Experimental Setup:

DC HV Probe

3.3nF @40KV

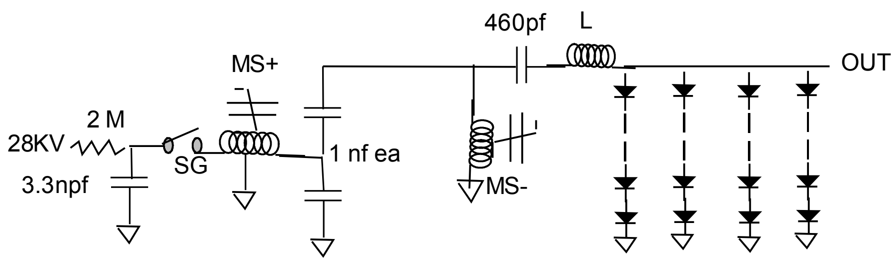
SG SW

L

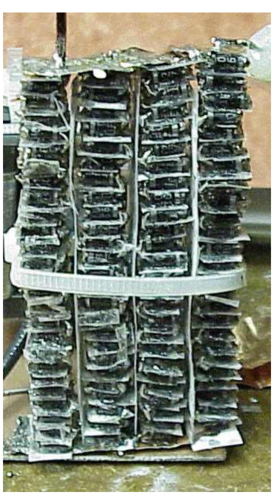
1K Probe

4X100UF1007

SOS



Component Close-up Photos:



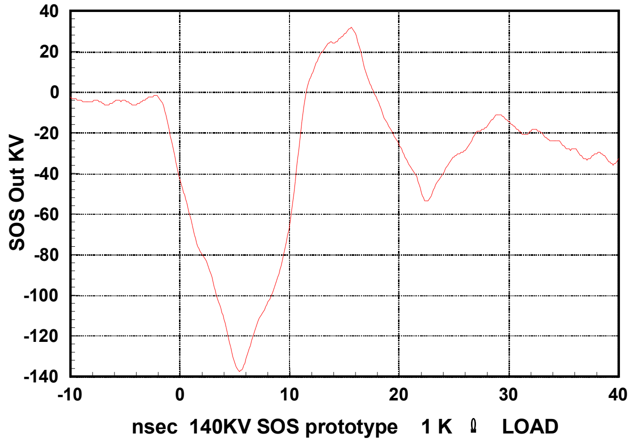
4 in Parallel ea.

100UF1007

MS+ MS-

4T

Output Waveforms:

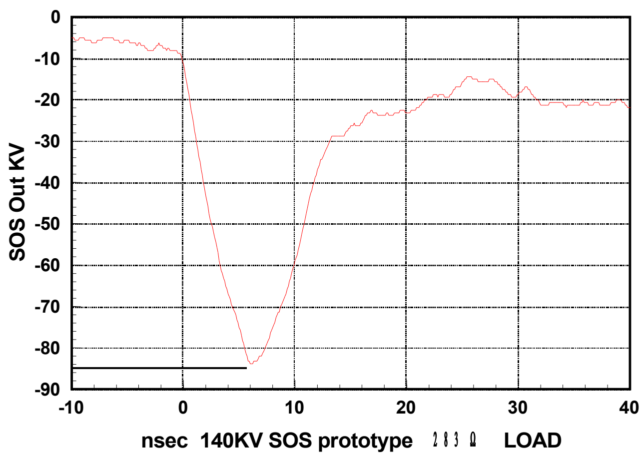


Load Z: 1 KΩ

Peak Voltage: 138KV

Peak Current: 138 Amps

Peak Power: 19MW

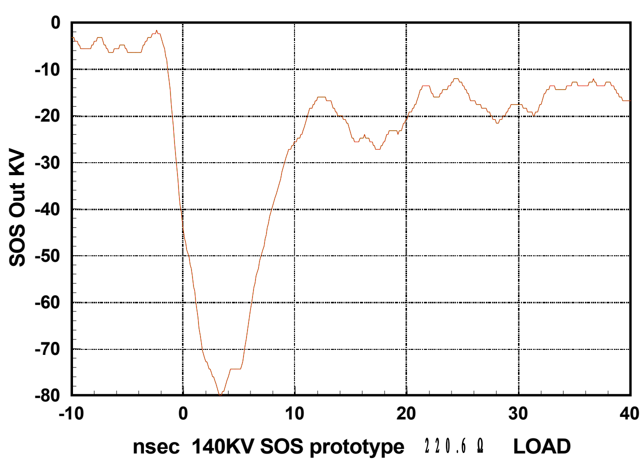


Load Z: 283 Ω

Peak Voltage: 85KV

Peak Current: 300.4 Amps

Peak Power: 25MW



Load Z: 220.6 Ω

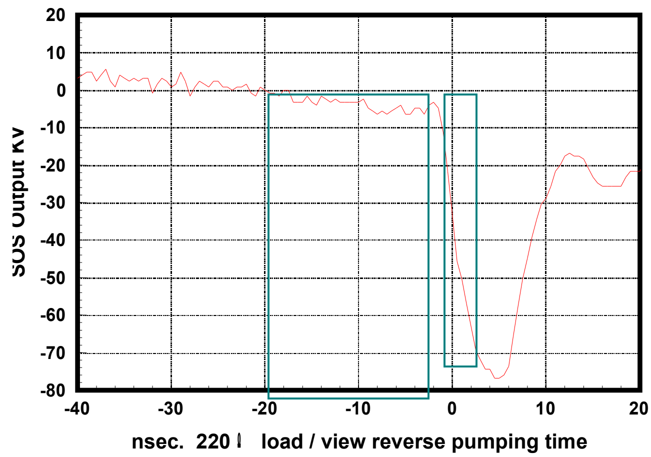
Peak Voltage: 80KV

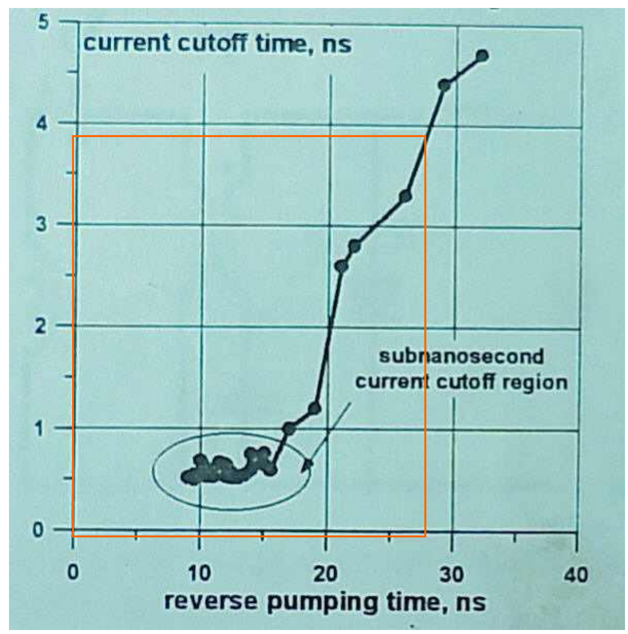
Peak Current: 362.6 Amps

Peak Power: 29MW

View The Reverse Pumping Time(220Ω Load):

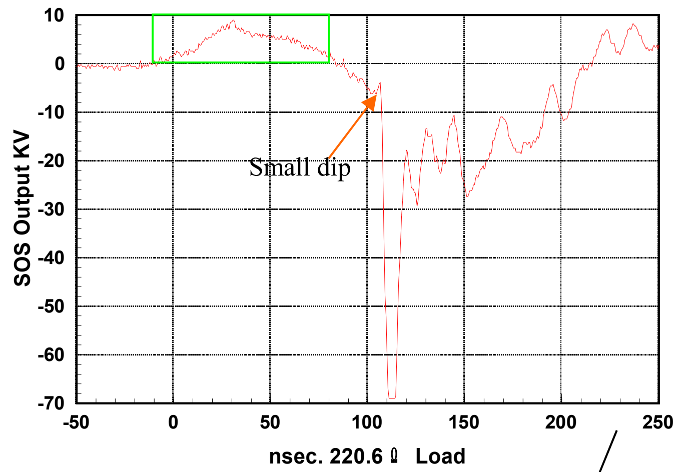
The reverse pumping time appears to be ` 28nsec. corresponding to a rise time of ~ 4 nsec. Comparing to the Russian literature (Repetitive Short Pulse SOS-Generators) the negative appears to agree fairly close to the Russian counter part.

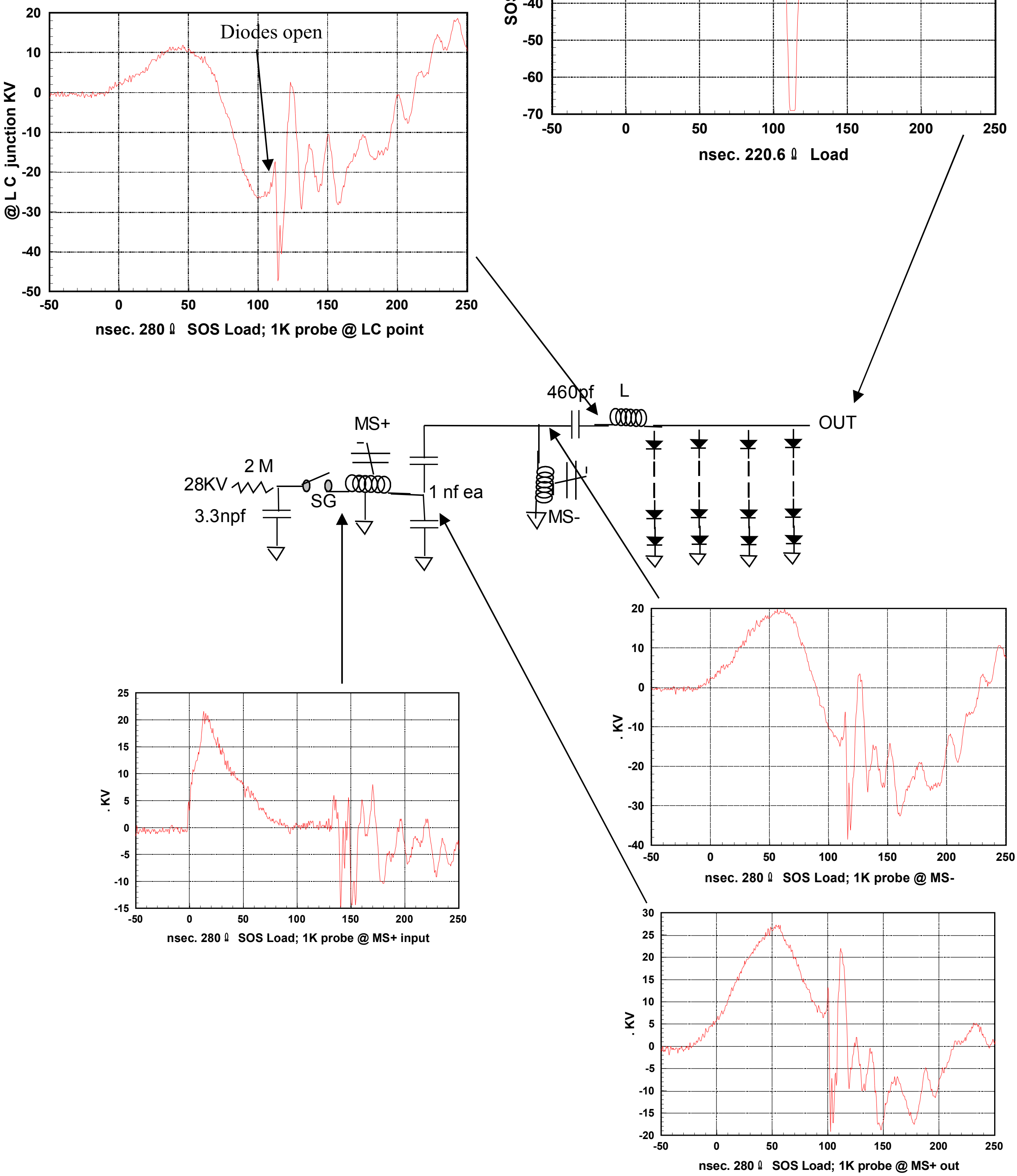


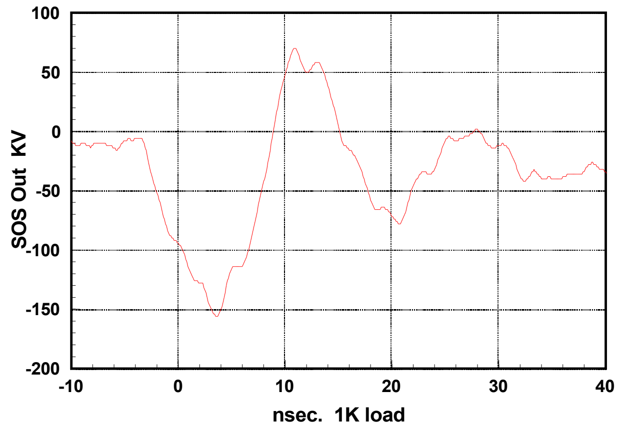


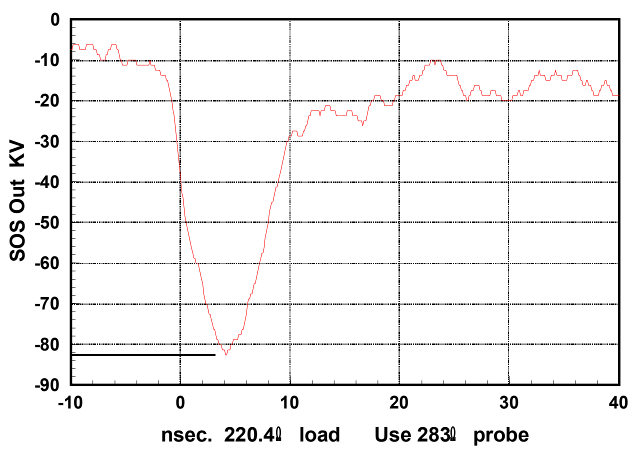
Voltage Waveforms @ Various Points:

The forward pumping time is ~ 88nsec at at ~ 10 KV froward voltage. During reverse pumping the diode finally opens some time after the minimal.







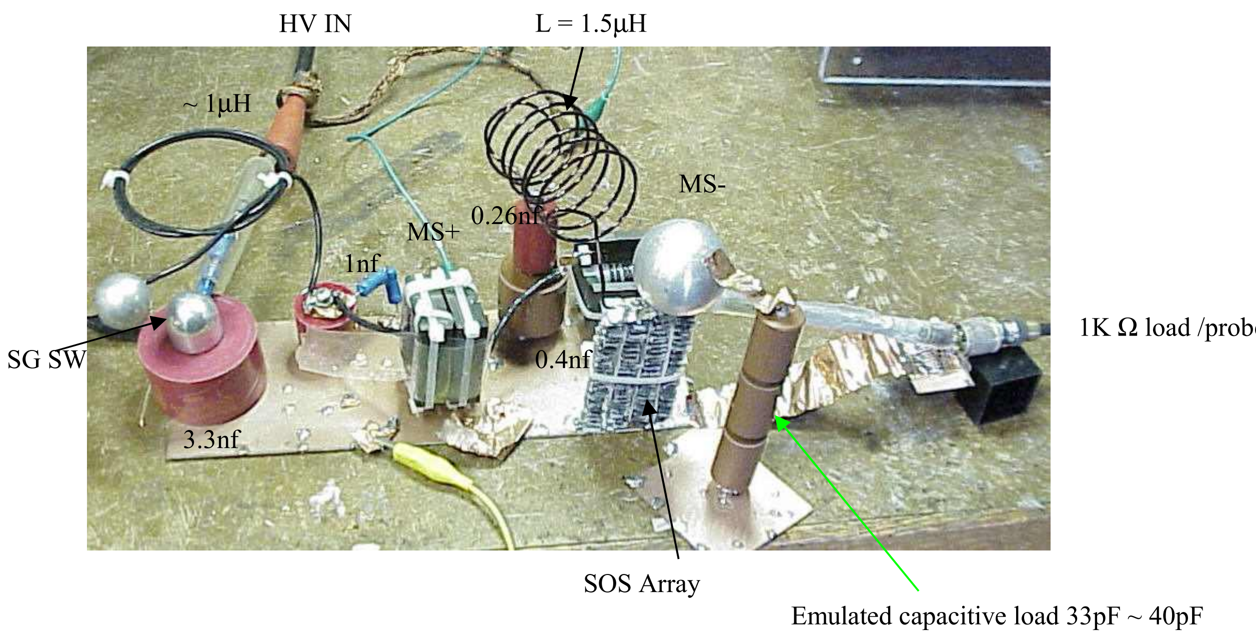


Peak Voltage: -83KV

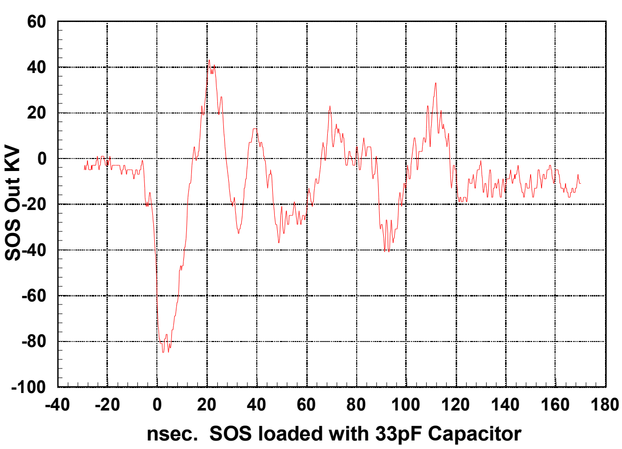
Peak Current: 376 Amps

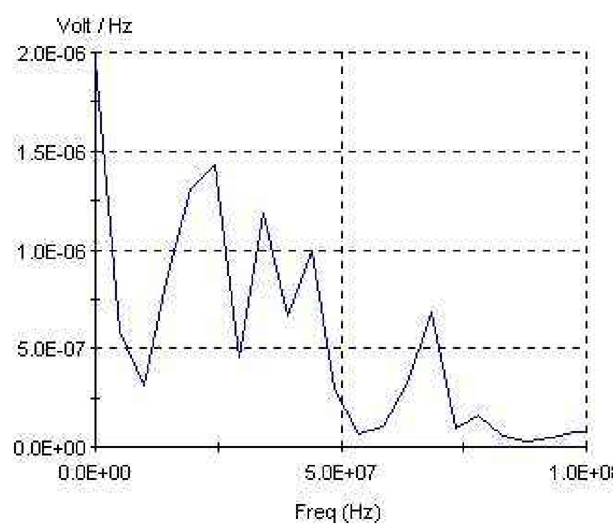
Peak Power: 31 MW

Experimental Setup:



