ANATOMY OF A REPEATER SITE

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VP LIMARC
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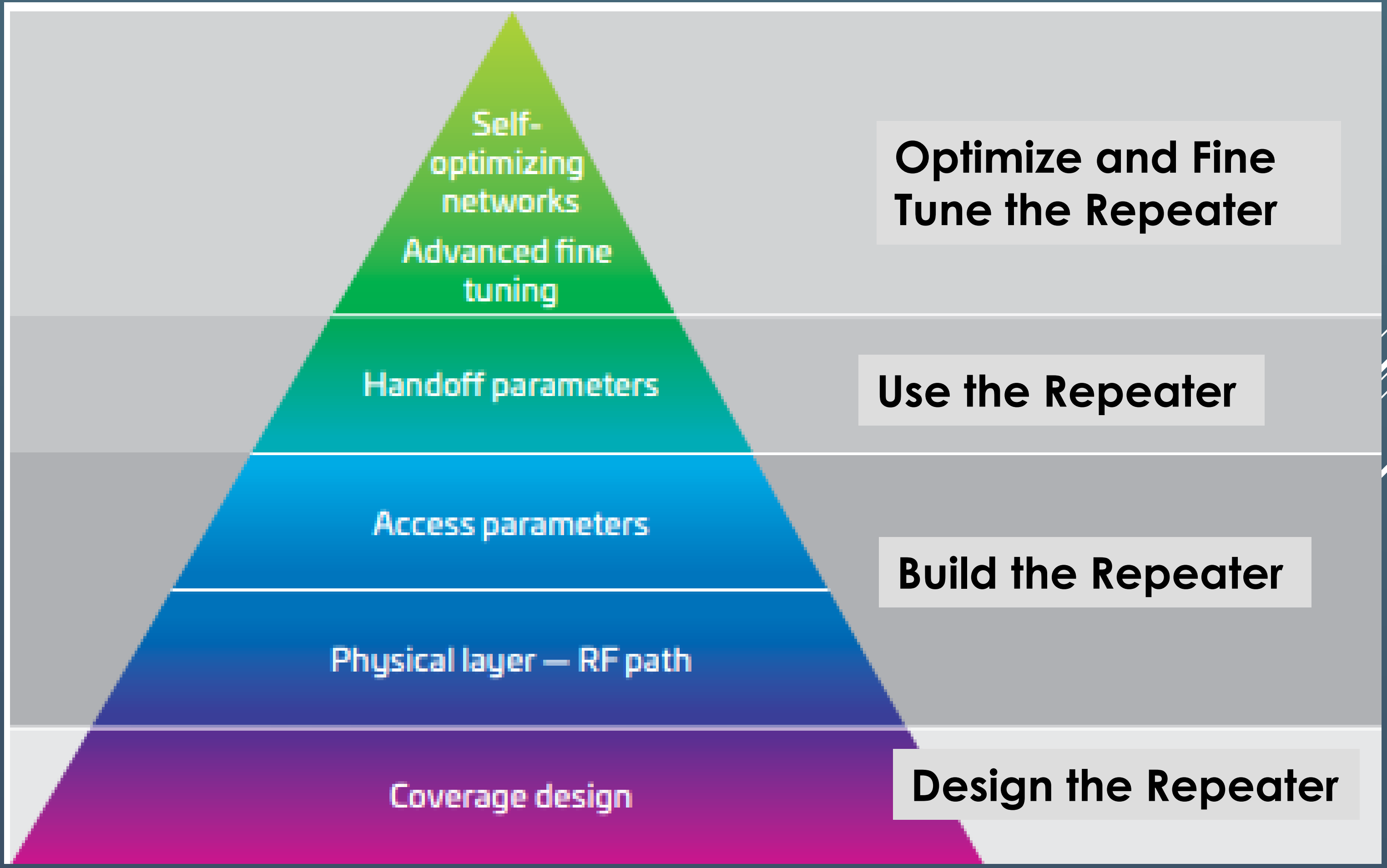
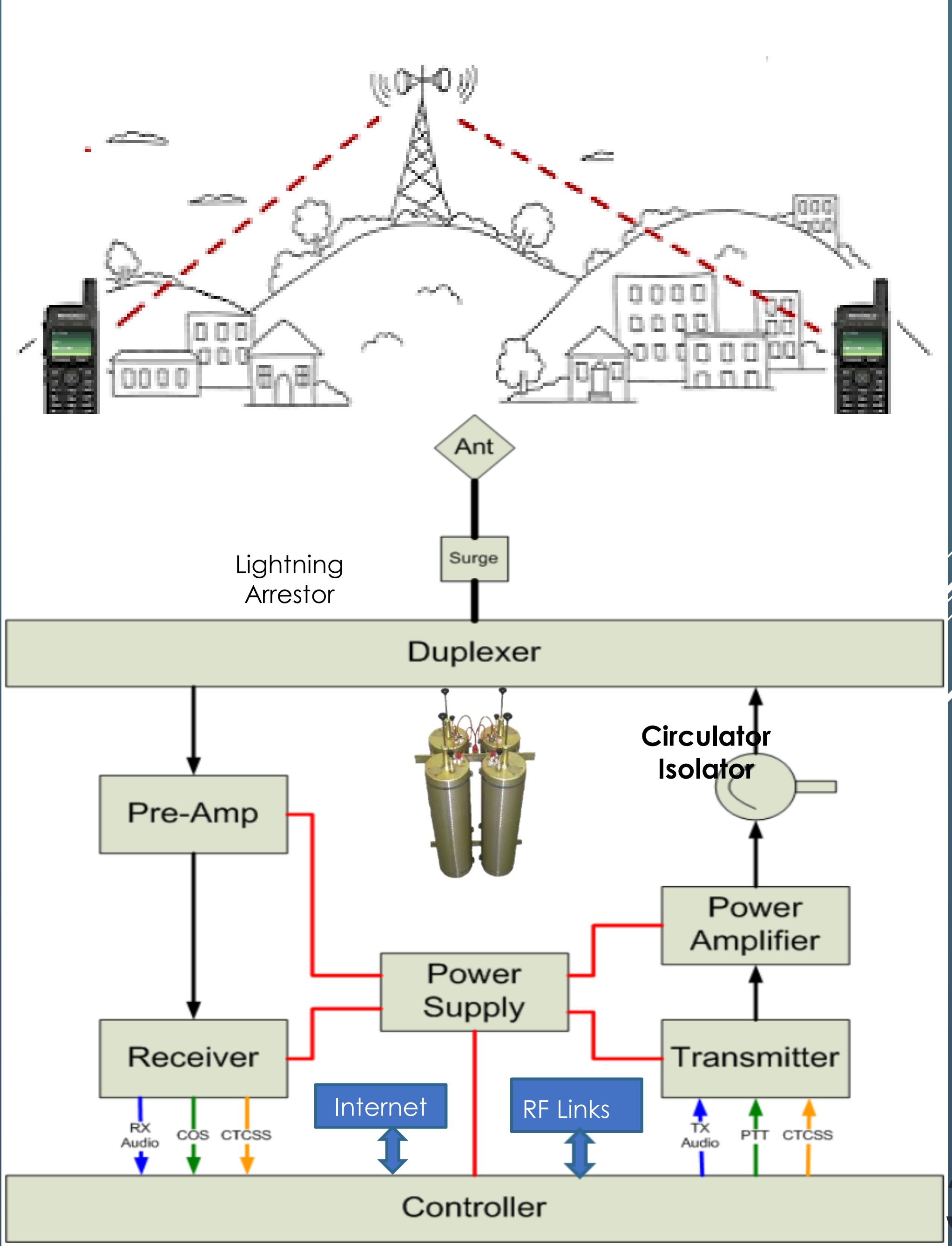
AGENDA

- What's Different about Repeaters vs. your Home Ham Radio Station
- What is a Repeater
- Coverage Area
- Site Environment
- Antenna System
- Power Source
- Receiver
- Transmitter
- Controller
- Linking
- Security
- Laws & Regulations
- Future Directions for Repeaters
- References

