SLAC's Experimental Program for This Year

Sami Tantawi

Outline

- New Ideas for accelerators
- Experimental work at SLAC and facilities
- Active pulse compression review
- On the active pulse compressor at 30 GHz

Novel Accelerator Structures

- *distributed coupling.*
  - It is well known that single cavities are capable of supporting higher fields than a coupled set of cavities.
  - We propose to test an accelerator structure composed of a coupled set of accelerating cavities.
  - The cavities are coupled only through a compact distribution system, which could be built into the cavity construction.
  - This idea has been reinvented by several people over the years but has never been properly designed and tested.
- *High Frequency Dielectric structures*
  - It is also well known that short pulse length improves the high gradient properties of most copper structures.
  - As we increase the frequency, the optimal fill time of an accelerator structure is reduced.
  - Because of pulsed surface heating, going to higher frequencies is very difficult, if not impossible, for metallic structures
  - This problem could be alleviated by using dielectric structures.

Summary of SLAC Facilities

- NLCTA (3 RF stations, one Injector, one Radiation shielding)
  - Two 240ns pulse compressor, 300 MW peak, powered by two X-band 50 MW klystrons
  - One 400 ns pulse compressor, 500 MW peak, powered by 4 X-band 50 MW klystrons (being reduced in size to 300 MW peak, powered by two 50 MW klystrons)
  - 65 MeV injector with a 1 nC charge/bunch
  - Shielding enclosure suitable for up to 1 GeV
- Klystron Test Lab (3 RF stations, 3 modulators, 2 shielding enclosures)

  RF Stations
  - Stations 6 and 8, two 50 MW klystrons that can be combined and 150 ns pulse compressor that can produce up to 480 MW.
  - Station 4, 50 MW klystron,
  - Station 1, 50 MW klystron

  Modulators
  - Station 2, ~500 kV, ~200 A modulator
  - Station 13, ~500 kV, ~200 A modulator
  - Station 3, 500 kV, ~xxx A modulator

  Radiation Shielding
  - A shielding enclosure suitable for up to 100 MeV (ASTA Bunker)
  - A shielding enclosure suitable for up to 5 MeV

NLCTA

- At the moment we have only two station at NLCTA
- For the next year, these will serve as the only test bed for two SLAC programs and for testing structure for CERN, KEK and other collaborators.
- The turn around time is ~ 6 weeks

Klystron Test Lab

- Much simpler setups and faster turn around
- One can modify most of the experiments on the fly
- Modulators near the shielding enclosures could be used for different frequency experiments
- Most of the devices could be run at 60 Hz or higher repetition rates.

Work Done at the ASTA Bunker

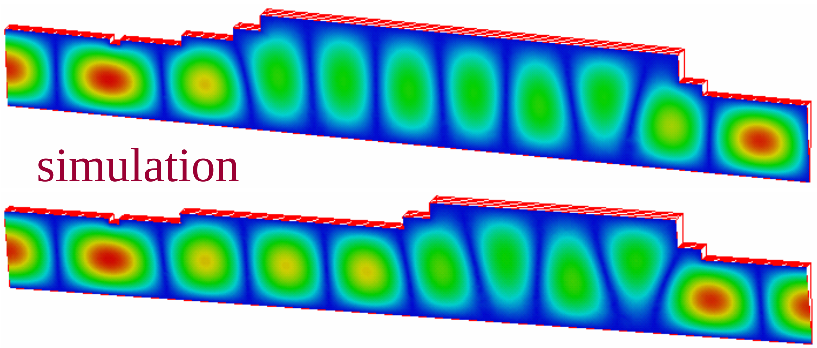
- The roof of the ASTA bunker was the birth place for most of the developments of rf components, including flower petal mode converters, wraparound mode converters and planer components
- Initial testing of high gradient accelerator structures
- All the waveguide breakdown test have been performed on the roof of the ASTA buncker
- These activities stopped around 2001 and as a consequence:
  - Our *basic physics* experimental program on high gradient has stopped
  - The testing of ANL's dielectric accelerator was cancelled
  - The NRL 11.4 GHz magnicon facility started to fill in this void

Proposed Work at the ASTA Bunker

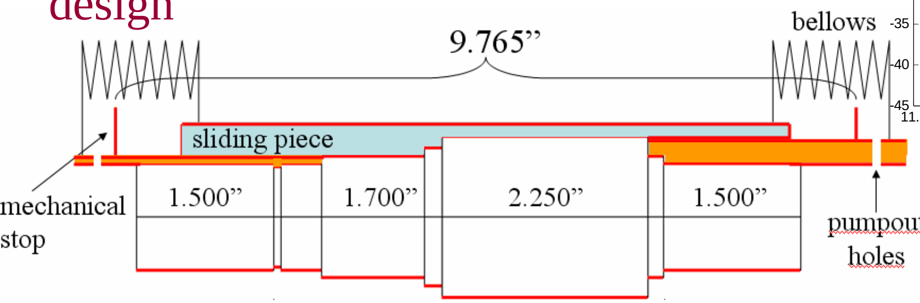
- Most of the experiments proposed inside the bunker takes very little power (tens of MW) while the system is capable of hundreds of MW one the pulse compressor is connected
- One can create an RF system which divert the power from one point to another, hence utilizing this facility to its full potential
- The roof of the ASTA bunker is an ideal place for a lot of experiments, specially waveguide breakdown experiments
- The inside of the bunker is ideal for multi-cell test structures, the only other place is the NLCTA
- This facility might be available for work in 9 month

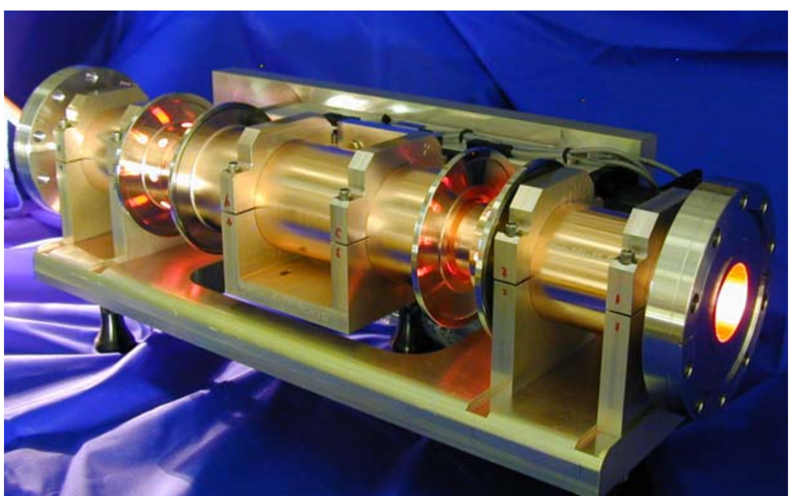
Circular TE_{01} Mode Slide Phase Shifter

simulation

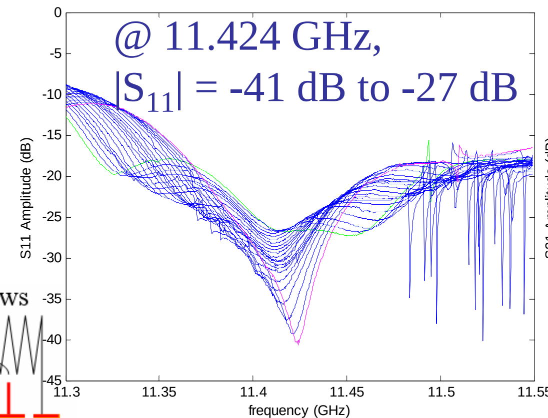


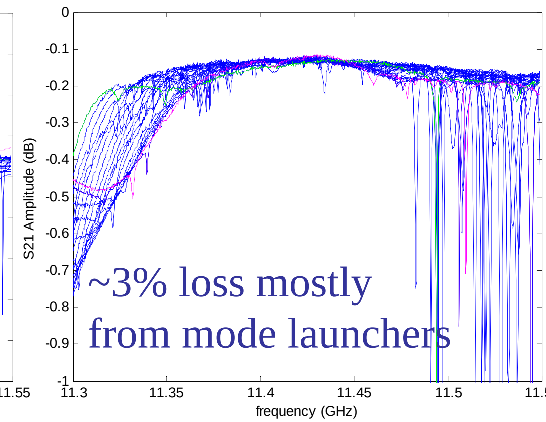
design

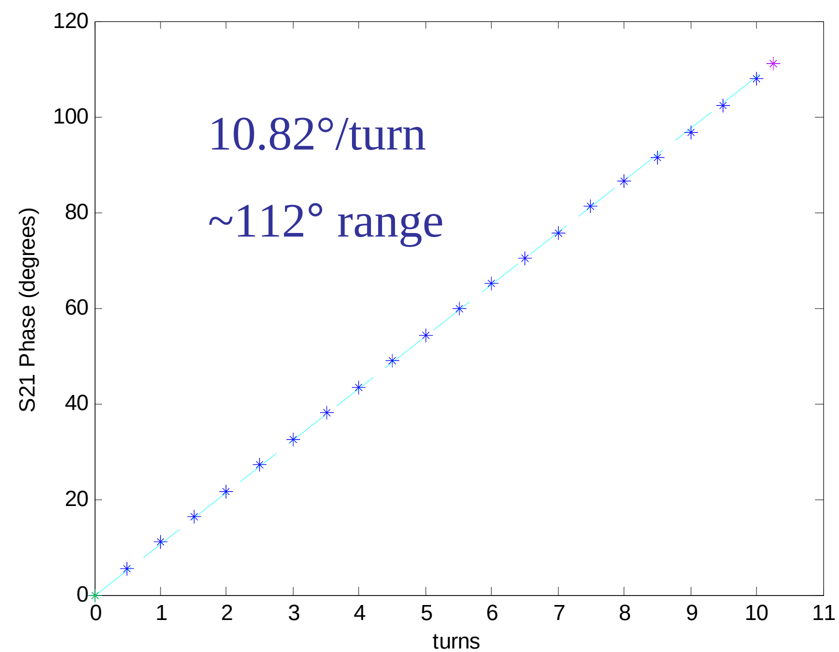




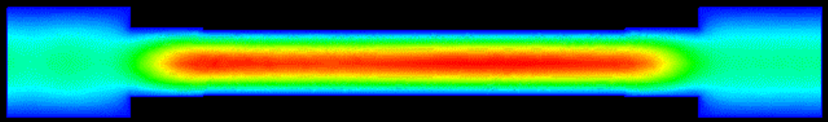
cold test results



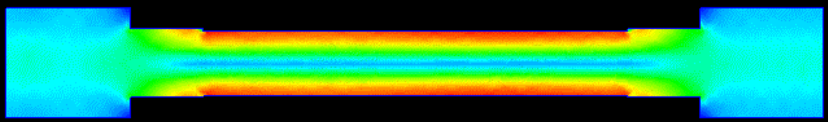




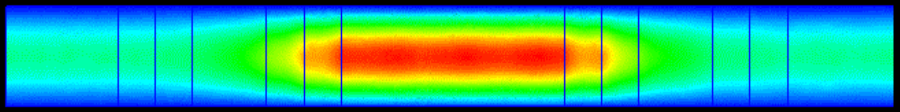
Geometrical Effects in Waveguides

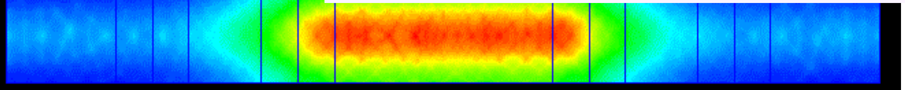


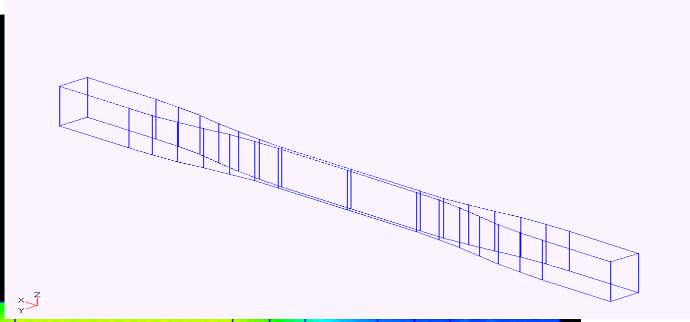
Electric Field Distribution



Magnetic Field Distribution

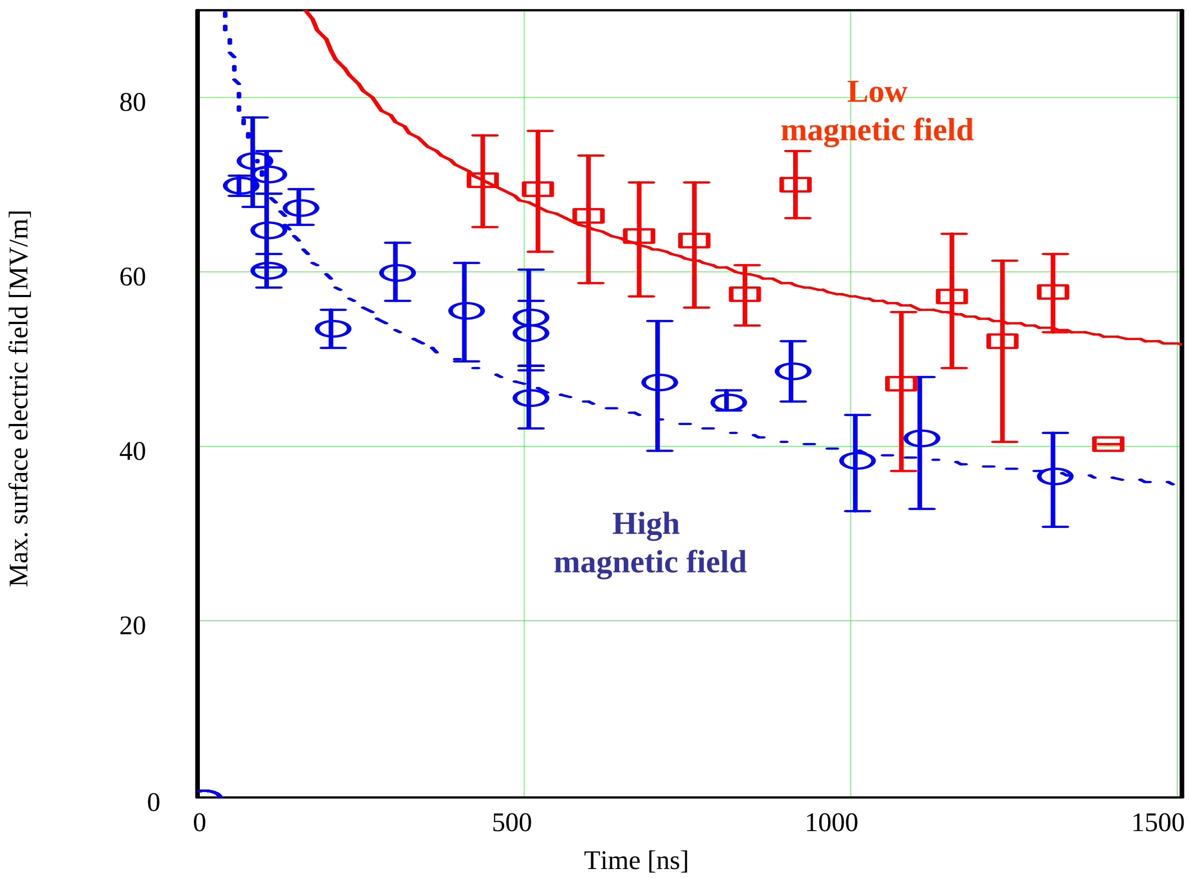






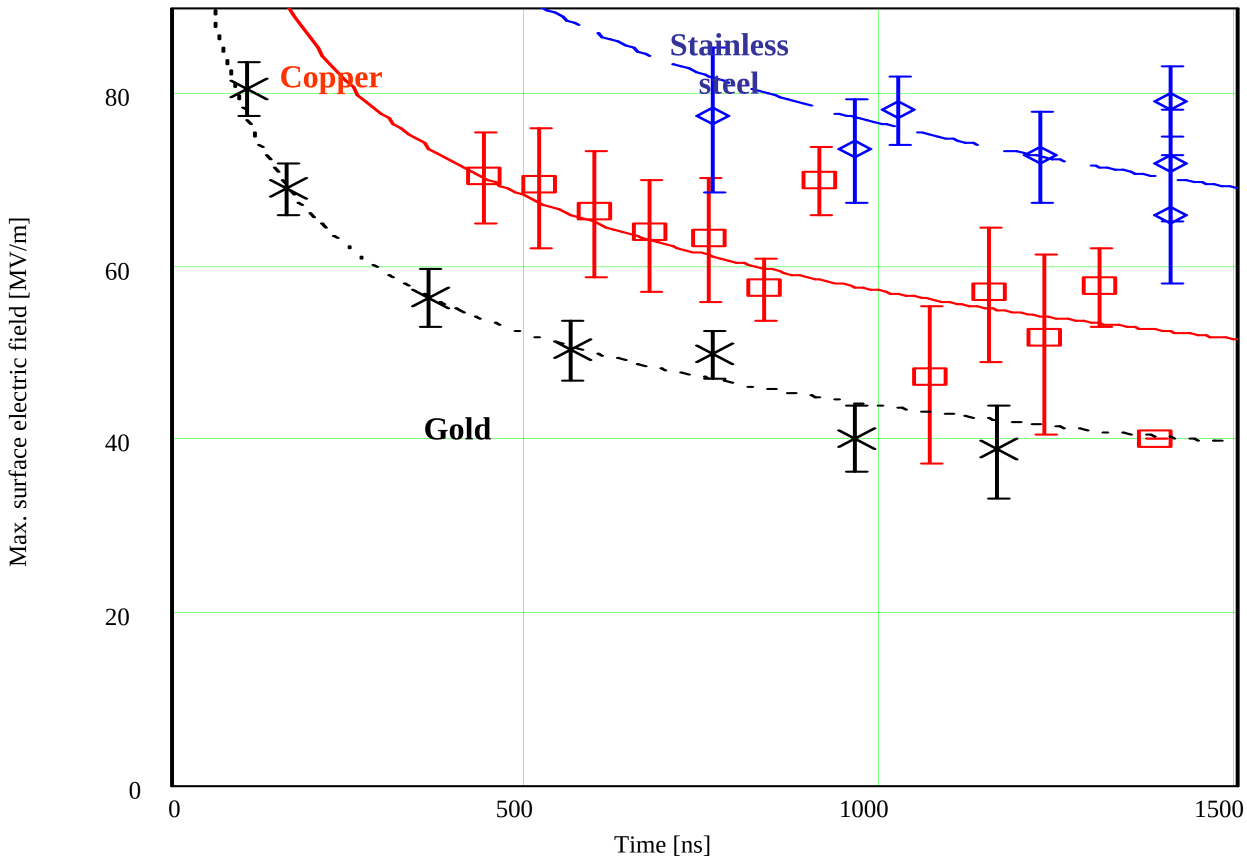
- The peak electric field surface area equal that of the low magnetic field waveguide
- For a given input power both waveguide have the same peak electric field
- Ratio between magnetic field at peak electric field between both guides=21

