TRIUMF Kicker R&D and Other Possibilities

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Cornell Damping Ring Workshop
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TRIUMF Kicker R&D

TRIUMF in Vancouver has a kicker group that has built things for CERN, DESY, PSI, Brookhaven, and other places as well. They have built several FET stack pulsers. The fastest is the PSI pulser, with 40 nsec rise and fall at 75 kHz. They stack 17 FETs to get to 25 kV.

The PSI pulser FETs are running at a higher CW average rep rate than the ILC needs, although it doesn't need the fast burst.

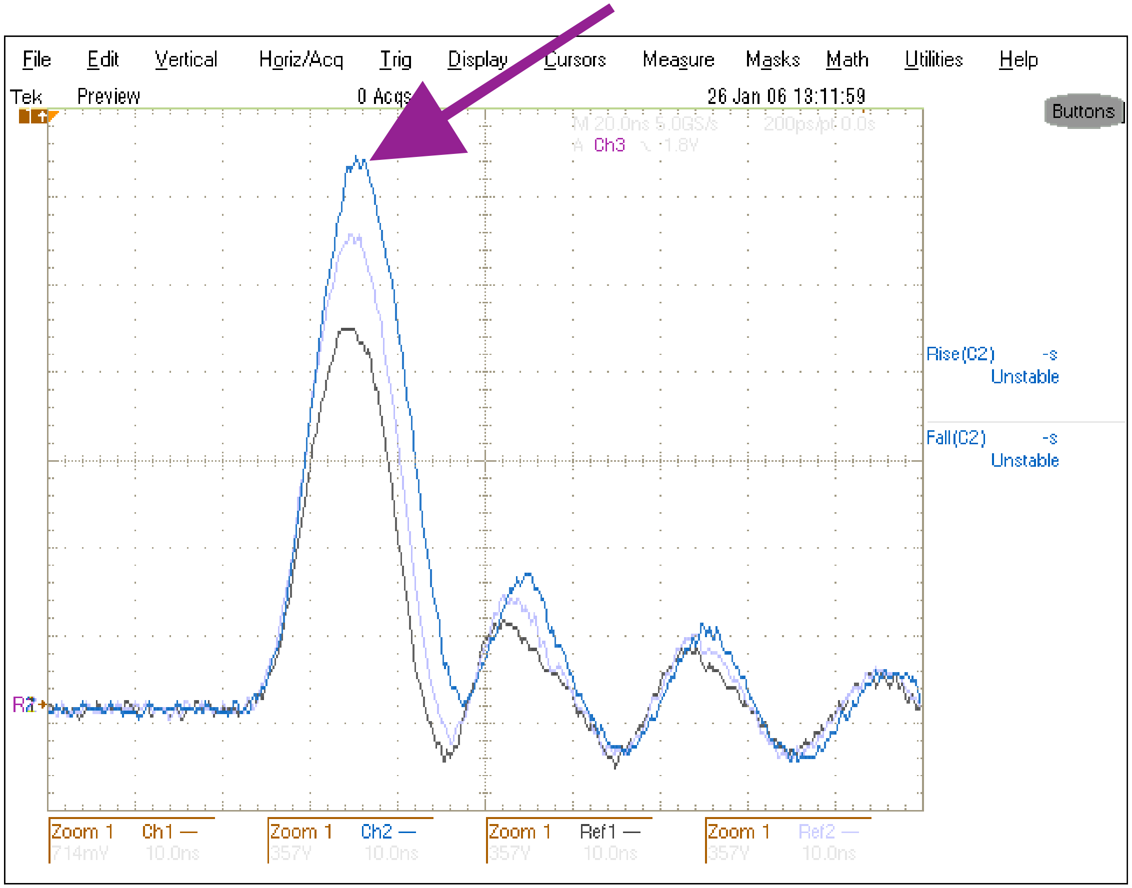
Their ILC test pulser uses Directed Energy FETs directly in series. They use DEI gate-drivers that have to float up with the stacked FETS, so they use optical fiber triggering. The gate driver power is provided by an isolation transformer.