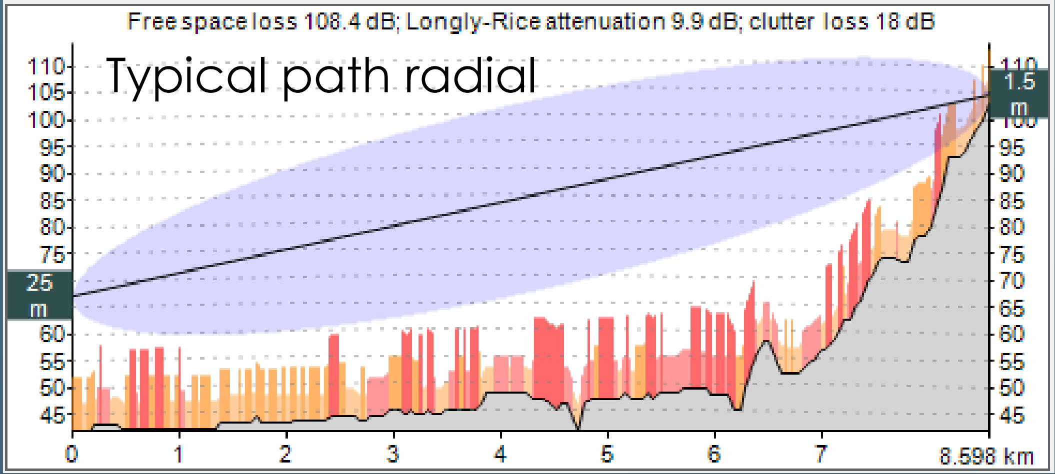


WHAT IS A REPEATER

- A radio repeater is a receiver and a transmitter that receives a signal and retransmits it to cover longer distances. A repeater at a high elevation enables radios without line-of-sight to communicate.
- Most repeater systems use two different radio frequencies; the mobiles transmit on one frequency, and the repeater receives them and transmits on a second frequency.
- Since the repeater simultaneously transmits and receives, and may use the same antenna for both, very hi-Q RF filters prevent the receiver from being overloaded by the transmitted signal.
- Many repeaters have auxiliary connectivity features such as Internet, IRLP, EchoLink, AllStar, autopatch, voting receivers, and/or RF links to other repeaters



COVERAGE AREA



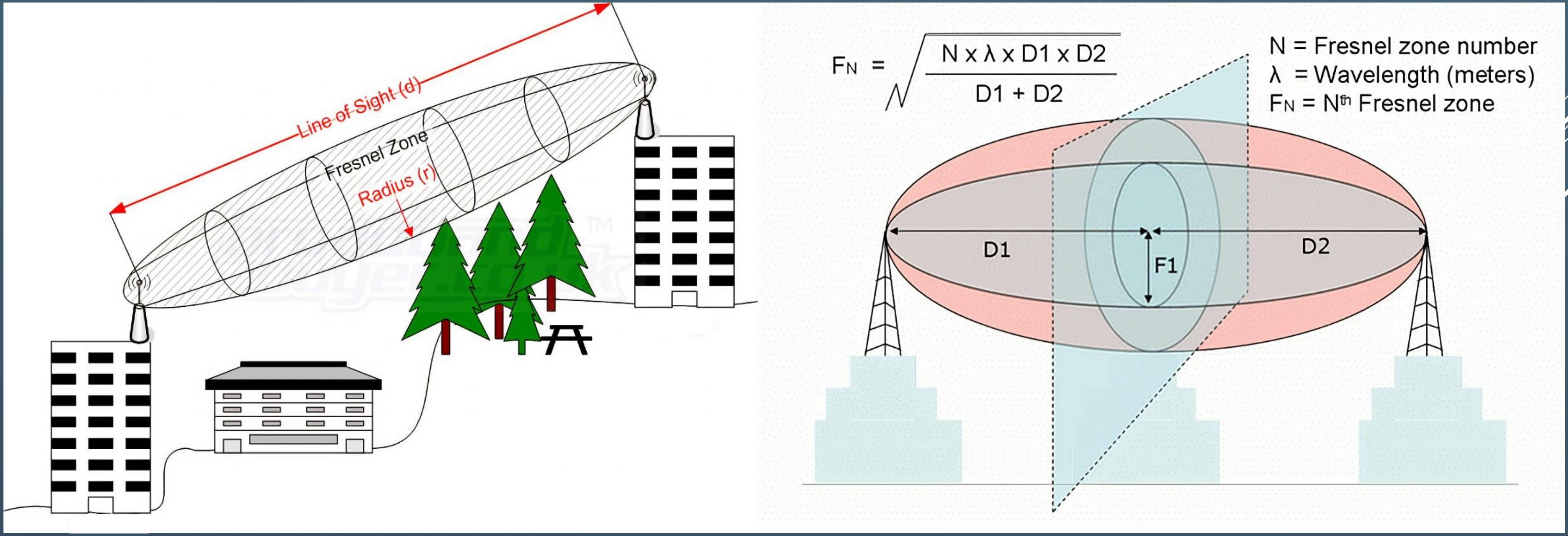
- **Determine Where Radio Coverage is Required**
  - **Line-of-Site, Power Levels, and Channel Occupancy**
- **Strength of Mobile/Portable Stations Usually Limiting Factor**
  - **Assume handheld radio** +30dBm **(1 watt) tx at a height of 1.5 meters)**
  - **Assume** -6dBi **gain handheld antenna (typical rubber-duckie)**
  - **Convert Rx sensitivity from µV to dBm:** $dBm = 20 * \log_{10}(uV) - 107$ (assume Z=50Ω)
- **Predict signal strength and line-of-site distance**

  ← path loss →

  - **Signal strength from Friis transmission equation:** $P_r^{(dBm)} = P_t^{(dBm)} + G_t^{(dBi)} + G_r^{(dBi)} + 20\log_{10}(\lambda/4\pi d)$
    Where λ **is the wavelength,** d **is the distance between Tx and x antennas (**λ **and** d **must be in the same units, power is measured at the Tx RF output jack, power referenced as** dBm **where 1 milliwatt = 0 dBm)**
  - **Line of site (distance to horizon) for** h **in meters and** d **in kilometers.** $d = 3.57\sqrt{h_t} + 3.57\sqrt{h_r}$
  - **Calculate Fresnel Zone Clearance (mid-path usually worst case)**
  - **Terrain obstacles may exist along the path –** use path mapping software:
    (https://www.qsl.net/kd2bd/splat.html) (https://www.dxzone.com/dx10770/radio-mobile.html)
    - **Perform at ≤3° Intervals for complete coverage picture (≥120 path radials from antenna site to LoS distance)**
- **Perform Site Survey**
  - **Locate likely sites, Determine suitability**

FRESNEL ZONE CLEARANCE

Objects within the Fresnel zone can disturb line of sight propagation even if they don't block the geometric line between antennas.



GLEN OAKS MOBILE COVERAGE

146.25 - 146.85

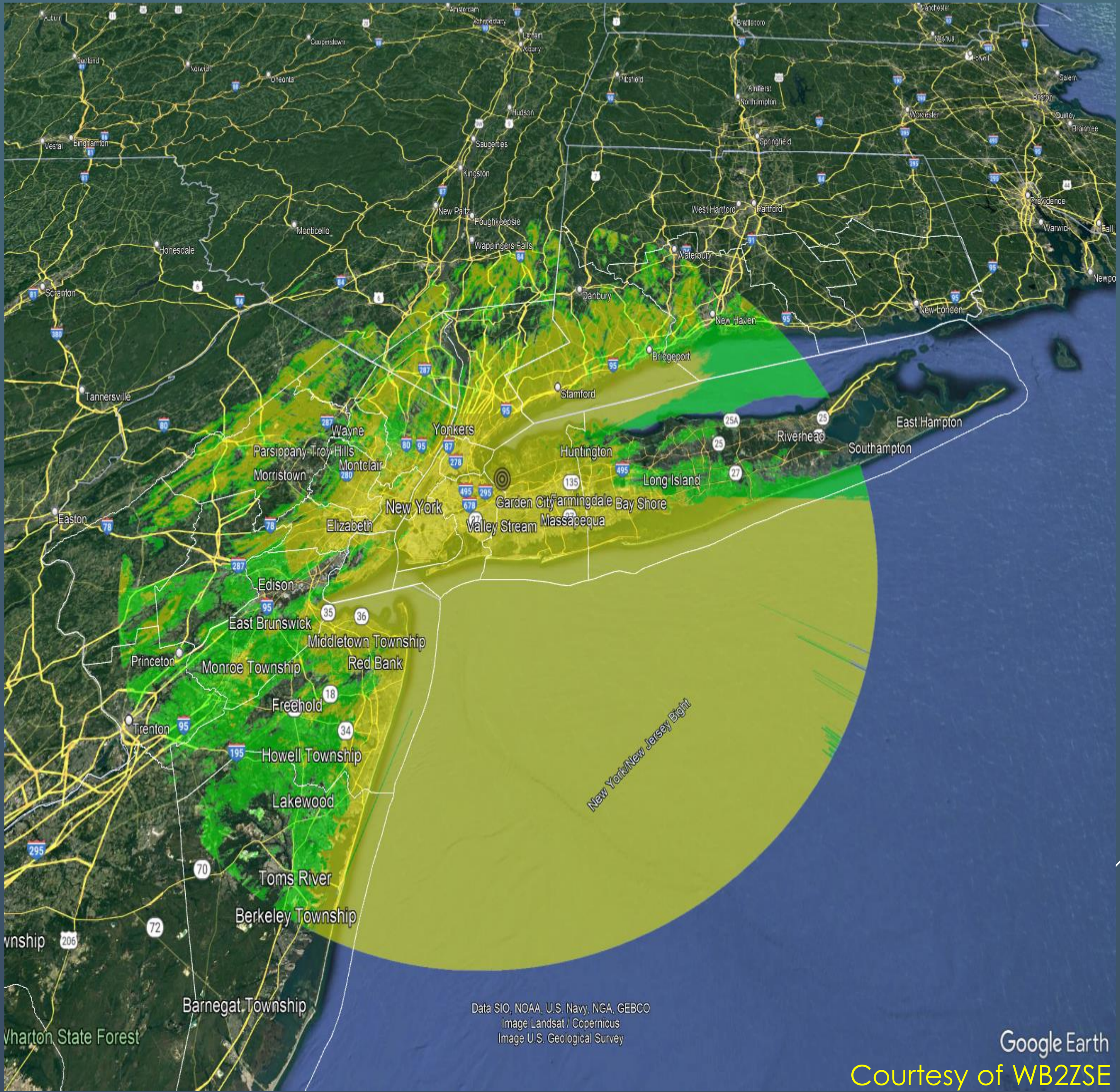
Repeater site is 78 Meters above sea level

