THE BIGGEST LITTLE ANTENNA IN THE WORLD

Ed Kardjala

The Navy's VLF Antenna at Cutler Maine

Edward M. Newman W2EMN April 2020

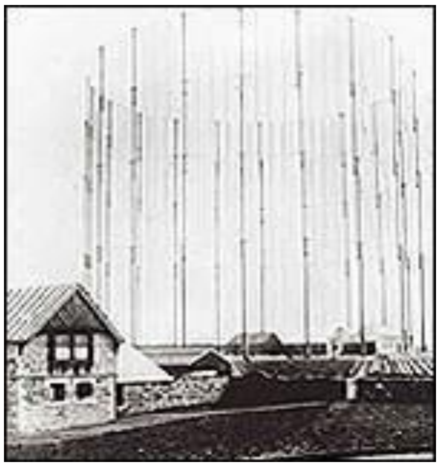
A small SMALL ANTENNA

Electrically and Physically Small

CUTLER VLF (3-30 KHz) ANTENNA

- Why A VLF Antenna?
- Types Of Antennas
- The Designers
- Trideco Design At Cutler, Me.
- Towers and Top Load
- Tuning Network
- Deicing
- Ground System
- Modulation and Reception
- Long Island VLF Stations and New LF Ham Bands

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

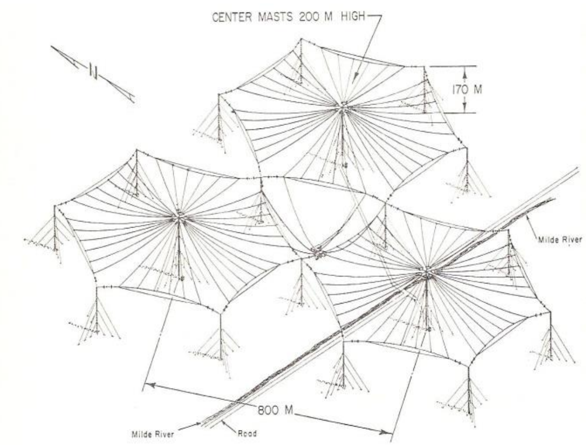


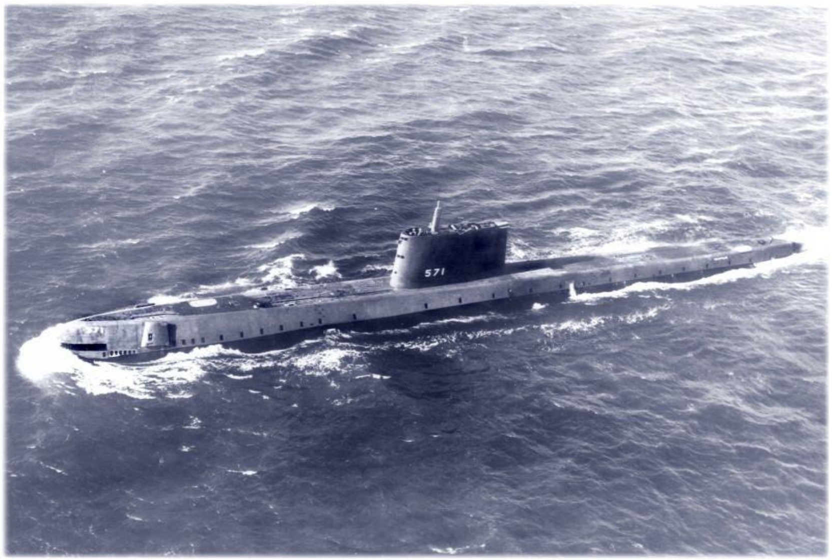
FIG. 2.8.16. Pictorial view of Goliath antenna.

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

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)

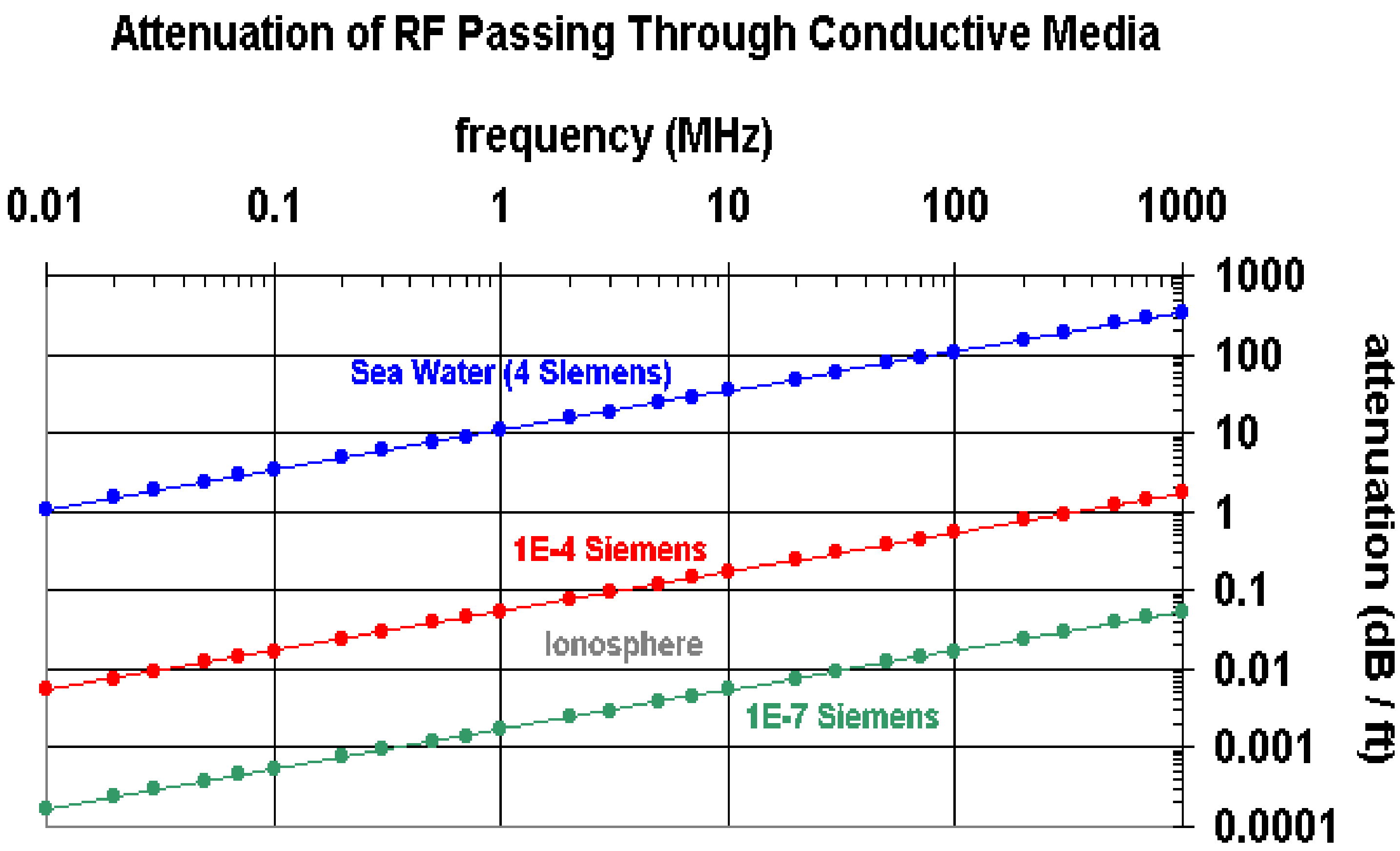
BALLISTIC MISSILE SUBMARINES



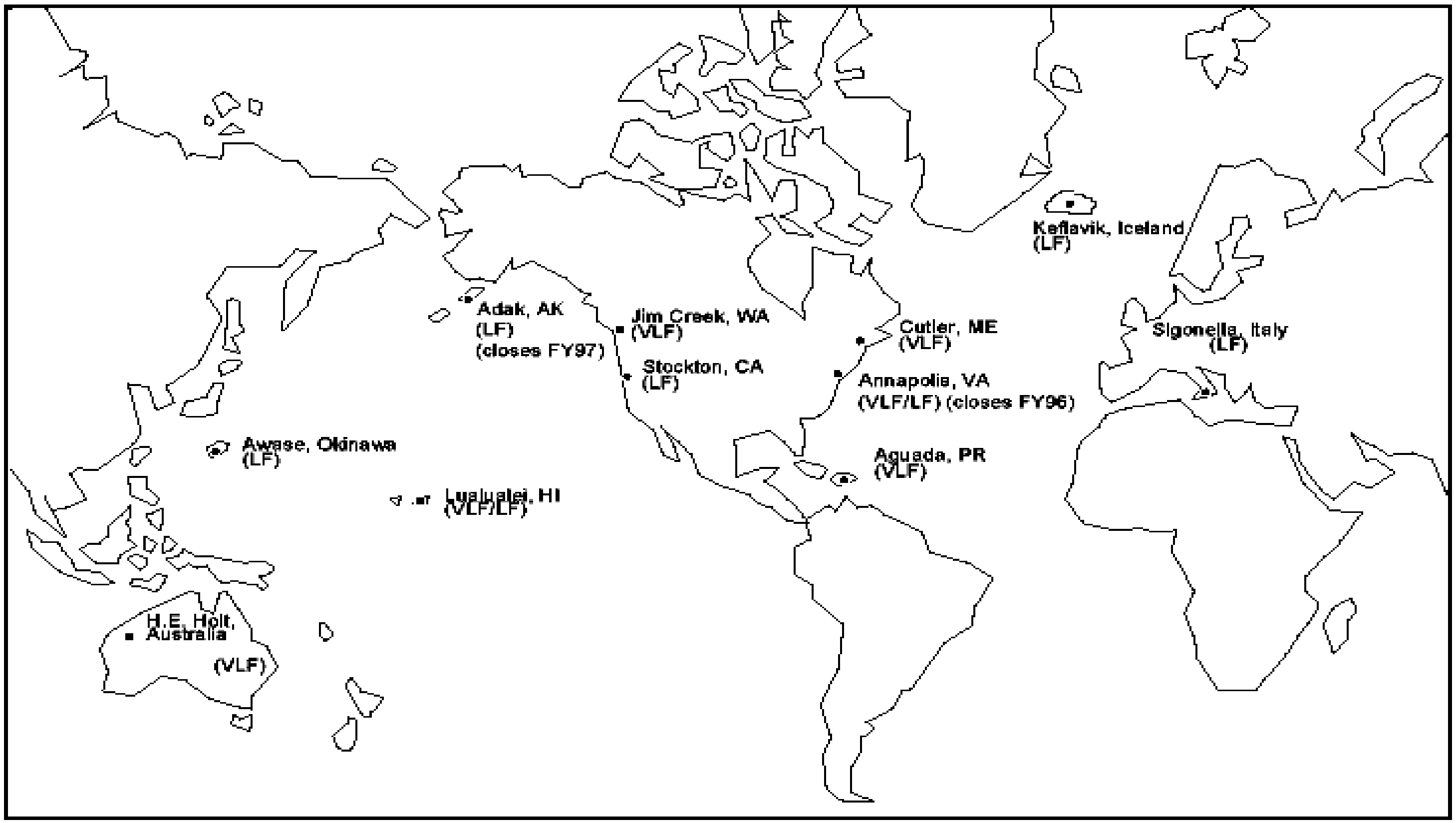
- USS NAUTILUS
- FIRST NUCLEAR-POWERED SUB
- COMMISSIONED 1954
- OPERATE SUBMERGED FOR MONTHS

- 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

NAVY 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

KEY ENGINEERS

- Wheeler (3QK) was the recognized expert in designing electrically small antennas
  - Developed simple formulas to predict performance
- Developmental Engineering Corp was system designer and general contractor
  - Navy contractor for specialized transmitters
  - Boynton Hagaman AA4QY antenna designer
- Jim Weldon Continental Electronics- transmitter
- Willard Heidig W2KM

HAROLD WHEELER (1903-1996)

Photo 8 — Radio station (3QK) 201215.
Receiving first broadcast of Radio Market News Service.

HAROLD WHEELER

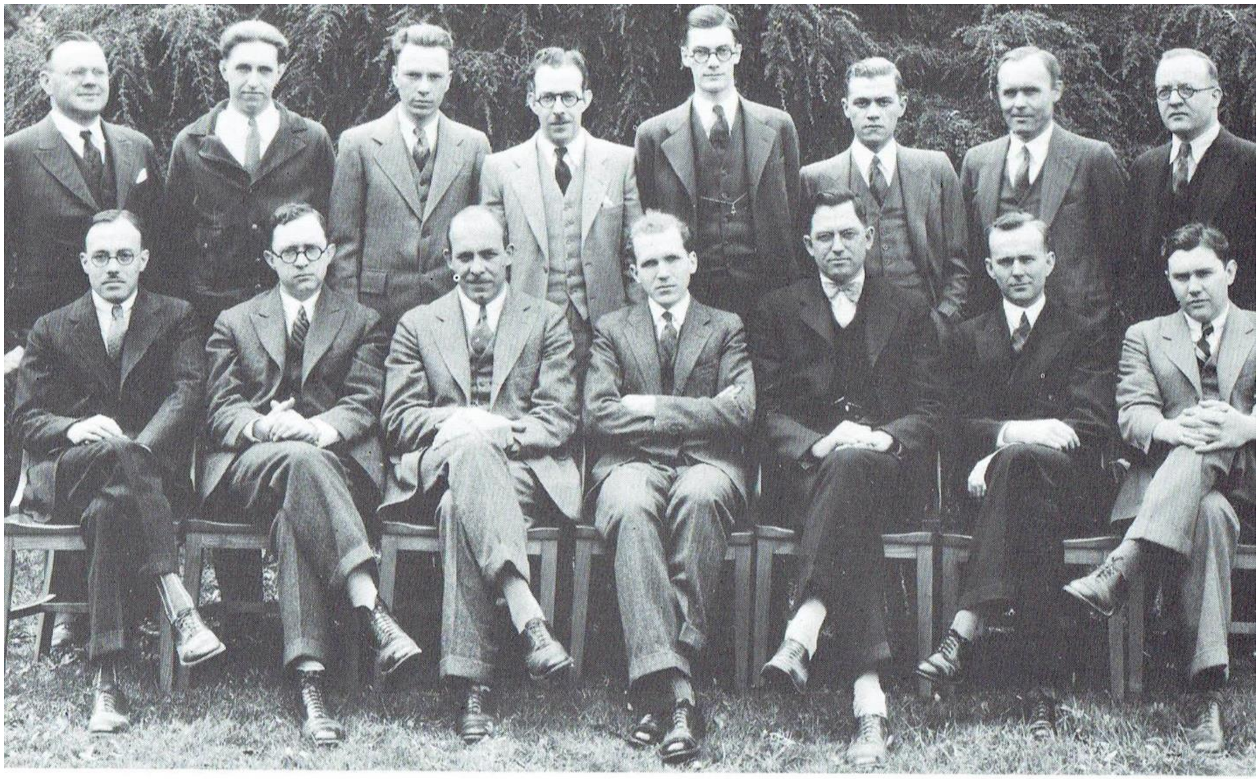


Photo 12 — Bayside laboratory staff 1931.
Front row: Case, Dean, Lewis, Wheeler, Brock, Whitman, Cawein.
Back row: E. Brillat, Quebe, Swinyard, Hynes, Huxtable, J. Curran, Frossard, Muller