Waveguide High Gradient Study
Maximum breakdown electric fields for different geometries



Material Dependence

Waveguide High Gradient Study Maximum breakdown electric fields for different Materials



Planned waveguide tests

- Molybdenum waveguide
- Stainless steel high magnetic field waveguide
- Chromium waveguide

Single Cell Accelerator Structure Motivations Motivation

Goals

- Study rf breakdown in practical accelerating structures: dependence on circuit parameters, materials, cell shapes and surface processing techniques

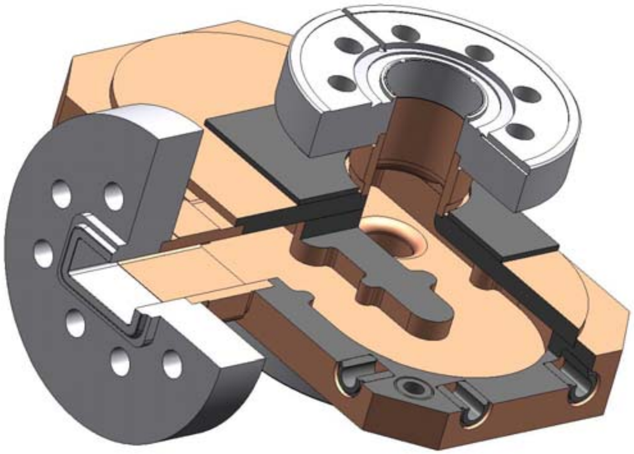
Difficulties

- Full scale structures are long, complex, and expensive

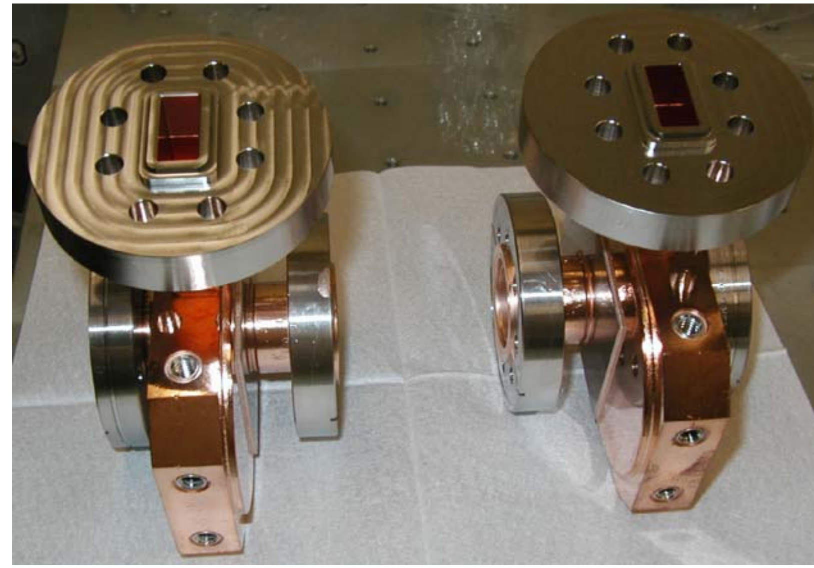
Solution

- ***Single cell Traveling wave (TW)*** and ***single cell standing wave (SW)*** structures with properties close to that of full scale structures
- Reusable couplers

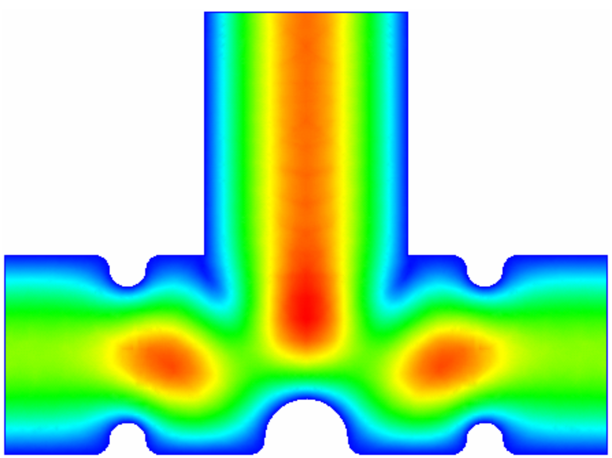
TM_{01} Mode Launcher



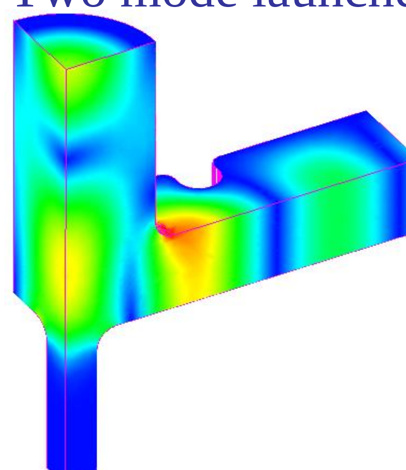
Cutaway view of the mode launcher



Two mode launchers

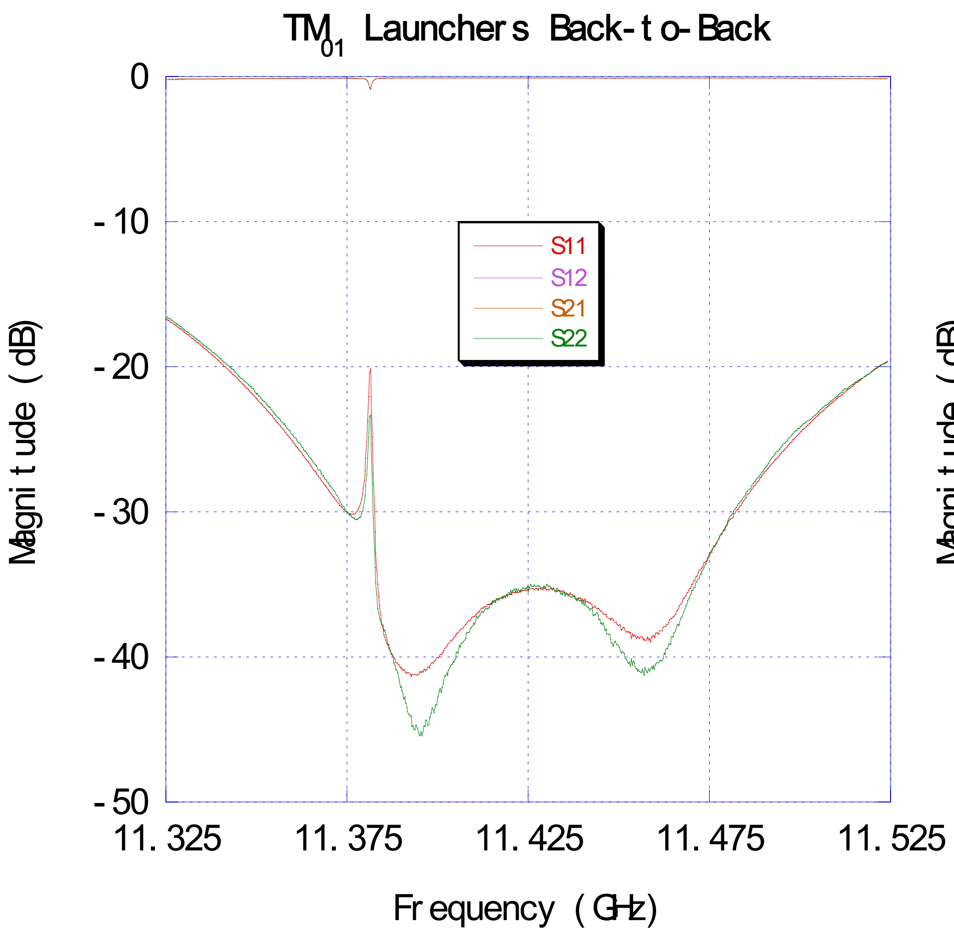


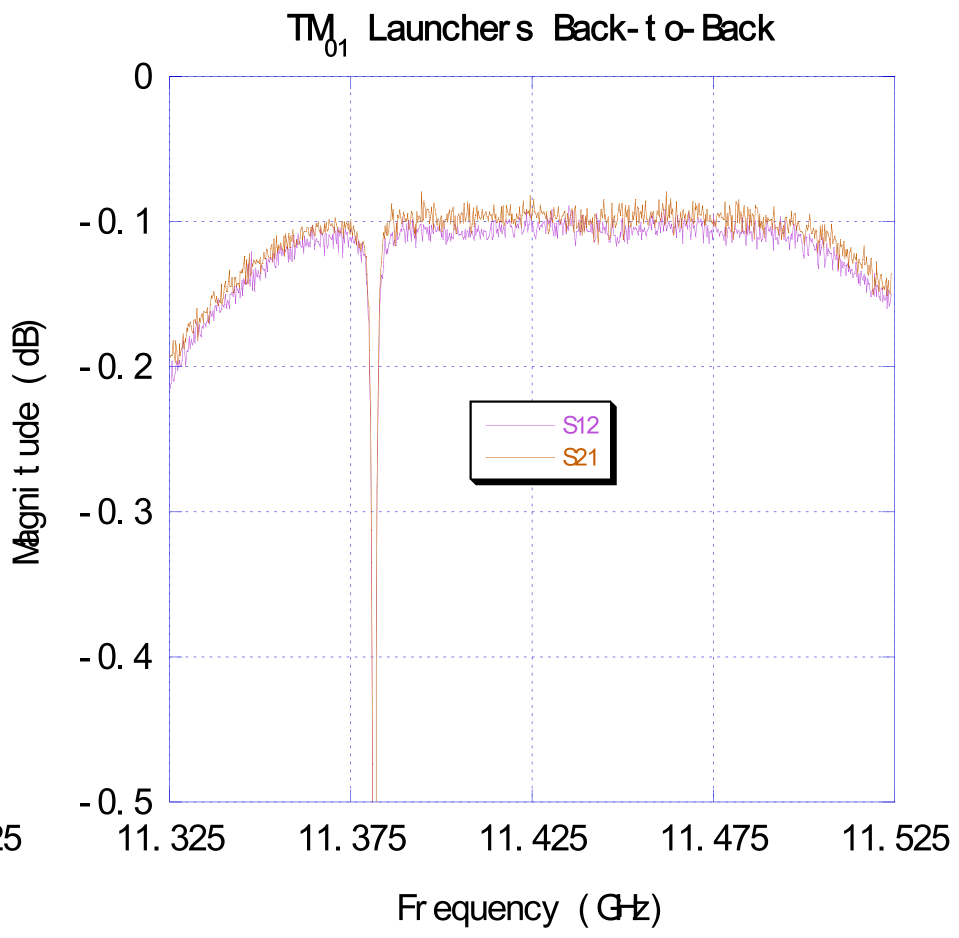
Surface electric fields in T splitter,
E_{max}= 30 MV/m for 100 MW



Surface electric fields in the mode launcher
E_{max}= 49 MV/m for 100 MW

TM_{01} Mode Launcher Cold Test





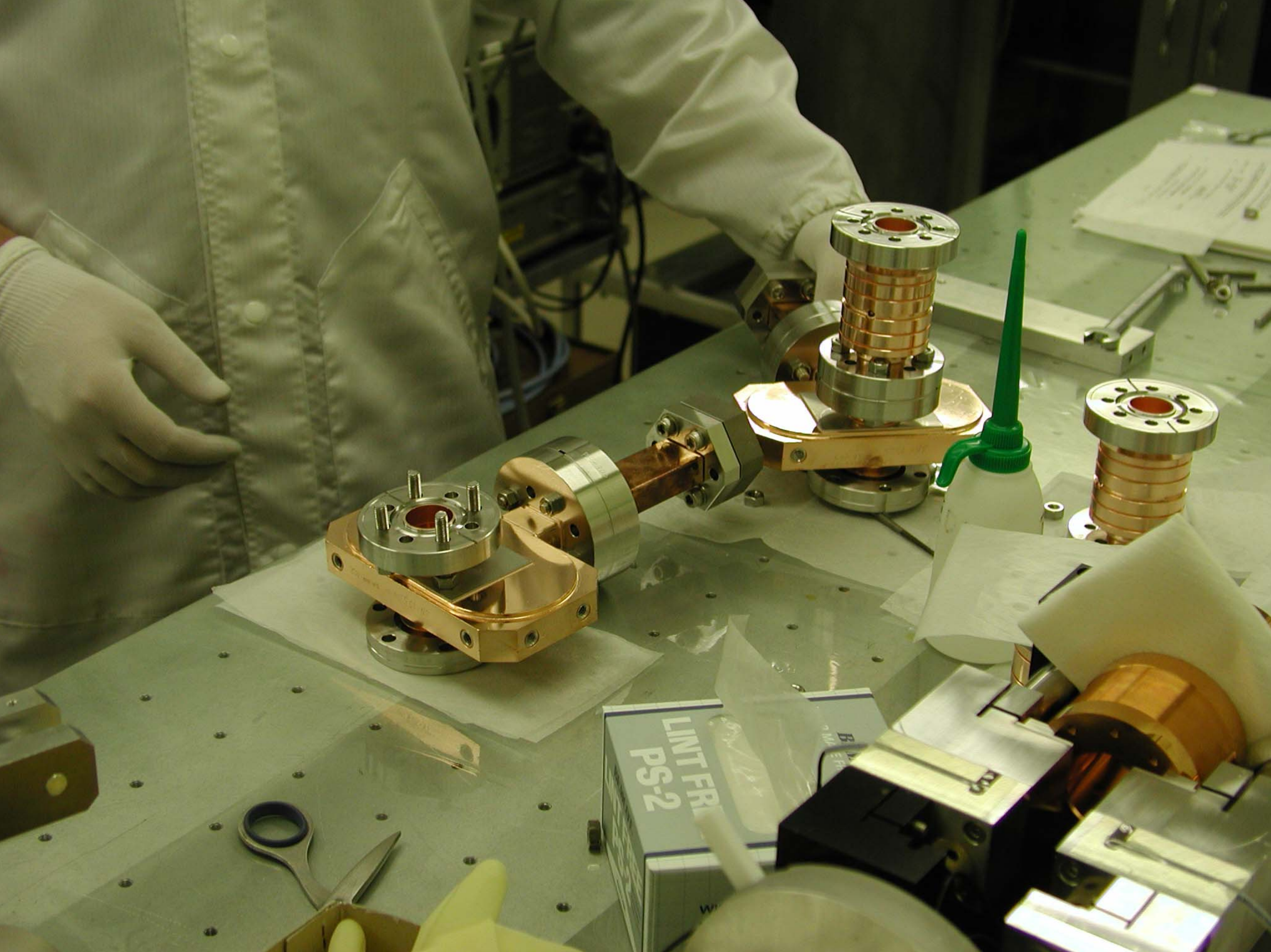
Single Cell Structures

Traveling Wave

- Fields are the same as in first cell of NLC structure T53VG3
- High electric and magnetic fields are **only in this cell** (not in couplers)
- **Reusable couplers** – mode launchers that transform the TE_{10} mode of rectangular waveguide into the "accelerating" circular TM_{01} mode

Standing Wave

- Fields in the middle cell of the SW structure are similar to fields of a large-aperture SW structure SW20a565
- Fields in the middle cell twice as high as in other two cells
- Breakdowns in one cell => **easy diagnostic**
- Small geometry => **easy simulation** with 3D particle and electromagnetic codes


LINT
PS-2

Structure Fabrication

- **SLAC**: Mode launchers and copper TW structures
- **KEK**: Copper, molybdenum-copper, molybdenum SW and TW structures

Planned Experiments

- RF breakdown *vs.* circuit parameters (SW *vs.* TW)
- RF breakdown *vs.* different surface processing technique (light etching, high pressure water rinsing, baking)
- RF breakdown *vs.* different materials: copper, molybdenum, molybdenum-copper

NLC structure testing (C. Adolphsen)

- Reduce the temperature of a structure from 45C to 10C and retest
- Seal a structure and retest it back and retest it.
- Retest the T53 structure
- Test the correlation between breakdown pulses by sending two consecutive short pulses to be done with a fourth accelerator structure.
- These test will most likely consume one station at NLCTA for the next year

Stand Alone RF Source

RF Sources at High Frequency

- Options
  - Gyrotron (Oscillator)
  - Gyroklystron (Amplifier)
  - Magnicon (Amplifier, Very Narrow band)
  - Sheet Beam Klystron
  - Free Electron Masers
  - Harmonic Converters (which may include any of the above amplifier devices)

Current Research and facilities

- Gyroklystrons (U of Maryland)
  - Have very good set of codes for designing these devices, and strong theoretical team. The facilities and designs need to improve for high average power
- Gyroklystron (CCR)
  - SBIR dependent, hence the development time ~ 3 Years
- Magnicon (Omega-P/NRL)
  - A 34 GHz magnicon is still processing
- Gyrotrons
  - Experts are available at MIT, UMD, CCR, CPI, NRL, Yale, This collaboration has the lion share of advanced Gyrotron experts.
- FEM
  - Used to be done at MIT
- Sheet beam klystron
  - . It has been proposed by Chipping Chen at MIT, who has a good theoretical group, but he wanted the help of George Caryotakis to build it, George did not want to collaborate. At the moment both George and Chipping believe that they can do it alone. This is truly a research program specially at 30 GHz

Options

- The Gyrotron is our best bet for a workhorse device in a short period of time.
  - We can buy this device. CPI can do it
  - If we make it we will use the same people with the addition to SLAC's experience to make electron guns. In this case we will have all the world experts working on this at the same time. ***It will also force us to talk to each other and collaborate***.
  - No mater what this is a research device and the risk is high.
  - All the first and second generation experts, within the US, on Gyro devices are in this collaboration

- The Gyroklystron is a distant second

- FEM is also possible but require research, there is not much experience around the world with FEL like devices using law voltages ($\gamma \sim 2$)

- A harmonic generator, Jay Hirshfield proposed one, it might have a chance, but certainly need SLAC's help, and I t is also based on SBIRs

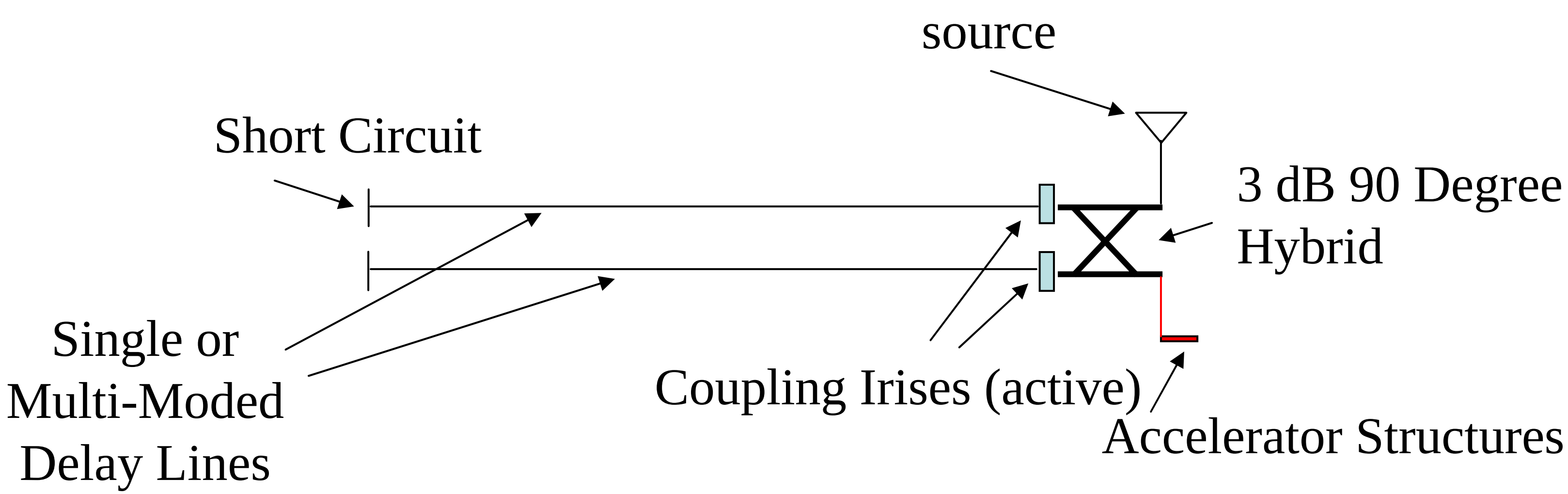
- there is a magnicon under test at 34 GHz. Hence, I do not believe it is a correct choice

- Sheet beam Klystron are not a correct choice either.