Antenna site is 105 Meters above ground

2M Line of Site path estimated to be 48.3 Km or ≈ 30 miles

1st 2M Fresnel zone at LoS range estimated to be 24 meters

2M Receiver input power over a 42Km path estimated to be -78dBm from a 1watt hand-held radio with a Rubber - duckie antenna

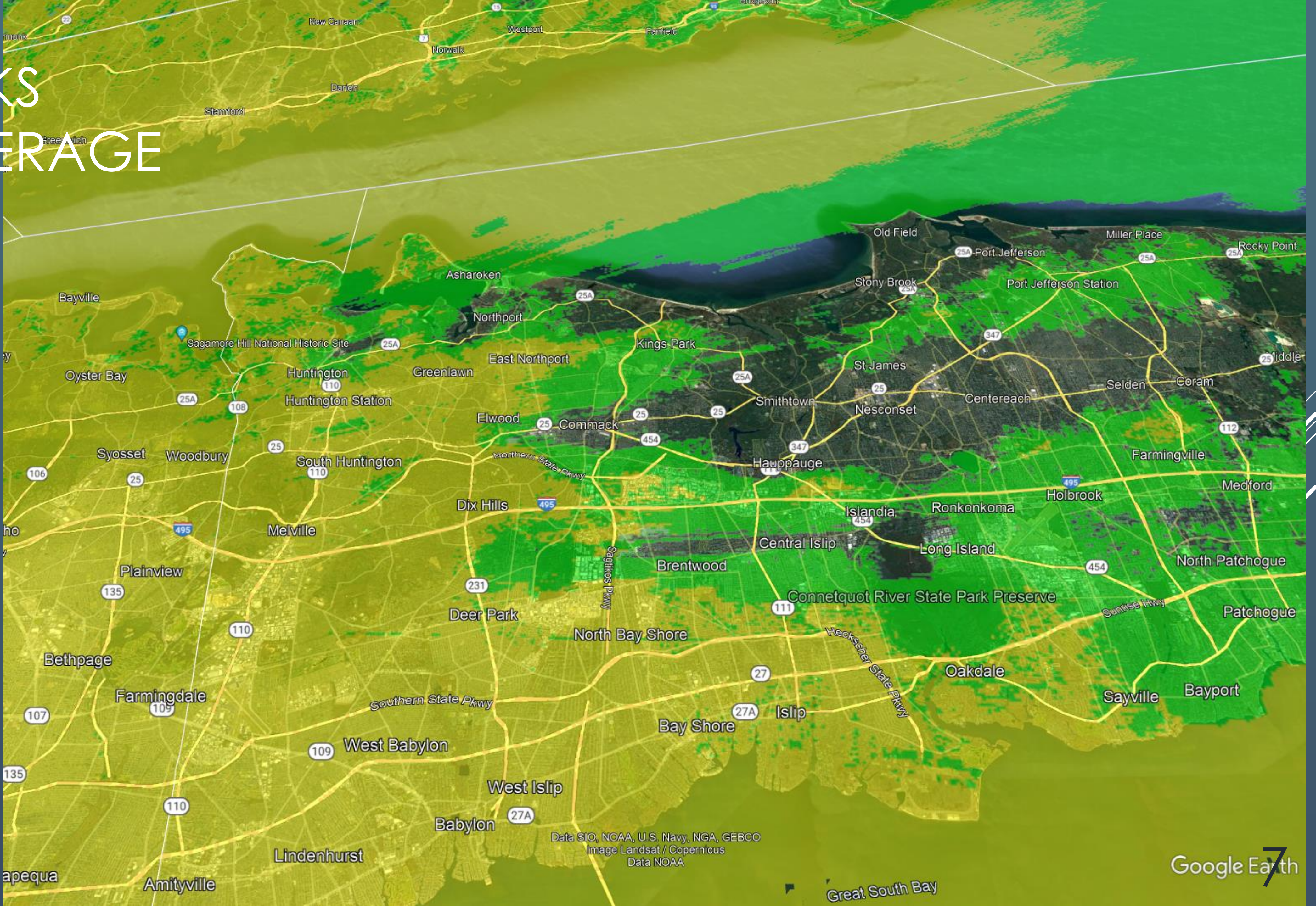


Courtesy of WB2ZSE

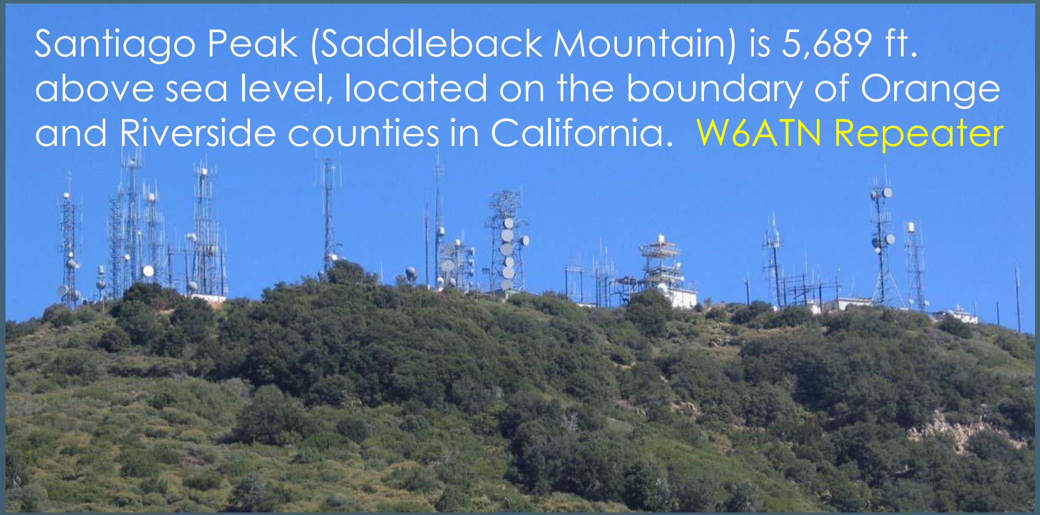
Legend
Yellow < 0 dBm
Green < -90 dBm

GLEN OAKS VHF COVERAGE CLOSE-UP

Legend
Yellow < 0 dBm
Green < -90 dBm



SITE ENVIRONMENT PICTURES



ANTENNA SYSTEM

- **Tower – TIA-222 Antenna structural support**
- **Electrical – VSWR, Gain, Pattern, Beam Tilt**
- **Feedline – dB loss, power handling, connectors, pressurized vs dielectric**
- **Mechanical – Mount to prevent Aeolian flexure, ice build-up, shadowing**
- **Environmental: Lightning Arrester**
- **Grounding & Bonding System**

Type N F/M Coaxial RF Surge Protector, 50MHz - 700MHz, DC Block, 200W, 313uJ, 50kA, Blocking Cap, Bracket Up, Hole Mount