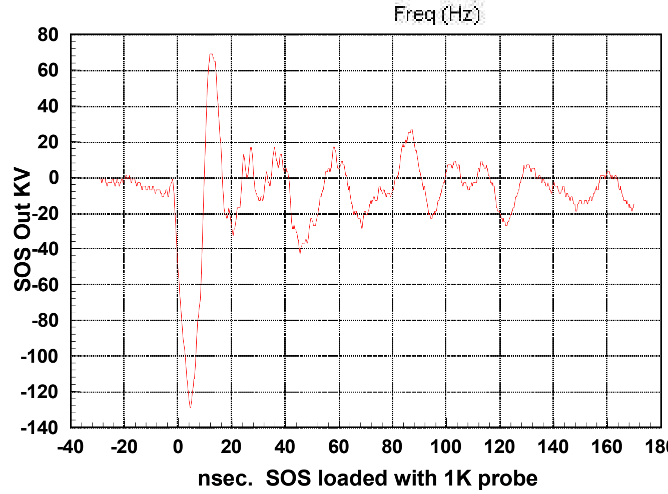
Waveform/ SOS OUT with 33pF & 1K Load:





Waveform / SOS OUT with 1K Load Only:

Peak Voltage: 130KV
Peak Current: 130 A
Peak Power: 17 MW

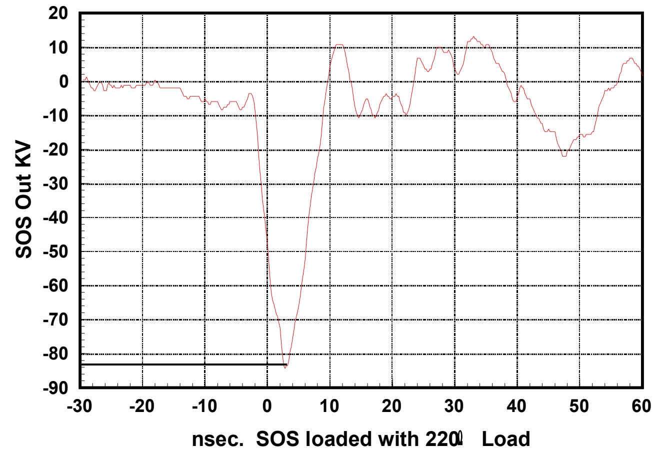


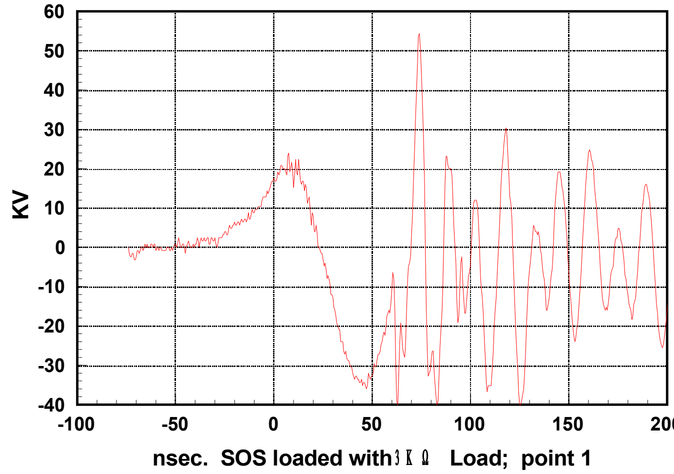
Waveform/ KV out with 220Ω load:

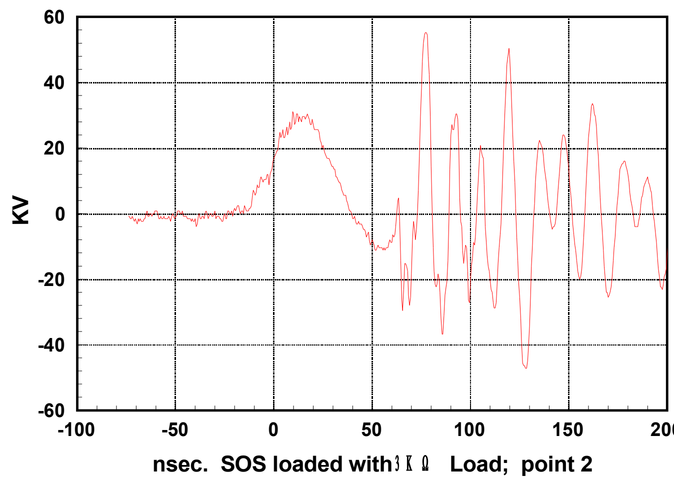
Peak Voltage: ~85KV

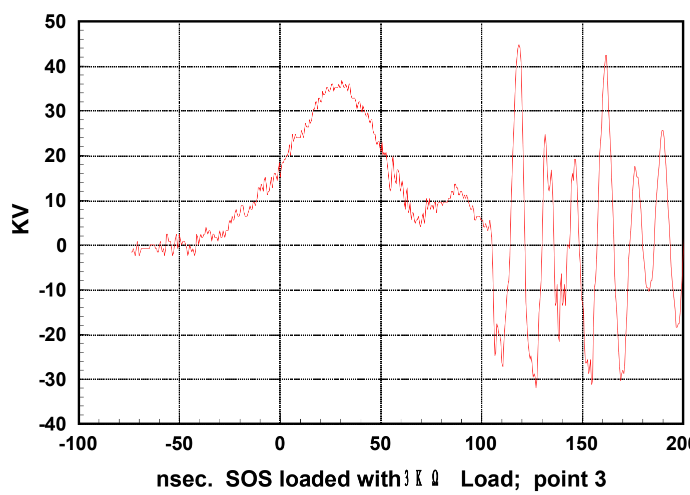
Peak Current: 385 A

Peak Power 33 MW




KV
60
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150
200
nsec. SOS loaded with 3KΩ Load; point 1

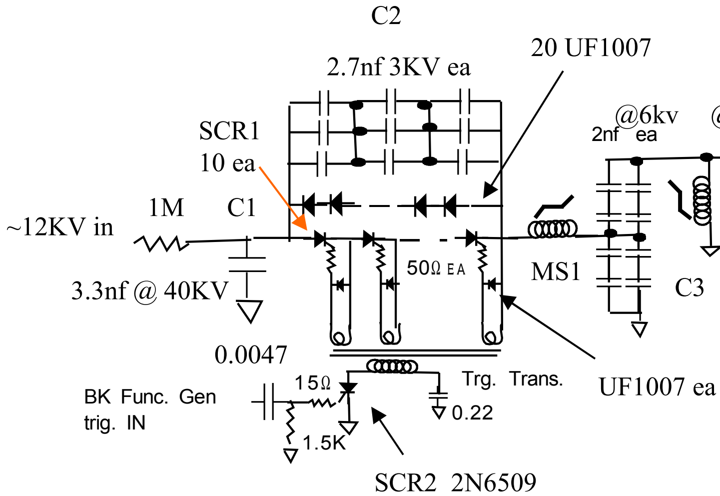

KV
60
40
20
0
-20
-40
-60
-100
-50
0
50
100
150
200
nsec. SOS loaded with 3KΩ Load; point 2


KV
50
40
30
20
10
0
-10
-20
-30
-40
-100
-50
0
50
100
150
200
nsec. SOS loaded with 3KΩ Load; point 3

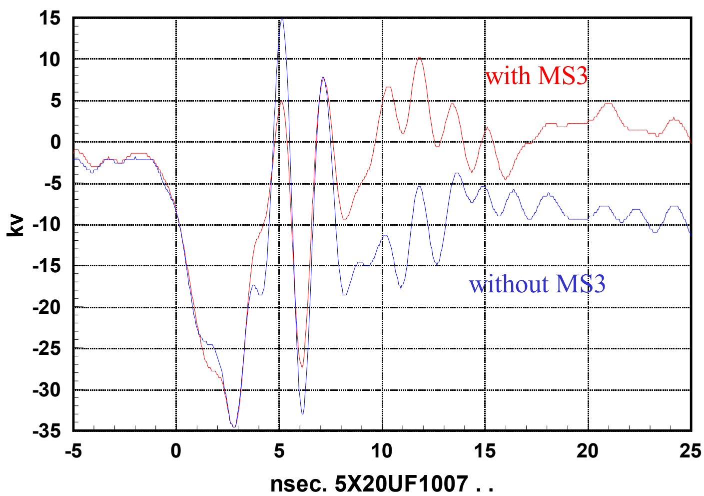
Notes: Modified 44SOS => 20 SOS / 4 in parallel . 20 Mar 02.P1

Purpose: => document voltage waveforms @ various test points

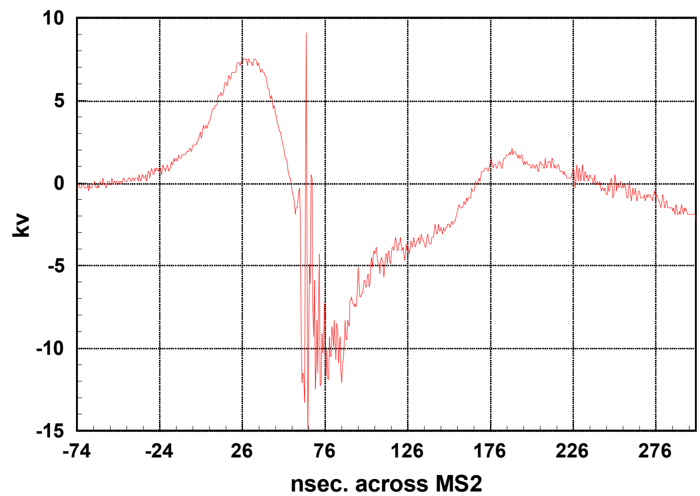
Schematic (final 5 Feb 02):

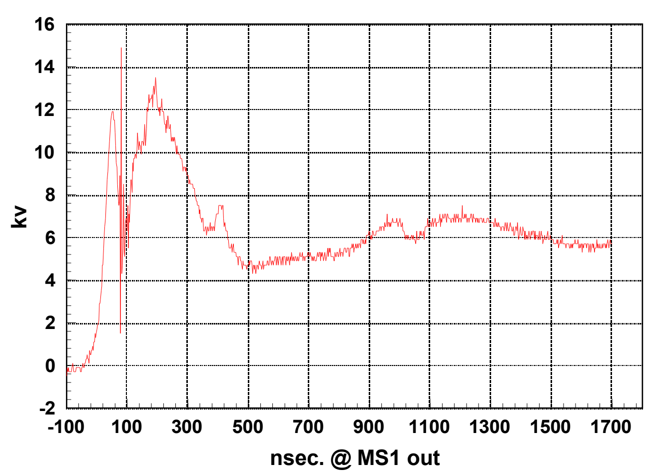


Across SOS / / 1000:1 probe/



Across MS2





Comments:

> The 10 SCR SW is rated at 12KV; the experimental device has been used at voltages exceeding that value by ~ 2 to 3 KV. While testing various component changes non- intended spark discharges occurred causing the SCR array to fail; suggesting that had these changes not been made, the SCR array may still be functional. However the non - intended spark appeared to be weak suggesting over voltage stress.

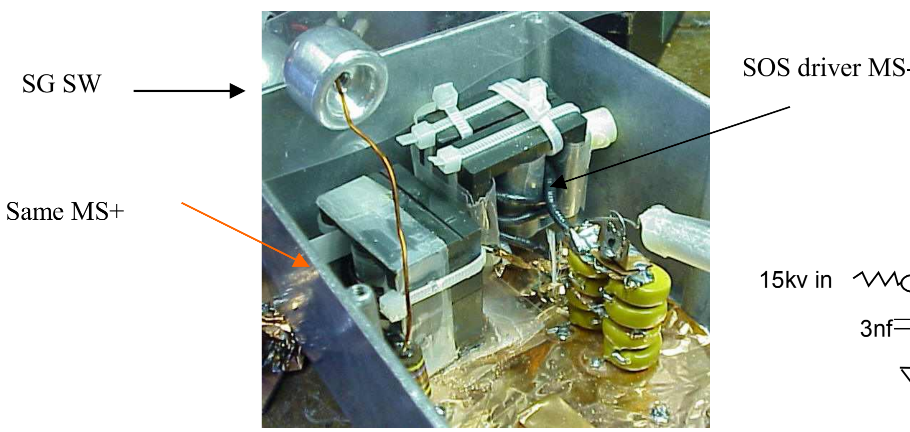
> During the 44 SOS field testing the SOS array was being operated at and above the rated value in order to get the ~ 2KV/m @ 1 m fiele strength; hence it is desirable to operate the switch above 12KV (~ 15KV). For this reason the SCR array is being increased to 15 SCRs in series giving it a 18KV rating.

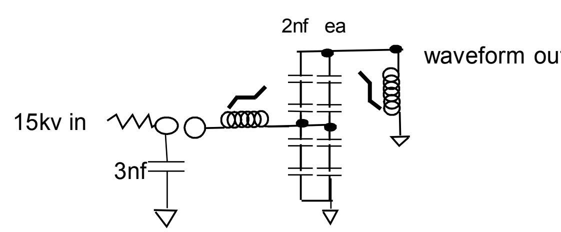
> The original SOS driver used a step up magnetic saturating transformer; the circuit was tested recently and compared to the 5X20SOS driver; it appears that the transformer is very inefficient voltage wise when compared. For this reason the transformer has been temporarly abandoned in favor of using the simpler magnetic switch design.

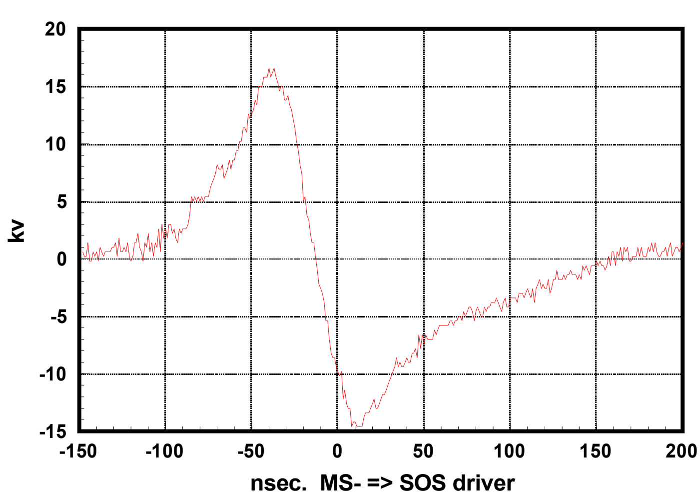
> The same ferrite core was used for the above described transformer and MS SOS driver, in the latter configuration the peak positive and negative swing appeared to be good; however the magnetic switching speed looked like it needed improvement. It is desirable to reverse the current as fast as possible after the SOS array has been forward pumped in order to improve the SOS opening speed. The core volt-sec seemed OK but that the saturated inductance was too large; hence a much larger core design was sought in order to keep the volt-sec rating yet reduce the saturation inductance and hence reduced switching time.

> Because many changes are being done; the experimental device has been tailored to a modular type in order to facilitate testing various changes.

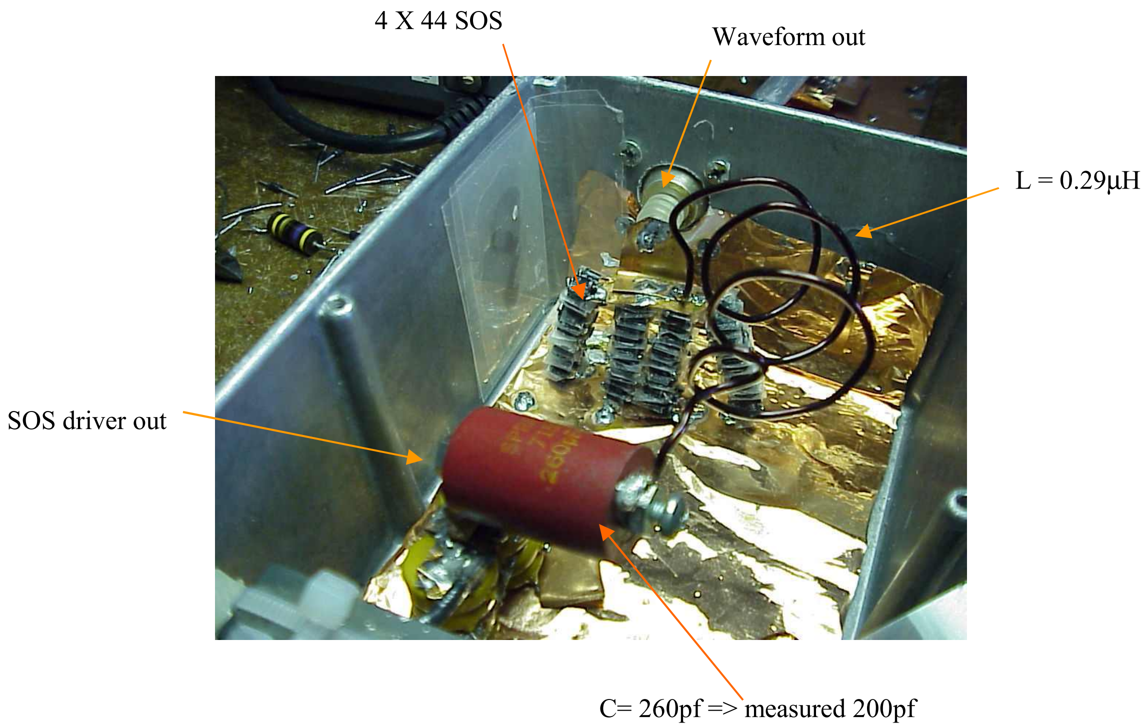
SOS Driver:



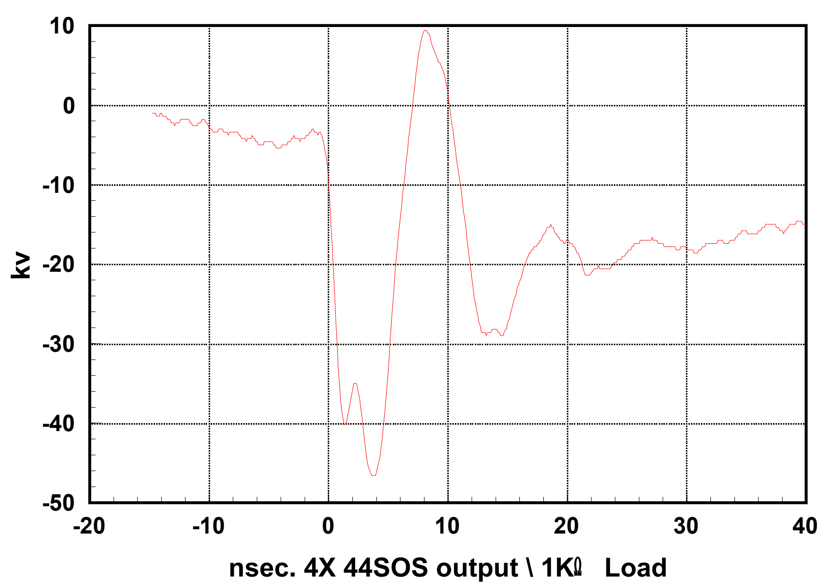




Driver & SOS Assembly:



SOS Voltage Waveform Out \ 1KΩ:

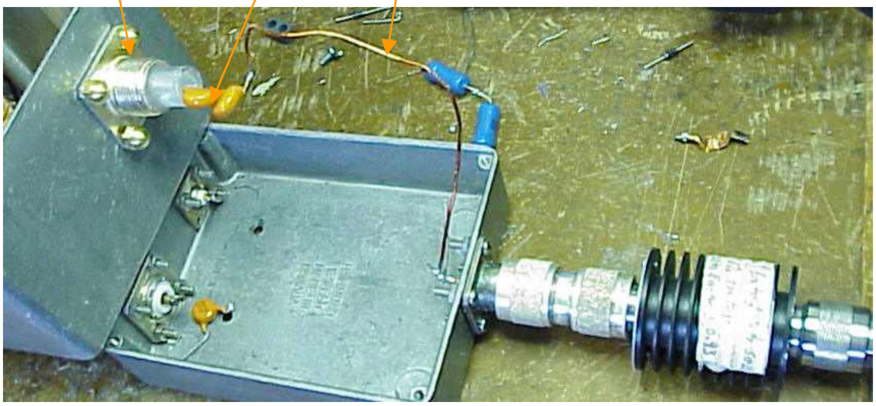


SOS to 50W Circuit:

SOS out

C= 22/2pf

L

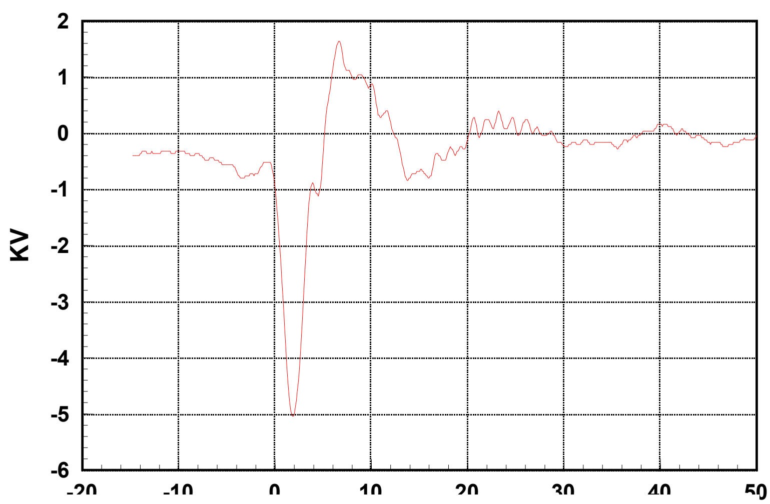


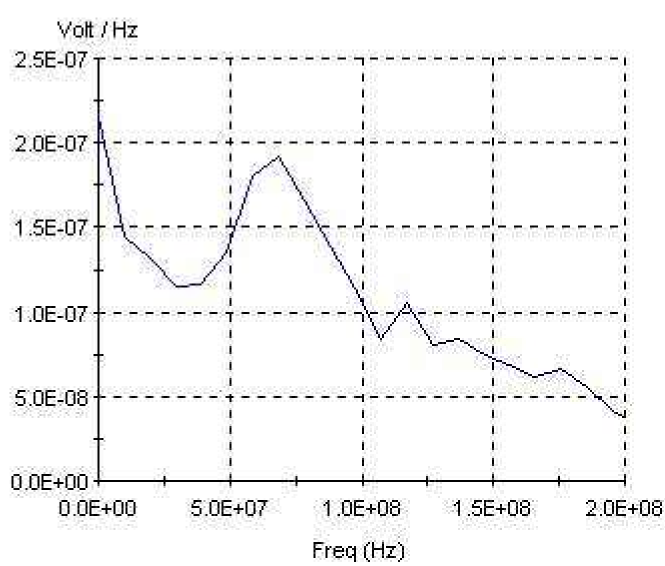
waveform

SOS to 50 Ω adapter

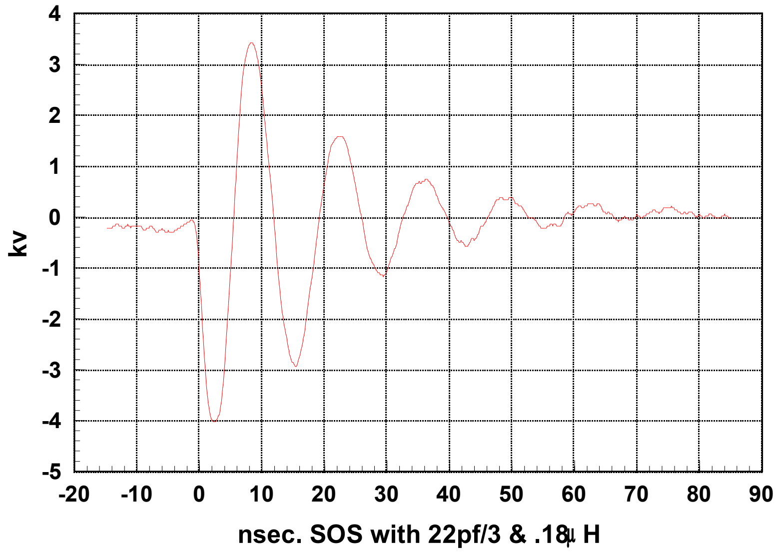
Attenuator X100

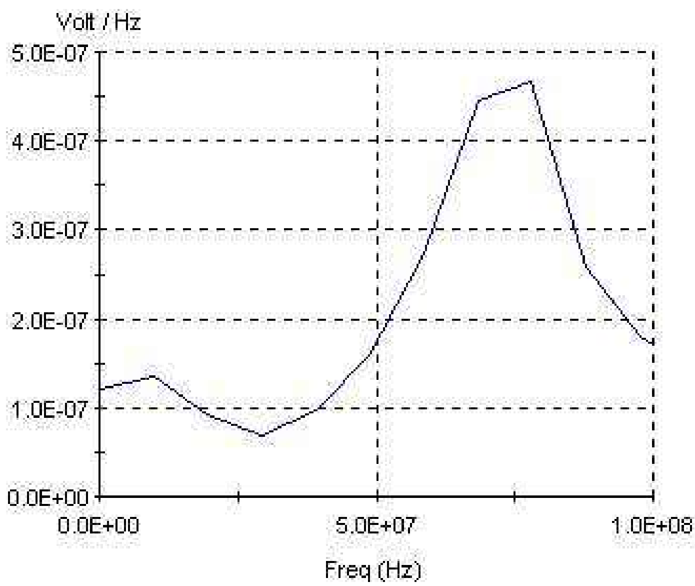
50 Ω Waveform

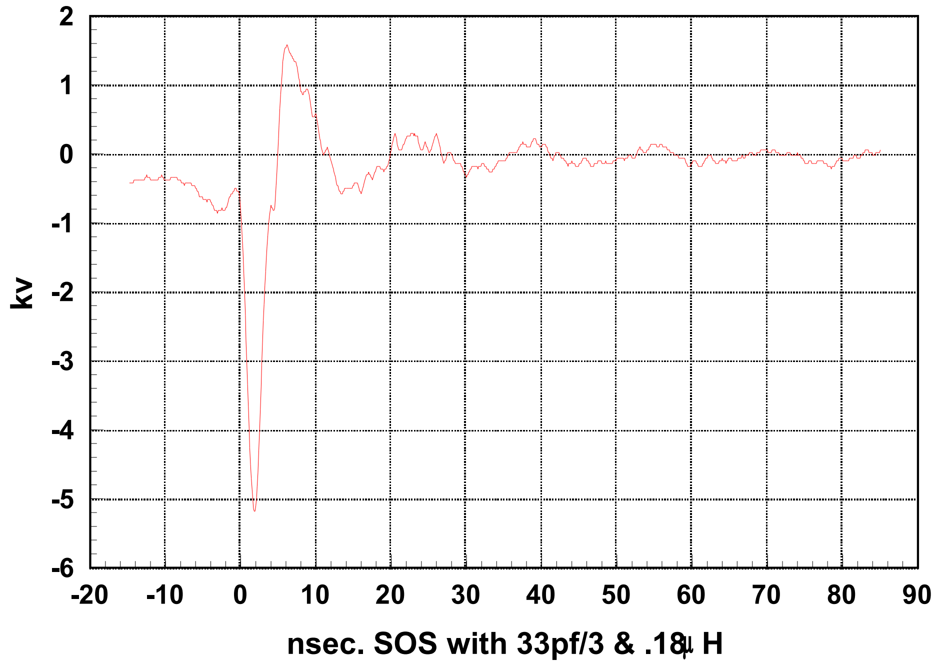


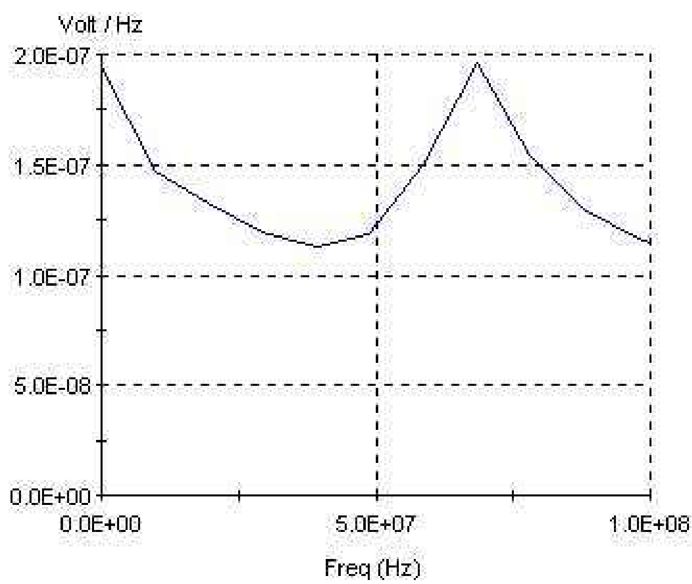


Notes: Use 22pf/3   Waveform   2 April 02a

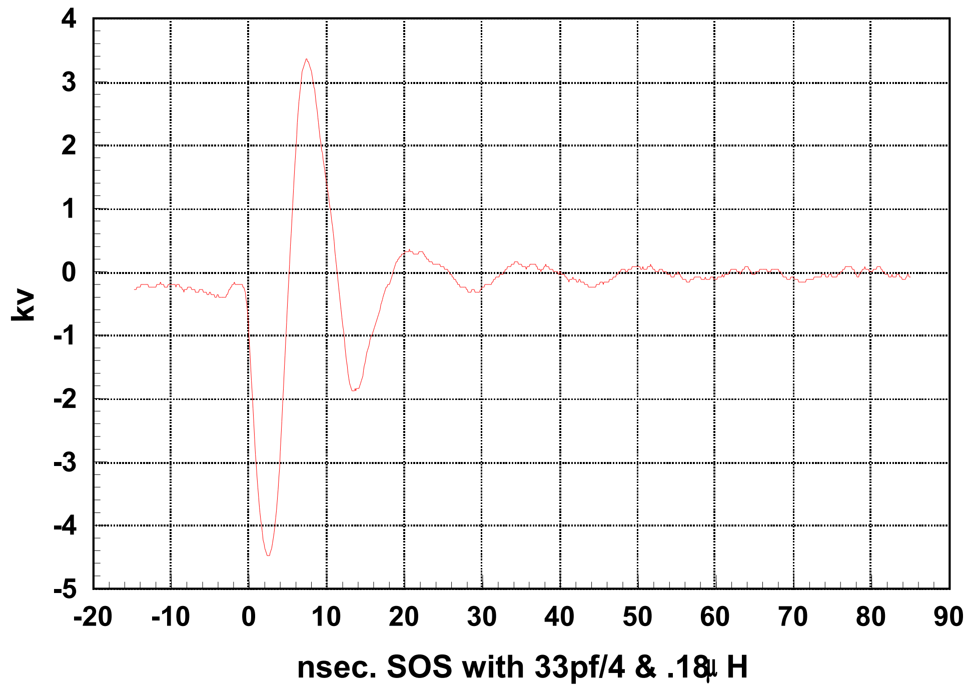


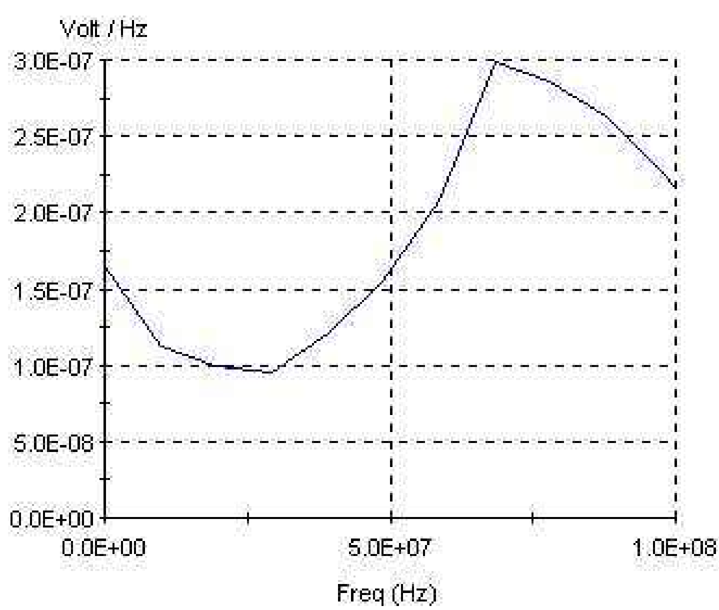


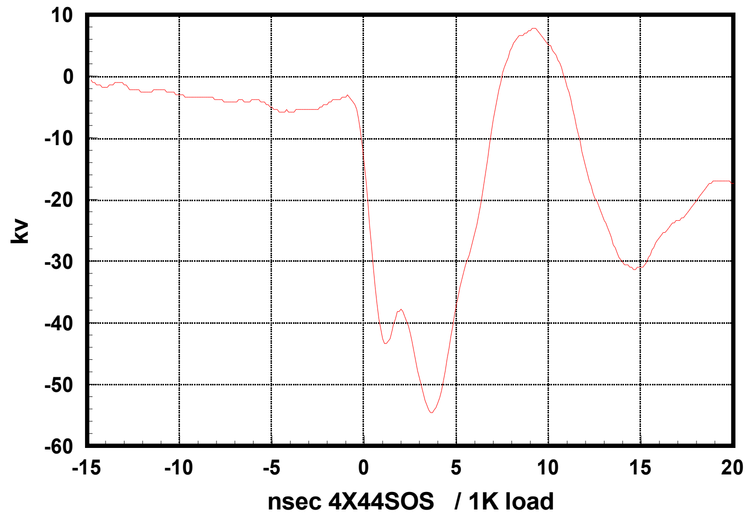

kv
2
1
0
-1
-2
-3
-4
-5
-6
-20
-10
0
10
20
30
40
50
60
70
80
90
nsec. SOS with 33pf/3 & .18μ H

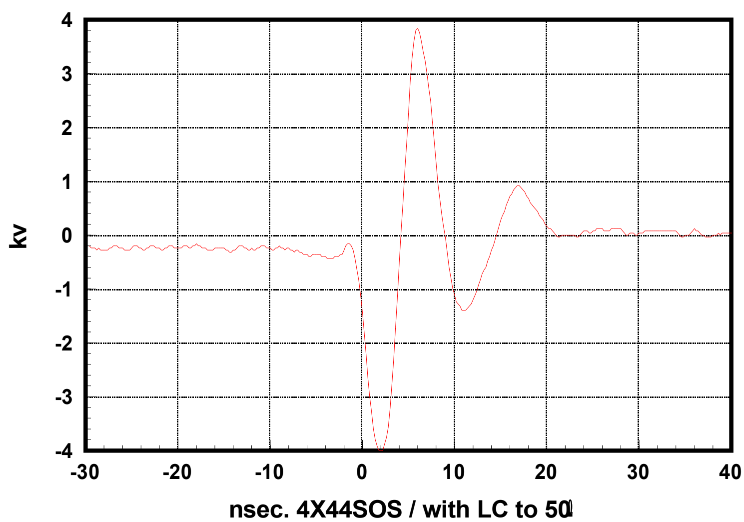

Volt / Hz
2.0E-07
1.5E-07
1.0E-07
5.0E-08
0.0E+00
0.0E+00
5.0E+07
1.0E+08
Freq (Hz)