They use the stray capacitance of the FETs as part of an LC transmission line. This is a cute trick to reduce the effect of the FET inductance.

The line impedance is 100 Ohms, so they run two stacks in parallel for 50 Ohms.

TRIUMF Pulser Status

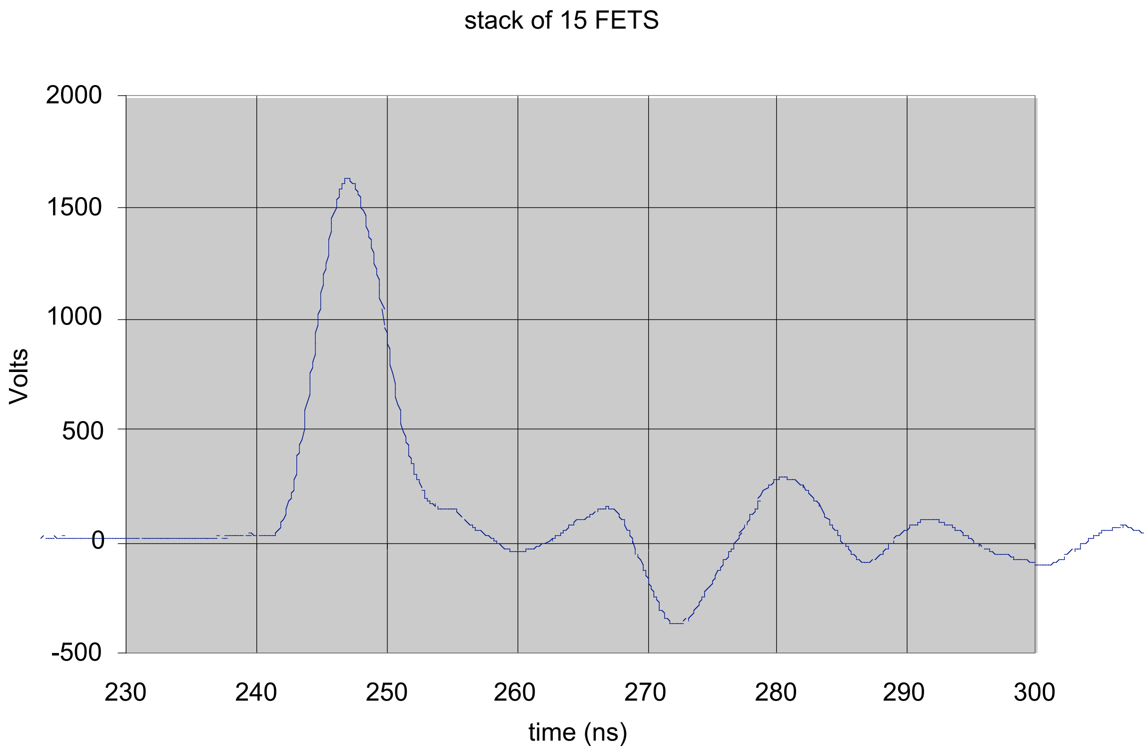
4.6kV



Their best performance is 4.6 kV pulses with 6 nsec rise and fall times at 1 kHz. Some of this is FET rise time, and some of it is signal development through the transmission line (which depends on FET and interconnection inductance). The ringing afterwards is mostly from their kludgy load.

TRIUMF Pulser Progress

They have new FET boards and backplane with lower geometric inductance. These are the first results, with not much tuning.



TRIUMF Pulser Prospects

They need to develop a scheme to recharge the FET stack for ILC bursts. They want to improve the optical fiber triggering scheme, it requires trimming to get all the FETs to fire at the same time.

The main engineer is about to go to CERN for three years. The CLIC people are interested in the pulser, so it will probably be shipped to CERN and further development will happen there.

The other physicist-engineer is officially retired, and comes in part-time on contract. So probably not much will happen at TRIUMF after the end of the year.