IS-NEMP-C1-ME

HELIAX® Coaxial Cable Selection Guide - 50-ohm, Foam Dielectric

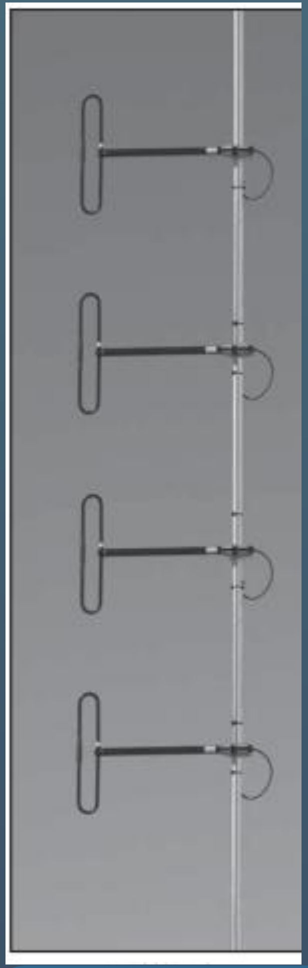
Foam Dielectric, LDF Series							
1/4" 491	3/8" 493	1/2" 496	5/8" 500	7/8" 506	1-1/4" 513	1-5/8" 520	2-1/4" 524
Standard Cables							
LDF1-50	LDF2-50	LDF4-50A	LDF4.5-50	LDF5-50A	LDF6-50	LDF7-50A	LDF12-50
Fire Retardant Cables							
LDF1RN-50	LDF2RN-50	LDF4RN-50A	LDF4.5RN-50	LDF5RN-50A	LDF6RN-50	LDF7RN-50A	LDF12RN-50
LDF1RN-50	LDF2RN-50	LDF4RN-50A	LDF4.5RN-50	LDF5RN-50A	LDF6RN-50	LDF7RN-50A	LDF12RN-50
LDF1RN-50	LDF2RN-50	LDF4RN-50A	LDF4.5RN-50	LDF5RN-50A	LDF6RN-50	LDF7RN-50A	LDF12RN-50
Low VSWR Cables, Specially Tested							
LDF1P-50-(**)	LDF2P-50-(**)	LDF4P-50A-(**)	LDF4.5P-50-(**)	LDF5P-50A-(**)	LDF6P-50-(**)	LDF7P-50A-(**)	LDF12P-50-(**)
Special Application Cables							
p. 590	p. 590	p. 590	–	p. 590	–	–	–
Characteristics							
15800	13500	8800	6100	5000	3300	2500	2200
12.1	15.6	40	62	91	205	315	425
86	88	88	89	89	89	88	88
3 (76)	3.75 (95)	5 (125)	8 (200)	10 (250)	15 (380)	20 (510)	24 (610)
Attenuation, dB/100 ft (dB/100 m) Standard conditions: VSWR 1.0; ambient temperature 20°C (68°F).							
0.667 (2.19)	0.563 (1.85)	0.357 (1.17)	0.254 (0.834)	0.195 (0.641)	0.135 (0.444)	0.109 (0.356)	0.091 (0.299)
1.23 (4.05)	1.04 (3.42)	0.661 (2.17)	0.473 (1.55)	0.364 (1.19)	0.254 (0.832)	0.205 (0.671)	0.173 (0.566)
2.71 (8.88)	2.29 (7.51)	1.45 (4.75)	1.05 (3.46)	0.808 (2.65)	0.571 (1.87)	0.467 (1.53)	0.400 (1.31)
4.16 (13.6)	3.52 (11.6)	2.22 (7.28)	1.64 (5.38)	1.25 (4.12)	0.897 (2.94)	0.742 (2.43)	0.644 (2.11)
6.10 (20)	5.17 (17)	3.25 (10.7)	2.44 (8.02)	1.86 (6.11)	1.35 (4.43)	1.13 (3.71)	0.994 (3.26)
11.5 (37.7)	9.79 (32.1)	6.11 (20.1)	4.76 (15.6)	–	–	–	–
15.7 (51.5)	13.4 (43.9)	–	–	–	–	–	–
Average Power Rating, kW Standard conditions: VSWR 1.0; ambient temperature 40°C (104°F); inner conductor temperature 100°C (212°F); no solar loading.							
3.32	4.14	6.46	9.57	14.1	22.0	30.9	39.8
1.79	2.24	3.49	5.14	7.56	11.7	16.4	21.0
0.818	1.02	1.59	2.31	3.41	5.22	7.18	9.06
0.533	0.663	1.04	1.48	2.19	3.32	4.52	5.64
0.363	0.451	0.710	0.996	1.48	2.21	2.96	3.65
0.193	0.239	0.378	0.511	–	–	–	–
0.141	0.175	–	–	–	–	–	–

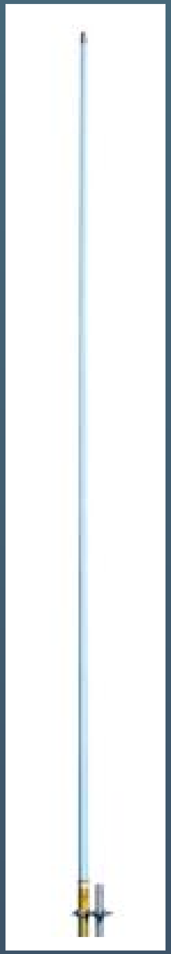
Passive intermodulation (PIM)

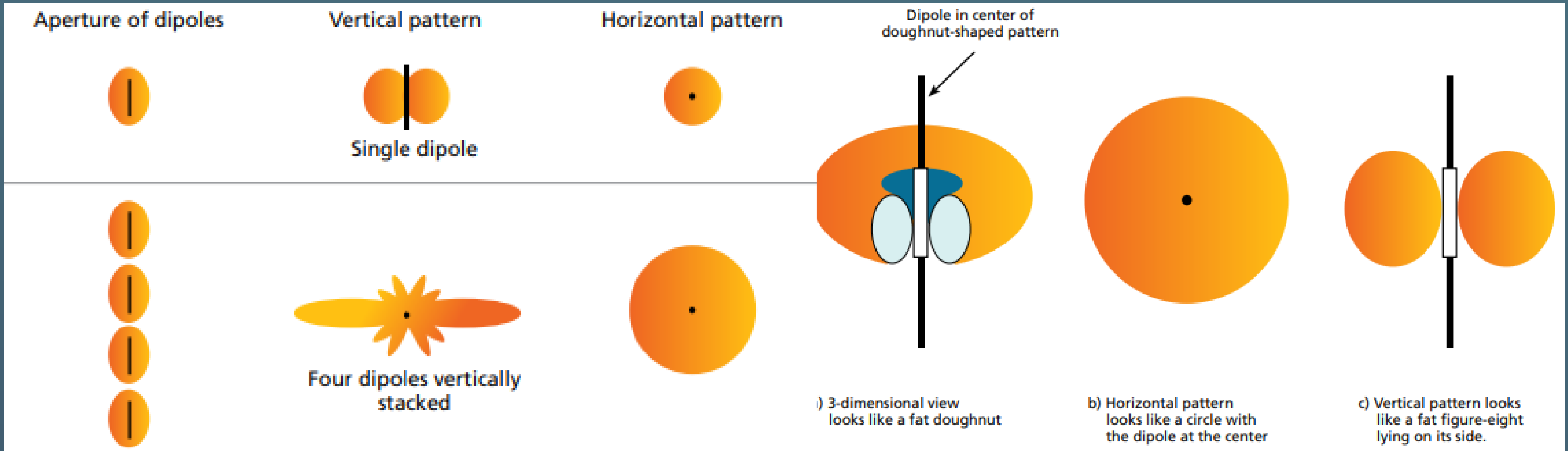
A potential side effect of having more than one high-powered signal operating on a passive device such as a cable or antenna.

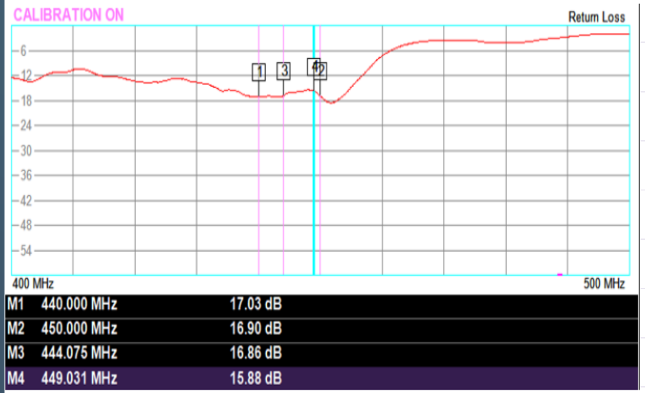
PIM occurs at non-linear points in a system, such as junctions, connections or interfaces between dissimilar metal conductors—creating interfering frequencies that can decrease efficiency. The higher the signal amplitude, or power, the greater the effect.

