THE BIGGEST LITTLE ANTENNA IN THE WORLD

Ed Kardjala

The Navy's VLF antenna at Cutler Maine

Edward M. Newman

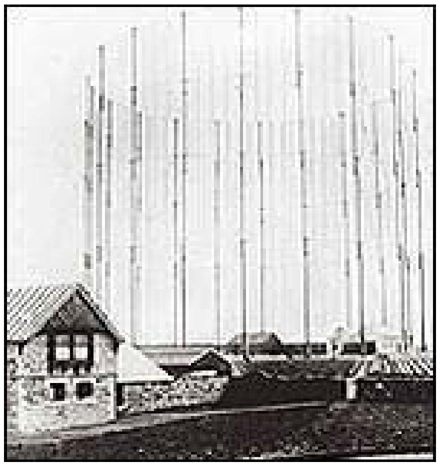
AP-S Nov. 14, 2012

A small SMALL ANTENNA

CUTLER VLF (3-30 KHz) ANTENNA

- Why A VLF Antenna?
- Types Of Antennas
- Trideco Design At Cutler, Me.
- Towers and Top Load
- Tuning Network
- Ground System
- Deicing
- Modulation and Reception

HISTORICAL VLF ANTENNAS



- Marconi transmitter at Poldhu, UK
- Height: 200 ft.
- Built 1900
- Destroyed by Storm 1901
- 24 KW
- 80 KHz

- Telefunken Transmitter at Sayville
- Height: 477 ft.
- Built 1912
- 200 KW
- 32 KHz

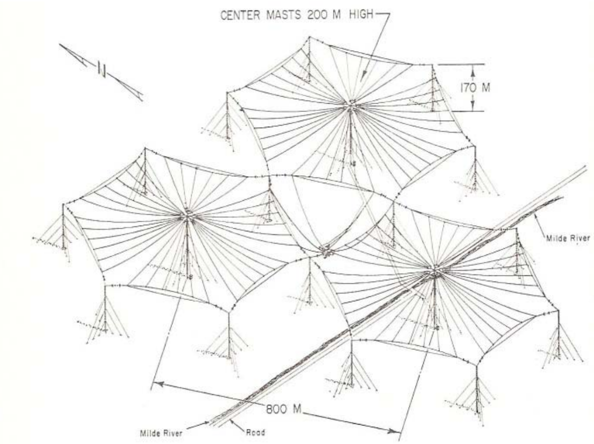


FIG. 2.8.16. Pictorial view of Goliath antenna.

- German WW II VLF Antenna (Goliath)
- Height: 673 ft.
- Removed by Soviets After the War
- 1800 KW
- 16 KHz

“ka” MEASURE OF ANTENNA ELECTRICAL SIZE

Wave Number = k = $2\pi/\lambda$
Wavelength = λ
Radianlength = $\lambda/2\pi = 1/k$
a = radius of sphere (Chu Sphere) that circumscribes antenna
ka = 1/2 largest antenna dimension in Radianlengths
Electrically small antenna = $ka<0.5$

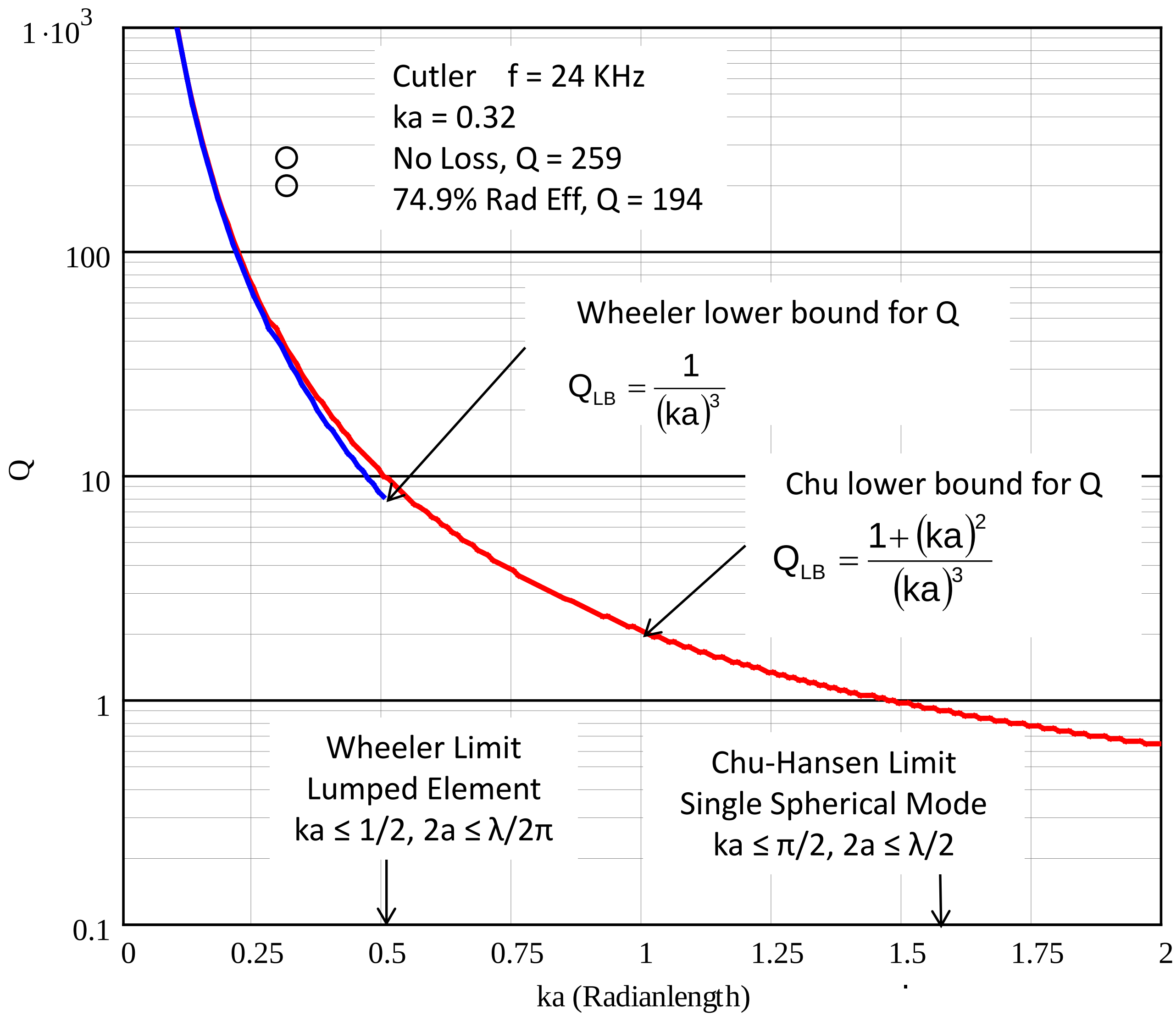
<u>FOR CUTLER ANTENNA</u>

Frequency = 15 KHz
λ = 20 Km
Effective Height = H = 140 m
Physical Radius = R_P = 625 m
a = SQRT($R_P^2 + H^2$) = 640 m
ka = $2\pi a/\lambda$ = 0.20

H/λ = 140/20,000 = .007

a/λ = 640/20000 = .032

Q LIMITS FOR SMALL ANTENNAS



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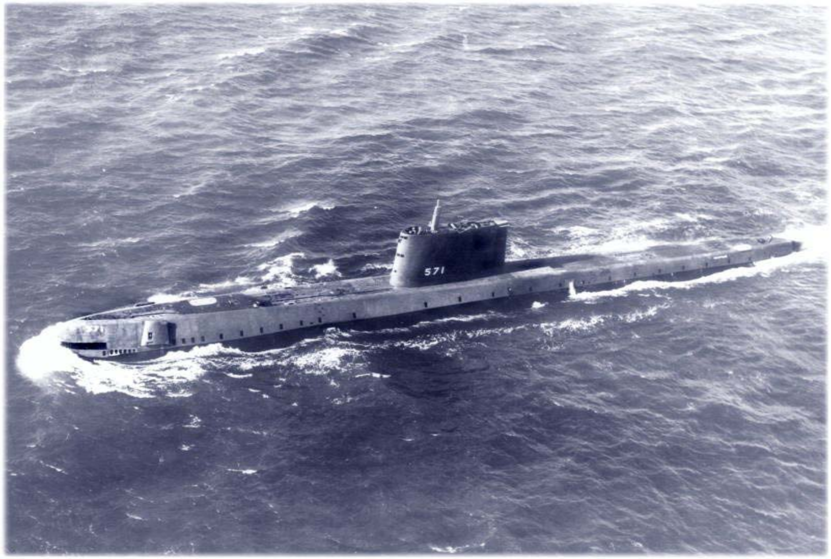
WHY A VLF SYSTEM?

- With the creation of ballistic missile submarines it became essential to maintain communications
- To avoid detection, nuclear submarines must remain submerged
- VLF provided penetration of seawater 30 to 100 feet because of the very long wavelength
- Very low loss propagation (2 dB/1000 Km)

