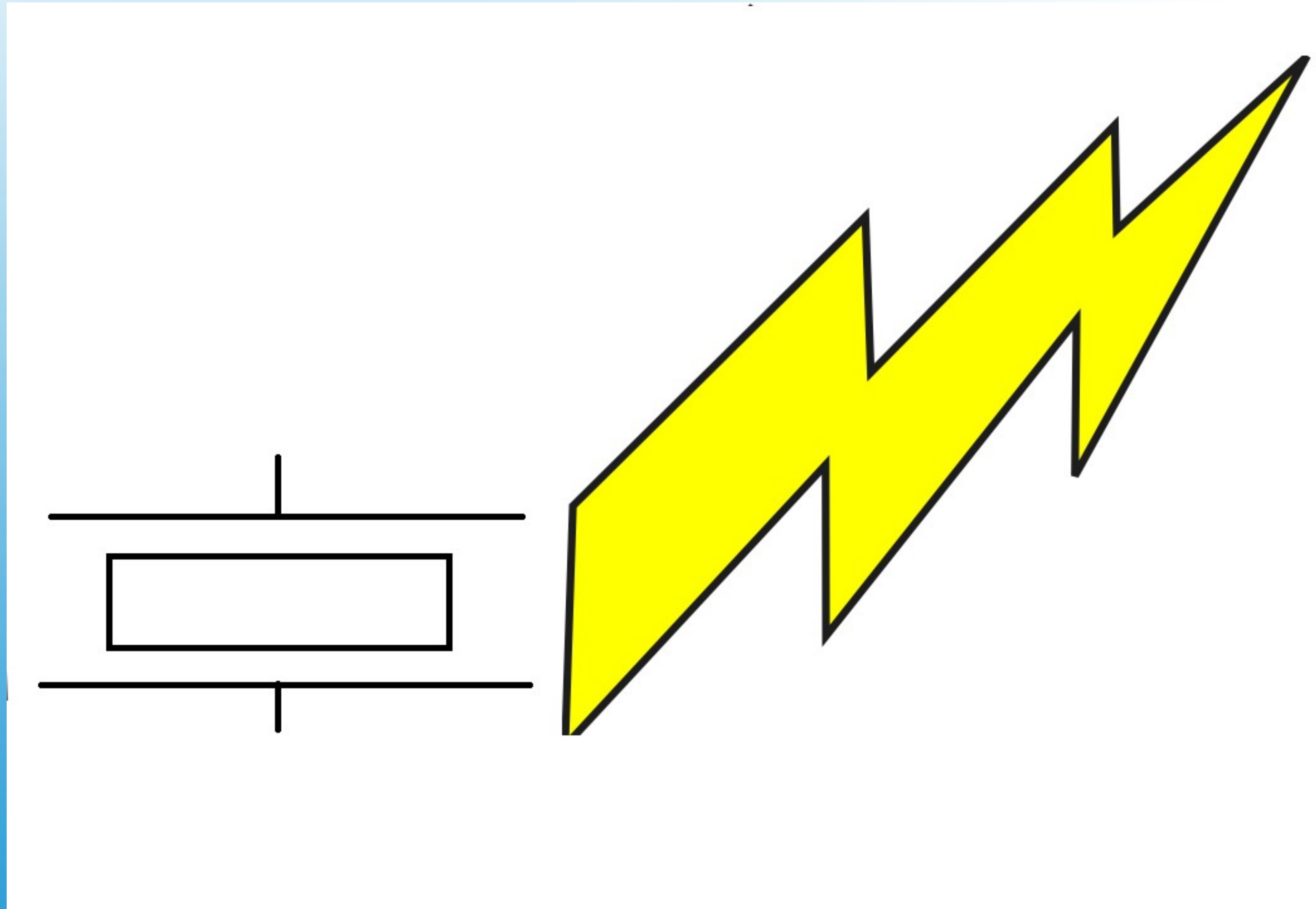
Comments on a Proposed New High Efficiency VLF Miniature Piezoelectric Dipole for Through The Earth Communications

Brian Pease



The proposed antenna is described in the open source paper titled
A High Q Piezoelectric Resonator as a Portable VLF Transmitter
by Mark Kemp and 6 others, published 12 April 2019, in the peer reviewed online journal ***Nature Communications,*** at nature.com

ABSTRACT FROM THE PAPER

Very low frequency communication systems (3 kHz–30 kHz) enable applications not feasible at higher frequencies. However, the highest radiation efficiency antennas require size at the scale of the wavelength (here, >1 km), making portable transmitters extremely challenging. Facilitating transmitters at the 10 cm scale, we demonstrate an ultra-low loss lithium niobate piezoelectric electric dipole driven at acoustic resonance that radiates with greater than 300x higher efficiency compared to the previous state of the art at a comparable electrical size. A piezoelectric radiating element eliminates the need for large impedance matching networks as it self-resonates at the acoustic wavelength. Temporal modulation of this resonance demonstrates a device bandwidth greater than 83x beyond the conventional Bode-Fano limit, thus increasing the transmitter bitrate while still minimizing losses. These results will open new applications for portable, electrically small antennas.