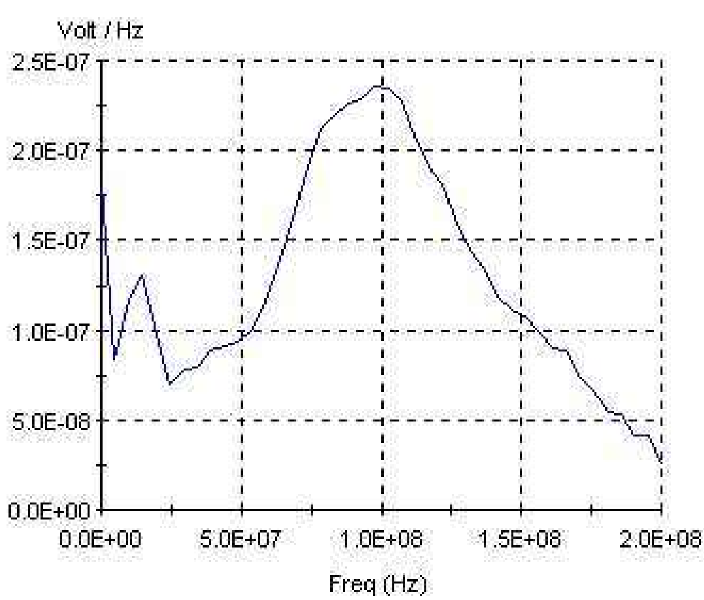
Notes: Use 33pf/4 Waveform 2 April 02c

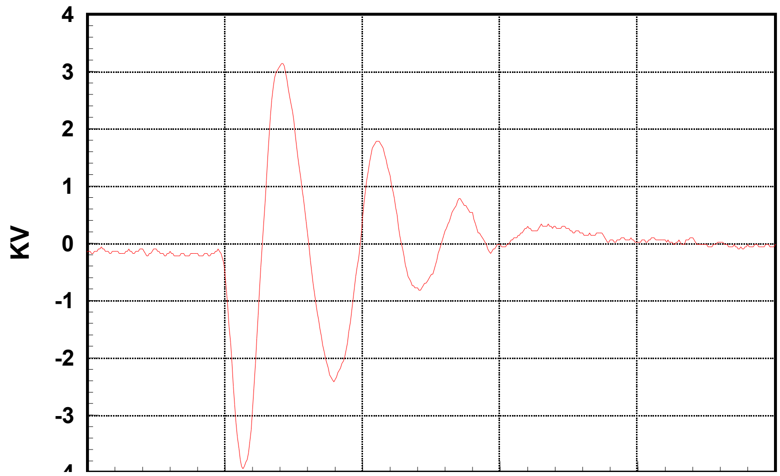


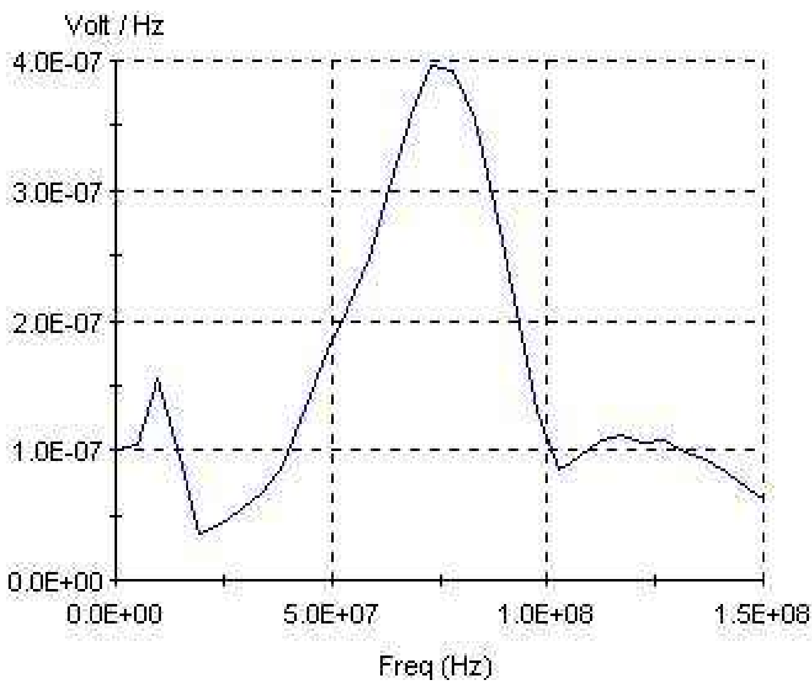


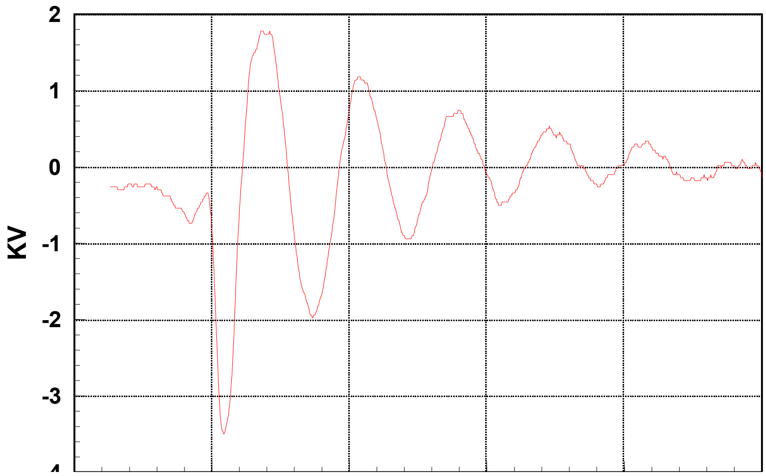

kv
nsec 4X44SOS / 1K load

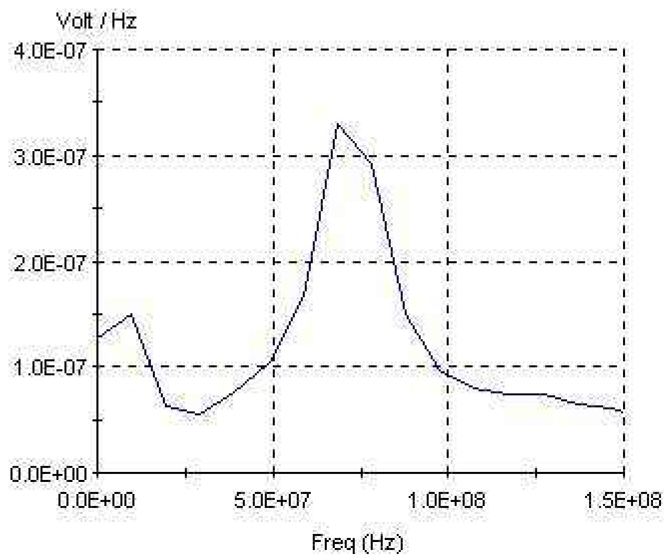

kv
nsec. 4X44SOS / with LC to 50

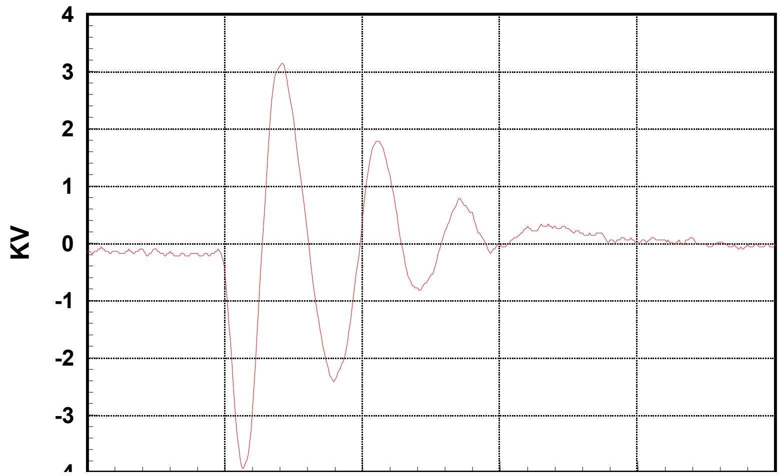

Volt / Hz
Freq (Hz)

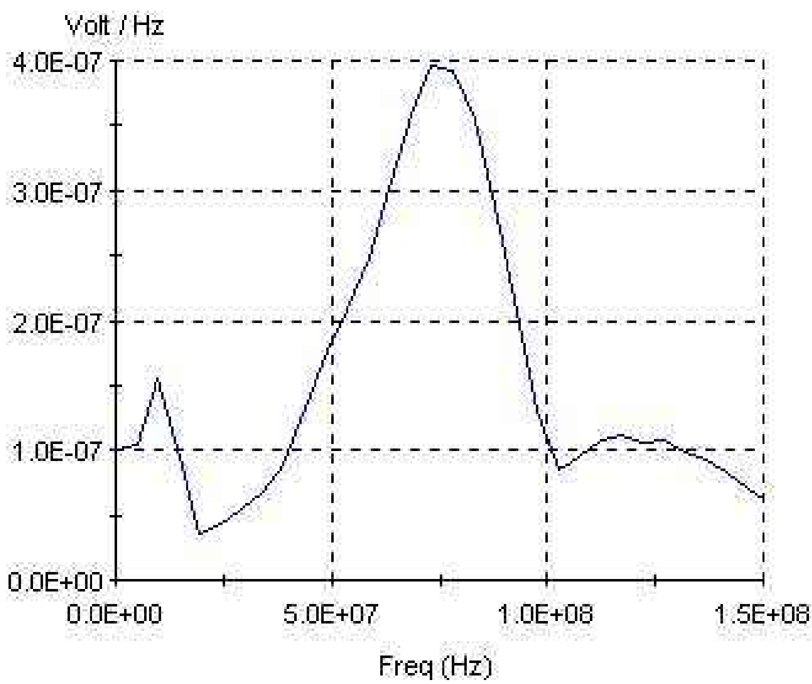

4
3
2
1
0
-1
-2
-3
KV


Volt / Hz
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
0.0E+00
5.0E+07
1.0E+08
1.5E+08
Freq (Hz)


2
1
0
-1
-2
-3
KV

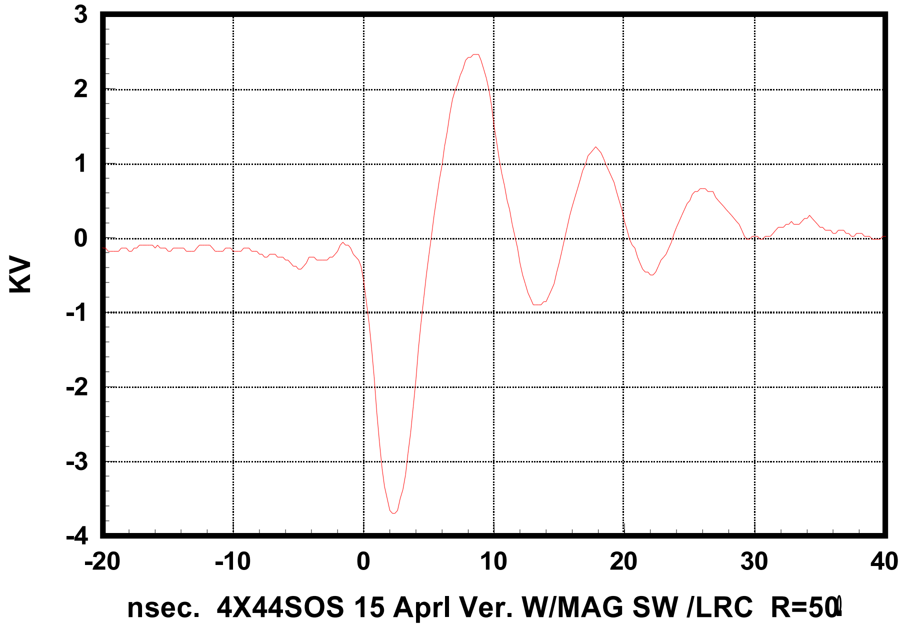

Volt / Hz
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
0.0E+00
5.0E+07
1.0E+08
1.5E+08
Freq (Hz)


KV
4
3
2
1
0
-1
-2
-3


Volt / Hz
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
0.0E+00
5.0E+07
1.0E+08
1.5E+08
Freq (Hz)

50 Ω Output Waveform:

HVPS @ 18.3KV



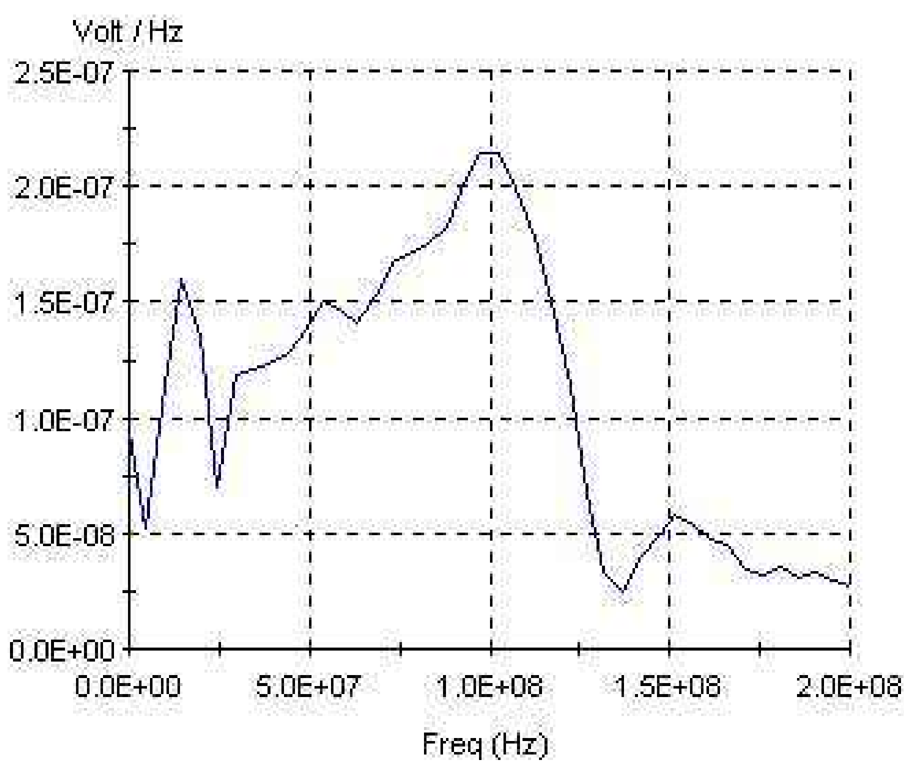
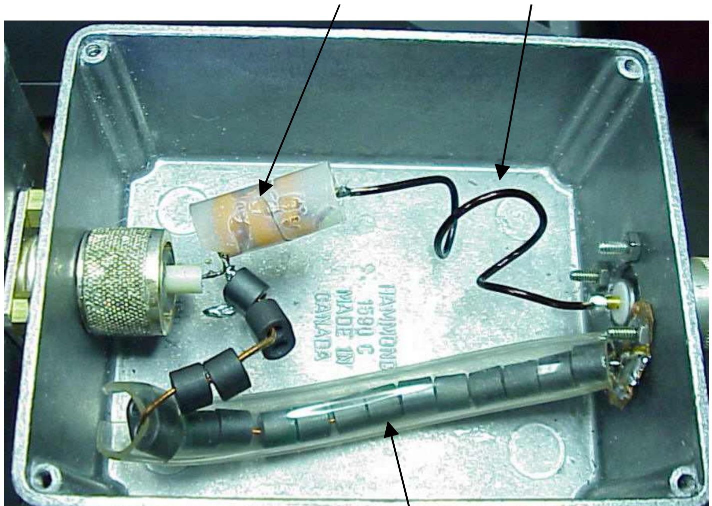


Photo of Entire Device:

50Ω out

Energy Storage Caps & SCR SW   MS SWs & 44SOS   Pulse Shaper & LRC

Photo/ Pulse Shaper &LRC: C = 22pf/3   L = ~ 0.2µH

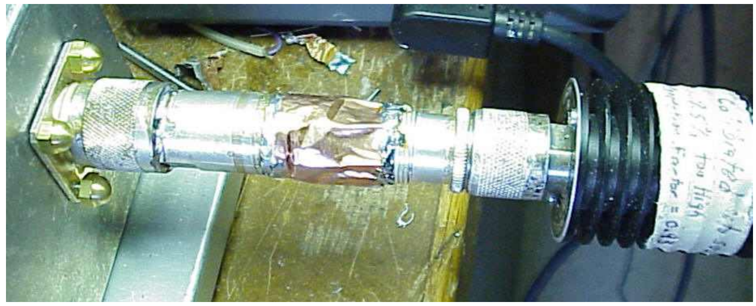


SOS OUT

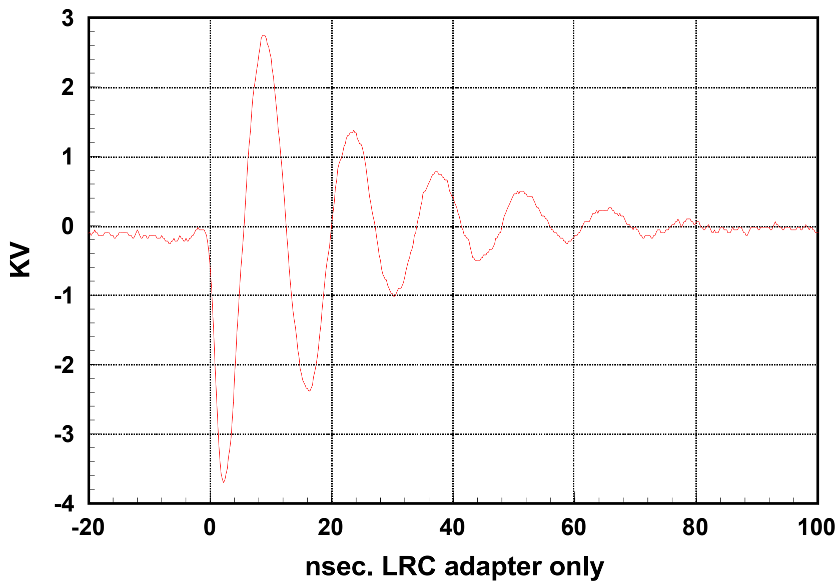
50 Ω Out

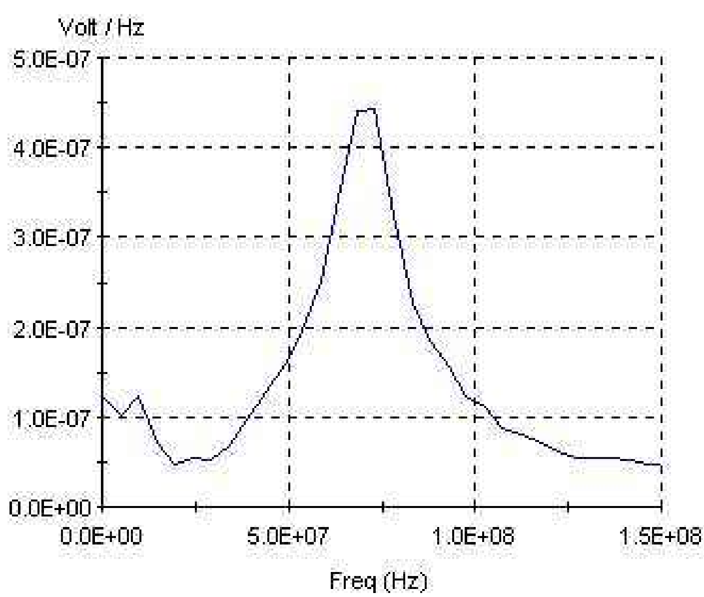
MS Pulse Shaper

Photo/ LRC only 50 Ω Adapter:



Output Waveforms:



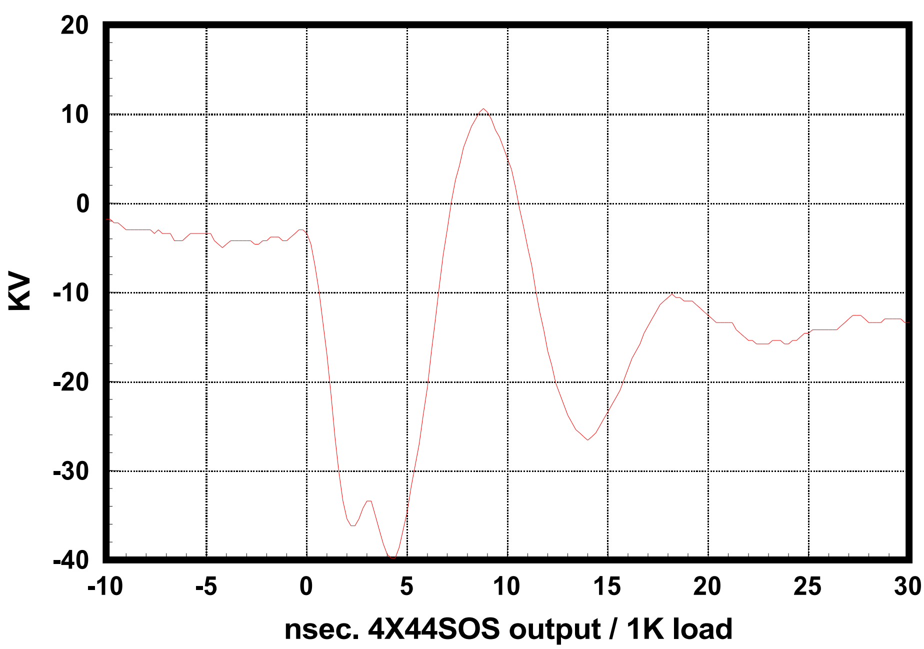


Photo/ Measure SOS Output Voltage:

10:1 Tek probe

1000 W Load/ 1000:1 probe

SOS Output Waveform:

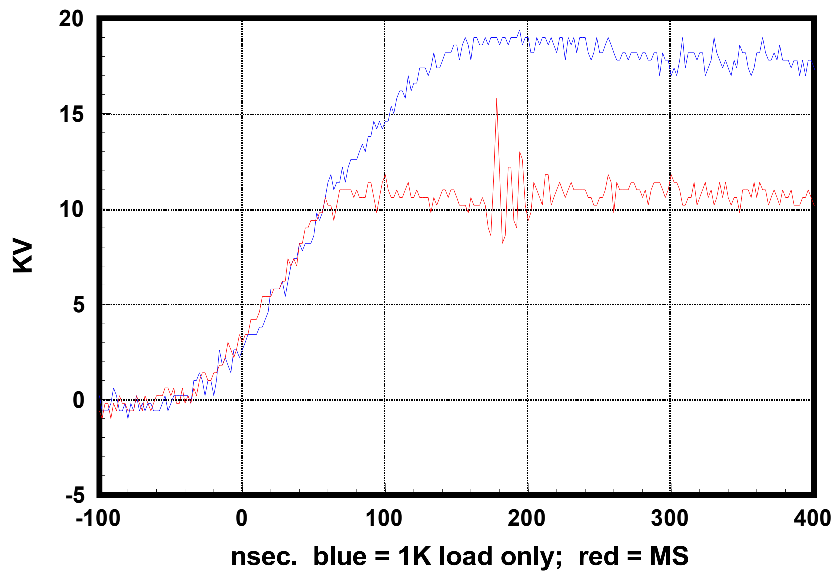


Notes: 4X44SOS/ with 20SCR @ 18.3KV/ Document Exp Setup 22 aprl 02 p1

Problems noted: 1) output is decreasing for some mysterious reason
2) SCR array not closing as good as spark gap / output not near as good as expected

Comment:

Initial investigation with small SCR arrays => could get 10 - 90 % ~ 60nsec switching. When applied to SOS like devices the 1st MS compressor was designed to close after the SCR array was fully turned on. The design procedure was to 1st test out the system with a spark gap and then afterward replacing it with the SCR array. For small arrays this seemed to work with some output loss. As the SCR array got larger it appeared that the array became more and more inefficient (additional commutation and energy storage capacitors were required in order to get sufficient SOS output) . For a 20 SCR array the output waveform (going to the 1st MS stage) was investigated:



The blue trace shows the SCR output into a 1K load (~ 18.5KV); as can be seen the rise time is much less than the expected 60 nsec. Rise; ~ 200nsec min -to-max. The 1st stage MS was designed to remain off for ~100 nsec. The red trace shows the output waveform going in the MS load; as can be seen it switched on well before the SCR is fully turned on (~ 12KV max MS input). It appears that there is a gross mismatch between the SCR array and MS; that the MS needs to be rebuilt for 200nsec hold off or using an additional MS stage.

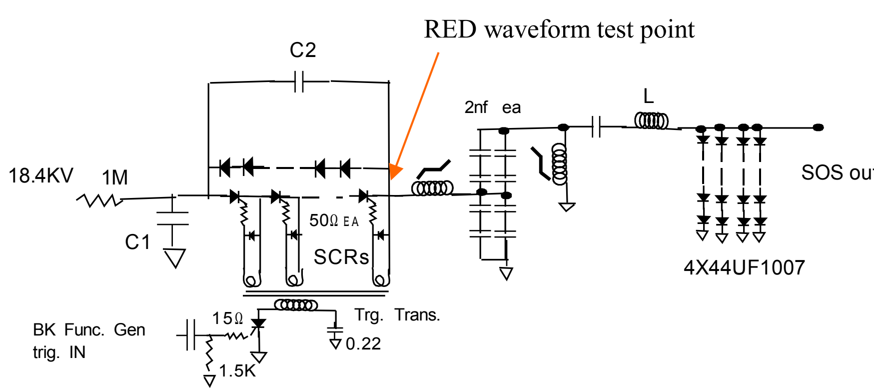
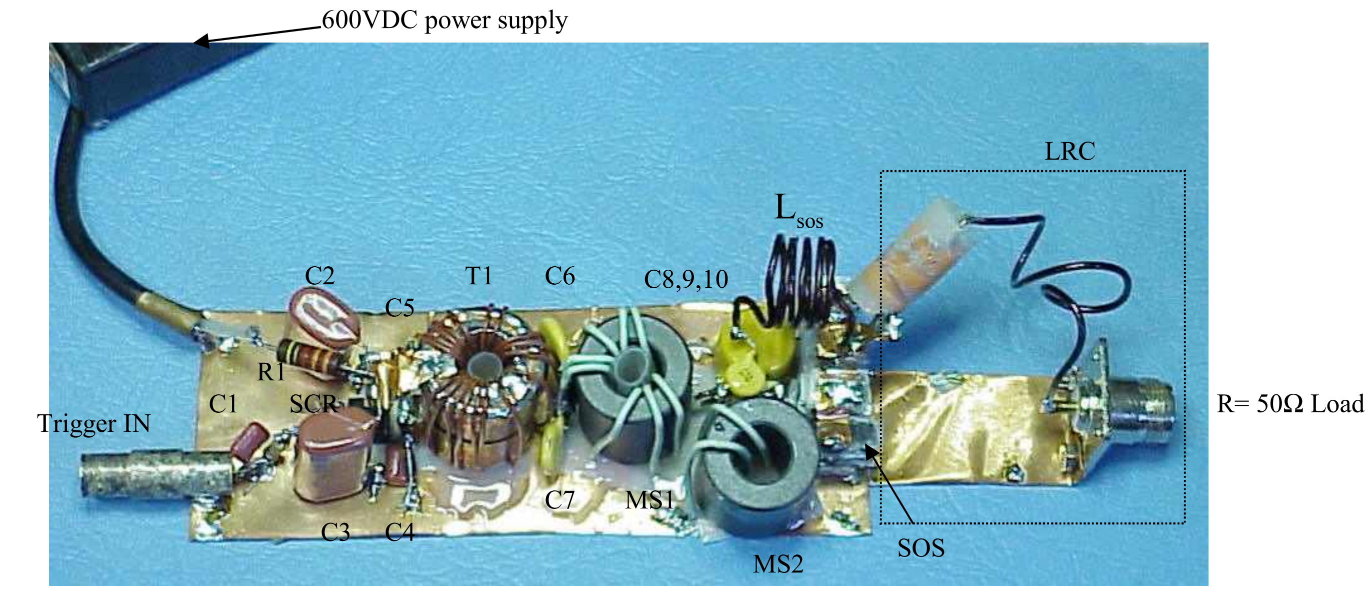


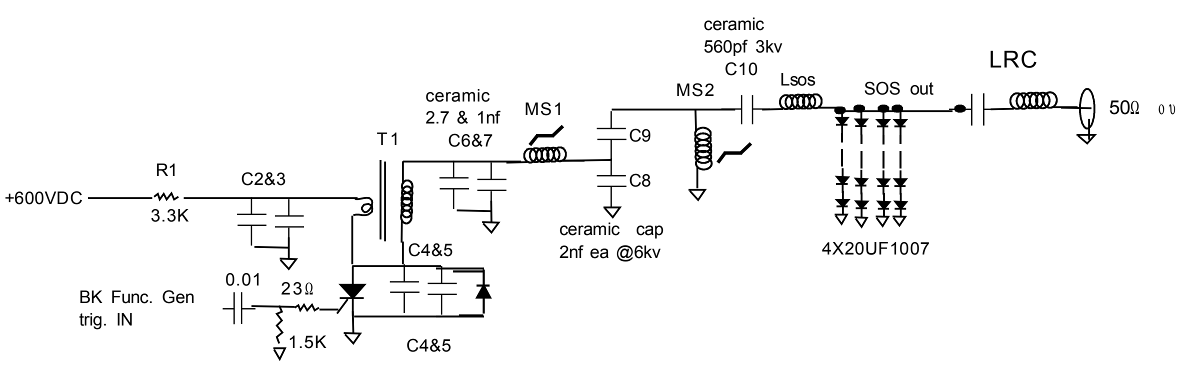
Photo \Experimental Device:



Note1: Ferrite used for T1, MS1, & MS2 => Digi-Key PN 240-2081-ND ; the Ni X Fe ratio has not been investigated as of this time which is of interrest regarding the ferro magnetic resonance frequency.

Note2: The SCR used is ON type 2N6502 (800V , 25A); this SCR type was used instead of the 1200V type because it appears (from previous experiments) to have lower turn on resistance. This is desirable for making transformer T1 operate properly.

Note3: C4 & 5 are arranged for a low inductance shunt configuration; it has been experimentally verified that T1 output increased by shunting two 0.01mf (Panasonic E-Series Metallized Polyester Caps) 630V acros the SCR's anode and cathode.



Description:

The above circuit represents several functional sections: 1st the 600 to ~5KV voltage step up; 2nd the 1st stage magnetic compressor utilizing MS1; 3rd the SOS forward/ reverse pump incorporating MS2 ; 4th the SOS and energy storage; and 5th the SOS shock LRC where R => is the 50Ω load.

The 1st section consists of the SCR gate trigger circuitry: the 0.01µf capacitor and 1.5K resistor and 23Ω current limiter . The capacitor causes the SCR to trigger only on the input edge only. This prevents the input pulse from keeping the SCR turned on during the trigger's positive cycle.

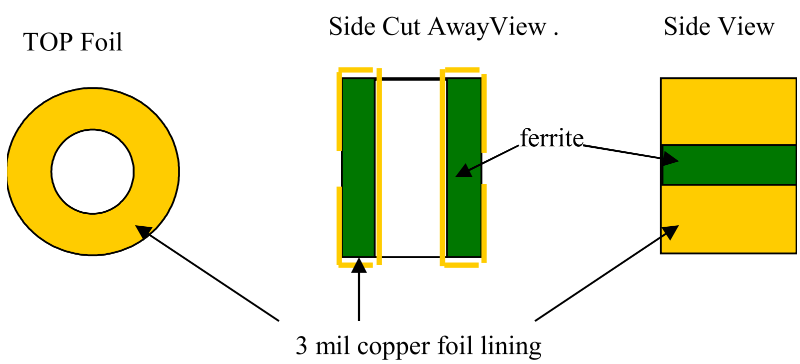
The SCR has a diode shunt in addition to C4&5; its function is to provide a conducting path to current reversals. The diode type is UZ1007 (ultra-fast 1KV @ 1A).

The SCR's function is to switch on the initially charged energy storage capacitors in the primary of T1. Both capacitors are Panasonic metallized polyester types each rated at 630VDC 0.47µf. The secondary (8:1) charges C6&7 to ~ 5KV. Although the secondary capacitance should be ~ C2&3/ N^2 (where N = ~8)~ 10pf; the experimentally determined optimized value to be about 37% that value (3.7pf). It should be that C4&5 is part of the charge path (for reasons described below) to C6&7 meaning that there is some capacitance reactance drop.

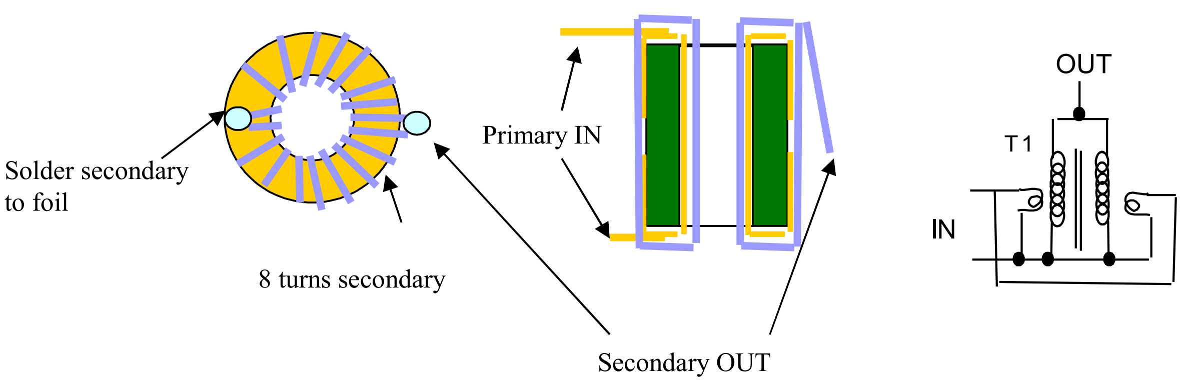
Transformer T1 incorporates flux guide features not tried previously based upon two references (SRL report & a magnetic switch pulse pwr lecture). The idea of the flux guide is to increasing coupling (decrease stray inductance) between the primary and secondary; the induced eddy currents in the guide is supposed to prevent magnetic flux from leaking away and keep it confined . One reference states that if one terminal of the secondary is connected to the flux guide than flux coupling is enhanced further.

Comment: need to experimentally determine whether or not connecting the secondary to the flux guide enhancement overrides the series loss effects on the secondary of C4&5; for a single SCR it was convient to connect its cathode to system return.

T1 Construction:



1st: the ferrite cyllinder is lined with copper foil as shown above; the inside is soldered to the top's inner edge and the outer lining is soldered to the top's outer edge.



2nd: the Teflon covered wire is wrapped around the primary flux guide (8 turns on each side); the single turn flux guide is the primary . The secondary winding technique is commonly used in magnetic switching to lower the saturated inductance (referenced in MS lecture series). The schematic shows the actual T1 winding configuration.

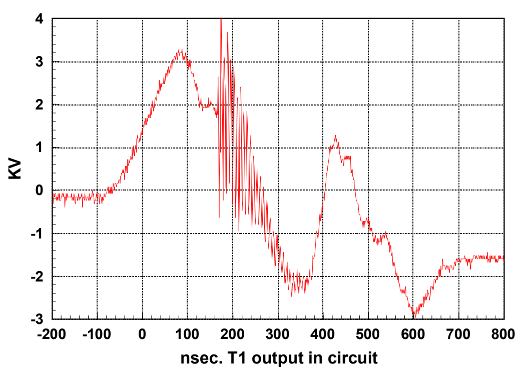
MS1: Magnetic switch 1 is designed to provide large inductance (unsaturated) while C6z7 are charging; based upon the time and voltage the number of turns on the ferrite core is matched to the desired volt-seconds. The actual winding consists of two winding in the same manner as that used for T1 so that when the core saturates L is very low. Hence when MS1 saturates C6&7 are discharged through MS1 and resonant charges C8&9 much quicker than C6& 7 are charged by T1 which results in magnetic compression. Note: what is desired here is a fast pulse edge for the process that follows.

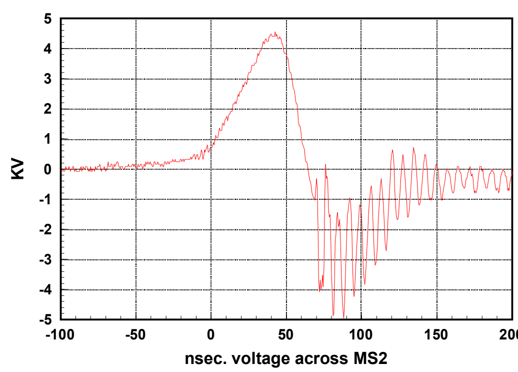
MS2: The main purpose that MS2 provides is fast forward and reverse SOS pumping. The1st positive rectangular pulse appearing across C8 is differentiated by C9. During the positive edge the voltage builds up until MS2 saturates; if saturation occurs ~ simultaneously when the negative edge occurs then a very fast voltage reversal with a large negative peak occurs across MS2.

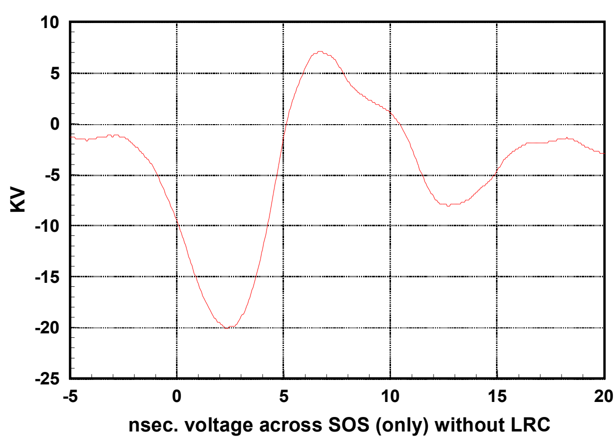
SOS & associated LC: The solid state opening switch incorperated ultrafast UZ1007 (70ns, 1KV, @ 1A) diodes connected in series (20) and parallel (4). During the positive portion of MS2 the diodes array is forward pumped via. C10 and L sos. Injecting charge in the diode junctions. When MS2 reverses the trapped charge is extracted from the junctions causing large currents to flow through Lsos storing energy (1/2 Li^2). When most of the charge is extracted the junction behaves as a reverse biased diode or opening switch (the faster the MS2 reversal the faster the diode opens) causing a very large counter EMF to appear from Lsos. C10 and Lsos and the diode junction capacitance form a dynamic tuned LR circuit. C10's value was experimentally optimized.

