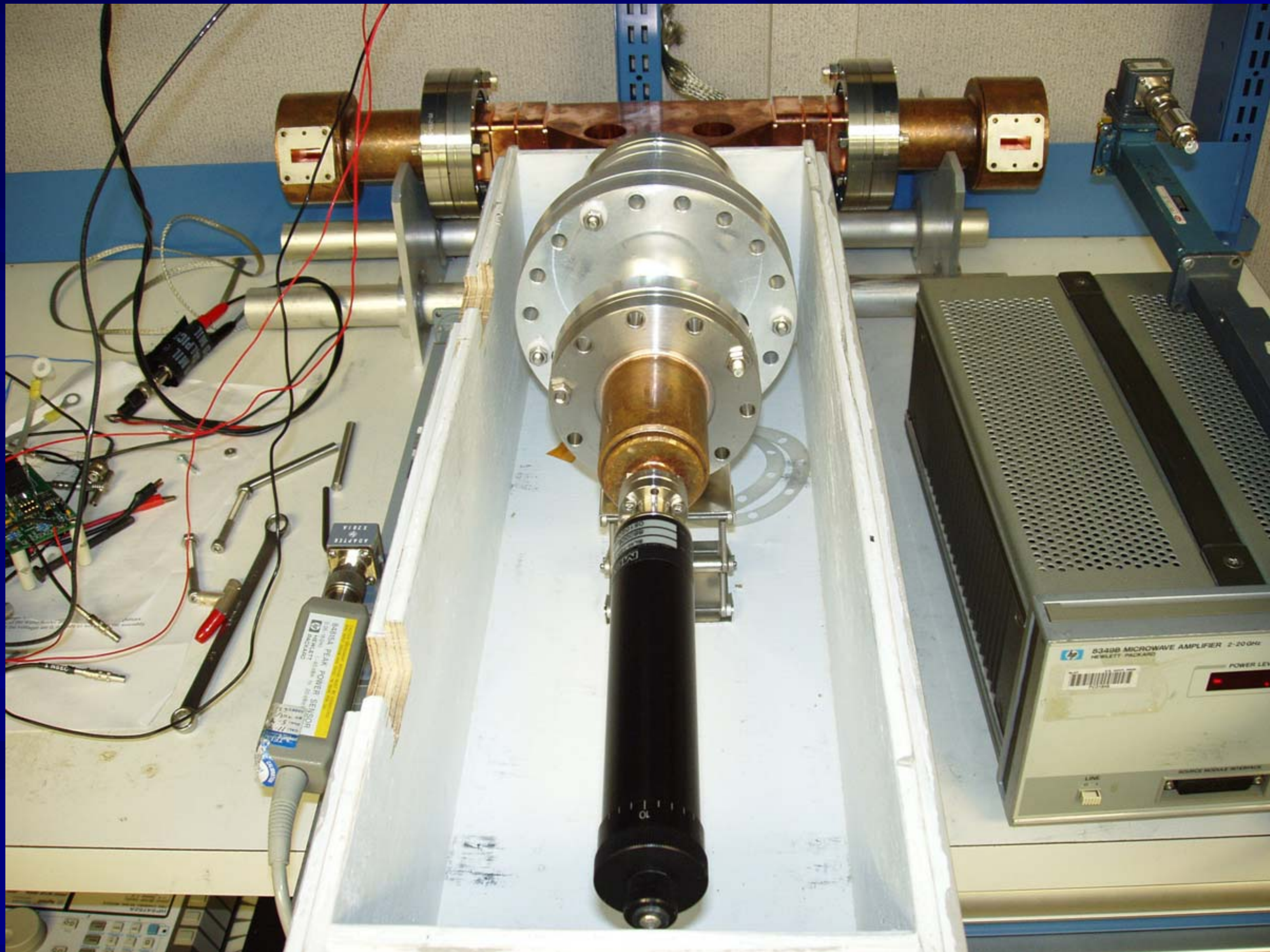

Input
Output
Cr=32, Gain=11
4 10^4
3.2 10^4
2.4 10^4
1.6 10^4
8000
0
Power(Watts)
500
1000
1500
2000
2500
Time(nS)