https://doi.org/10.1038/s41467-019-09680-2 **OPEN**

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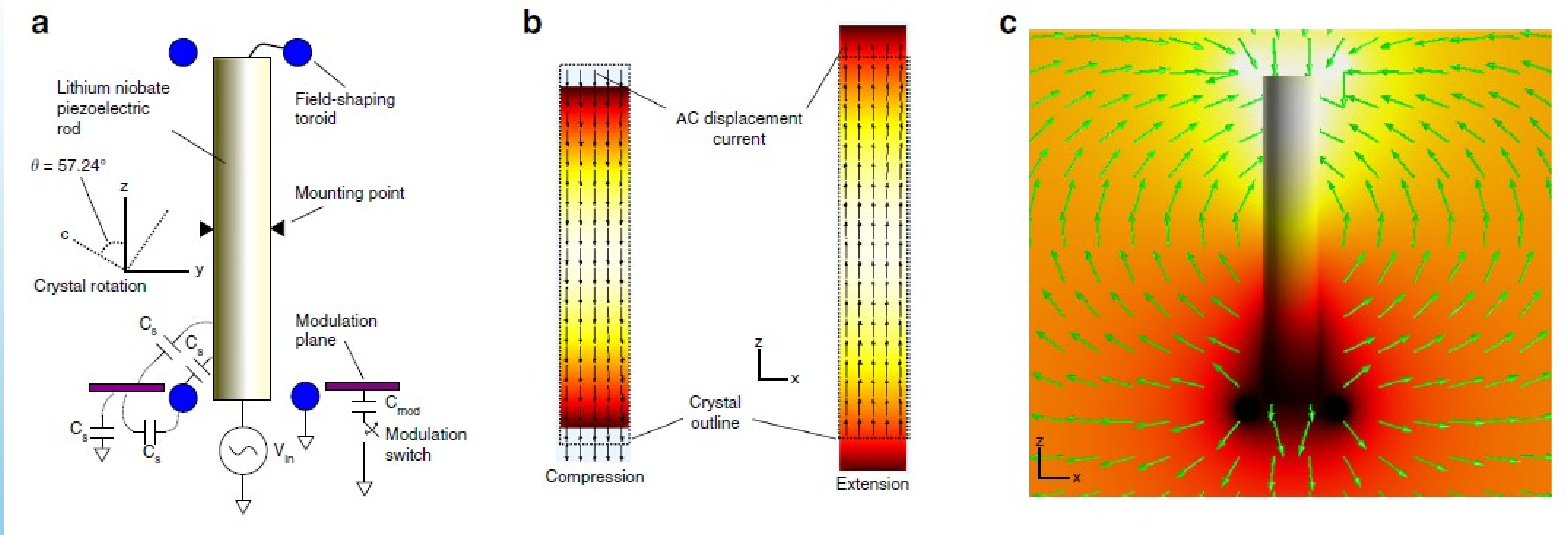
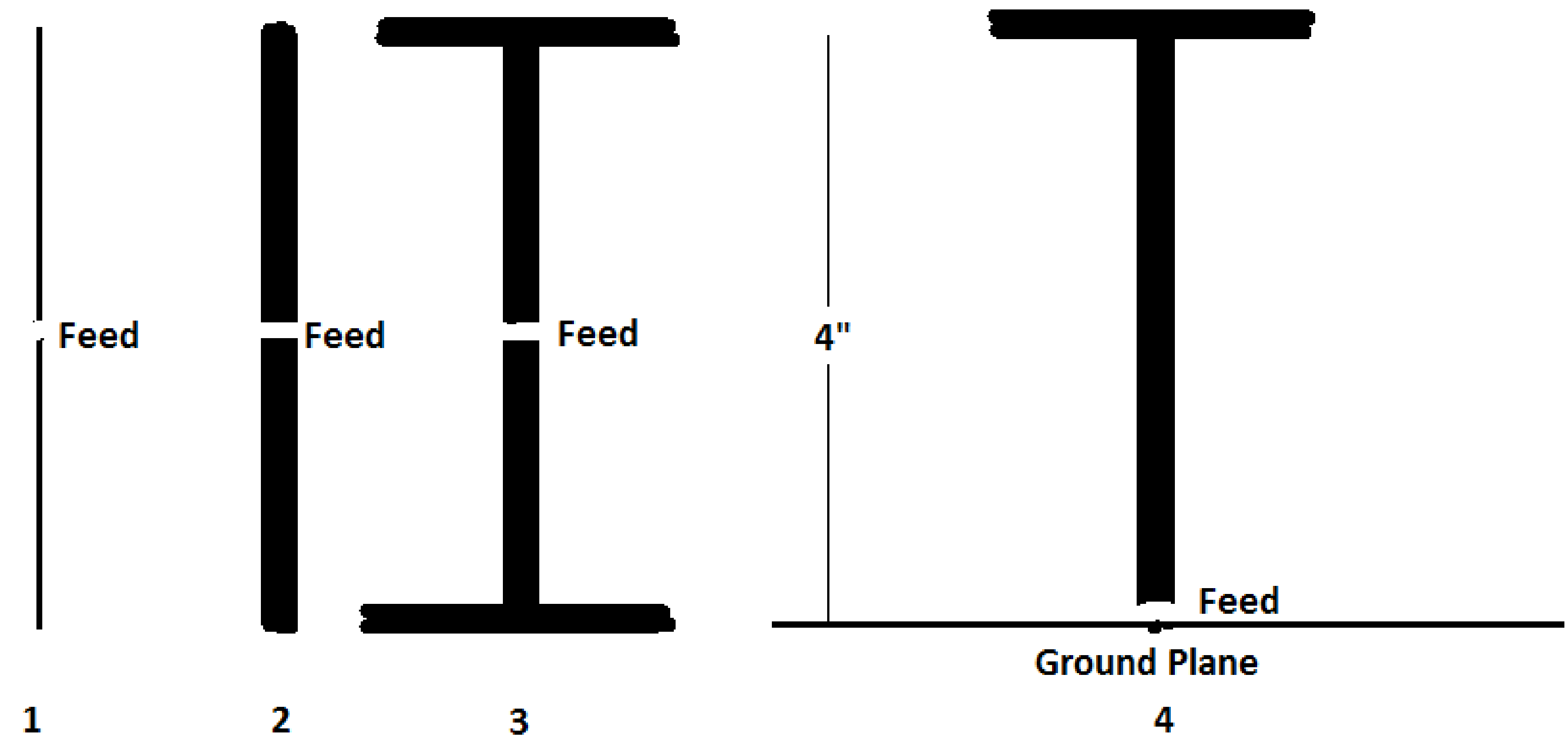
Henry Schneiker brough this to my attention
It sure sounded great



From Figure 1 of the paper

The Lithium Niobate (LN) crystal is 4 inches (9.4cm) long by 5/8 inch (1.6cm) diameter and weighs about 88 grams (3.1oz) without toroids or mount. It is operated in series resonance (low impedance) at 35.5 kHz. Q is 300000 In a vacuum but drops to 30000 in an insulating gas or open air.

This LN crystal dipole is compared to a 4 inch electric dipole, which requires a tuning network with Q assumed to be 1000. The LN dipole has a 300x advantage in a vacuum but only 30x in practical gas or air.



Evolution of LN Dipole Models

My goal was to compare the LN dipole to a 4” diameter loop antenna of similar weight. The results for the LN dipole given in my abstract are too pessimistic (my bad!) because I used the wrong dipole model.

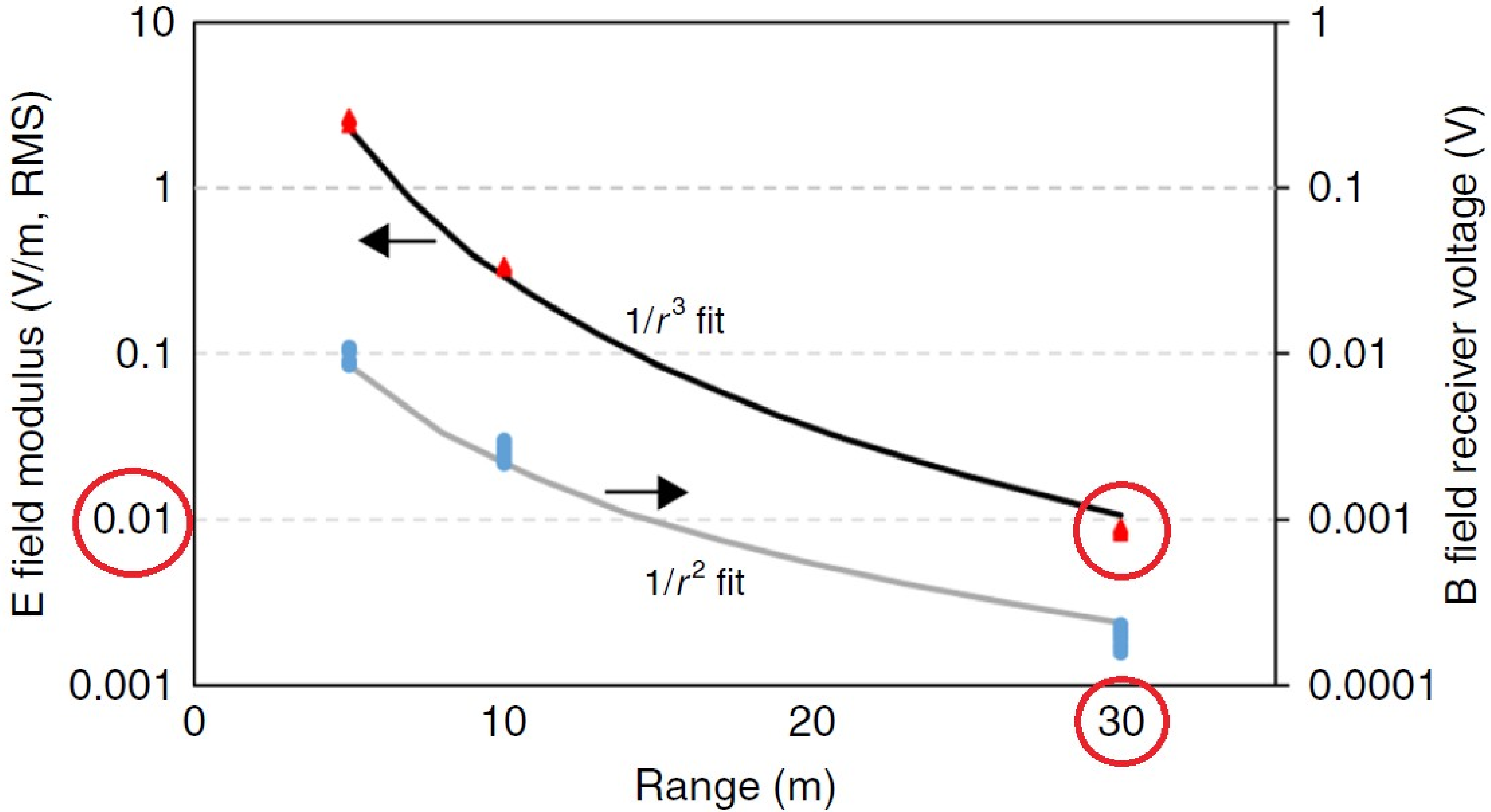
Four things to compare between the LN and loop antennas are:

1) The strength of the Electric and Magnetic fields underground

2) The antenna's Bandwidth and modulation capability

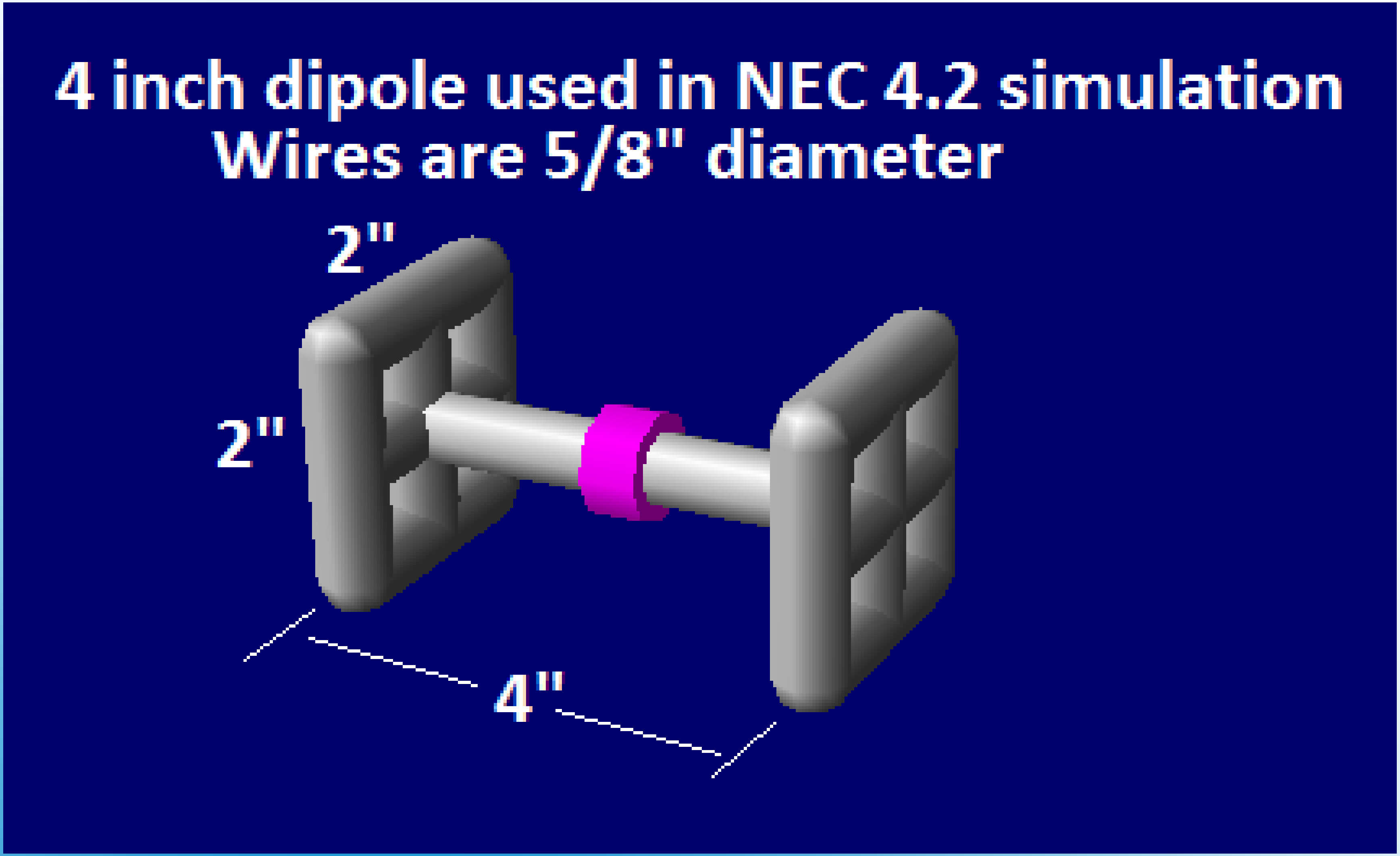
3) The ability to receive the same modulated signals it transmits