LRC Out: The LRC values is based upon previous design and experimental considerations; the SOS output shock excites it causing a damped ~70Mhz ring of several cycles 50 Ω drive OUT.

Waveforms:







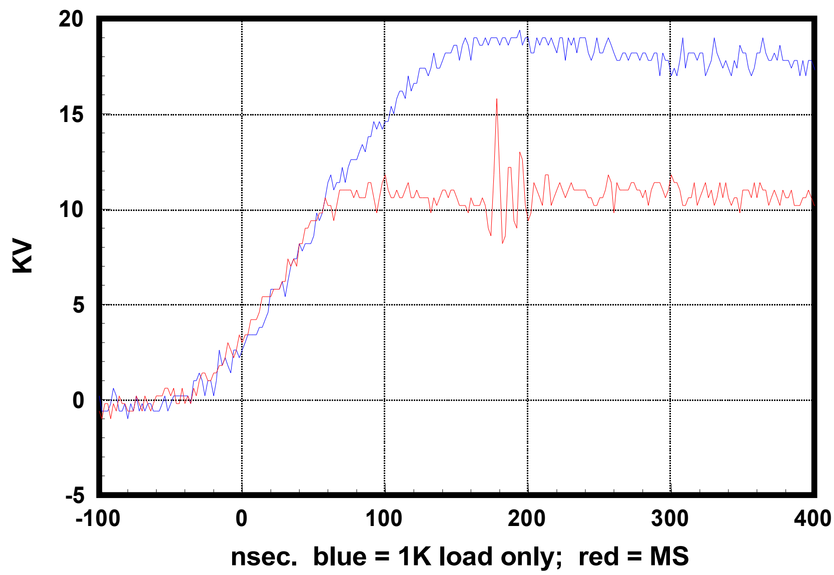
Comment: It should be noted that simply scaling up this design is NOT all that is needed to get much greater output voltage. Certainly for the package size used, SOS output voltage has certainly not been optimized; however to keep things in the same time frame at much higher voltages will certainly require larger ferrite core area. 1st if the voltage is increased then the required volt seconds is increased. If the core area is not changed then the number of turns use in the magnetic switch is increased at the expense if increased saturated inductance. If the saturated L must not change then the core size must be increased.

Notes: 4X44SOS/ with 20SCR @ 18.3KV/ Document Exp Setup 22 aprl 02 p1

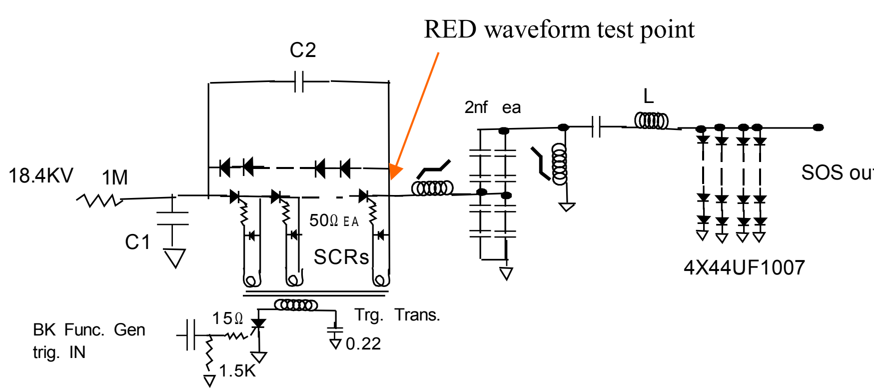
Problems noted: 1) output is decreasing for some mysterious reason
2) SCR array not closing as good as spark gap / output not near as good as expected

Comment:

Initial investigation with small SCR arrays => could get 10 - 90 % ~ 60nsec switching. When applied to SOS like devices the 1st MS compressor was designed to close after the SCR array was fully turned on. The design procedure was to 1st test out the system with a spark gap and then afterward replacing it with the SCR array. For small arrays this seemed to work with some output loss. As the SCR array got larger it appeared that the array became more and more inefficient (additional commutation and energy storage capacitors were required in order to get sufficient SOS output) . For a 20 SCR array the output waveform (going to the 1st MS stage) was investigated:



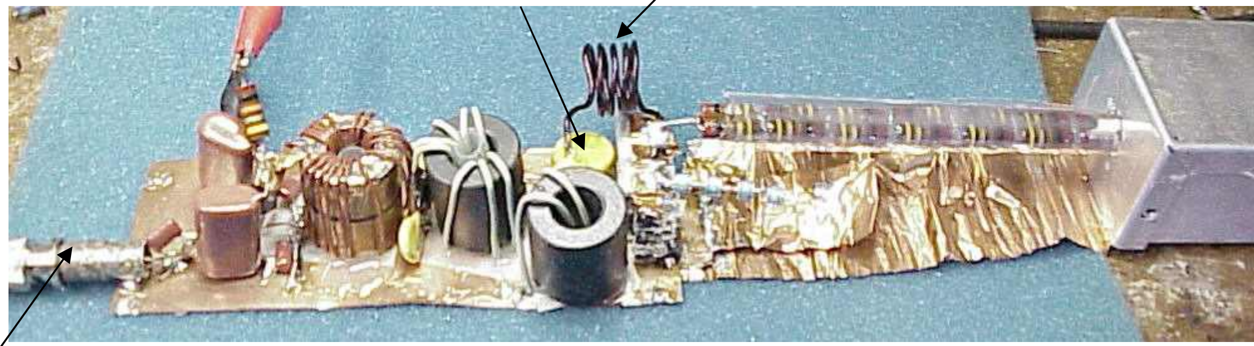
The blue trace shows the SCR output into a 1K load (~ 18.5KV); as can be seen the rise time is much less than the expected 60 nsec. Rise; ~ 200nsec min -to-max. The 1st stage MS was designed to remain off for ~100 nsec. The red trace shows the output waveform going in the MS load; as can be seen it switched on well before the SCR is fully turned on (~ 12KV max MS input). It appears that there is a gross mismatch between the SCR array and MS; that the MS needs to be rebuilt for 200nsec hold off or using an additional MS stage.



Missing 7 NOV 02A

Experimental Set Up:

780VDC IN C = 560pf L = 0.36µH 1K 1000:1 Probe



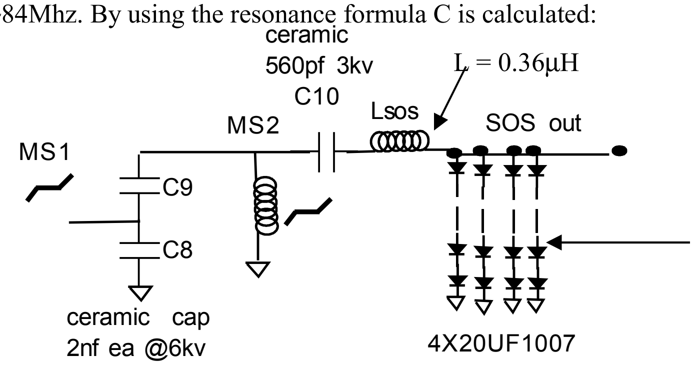
Trig IN

Comment:

Previously the 1000:1 probe BNC out was terminated by a 10 M 400Mhz Tek Probe modified for BNC connection as an added protection barrier to the DSO input ; good waveform results occurred for switching times up to ~ .3 nsec. For pulse edges approaching 1 nsec severe reactive ringing made it difficult to resolve the pule shape. To address this problem the DSO X10 buffer had to be replaced with a short 50Ω coax and terminated at the DSO input with a 50Ω BNC terminator. The other end of the coax connects to the 1000:1 probe BNC output (1Ω shunt). Although the X10 DSO IN safety buffer had to be eliminated unwanted ringing is significantly reduced allowing one to view the wave shape. For this reason the latter configuration is being adapted for further experimentation.

Seek SOS Parameter/ Diode Opening Capacitance:

The desired SOS parameter that this investigator seeks is the effective diode opening capacitance. Looking at the schematic of the SOS components Lsos was measured to be 0.36µH. The SOS output damped wave period was measured using the DSO cursors to be ~84Mhz. By using the resonance formula C is calculated:

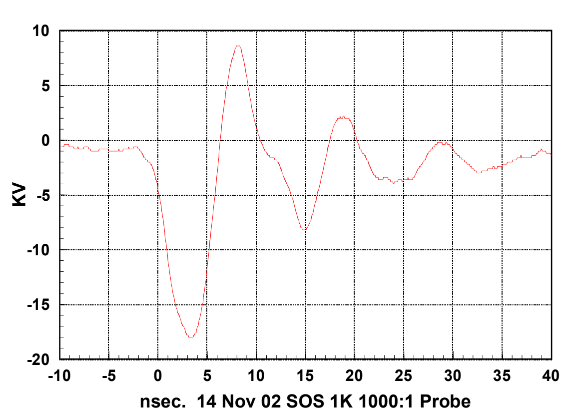


Seek Diode Opening Cap

Using the formula $F = [2\pi(LC)^{1/2}]^{-1}$

$$C = [(2\pi)^2(Lf^2)]^{-1} = \sim 10 \text{ pF} << 560\text{pf}$$

The LC impedance is $Z = Q(L/C)^{1/2} = Q190\ \Omega$

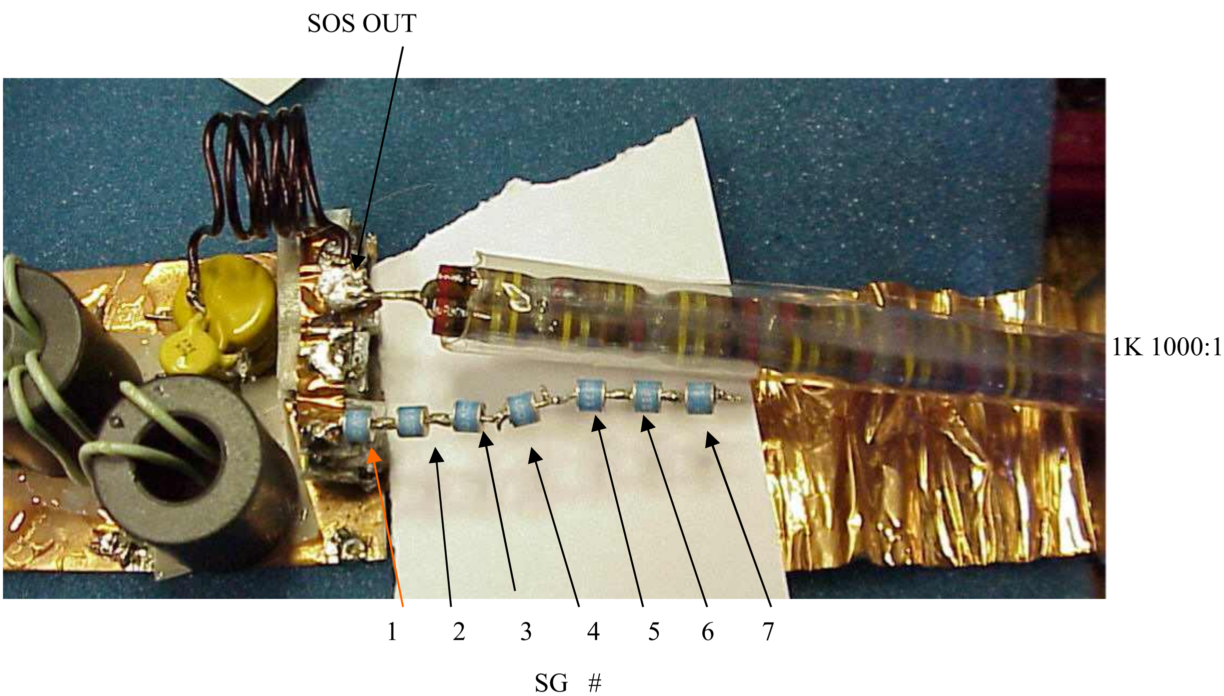


The damp wave exponentially decays at => $e^{-\alpha t}$

Background:

The pulse source is that described in the 14 Nov 02A note. The purpose is to investigate how the experimental 400V SGs behave at various SOS output load configurations:

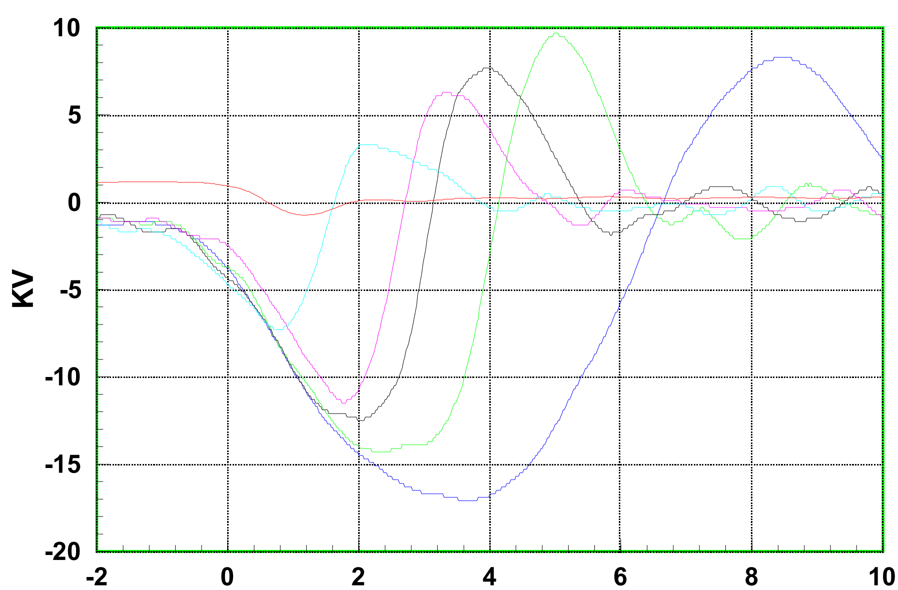
Conf: 1



Experimental Procedure:

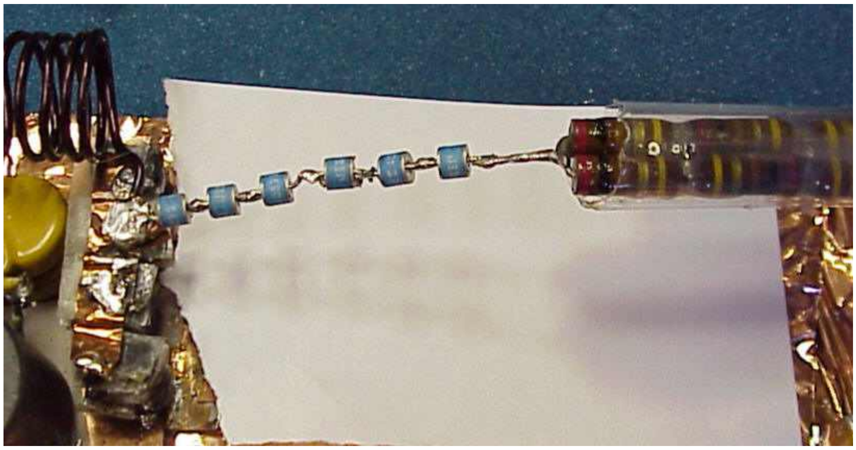
a) capture output waveform 0 \ SG open
b) " " 1\ SG 7 to GND
c) " "2\ SG 5 to GND
d) " "3 \ SG 3 to GND
e) " "4 \ SG 2 to GND
f) " "5\ SG 1 to GND

Waveforms:



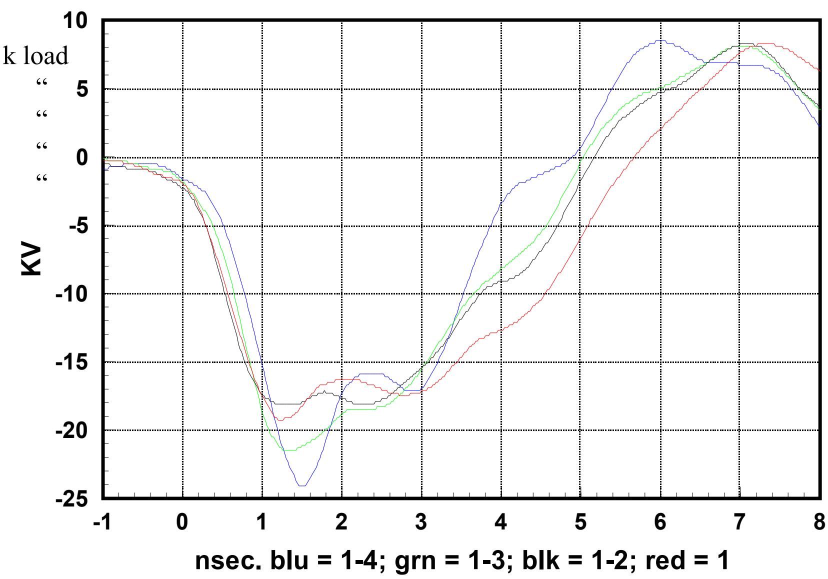
nsec. SOS out a) blue, b) grn, c) blk, d) purple, e) blue, f) red

Conf: 2

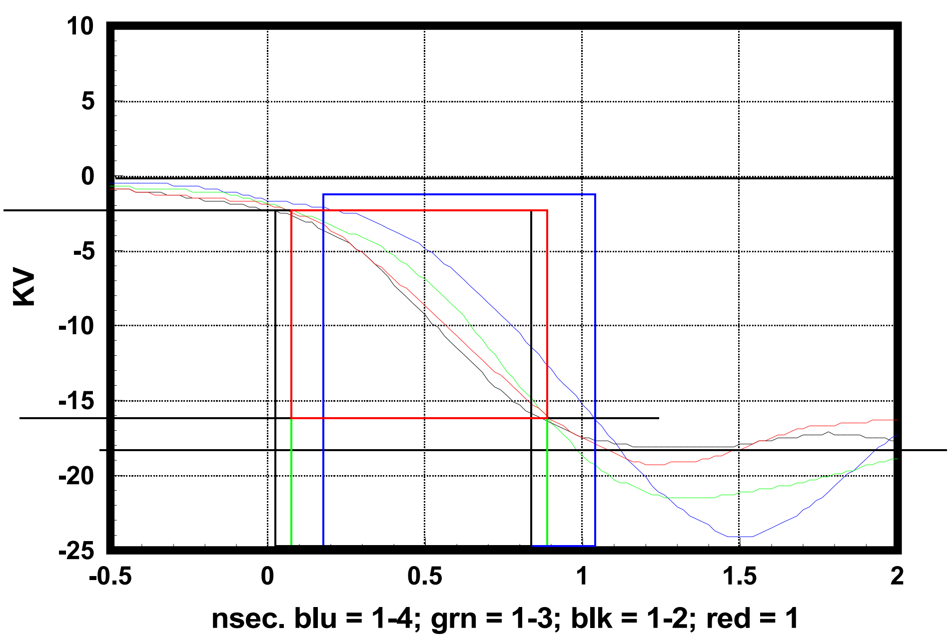


Procedure:

a) waveform SGs 1-6 series => 1k load
b) " " SGs 1-4 " "
c))" " SGs 1-3 " "
d) " " SGs 1-2 " "
e) " " SG 1 " "