ANTENNAS









Courtesy WB2QGZ

17.03 dB RL= 1.328:1 VSWR, 16.90 dB RL=1.333:1 VSWR, 16.86 dB RL=1.335 VSWR, 15.88 dB=1.383:1 VSWR

Item Weight	32 lb	**Vertical Beamwidth**	20 deg
Item Height	256 in	**Maximum VSWR**	1.5:1
Item Width	2.75 in	**Maximum Rated Wind Velocity**	150 mile/h
Item Length	2.75 in	**Tuned Frequency (MHz)**	144-151
Gain dBd	6 dBd	**Lightning Protection**	DC Ground
Gain dBi	8.15 dBi	**Lateral Thrust @ RWV (lb)**	162 Lbs. @ 100 MPH
Jumper Included	Yes	**Support Pipe Dia.**	2.75"
RF Connectors	N Female	**Support Pipe Length**	26"
Polarization	Vertical	**Frequency Band**	VHF
Specific Frequency	144-151 MHz		

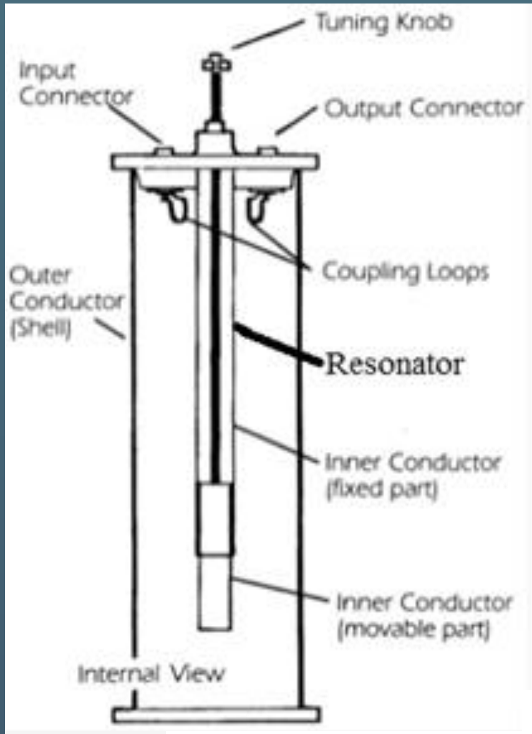
Master Antenna Systems

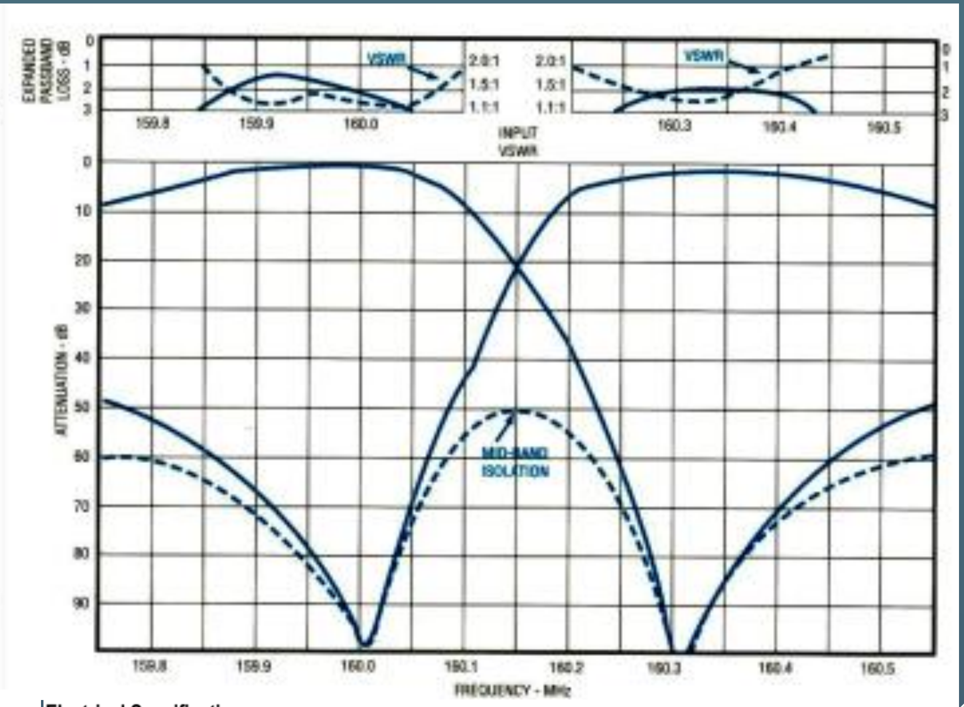
Some sites have an antenna at the top of the tower with low-loss feedline connected to a series of bandpass filters and a distribution amplifier that connects to all of the repeater receivers. The receive antenna is a broadband design that feeds cavity bandpass filters, one for each receiver.

Master receive antenna systems are usually paired with combined transmit antennas. If a master receive antenna and a shared transmit antenna (a combiner) is installed then no duplexer is needed. The combiner includes an isolator or circulator.

RF CAVITY FILTERS

The Q201 series duplexers utilizes Sinclair's Q-circuit design in a 6-cavity configuration to provide very high attenuation at extremely close frequency separation in the 132-148 MHz band. This design provides a quasi-bandpass response, resulting in suppression of spurious and sideband transmitter noise between, and adjacent to, the duplex frequencies. The typical isolation attained between duplex frequencies is greater than 50 dB.

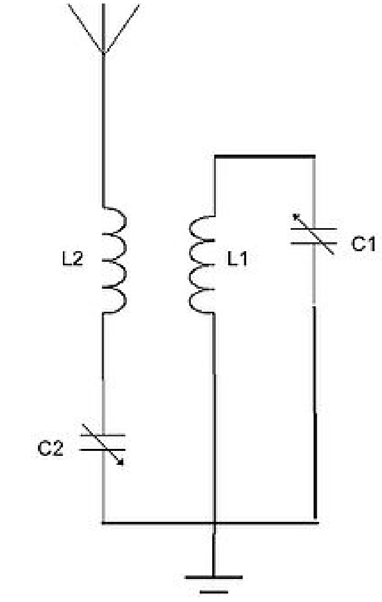




A cavity filter is a resonator inside a conducting "volumetric space" with input and output coupling loops. Higher "Q" and increased stability at closely spaced frequencies is achieved by increasing the internal volume of the filter cavities.

Physical length of conventional cavity filters varies proportionately with wavelength.

Cavities are often grouped in series with each other to increase filter effectiveness by making the pass band deeper with respect to surrounding frequencies.



Electrical Specifications		
Frequency Range	MHz	132 to 148
Input VSWR (max)		1.5:1
Impedance	Ω	50
Average Power Input (max)	W	350
Connectors		N-Female
Frequency separation (min)	MHz	0.3
Insertion Loss (max) Tx to Ant	dB	2.2
Isolation (min)	dB	95

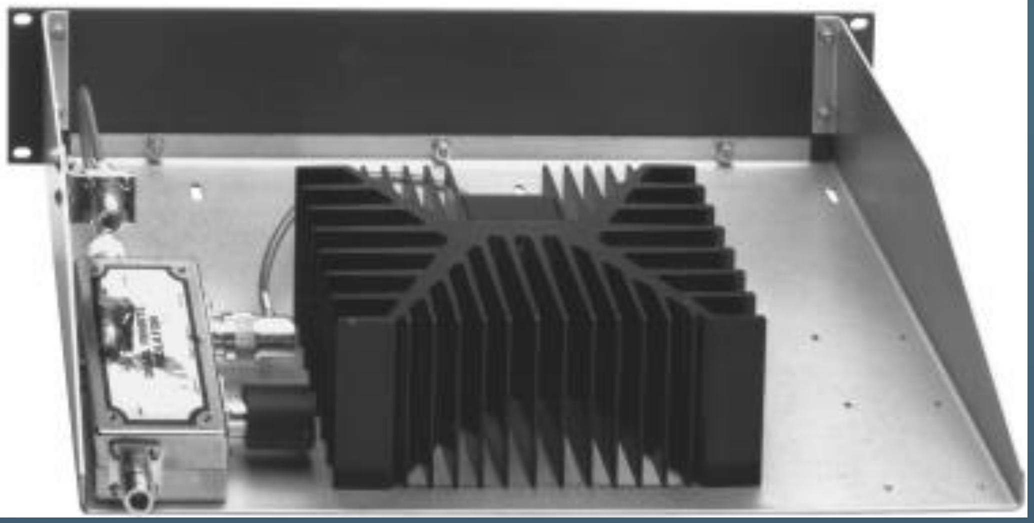
Mechanical Specifications		
Width	in (mm)	19 (483)
Depth	in (mm)	15 (381)
Length/ Height	in (mm)	61 (1549)
Weight	lbs (kg)	95 (43.13)
Shipping weight (package 1)	lbs (kg)	60 (27.24)
Shipping weight (package 2)	lbs (kg)	60 (27.24)
Shipping dimensions (package 1)	in (mm)	22x18x38 (559x457x965)
Shipping dimensions (package 2)	in (mm)	22x18x38 (559x457x965)
Mounting configurations		19 inch rack

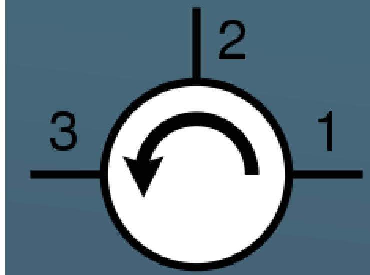
Environmental Specifications		
Temperature range	°F (°C)	-40 to +140 (-40 to +60)

CIRCULATOR / ISOLATOR

Mechanical Specifications		
Width	in (mm)	19 (483)
Depth	in (mm)	9.13 (232)
Length/ Height	in (mm)	3.5 (89)
Actual shipping weight	lbs (kg)	20 (9.08)
Electrical Specifications		
Frequency Range	MHz	132 to 174
Bandwidth	MHz	5
VSWR (max)		1.25:1
Isolation (typ)	dB	75
Average Power Input (max)	W	125
Connectors		N-Female
Insertion Loss (typ) Tx to Ant	dB	0.7
Insertion Loss (max) Tx to Ant	dB	1
Isolation (min)	dB	50

