Operational Next Generation Transmitter Technology for (e)LORAN

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Making Digital Radio **Work.**

Overview

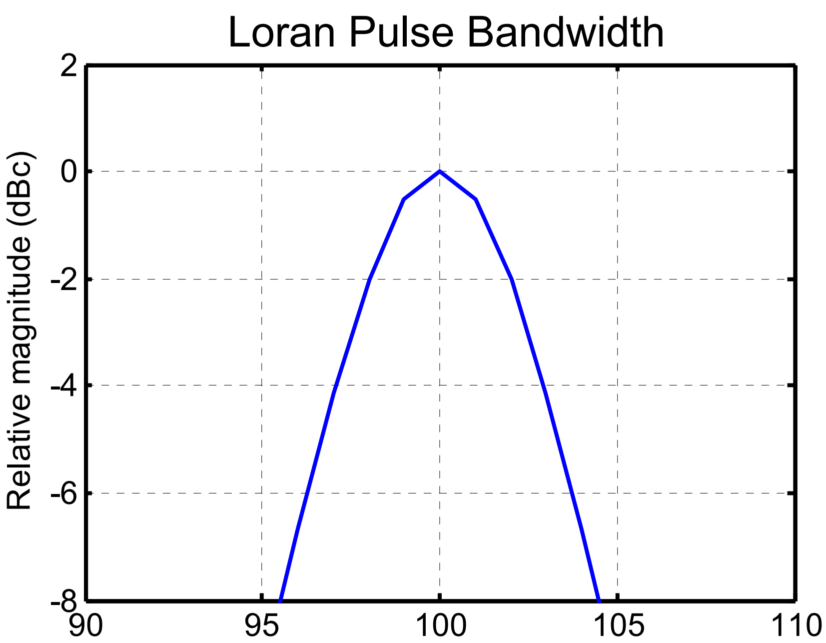
Theory:

- Typical antenna bandwidth limitation
- Transmitting loran with a voltage source
- Alternate waveform capabilities
- IFM pulse example

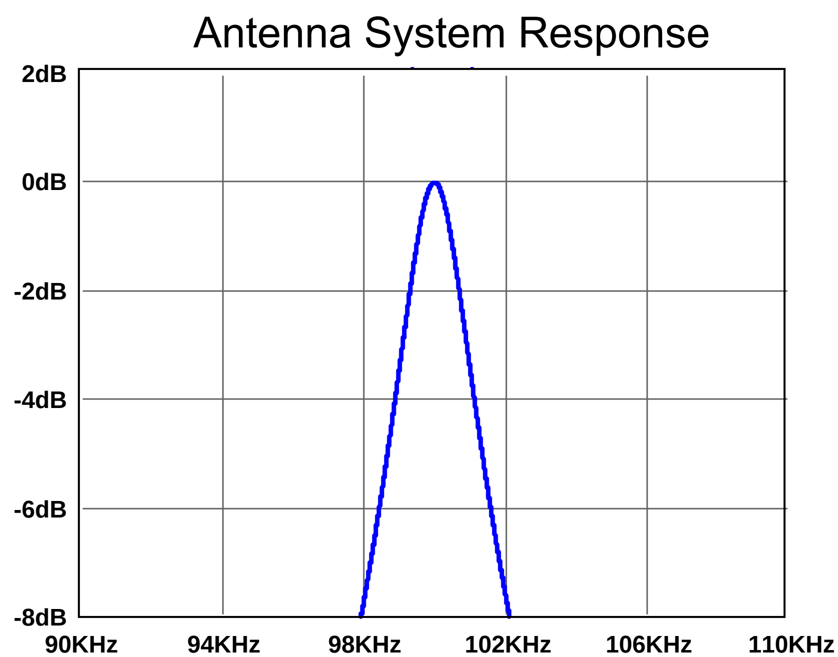
Transmitter system design for high availability:

- Redundancy
- Parallel Architecture
- Scalability
- Transient Protection

Typical Antenna Bandwidth Deficit



3dB BW = 5 kHz



3dB BW = 1.8 kHz

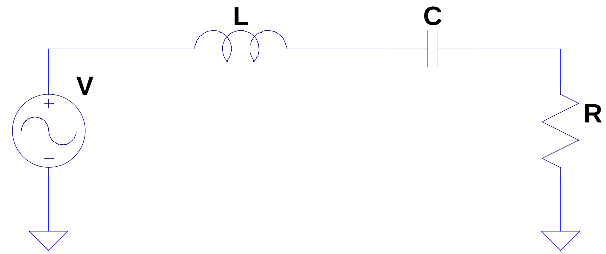
Pulse bandwidth is ~3 times greater than antenna bandwidth for Q = 60

Steady state assumptions do not apply!

Voltage Mode Operation

Transmitter operates as a voltage source.

Antenna is tuned to series resonance. Q factor is typically 25 to 80.