4) Practical aspects such as stability, safety, flexibility

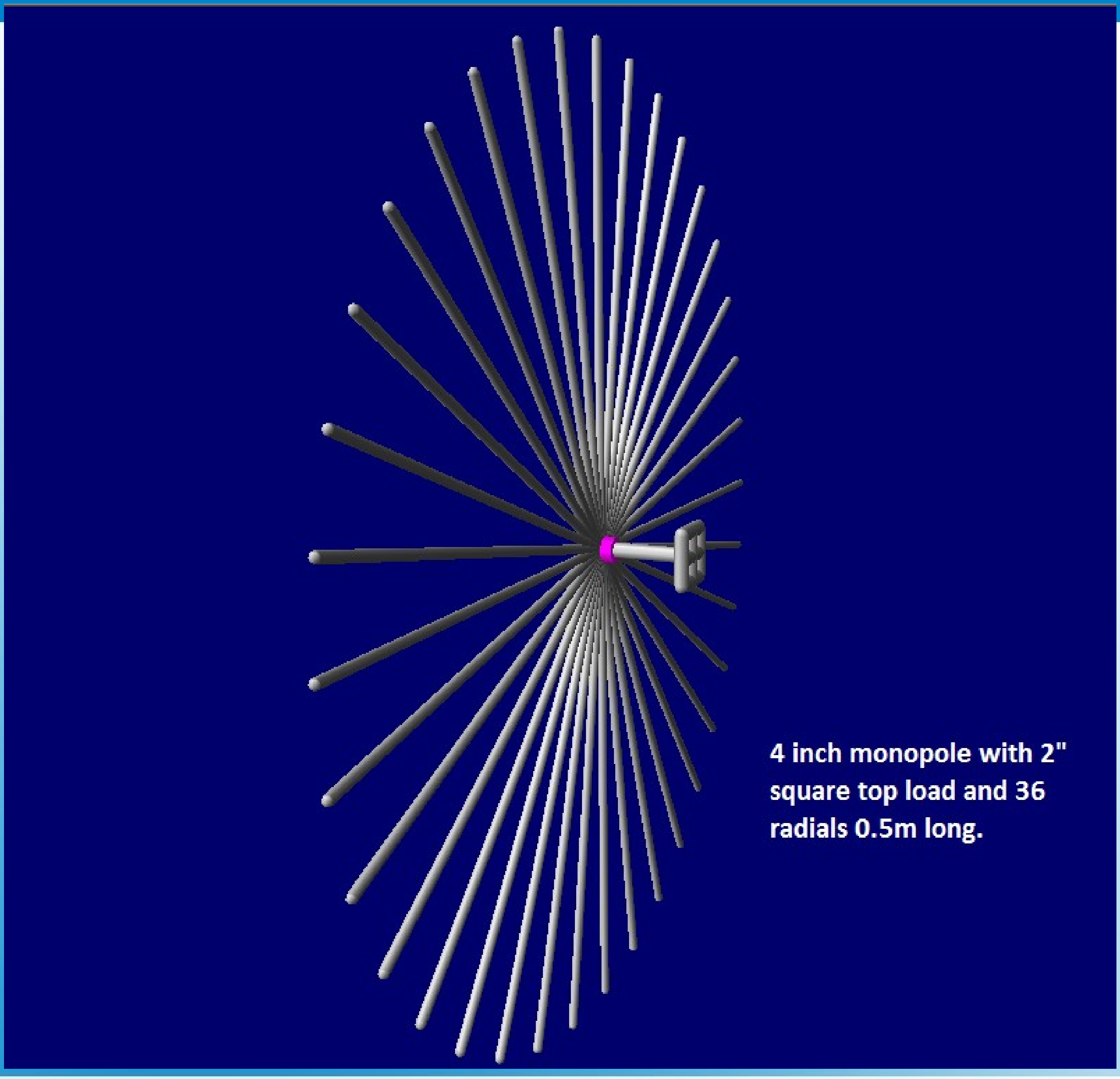


1) Field Strength

Figure 8 from the paper gives the free space E field of the LN dipole as 10mA/meter at 30 meters range. My model must do the same.

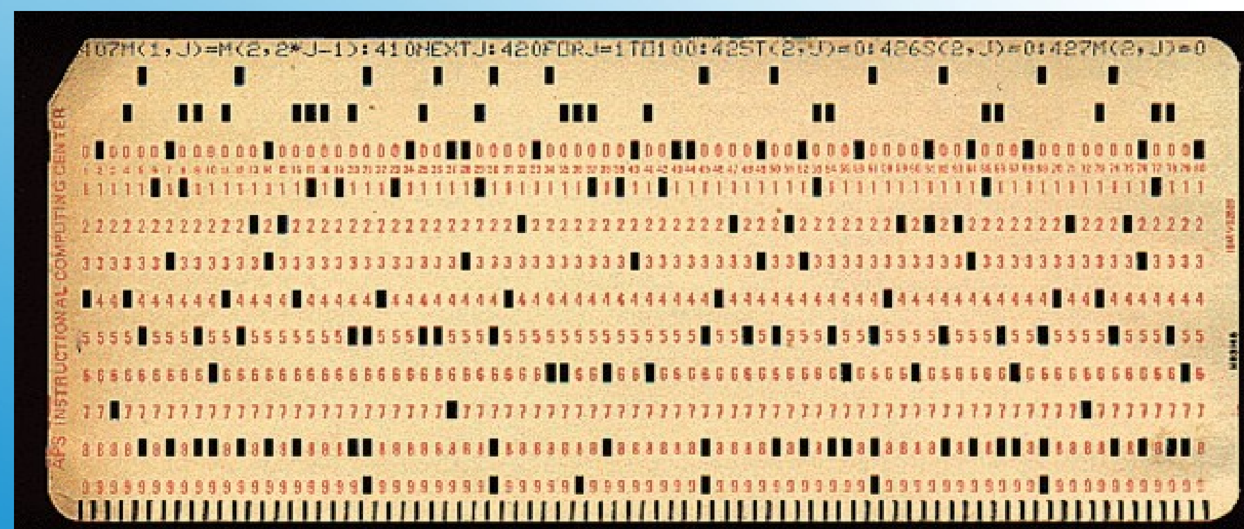


Model #3 was much better than the simple straight wire models 1 & 2



This strange looking monopole with a ground plane gives exactly the same radiated electric field as the LN crystal. It mimics their test setup with a ground plate and top load.

CM 4 inch long horizontal dipole, 5/8" dia, at 35kHz, 1 meter above ground
CM 125KV RMS on dipole
GW 1,3,-.0508,0,1,.0508,0,1,.0081 ! 4” dipole along x axis, 16.2mm dia.
GE -1,0 ! End of geometry input. Ground plane included
FR 0,1,0,0,.035,0 ! 35kHz excitation frequency
EX 0,1,2,1,125000,0 ! 125kV RMS drive at center of dipole
GN 3,0,0,0,13,.005 ! Standard Earth, cond=.005, Er=13
NE 0,1,1,100,0,0,1,0,0,-1 ! RMS Electric fields directly below dipole
NH 0,1,1,100,0,0,1,0,0,-1 ! RMS Magnetic fields directly below dipole
XQ ! Execute simulation
EN ! Terminate program