Dual stage isolator with 30+125 Watt load provides 75 dB (typ) isolation
Can be tuned over the 132-174 MHz band and comes with built-in harmonic filters

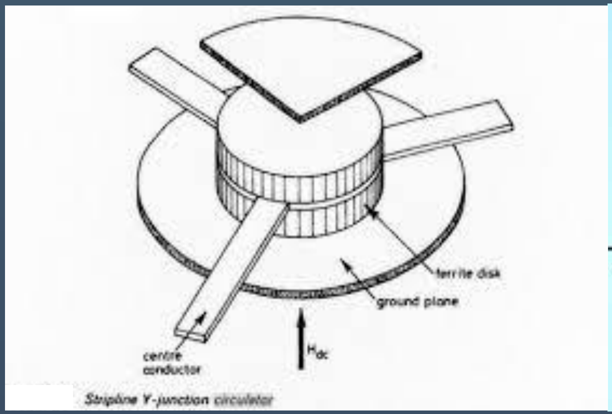




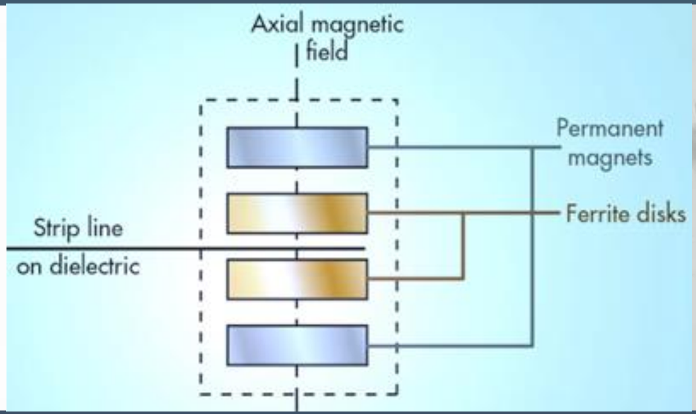
Ferrite isolators and circulators generate harmonics. These need to be followed by a bandpass or low pass filter.

The Y-junction assembly is sandwiched between two layers of ferrite material. Two strong permanent bias magnets are on either side of the ferrite disks. The magnets send a strong magnetic field axially through the ferrite disks. The ferrite material supports and focuses the magnetic field around the Y-junction.

When a signal is applied to one port, an electromagnetic field is set up in the strip line. This field interacts with the applied bias magnetic field, causing the signal to rotate in one direction to the next adjacent port.

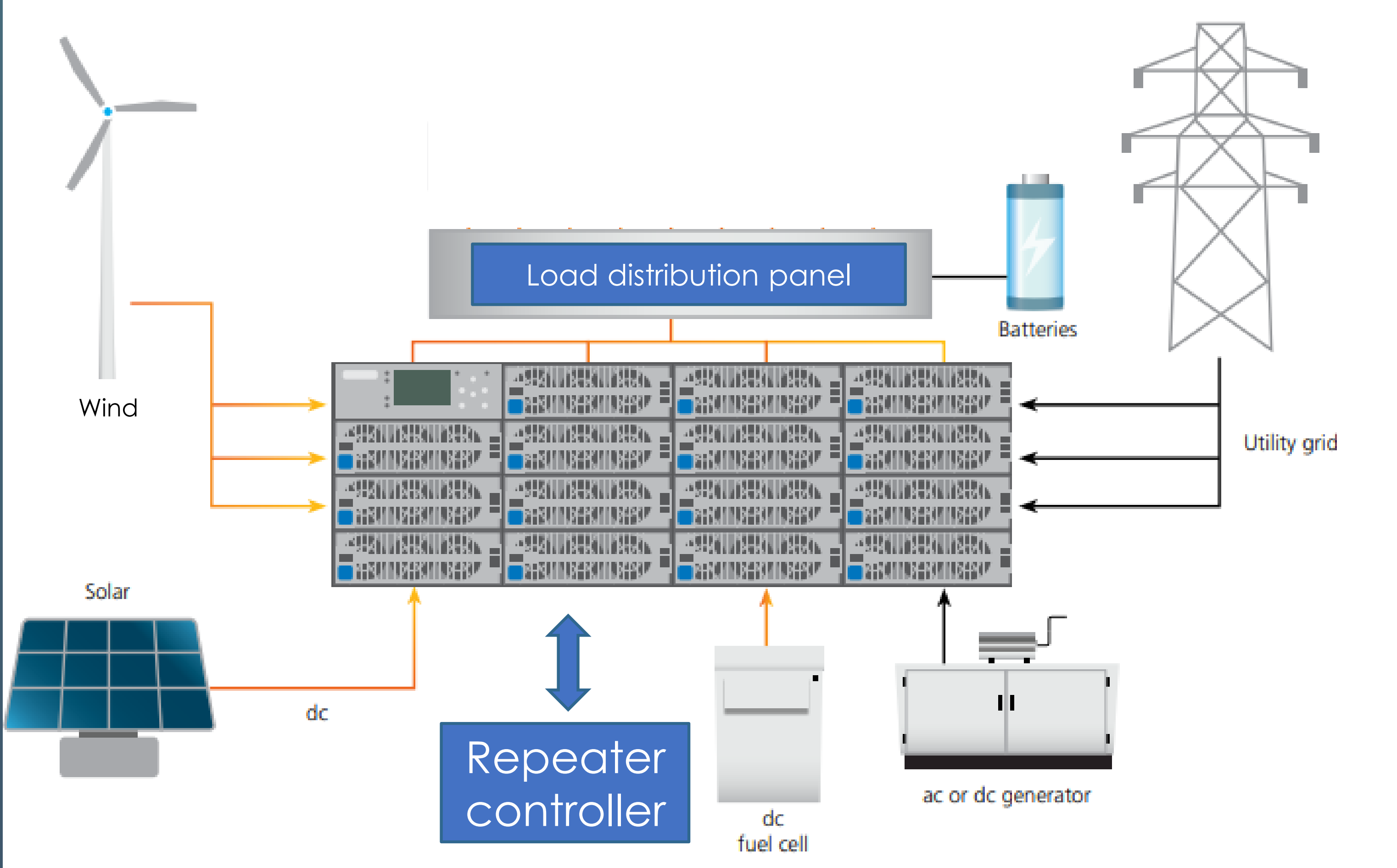


Stripline Y-junction circulator



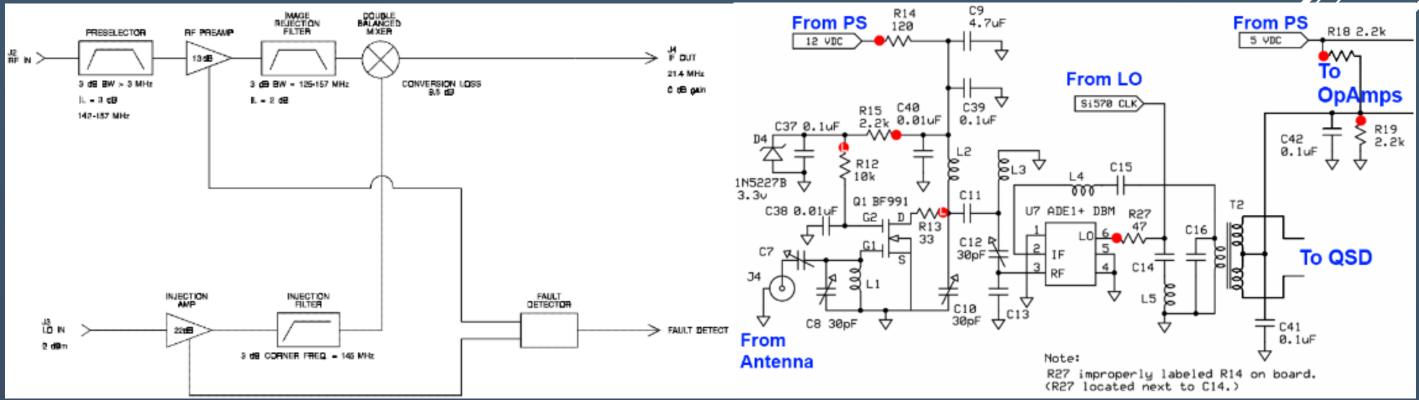
POWER

- Commercial 60Hz
  - 120 v / 240 v / 440v
  - Dedicated Circuit Breaker
  - Arc Fault/Ground Fault Breaker
  - EMI & Surge Protection
  - Locking Connectors (Twist-Lok)
- UPS
  - Battery Backup / Inverter
  - Generator / Auto Start
  - Fossil Fuel Source (runtime)
  - Transfer Switch
  - Renewable (solar / wind)
- Keep a **Log of Power Availability** with time-stamped logs of all outages, current drain, KWH used
- Document sharing arrangements (keys, fuses, breaker box access, etc.) with site users & management