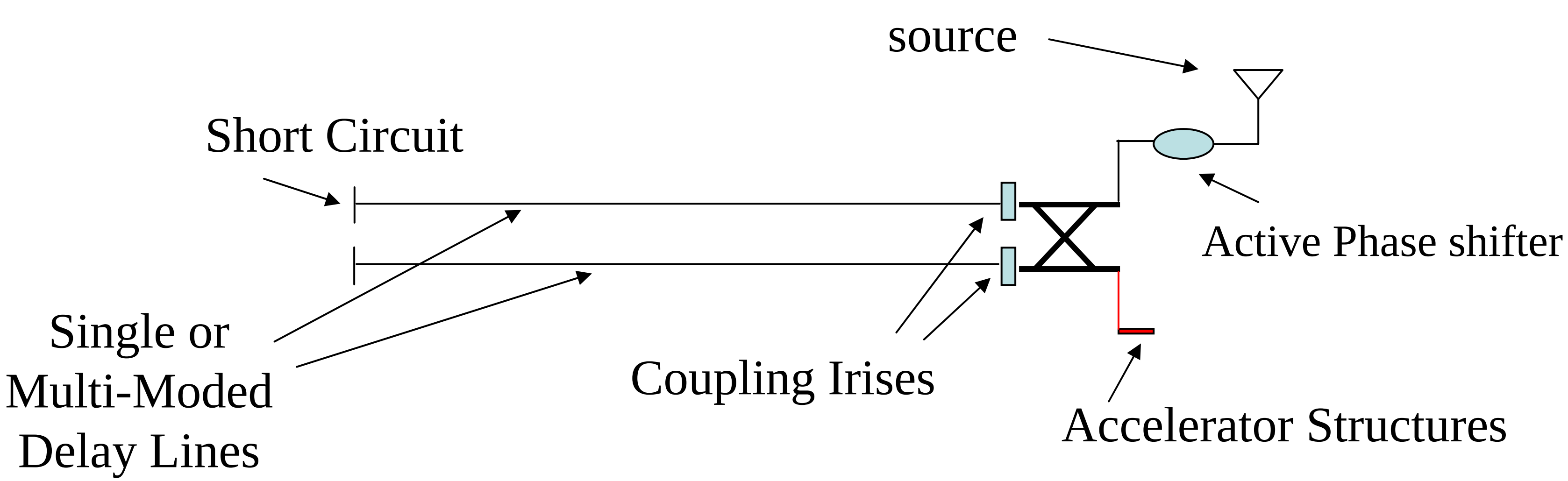
What is wrong with an oscillator?

- It can be used to test waveguide structures, No problem here.
- It needs an active pulse compressor. However, that is needed for CERN as well. We believe that we have the technology at hand.
- The device need to be tunable. I also believe that we can find good solutions for this

Active Pulse Compression



a) Sled-II Pulse compression system with active iris



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

Resonant delay line.

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

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

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

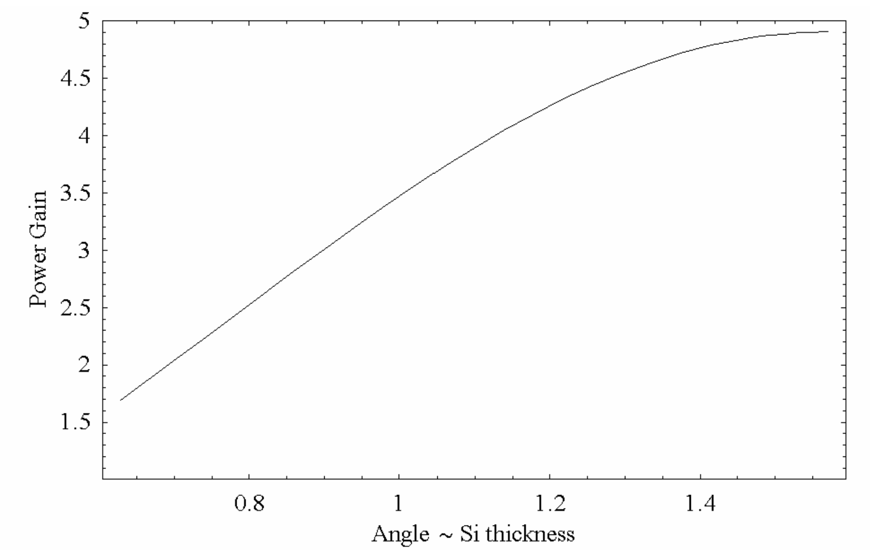
$$V_2^+(t) = V_2^-(t-\tau) e^{-j2\beta l}.$$

Discharging By Active Switching

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

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

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 η (%)	SLED II Opt. R_0	Switching During Charging Time η (%)	Switching During Charging Time Opt. R_0	Discharging After The Last Time Bin. η (%)	Discharging After The Last Time Bin. Opt R_0	Discharging Just Before The Last Time Bin η (%)	Discharging Just Before The Last Time Bin Opt. R_0	Discharging Just Before The Last Time Bin 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.

For SLED-II

$$Maximum\ Power\ Gain = \frac{17}{p^2} - 8 - \frac{12\sqrt{2(1-p^2)}}{p^2}$$

$$R_0 = \frac{1}{p} - \frac{\sqrt{8(1-p^2)}}{4p}$$

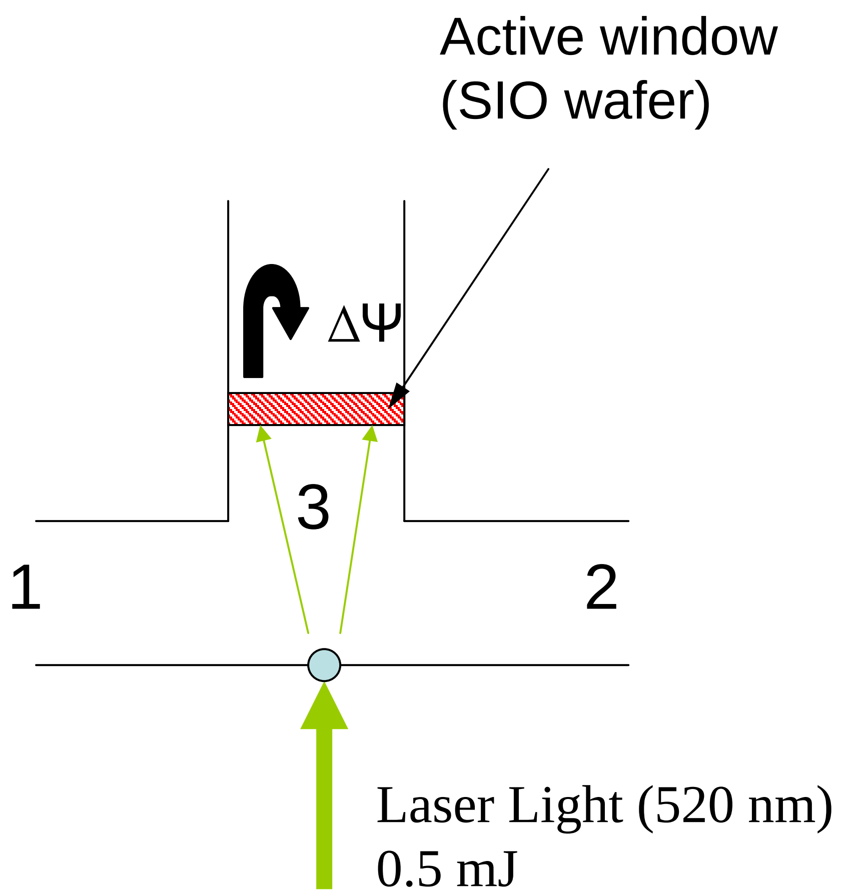
For Active Resonant Delay Line

$$Maximum\ Power\ Gain = \frac{p^2}{1-p^2}$$

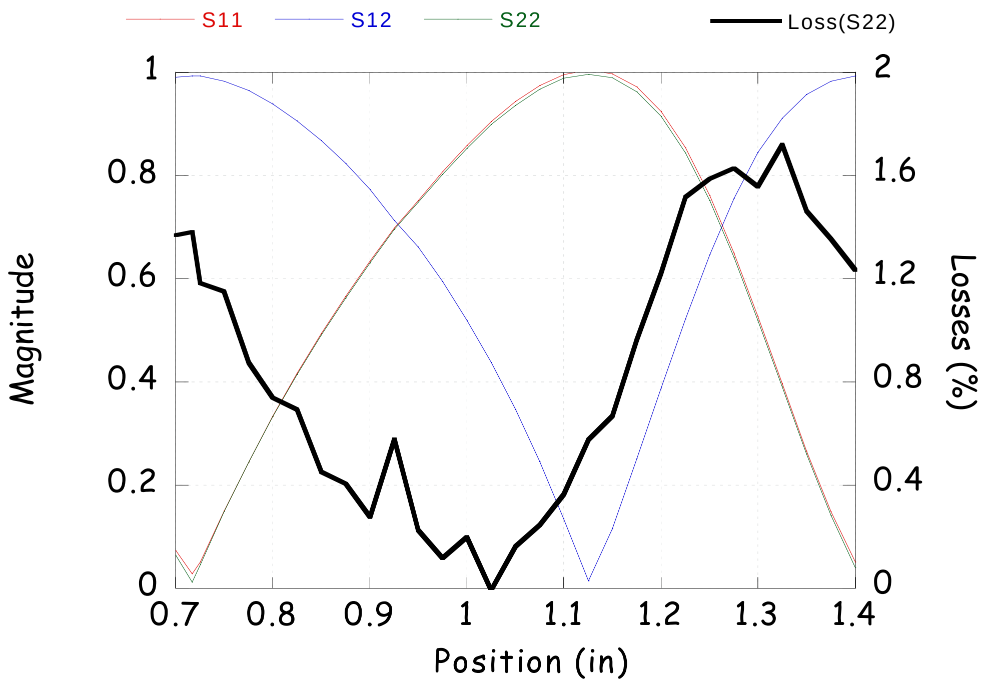
$$R_0 = p$$

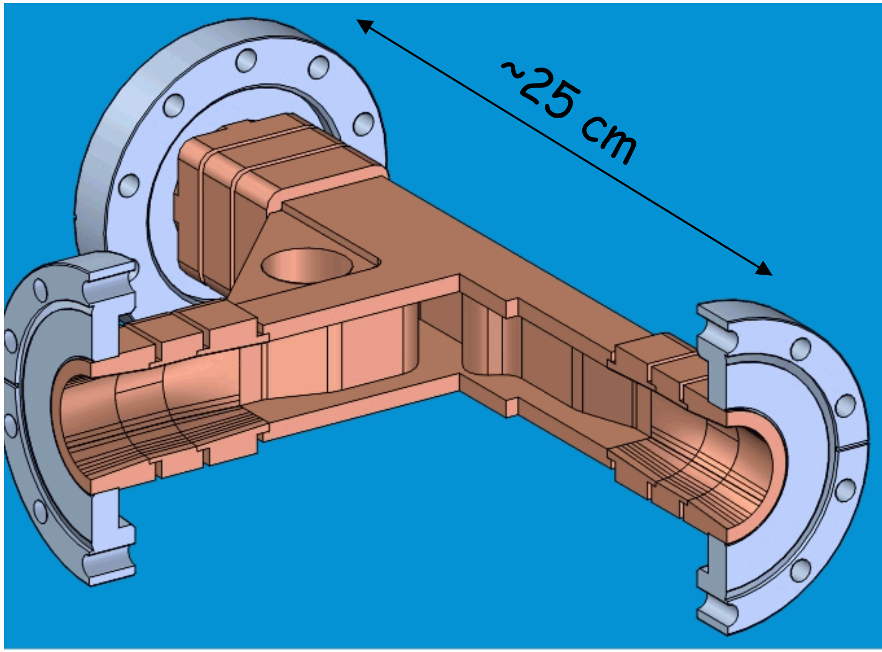
Design of the Switch Module (Suitable for high frequencies)

- 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.

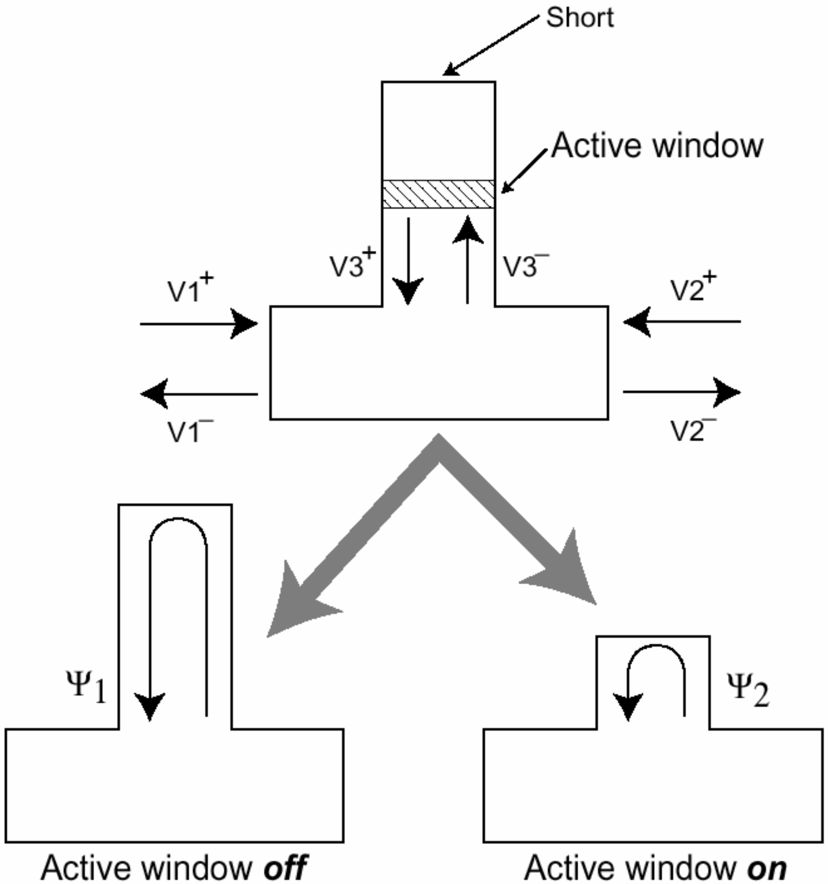


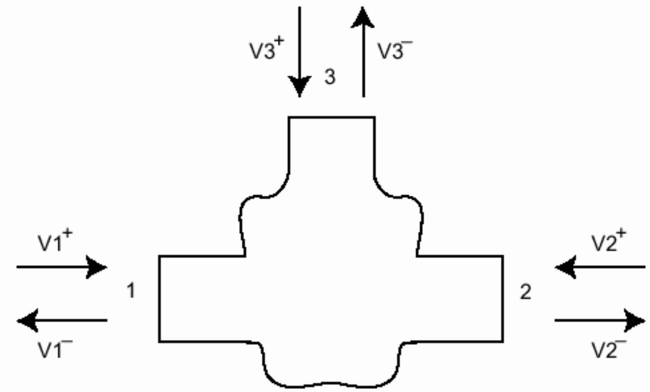
TE_{01} Mode Tee (Variable Iris)