First employee of Hazeltine

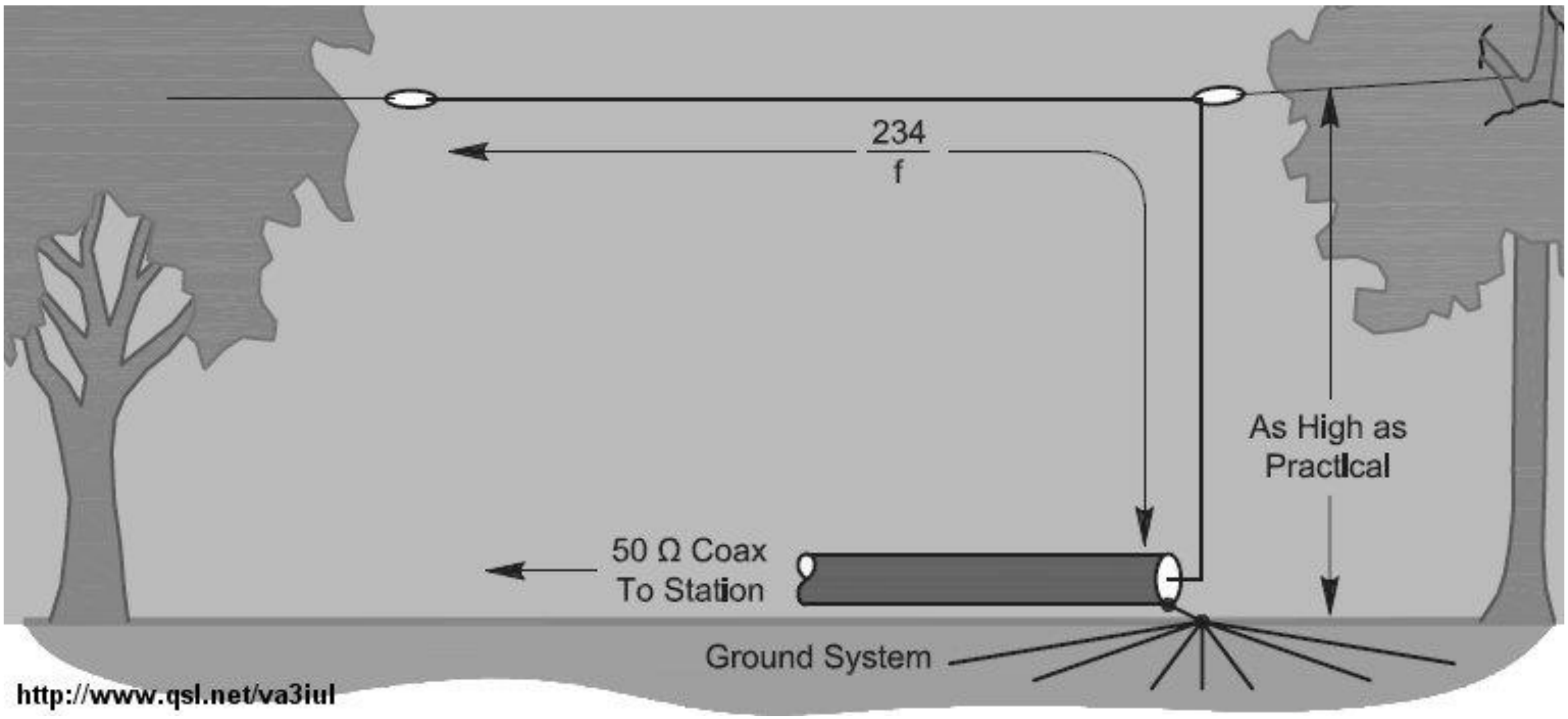
BOYNTON HAGAMAN (1917-2006)

- DECO's principal engineer during antenna design
- Ham license at age 13 (AA4QY later)
- Self-taught engineer-college dropout
- Pilot's license in high school
- Accomplished musician
- Consultant on other VLF antenna designs

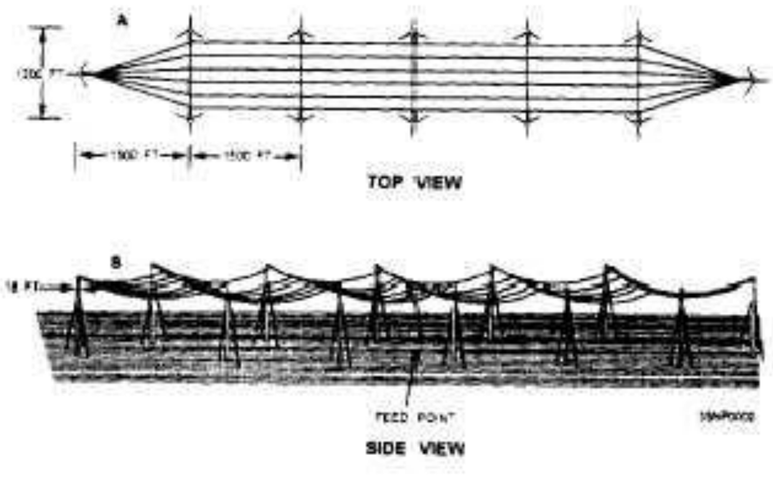
DESIGN ISSUE :ELECTRICALLY SMALL ANTENNA

- An antenna smaller than 0.1 wavelength
  - Cutler is approx. 300m/20,000m = .015
- Antenna bandwidth is limited
- Radiation resistance is very small and in series with ground loss and tuning network loss
- Increasing height and adding capacitive top load increases radiation resistance
- Extensive ground system reduces losses

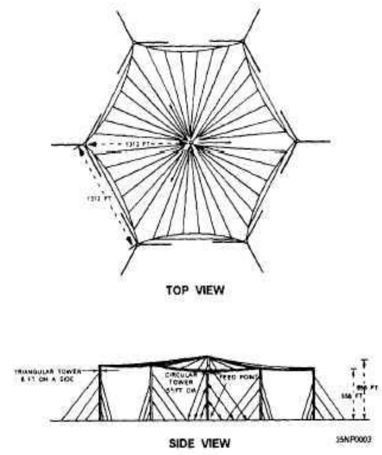
TYPICAL 160 M ANTENNA



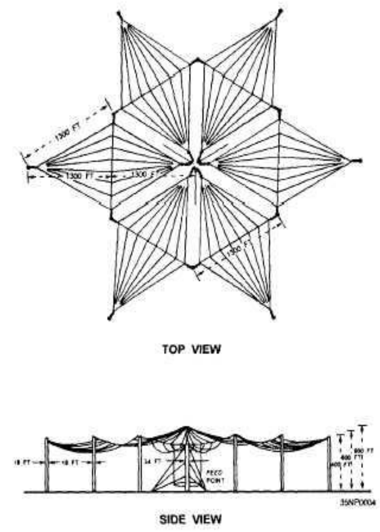
ANTENNA CONFIGURATIONS



TRIATIC TOP LOAD



UMBRELLA TOP LOAD



TRIDECO TOP LOAD

EXAMPLE OF TRIATIC

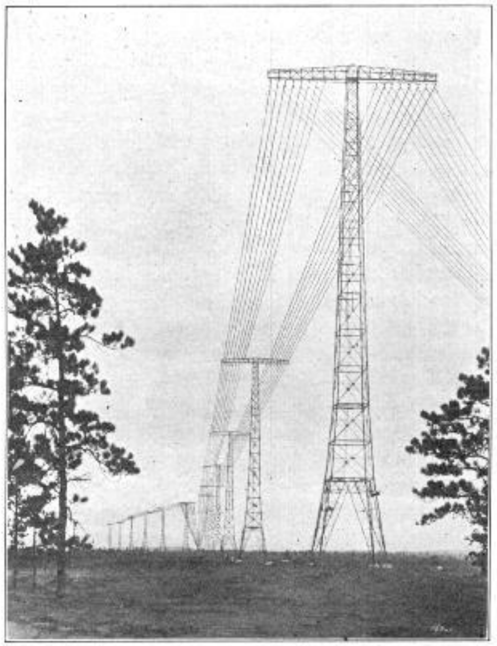
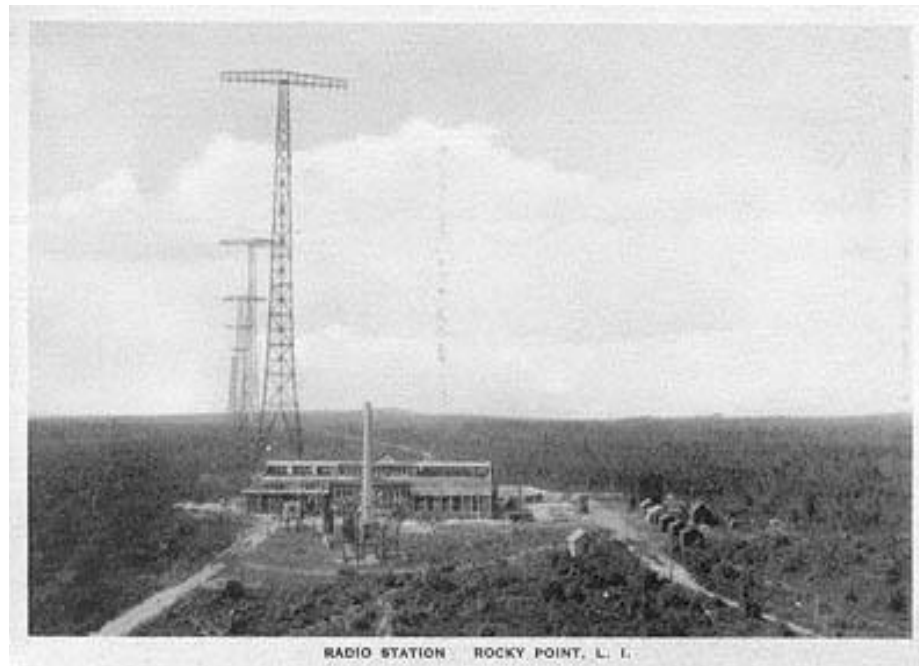


FIG. 172.—Two of the immense antennæ at Radio Central.



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

TRIDECO ANTENNA

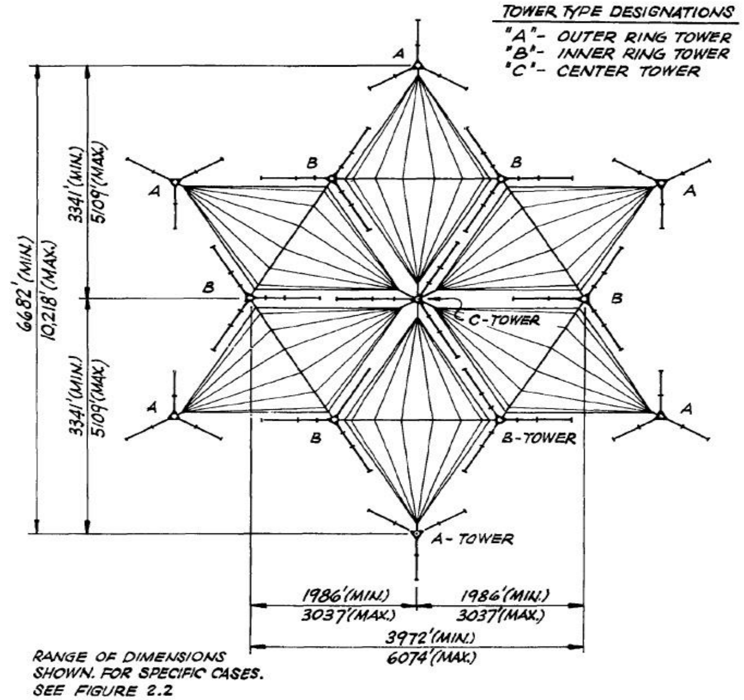


FIG. 2-1 LAYOUT OF ANTENNA ARRAY

-Six 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

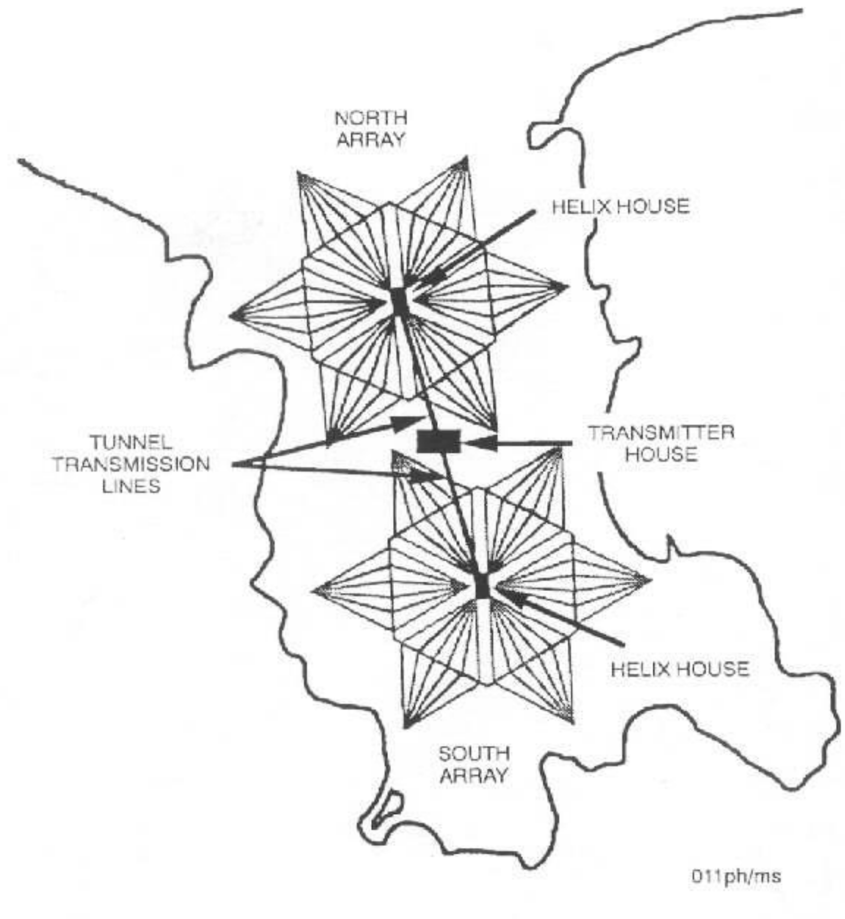


Figure 1. VLF Cutler.