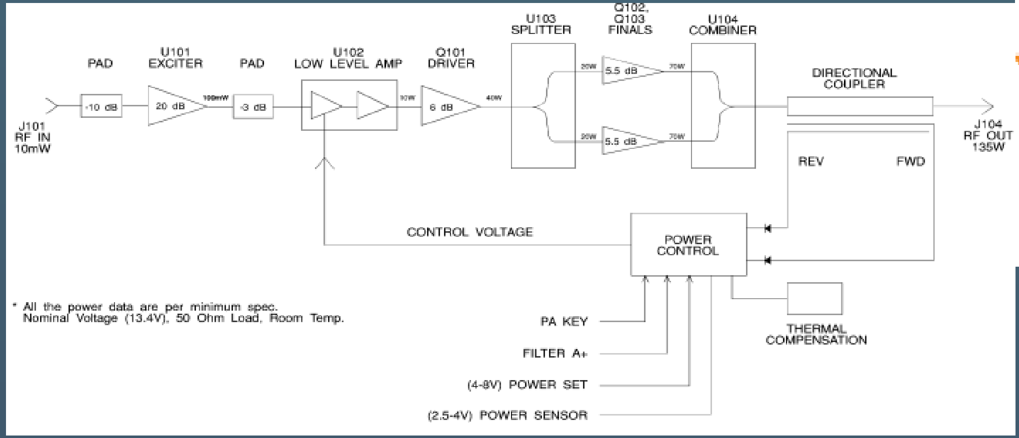
RECEIVER

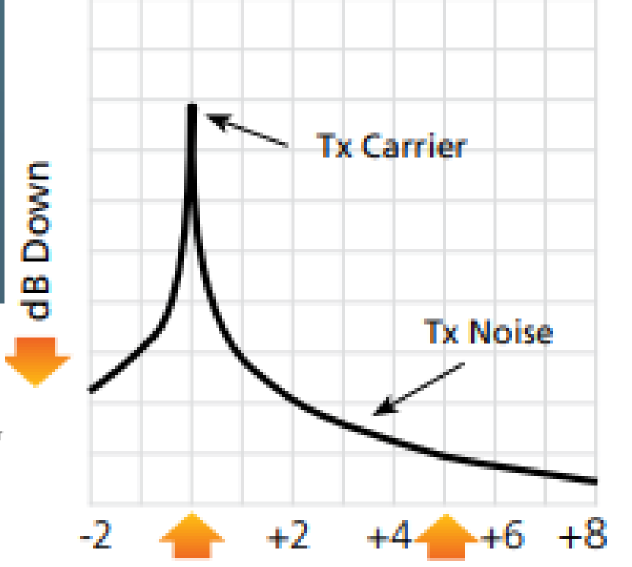
- LNA optional
- RF Input (minimum dBm for full quieting)
- Desensitization - Rx picks up noise energy from Tx thus lowering S/N ratio
- IF Output (Translator)
- Audio Output to Mixer Bus, Local Site Speaker
- Valid Carrier Detect
  - Should have RSSI in dBm sysd logged and time stamped
- PL Present /PL Output – reverse burst results in no burst of squelch noise being heard.
- Discriminator Output
- Status Outputs (test points)
- Power Supply Input



TRANSMITTER

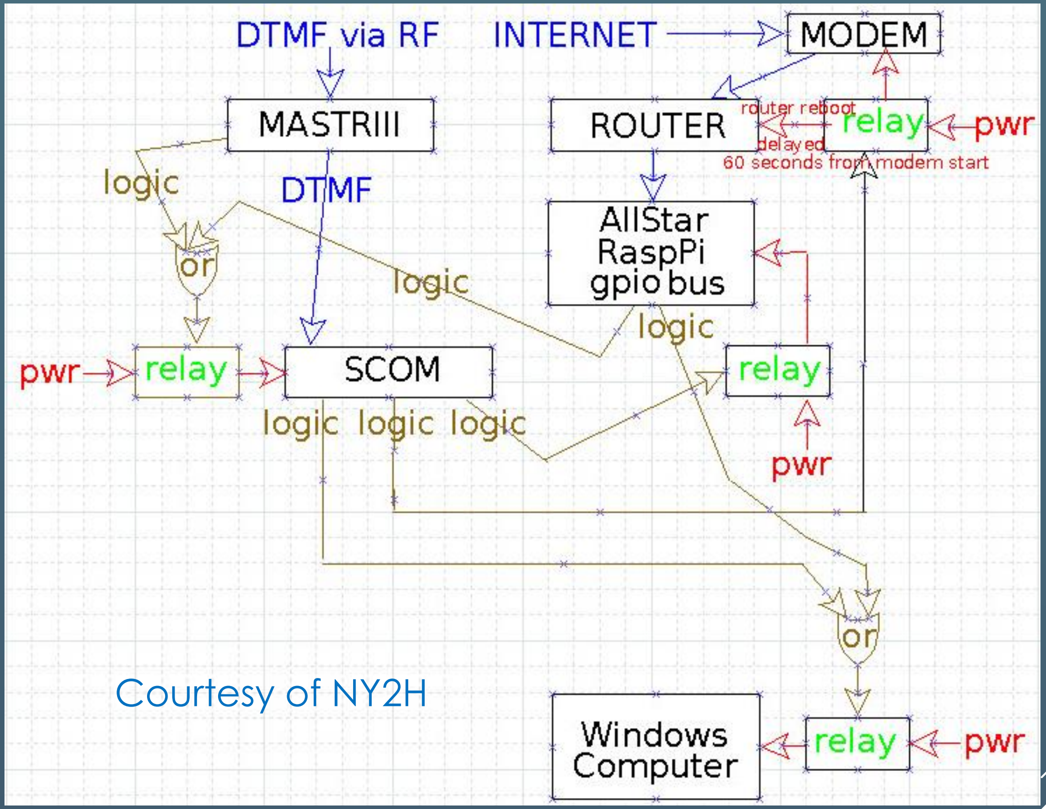
- **RF Output (1 to 250 watts, 30 dBm to 54dBm)**
- **Power Supply Input (monitor Tx current drain)**
- **Audio Input**
- **PL Handling**
- **IF Input (Translator)**
- **Carrier Enable (PTT)**
  - **Delay between PTT initialization and full power output (≈50 mSec to ≈2 Sec)**
- **VSWR Detection and Alarm notification (High VSWR power foldback)**
- **Transmitter FM, AM, and Phase Noise**
- **Status Outputs**



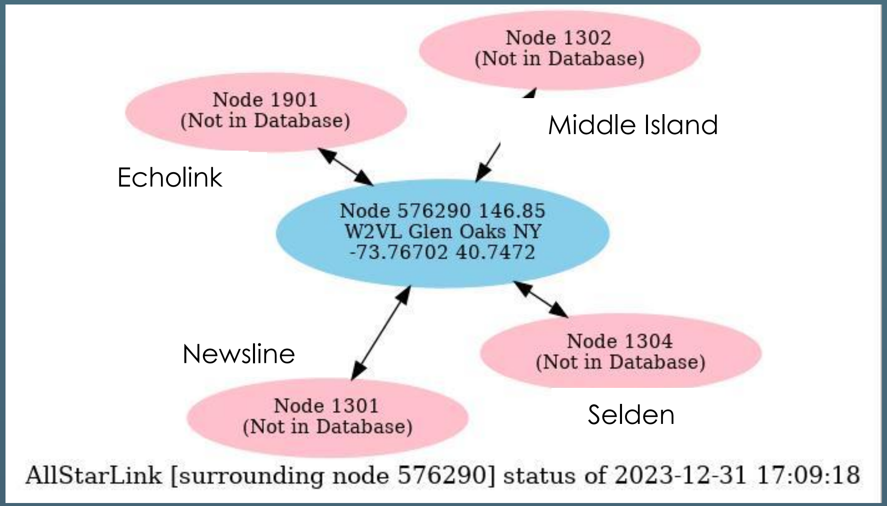


CONTROLLERS

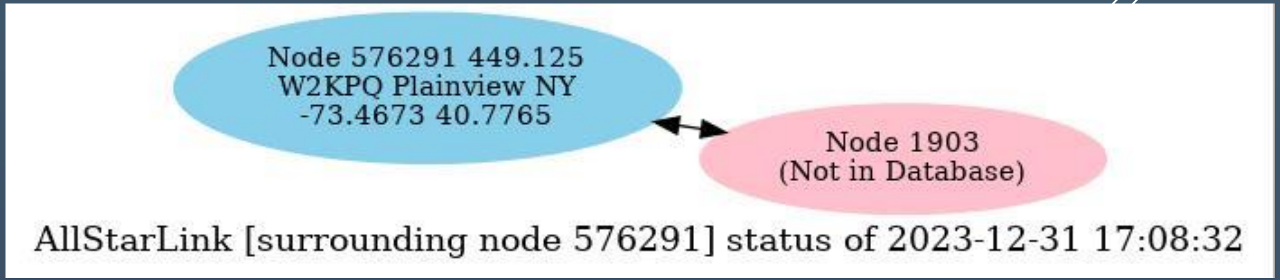
- **Key repeater Tx upon valid RX signal**
- **Required Control Functions**
  - **FCC ID every 10 Minutes**
  - **Tx Disable (as required by control op)**
  - **Timeout timer (long-winded talker protection)**
- **Local Control Panel (Spkr., PTT, Mic, Disc. Meter, Multi-meter)**
- **Control via Landline/Internet/Radio Link**
- **Over the Air Courtesy Tones**
- **Audio Mixing and Processing Bus**
- **Syslog Daemon (event recorder)**
- **Time Synchronization (NTP)**
- **Message Record/Store/Playback (news line & announcement function)**
- **Voting & Link Control**
- **Security Precautions**
  - **Physical, cybersecurity**