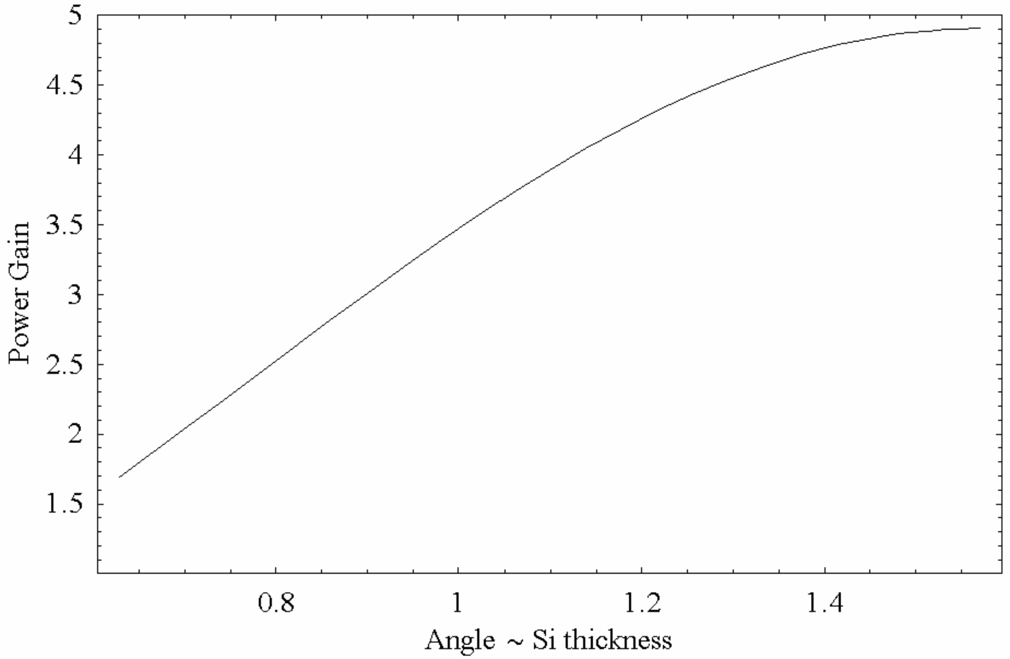


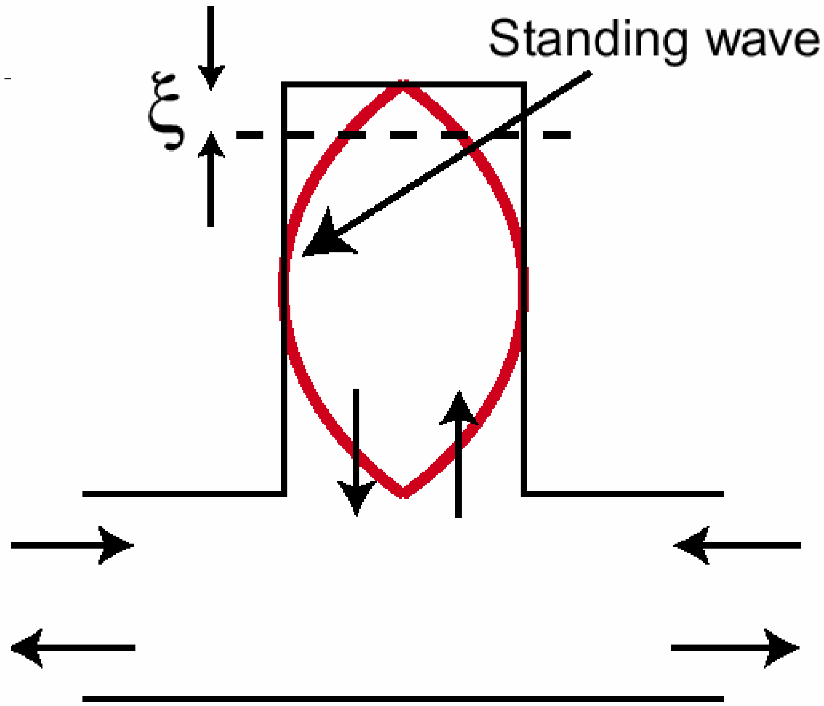
- The Tee body is planer rectangular guide operating in the TE_{20}
- We Taper from Circular to Rectangular with a special taper which generate the TE_{01} mode





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



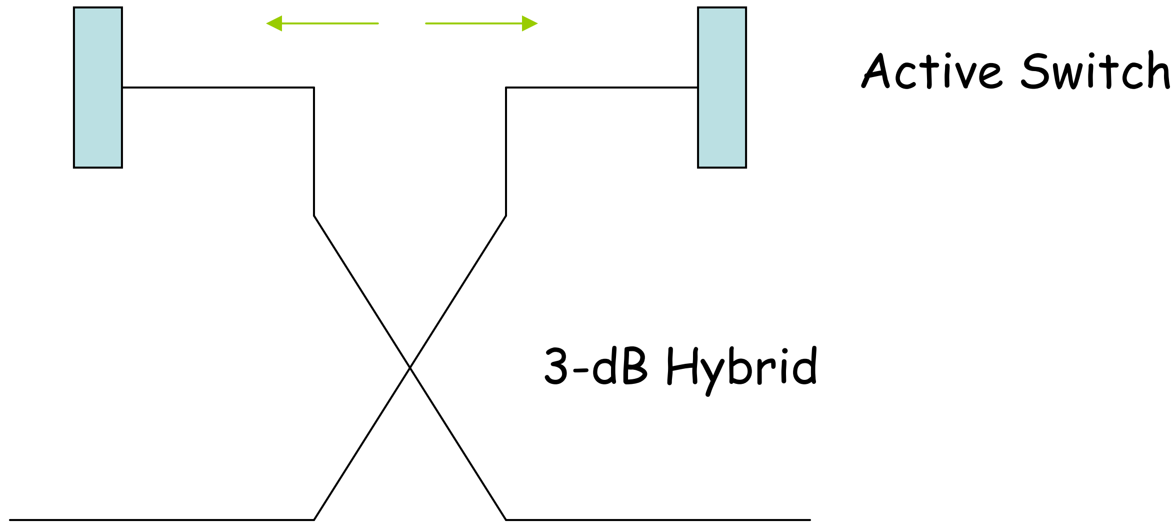


$$|V_3| = 2|V_3^-||\sin \beta_3 \xi|$$

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

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

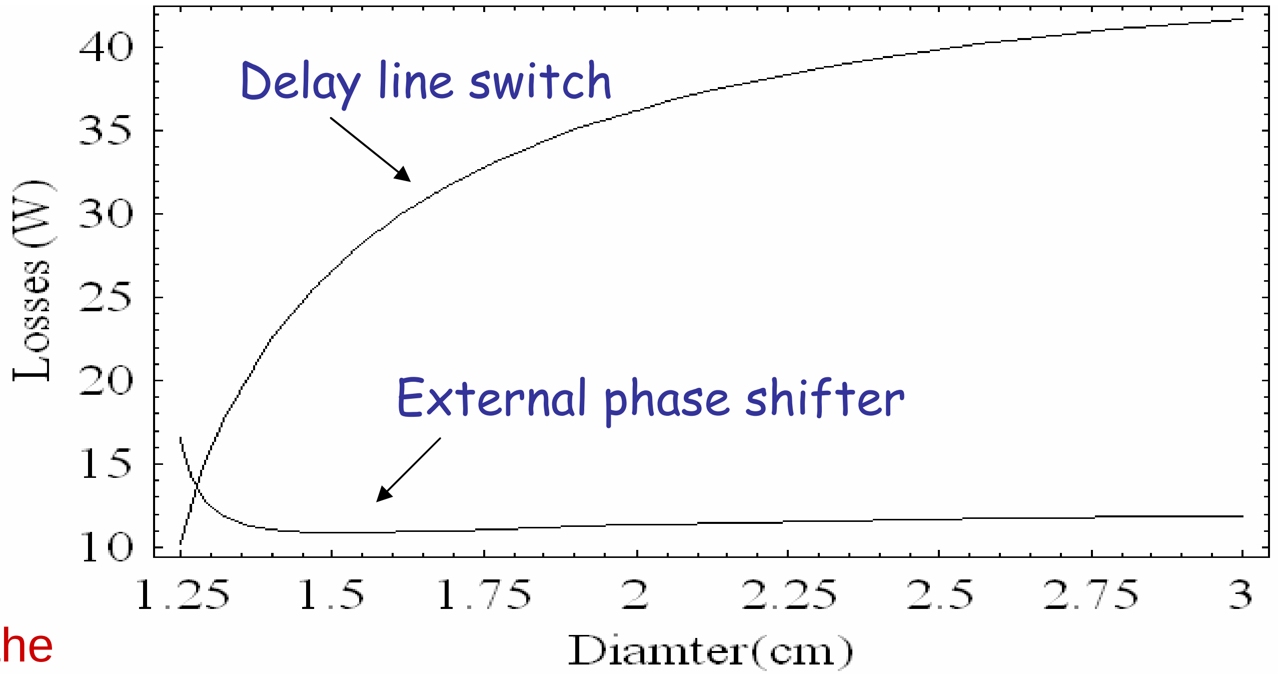
Pi Phase Shifter

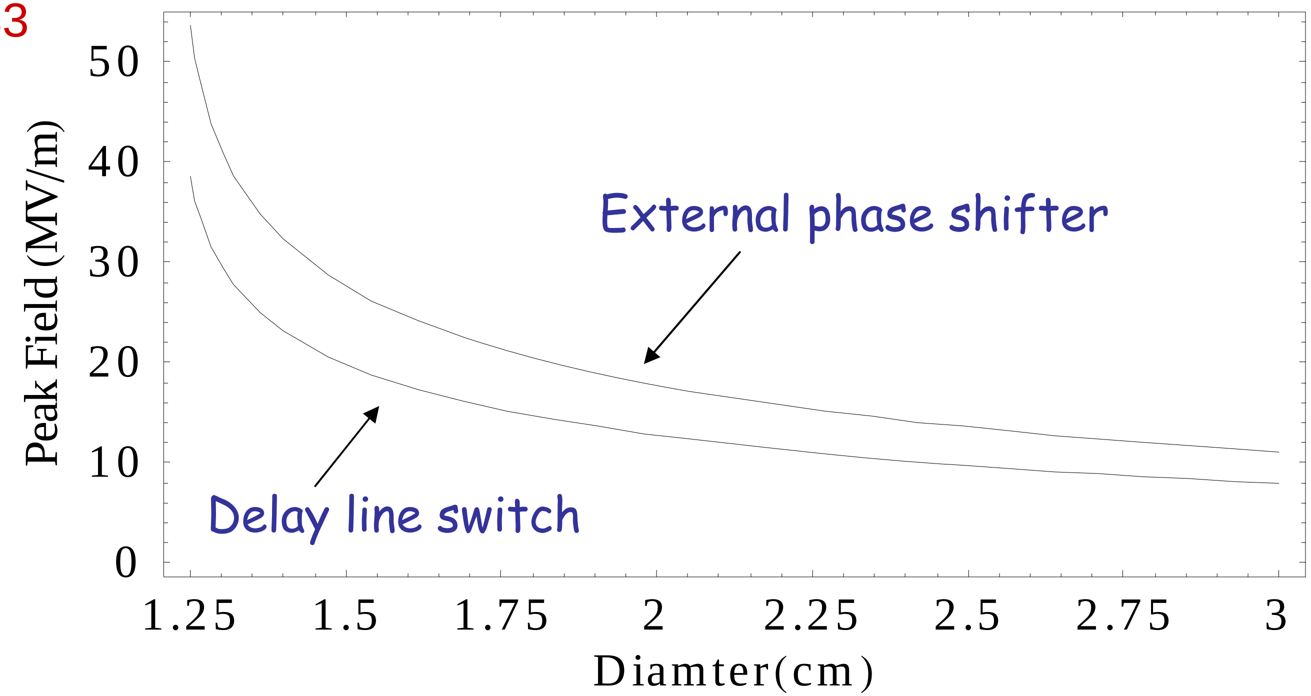


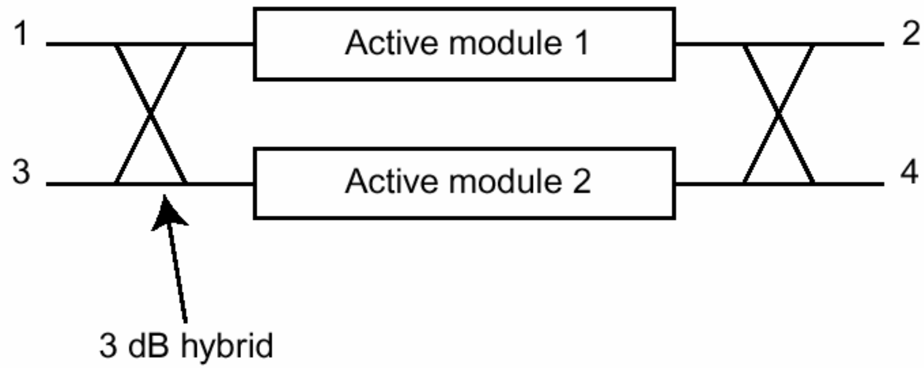
The switch has to change the phase by Pi. The thickness of the of the Si wafer is ~ 730 micron

Silicon Wafer Thickness for delay line switch ~ 153 microns

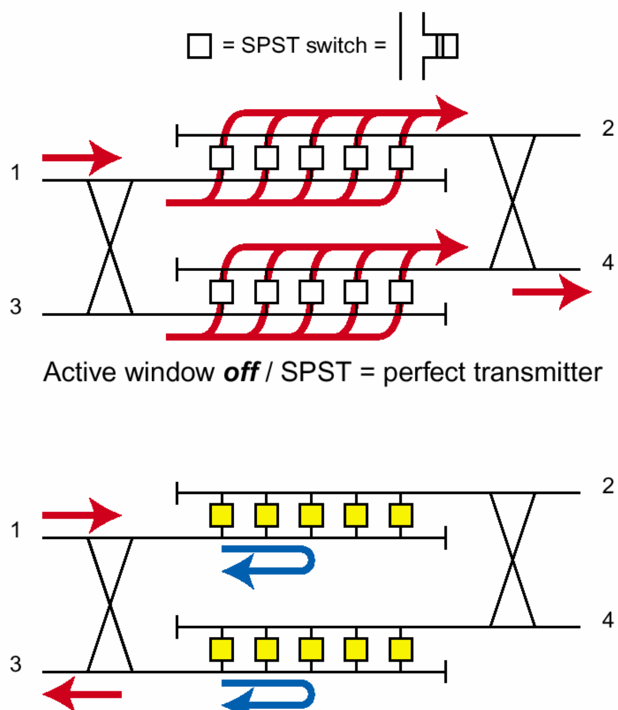
Silicon wafer thickness for the external phase shifter ~ 733 microns





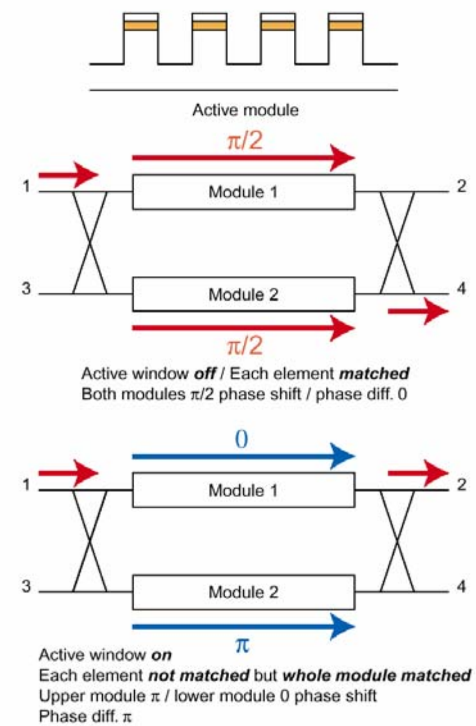


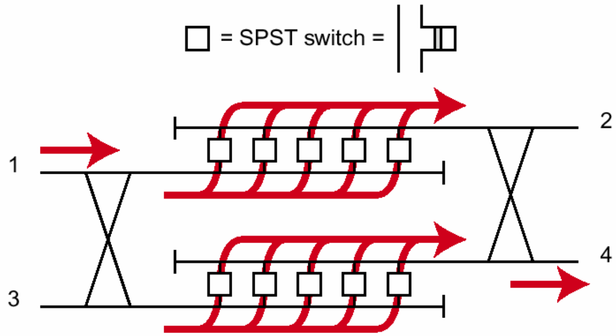
Active module = { SPST array / Cascaded phase shifter



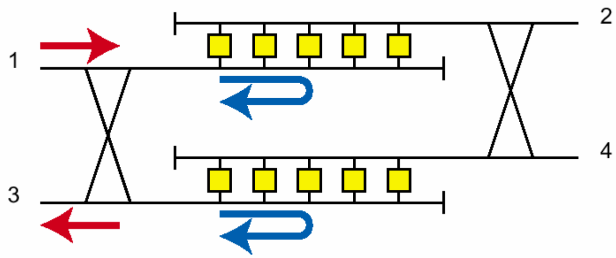
Active window ***off*** / SPST = perfect transmitter

Active window ***on*** / SPST = perfect reflector

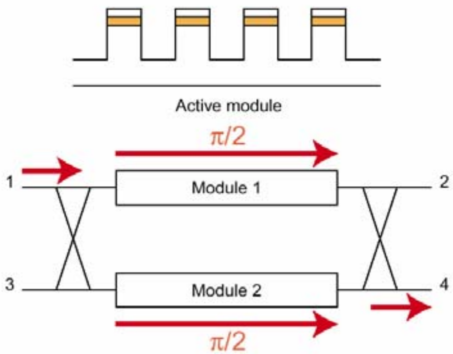




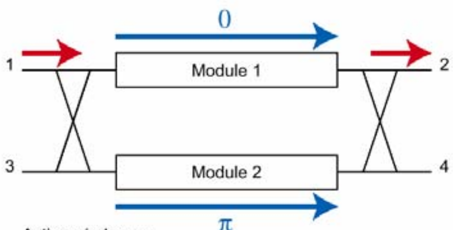
Active window ***off*** / SPST = perfect transmitter



Active window ***on*** / SPST = perfect reflector



Active window ***off*** / Each element ***matched***
Both modules π/2 phase shift / phase diff. 0



Active window ***on***
Each element ***not matched*** but ***whole module matched***
Upper module π / lower module 0 phase shift
Phase diff. π

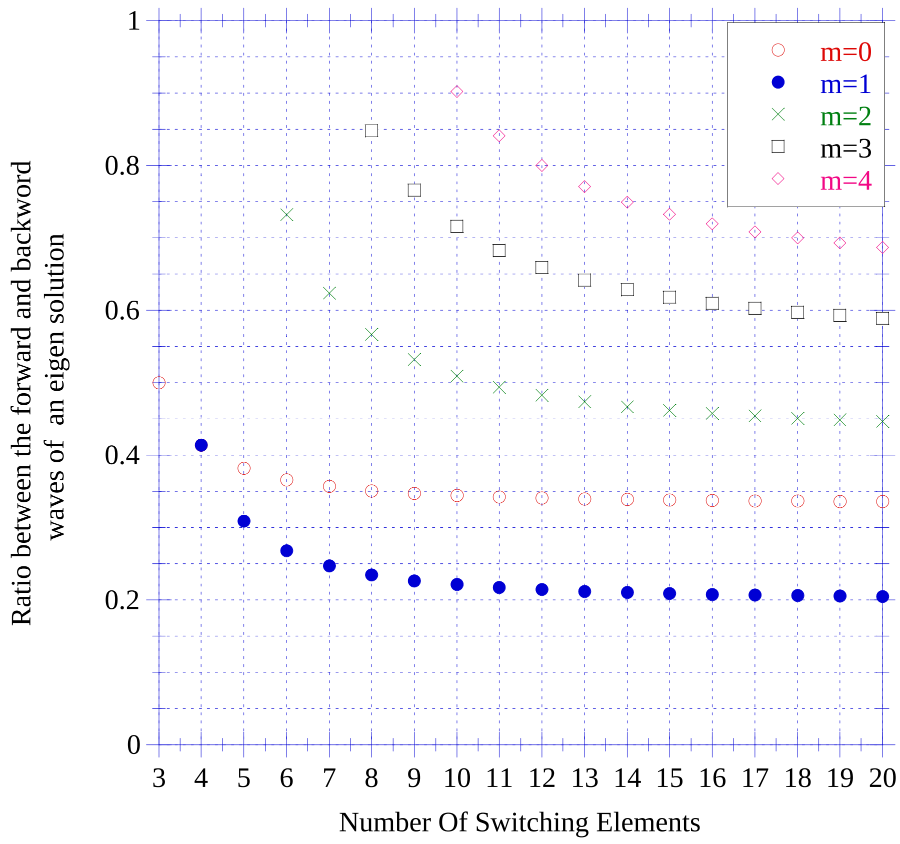
$$e^{j\Delta\Psi} = \frac{e^{j\phi} - \cos\theta}{-1 + e^{j\phi}\cos\theta}\,\frac{1 + e^{j\phi}\cos\theta}{e^{j\phi} + \cos\theta}.$$