Ref 6

OVERVIEW OF ANTENNA CONFIGURATION

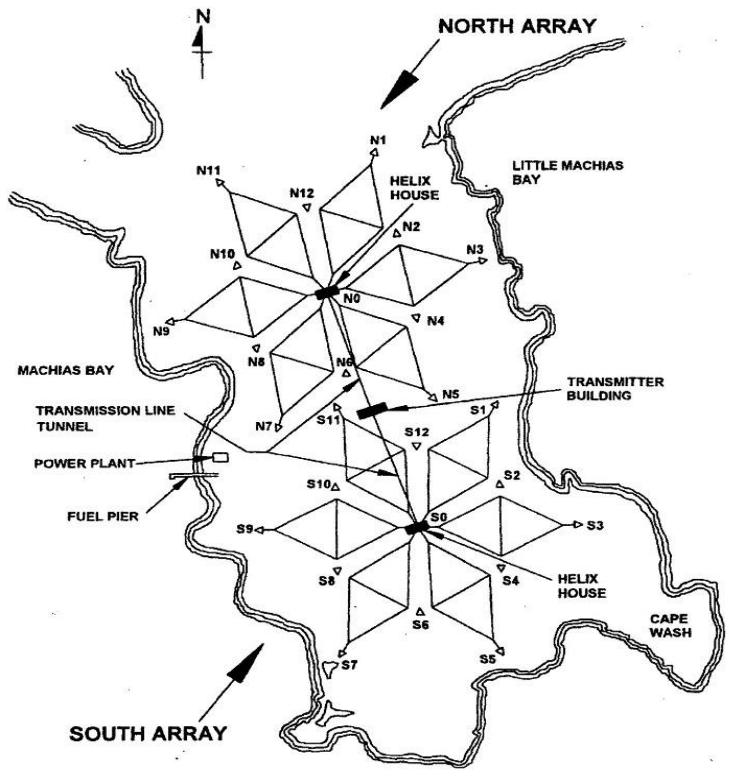


Figure 1. General layout, Cutler Peninsula.

Location, location

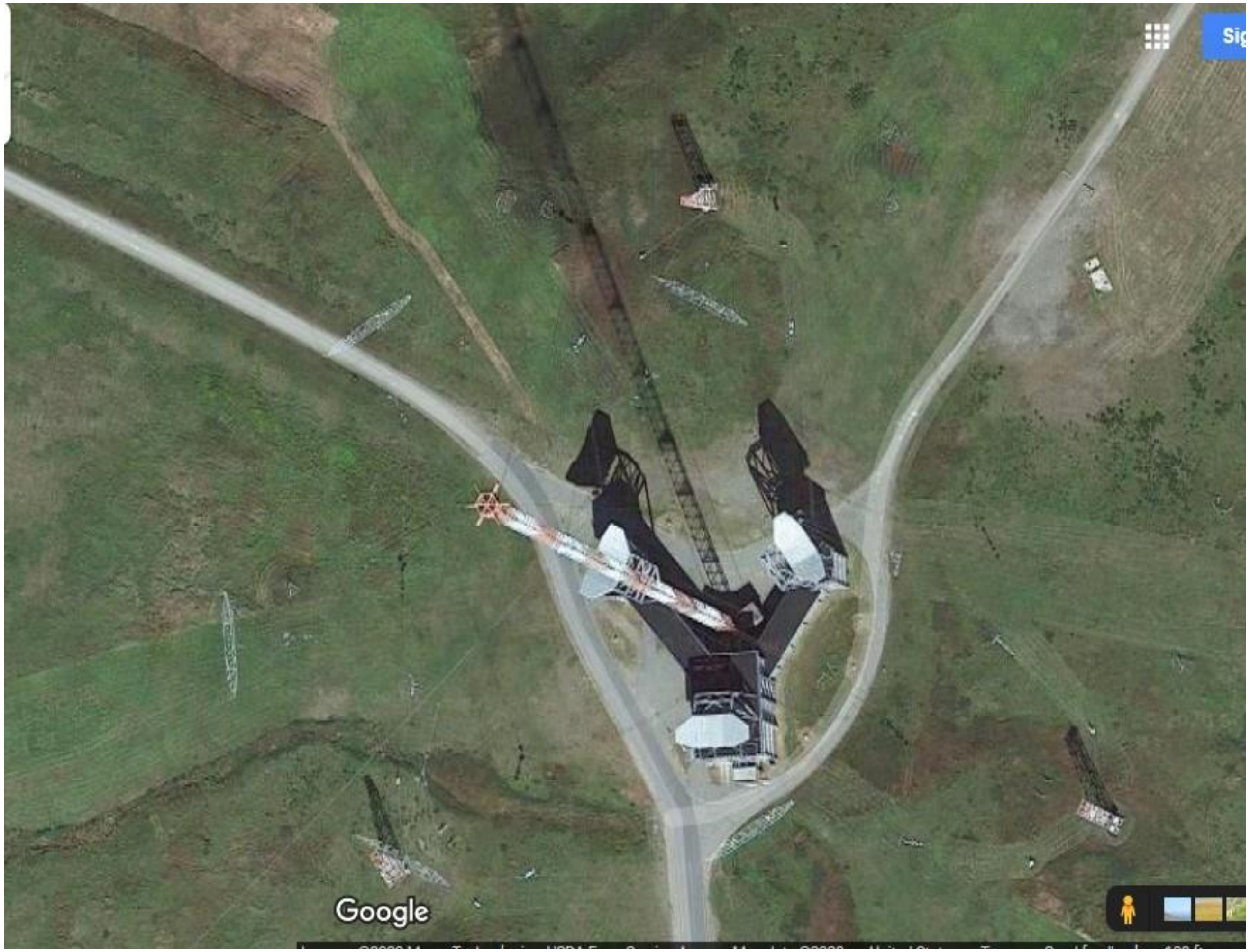
Ref 7

Google Maps

26 TOWERS- 850 to 1000 FT HIGH

Ref 8

SATELLITE IMAGES



Main Tower And Helix House

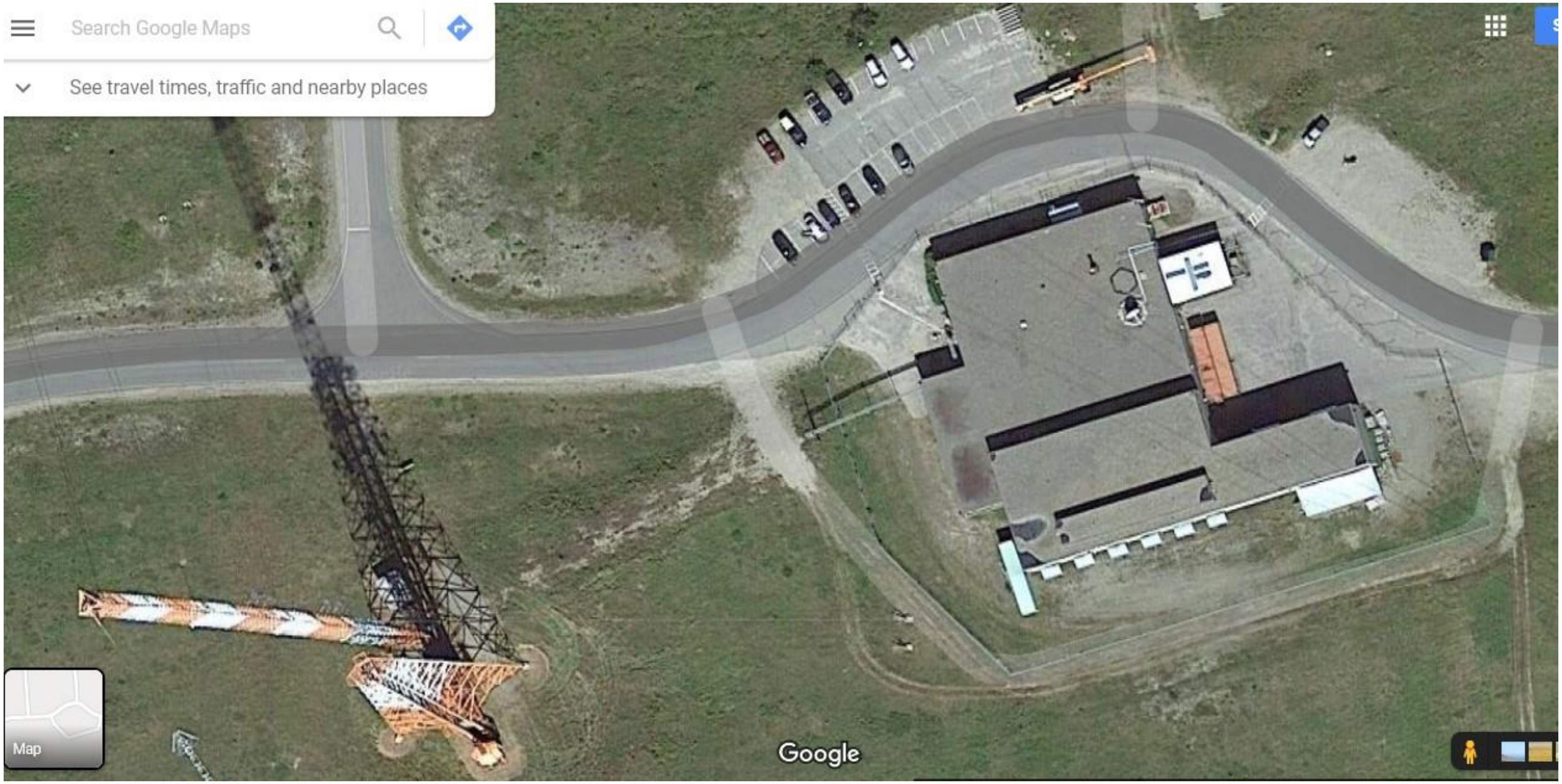
Google Maps

SATELLITE IMAGES

Power Plant 18 MW

Google Maps

SATELLITE IMAGES



Transmitter Building

Bing Maps

EACH ANTENNA CONSISTS OF 13 TOWERS

Exciting Engineering Work

Ref 8

TOPLOAD FEED SYSTEM

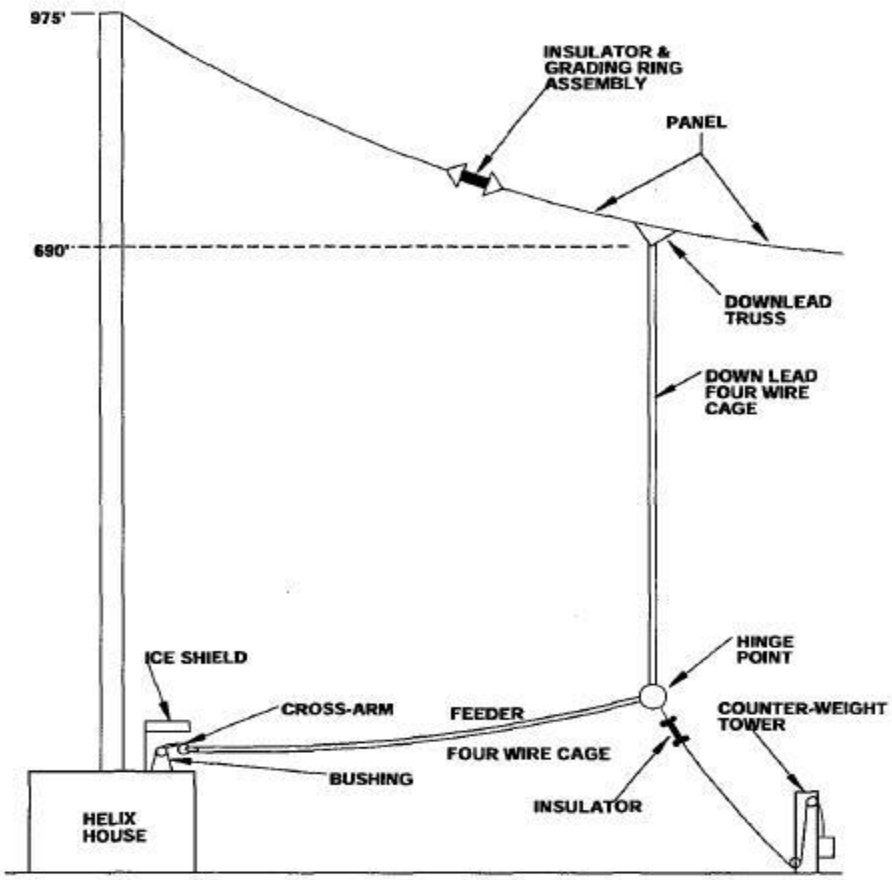


Figure 3. VLF Cutler feed-cage and counterweight configuration.