Diode array

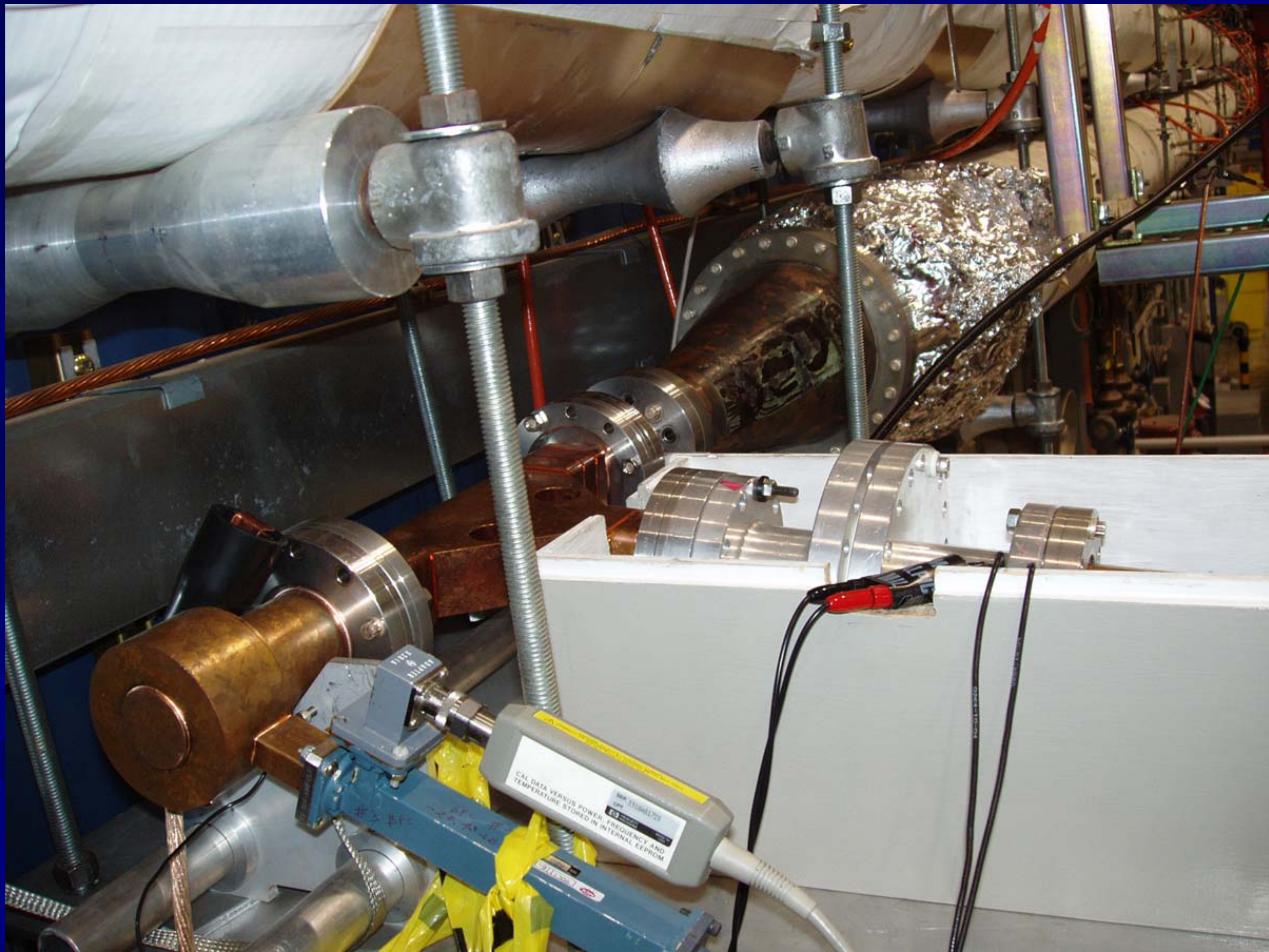


Testing structure

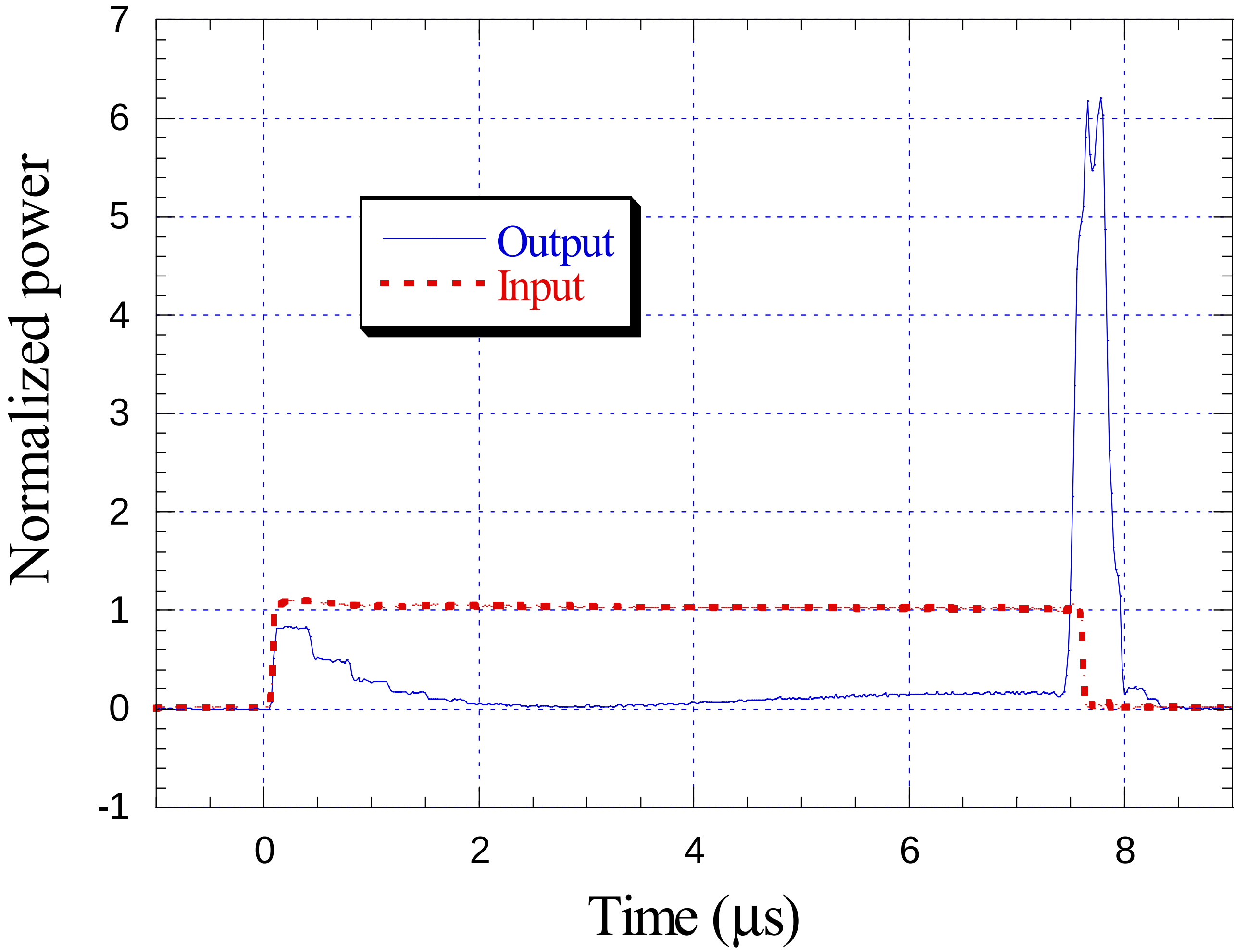
Test Setup with Circular T



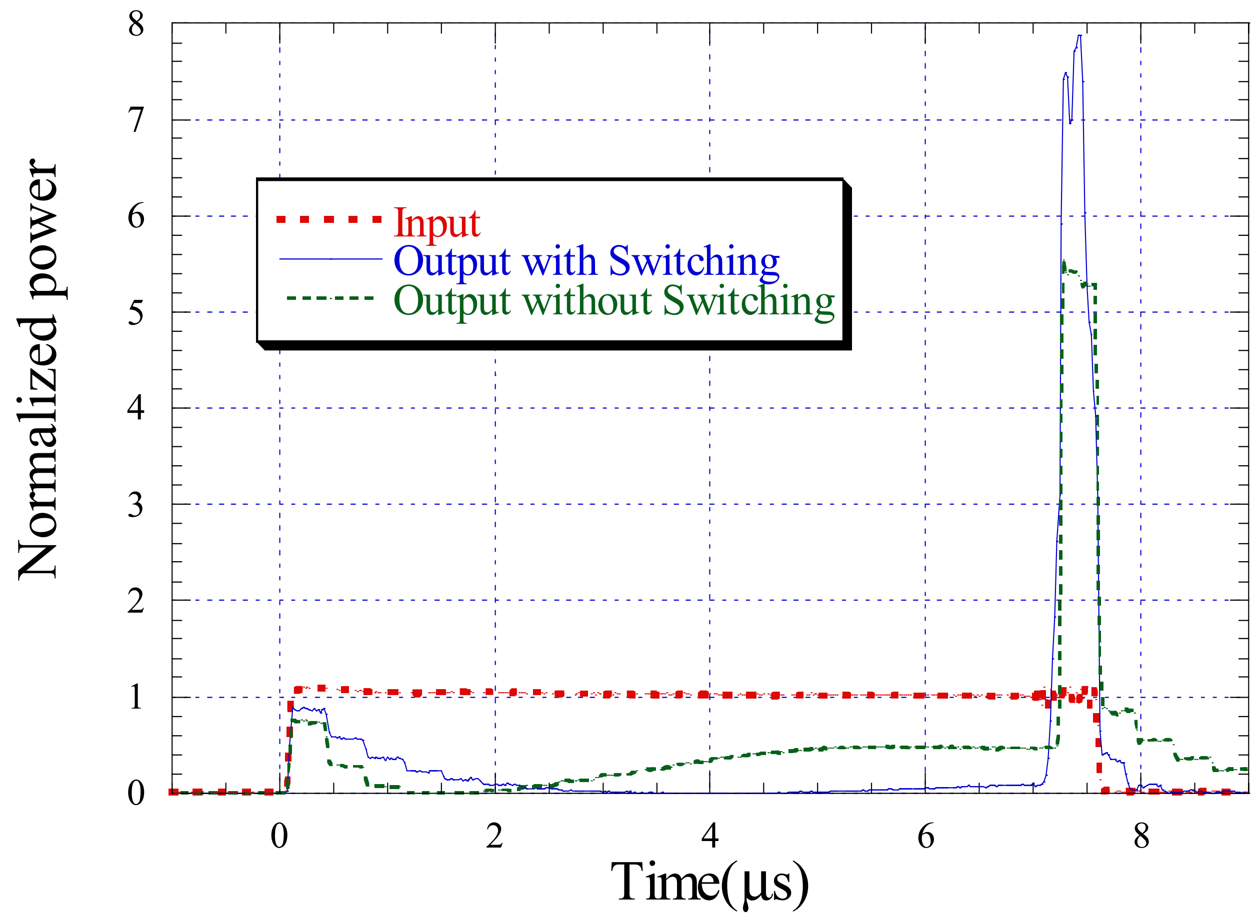
Active Compression Setup



Low Power Active Pulse Compression Test
Without Input Phase Flipping



Low Power Active Compression Test
With Input Phase Flipping



What should we do next

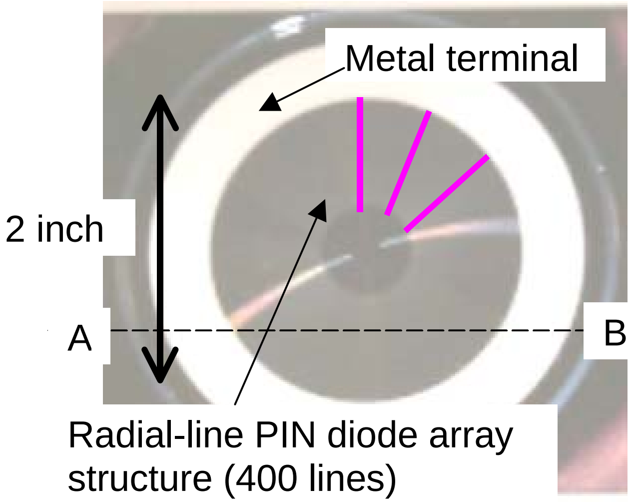
- Test the breakdown properties of Si
  - At X-band at SLAC
  - At Ka Band at CERN