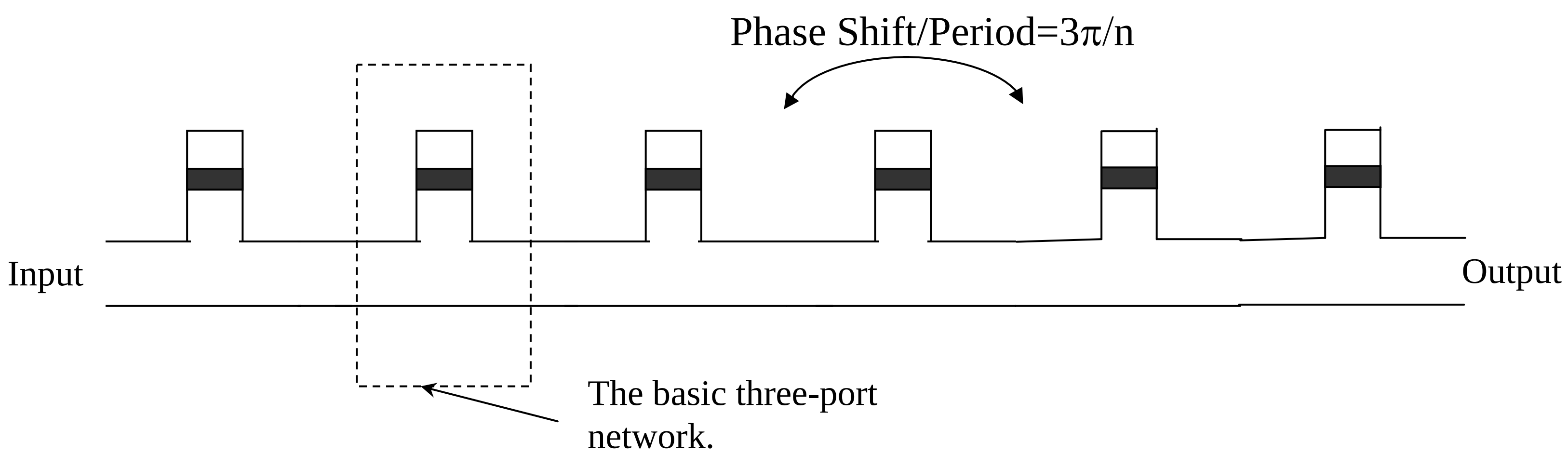
$$E_{max} = \frac{2}{\sqrt{n}}\sqrt{\frac{1 - 2\cos\theta\cos\phi + \cos^2\theta}{2\sin^2\theta}}\left|\sin\frac{\Delta\Psi}{2}\right|\sqrt{\frac{P_{in}Z_g}{AG}},$$

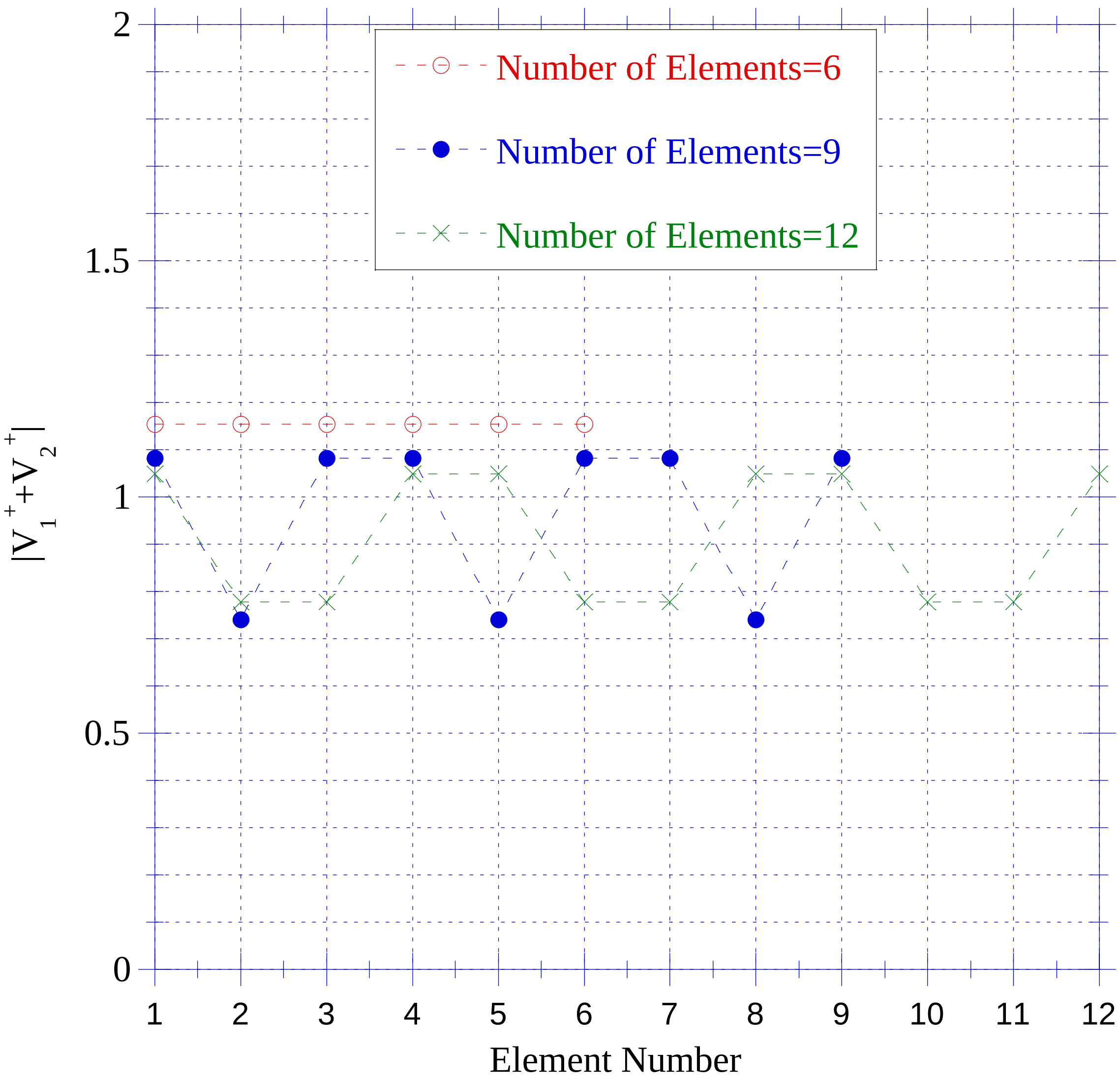
$$P_l = 4\times\frac{(1 + 2\cos\theta\cos\phi + \cos^2\theta)}{2\sin^2\theta}\frac{R_s}{Z_g}P_{in},$$

$$E_{max} = \sqrt{\frac{1 - 2\cos\theta\cos\phi + \cos^2\theta}{\sin^2\theta}}\left|\sin\frac{\Delta\Psi}{2}\right|\sqrt{\frac{P_{in}Z_g}{AG}},$$

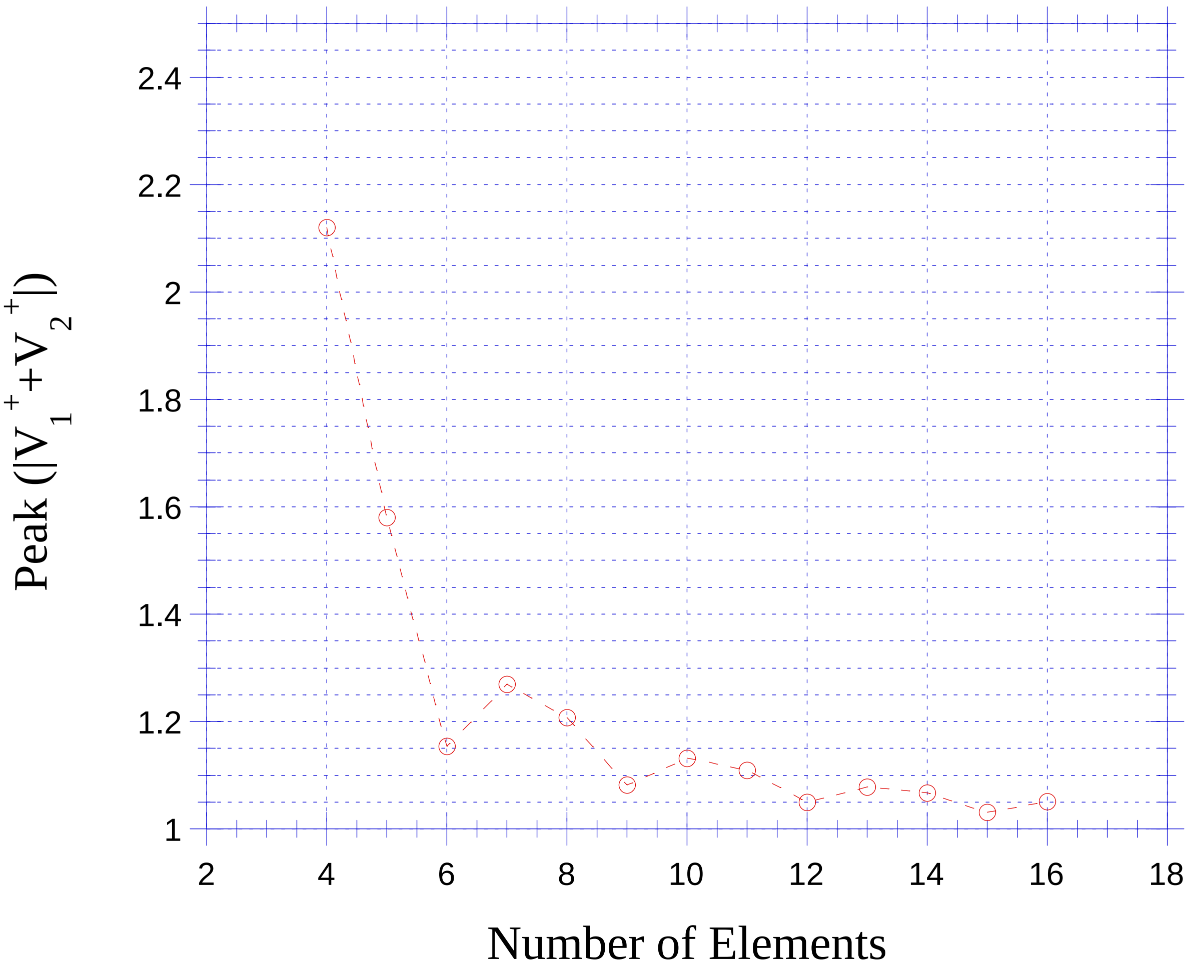
$$P_l \approx \frac{n(1 + 2\cos\theta\cos\zeta_1 + \cos^2\theta)}{\sin^2\theta}\frac{R_s}{Z_g}P_{in}.$$


m=0
m=1
m=2
m=3
m=4
Ratio between the forward and backword waves of an eigen solution
Number Of Switching Elements
1
0.8
0.6
0.4
0.2
0
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


Phase Shift/Period=3π/n
Input
Output
The basic three-port network.



Total Phase shift=3π



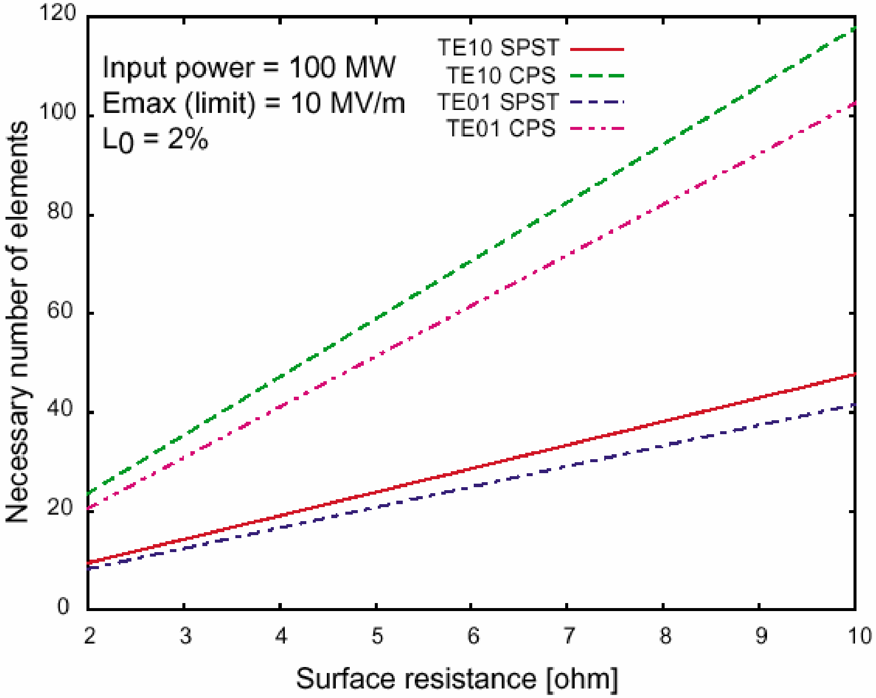
2.4
2.2
2
1.8
1.6
1.4
1.2
1
2
4
6
8
10
12
14
16
18
Peak ($|V_1^+ + V_2^+|$)
Number of Elements

Scaling Law

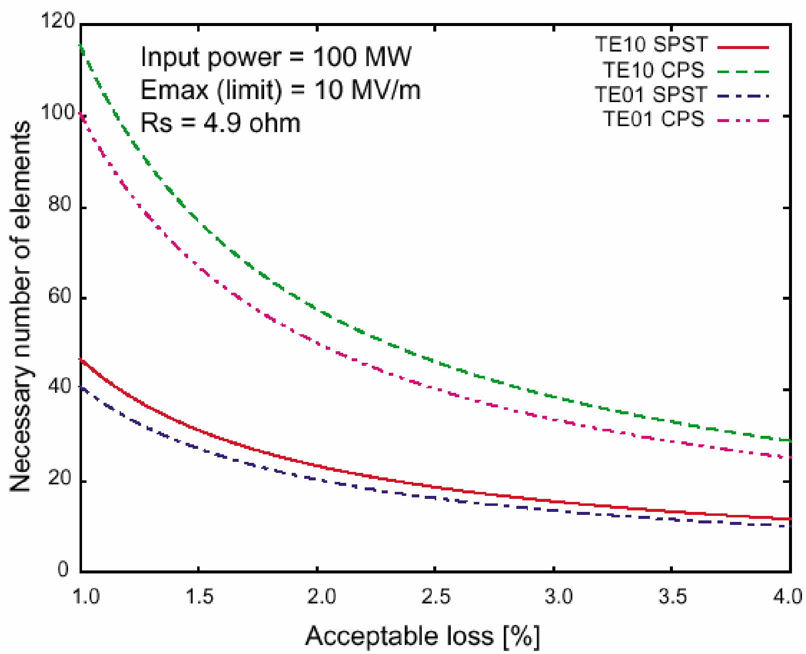
$$E_{\max} = C\sqrt{\frac{R_s}{nL_0}}\sqrt{\frac{P_{in}}{AG}}, \qquad \text{or} \qquad n = \frac{C^2 P_{in}}{AG}\frac{R_s}{L_0 E_{\max}^2}.$$

where P_{in} is the total input power, R_s the surface resistance of the active window with *on* status, L_0 the acceptable loss determined by external requirements, n the total number of active elements, A the cross sectional area of the waveguide, and G the geometrical factor that depends on the mode and the shape of the waveguide. In the above equation, C is a constant, π for the cascaded phase shifter, and 2 for the SPST switch array. This means that the case of the SPST array is better than that of the cascaded phase shifter.

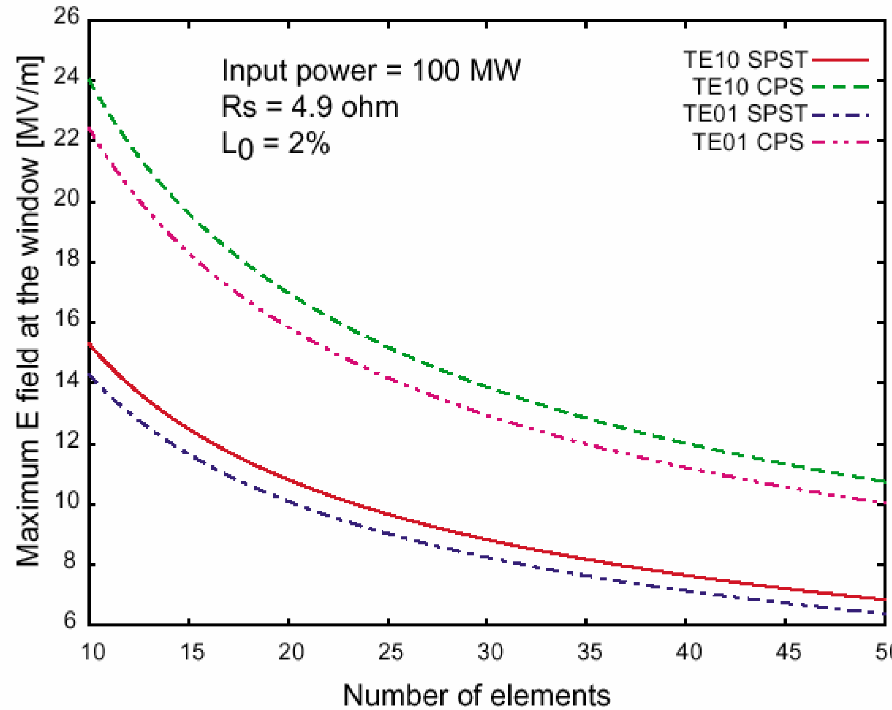
- The SPST array configuration needs less active elements than the cascaded phase shifter.
- The number of elements is proportional to the surface resistance, and inversely proportional to the acceptable loss. Hence, we should employ the active window with low loss when the window is *on*.
- The number of elements is inversely proportional to the square of the peak electric field limit. Thus, it is necessary to choose the material and the device which can endure in high electric fields, as the active window.
- The number of elements is independent of the waveguide impedance Z_g. The effects of Z_g on the increase of electric field and the decrease of loss cancel each other.