Ref 7

PHOTO OF FEED LINES

Heidig

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

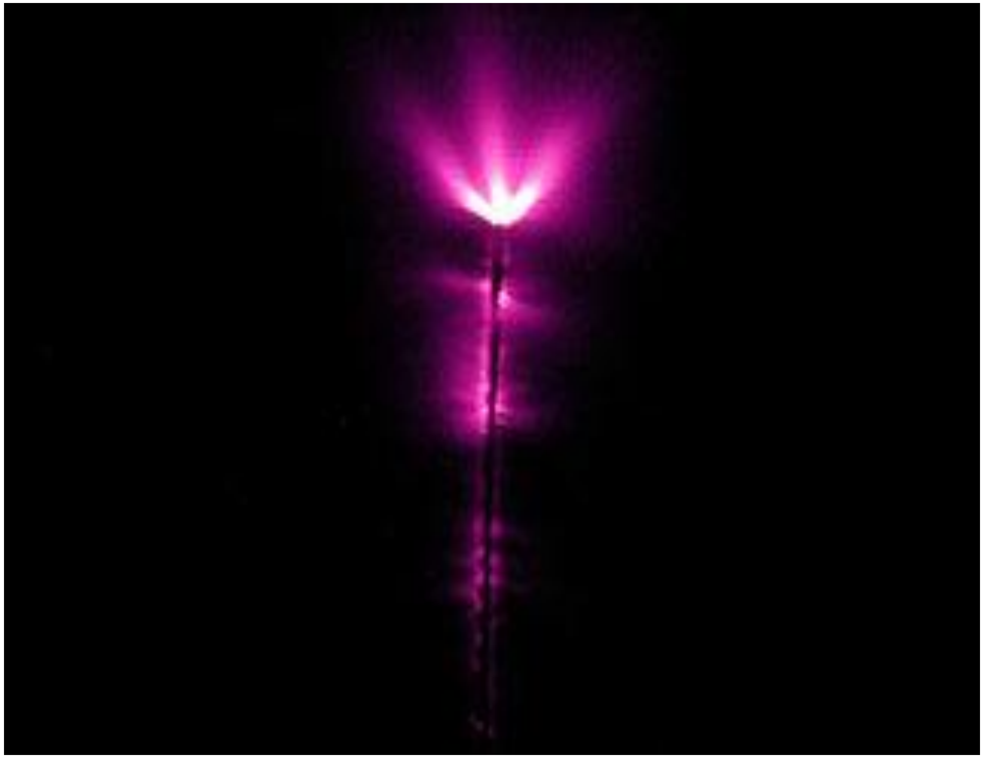
Ref 7

DESIGN ISSUES

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

DESIGN ISSUE: CORONA

- Actual Antenna Voltages 200 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

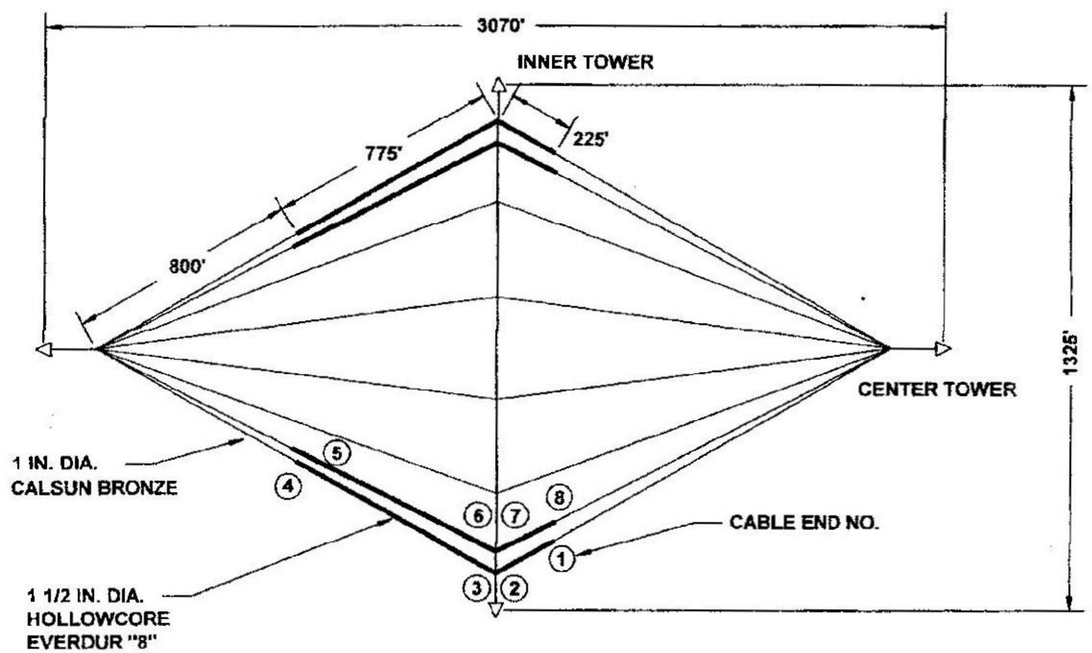


Figure 2. Plan view of a typical panel in VLF antenna array.

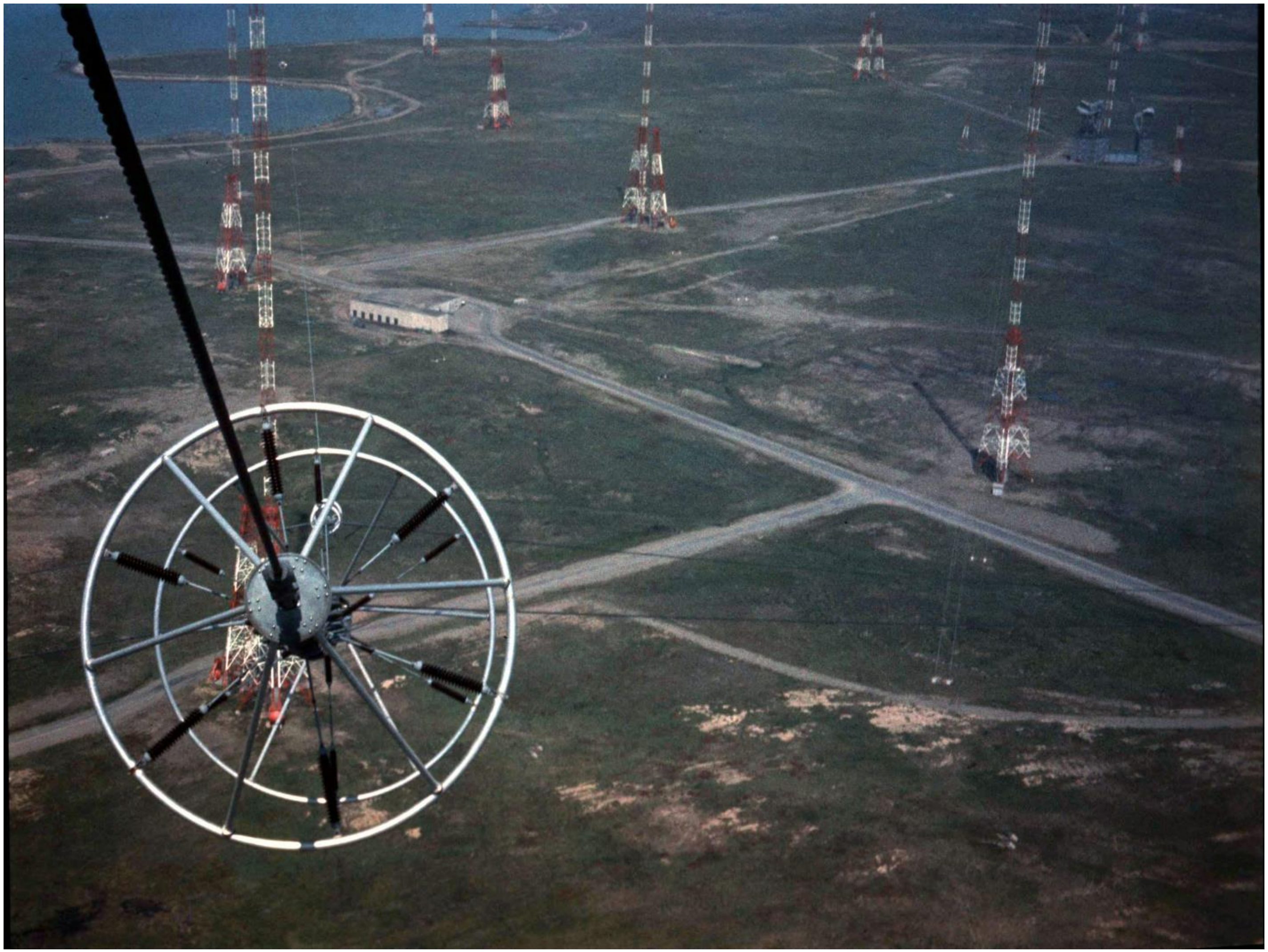
Ref 6

- 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

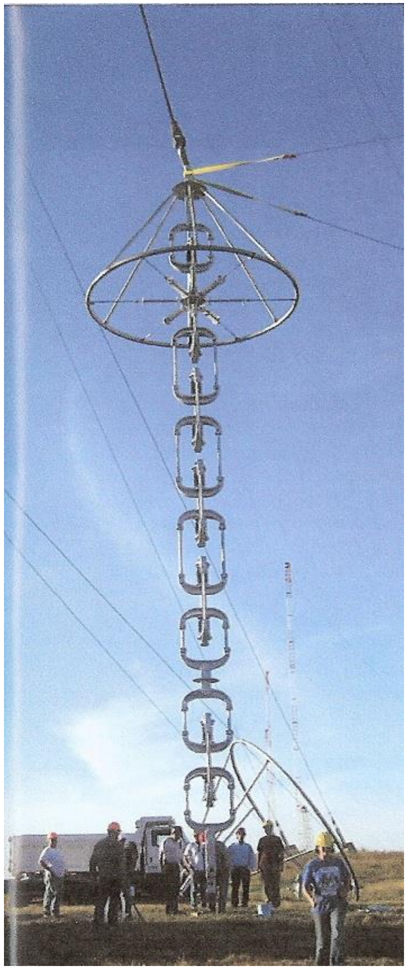
HAM ANTENNA INSULATORS

INSULATOR

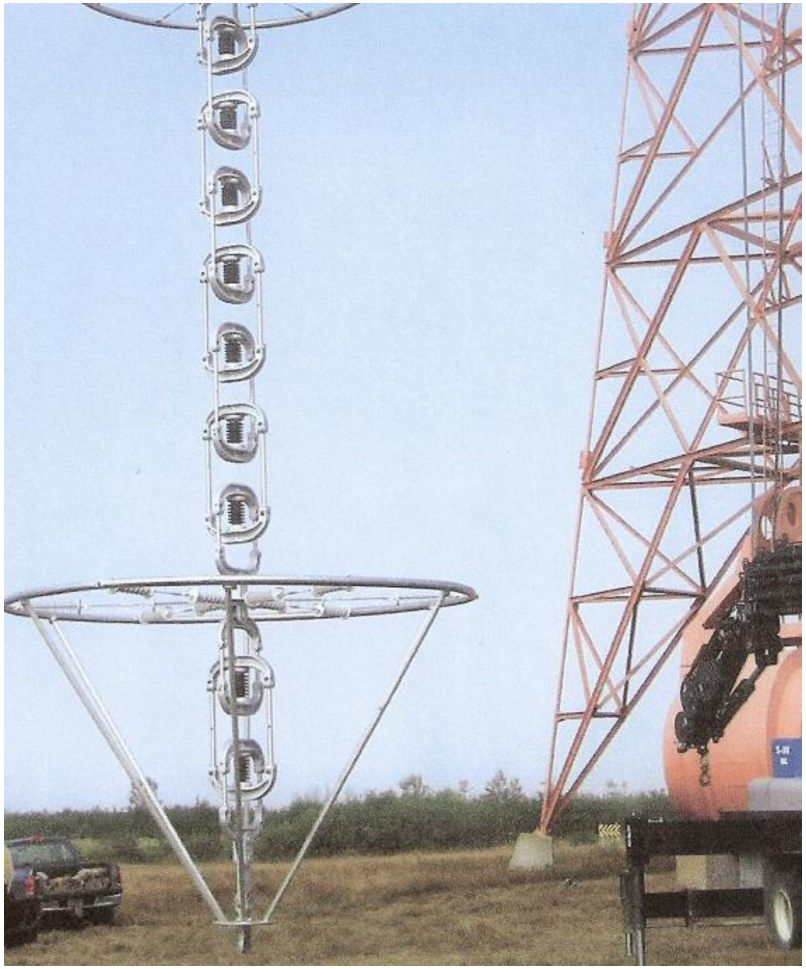


Heidig

EACH INSULATOR IS 57 FT LONG TO WITHSTAND 250 KV

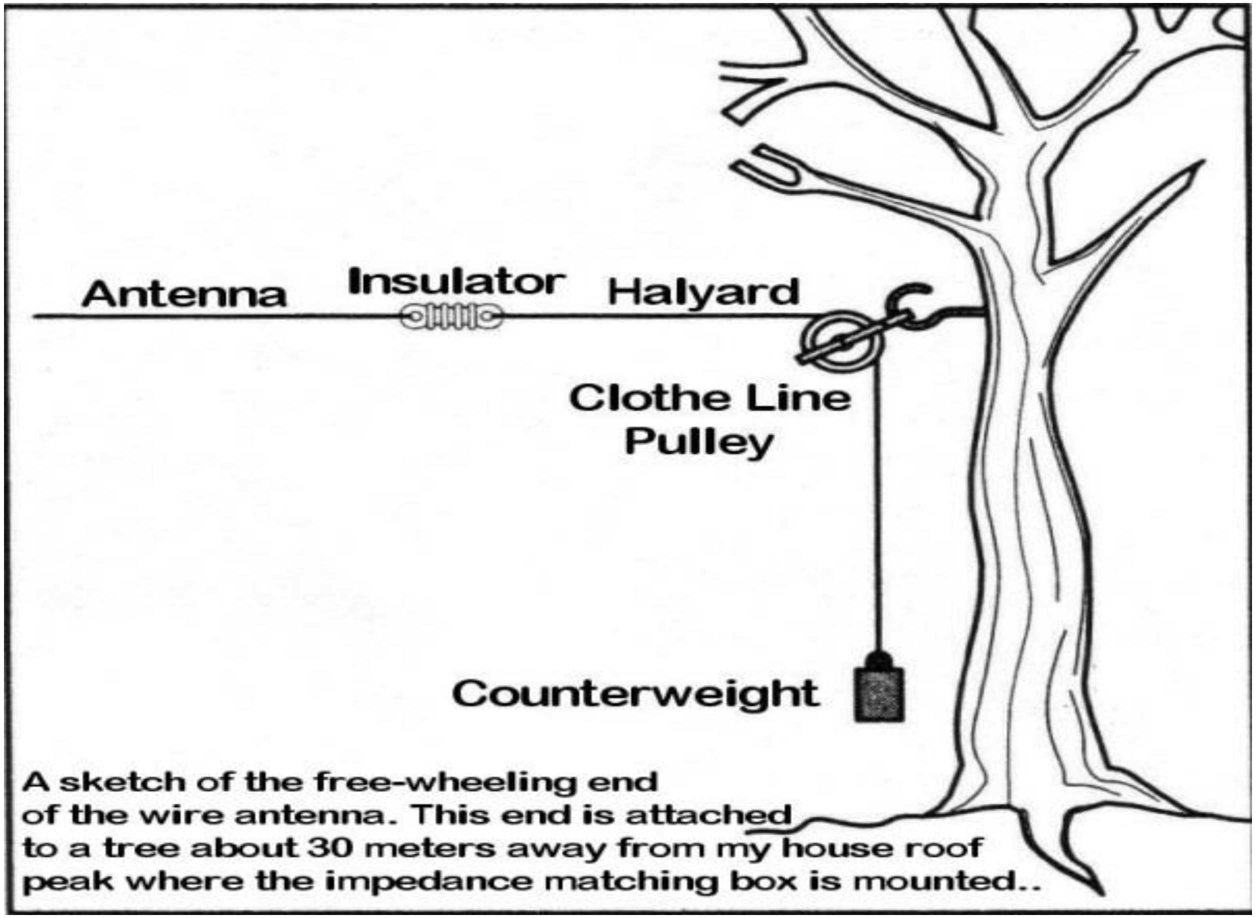


13,000 lbs.