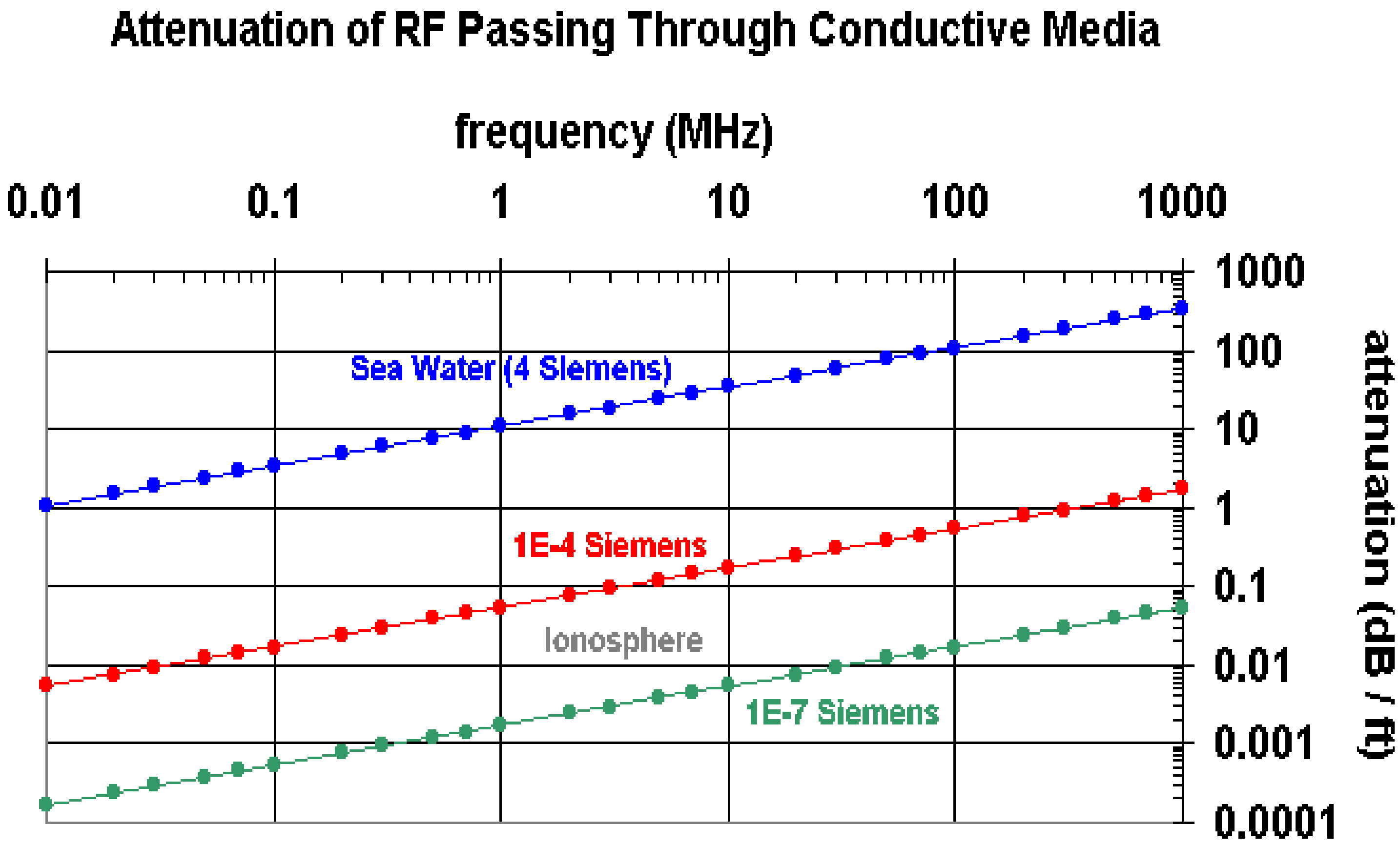
BALLISTIC MISSILE SUBMARINES



- USS NAUTILUS
- FIRST NUCLEAR-POWERED SUB
- COMMISSIONED 1954
- OPERATE SUBMERGED FOR MONTHS

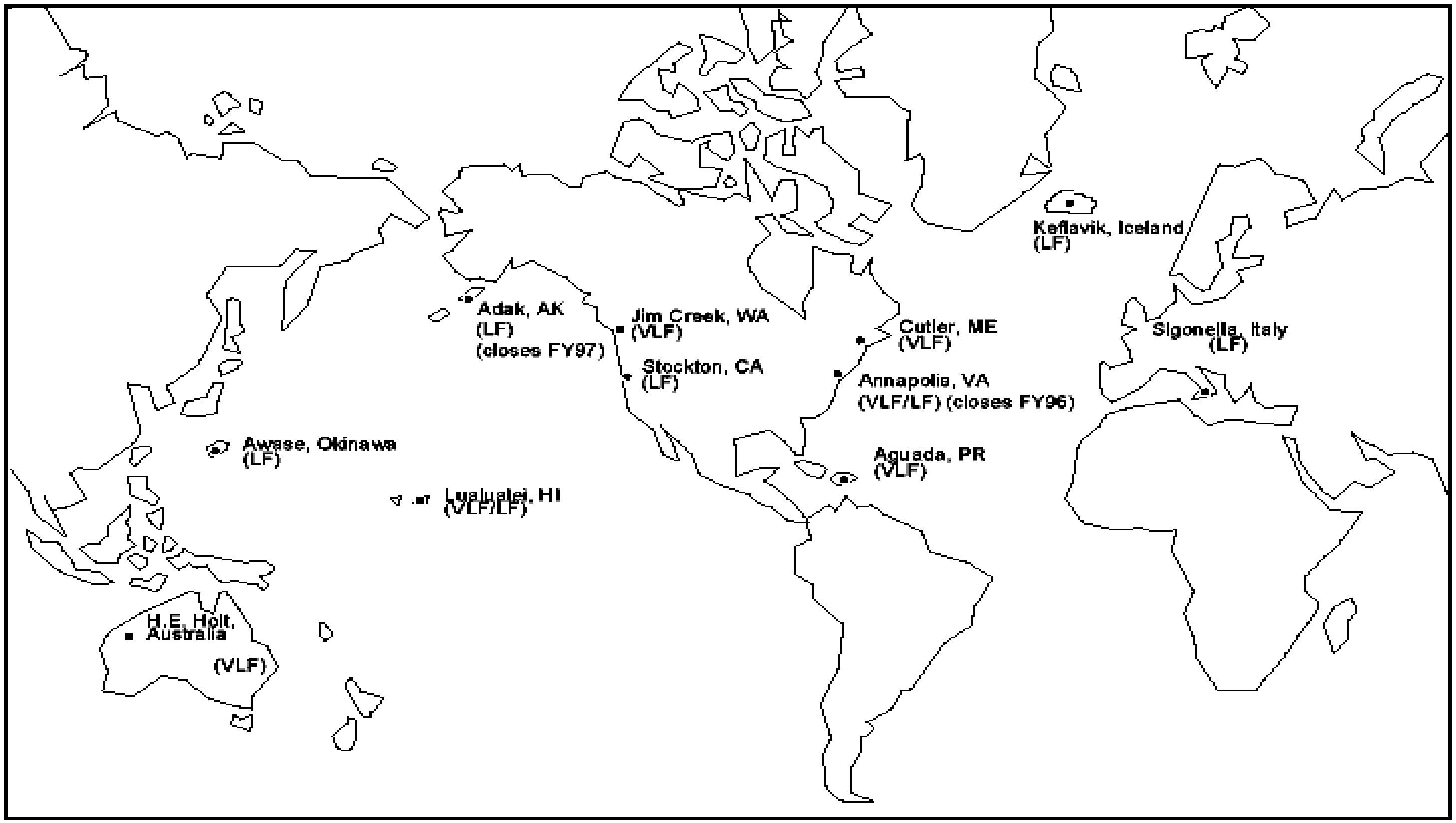
- USS GEORGE WASHINGTON
- FIRST BALLISTIC MISSILE SUB
- 16 POLARIS MISSILES
- COMMISSIONED DEC 1959

SKIN DEPTH



Attenuation of RF Passing Through Conductive Media
frequency (MHz)
0.01
0.1
1
10
100
1000
1000
100
10
1
0.1
0.01
0.001
0.0001
attenuation (dB / ft)
Sea Water (4 Siemens)
1E-4 Siemens
Ionosphere
1E-7 Siemens

US NAVY VLF COMMUNICATION SYSTEM (1990s)

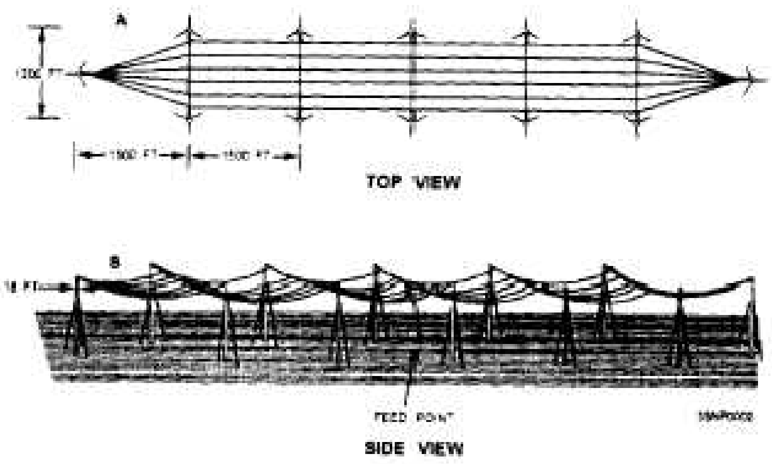


Very Low Frequency/Low Frequency Site Locations

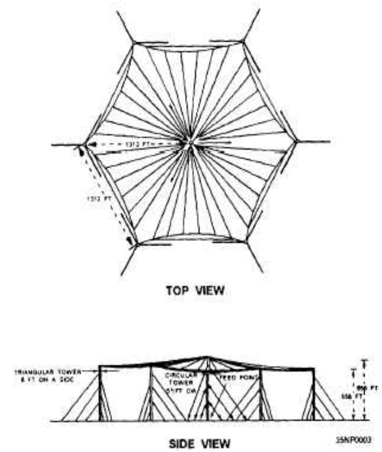
VLF ANTENNA SYSTEM REQUIREMENTS (1959)

- Tunable 14.3-30 KHz
- Radiated power: 1 MW
- Max voltage: 200KV; Max E-field: 0.65 KV/mm
- Efficiency: >50% ($500K penalty)
- Bandwidth: at least 30 Hz
- Operational conditions include 1 1/2-inch ice and 175-MPH winds
- Redundant for reliability and maintenance- two antennas

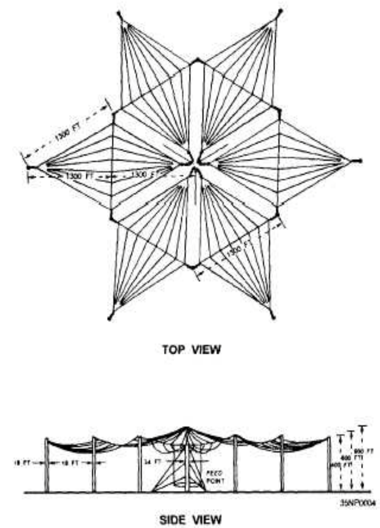
ANTENNA CONFIGURATIONS



TRIATIC TOP LOAD



UMBRELLA TOP LOAD



TRIDECO TOP LOAD

EXAMPLE OF TRIATIC

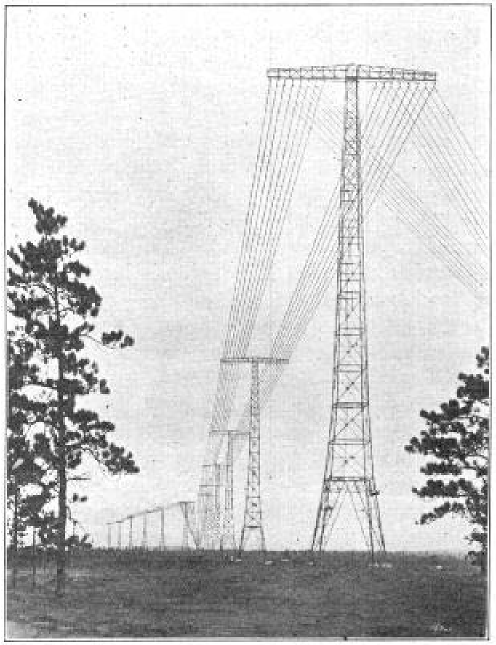
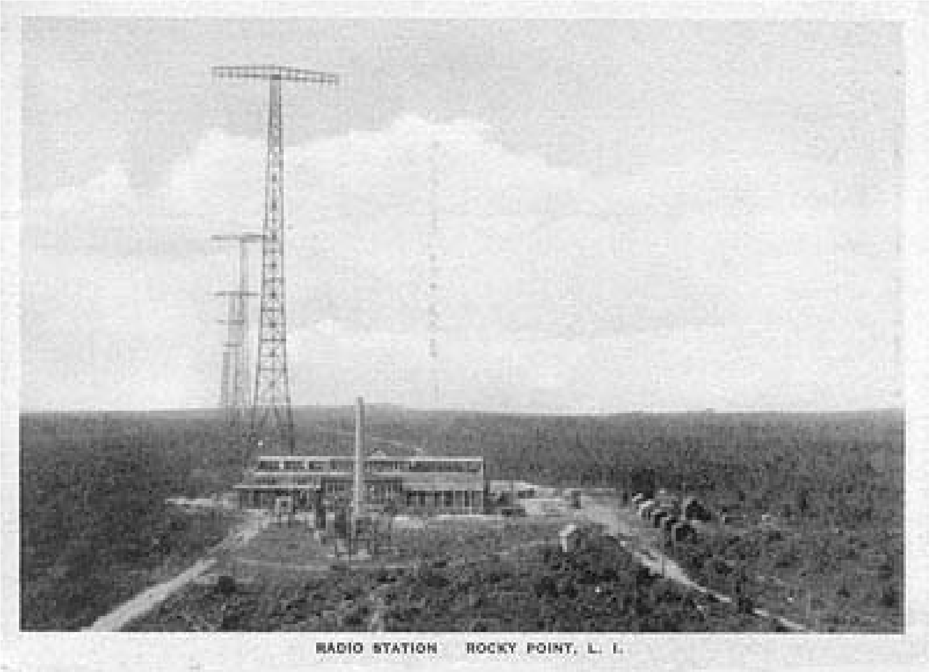


FIG. 172.—Two of the immense antennæ at Radio Central.



RCA's Radio Central at Rocky Point Used A Set Of Triatic Antennas

WHEELER ELECTRICAL DESIGN

Derived a few simple formulas which define the gross antenna dimensions

Assumptions

f = 15 KHz lambda = 20,000 m
p = power factor = .002
P = 1 Megawatt
A = effective area
h = effective height
Ah = effective volume
V = max. topload voltage = 200 KV
Ea = maximum E-field gradient on topload = .65 KV/mm
Aa = conductor area

1. Bandwidth defines effective volume

$$Ah = \frac{3p\lambda^3}{8\pi^2} = .608\ Km^3$$

2. Max. Voltage defines Topload effective area

$$AV = \left(\frac{3\lambda^2}{2\pi}\right)\sqrt{10P} = 604\ m^2 KV$$

for $V = 200\ KV$ $A = 3.02\ Km^2$ ($2.75\ Km^2$)

3. Effective height = .608/3.02 = 200 *m.* (140m)

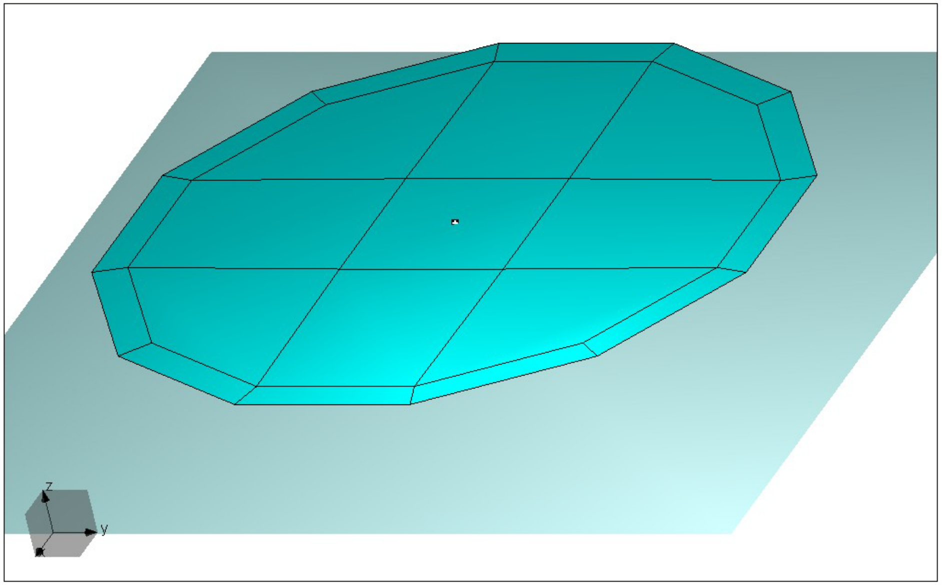
4. Max. voltage defines topload area

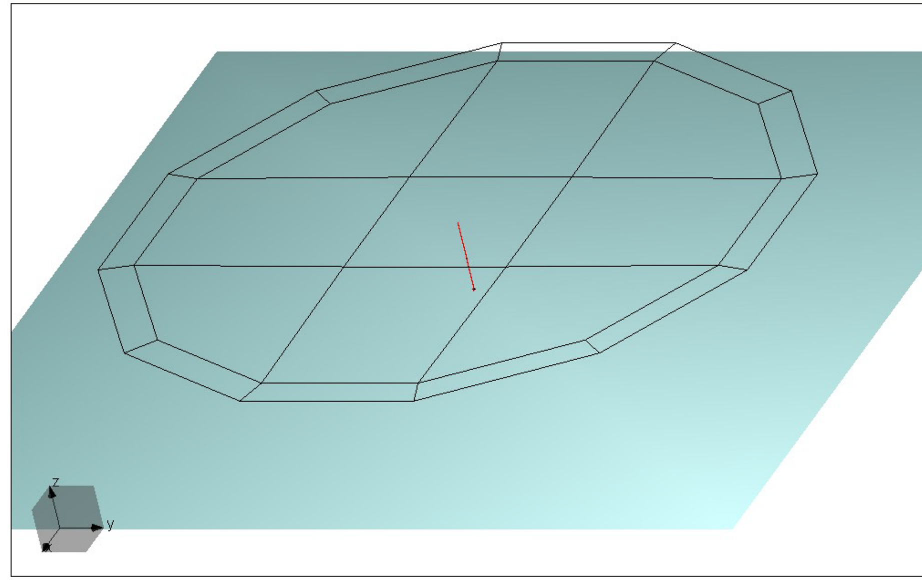
$$A_a = \pi\left(\frac{\lambda}{2\pi}\right)^2\left(\frac{3}{hE_a}\right)\sqrt{40P} = 4650\ m^2$$