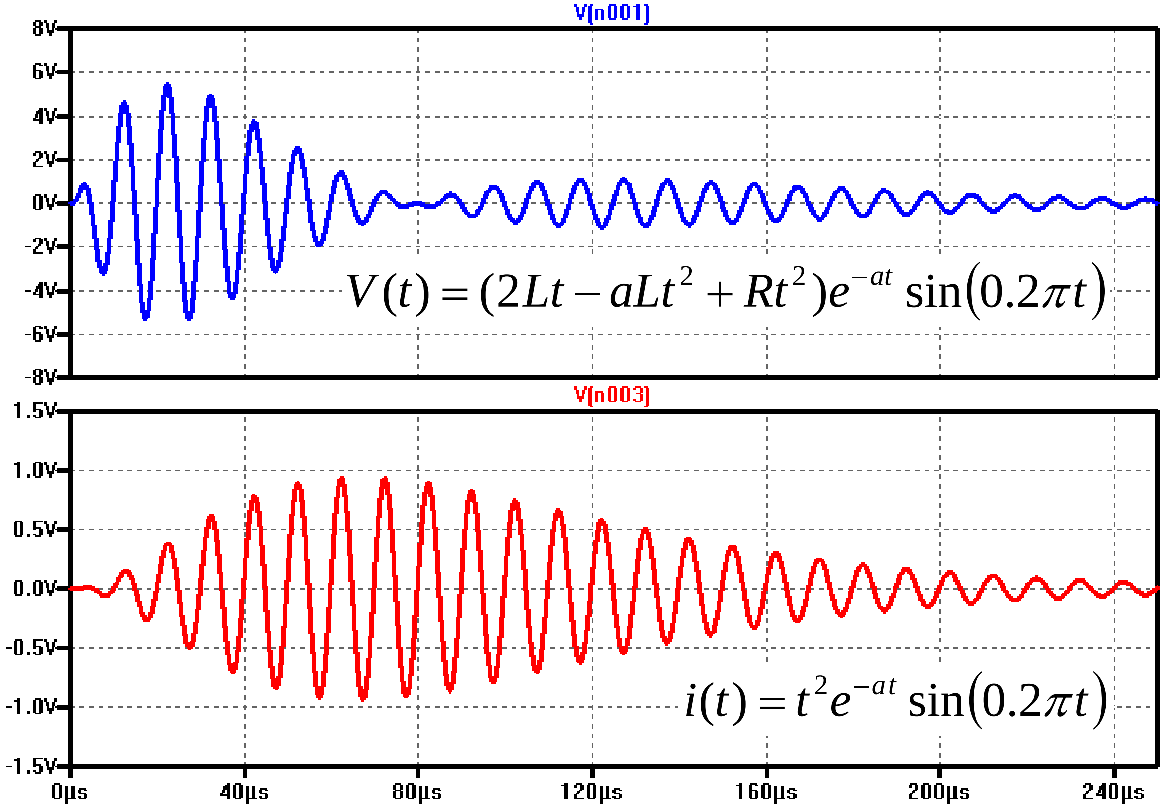
To induce the ideal current waveform: $i(t) = t^2 e^{-at} \sin(0.2\pi t)$

A corrected voltage waveform is required: $V(t) = (2Lt - aLt^2 + Rt^2)e^{-at} \sin(0.2\pi t)$

Standard Signal Spec. Pulse

Transmitter voltage fundamental component (blue)

Induced pulse current (red)