Ref 4

HAM ANTENNA COUNTERWEIGHT

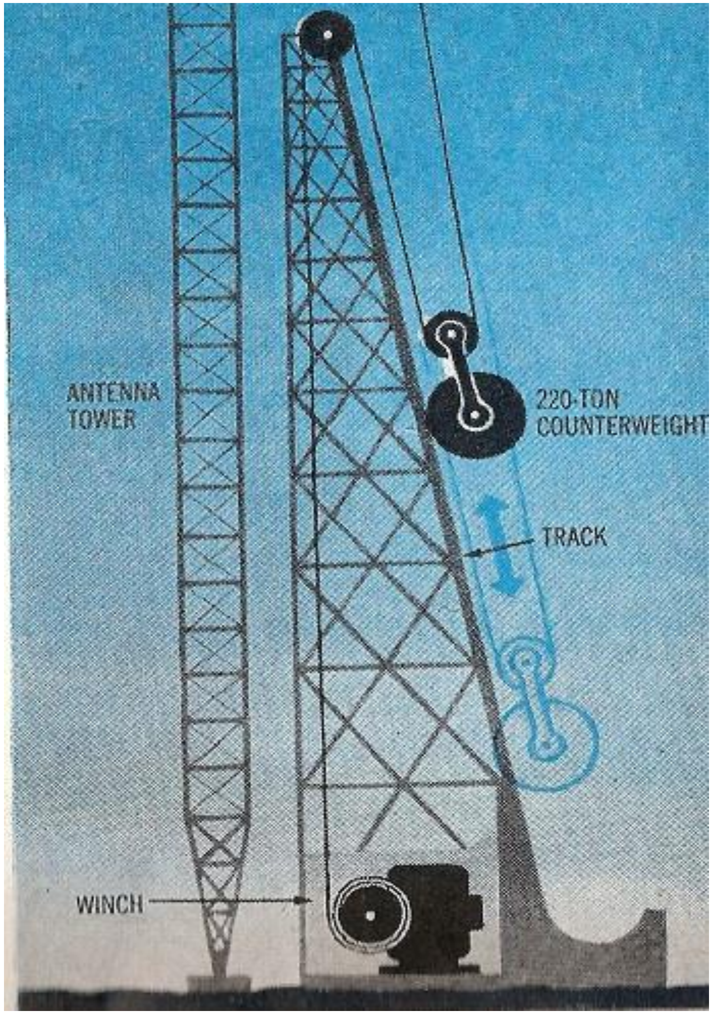


A sketch of the free-wheeling end of the wire antenna. This end is attached to a tree about 30 meters away from my house roof peak where the impedance matching box is mounted..

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

COUNTERWEIGHT SYSTEM

Heidig

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

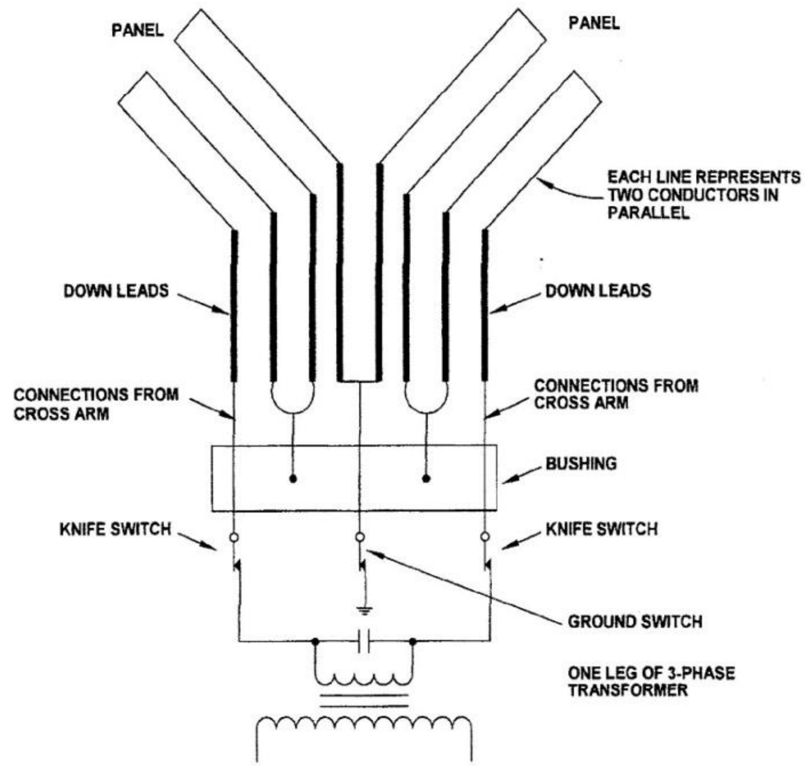


Figure 7. Simplified schematic diagram of one division in deicing mode.

Ref 7

TUNING NETWORK-HELIX HOUSE

TUNING NETWORK

- Handle 100 KV And 2000 Amps
- Very Low Loss <<0.1 Ohm
- Tune Antenna Over 14-28 KHz
- Tune Antenna with Modulation
- Antenna Impedance is Capacitive

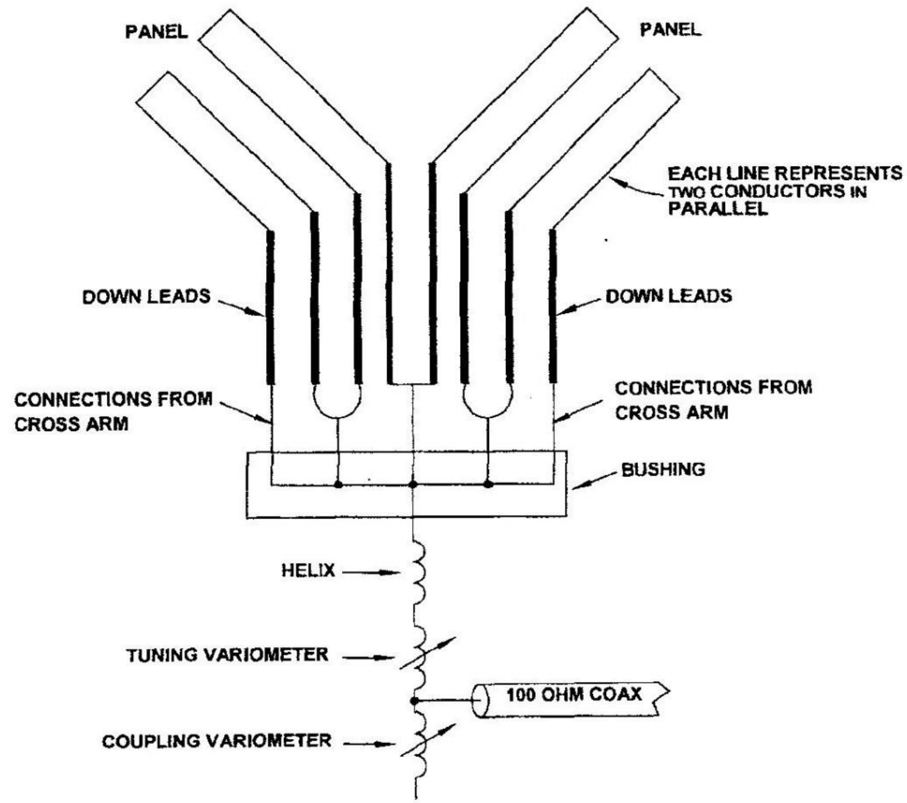


Figure 8. Simplified schematic diagram of one division in transmit mode.

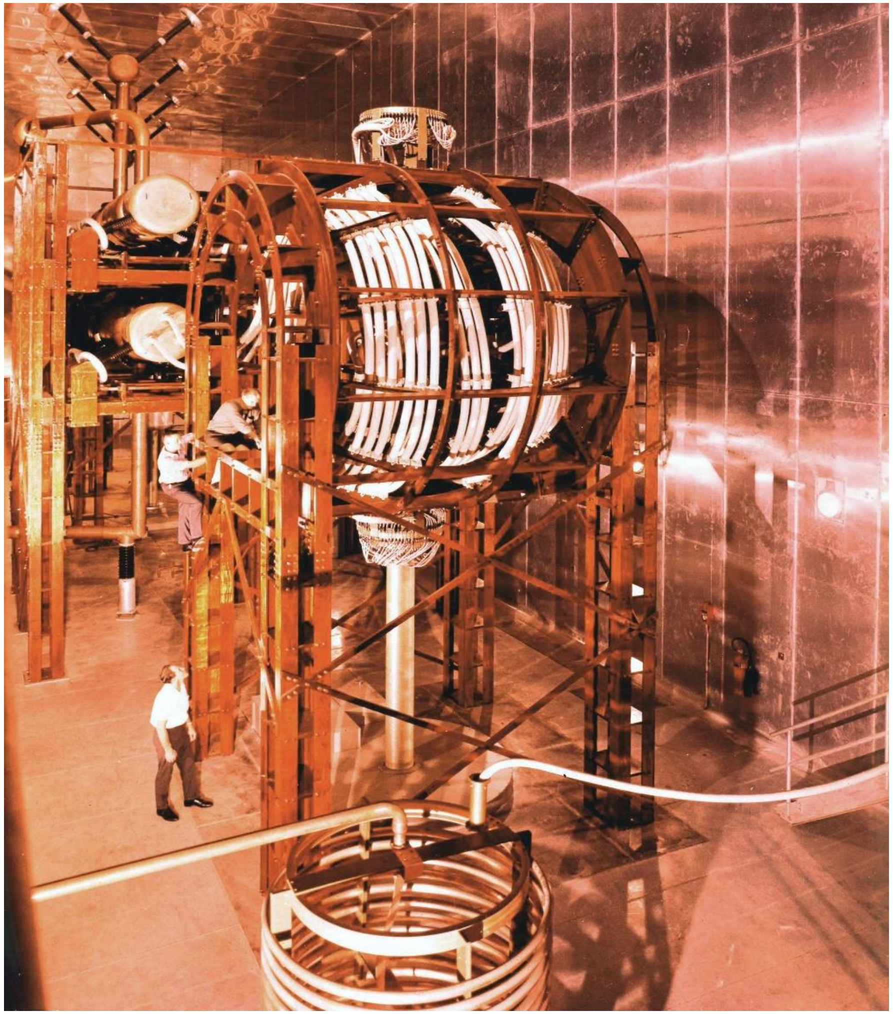
Ref 7

FEEDTHROUGH BUSHING

TUNING NETWORK- HELIX

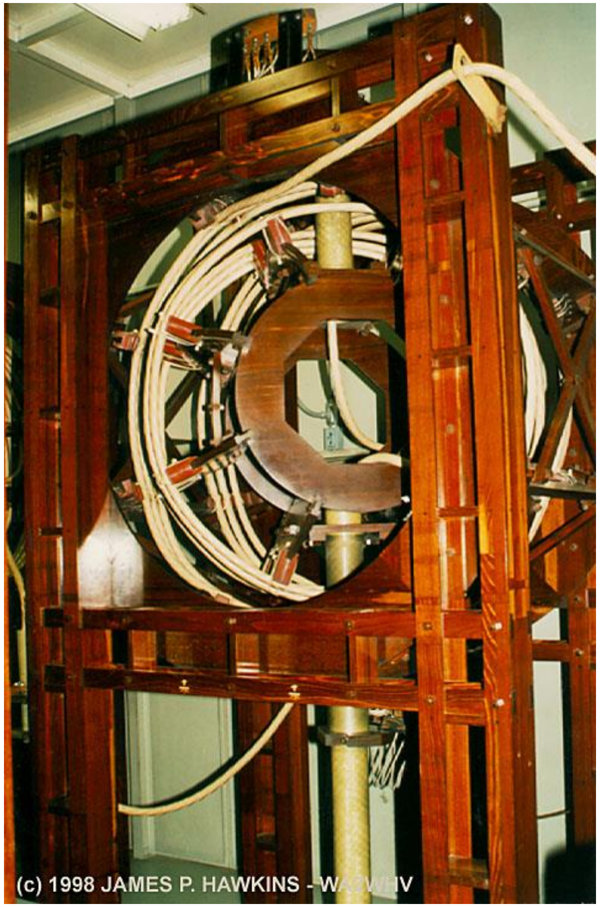
TUNING NETWORK- HELIX

TUNING NETWORK-VARIOMETER

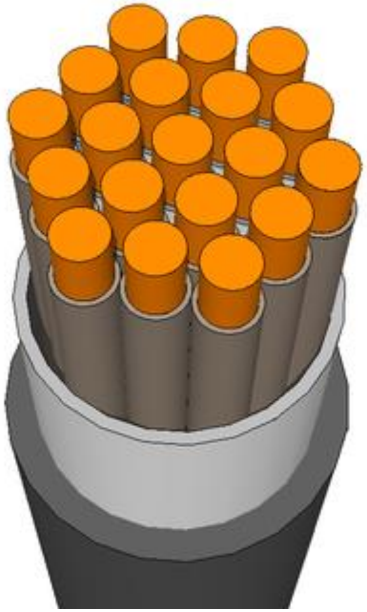


Heidig NAA Wires are 4 inches diameter NSS JP Hawkins

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
- Thousands of small wires are insulated, braided and packed in large conductor
- This equalizes current throughout a large conductor
- Cutler design is a Litz conductor 4 inches in diameter, with 3 parallel conductors