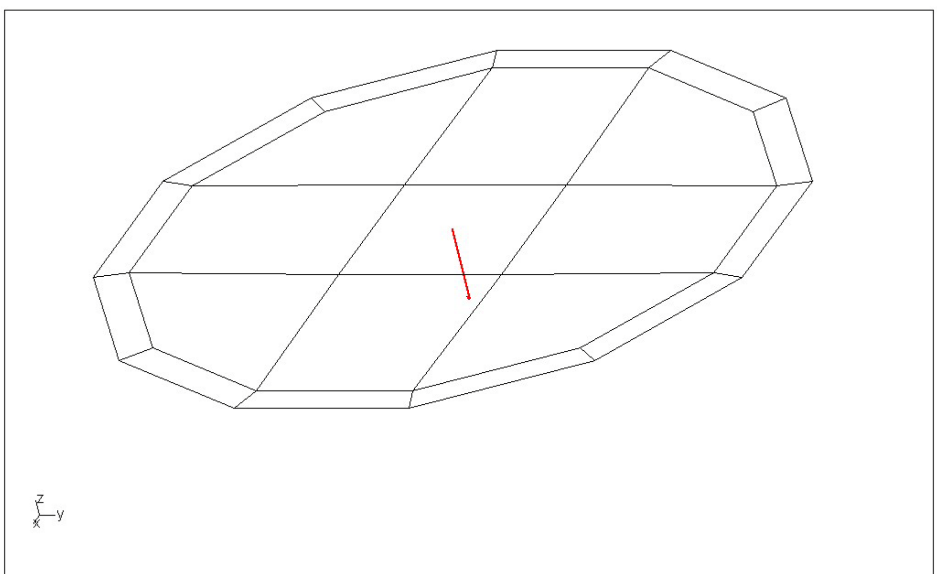
For 1" cable, length = 58 *Km* *(47 Km-98Km)*

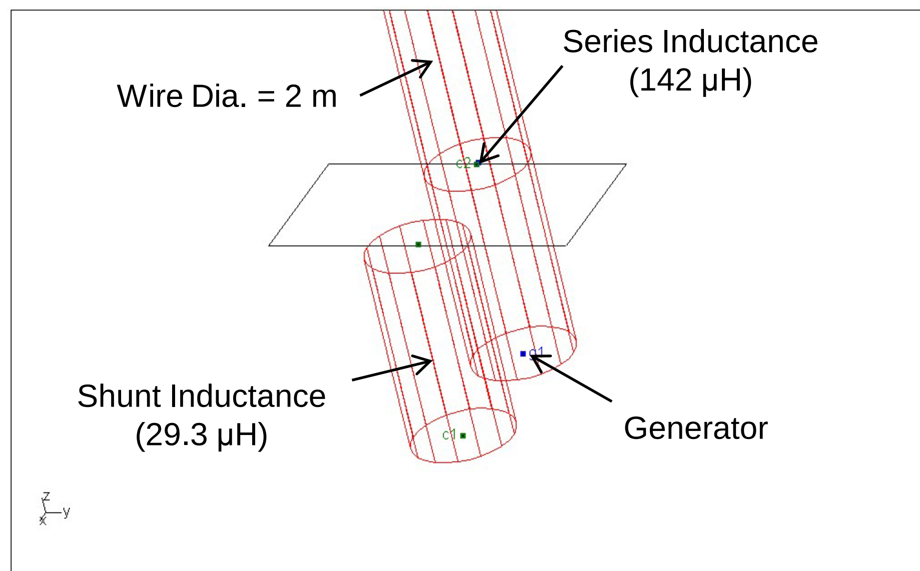
Ref 1

WIPL-D Model (Radius = 625 m, Height = 140 m)









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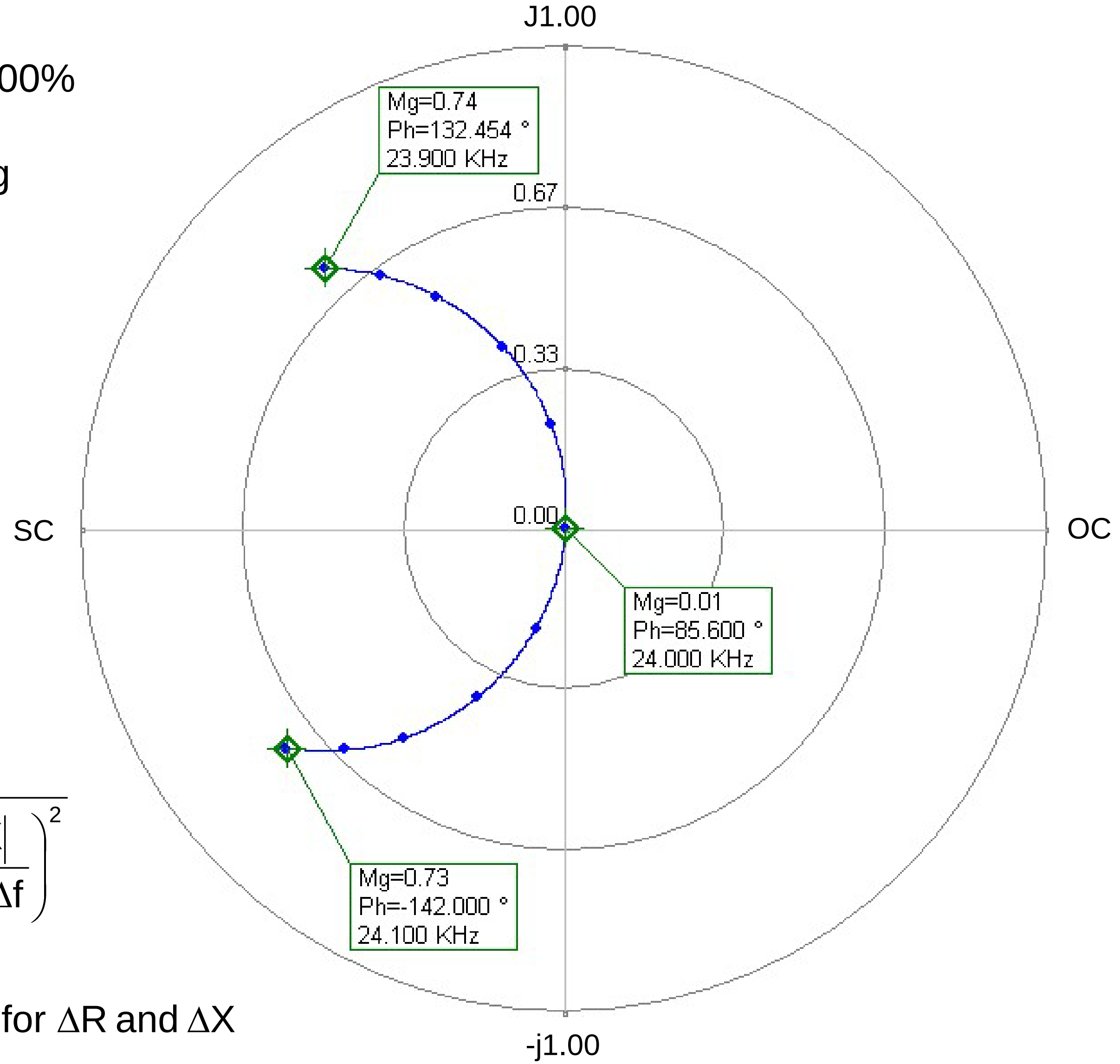
Computed Reflection (Impedance)

Radiation Efficiency = 100%
f = 24 KHz Q = 259
Note: Q computed using Yaghjian-Best Formula:
AP Trans., Apr 2005



$$Q = \frac{f/\Delta f}{2R}\sqrt{\Delta R^2 + \left(\Delta X + \frac{|X|}{f/\Delta f}\right)^2}$$

$f =$ Resonant frequency

$\Delta f =$ Frequency increment for ΔR and ΔX

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TRIDECO ANTENNA

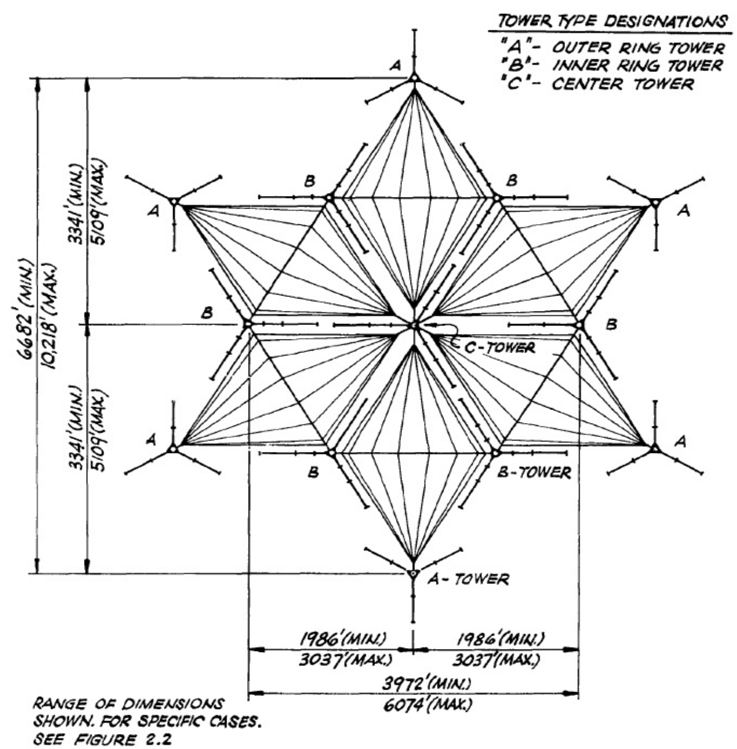


FIG. 2-1 LAYOUT OF ANTENNA ARRAY

- Six topload panels
- 13 towers
- Approx. 1000 Acres
- Minimizes Corona

TWO ANTENNAS OCCUPY 2000 ACRES ON A PENNINSULA

- Dual transmitter feeds helix house through 100 ohm coax
- Helix house contains tuner
- Trideco top load uses 6 panels for each monopole

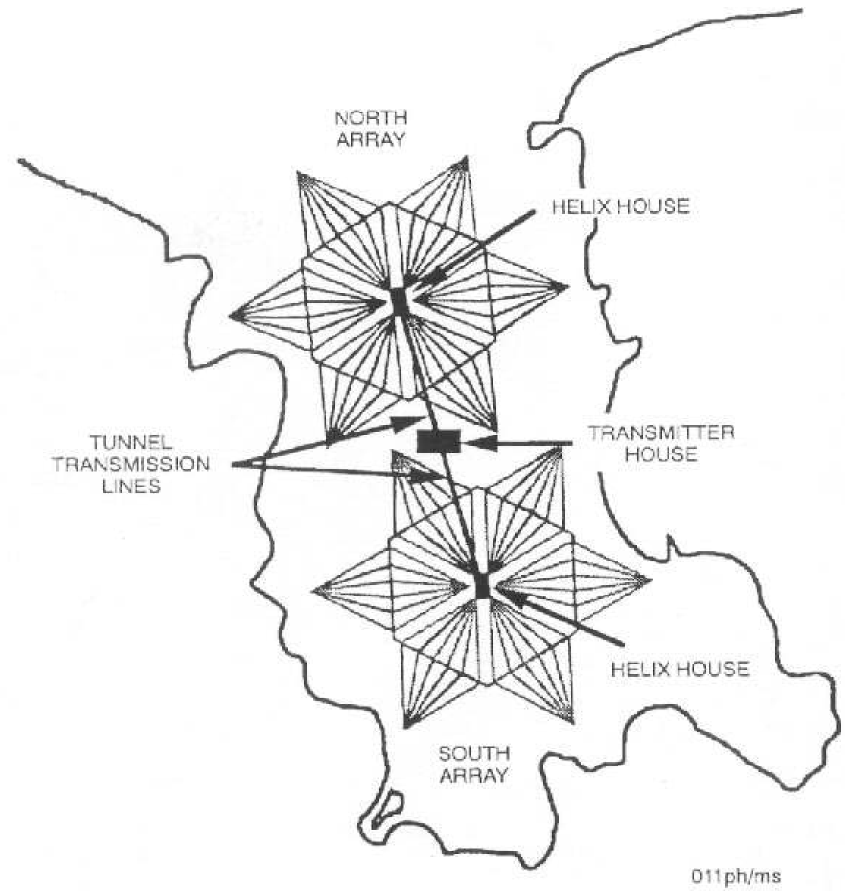


Figure 1. VLF Cutler.