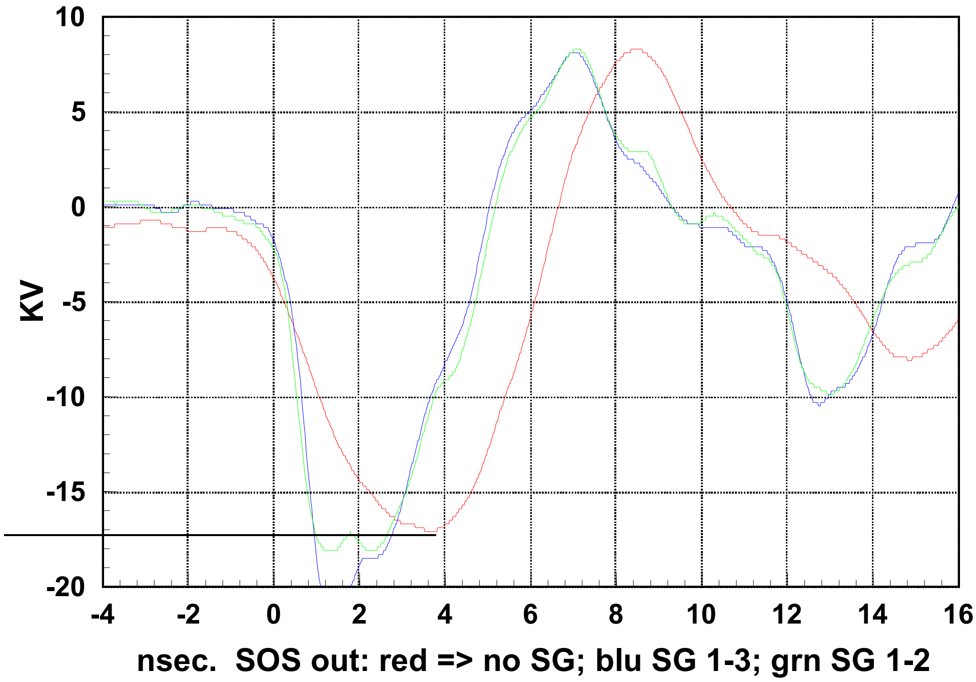
Rising Edge Expanded:



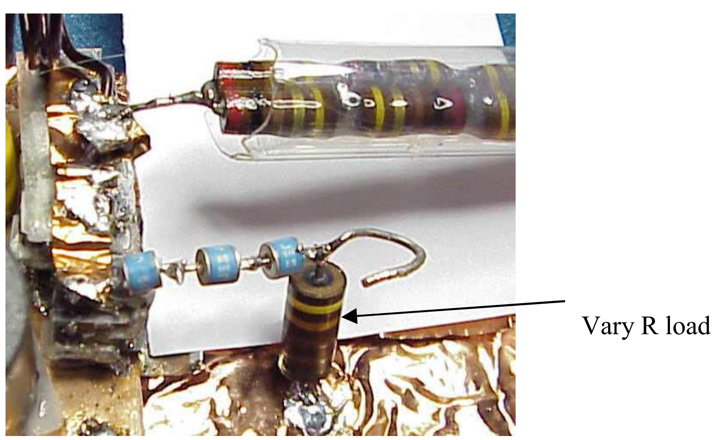
Comment:

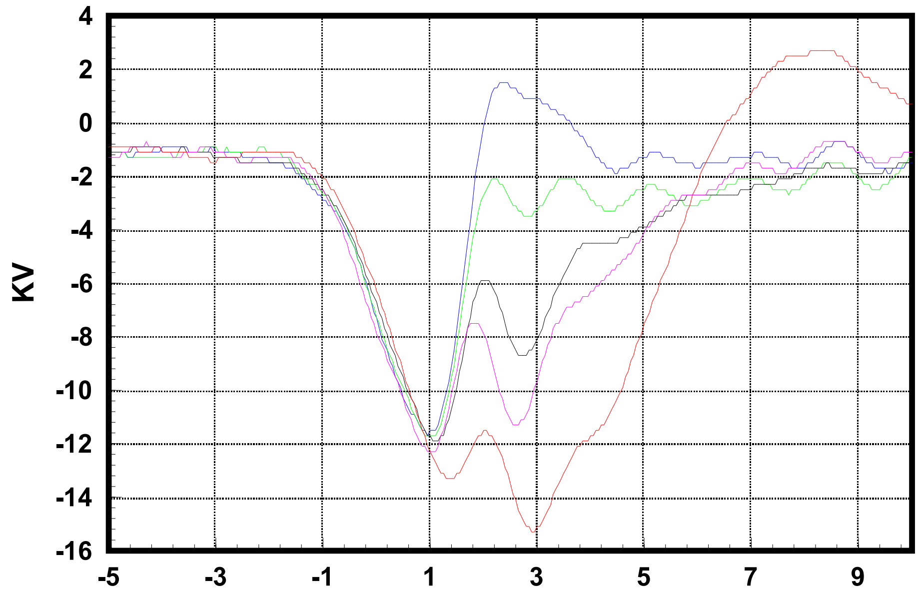
The 1000:1 1K probe has a 1 ohm BNC out terminated to a short length 50ohm coax; the other end is terminated with a 50 ohm TEK terminator which connects to CH1 of the DSO. Since the DSO has a 400Mhz BW then 0.35 of the period is 875psec max . Keeping this in mind the previous expanded waveform indicates (10 -to- 90%Vmax): ~ 860ps for SG 1-4; ~ 800ps for the other configurations.

SOS Out Waveform (without SG & with SG\s):



Config 3 => same as 1 except SG discharges through series resistance:

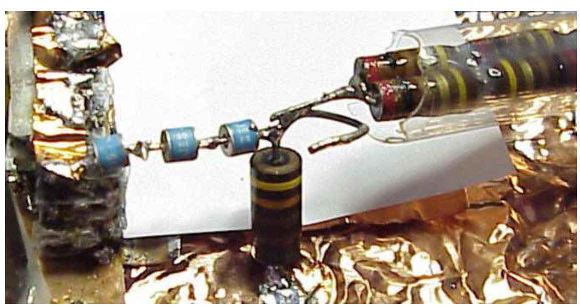


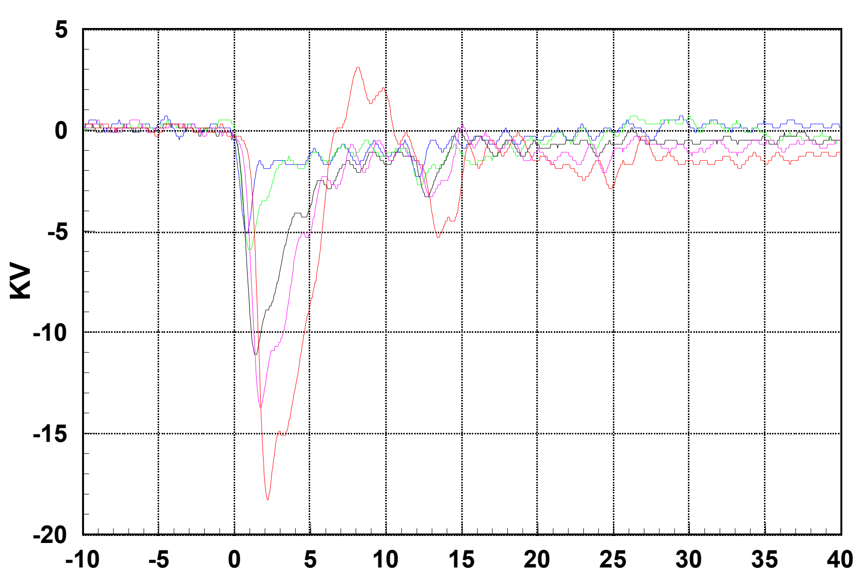


nsec blu = 22Ω ; grn = 50Ω ; blk = 91Ω ;
viol = 130Ω ; red [illegible]

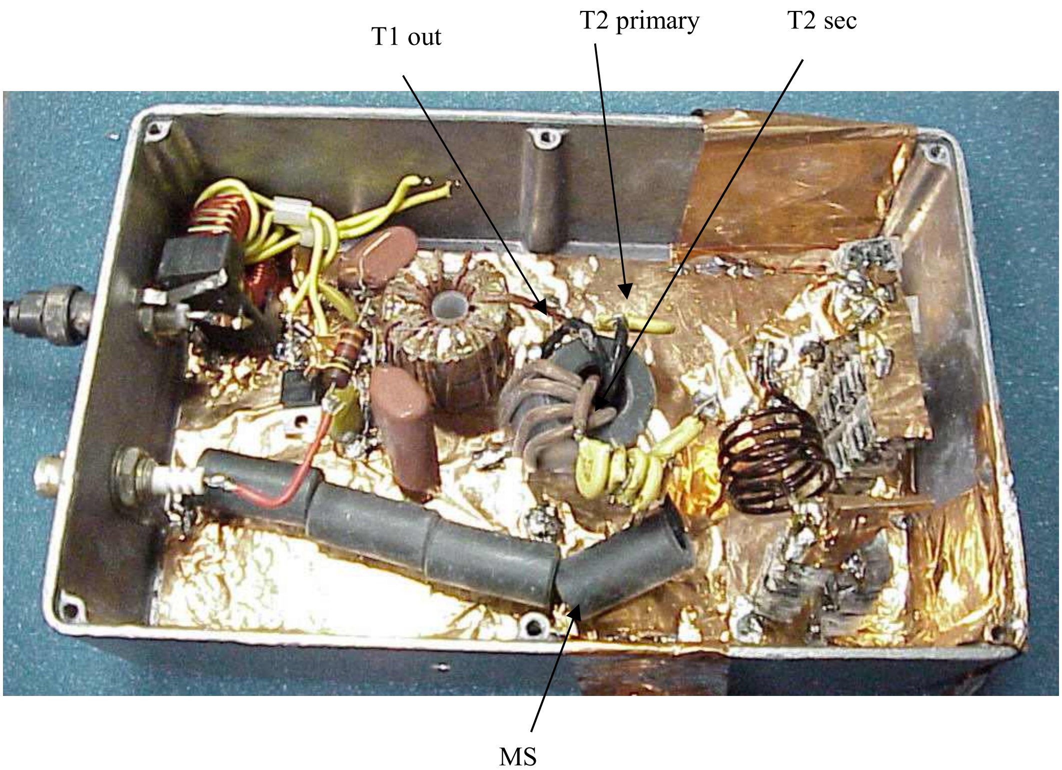
Borrowing from some probe ringing; the above waveform suggests ~ 50 to 100 ohm impedance

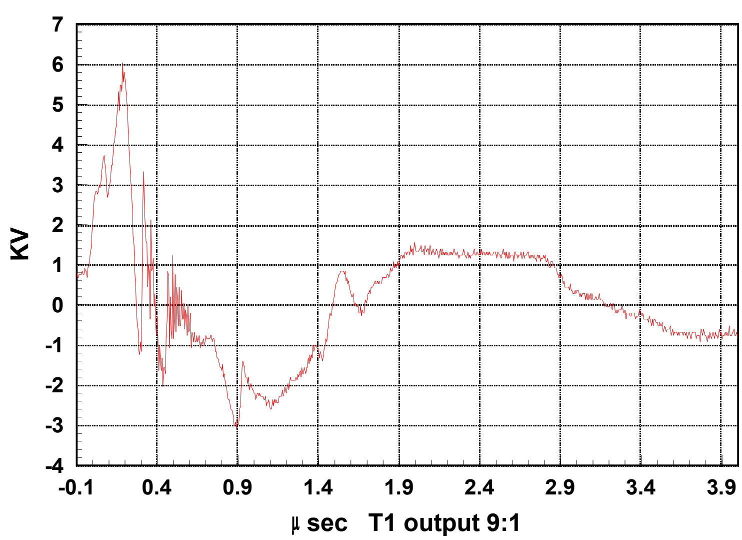
Config 4 => 1000:1 probe looks across SG load resistor (same as before fixed # SGs = 3):

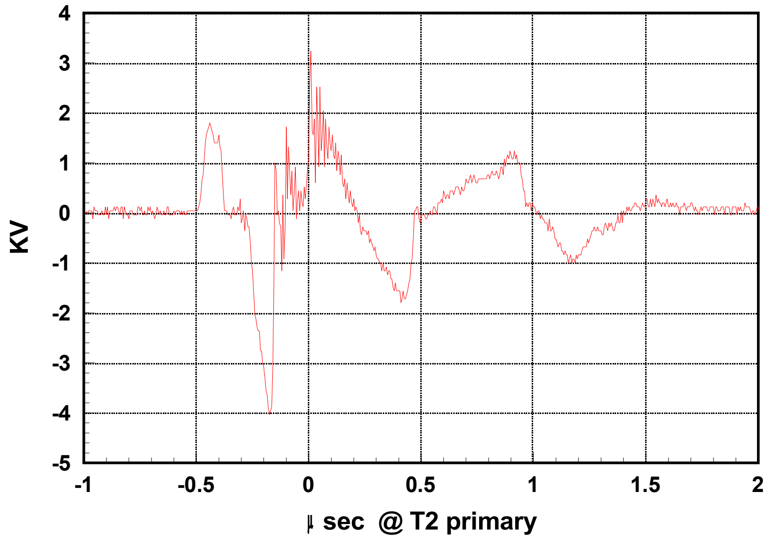


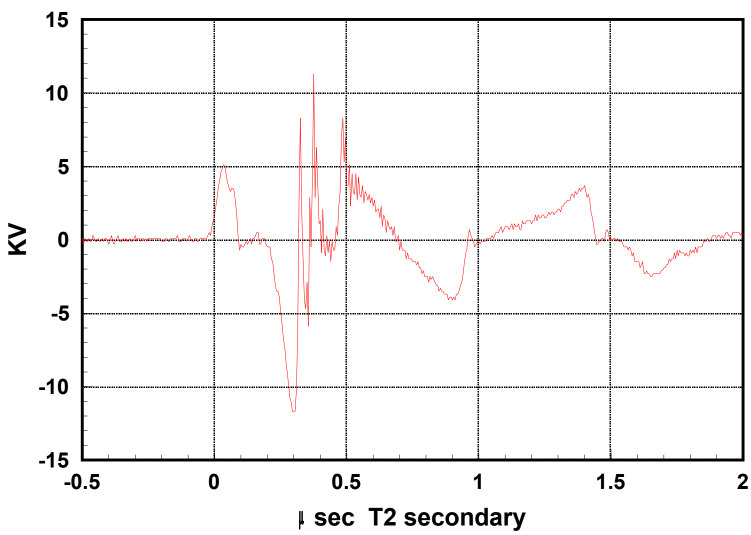


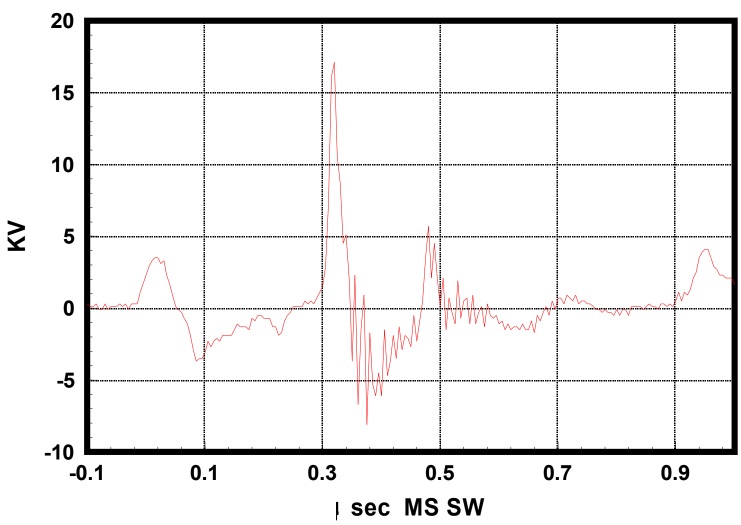
nsec blu = 22Ω ; grn=50Ω ; blk =91Ω ; viol=130W; red= 330Ω

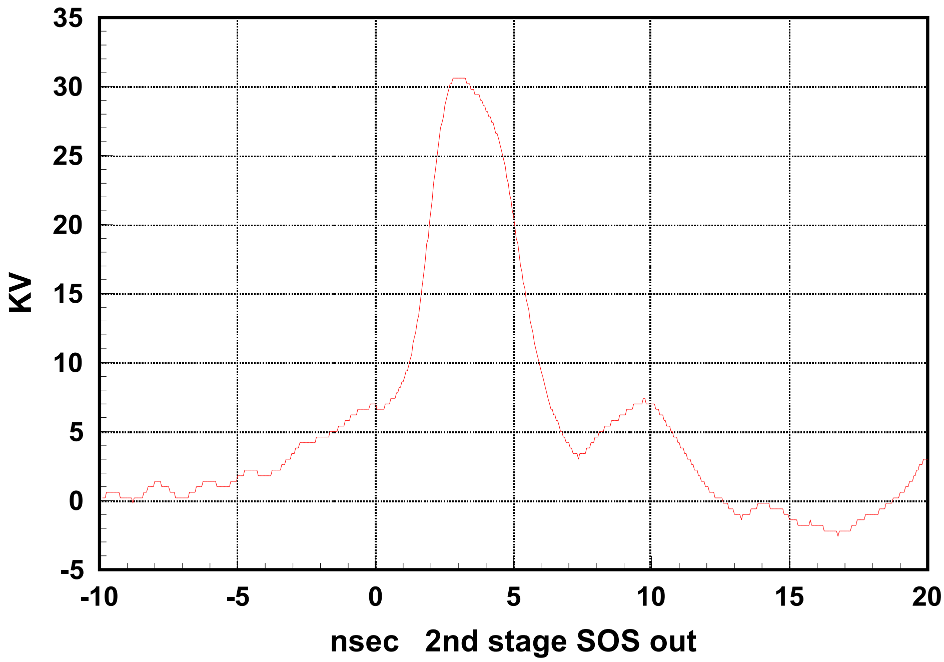

T1 out
T2 primary
T2 sec
MS


7
6
5
4
3
2
1
0
-1
-2
-3
-4
KV
-0.1
0.4
0.9
1.4
1.9
2.4
2.9
3.4
3.9
µ sec T1 output 9:1