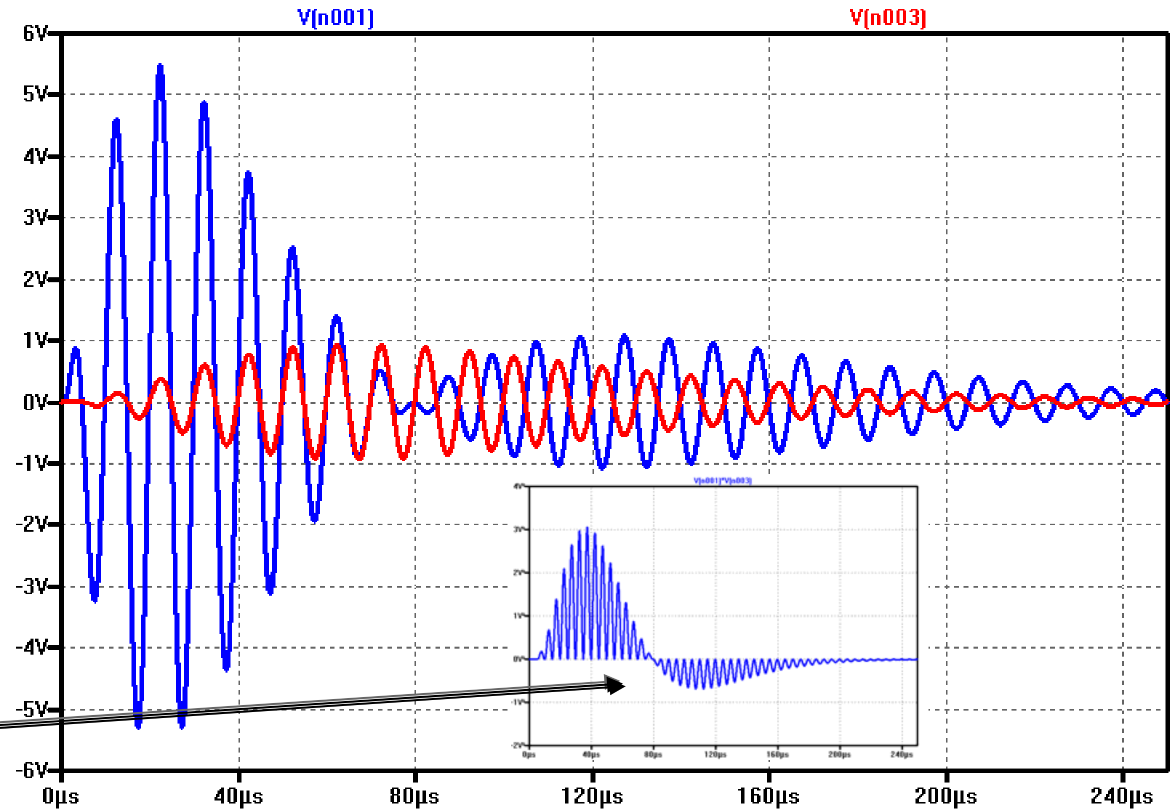


Standard Pulse (Demonstrated at LSU)

Voltage initially 5½ times higher than steady state requirement!

Voltage and current transition from in phase to out of phase.

Negative power flow in pulse tail. Energy may be recovered to improve system efficiency. (Inset shows power flow.)

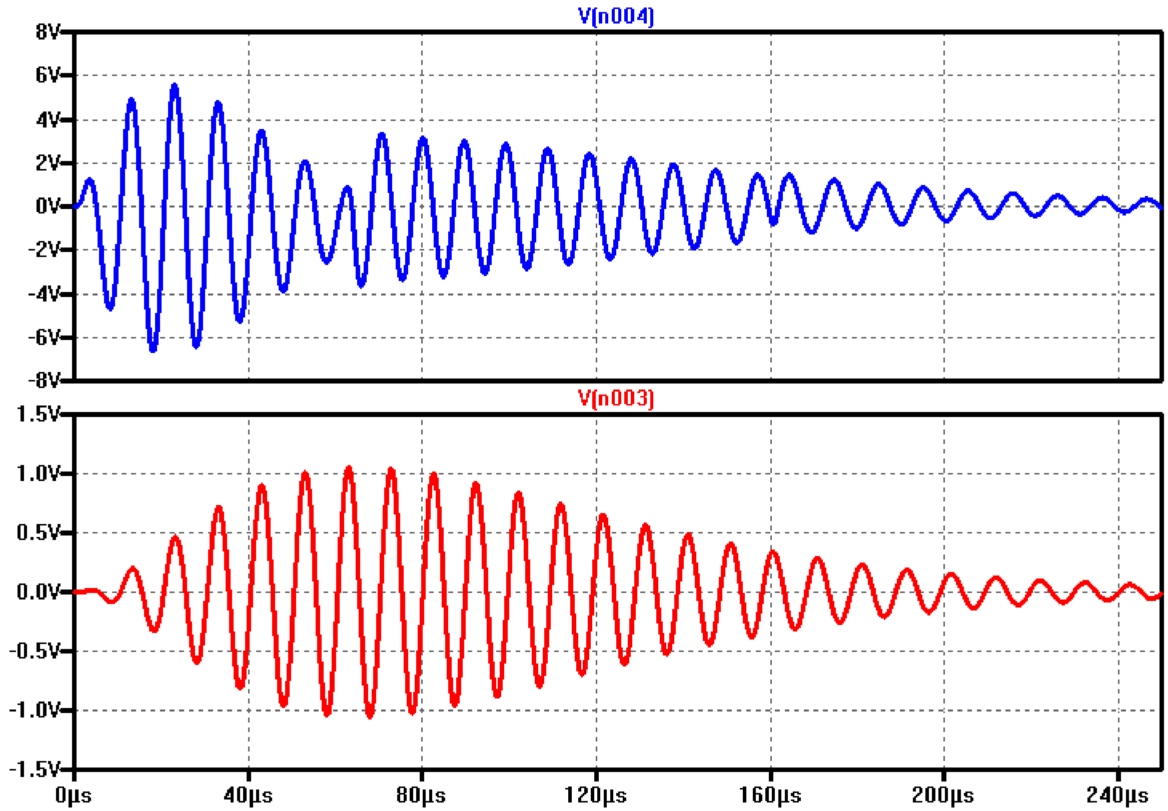


Typical IFM Pulse/Data Symbol

IFM employs discrete frequency changes in the pulse tail as a means to transmit data bearing symbols.