Ref 6

OVERVIEW OF ANTENNA CONFIGURATION

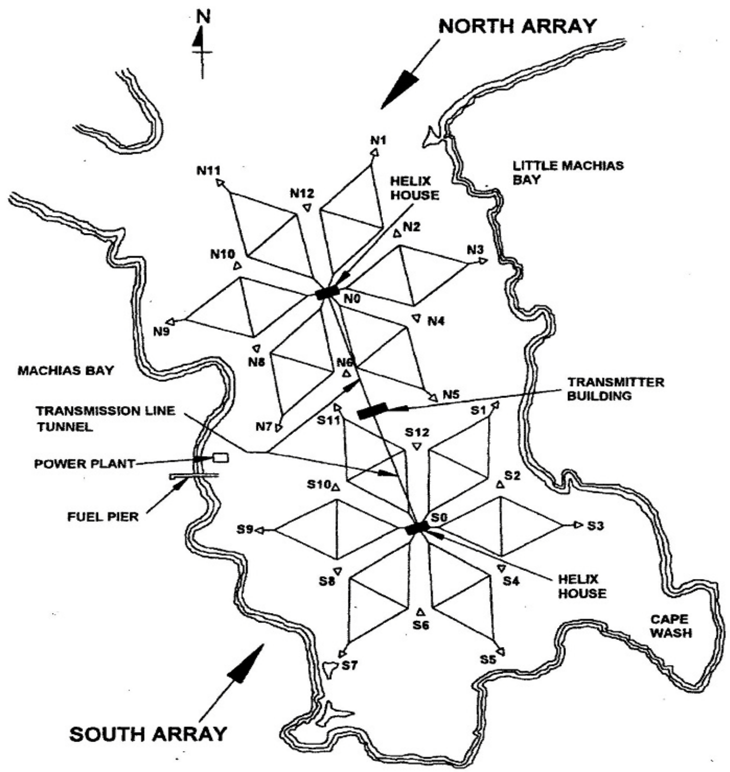


Figure 1. General layout, Cutler Peninsula.

Location, location

Ref 7

Google Maps

26 TOWERS- 850 to 1000 FT HIGH

Ref 8

SATELLITE IMAGES

Power Plant 18 MW

Main Tower And Helix House

Bing Maps

EACH ANTENNA CONSISTS OF 13 TOWERS

Exciting Engineering Work

Ref 8

TOPLOAD FEED SYSTEM

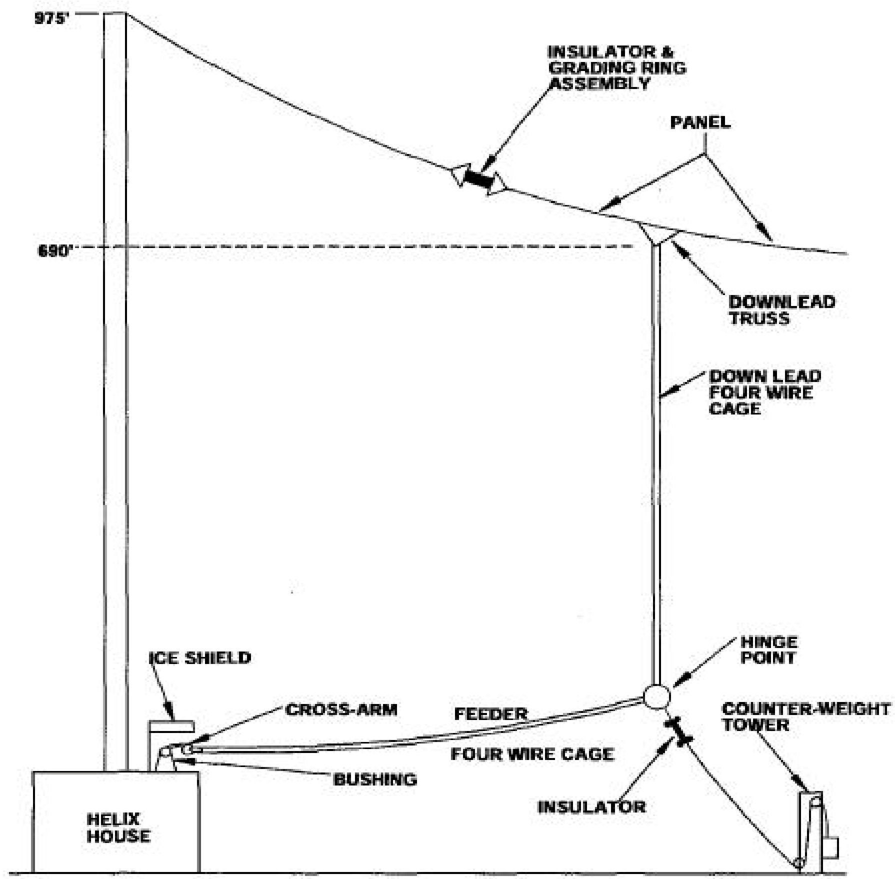


Figure 3. VLF Cutler feed-cage and counterweight configuration.

Ref 7

ANTENNA PERFORMANCE (24 KHz)

Table ES-1. South array antenna measurement results.

	Six-Panel Mode	Four-Panel Mode
Antenna effective height (m)	140.1 ± 2.8	130.4 ± 2.6
Antenna self resonance (kHz)	40.2	40.0
Antenna static capacitance (nF)	123.9	90.1
Gross resistance (ohms) measured at full power	0.2649	0.2675
Radiation resistance (ohms)	0.1984 ± 0.0077	0.1719 ± 0.0068
Antenna base reactance (ohms)	-j 35.4	-j 50.2
Antenna bandwidth (Hz) measured at low power	137.5	100
Antenna radiation efficiency (%)	74.9 %	64.3 %
Base voltage (kV)	65.5	99.7
Base current (A)	1850	1987
Radiated power (kW)	679	679

Ref 7

CUTLER PERFORMANCE VS FREQUENCY

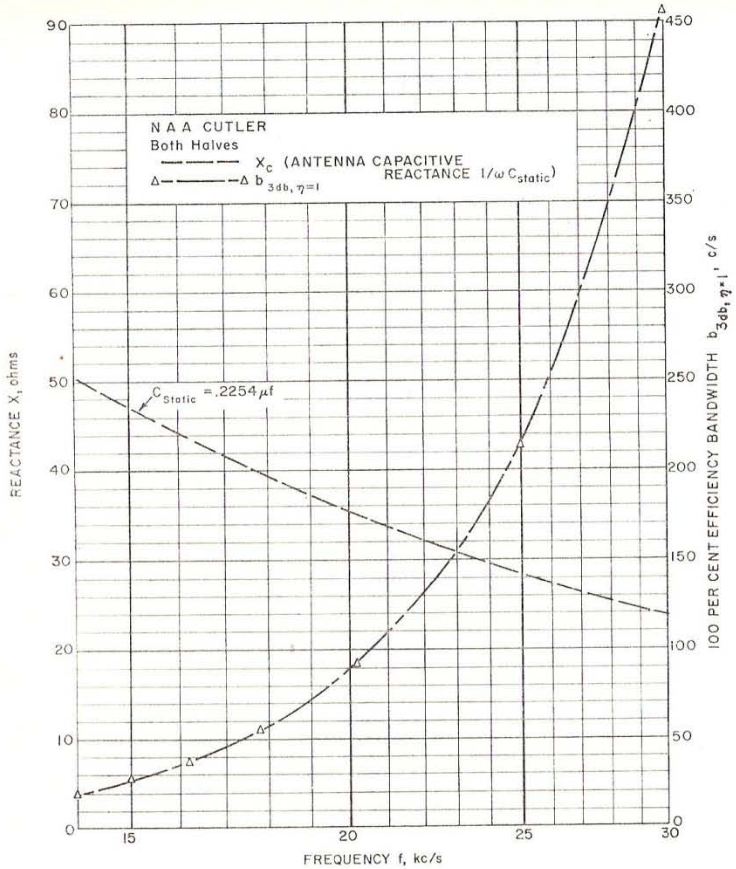


FIG. 2.8.14. Reactance and bandwidth vs. frequency, Cutler.

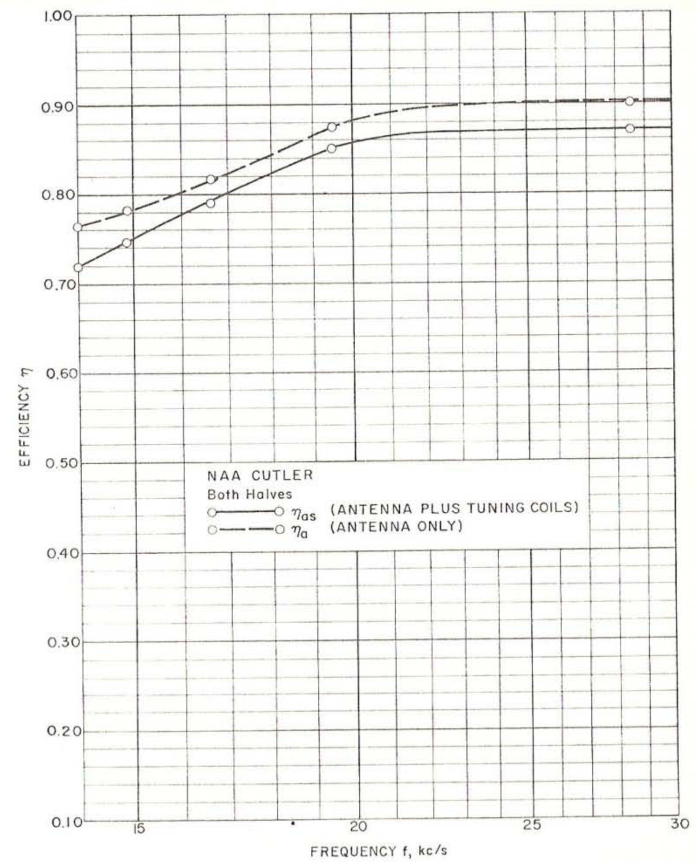


FIG. 2.8.15. Radiation efficiencies vs. frequency, Cutler.

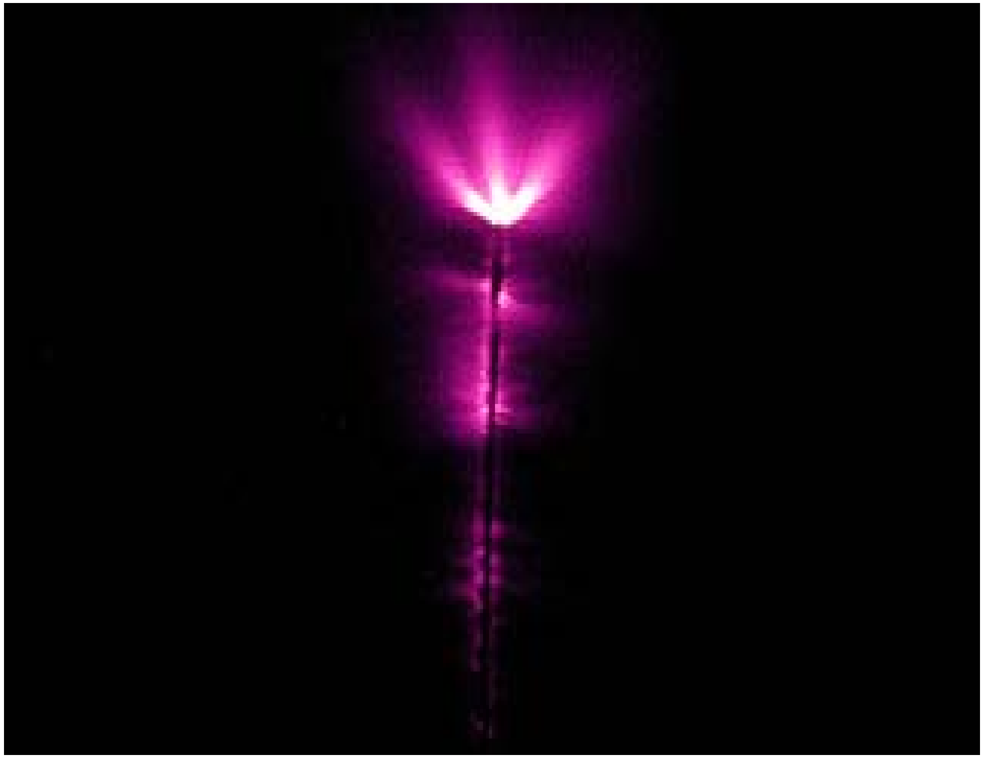
Ref 2

DESIGN ISSUES

- Corona/Lightning
- Mechanical Design
- Ice Load
- Antenna Impedance and Efficiency
- Ground system
- Transmitter

DESIGN ISSUE: CORONA

- Actual Antenna Voltages 250 KV Plus Lightning
- Electrical Breakdown of the Air
- Depends on Field Strength, Geometry and Air Pressure
- Designed in 1959 for Cutler Antenna using model and 50 KV
- Special hollow 1.5in cable used in critical areas