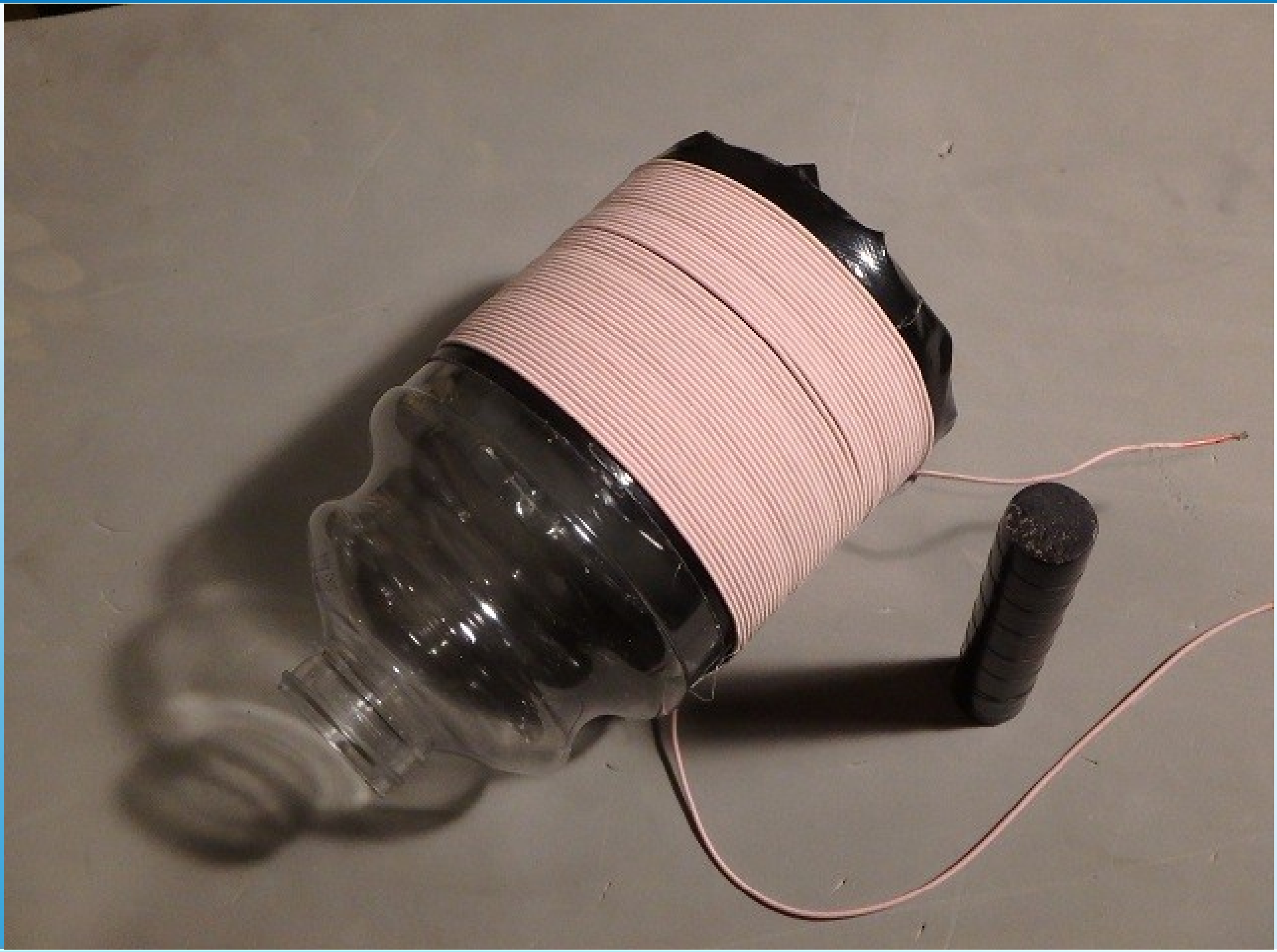


Numerical Electromagnetics Code (NEC 4.2) text input for the simple fat dipole #2, in vintage punch-card format. The commas can be replaced by spaces.

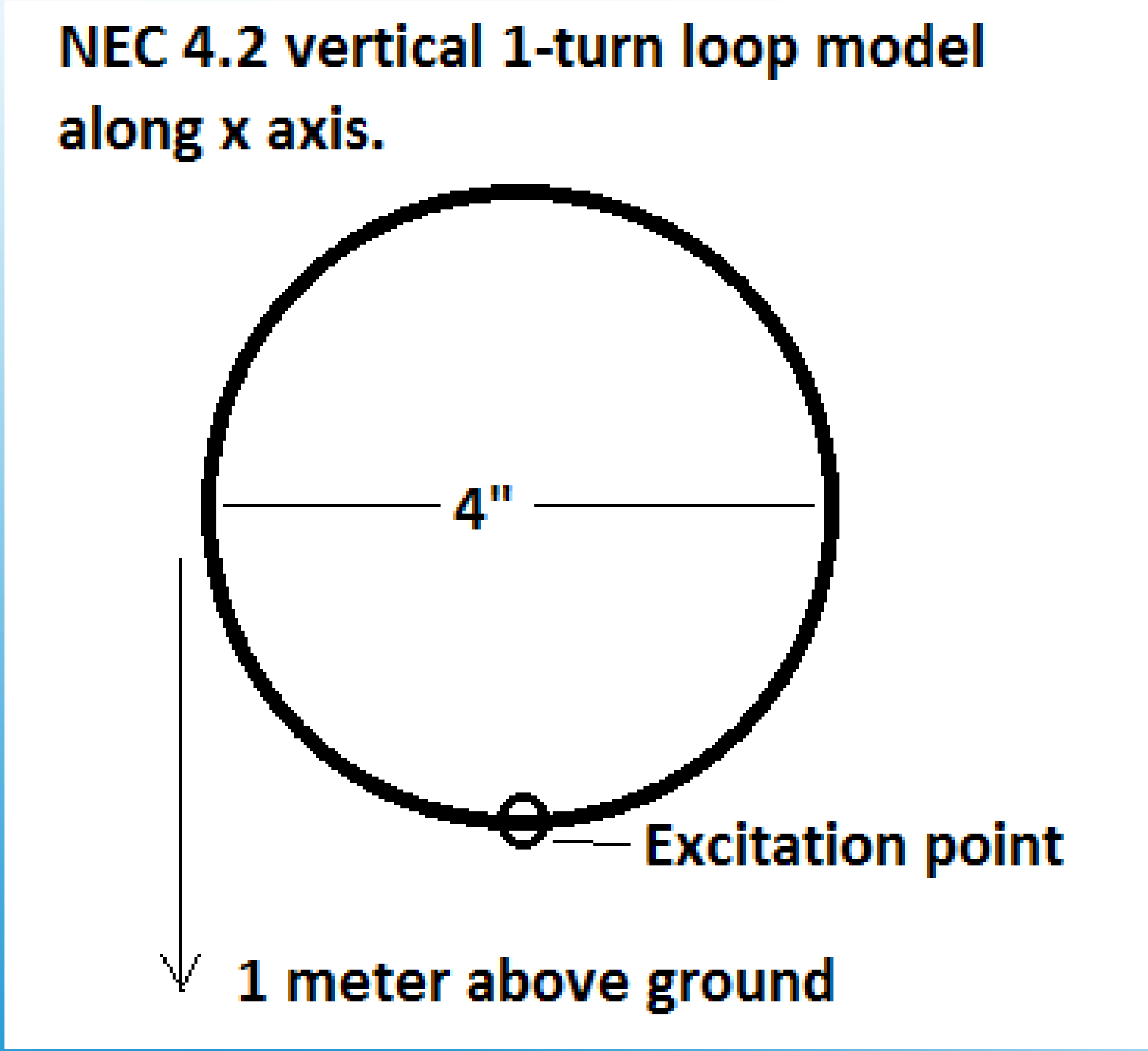
NEC 4.2 simulation results in free space

No.	4” Dipole Model	Feed Current, RMS	Ex, mV/m, RMS	Hy, uA/m, RMS
1	1mm dia wire	12.0 mA	0.69 mV/m	.0415 uA/m
2	16.2mm dia (5/8”)	28.5 mA	2.4 mV/m	0.143 uA/m
3	5/8” dia, 2” square End loads	56.2 mA	6.68 mV/m	0.404 uA/m
4	Monopole, 2” sq top Load, 1m dia gnd plane	100 mA	**10.2 mV/m**	0.616 uA/m