The intent is to minimally affect system PNT performance while offering increased data bearing capacity.

Required driving voltage may be predicted using analytical methods.



Standard pulse up to 60 µs

102.5 kHz from 60 to 160 µs

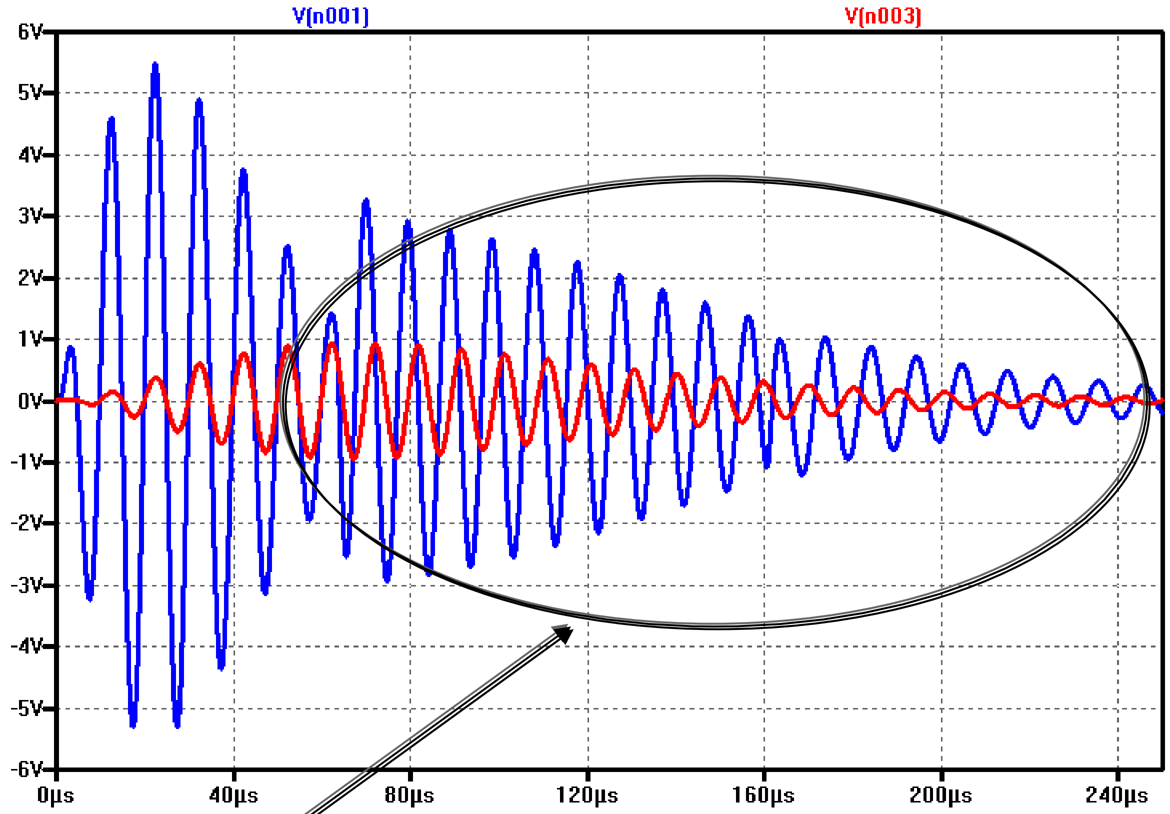
97.5 kHz after 160 µs

IFM Pulse

Peak voltage and RMS current are unaffected.

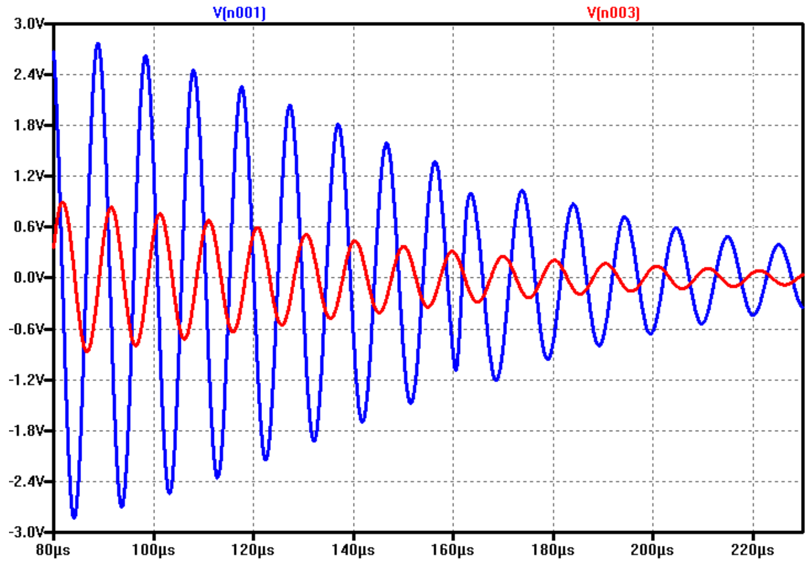
Transmitter power capability is unchanged.