TOPLOAD PANEL CONSTRUCTION

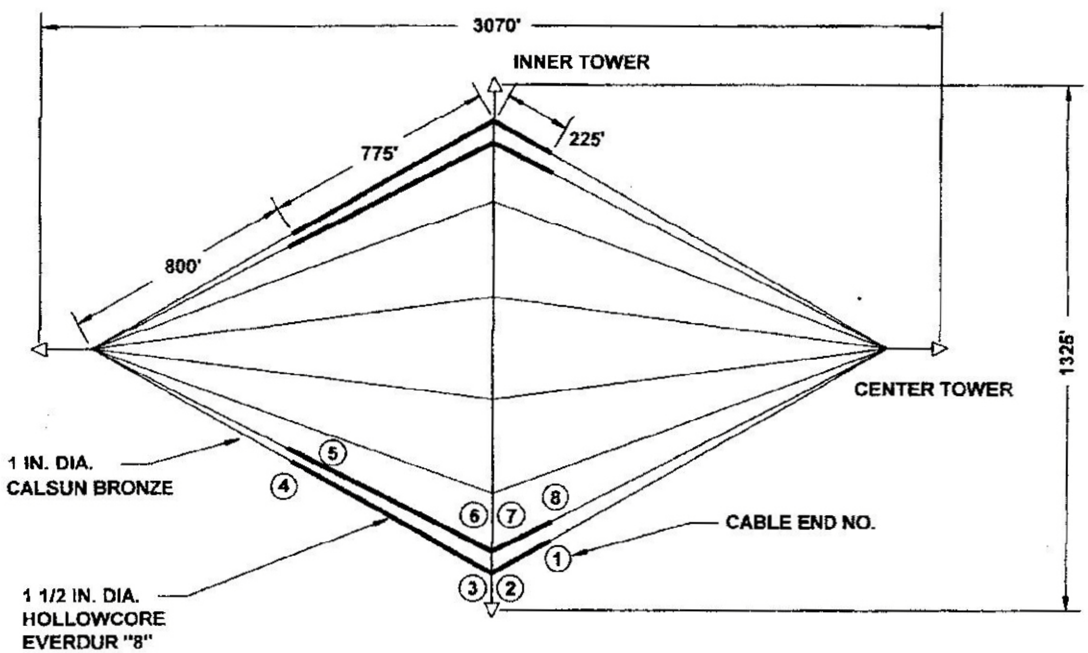


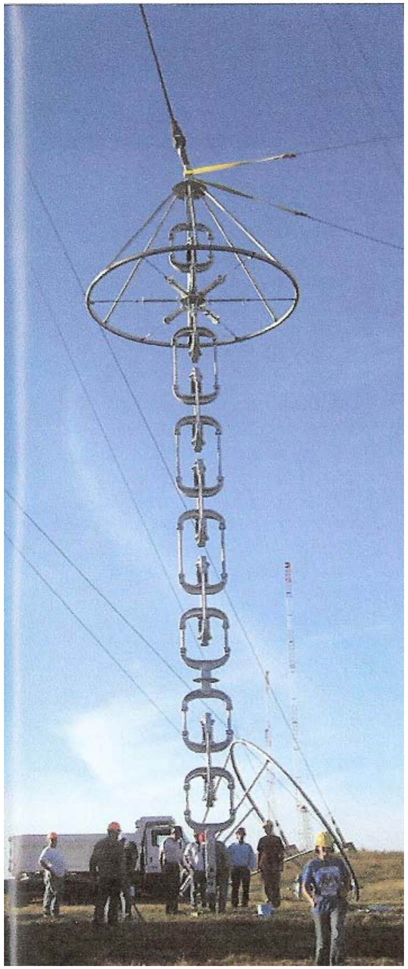
Figure 2. Plan view of a typical panel in VLF antenna array.

Ref 6

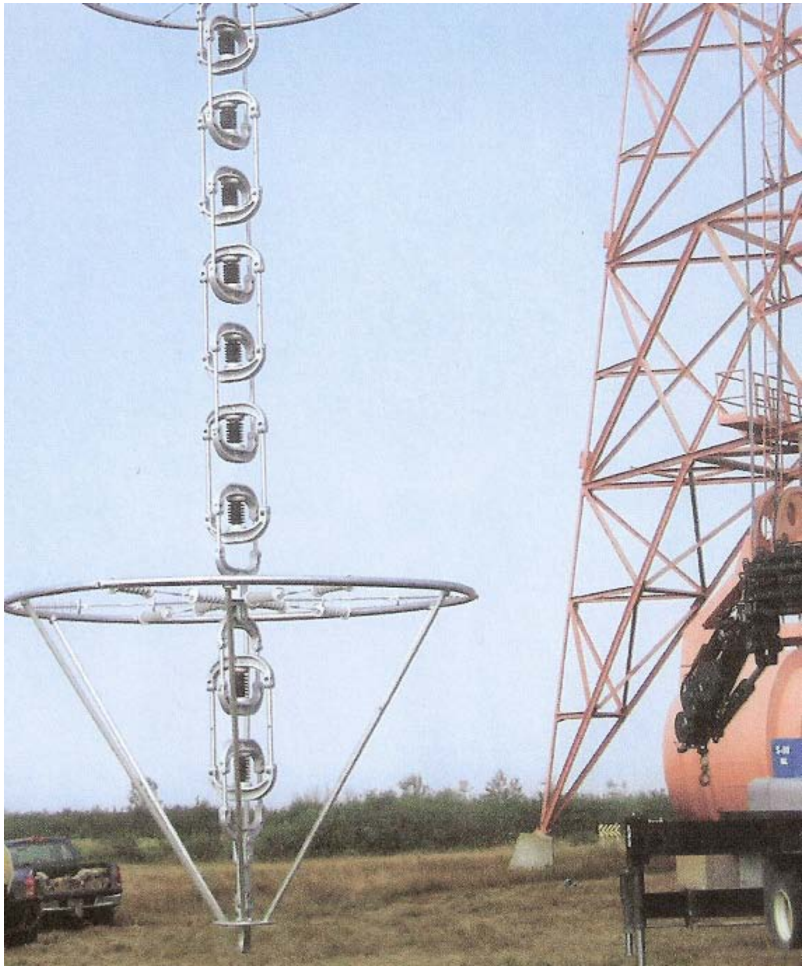
- 24,000 feet of cable – 120,000 pounds
- Wire spacing optimized for equal charge
- Wire diameter selected to meet specified electric field (0.65-0.8 KV/mm)

FEED LINES AND INSULATORS

EACH INSULATOR IS 57 FT LONG TO WITHSTAND 250 KV



13,000 lbs.

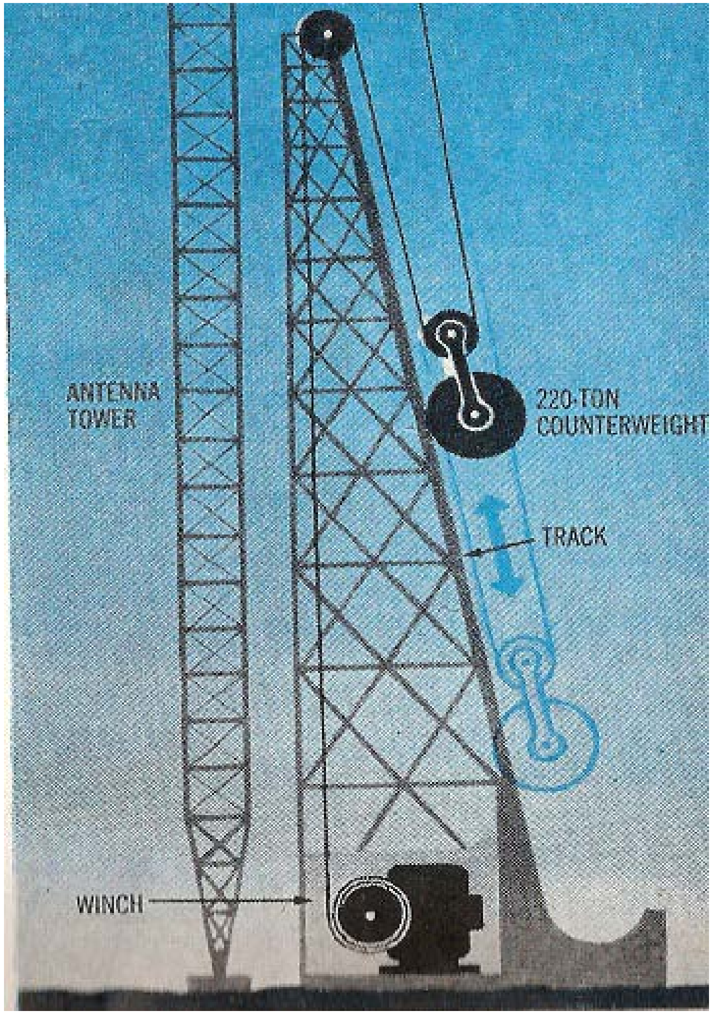


Ref 4

TOPLOAD COUNTERWEIGHT SYSTEM

TOPLOAD COUNTERWEIGHT SYSTEM

- Counterweights weight 220 Tons
- Panels can move with wind and ice load
- Panels can be lowered for maintenance
- Pulley system reduces weight movement



Ref 5

TOPLOAD COUNTERWEIGHT SYSTEM

Concrete filled wheel

Ref R. Mohn

TOPLOAD DEICING

DEICING POWER

- Deice one antenna at a time
- Topload designed to be lossy at 60 Hz
- 1.6 W/Sq. In =7.5 Megawatts to Deice
- Diesel generators provide 18 Mw

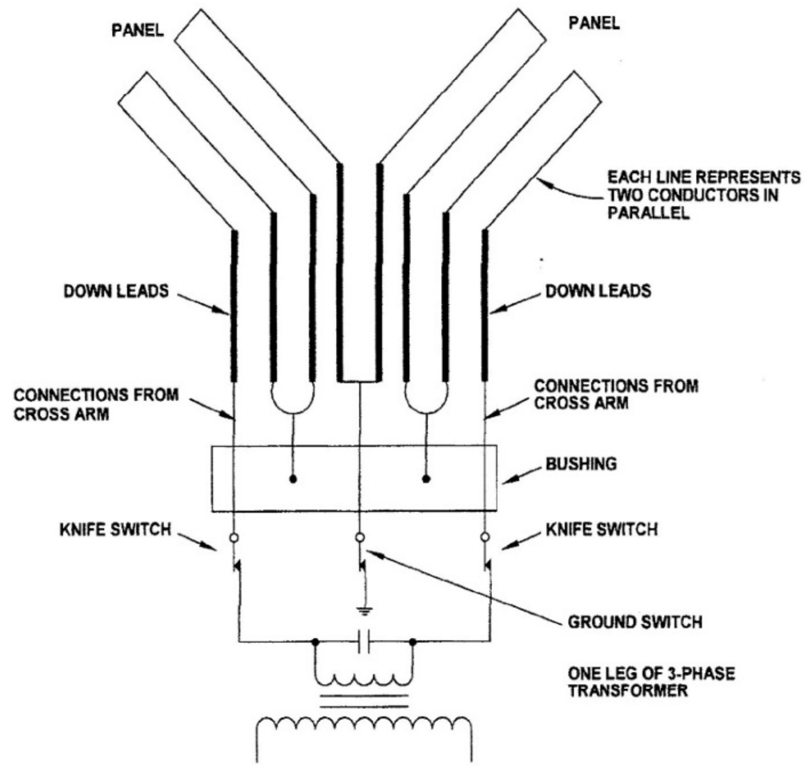


Figure 7. Simplified schematic diagram of one division in deicing mode.

Ref 7

TUNING NETWORK-HELIX HOUSE

TUNING NETWORK

- Handle 200 KV And 2000 Amps
- Very Low Loss <<0.1 Ohm
- Tune Antenna Over 14-28 KHz
- Tune Antenna with Modulation
- Antenna Impedance is Capacitive

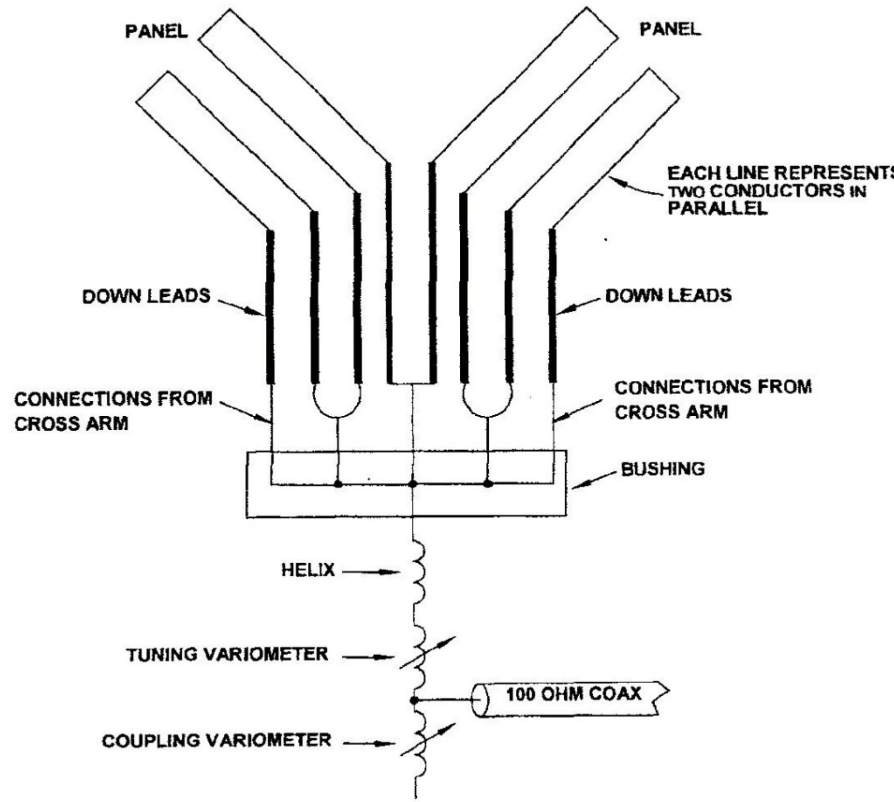
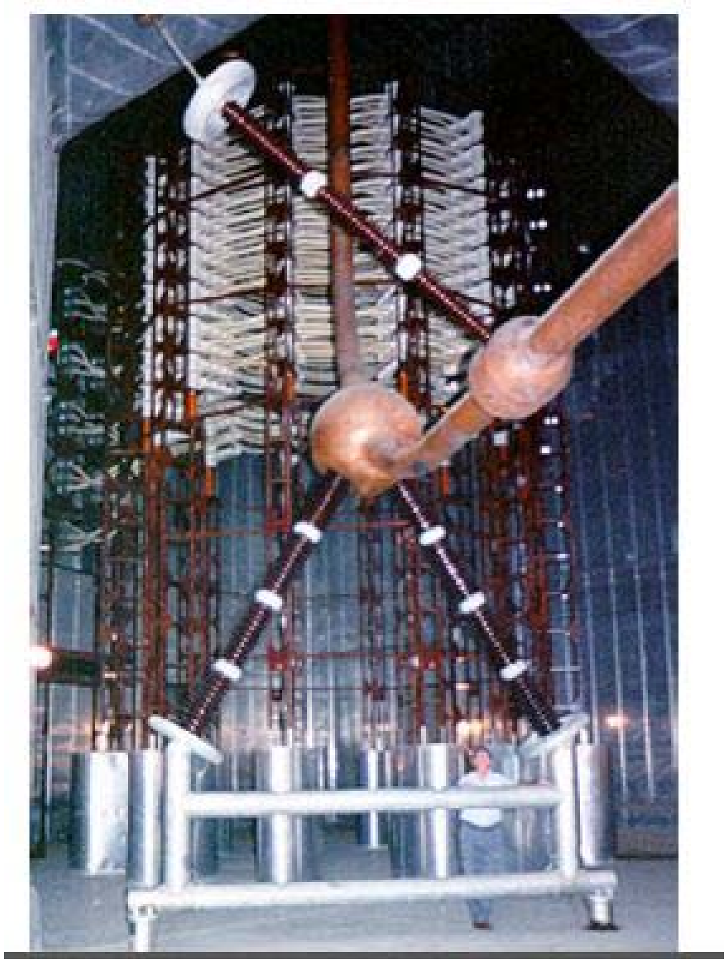


Figure 8. Simplified schematic diagram of one division in transmit mode.