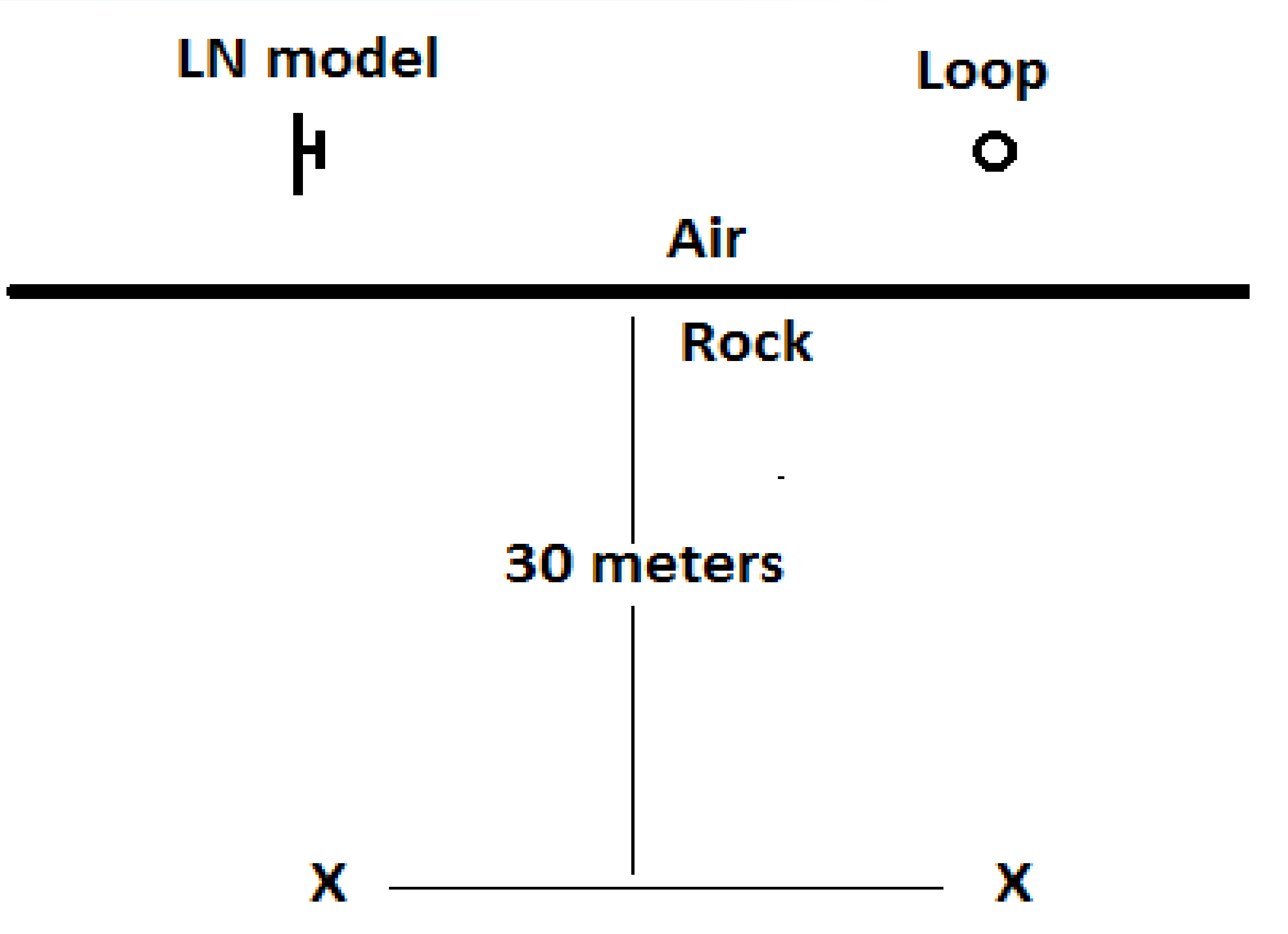
The 4” top-loaded monopole matches their results



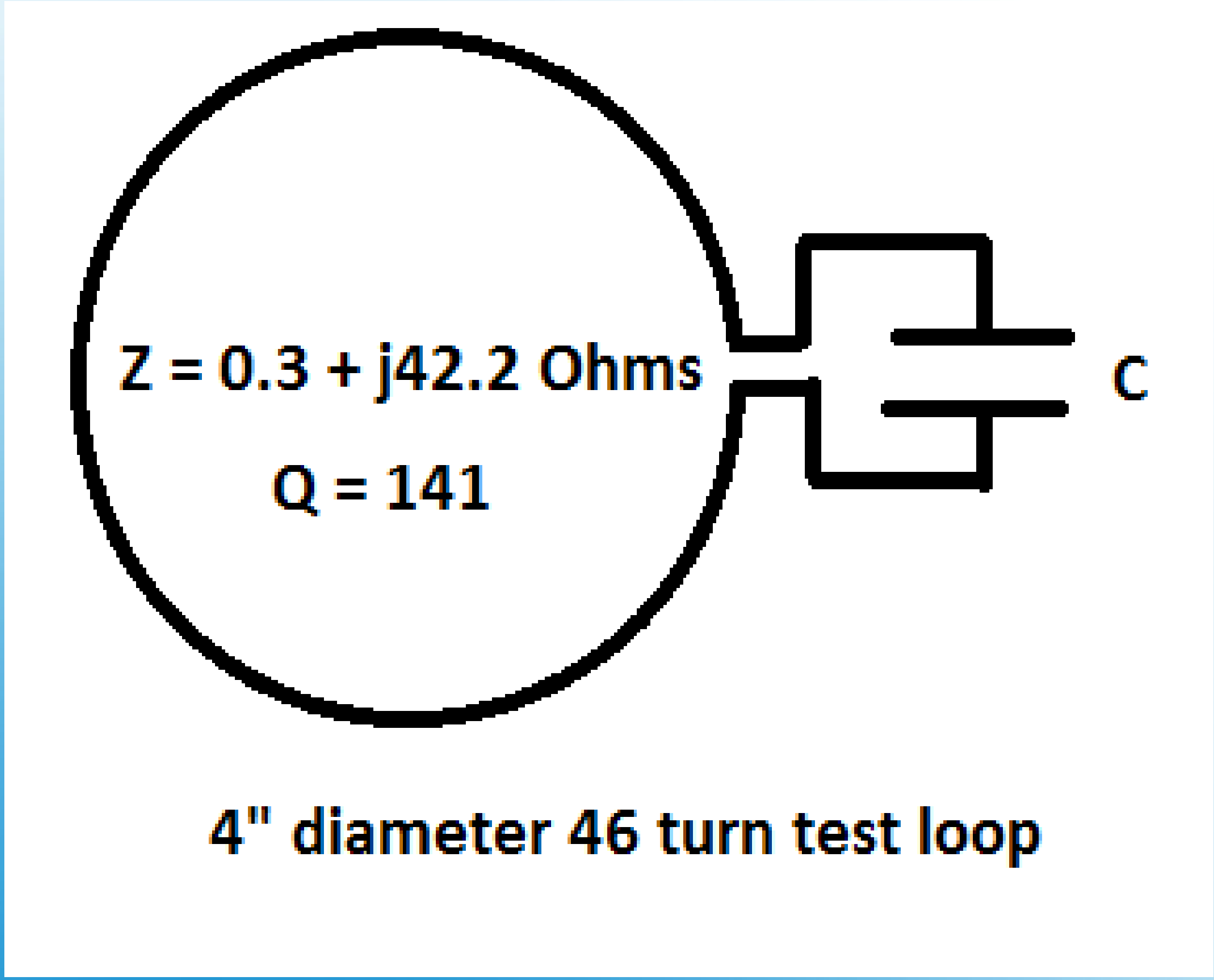
4 inch diameter loop, 46 turns of 660/46 Litz, winding 2.7” long.
At 35kHz, Z=0.30 + j42.2 Ohms, L=192 uh, Q=148, BW=248 Hz.
A model of the LN crystal is shown for scale.