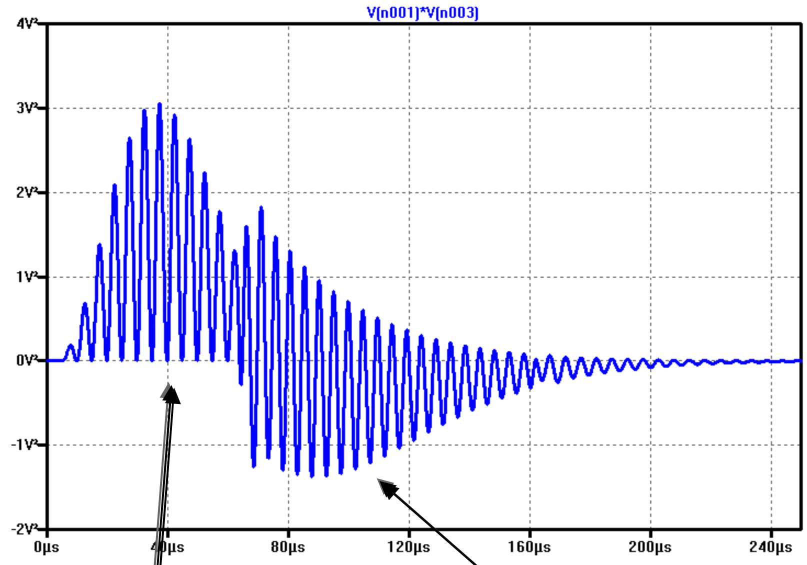
IFM is an example of a phase modulated signal.



Voltage waveform in pulse tail is modified to pull resonant frequency off centre.

Phase Modulation – Reactive Power Required





Transmitter operates as a synthetic capacitor or inductor to control resonant frequency of the antenna.

Amplifier switching transitions at high current.

Real power flowing to antenna.

Complex power flow with negative real power flowing to transmitter.

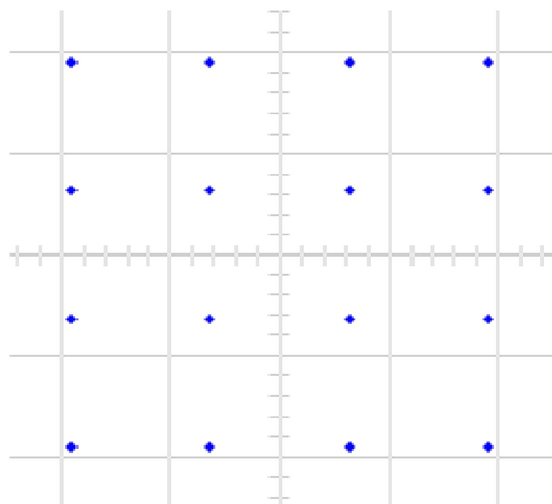
Alternate Waveforms – Transmitter Capabilities Summary

- The transmitter is essentially a synthesized voltage source capable of magnitude and phase modulation. Voltage is fixed over RF half-cycles which must be synchronous with the Cesium clock (200 nS period).
- The antenna Q and the transmitted signal together determine the requisite driving voltage based on the governing network equation.
- Increasing waveform bandwidth will increase driving voltage requirements with system power capability reduced proportionately. (The converse is also true!)
- Voltage pulse shapes would normally be calculated in advanced and stored in memory. It should also be possible to calculate voltage waveforms in real time if the desired signal space is too large to be stored in memory. (Equalization approach)

Consider 16-QAM Waveform?

Use 4 IFM States to transmit information with the pulse phase.

Modify tail damping coefficient to allow for 4 amplitude states.



16 States per pulse yields 4 bits per pulse, un-coded.

Using rate ½ coding and 100 pps, the data bearing capacity is 200 bps. 16 pulses per group would yield 400 bps.

Analysis of typical received Eb/No would help suggest appropriate waveform complexity ie. 4/8/16/32 states per pulse.

Proof of Concept – 2007/2008

Proof of Concept Transmitter was quickly built to validate the concept.

System was installed in ½ day at LSU in May 2008.

Several independent evaluations were performed to verify transmitter performance over 5 months. Test results were very positive.

Greater than 50 kW capable (625 TLM)

The system was not intended for permanent operations.