Ref 7

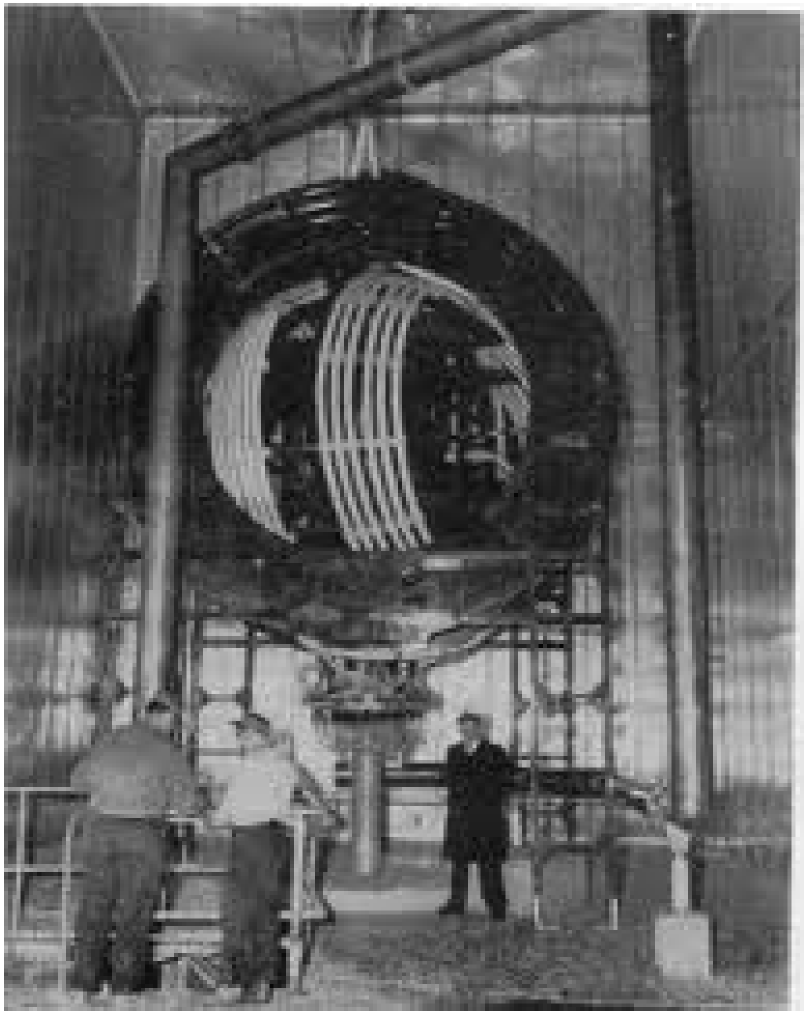
TUNING NETWORK- HELIX



Ref 8

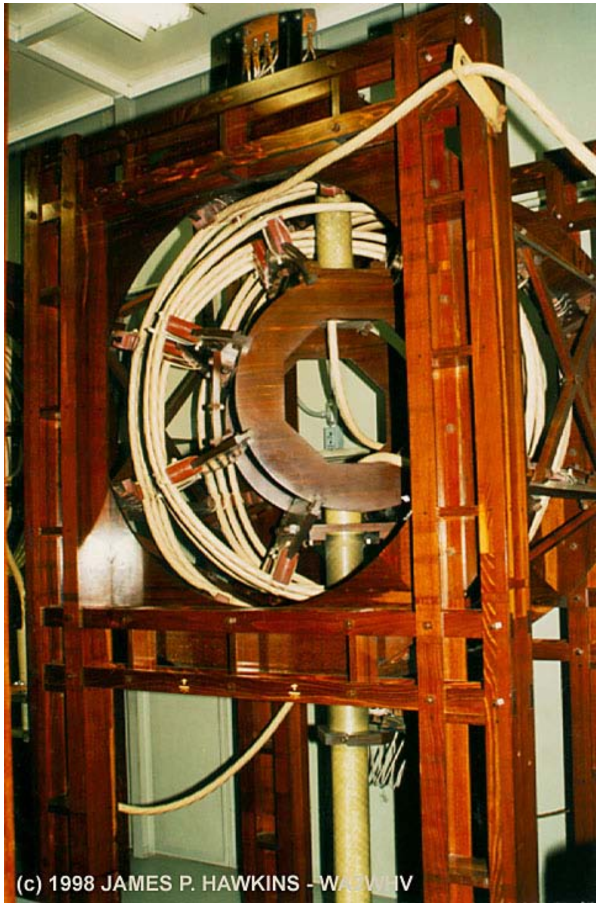
TUNING NETWORK- HELIX

TUNING NETWORK-VARIOMETER

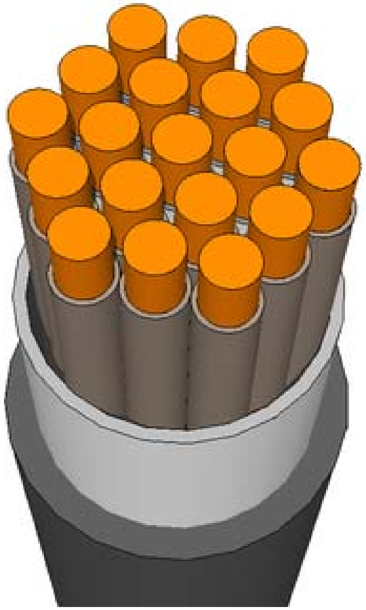


Ref 5 NAA Wires are 4 inches diameter NSS JP Hawkins

TUNING HELIX -LITZ WIRE



JP Hawkins



TUNING HELIX- LITZ WIRE

- Critical to reducing loss in high power tuning inductors
- Skin effect forces most AC current to the surface of a solid conductor, increasing resistance
- Litz wire equalizes current throughout a large conductor
- Thousands of small wires are insulated, braided and packed in large conductor
- Cutler design is a Litz conductor 4 inches in diameter, with 3 parallel conductors

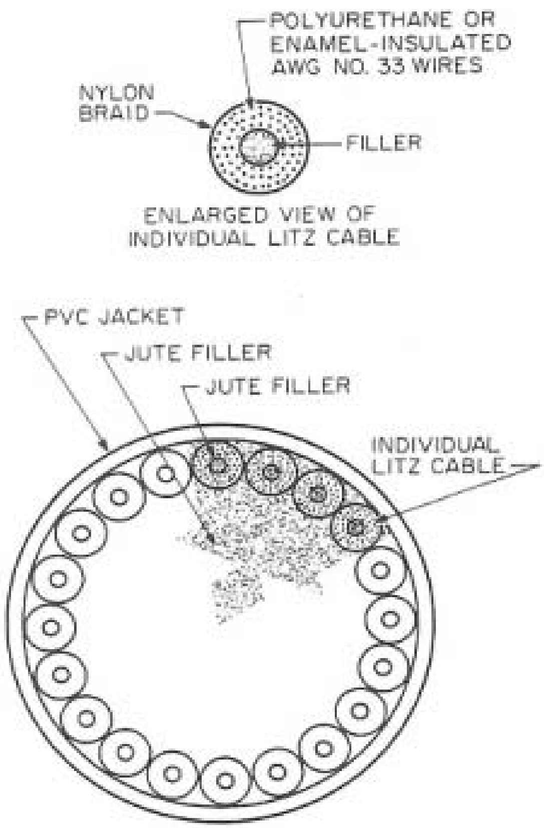
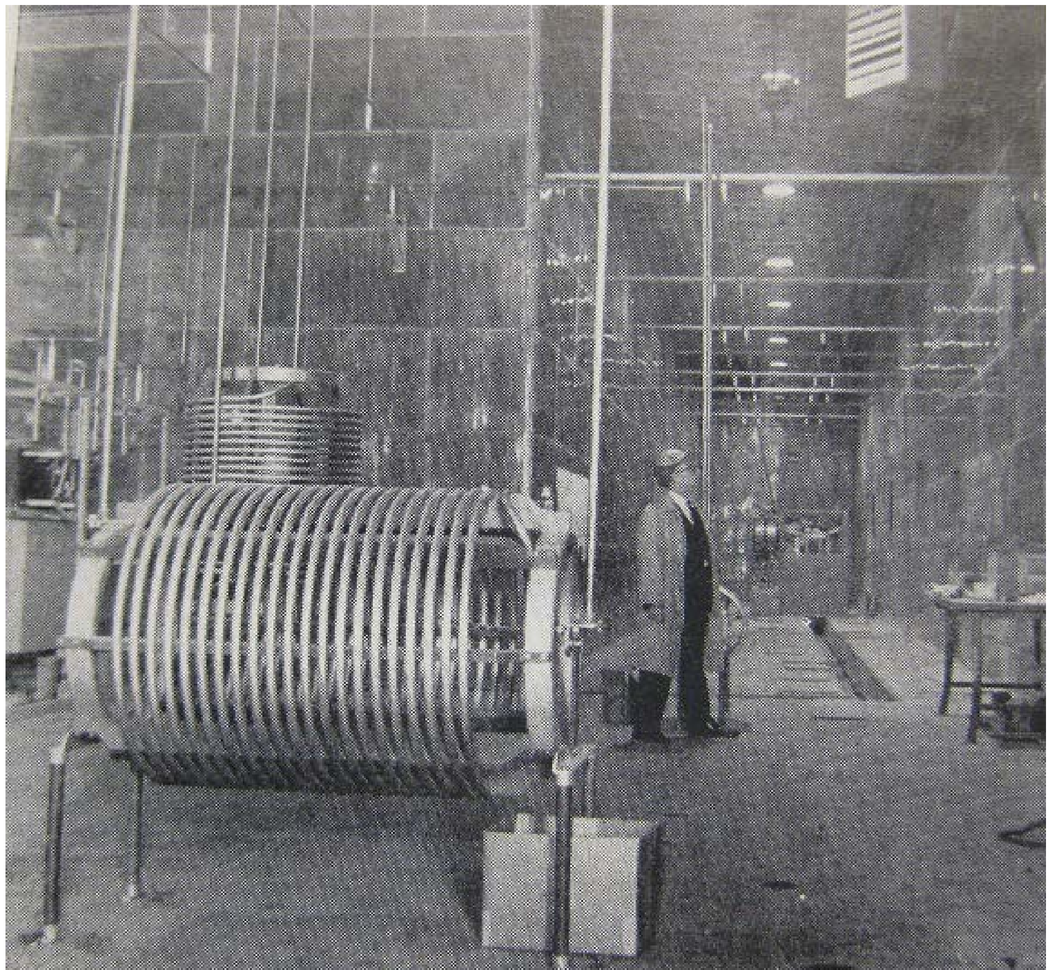


FIG. 24-11 Cross section of a large Litz conductor used in low-frequency inductor.

Ref 9

TUNING INDUCTOR IN HELIX HOUSE



Ref 5

TUNING NETWORK- TRANSMITTER OUTPUT TRANSFORMER

Ref 5

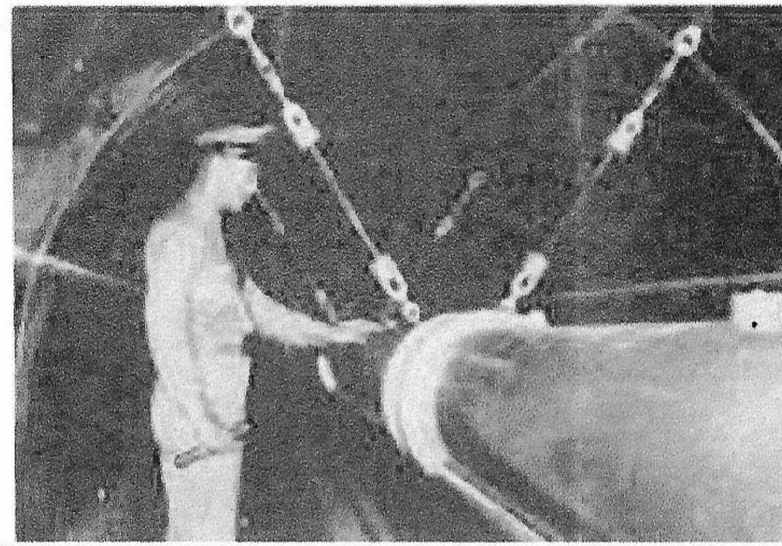
JP Hawkins

NAA

NSS

COAXIAL FEED LINE- TRANSMITTER TO HELIX HOUSE

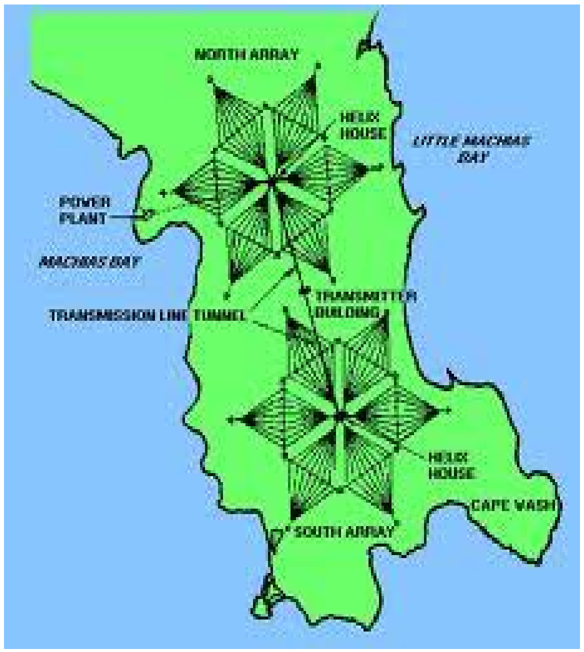
- 100 Ohm Feed Line From Transmitter To Helix House
- 1MW Power Capacity
- 100 KV
- 2000 Amps



"Ever see a man standing inside a coax matching section? Chief Electronic Technician Swan, who is in charge of all maintenance at NAA, stands inside the copper-lined concrete tunnel mentioned in the text."