- Real Thermal Analysis
- Chose a laser system (532 nm?)
- Enjoy a working active pulse compression system

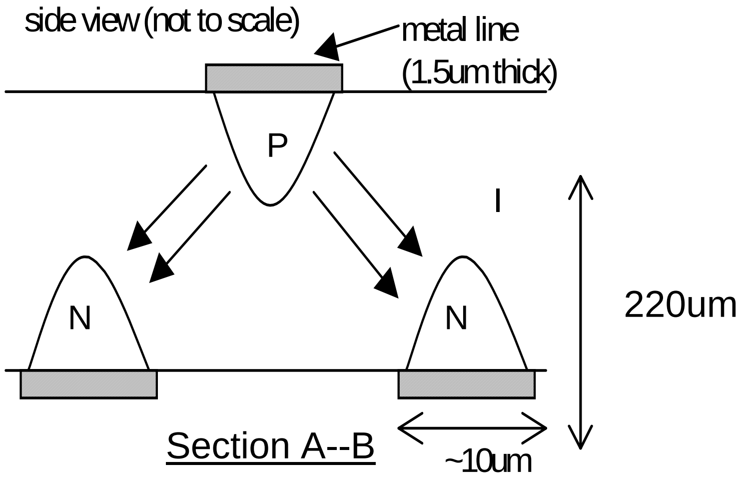
Design and Implementation of PIN/NIP Diode Array Active Window

PIN diode array Active Window

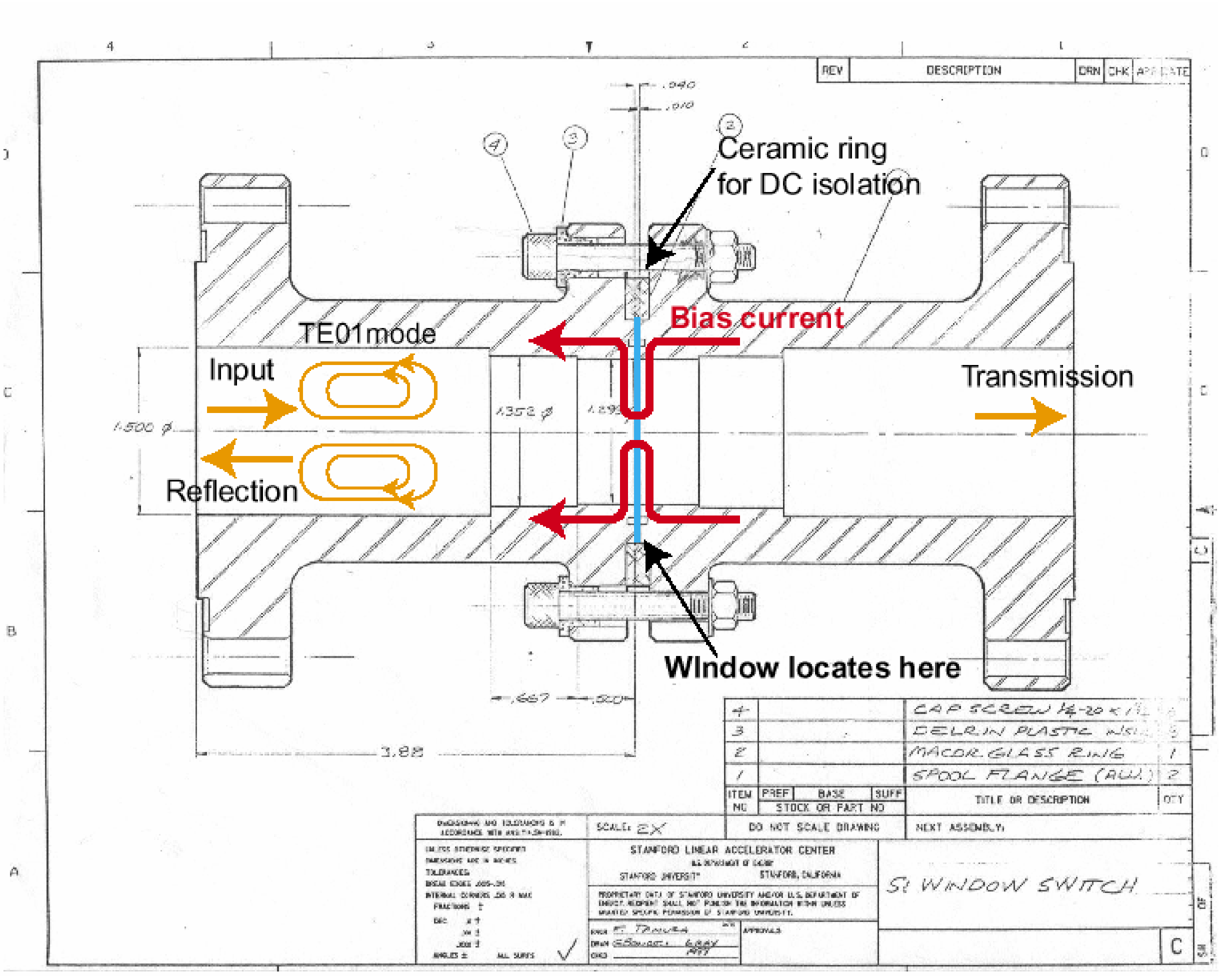
- All doping profile and metallic terminals on the window are radial, i.e. perpendicular to electric field of the TE_{01} mode. → Effect of doping and metal lines on RF signal is small when the diode is reverse biased.