The LN crystal dissipated 0.8 Watts, so the loop can do the same. 0.8 Watts gives a magnetic moment of 0.608 A-T-m squared. The 1-turn 4” diameter NEC 4.2 model will require 75.1 Amps RMS current

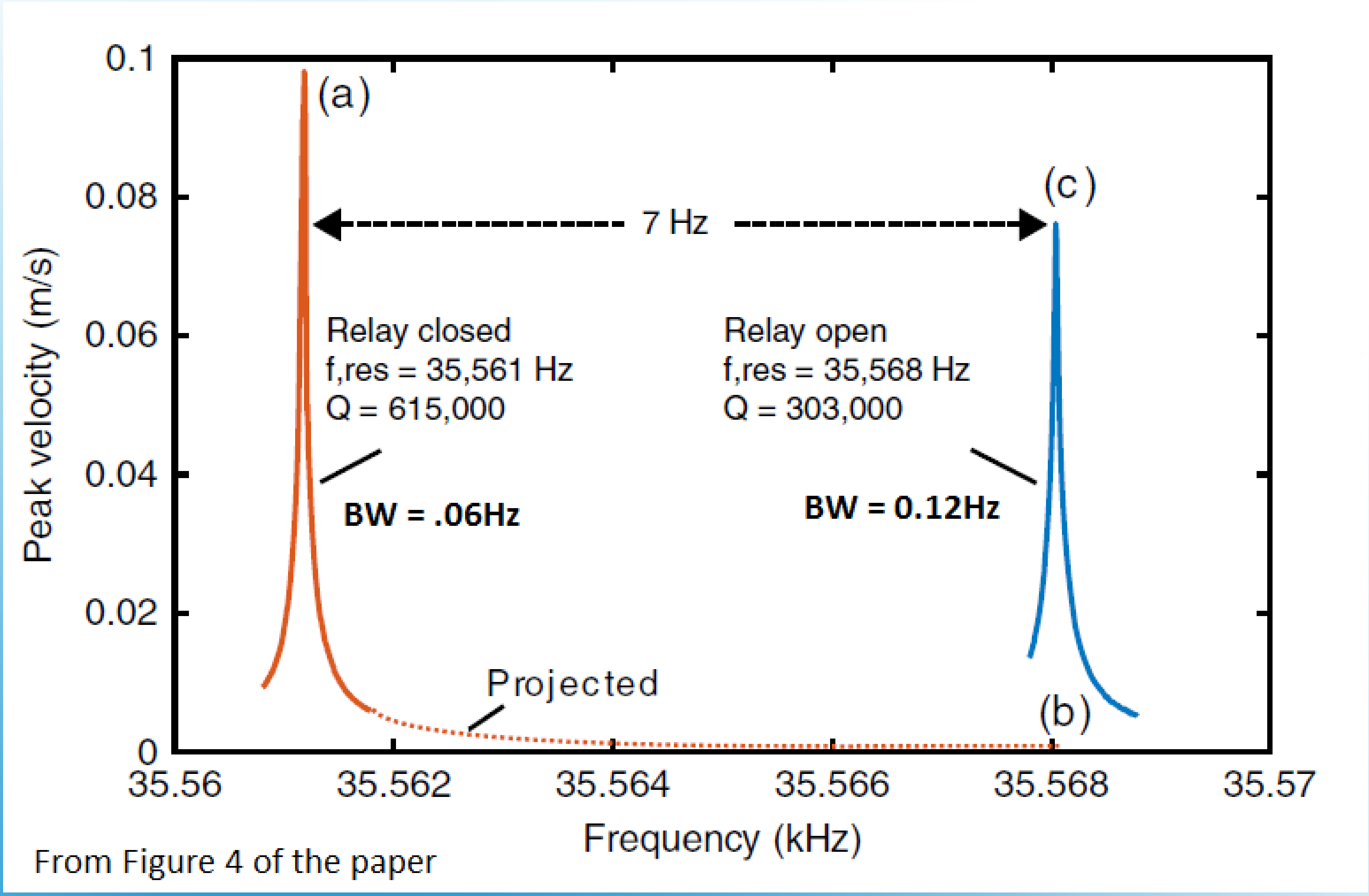


When Thru-The-Earth transmission is simulated to 30m (100 ft) depth in standard Earth (cond=.005 S/m, Er=13), the LN crystal has an electric field of +4.3dB and magnetic field of -5.6dB compared to the loop.
The LN crystal is not 300x (+50dB) better than the loop.



2) Bandwidth and Modulation

The 4” loop antenna has a bandwidth of 248Hz. In a noiseless channel, Nyquist allows up to 496 bits/sec with simple binary coding.



LN Crystal bandwidth

The LN dipole has far too narrow a bandwidth to support a reasonable bit rate. A technique called Direct Antenna Modulation (DAM) shifts the crystal resonance by 7Hz in sync with the 35.5kHz transmitter. They claim up to 50 bits/sec FM modulation. The loop could also use DAM.