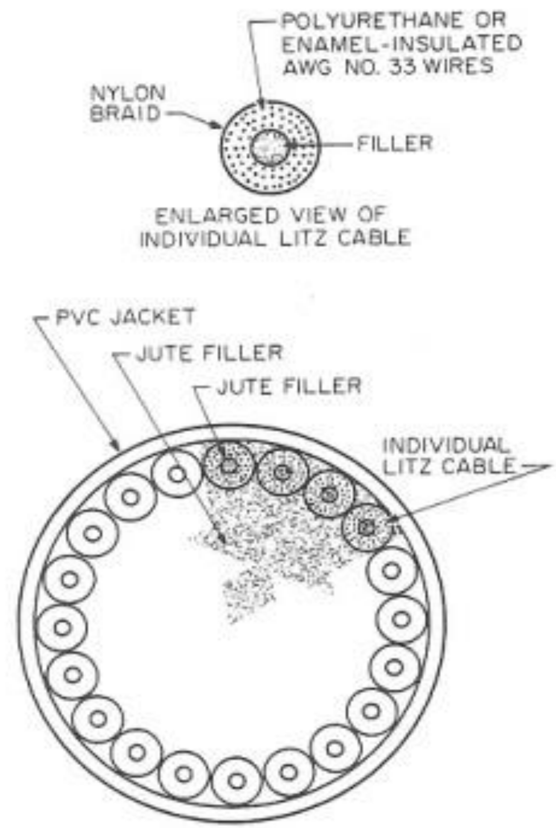
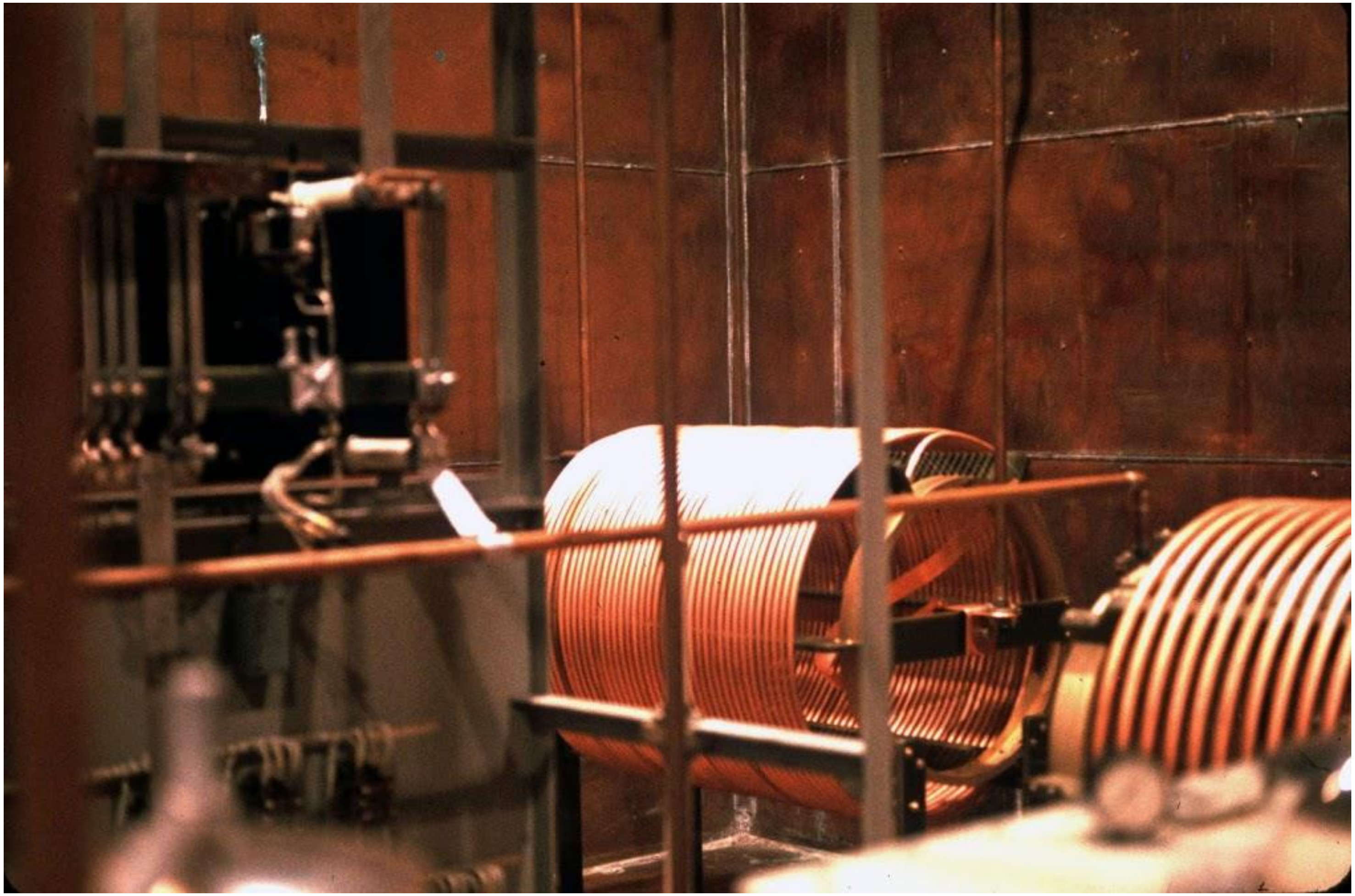


FIG. 24-11 Cross section of a large Litz conductor used in low-frequency inductor.

Ref 9

TUNING INDUCTORS IN HELIX HOUSE

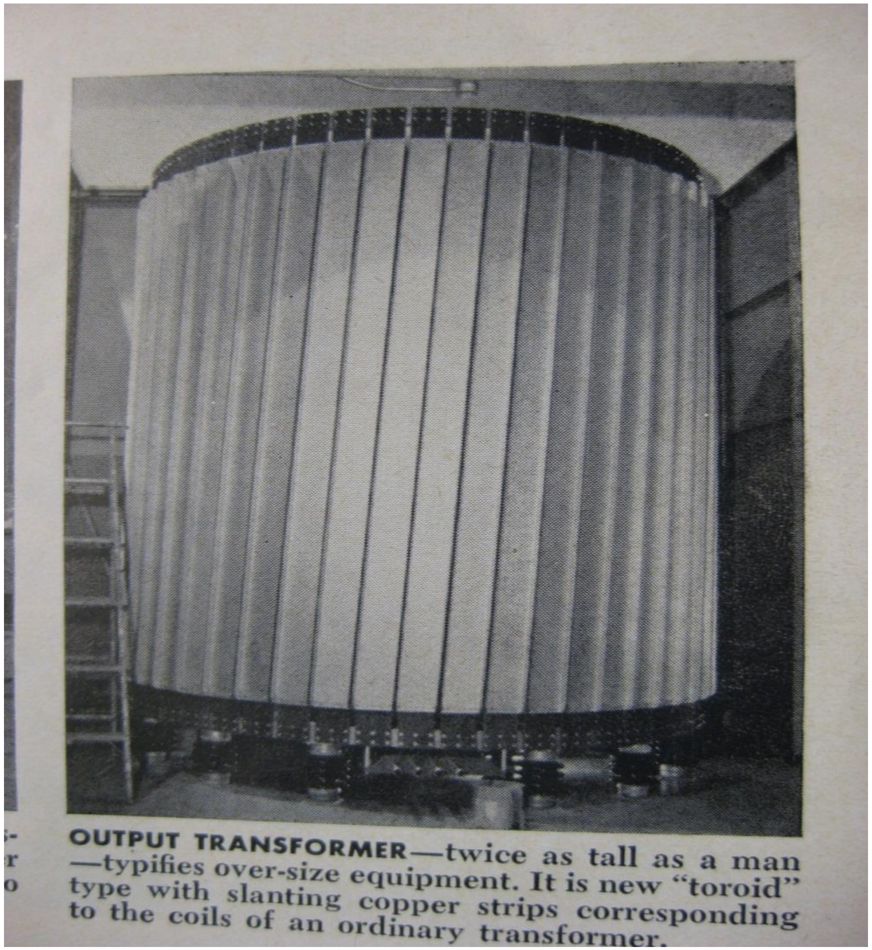


Heidig

TUNING INDUCTOR IN HELIX HOUSE

Heidig

TUNING NETWORK- TRANSFORMER



Ref 5

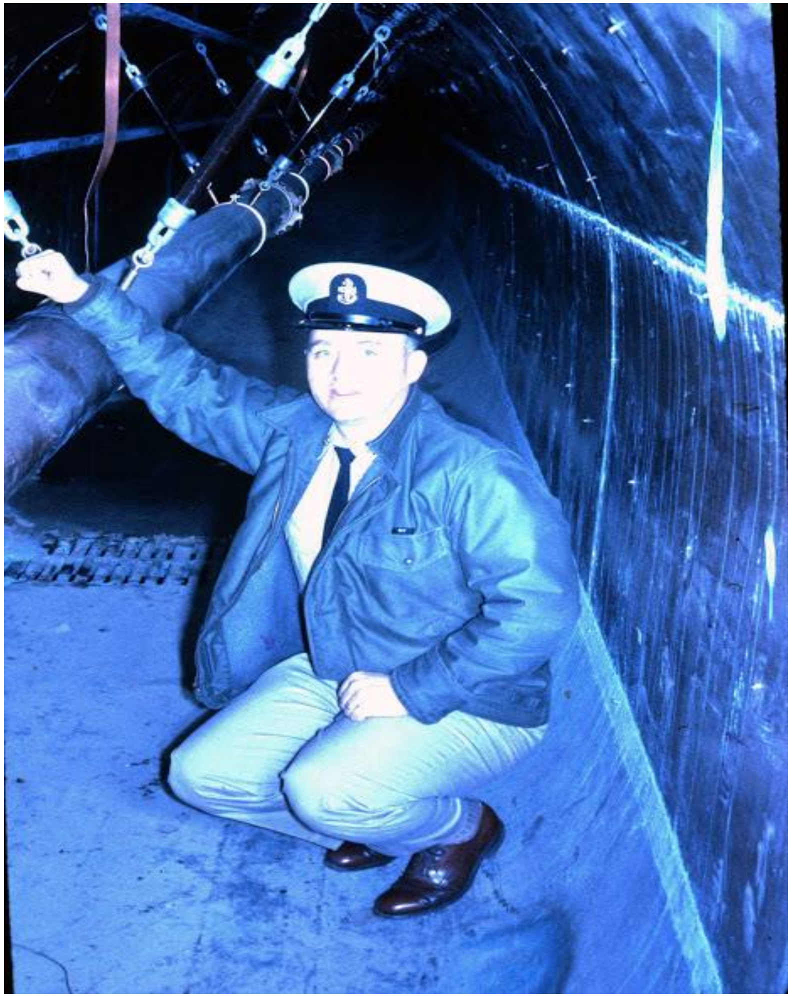
NAA

JP Hawkins

NSS

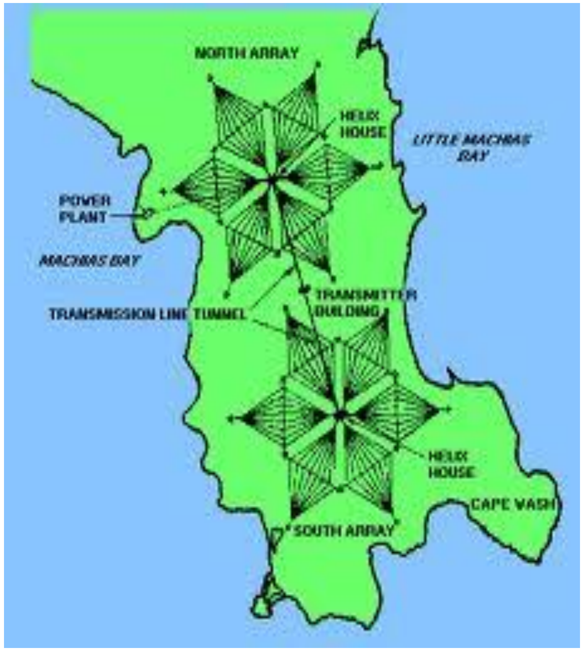
COAXIAL FEED LINE- TRANSMITTER TO HELIX HOUSE

- 100 Ohm Feed Line From Transmitter To Helix House- big enough to stand in
- 1MW Power Capacity
- 100 KV
- 2000 Amps