- With forward bias, carriers are injected into I region and I region becomes conductor → RF signal is reflected.



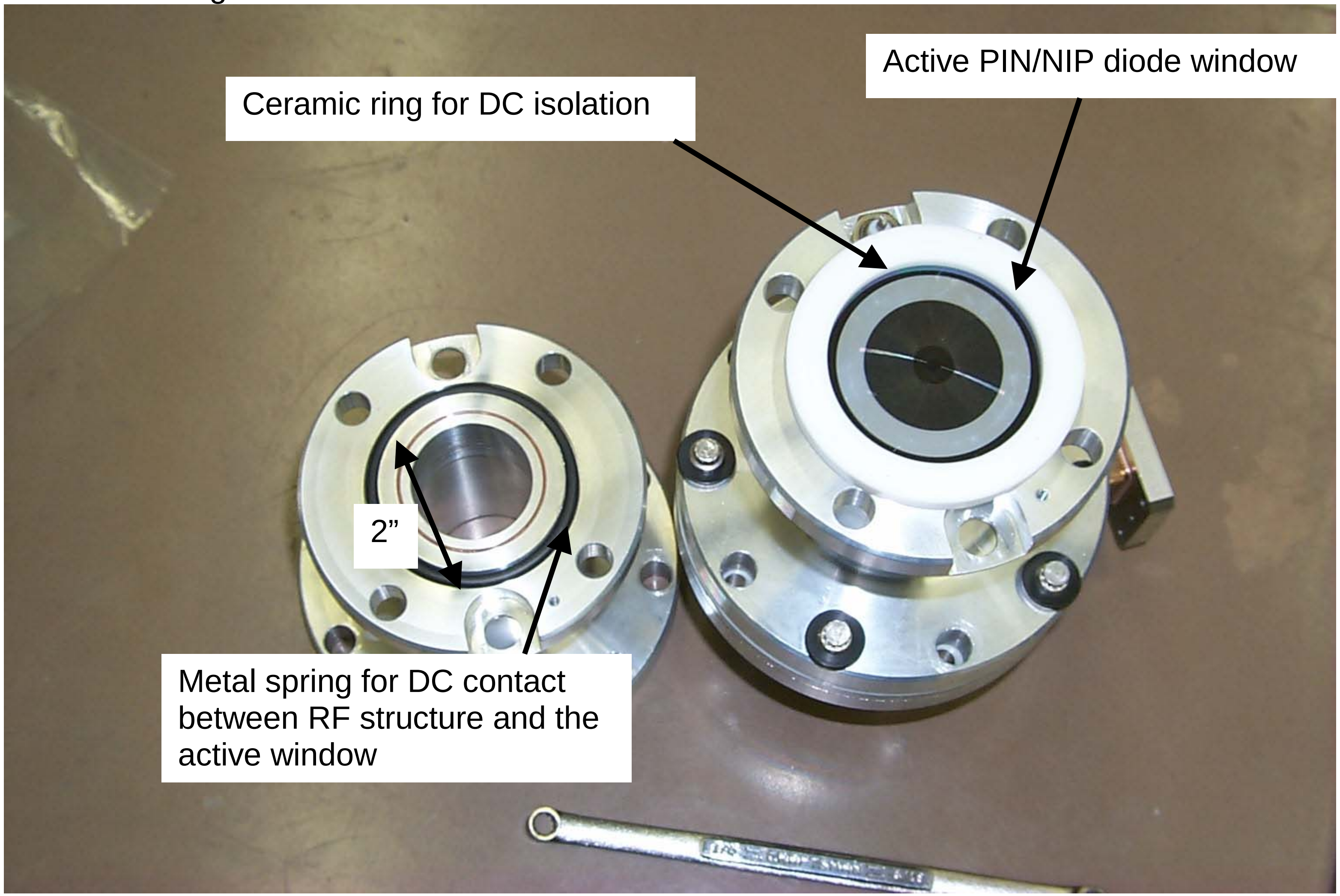


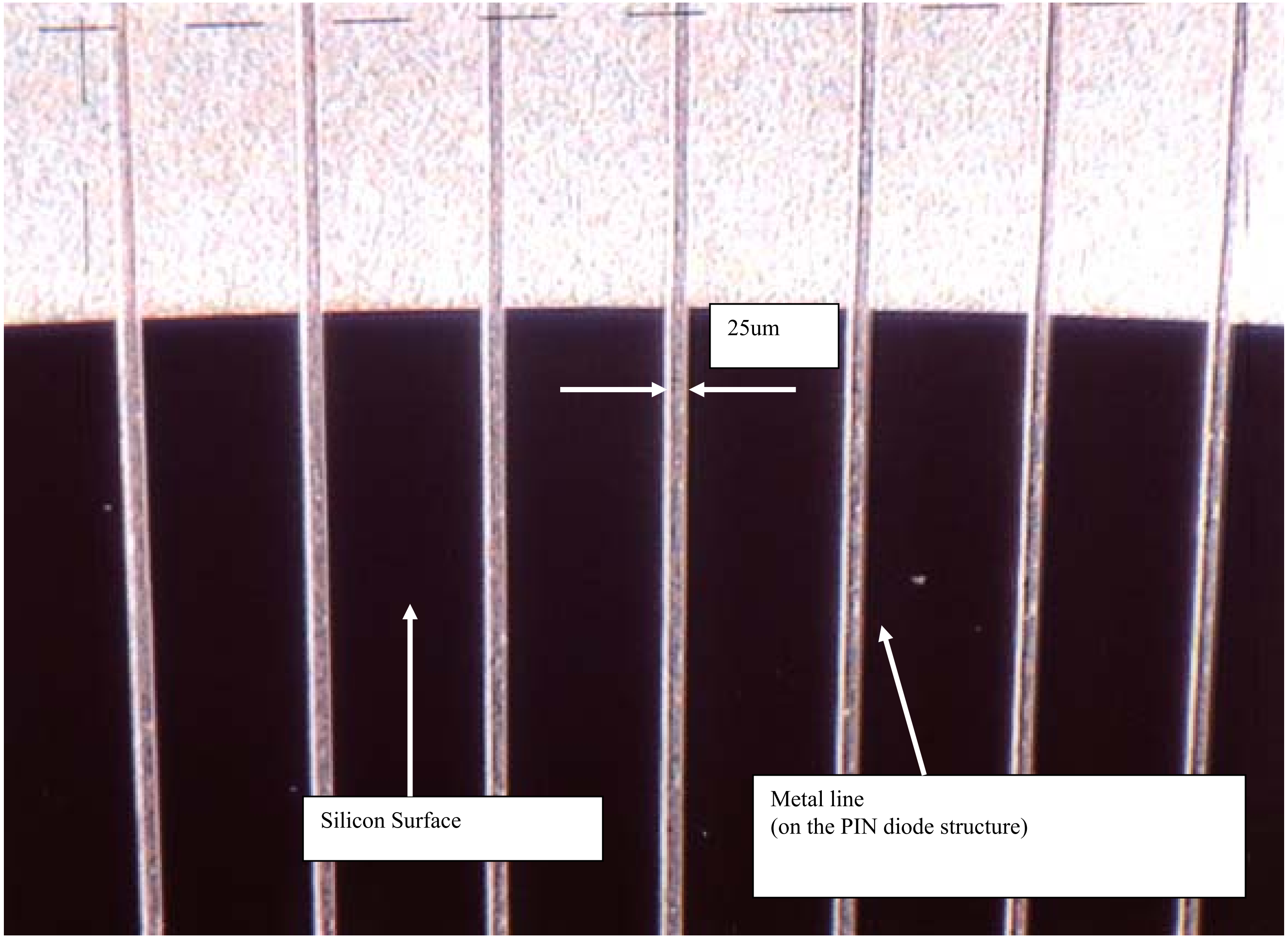
- Base material: high resistivity (pure) silicon, <5000ohm-cm, n-type
- Diameter of active region: 1.3 inch
- Thickness: **220um**
- Coverage (metal/doping line on the surface): ~10%