Ref 5

DESIGN ISSUE: GROUND SYSTEM LOSS



2000 Miles of #6 Copper Wire Cover the Peninsula and Run Into the Sea

Ref 5

CUTLER GROUND SYSTEM PERFORMANCE

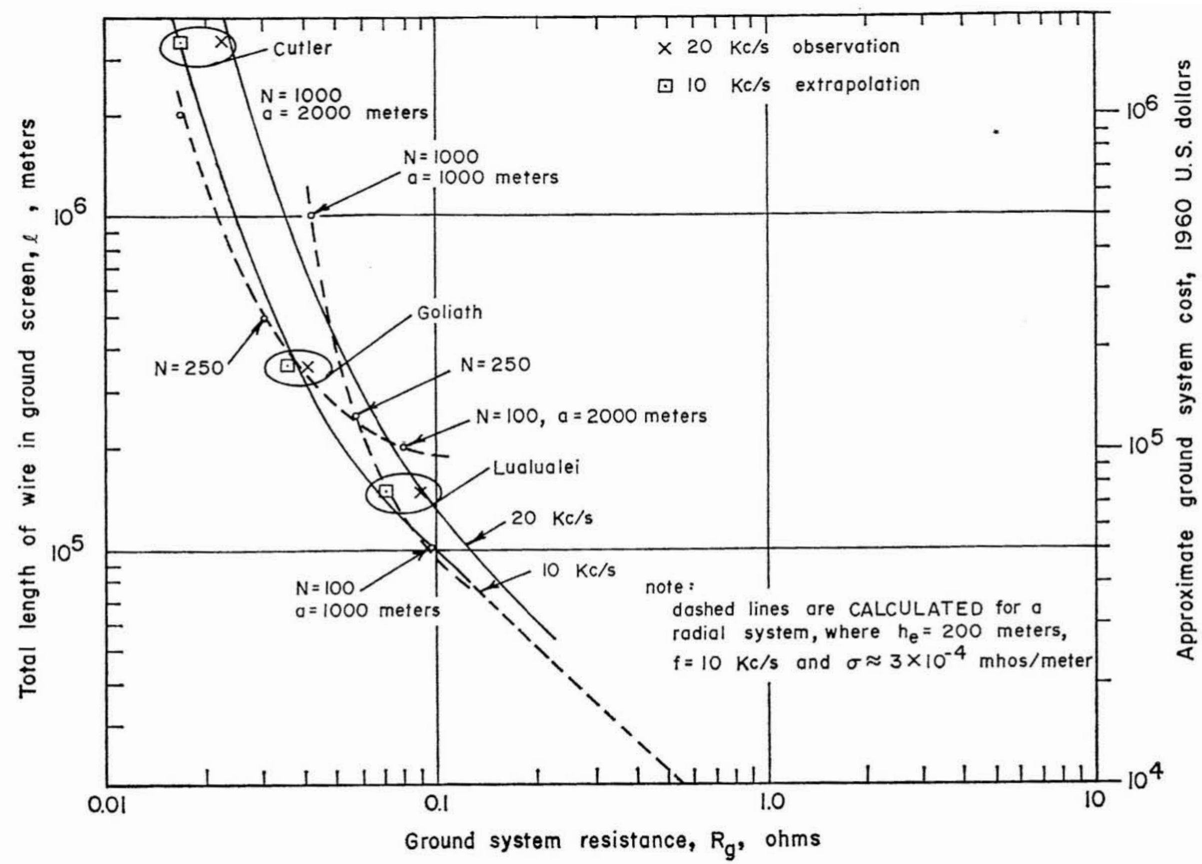
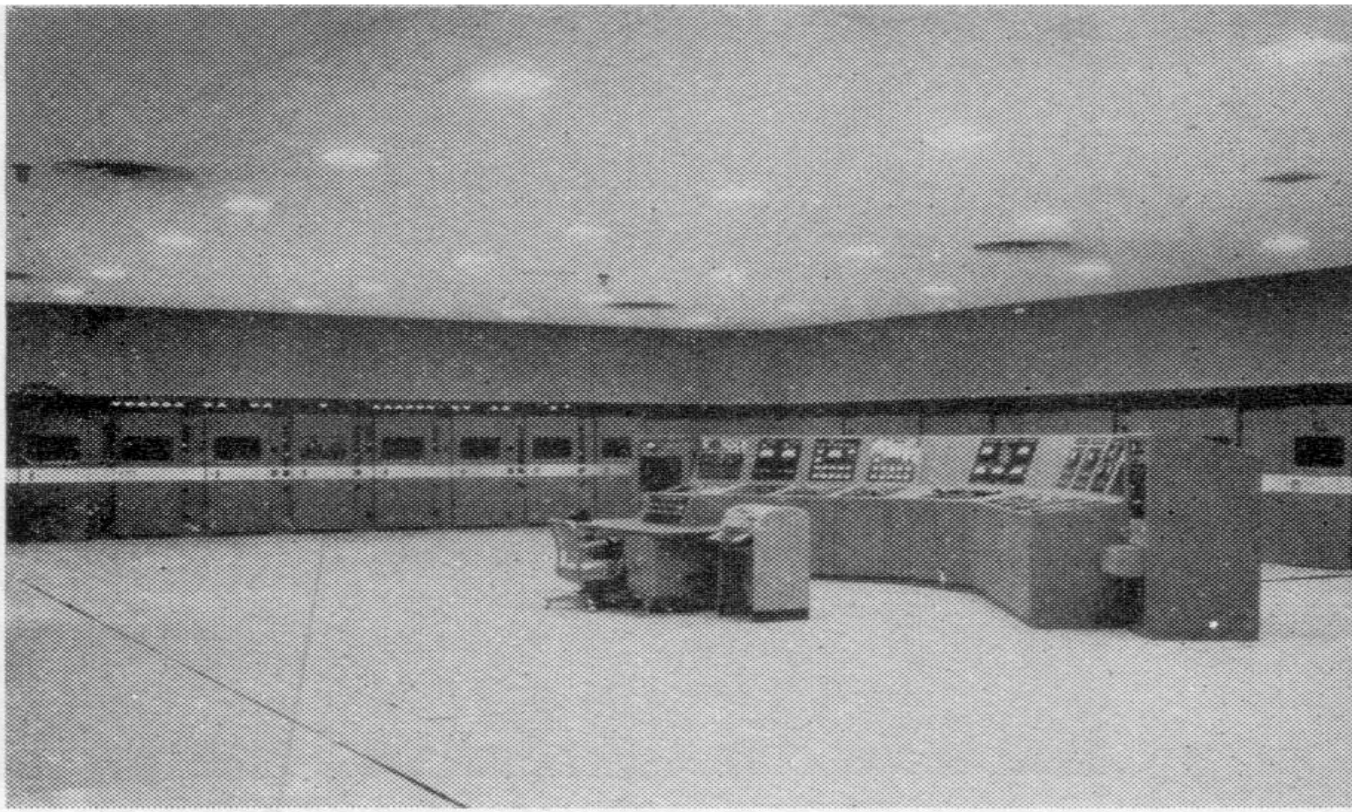


FIG. 7.4.2. Observed and calculated ground system wire length and approximate ground system costs as a function of ground system resistance.

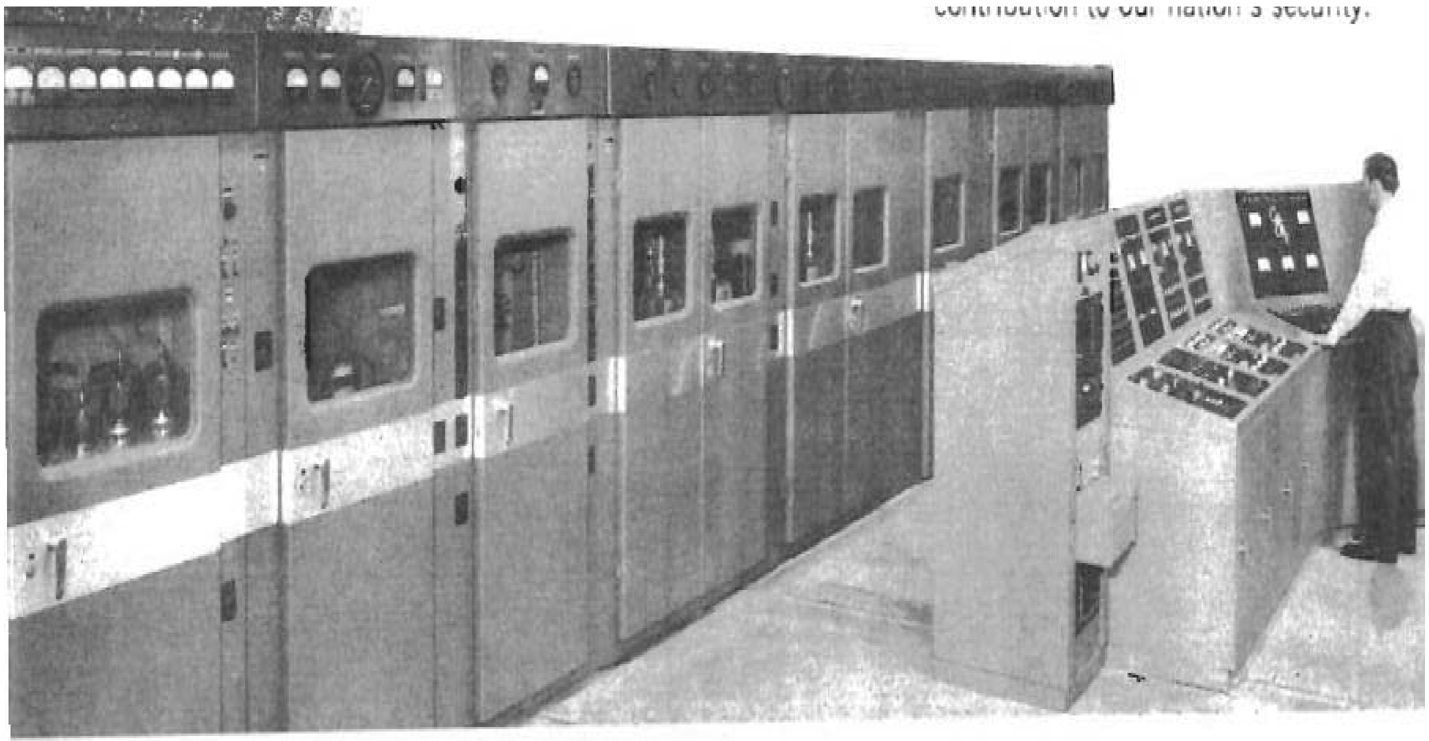
Ref 2

DUAL TRANSMITTERS: 1MW EACH



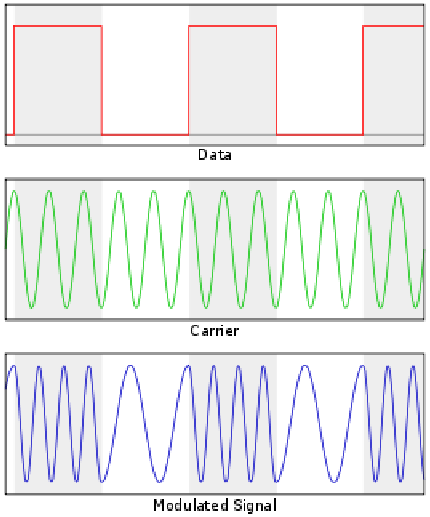
This is the control console for a two-megawatt transmitter. Driver stages and final amplifiers along the rear walls, with the ''guts'' of the units well-protected against accidental access.