KV
4
3
2
1
0
-1
-2
-3
-4
-5
-1
-0.5
0
0.5
1
1.5
2
sec @ T2 primary


KV
15
10
5
0
-5
-10
-15
-0.5
0
0.5
1
1.5
2
sec T2 secondary


KV
20
15
10
5
0
-5
-10
-0.1
0.1
0.3
0.5
0.7
0.9
sec MS SW

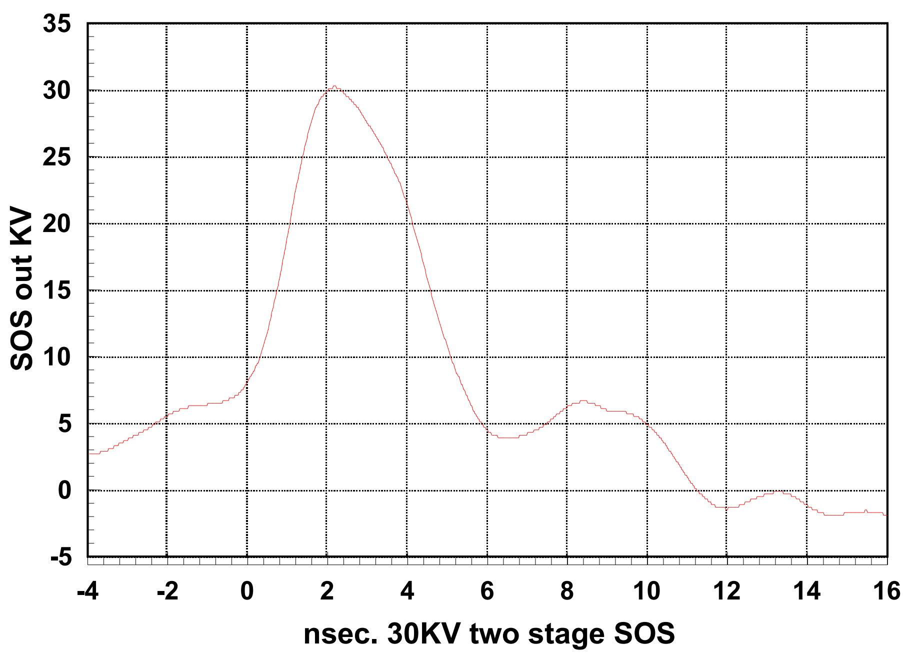

35
30
25
20
15
10
5
0
-5
KV
-10
-5
0
5
10
15
20
nsec 2nd stage SOS out

Experiment:

The purpose is to experimentally determine the degree of output pulse sharpening, of an experimental 30KV SOS device described below, obtained by applying a overvoltage pulse toseries connected 400V spark gaps (type JES 400V OB99) :

Photo\ SOS Device Only

Output Waveform (SOS only):



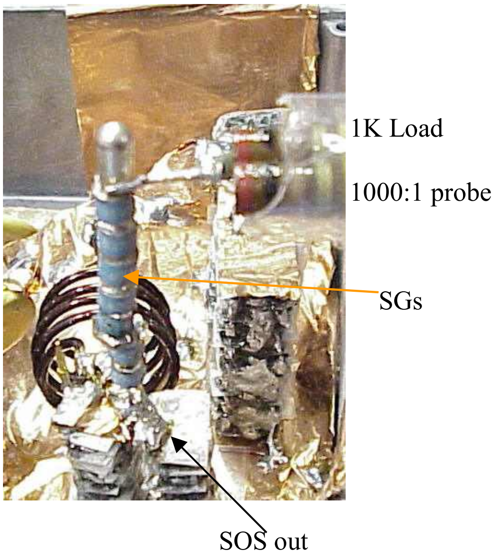
Notes:

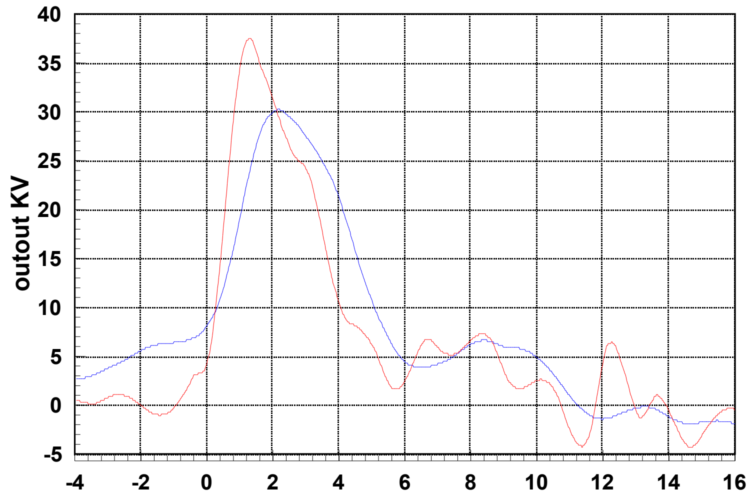
1).1000:1 probe: the probe's input resistance is 1KW ; which terminated to a 1Ω load (probe's output. A 50Ω coax is connected between the probe output and the TDS 380 DSO CH 1 input terminated with 50Ωs

2) TDS 380: the BW is rated at 400Mhz or rise time resolution to ~ 0.89nsec..

Pulse Sharpening:

The SOS output was modified with series connected SGs; shown below is a photo of the modification and the resulting sharpening for seven SGs in series:



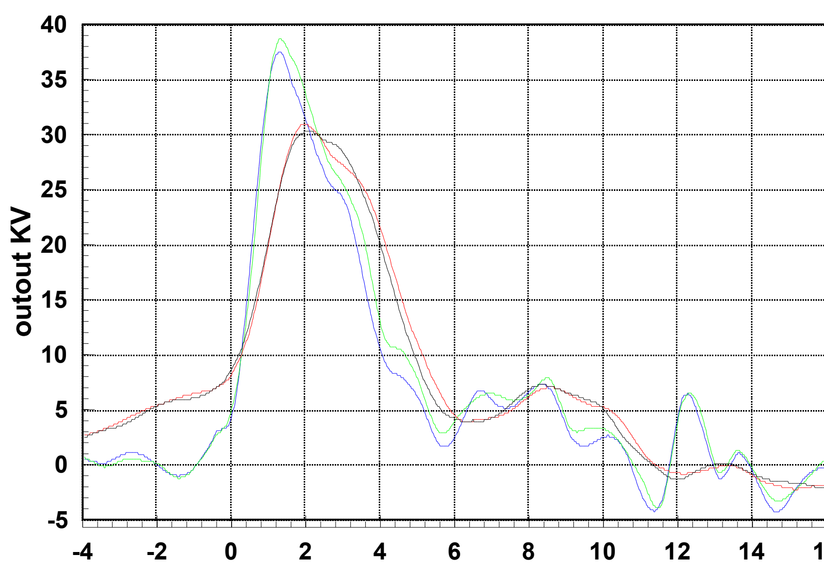


nsec. 30KV two stage SOS output => blue; with SG pulse sharpener => red

Comment: 1) the DSO's resolution is limited to slightly less than 1 nsec.
2) the waveform indicates ringing believed to be due to the probe; hence the apparent maximum amplitude appears to be an overshoot due to the sum of the actual waveform and the internal damped ringing component. This investigator assumes that the actual waveform is approximated by averaging out the maximum and minimum ringing components.

SG sharpening VS the number in series:

The waveforms shown below represent the sharpening verses the number of SGs connected in series; terminated to 1KΩ.



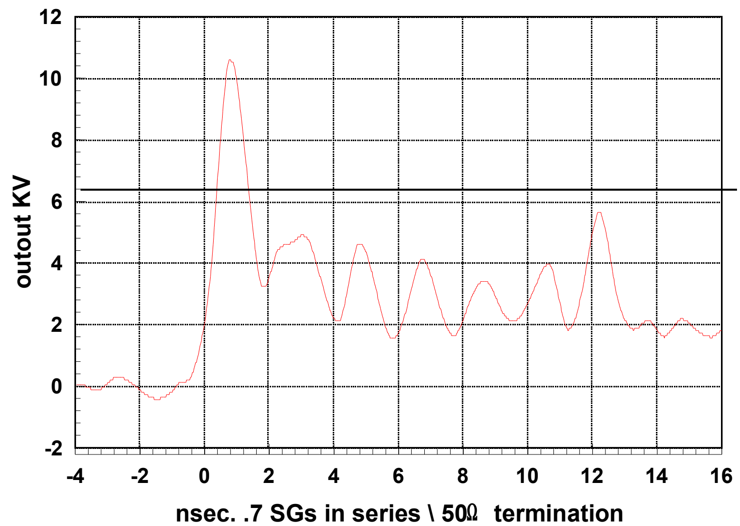
nsec. .6 SGs => blue;5 Sgs => grn; 4 SGs => blk; 2 SGs => red

Comment:

For the particular SOS output environment no pulse sharpening is noted until at least 5 SGs are used; up to 7 SGs in series (waveform not shown) has been investigated. The stability of the waveshape from pulse-to-pulse is fairly stable for the maximum of 7. The shape for 6 in series is close to that of 7 however the stability slightly degrades; for 5 the stability is much worse. For 4 or less the stability improves significantly but without any apparent sharpening.

Pulse Sharpener\ 50Ω Load:

The 7 stage SG pulse sharpener output was loaded with two 100Ω carbon resistors connected in parallel:



Comments:

1) averaging the probe ringing indicates the actual peak is ~ 6kv

2) carbon resistors are far from ideal pure resistance in the 100's Mhz region; I.e. one handboostates that carbon resistors exhibit significant inductance and capacitance; that surface mount resistors should be used; the above was used to get some approximation until a more suitable load could be used..

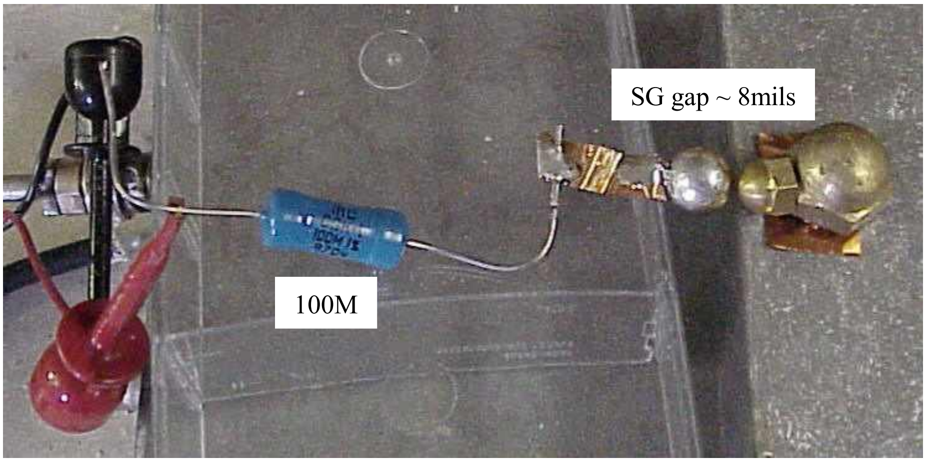
Missing 18NOV 02A

Background: => regarding Schriner's SG claims of achieving ~ 700psec by over volting a 3KV static gap to at least 300KV +

Purpose : => investigate whether a SG can be significantly over volted with ~ < 1nsec rise time

Experiment 1 test SG in question for ~ static breakdown voltage.

Adjustable HV PS

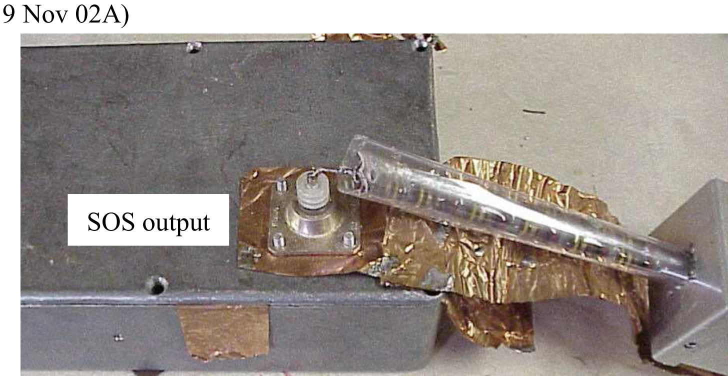


Results: The static breakdown was determined by increasing the HV output until breakdown was observed to be ~1.8KV

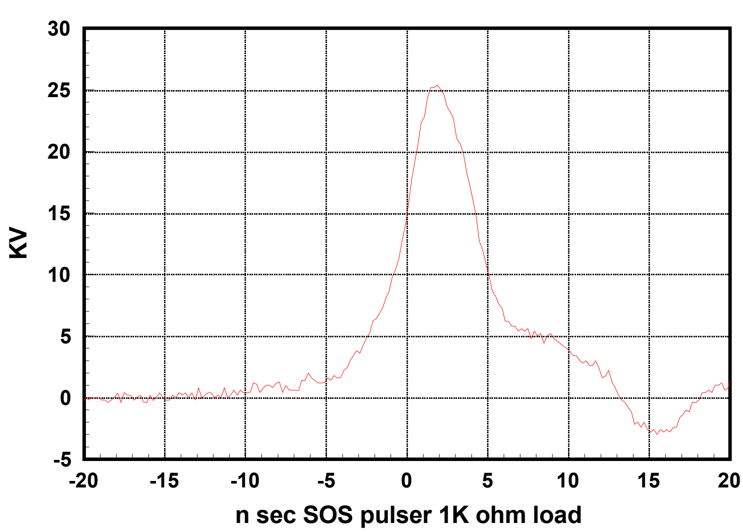
Experiment 2 test the above SG to fast pulse charging:

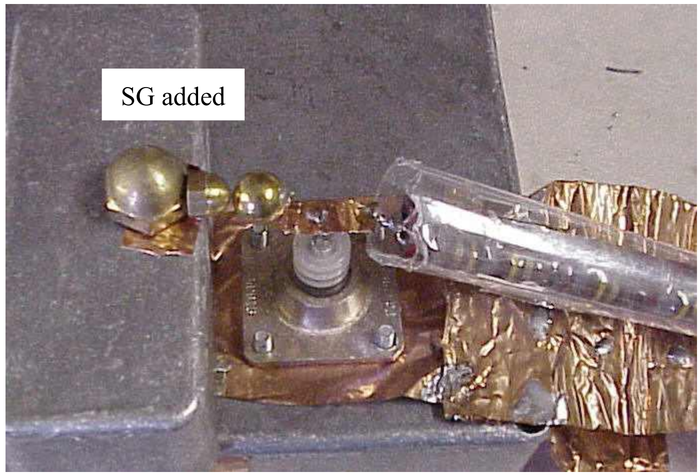
Pulsed Source : an SOS pulse generator (see 19 Nov 02A)

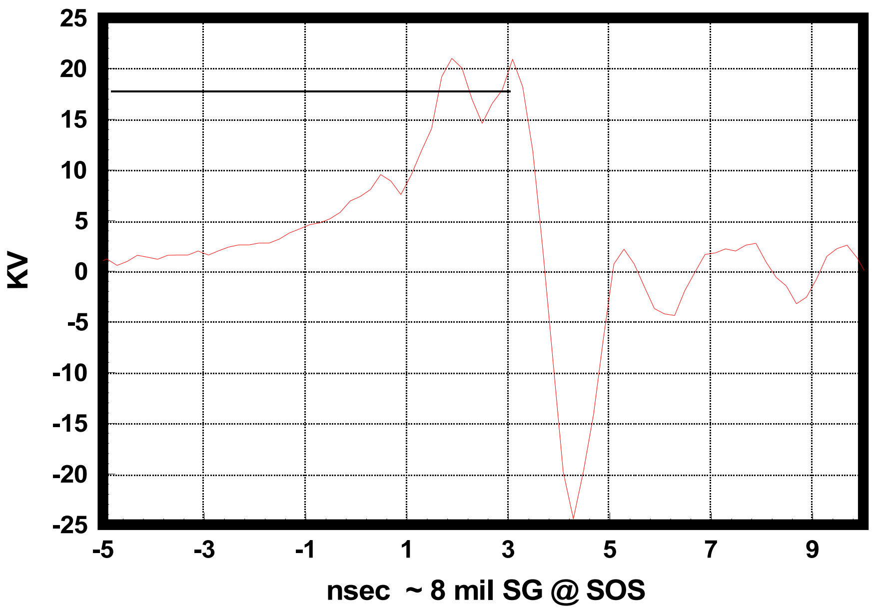
Pulsed Source without SG at output:



1K 1000:1







Result:

- the above waveform indicates ~ 18 KV pulsed breakdown (~avg) about a factor of 10 to static

- the falling edge indicates switching in the nsec region

bordering on the maximum BW resolution of the probe; hence the above waveform should be viewed with some caution.

Note: the 1 K probe tends to ring at several hundred Mhz. Damping can be minimized significantly when the copper strip (sig rtn) is kept close to the probe (determined using a rectangular pulse 50ohm coax source ; compared to a commercial type).

Conclusion:

The above seems to indicate that it is possible to over volt a SG by ~ 10X its static break down for the above experimental setup; however it does not indicate whether or not it is possible to pulse charge a 1/2 inch or less SG in the 300, 400, & 1000KV over voltage value (even when pressurized).

Use J.C. Martin's formulas "J.C. Martin on Pulsed Power"; for pulsed SGs

τ_l = L/Z source ~ 200ohm ?? Impedance L =(2l) ln a/b ln a/b ~= 7 l= 0.02 cm

- L = ~ 0.28nH

τ_l = 0.0014

τ_r = 88/($Z^{1/3}$ $E^{4/3}$) *(1 @ 1 ATM) nsec Z = 200 $Z^{1/3}$ =5.5 E = ~90 10KV/ cm $E^{4/3}$ =397

= 0.04 nsec