NL40 Next Generation LORAN Transmitter

Advanced User Interface (AUI)

Harmonic Filter & Antenna Tuning/Matching Rack

Control/Amplifier Rack

Amplifier Rack

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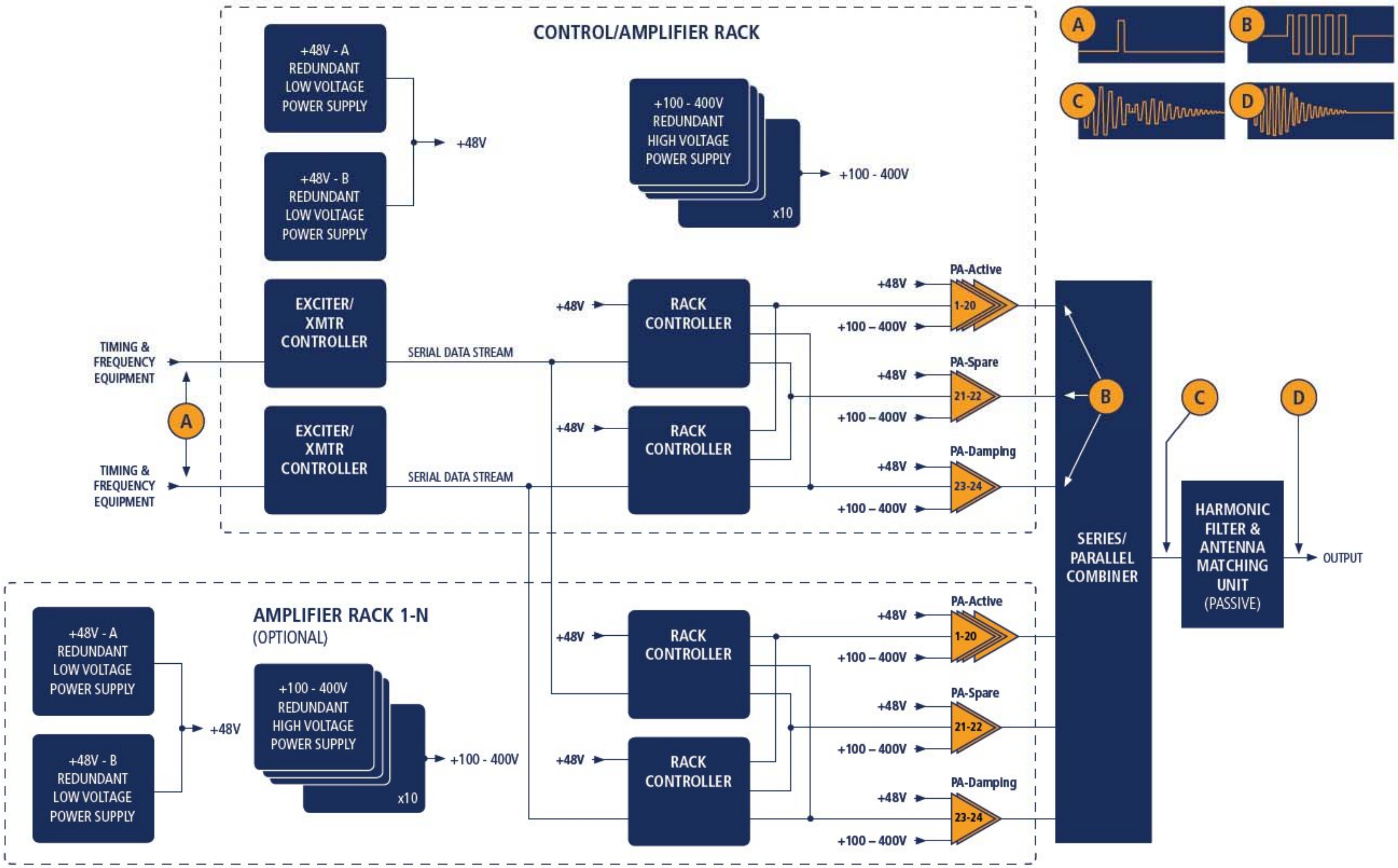
Redundant System - Block Diagram