Heidig

DESIGN ISSUE: GROUND SYSTEM LOSS



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

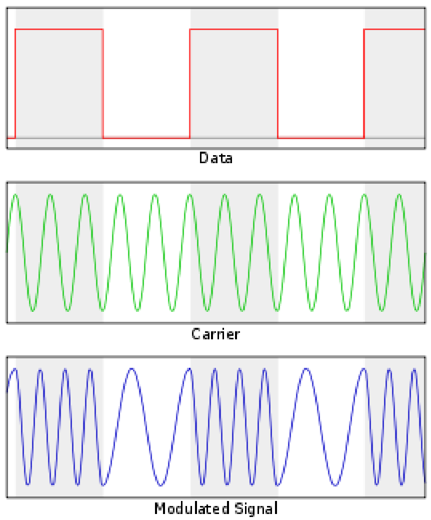
Ref 5

DUAL TRANSMITTERS: 1MW EACH

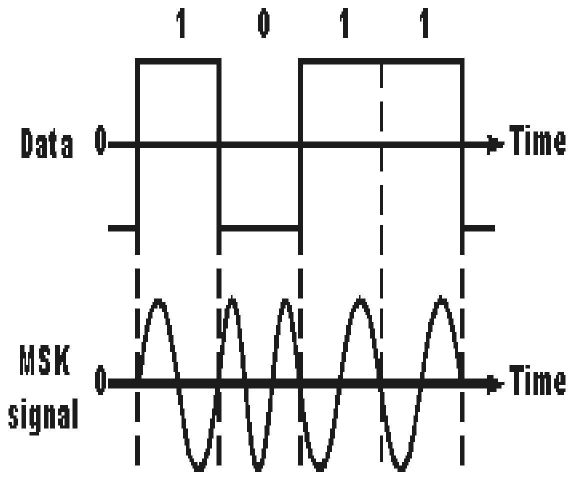
TRANSMITTER CONSOLE

DATA/MODULATION

FREQ SHIFT KEYING

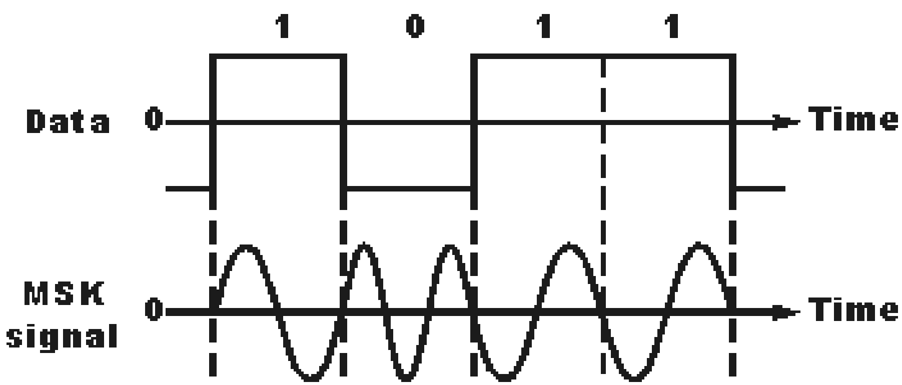


MINIMUM SHIFT KEYING



MODULATION

- Narrowband MSK (50-200 bps)



- Continuous Modulation
- Encrypted
- Antenna reactor tunes with modulation

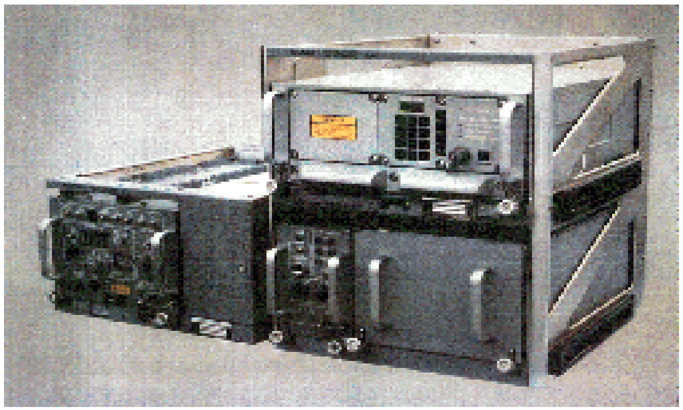
SUBMARINE RADIO RECEIVERS

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

LONG ISLAND VLF STATIONS

- RCA RADIO CENTRAL in ROCKY POINT

-TELEFUNKEN in SAYVILLE

RADIO CENTRAL ANTENNA PLAN

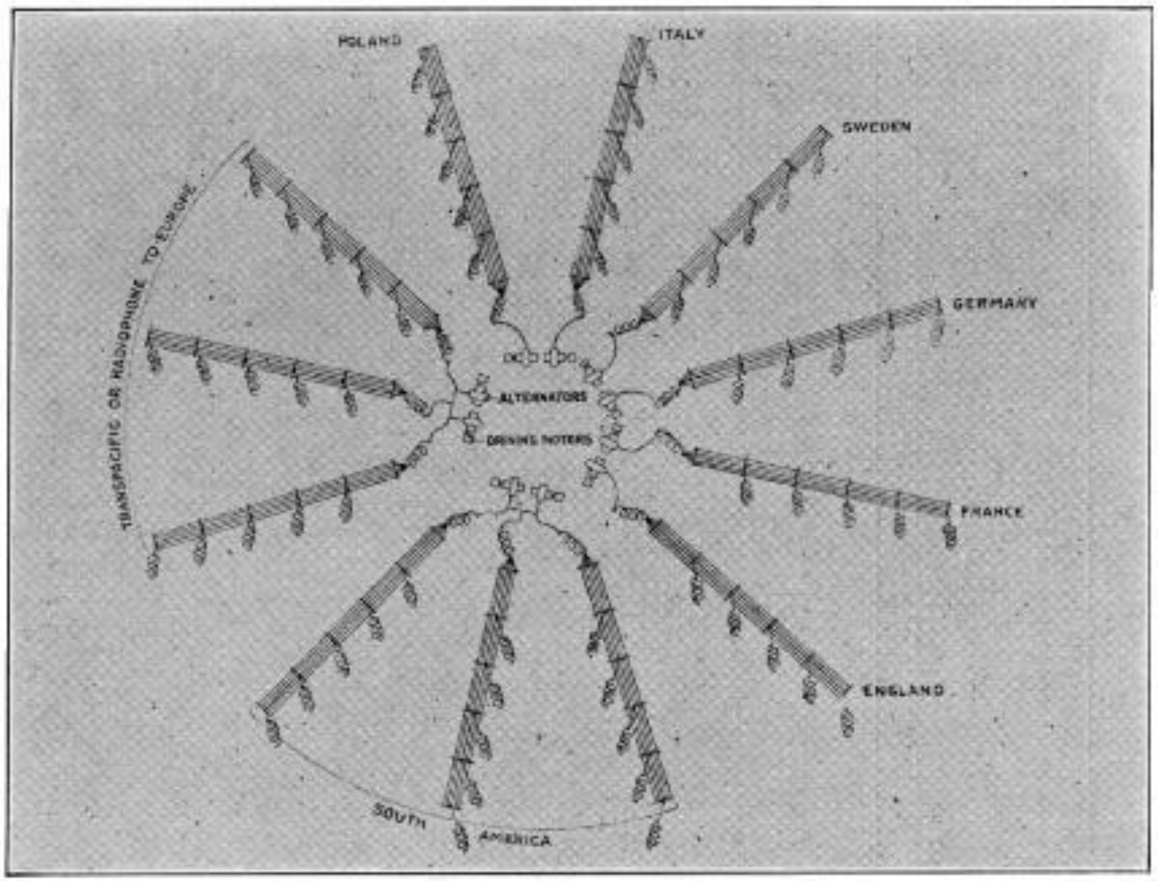


FIG. 175.—Schematic diagram of the antenna system at Radio Central, as it will look at completion.

RADIO CENTRAL ANTENNA

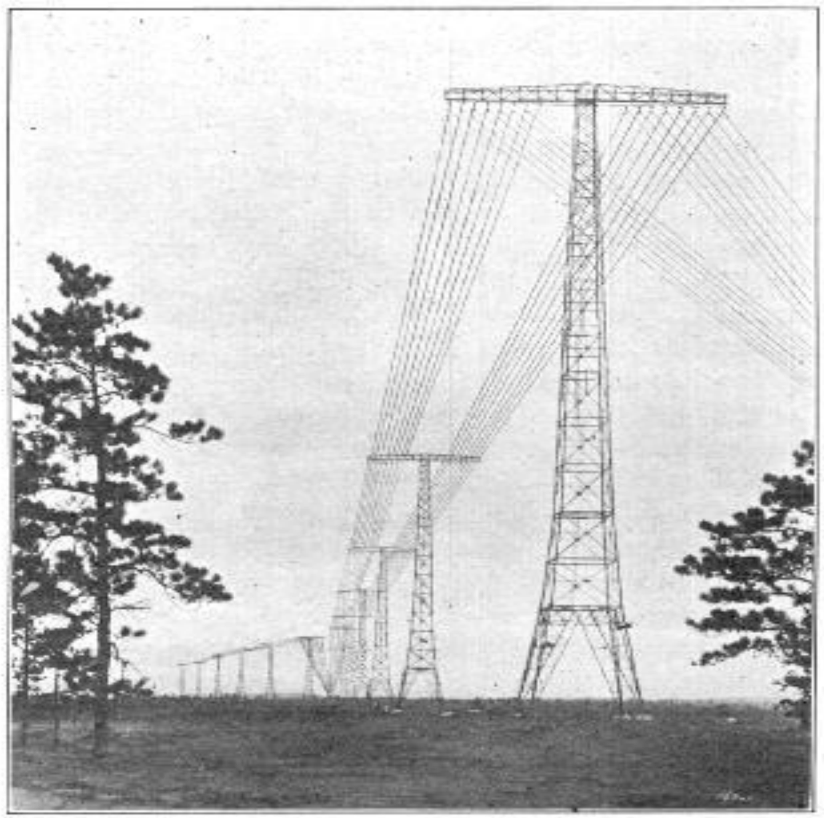


FIG. 172.—Two of the immense antennæ at Radio Central.

HISTORICAL NOTES: RADIO CENTRAL TUNING NETWORK

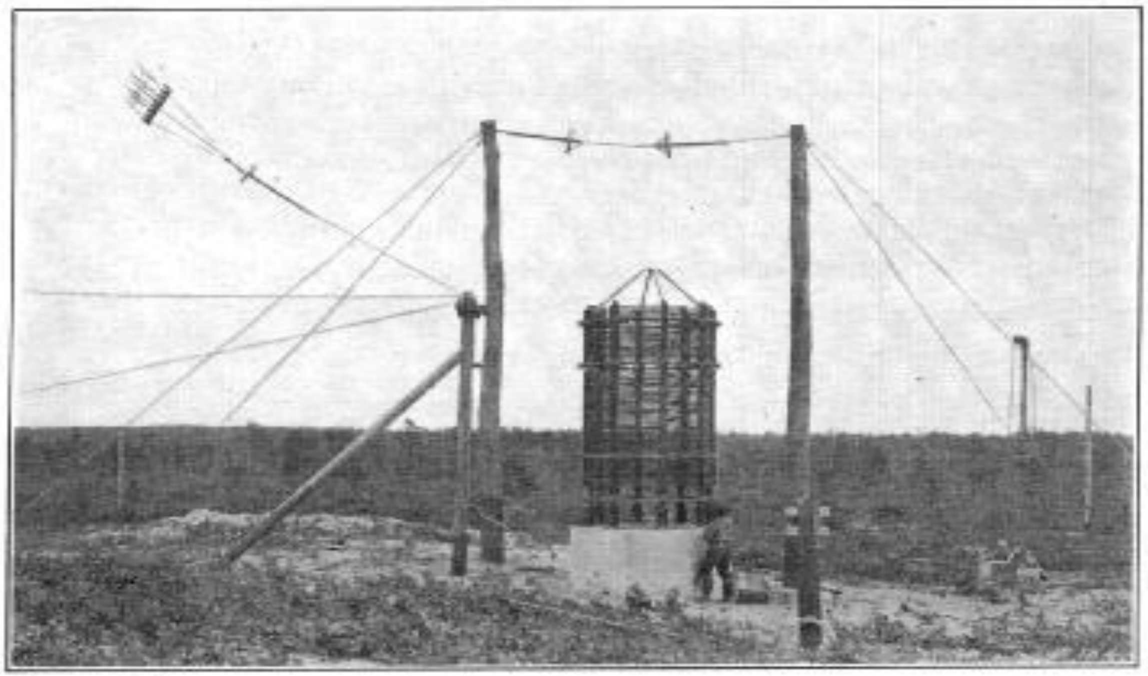


FIG. 174.—An immense transmitting tuning coil at Radio Central. Note the size, compared with the man standing at its base.