BACKHAUL & LINKING



- **Land Line & Answering Machine**
- **Internet Interface**
  - **Ethernet**
  - **Wi-Fi**
- ***AllStarLink* is a global network accessible via the Internet and/or private IP networks.**
  - **AllStarLink has 30,868 users and 30,487 nodes.**
  - ***AllStar* software runs on a dedicated Linux computer (such as a Raspberry Pi).**
  - ***AllStar* is based on the open source Asterisk PBX.**
  - **The core of *AllStar* and *AllStarLink* are the applications and modules in the Asterisk PBX system.**
  - **AllMon and/or SuperMon are monitoring & control software options in AllStar**
- **EchoLink - VoIP via Internet designed by Jonathan Taylor, K1RFD**
- **Internet Radio Linking Project (IRLP)**
- **VHF/UHF RF Link**
- **Wi-Fi (microwave) Link**
- **FreeSpace Optical Link**



SECURITY

- **Availability - improving MTBF**
- **Documentation & Records**
- **Cyber Security precautions for all remotely accessible devices**
  - **Keep software patches and fixes current**
- **Site Physical Security**
  - **Access alarms, Fence, Locks & Keys, Drainage**
  - **Ice shields for cable runs up tower**
  - **Remotely Controllable Surveillance Cameras**
  - **Vandal Proof, protect against Small Arms "Target Practice"**
- **Log and send alarms to control operators**
- **Insurance for Equipment, Personnel, Liability**
- **Signal Recognition for AntiJam – waveform analysis and auto lockout – enhanced by AI technology**
- **Cooperative Direction Finding via directional rx antennas, voting rx, repeater networks, time difference of arrival**

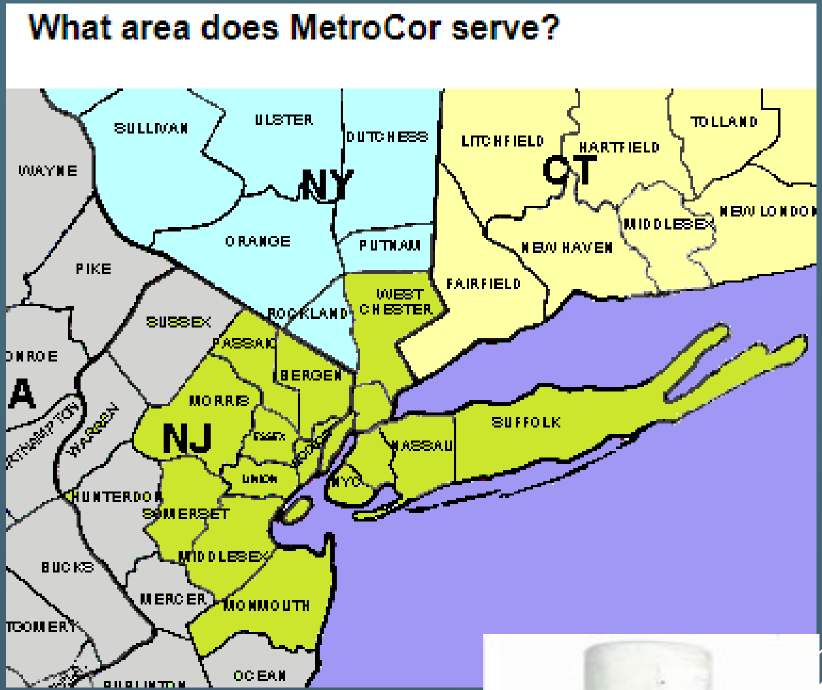
User authentication and authorization remain as a continuing problem.

FCC rules prohibit encryption within the amateur service.

LAWS & REGULATIONS

Frequency Range	Maximum Allowable Field Strength
MHz.	uV per Meter at 3 meters distance
30-88	100
88-216	150
216-960	200
>960	500

- **FCC 97.205 Repeater station**
- **RF Radiation Exposure Limitation**
- **FCC Part 15 (electronic good neighbor)**
- **FCC Part 17 (tower lights and obstruction markings)**
- **State Regulations:** PRB-1 is a legal document from the FCC that requires that local governments reasonably accommodate Amateur Radio installations has been adopted by 32 states. (but Not NY, CT, or NJ)
- **Radio Amateur Frequency Coordination (MetroCor)**
- **Site Management**
  - **Site Specific Rules**
- **Trade Unions**
  - **Equipment installation**
  - **Elevator operation**
  - **Loading Docks**



Tower structures over 200 feet (sometimes less) require FAA notification and a "no hazard" determination prior to FCC antenna structure registration (ASR).

Antenna structure owners must maintain records of tower lighting problems. The rules "require antenna structure owners to maintain a record of observed or otherwise known extinguishments or improper functioning of structure lights for two years, and to provide such records to the Commission upon request."

FUTURE CONSIDERATIONS

Use of AI Technologies

Implementation of AI algorithms for automatic signal enhancement, noise reduction, and adaptive filtering to improve overall communication quality. AI Speech recognition could be employed to curb repeat offender jammers.

Automatic Frequency Adjustment

Systems that dynamically adjust receive frequencies based on following received signal frequency to avoid off-channel signal distortion.

Integrated GPS for Location-Based Services

Integration of GPS technology into mobile and hand held units to provide location information for emergency services, tracking, and location-based features.

Enhanced Emergency Communication Features

Improved emergency alert systems, possibly with automated weather alerts, geofencing capabilities, and on-demand integrated interfaces with public safety networks.

User Authentication and Access Controls

Implementation of more robust user authentication systems, possibly incorporating voice recognition biometrics, to enhance security and prevent unauthorized access.

Voice Command Capabilities

Integration of over-the-air voice-activated commands for hands-free operation, facilitating ease of use and accessibility

Collaborative Repeater Networks

Development of protocols and standards to enable seamless collaboration between different repeater networks, promoting interoperability and expanded coverage. International networks with automatic speech translation on demand are anticipated.

Log and Time Stamp Everything that Happens

Event recorder style logs facilitate both troubleshooting and collection of demographic data

FUTURE DIRECTIONS FOR REPEATERS (TAPR)

It's insane that Amateur Radio VHF / UHF spectrum is technologically divided by incompatible modes. A radio built for Digital Mobile Radio (DMR) cannot operate using digital voice on a repeater built for D-Star. And only D-Star (partially) makes an accommodation for data over D-Star repeaters. Some features of a "Century 21" (C21) repeater:

- **Based on Open Source and SDR technology** - the operational parameters of the repeater can be updated with software. While the reality of repeater operations in high-density sites probably preclude easily changing transmit frequencies, an SDR receiver(s) are a normal part of a C21 repeater. Thus repeaters can be linked, perhaps even dynamically, by listening to another repeater's transmissions.

- **Single-frequency repeaters** - now feasible using Time Division Duplex (TDD) protocols. This has been demonstrated by modifying DMR's two time slots (normally used for two independent channels) for simultaneous Rx and Tx on a single channel.

- **C21 repeaters can be aggregated.** (channel bonding) For example, digital video requires a minimum bandwidth which isn't available on a single repeater (using conventional 25 kHz channels). C21 repeaters can, on demand, aggregate together to provide greater bandwidth such as 4 repeaters at a single site aggregating into a 100 kHz channel.

- **C21 repeaters can transfer data as easily as voice** - "bits are bits" - voice is just another bitstream with a "voice" tag. C21 repeaters are also usable not just for human use, but for Amateur Radio computers to "file sync". In the wee hours when there is little human usage, C21 user radios use otherwise wasted airtime to transmit Amateur Radio call sign database updates, bulletins, low-priority email messages, satellite predictions, tutorials, etc. The airtime has no extra cost, and demonstrates a unique Amateur Radio capability.

- **User radios for C21 repeaters** can be less expensive because they're based on open source designs that are largely software - basically fast Digital to Analog (D/A) and Analog to Digital (A/D) converters, a Field Programmable Gate Array (FPGA), a processor, and a power amplifier… all of which are getting cheaper and cheaper. The rest is software.

- **Experimentation** is encouraged. C21 repeaters, and user radios, are software defined, and based on Open Source, thus the barrier to changing something about the operation of a repeater or a radio is low; if something doesn't work, the base level of software can easily be reloaded.

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