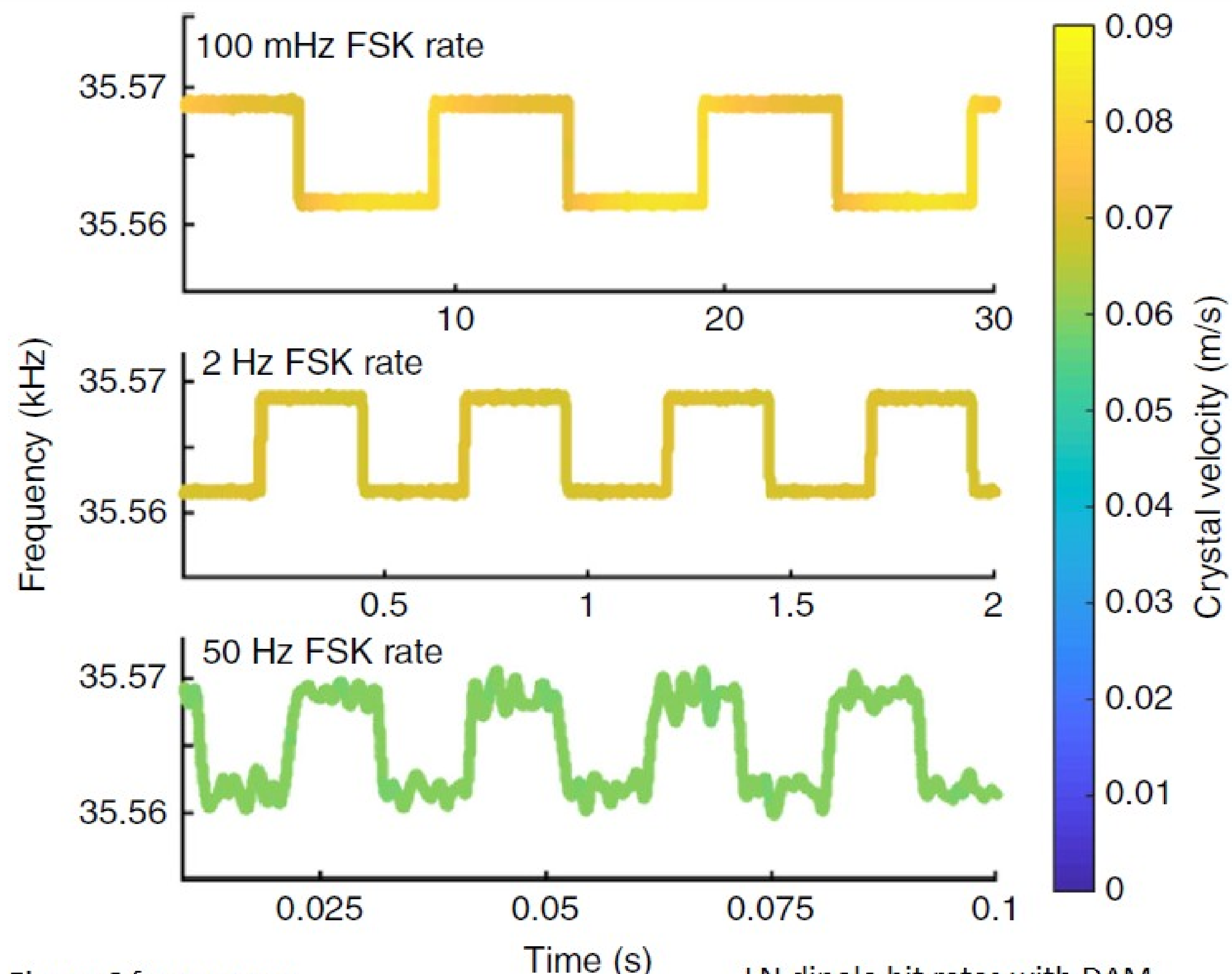


Figure 6 from paper

LN dipole bit rates with DAM

DAM is an interesting concept that could work with any narrowband tuned antenna. The LN dipole might work well at 10-20Hz bit rate.

3) Receiving signals

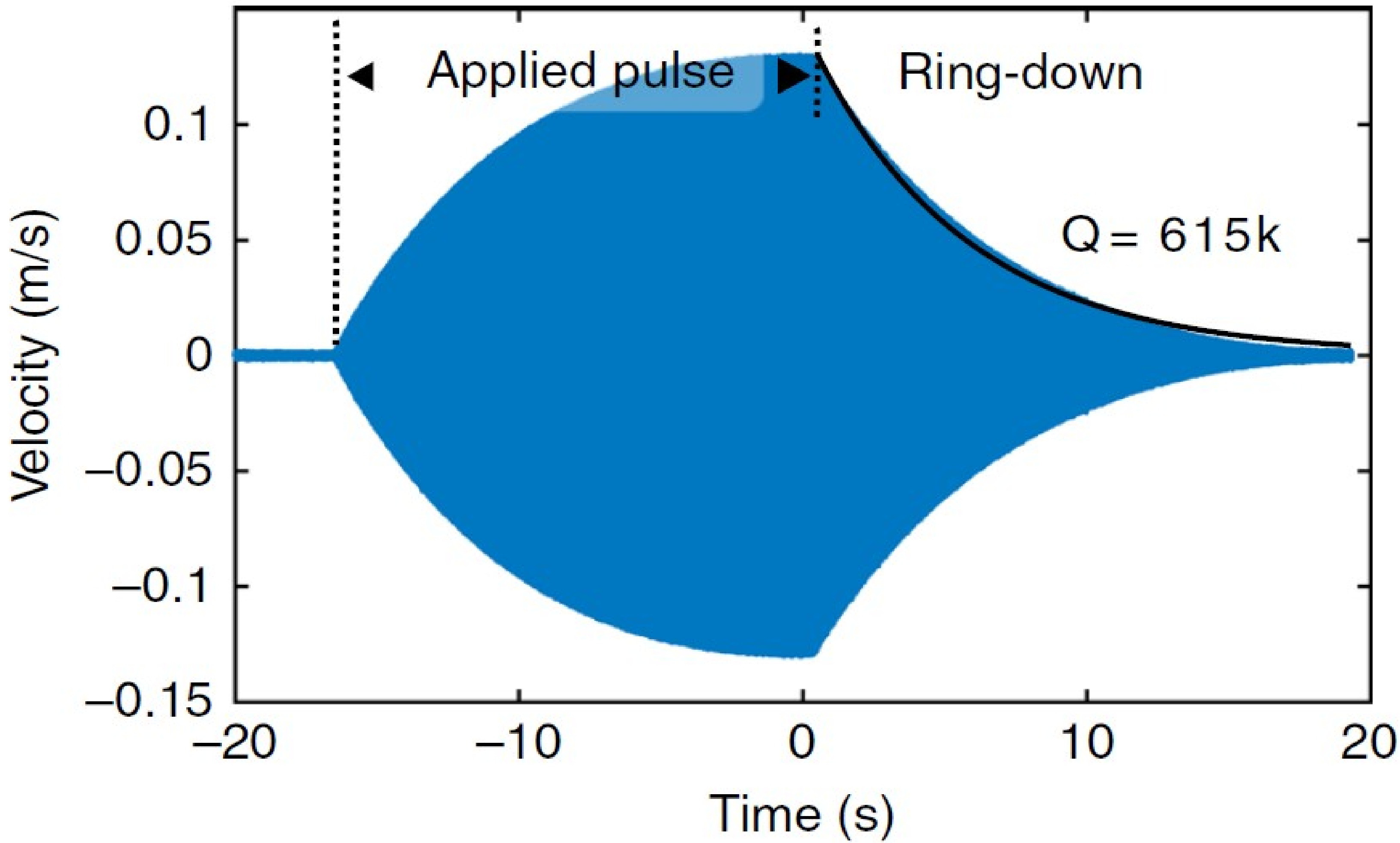


Figure 2 from the paper

There doesn't appear to be any way that DAM can be used for receiving signals, even with two LN dipoles tuned to the two frequencies. The maximum received data rate would be about 1Hz in open air. Without DAM, the loop antenna can receive anything it can transmit.

4) PRACTICAL ASPECTS OF THE LITHIUM NIOBATE DIPOLE

1) The LN antenna is a fragile crystal.

2) Highest Q (and efficiency) is in a vacuum, which may not be realistic.

3) The narrow bandwidth and DAM limit the LN dipole to a single RF channel and binary FM modulation.

4) 125kV RMS is dangerous especially in a handheld device.

5) The slightest shift in resonance due to temperature or movement of a nearby object will effectively stop transmission.

6) The need for a ground plane and top toroid makes it relatively large.

CONCLUSIONS

1) It appears that the LN dipole can be used only for transmitting and would require a separate receiving antenna, ie a loop.

2) The LN crystal can handle only limited power without shattering.

3) A loop receives the magnetic near field, which is 5.6dB stronger if transmitted by a 4” loop rather than by the LN dipole in my Thru-The-Earth simulation.

4) Loops have none of the faults shown in the previous slide.

5) The 300x improvement claim, in the paper's abstract, applies only to an equal size metal dipole with tuning network and not to an equal size loop, which is far far better than the metal dipole.

6) The DAM technique is interesting and worth a look for tuned loops.