Ceramic ring
for DC isolation
Bias current
TE01mode
Input
Reflection
Transmission
WIndow locates here
REV
DESCRIPTION
DRN
CHK
.040
.010
1.500 ϕ
1.352 ϕ
.667
.500
3.88
CAP SCREW 1/4-20
DELRIN PLASTIC
MACOR GLASS RING
SPOOL FLANGE (AL)
ITEM NO
PREF
BASE
SUFF
STOCK OR PART NO
TITLE OR DESCRIPTION
QTY
SCALE: 2X
DO NOT SCALE DRAWING
NEXT ASSEMBLY
STANFORD LINEAR ACCELERATOR CENTER
STANFORD UNIVERSITY
STANFORD, CALIFORNIA
APPROVALS
Si WINDOW SWITCH
C

RF structure

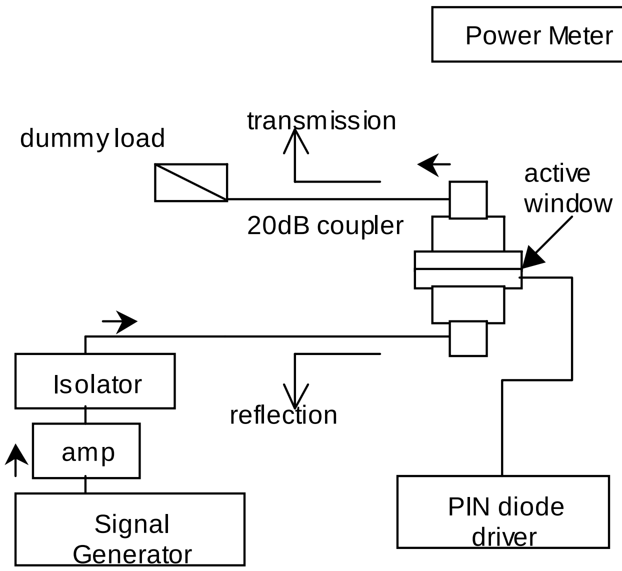
- DC isolation by Al_2O_3 ceramic ring
- No RF choke is needed (TE_{01} mode)
- Higher impedance (Zg / Z0 ~4, close to cutoff) for this experiment
  - Enhance the effect of window switching status
  - Lower loss at the window during forward bias
  - Huge mismatch without bias




25um
Silicon Surface
Metal line
(on the PIN diode structure)

Low Power Measurement

Setup:

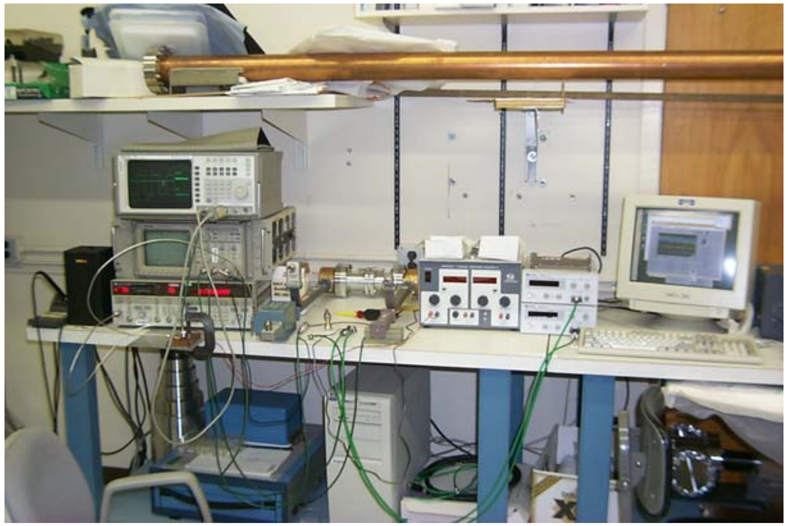


Peak power meter

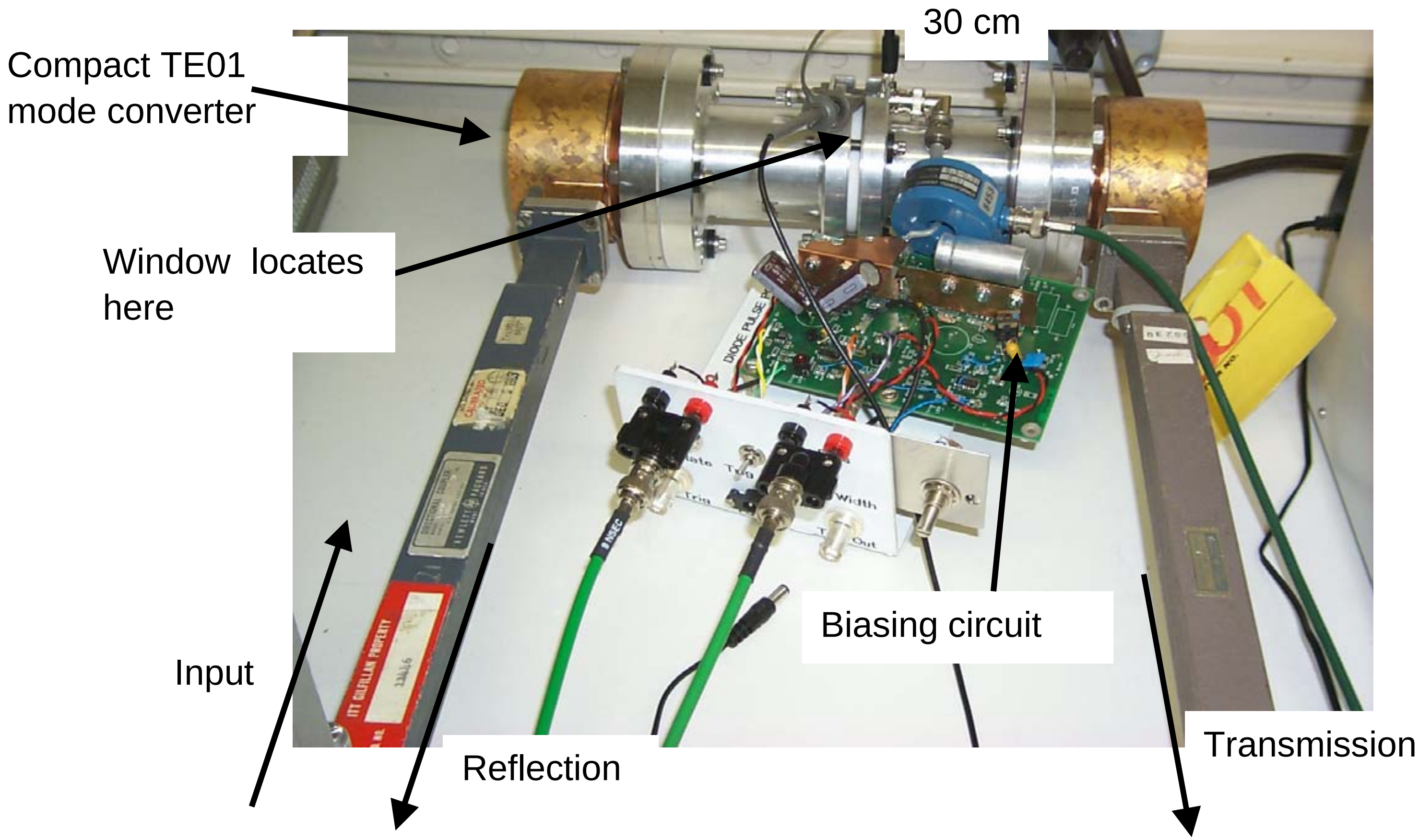
RF source

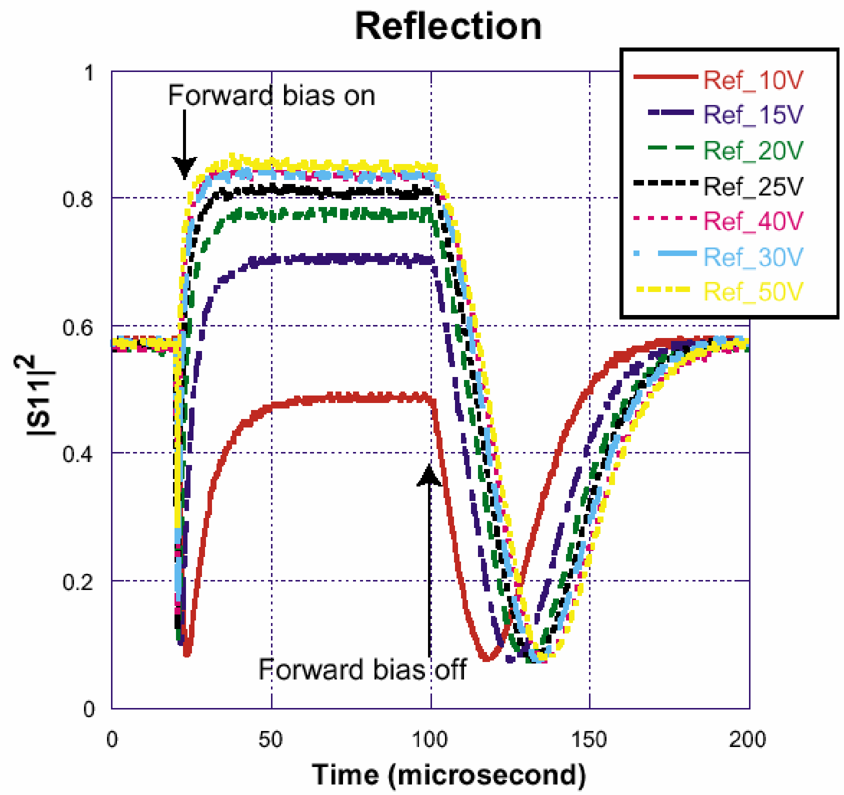
Active window

Low power measurement system

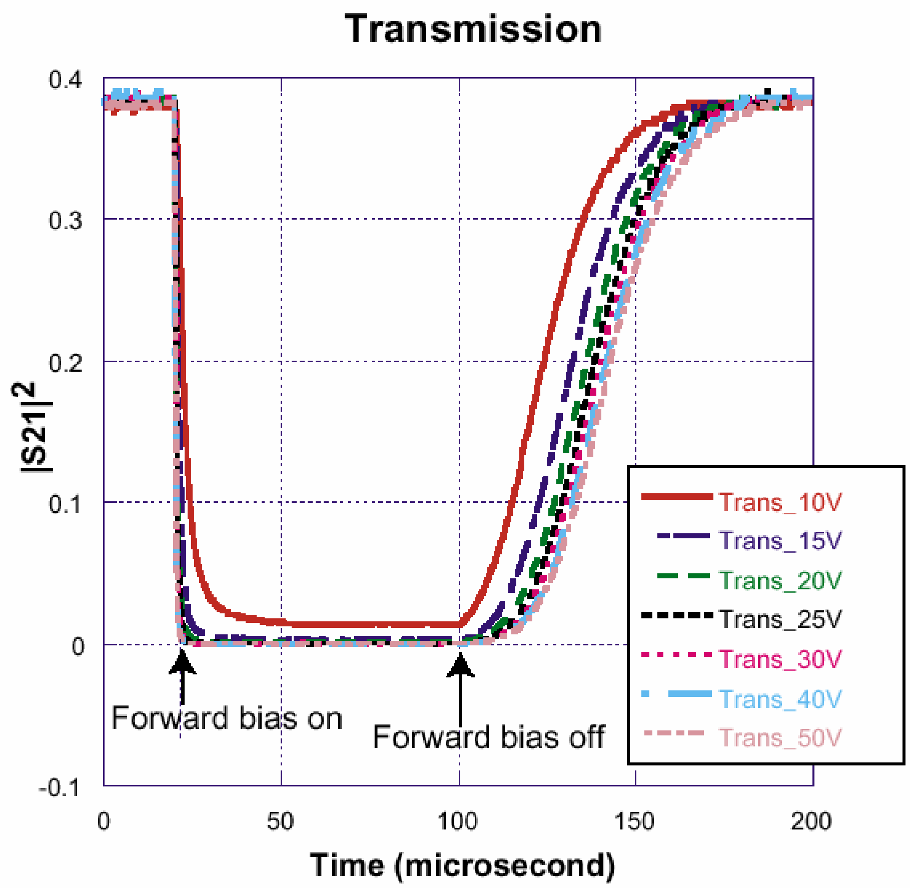


- Current is measured by current transformer


30 cm
Compact TE01 mode converter
Window locates here
Biasing circuit
Input
Reflection
Transmission