Other possibilities

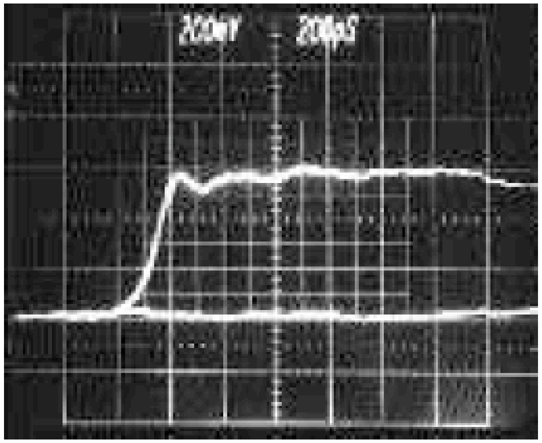
There are a few other fast pulser technologies I have heard of, besides FETs, step-recovery diodes, and FIDs: avalanche transistors, hard-tubes, and ferrite shocklines.

A few companies make Pockels cell drivers using avalanche transistors. Avalanche transistors are fairly standard bipolar transistors. They have very fast rise times, but you can't switch them off. Any transistor will avalanche with a reasonably fast rise time. They have long recovery times (many microseconds) after the energy storage is discharged. They are similar to FIDs , but at much lower power per device. You also have fairly low power per device, so you have to use lots of them.

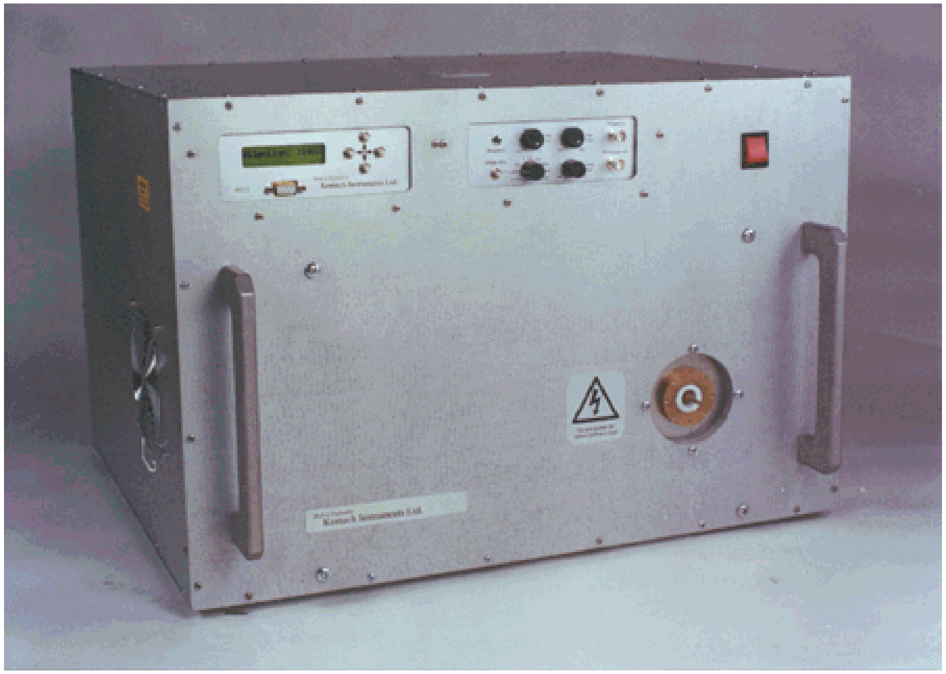
It may be worth buying an avalanche transistor pulser, if only to take it apart to learn more about stacking other devices like FETs. They seem to know something that we don't.

Slides from Joe Frisch, October 2004

- Avalanche Transistors
  - <200 picoseconds to 200V, ~50 Amps (10KW)
  - Arrays (tapered transmission lines) demonstrated to 40KV, 800A, 200ps. (Kentech)
  - Recovery time too long except in liquid nitrogen (50nsec reported)
  - Average power limited to ~1W / device.
  - Combining may lead to ringing.
  - Possible – but probably not best solution