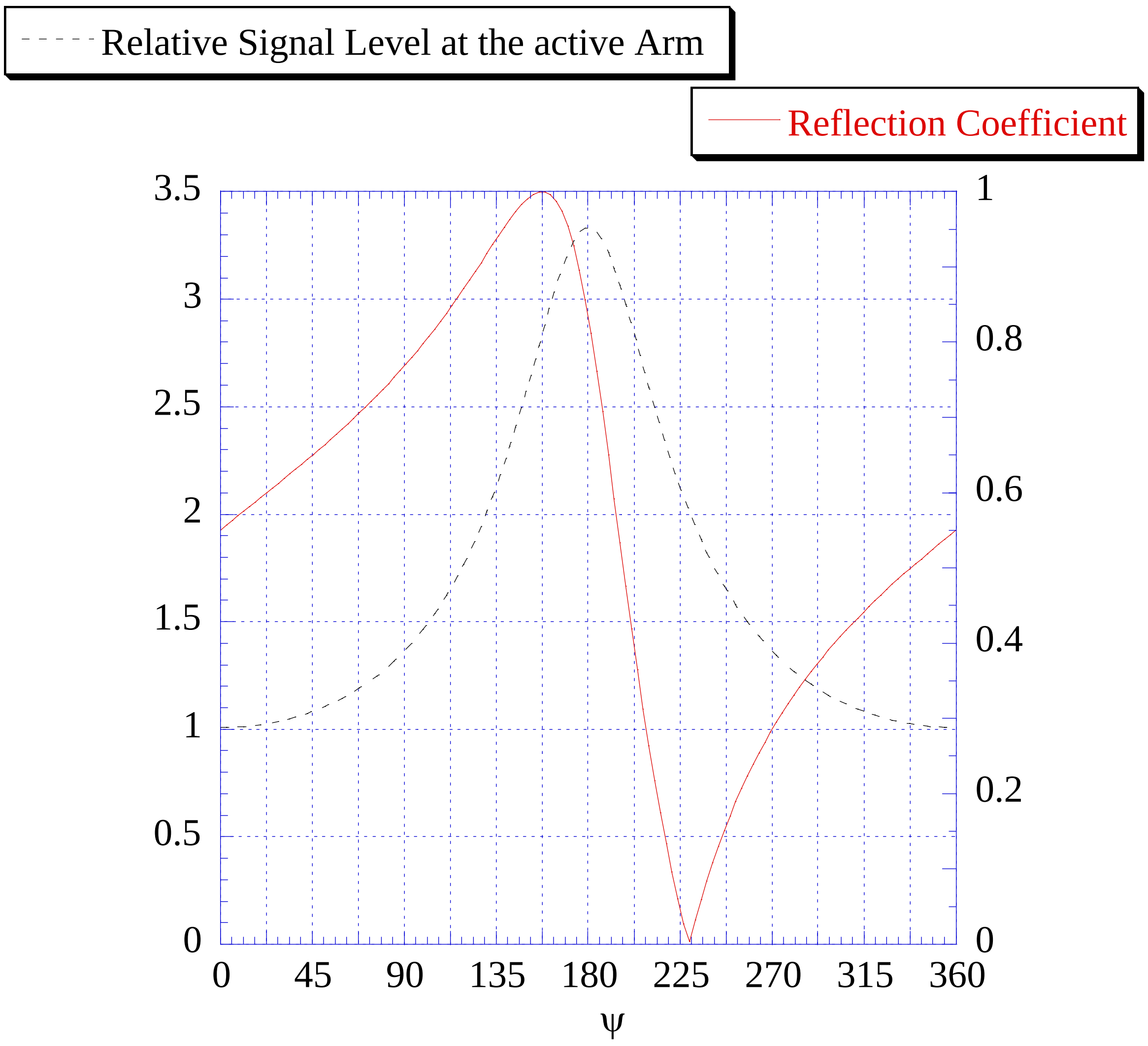
Input power = 100 MW
Emax (limit) = 10 MV/m
L0 = 2%
TE10 SPST
TE10 CPS
TE01 SPST
TE01 CPS
Necessary number of elements
Surface resistance [ohm]
0
20
40
60
80
100
120
2
3
4
5
6
7
8
9
10



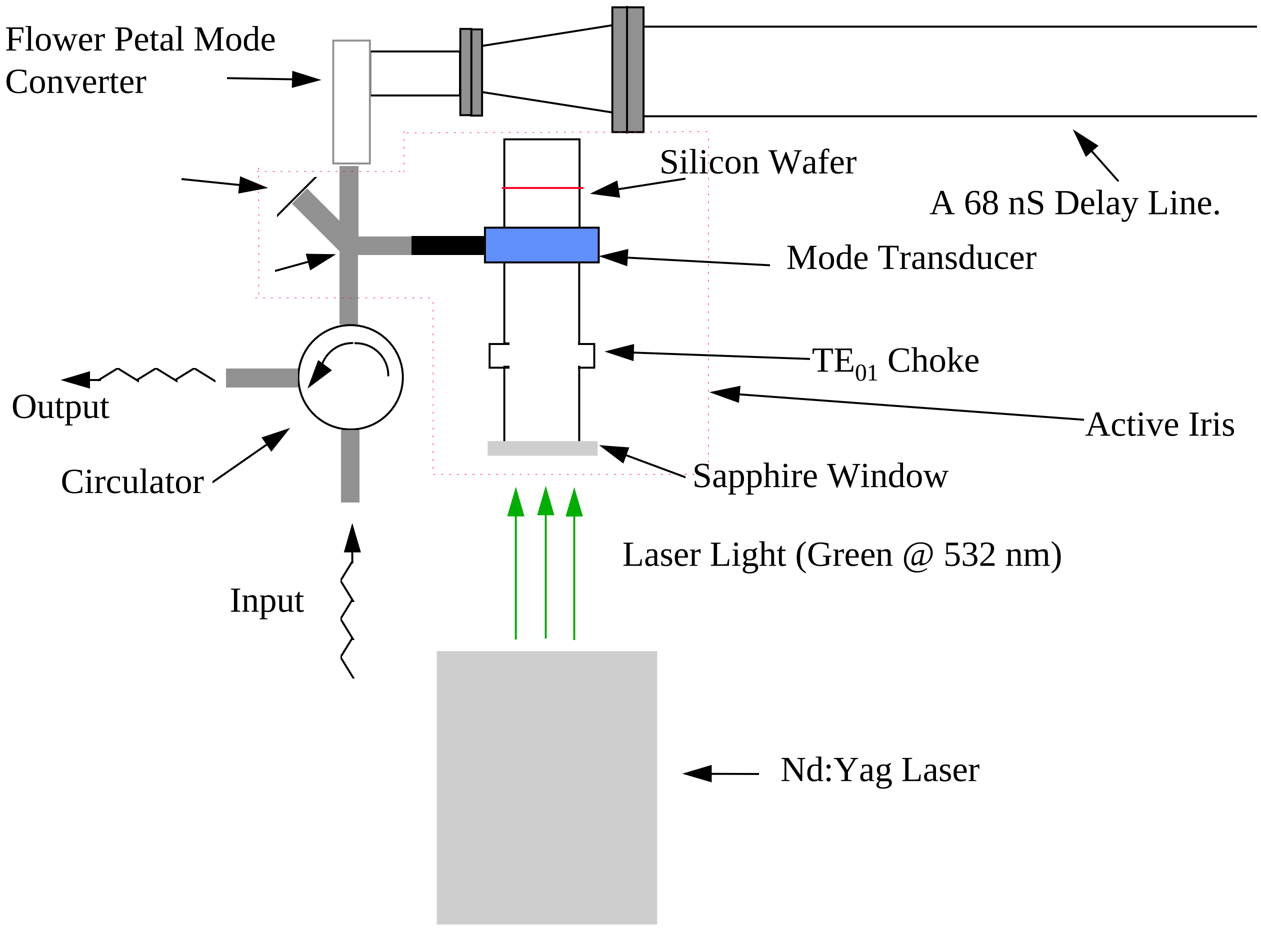
Input power = 100 MW
Emax (limit) = 10 MV/m
Rs = 4.9 ohm
TE10 SPST
TE10 CPS
TE01 SPST
TE01 CPS
Necessary number of elements
Acceptable loss [%]
0
20
40
60
80
100
120
1.0
1.5
2.0
2.5
3.0
3.5
4.0

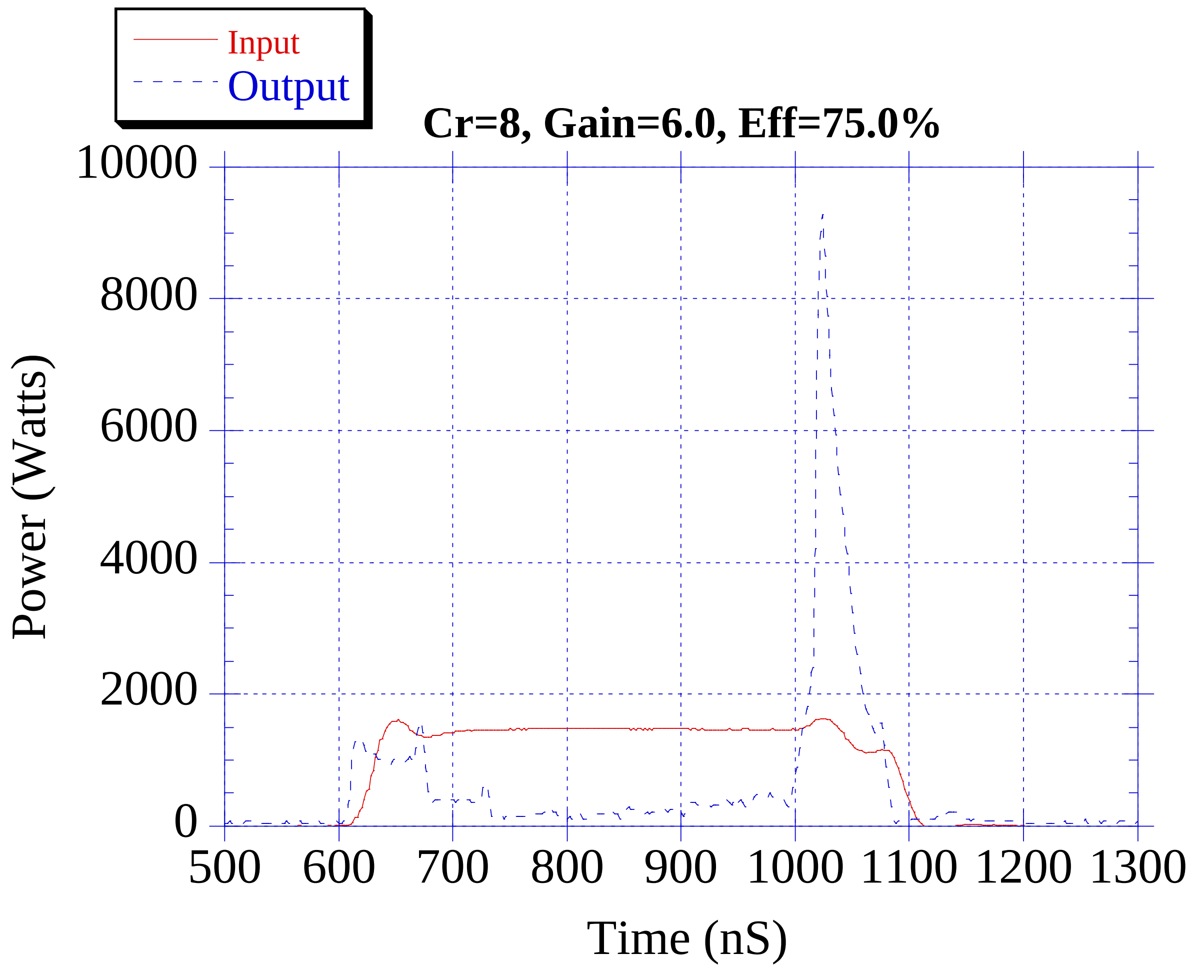


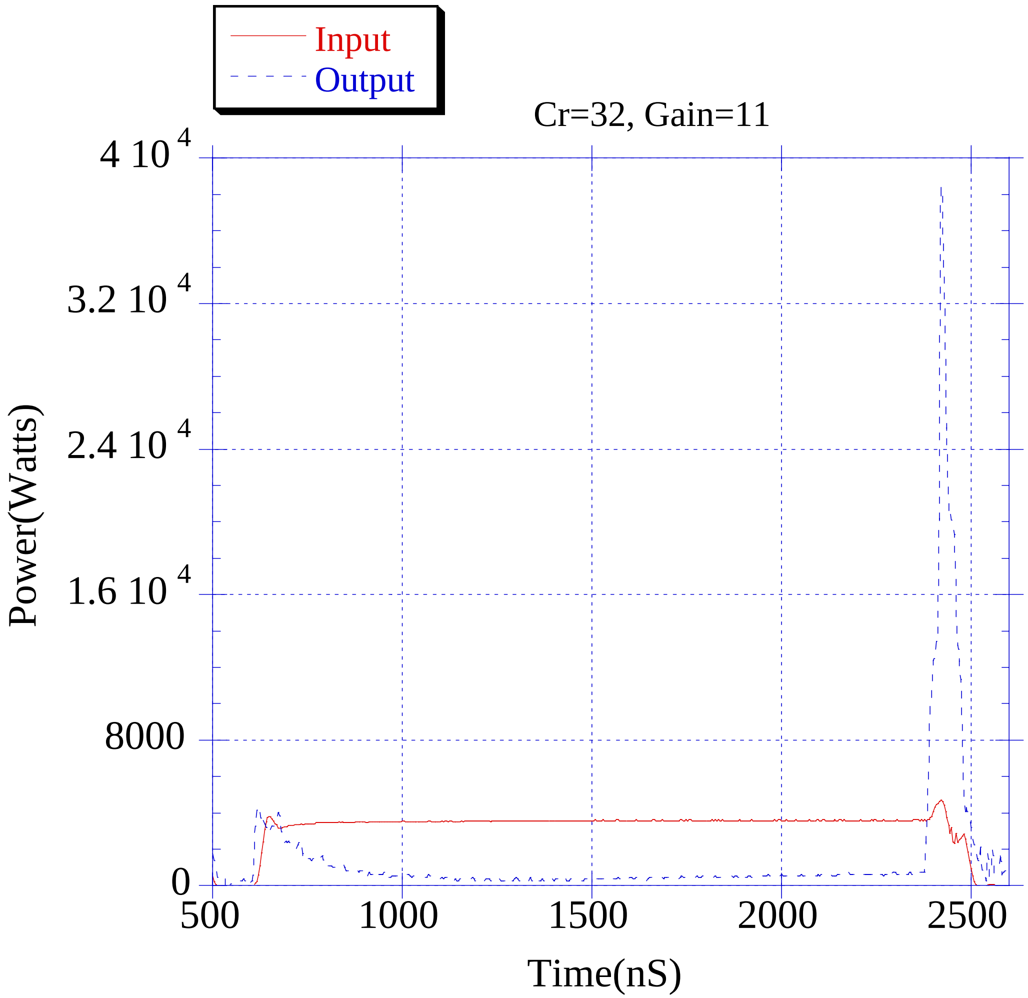
Input power = 100 MW
Rs = 4.9 ohm
L0 = 2%
TE10 SPST
TE10 CPS
TE01 SPST
TE01 CPS
Maximum E field at the window [MV/m]
Number of elements
6
8
10
12
14
16
18
20
22
24
26
10
15
20
25
30
35
40
45
50



Relative Signal Level at the active Arm
Reflection Coefficient
3.5
3
2.5
2
1.5
1
0.5
0
1
0.8
0.6
0.4
0.2
0
0
45
90
135
180
225
270
315
360
ψ


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
Power (Watts)
500
600
700
800
900
1000
1100
1200
1300
Time (nS)



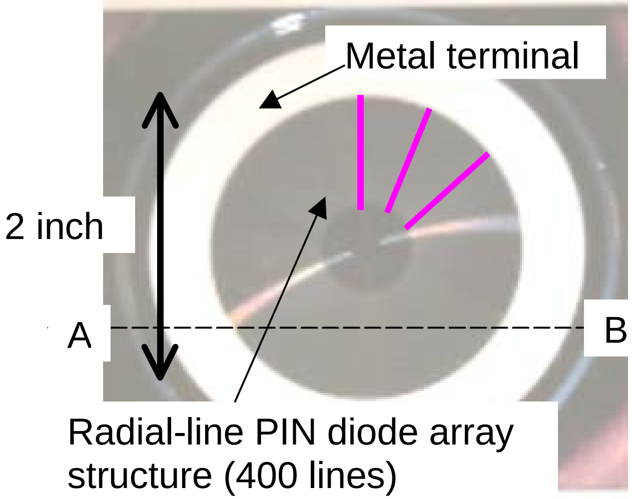
Input
Output
Cr=32, Gain=11
4 10 4
3.2 10 4
2.4 10 4
1.6 10 4
8000
0
500
1000
1500
2000
2500
Power(Watts)
Time(nS)

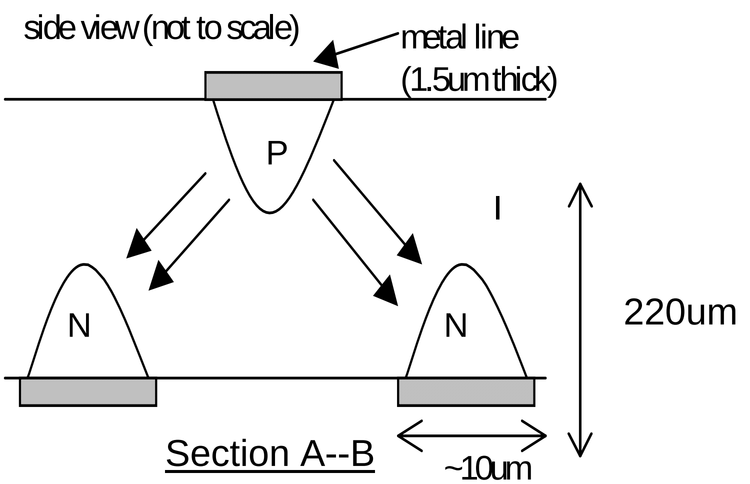
Design and Implementation of PIN/NIP Diode Array Active Window