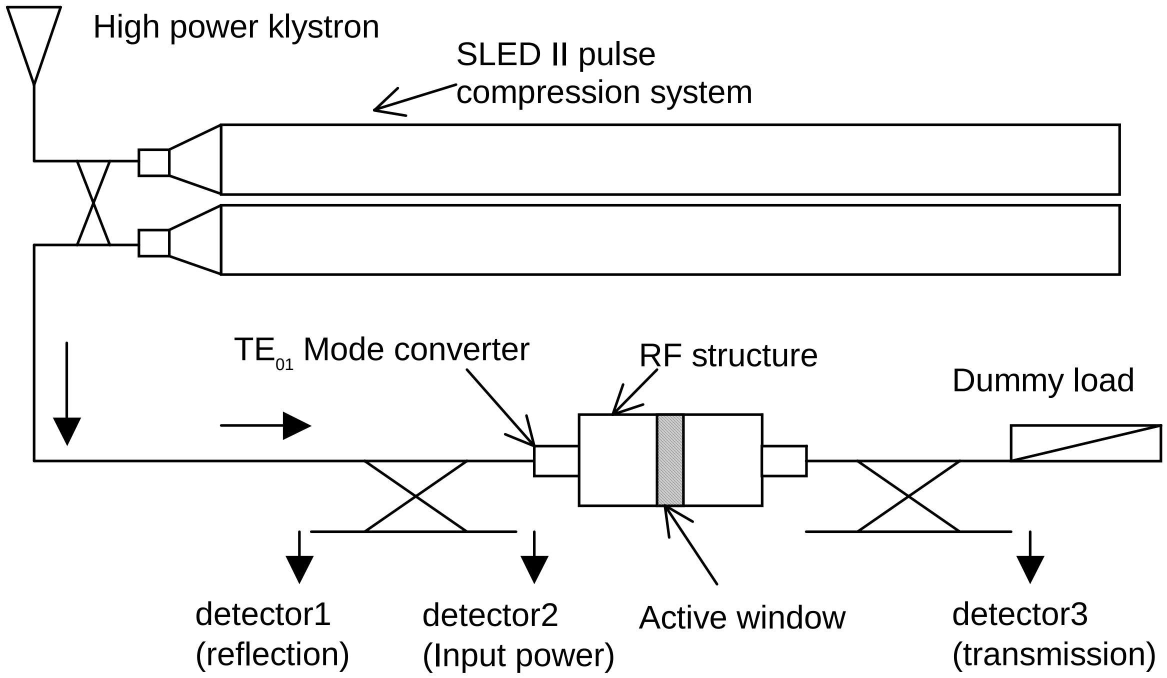
Reflection
Forward bias on
Forward bias off
Ref_10V
Ref_15V
Ref_20V
Ref_25V
Ref_40V
Ref_30V
Ref_50V
|S11|^2
Time (microsecond)



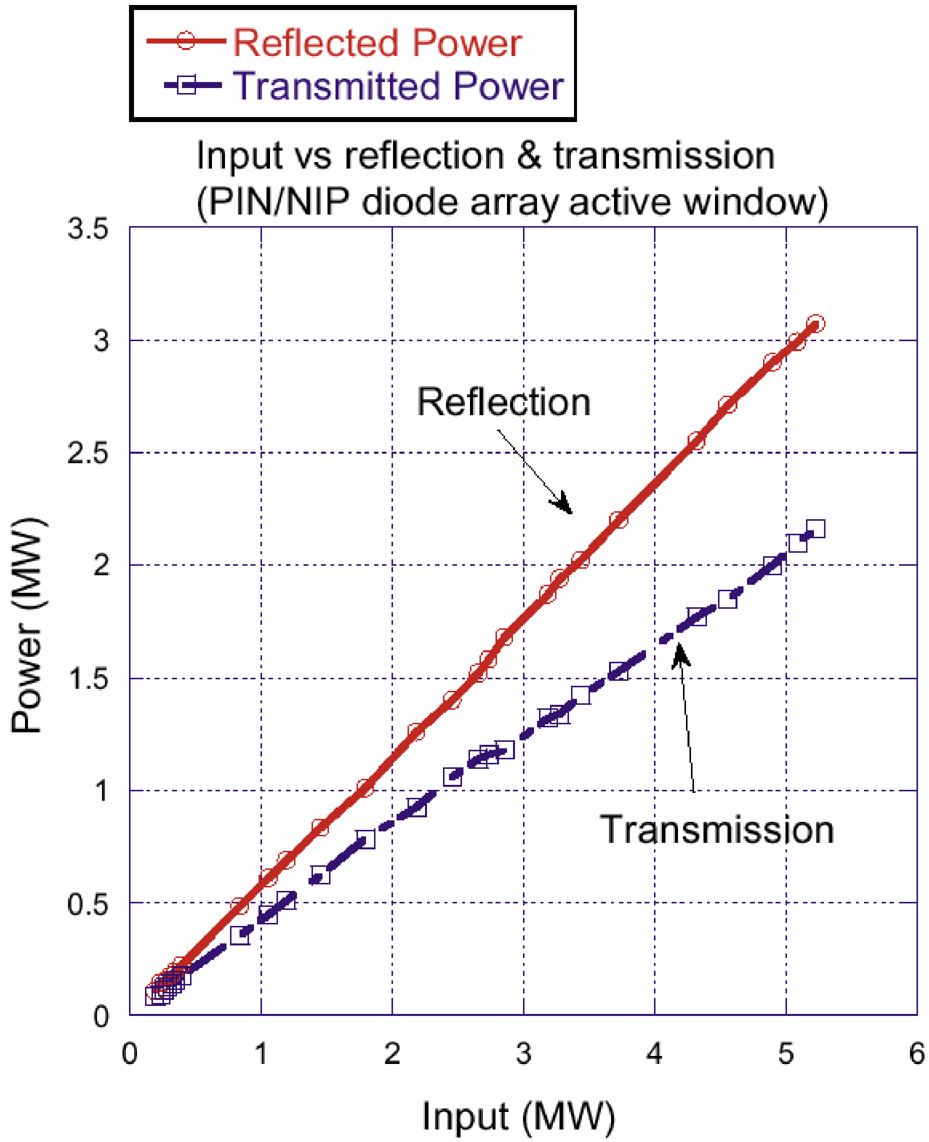
Transmission
Forward bias on
Forward bias off
Trans_10V
Trans_15V
Trans_20V
Trans_25V
Trans_30V
Trans_40V
Trans_50V
|S21|^2
Time (microsecond)