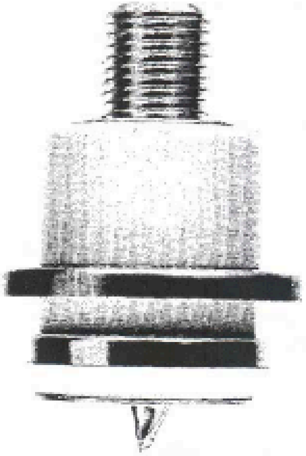


40 KV in 200ps rise time (Kentech)



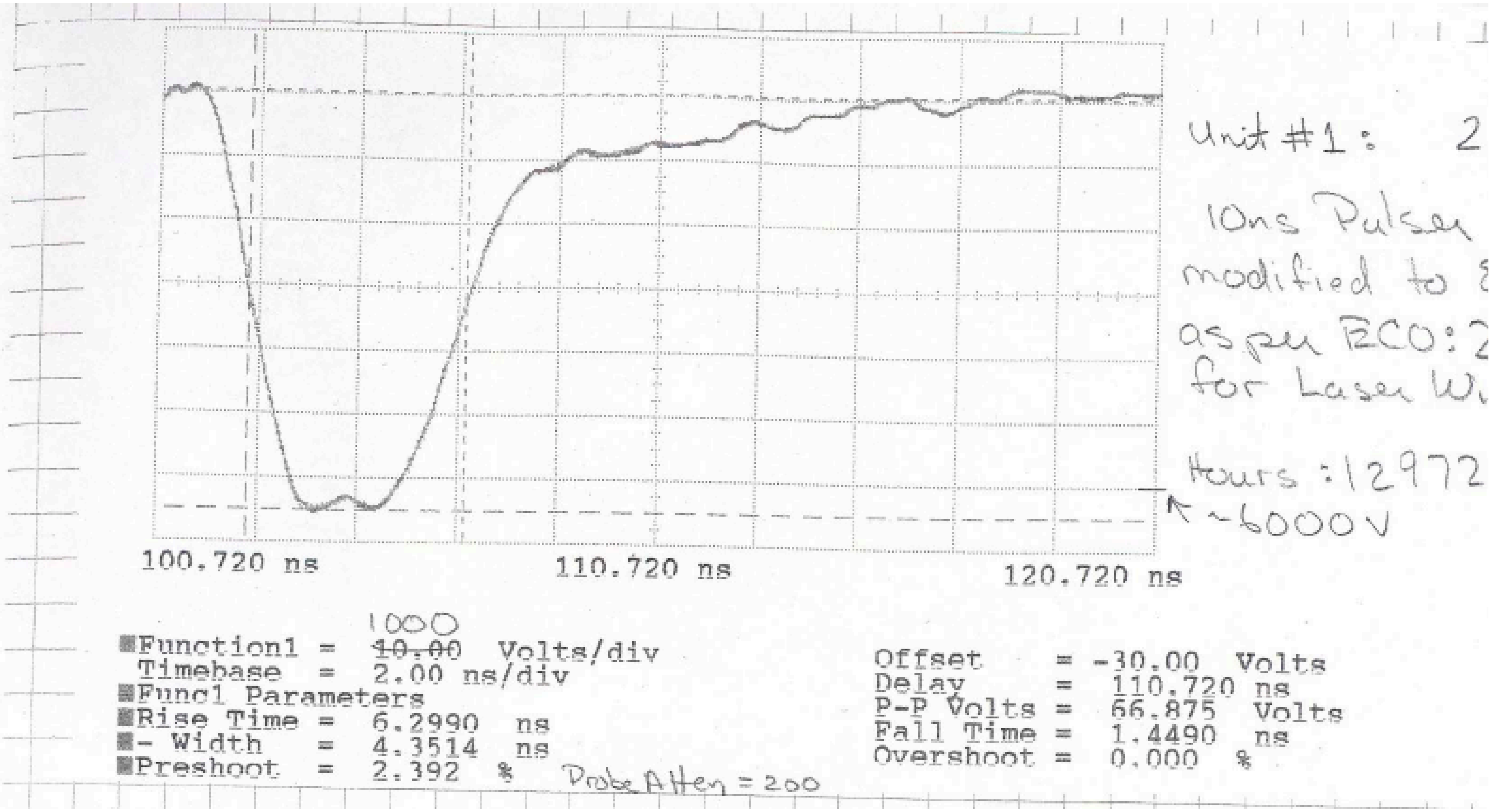
Hard Tube Switches

- Pulser based on Eimac Y-690 tube used for Pockels Cell drive at SLAC (M. Browne, D. Brown).
  - 6KV, 30 Amps, <1.5ns rise time.
  - Driven by avalanche transistors – not appropriate for high repetition rate
  - Would need to parallel 2 tubes for ILC kicker (easy)
- Nonlinearity of tubes helps with settling time.
- Average power “not unreasonable” but would need to check. (grid dissipation)