HISTORICAL NOTES: RADIO CENTRAL TRANSMITTER

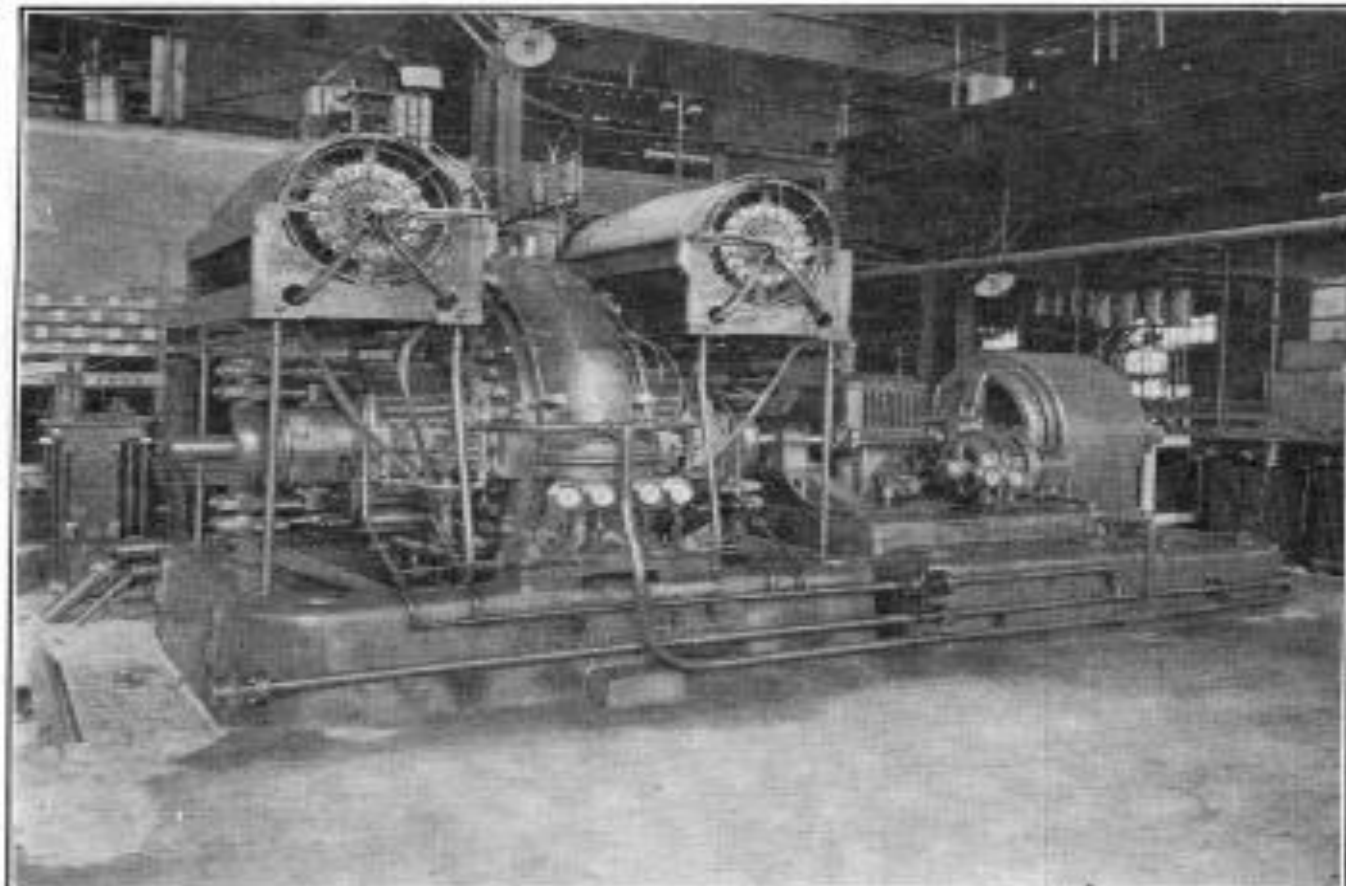
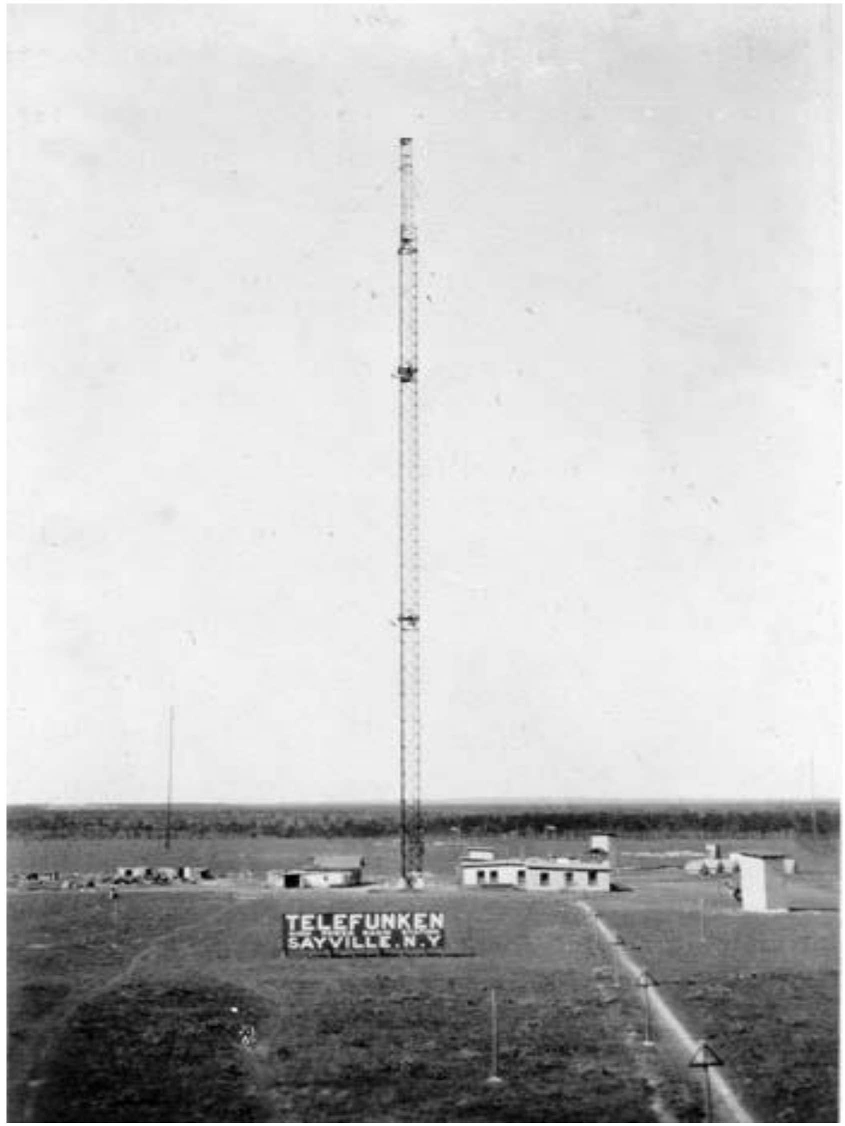
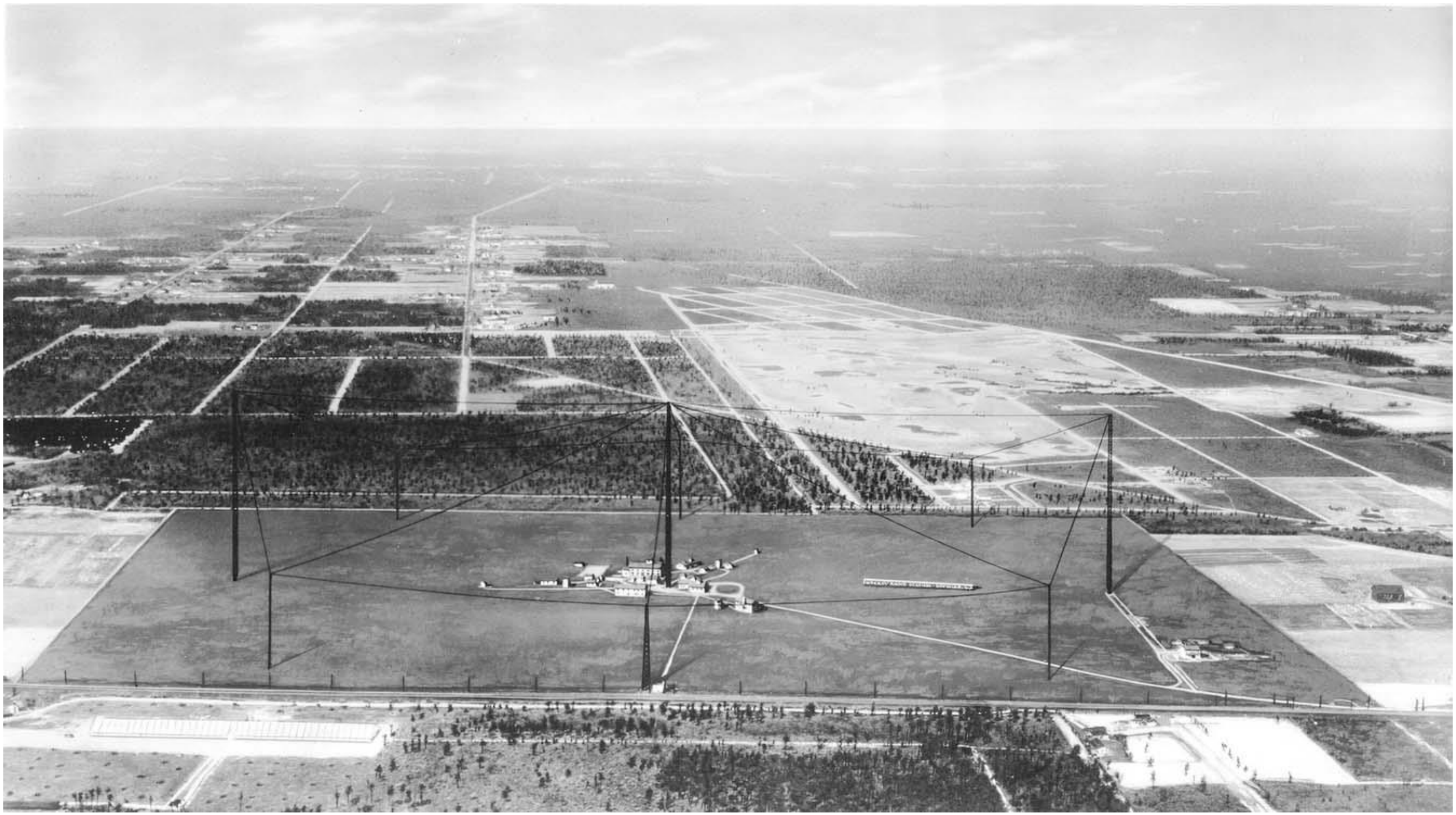


FIG. 173.—An Alexanderson high-frequency Alternator, capable of putting 700 amperes of high-frequency current into the antenna.

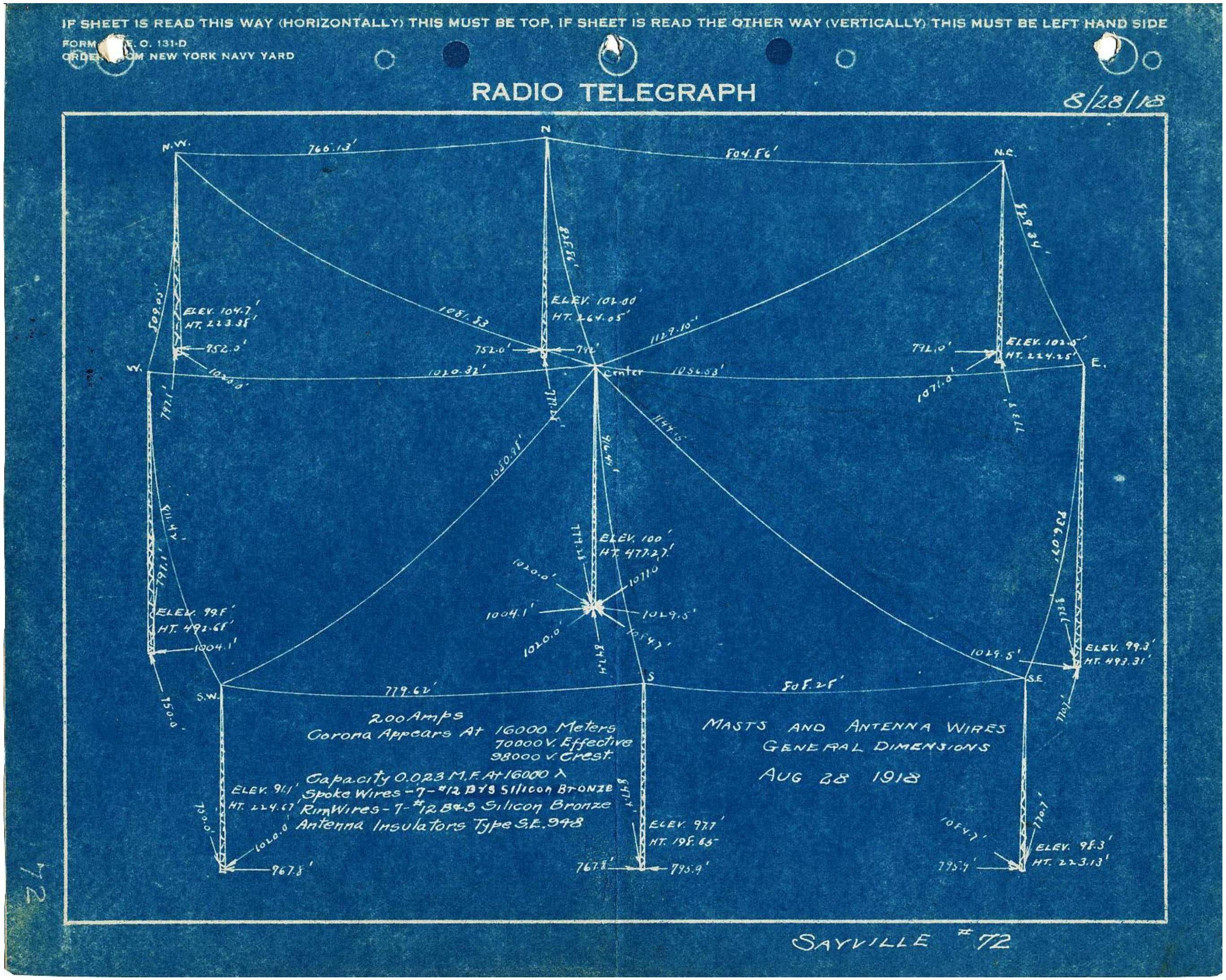
SAYVILLE TRANSMITTING SITE (1918)



SAYVILLE ANTENNA CONFIGURATION



SAYVILLE DESIGN INFORMATION- 1918



ACKNOWLEDGEMENTS

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

REFERENCES

1. H.A. Wheeler, “Fundamental Relations in the Design of a VLF Transmitting Antenna” IRE Trans. AP, vol AP-6, January 1958, pp 120-122

2. Watt, A. D., “VLF Radio Engineering”, Elmsford, N.Y., Pergamon Press, 1967

3. Peder Hansen, Doeg Rodriguez, “High Power VLF/LF Transmitting Antennas- Wheeler’s Circuit Approximations Applied to Power Limitations, IEEE AP-S Symposium, 2012

4. Jim Holmes, “New Insulators Keep Antenna System Up & Running, SPAWAR Bulletin

5. M. Mann, “Navy Builds Worlds Most Powerful transmitter”, Popular Science, pp 60-63, Sept. 1960

6. P. Hansen, R. Olsen “VLF Cutler Hollow core cable Repair Replacement” Technical Report 1681, Sept. 1994

7. P. Hansen, J. Chavez, VLF Cutler: Four-Panel tests; RADHAZARD Field Strength Measurement, Tech Report 1761, Jan 1998

8. P. Hansen, “US Navy FVLF/LF Transmitters- Large electrically Small Antennas”, SS-PAC San Diego SDSU Feb. 2010

9. Jasik& Johnson, “Antenna Engineering Handbook, 2nd edition” McGraw-Hill Book Co. 1961
   Chapter 6 H. A. Wheeler; Chapter 24 B. G. Hagaman

10. NAVELEX MANUAL 0101,113 “VLF Communication Equipment”

11. navy-radio.com and Willard Heidig

12. H. A. Wheeler Design Notes ARLAssociates.com

NEW AMATEUR LF BANDS (FCC REQUIREMENTS)

2200 meters

- Max EIRP 1 watt
- Max transmitter power 500 watts PEP
- Max antenna height 60 meters
- Height in wavelengths .027
- (VLF Cutler height .015)

630 meters

- Max EIRP 5 watts
- Max transmitter power 1500 watts PEP
- Max antenna height 60 meters
- Height in wavelengths .095

LF ANTENNA CONCLUSIONS

- Use capacitive top hat (panel) to improve bandwidth and efficiency
- Use extensive ground system to improve efficiency
- Use large inductors to reduce tuning loss
- Be careful of high voltages on antenna and tuning components
- Modeling can be used to evaluate designs