TRANSMITTERS

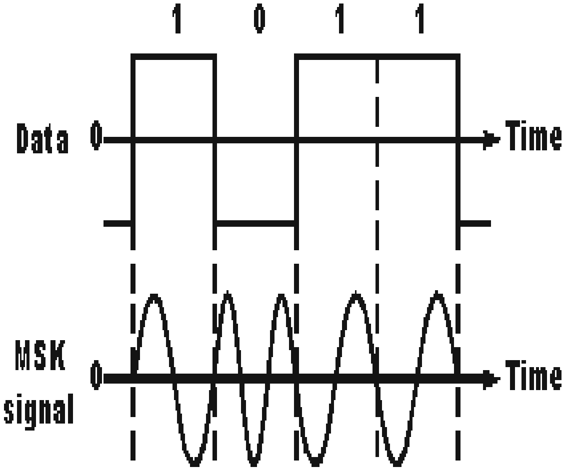


DATA/MODULATION

FREQ SHIFT KEYING

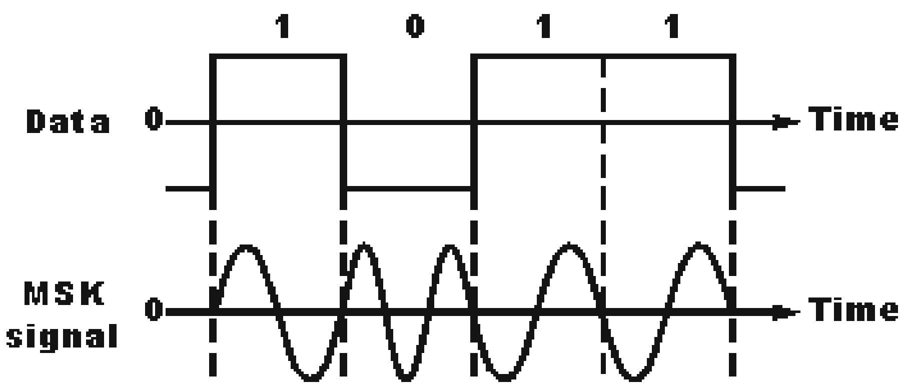


MINIMUM SHIFT KEYING



MODULATION

- Narrowband MSK (50-200 bps)



- Continuous Modulation
- Encrypted
- Antenna reactor tunes with modulation

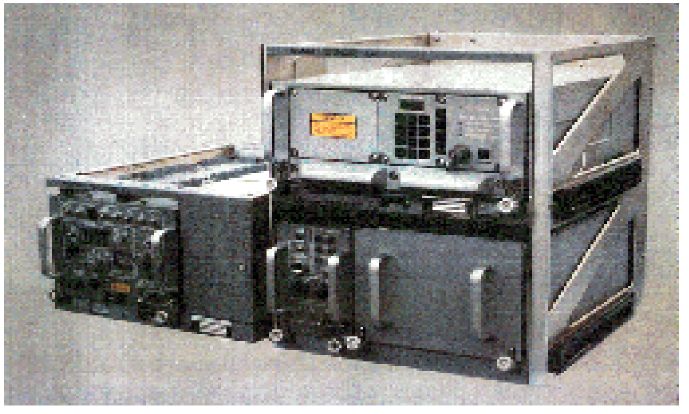
SUBMARINE RADIO RECEIVERS

USS Robert E Lee 1966

USS Nautilus 1970s

MODERN VLF RECEIVER

ENHANCED VERDIN



TECHNICAL DESCRIPTION

- **Requirement:** CNO ltr 204D Ser/941D/8U536539 of 18 Oct 89
- **Basic Description of System:**
  - VERDIN/EVS Provides Shore-to-Sub Communications for Subs at Speed and Moderate Depth.
  - The Equipment is Installed in all Submarines and TACAMO Aircraft and the Program is in Post-Production/Operational Phase, Supported by NRaD.
  - Shore System Components Include ISABPS and VERDINs at all FVLF Shore Sites, Off-the-Air Monitor Systems, Trainers, and TACAMO Communication Centers.
  - VERDIN/EVS Systems are Compatible with NATO, MEECN, and Sub BCS GENSER/SI Modes.
  - The VERDIN/EVS Receiver will be Replaced by SLVR.

- UP TO FOUR 50 BPS CHANNELS
- MULTIPLEXED, ENCRYPT AND ENCODE
- MSK MODULATION

ACKNOWLEDGEMENTS

My thanks to Al Lopez, Peder Hansen, Nick England and Harold Wheeler for their invaluable contributions.

REFERENCES

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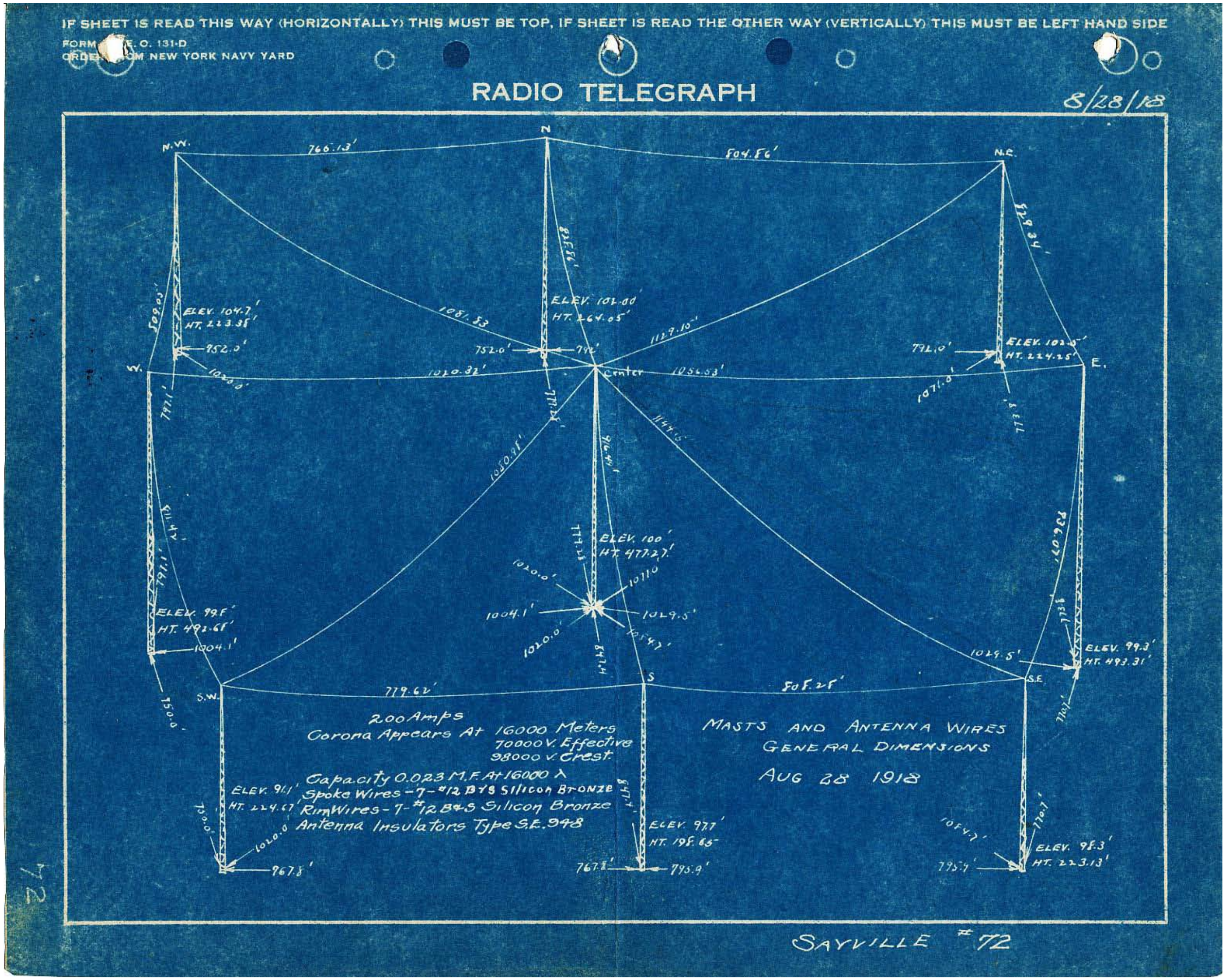
HISTORICAL NOTES:SAYVILLE DESIGN INFORMATION- 1918



HISTORICAL NOTES: RADIO CENTRAL TUNING NETWORK

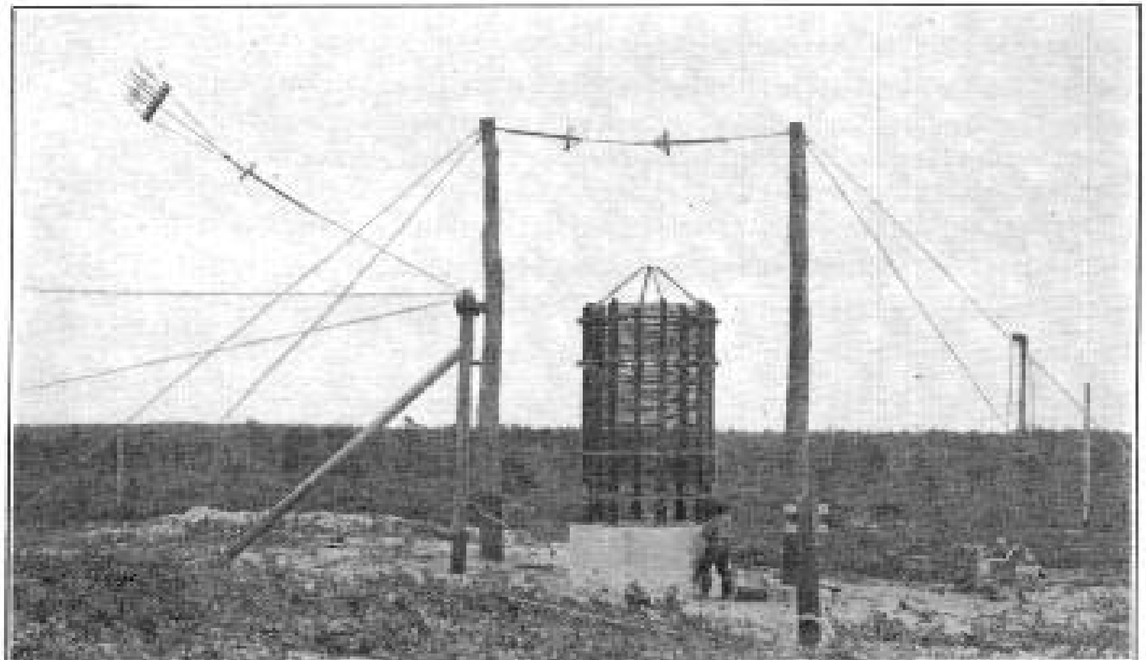


FIG. 174.—An immense transmitting tuning coil at Radio Central. Note the size, compared with the man standing at its base.

HISTORICAL NOTES: RADIO CENTRAL TRANSMITTER

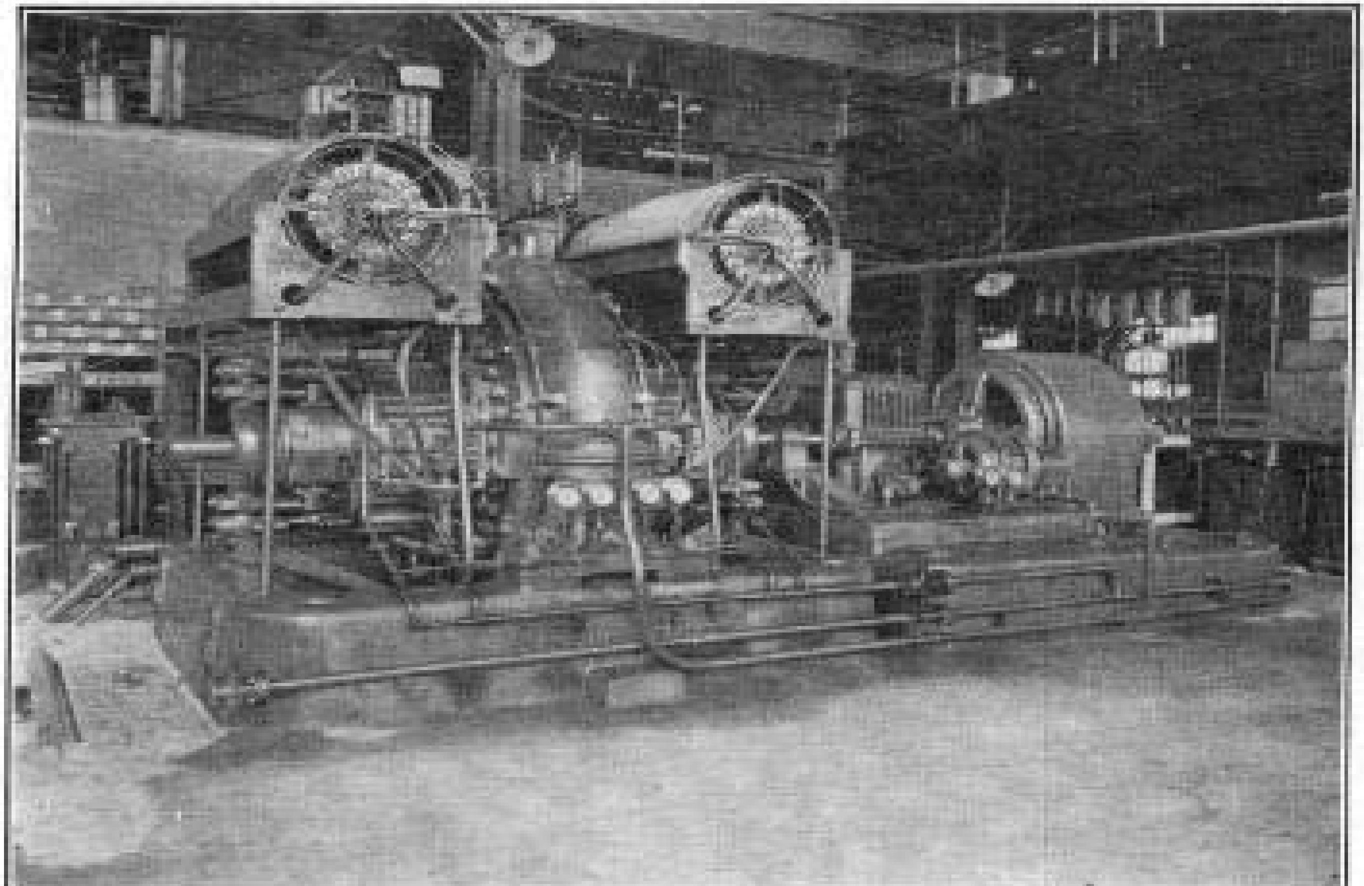


FIG. 173.—An Alexanderson high-frequency Alternator, capable of putting 700 amperes of high-frequency current into the antenna.