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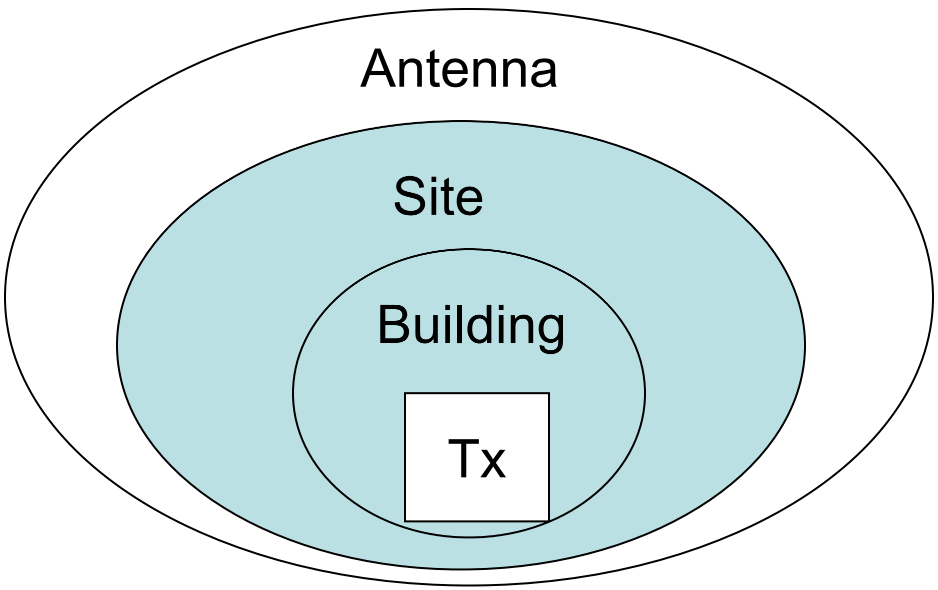
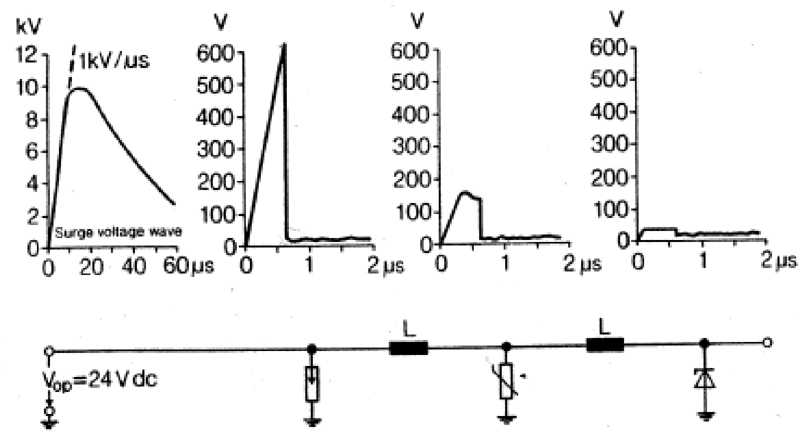
Transient, Lightning & EMP Protection

Stages of protection are used to reduce transient energy as it gets closer to sensitive components. Primary threat is conducted energy.

Nautel has 40 years experience with transient protection in solid-state transmitter systems and is recognized as an industry leader.