Hard Tube Pulser

Note, tail on pulse believed to be due to output Transformer (not needed for ILC kicker)



Unit #1: 2

10ns Pulser
modified to
as per ECO:
for Laser W

Hours : 12972

~6000V

Function1 = ~~10.00~~ 1000 Volts/div
Timebase = 2.00 ns/div
Func1 Parameters
Rise Time = 6.2990 ns
- Width = 4.3514 ns
Preshoot = 2.392 %

Probe Atten = 200

Offset = -30.00 Volts
Delay = 110.720 ns
P-P Volts = 66.875 Volts
Fall Time = 1.4490 ns
Overshoot = 0.000 %

Ferrite Shocklines

Make a coaxial transmission line that is loaded with ferrite.

Choose the geometry so that when the ferrite is saturated, the transmission line is 50 ohms. When the ferrite is not saturated, the impedance is much higher, and the propagation speed is much lower.

Choose the absolute diameter scale so the ferrite saturates at somewhat less than the peak pulse amplitude you get.

Put the ferrite-loaded line between the load and a pulser. The pulser rise time should be reasonably fast, but that's not too important.

For the early part of the rise, the line is mismatched. Most of the power is reflected back to the pulser. The small amount of power that is transmitted propagates slowly.

Eventually, the drive pulse gets to the saturation level. The line is then matched, and the power is transmitted instead of reflected. The transmitted wave overtakes and "eats" the little bit of early leakage.

The result is a slow-rising pulse goes in, and a fast-rising pulse comes out.

The rise time is set by how fast magnetic moments in the ferrite precess, which gets faster as the magnetic field of the pulse increases. Bigger pulses give faster rise times!

SLC Damping Ring Kicker Shockline

SLAC kickers used thyratrons, basically 30 nsec thyratron pulse rise time, 30 nsec magnet transit time (slow transmission line), for 60 nsec bunch spacing.

Thyratrons were multi-gap, with “prepulse” of a few percent of peak amplitude, tens of nsec before main rise.

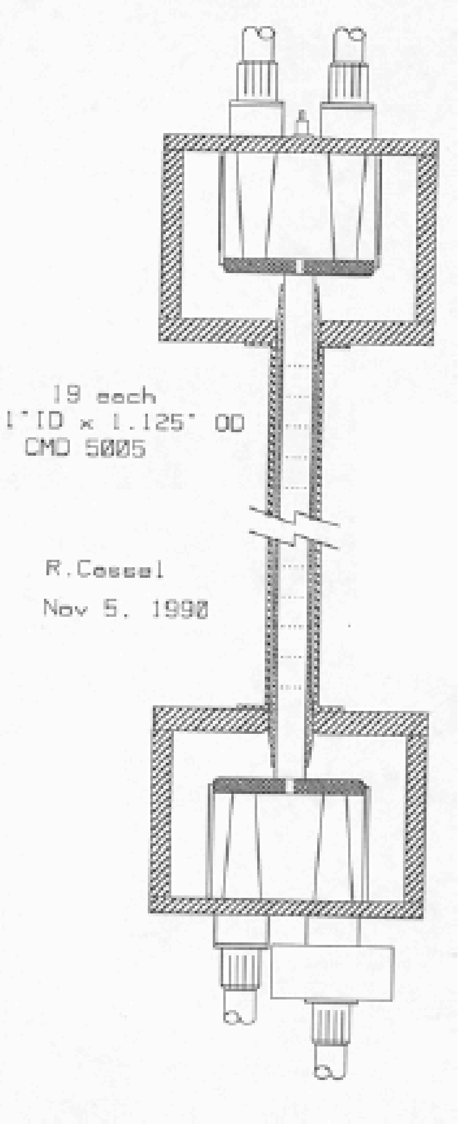
To deal with prepulse, we built a ferrite shock line 12.5 ohm system (4 cables). It was oil insulated, and quite reliable (as long as there were no bubbles in the oil).