High Power Experiment

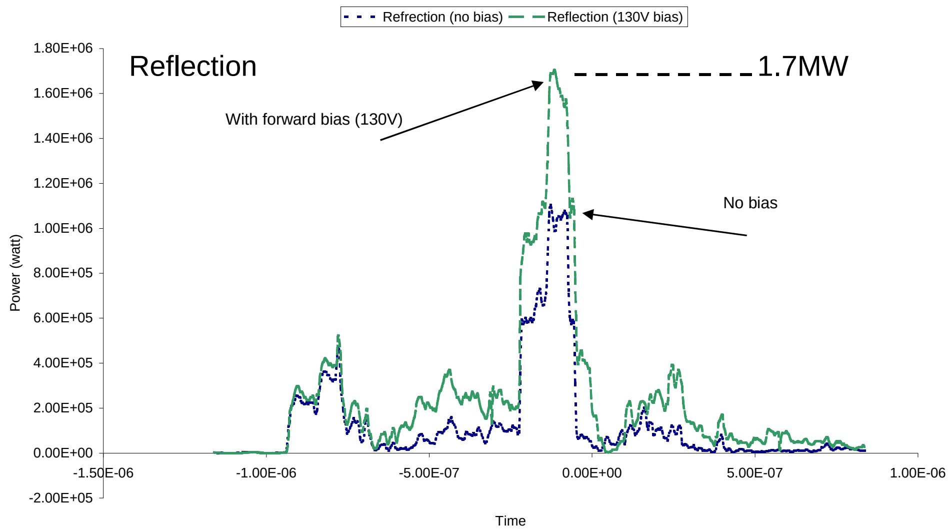
- Setup

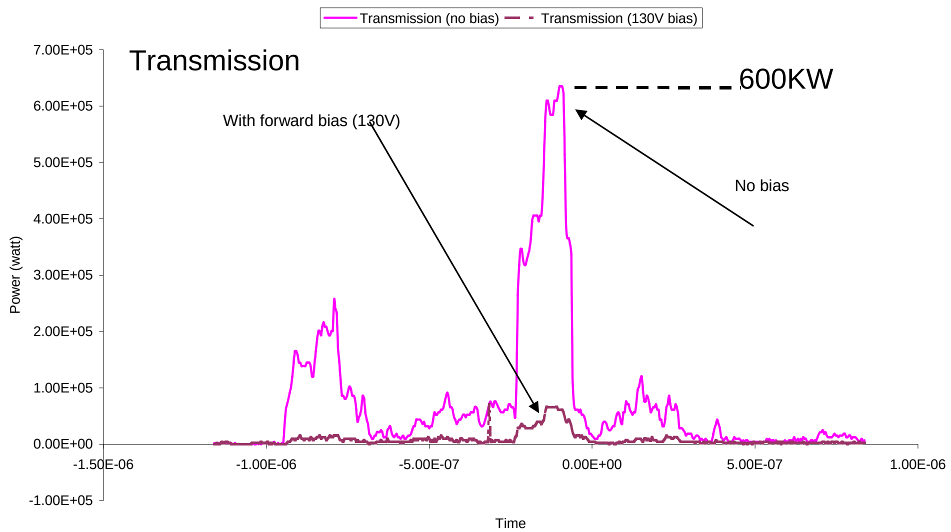


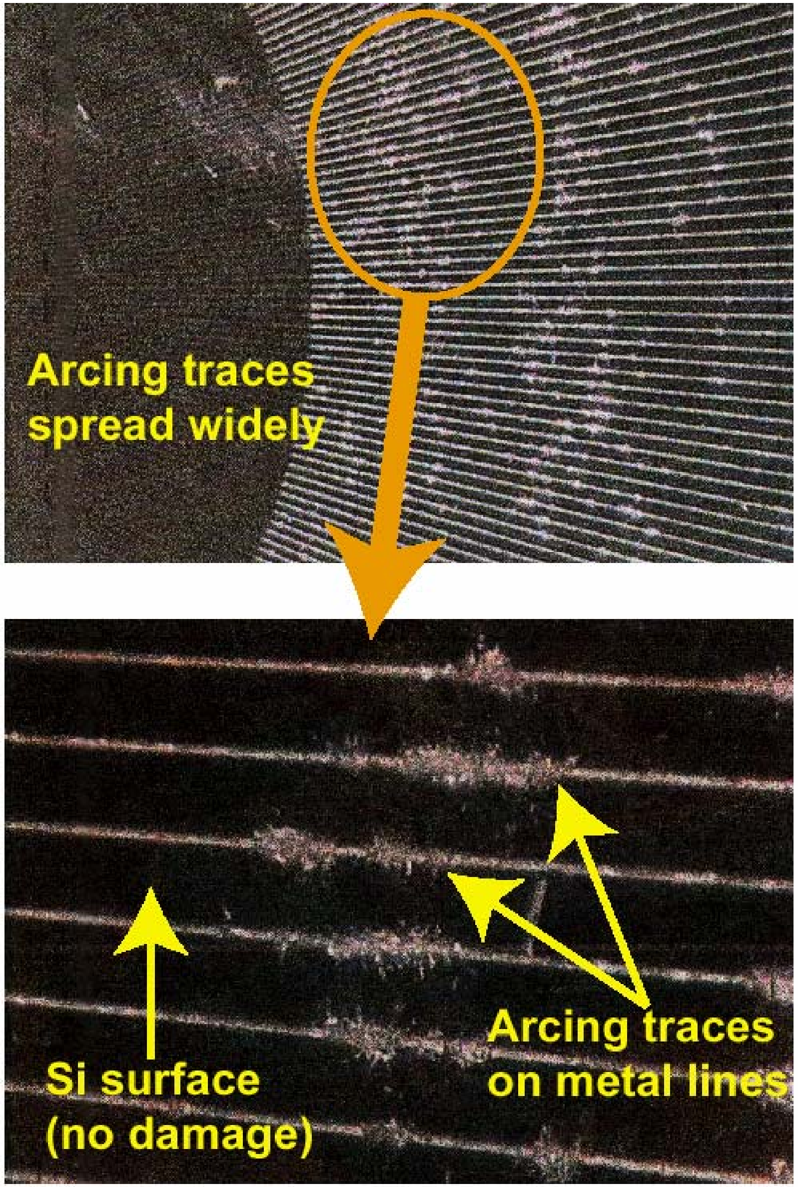
- SLED II output pulse width ~ 150nsec, up to ~10MW can be produced by this system
- Purpose:
  - Investigating failure modes with increasing electric field strength of RF signals
  - Demonstration of switching capabilities at a multi-megawatt power levels at X-band

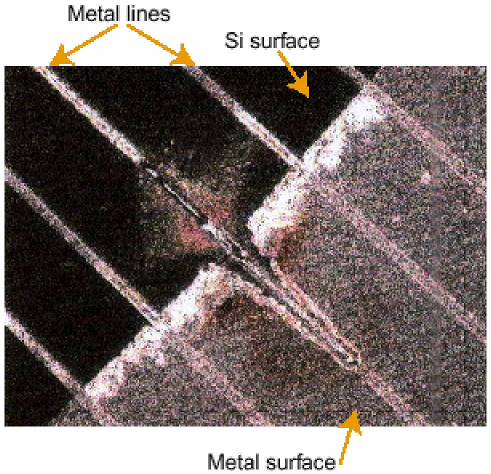


Reflected Power
Transmitted Power
Input vs reflection & transmission
(PIN/NIP diode array active window)
Reflection
Transmission
Power (MW)
Input (MW)
0
0.5
1
1.5
2
2.5
3
3.5
0
1
2
3
4
5
6


Refrection (no bias)
Reflection (130V bias)
Reflection
1.7MW
With forward bias (130V)
No bias
Power (watt)
1.80E+06
1.60E+06
1.40E+06
1.20E+06
1.00E+06
8.00E+05
6.00E+05
4.00E+05
2.00E+05
0.00E+00
-2.00E+05
-1.50E-06
-1.00E-06
-5.00E-07
0.00E+00
5.00E-07
1.00E-06
Time


Transmission (no bias)
Transmission (130V bias)
Transmission
600KW
With forward bias (130V)
No bias
Power (watt)
7.00E+05
6.00E+05
5.00E+05
4.00E+05
3.00E+05
2.00E+05
1.00E+05
0.00E+00
-1.00E+05
-1.50E-06
-1.00E-06
-5.00E-07
0.00E+00
5.00E-07
1.00E-06
Time


Arcing traces
spread widely
Si surface
(no damage)
Arcing traces
on metal lines


Metal lines
Si surface
Metal surface