PIN diode array Active Window

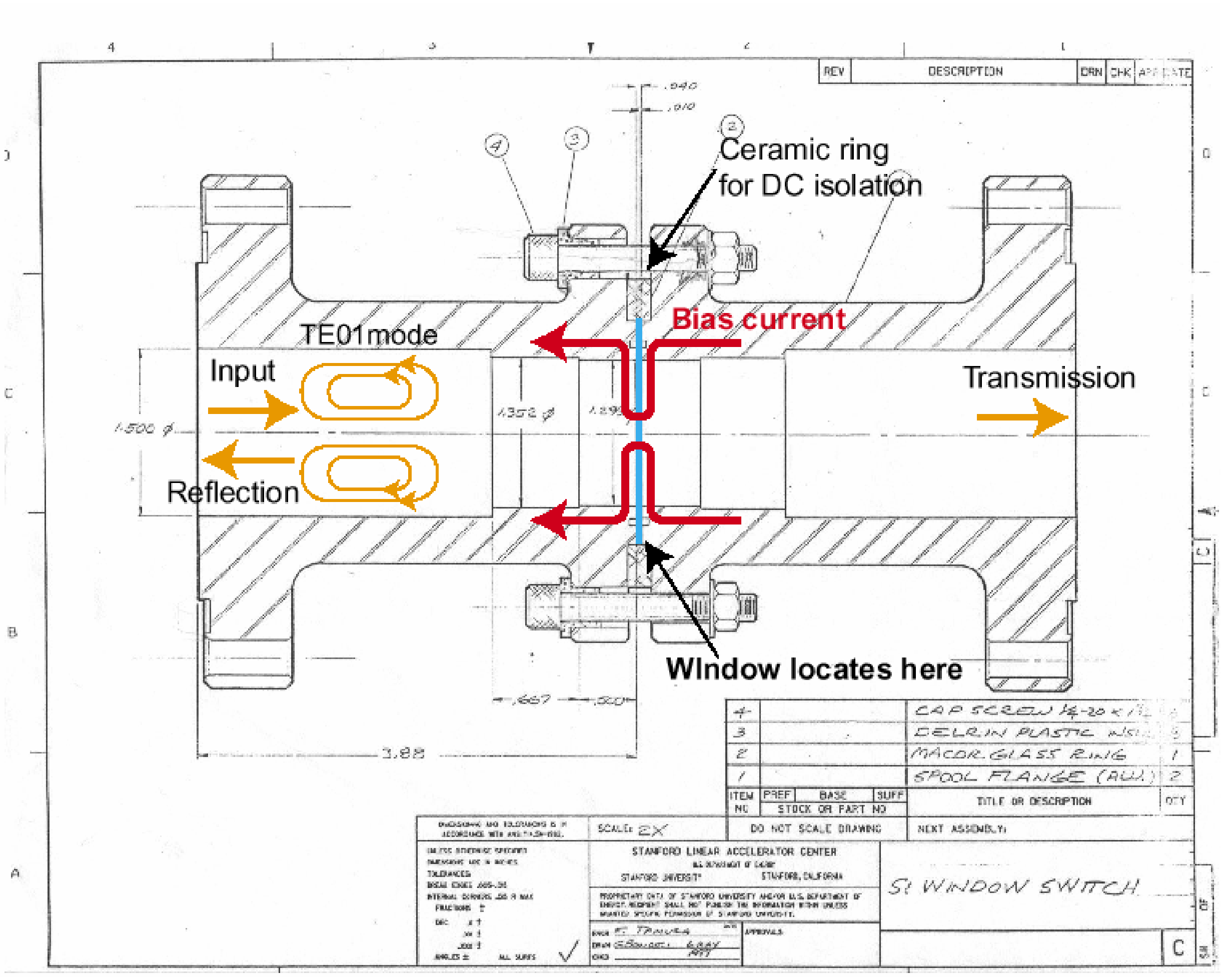
- All doping profile and metallic terminals on the window are radial, i.e. perpendicular to electric field of the TE_{01} mode. → Effect of doping and metal lines on RF signal is small when the diode is reverse biased.

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





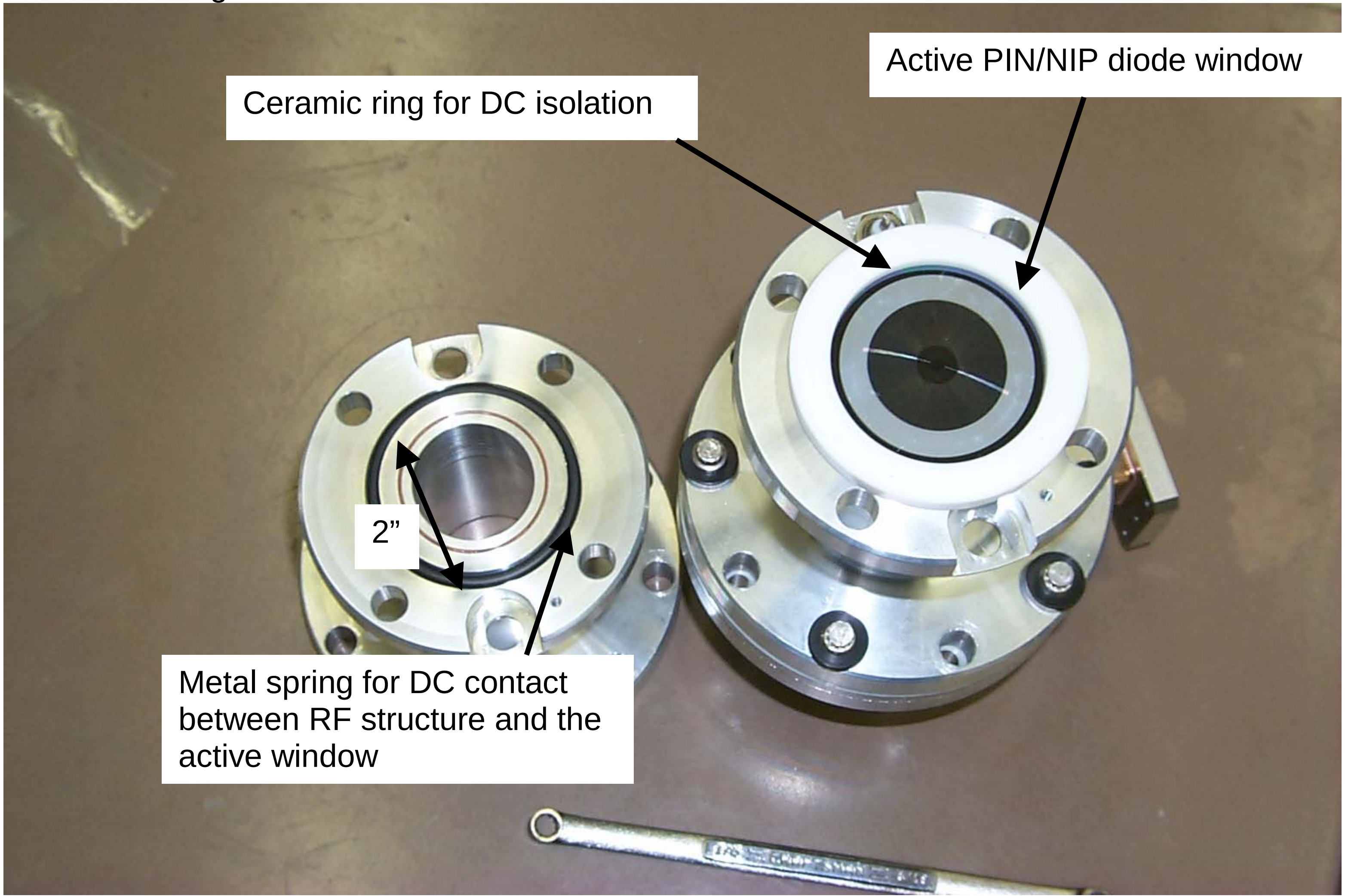
- Base material: high resistivity (pure) silicon, <5000ohm-cm, n-type
- Diameter of active region: 1.3 inch
- Thickness: **220um**
- Coverage (metal/doping line on the surface): ~10%

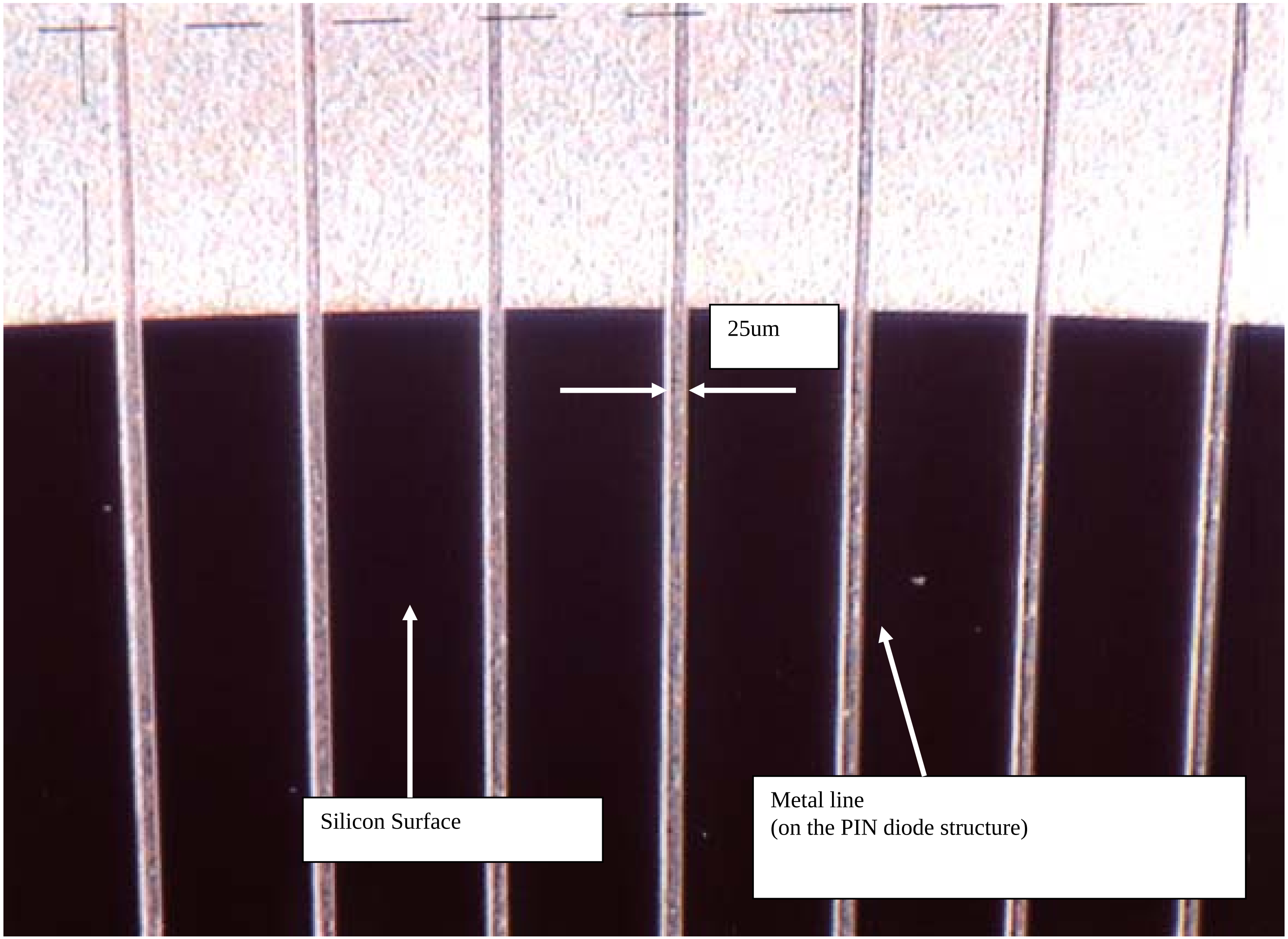


Ceramic ring
for DC isolation
Bias current
TE01mode
Input
Reflection
Transmission
WIndow locates here
CAP SCREW 1/4-20 x
DELRIN PLASTIC
MACOR GLASS RING
SPOOL FLANGE (AL.)
TITLE OR DESCRIPTION
DO NOT SCALE DRAWING
STANFORD LINEAR ACCELERATOR CENTER
SI WINDOW SWITCH

RF structure

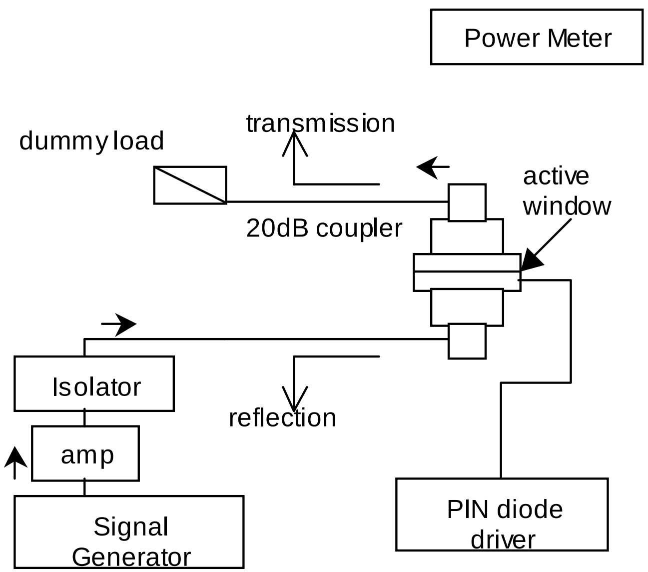
- DC isolation by Al_2O_3 ceramic ring
- No RF choke is needed (TE_{01} mode)
- Higher impedance (Zg / Z0 ~4, close to cutoff) for this experiment
    - o Enhance the effect of window switching status
    - o Lower loss at the window during forward bias
    - o Huge mismatch without bias




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

Low Power Measurement

Setup:

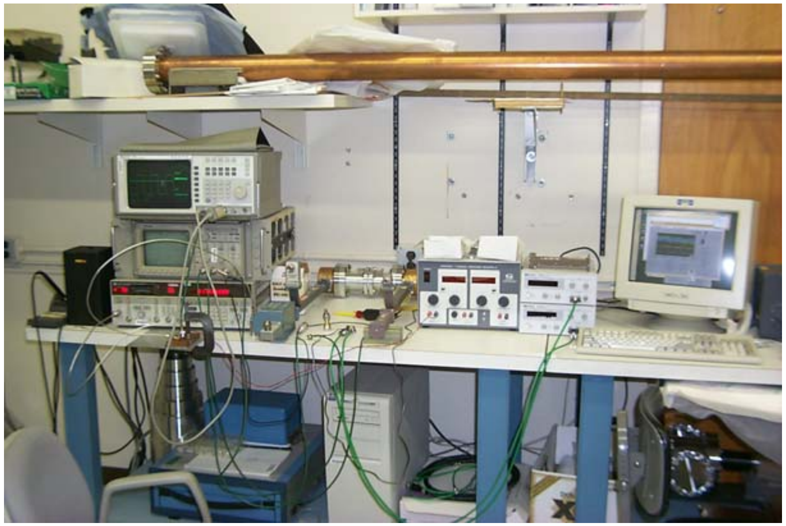


Peak power meter

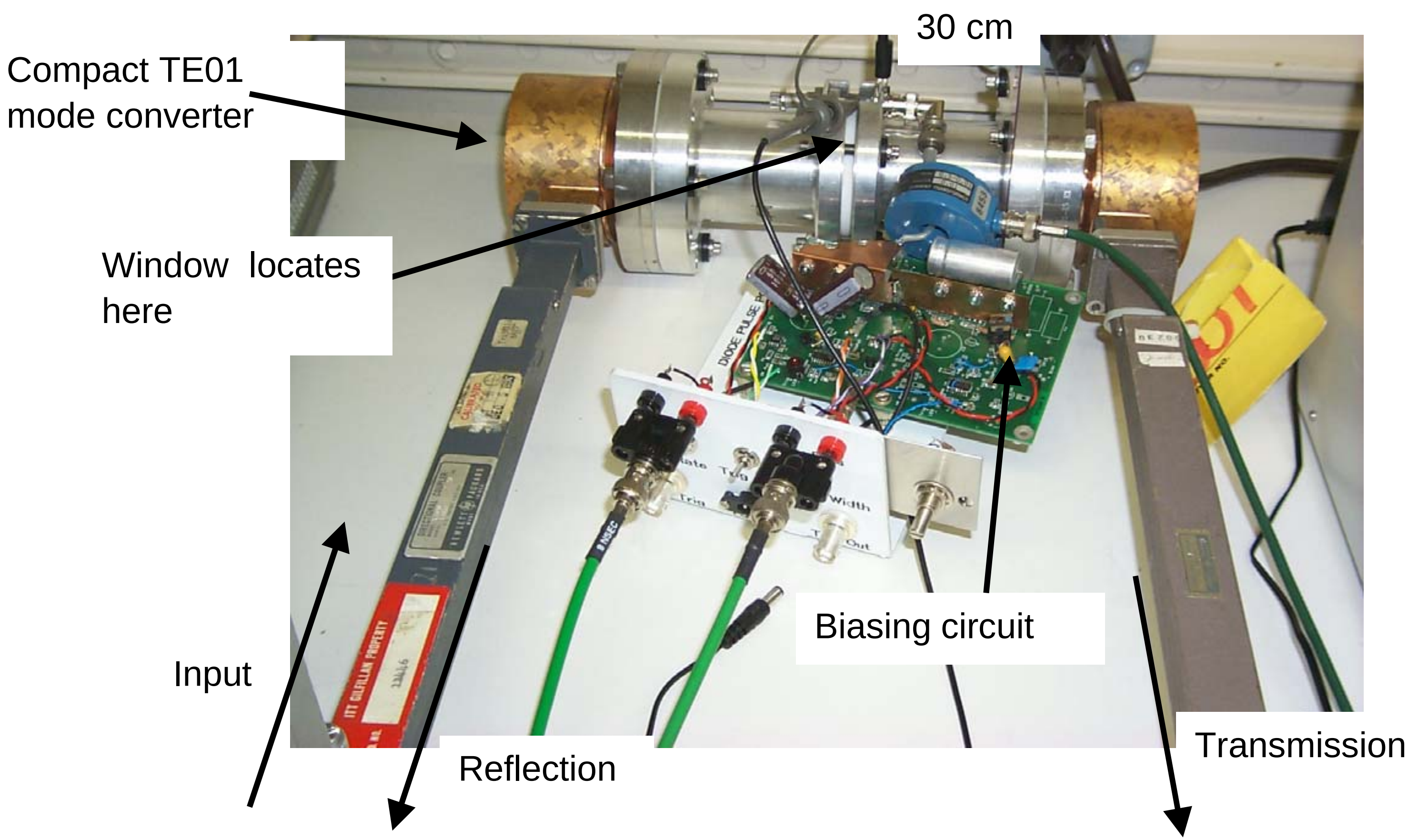
RF source

Active window

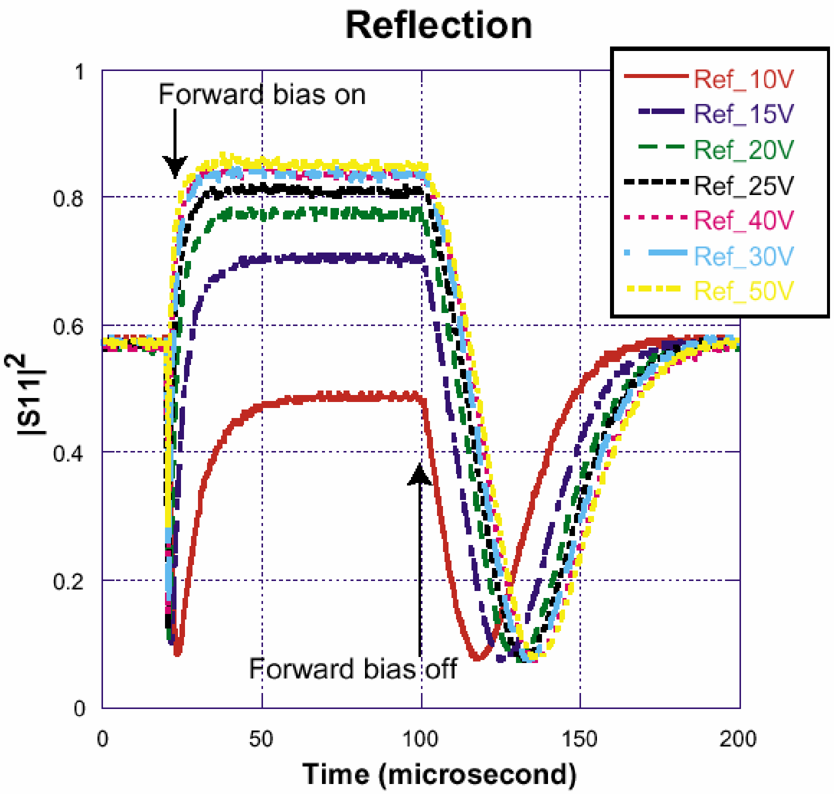
Low power measurement system



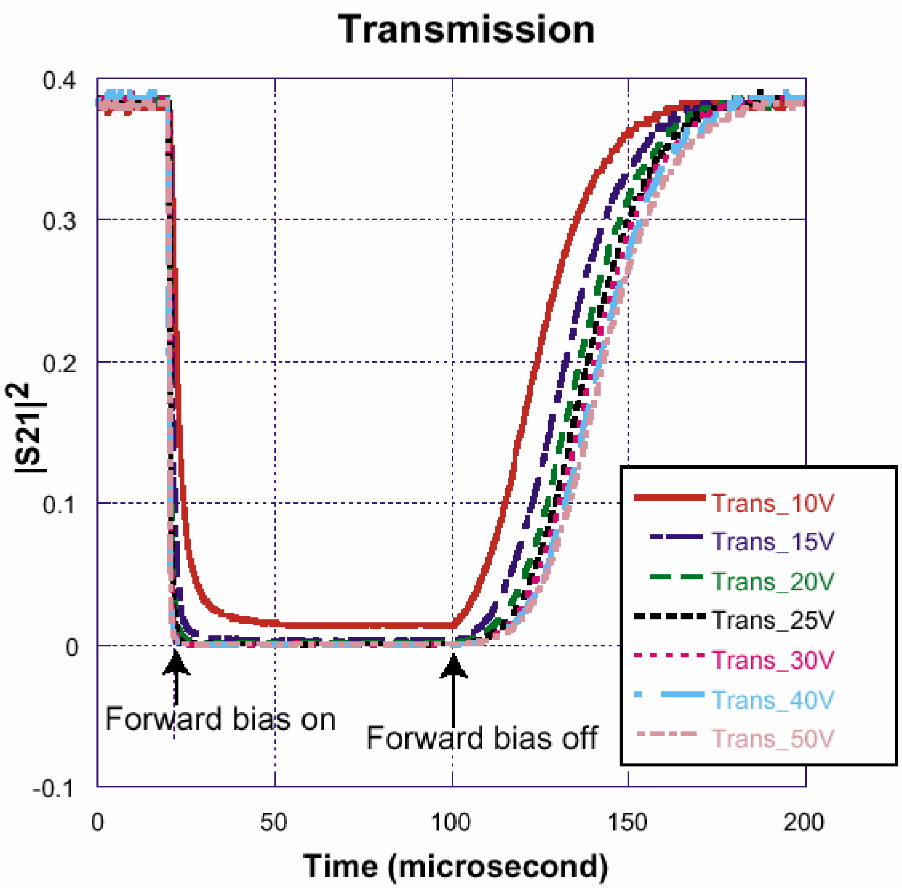
- Current is measured by current transformer



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



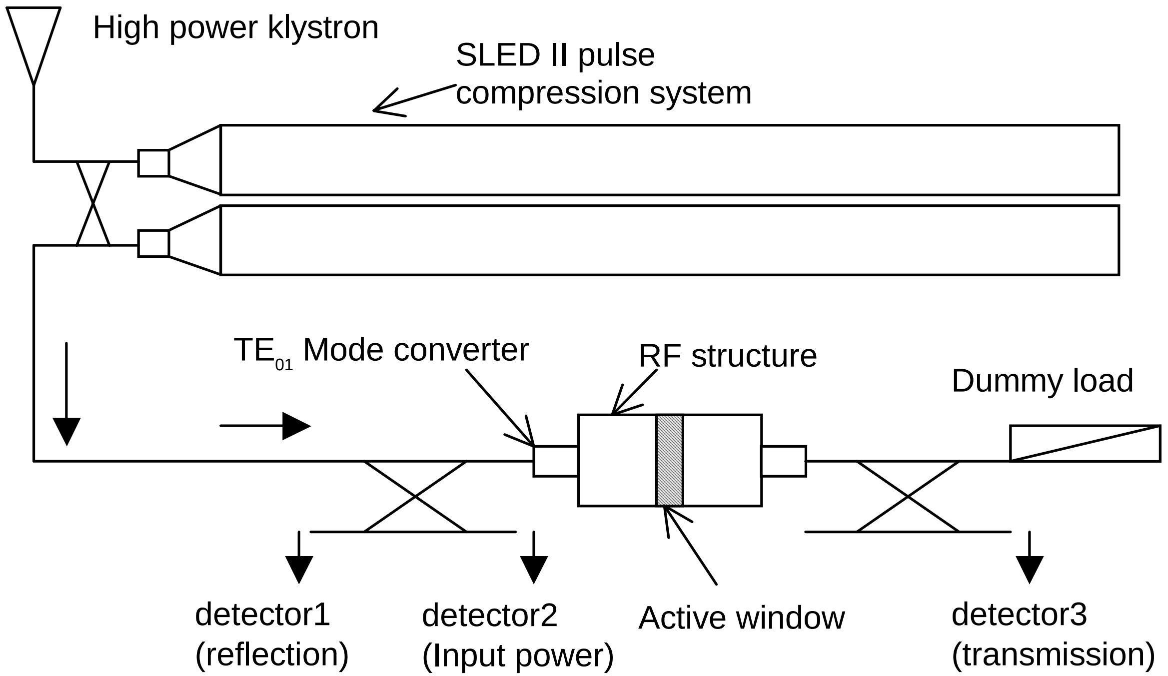
Reflection
Forward bias on
Forward bias off
|S11|^2
Time (microsecond)
Ref_10V
Ref_15V
Ref_20V
Ref_25V
Ref_40V
Ref_30V
Ref_50V
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200



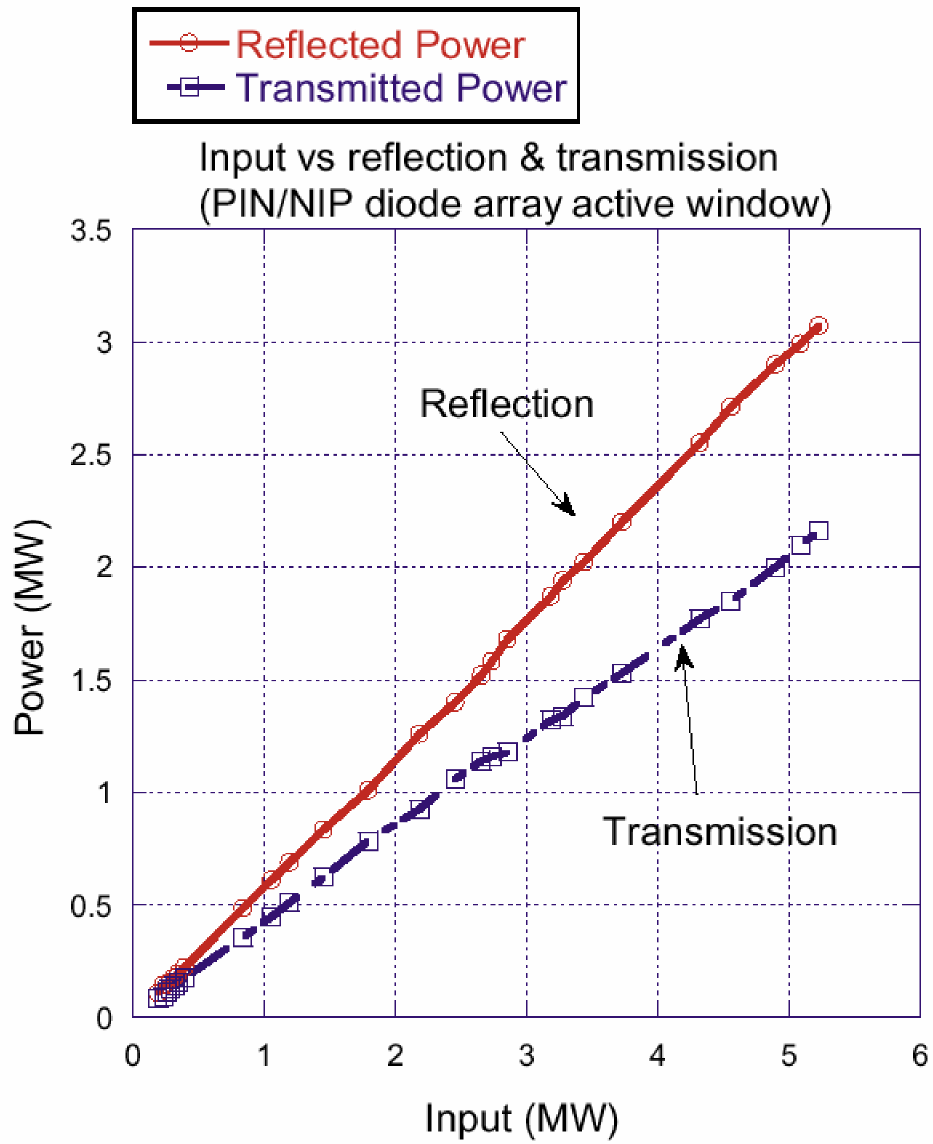
Transmission
Forward bias on
Forward bias off
|S21|^2
Time (microsecond)
Trans_10V
Trans_15V
Trans_20V
Trans_25V
Trans_30V
Trans_40V
Trans_50V
0.4
0.3
0.2
0.1
0
-0.1
0
50
100
150
200

High Power Experiment

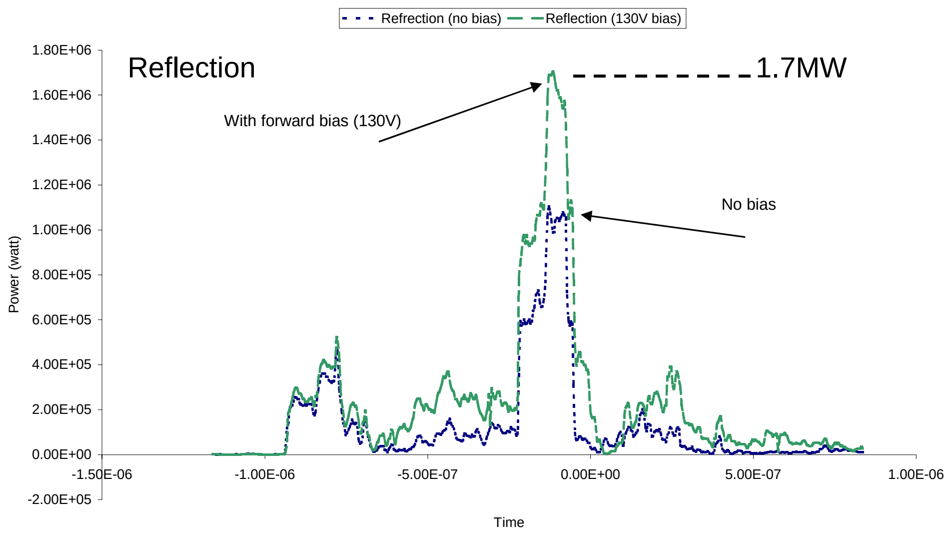
- Setup

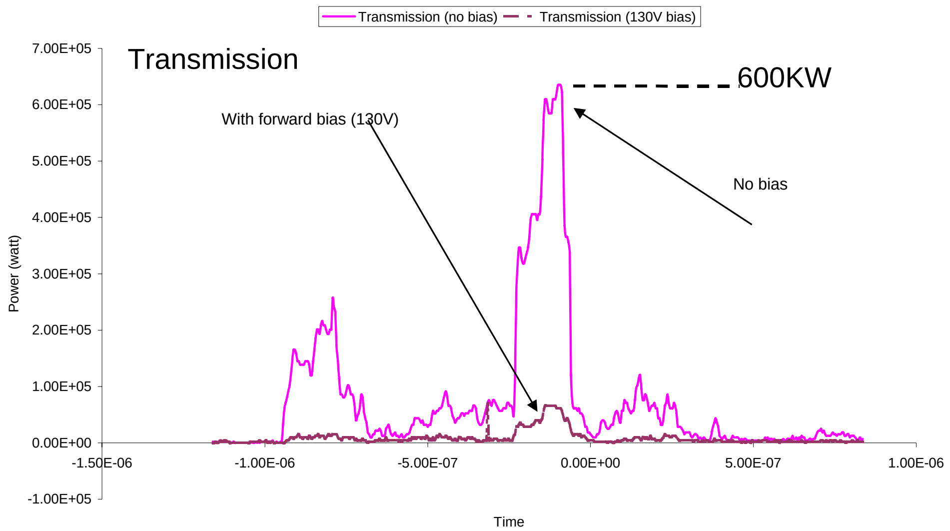


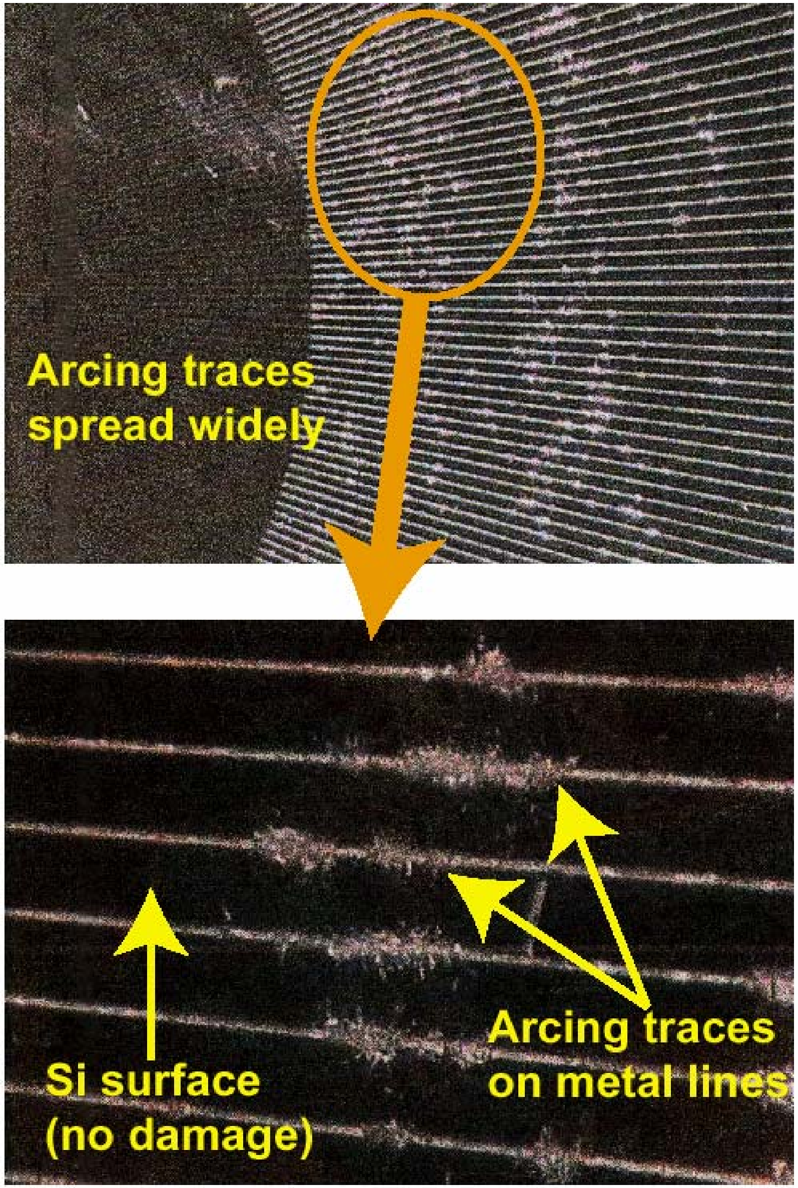
- SLED II output pulse width ~ 150nsec, up to ~10MW can be produced by this system
- Purpose:
  - Investigating failure modes with increasing electric field strength of RF signals
  - Demonstration of switching capabilities at a multi-megawatt power levels at X-band

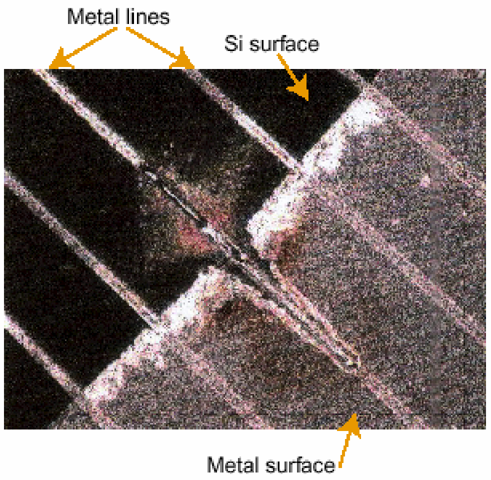


Reflected Power
Transmitted Power
Input vs reflection & transmission
(PIN/NIP diode array active window)
Reflection
Transmission
Power (MW)
Input (MW)
0
0.5
1
1.5
2
2.5
3
3.5
0
1
2
3
4
5
6


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

What should we do next

- Test the breakdown properties of Si
- Real Thermal Analysis
- Chose a laser system (532 nm?)
- Enjoy a working active pulse compression system