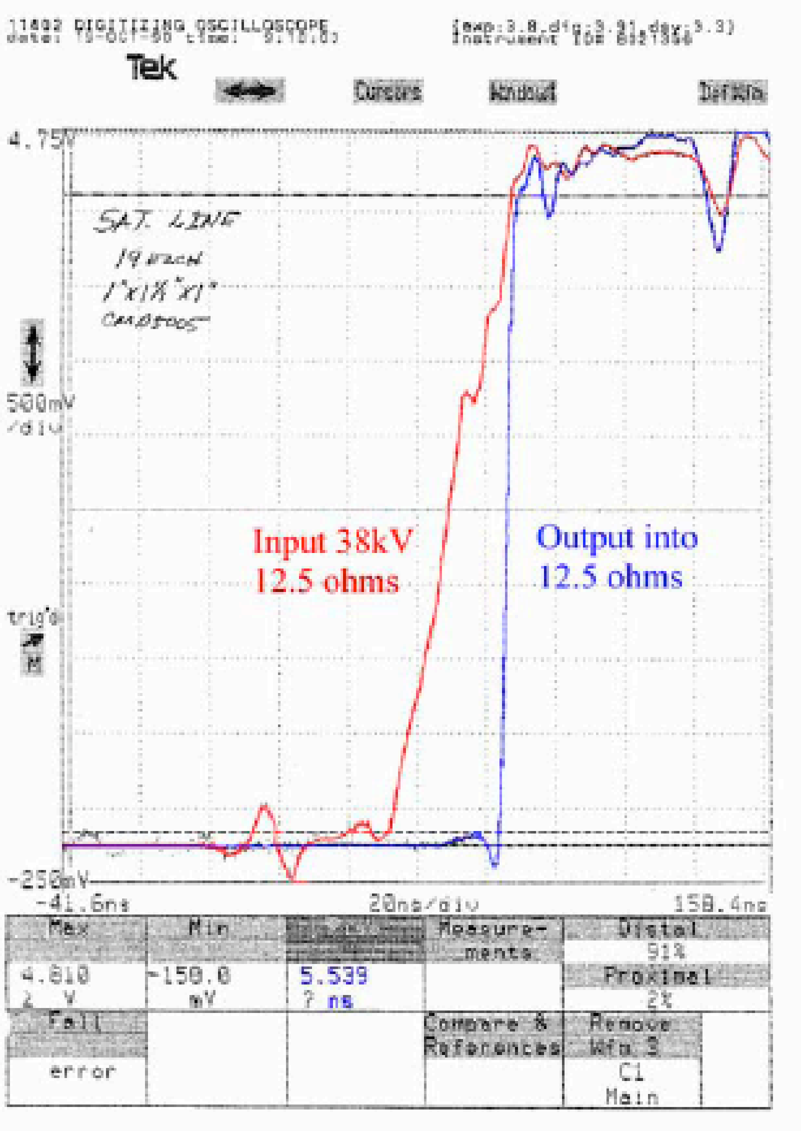
It worked great, not only on the prepulse, but it made the main pulse rise time basically too fast to measure (the instrumentation pulse transformers may have been the limit).

A drawback of shocklines is that the pulse fall time gets worse. The ring was empty after extraction, so that was OK.

The fall time would have been a problem for the injector, but the ring was empty for the prepulse, so we didn't use a shockline for the injector.

Shock Lines – Ferromagnetic (SLAC)





Input 38kV
12.5 ohms

Output into
12.5 ohms

How Fast Can It Be?

Higher voltage pulses give faster rise times. At 50-100 kV, sub-nanosecond risetimes!