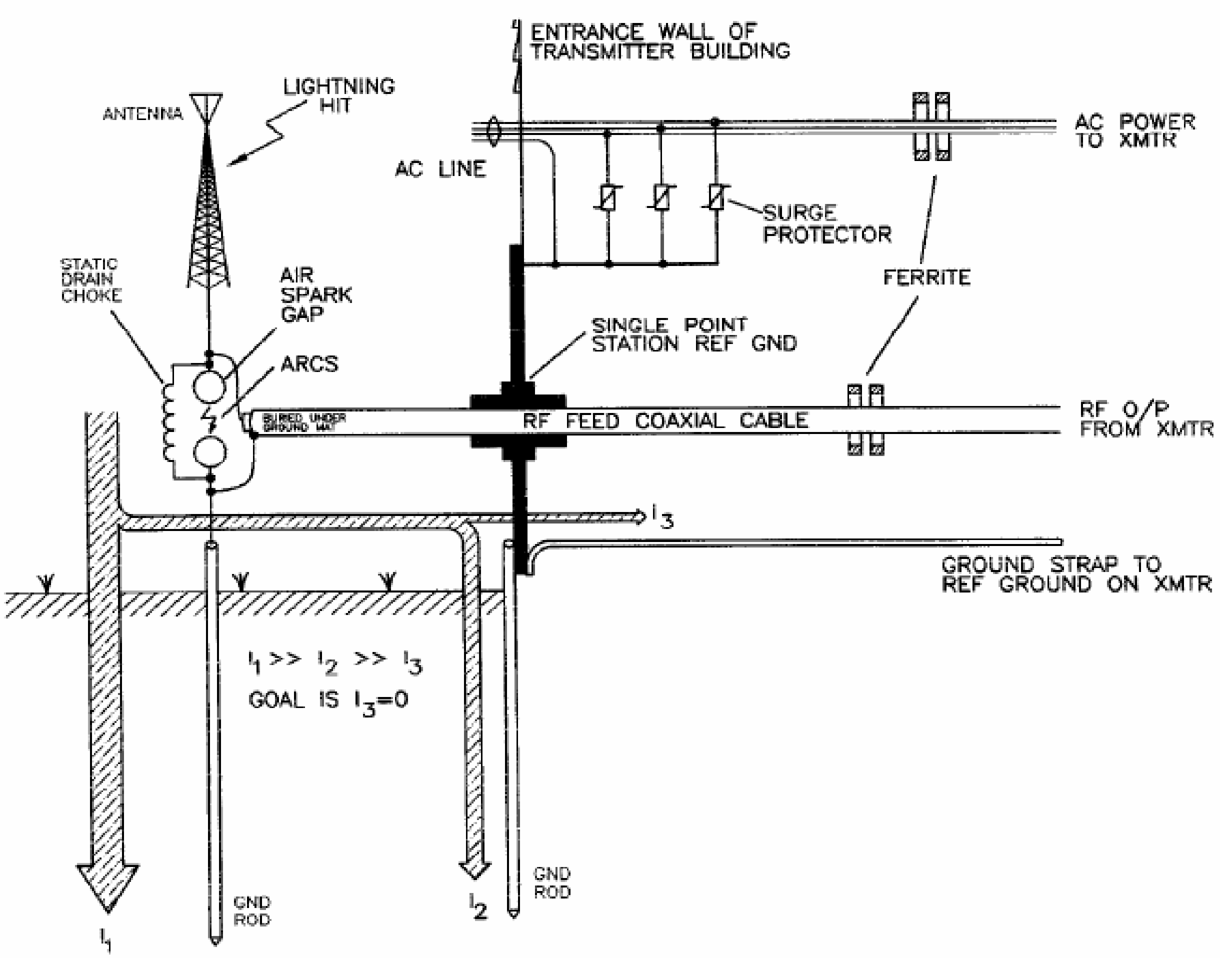


System level



Transmitter sub-assembly

Site Layout to Improve Transient Immunity



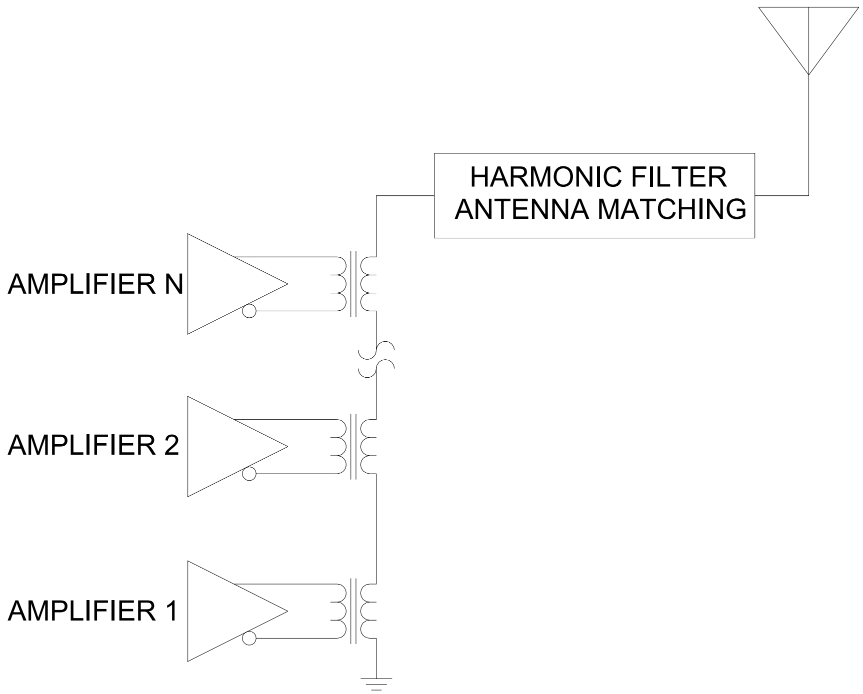
Series Combining – Field Proven and Scalable

Series combining has been in use for 25 years in broadcast transmitter systems operating as high as 10 MW peak envelope power.

Amplifier output voltages are summed with series connected transformer secondary windings. Transformer turns ratio is constrained to a single secondary turn which allows for excellent conductor geometry and conservative operation up to 10 kV peak output.

High power levels may be achieved by paralleling series combiners.

The series combing method assures equal amplifier currents and allows for differences in amplifier output voltage effectively isolating the amplifiers from each other.



NL40 Next Generation LORAN Transmitter

Series/Parallel Combiner

Harmonic Filter & Antenna Tuning/Matching Rack

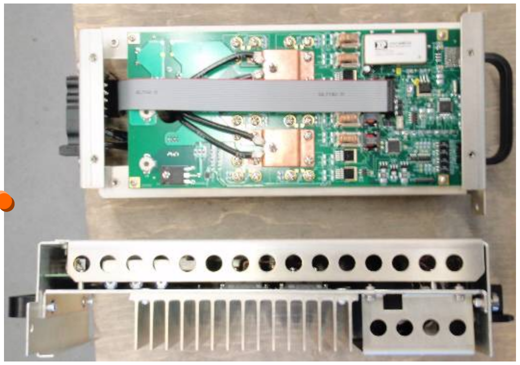
Amplifier Rack

Control/Amplifier Rack

NL Next Generation LORAN Transmitter

Control/Amplifier Rack

Amplifier Modules



Amplifier and P/S modules are "hot pluggable" to reduce MTTR..

Primary DC Power Supplies

NL Series LORAN Transmitters

Features

- Greater than 70% efficient AC in to RF out
- Patent pending pulse power recovery technique
- Scalable from low power to multi mega-watt level
- Redundant/parallel architecture for high availability
- Precise pulse shape control – software configurable
- Exceptional pulse stability
- Compact
- Automatic antenna tuning for antenna system capacitance changes
- Pulse optimization for antenna system resistance changes
- Loran data acquisition and diagnostic functionality
- LRU diagnostics and fault monitoring

Thank You!

Questions?