The rise time is set by how fast magnetic moments in the ferrite precess, which gets faster as the magnetic field of the pulse increases. So you should be able to get fast rise at lower voltages, if you scale the diameter down so the magnetic field is the same.

A trick is to put a bias solenoid on the structure, which also improves the rise time (compared to reverse-DC-currentt bias like we used at SLAC).

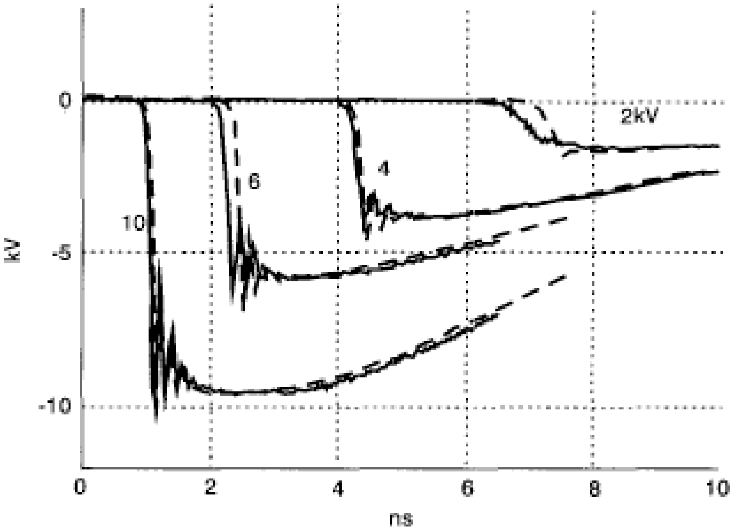
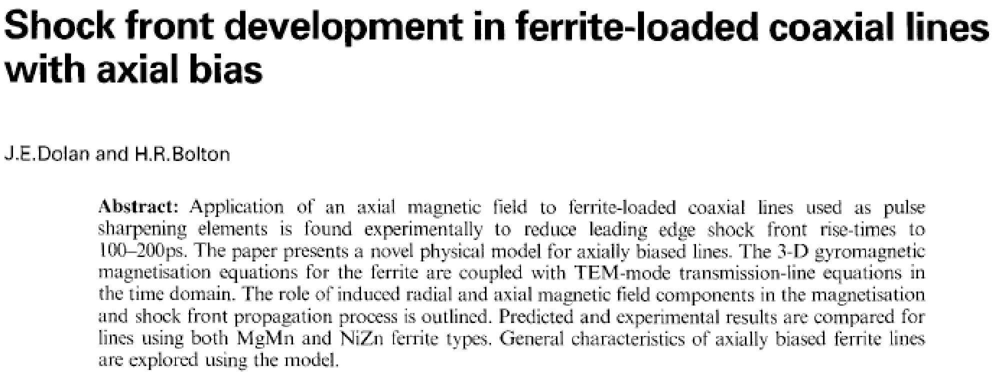


Fig. 7 *Measured and simulated I/P and O/P waveforms for NiZn line for pulse voltages 2, 4, 6, 10kV*

——— measured

– – – – simulated



Shock front development in ferrite-loaded coaxial lines with axial bias

J.E.Dolan and H.R.Bolton

Abstract: Application of an axial magnetic field to ferrite-loaded coaxial lines used as pulse sharpening elements is found experimentally to reduce leading edge shock front rise-times to 100–200ps. The paper presents a novel physical model for axially biased lines. The 3-D gyromagnetic magnetisation equations for the ferrite are coupled with TEM-mode transmission-line equations in the time domain. The role of induced radial and axial magnetic field components in the magnetisation and shock front propagation process is outlined. Predicted and experimental results are compared for lines using both MgMn and NiZn ferrite types. General characteristics of axially biased ferrite lines are explored using the model.

The pulse can also be accurately modelled. The early ring is real, it's the ferrite moments precessing.

We Should Be Playing With Shocklines!

A shockline could improve the risetime of a simple pulser, like a FET stack, and make it competitive with a FID.

We need to learn what we can really do, and about the drawbacks like the initial ring, the fall time, and the dependence of time delay on amplitude.

It's not very expensive. I'm seriously considering doing some of this myself.