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Amateur Radio Exam Course — USA, General Class

FCC Element 3, General Class: one chapter for each of the 35 topic groups of the official NCVEC 2023-2027 question pool.

Author, contact and licence

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Commission's Rules

G1A General class frequency privileges

HF privileges of a General

Band	CW and data	Phone and image
160 m	1.800 to 2.000 MHz	1.800 to 2.000 MHz
80 m	3.525 to 3.600 MHz	3.800 to 4.000 MHz
40 m	7.025 to 7.125 MHz	7.175 to 7.300 MHz
30 m	10.100 to 10.150 MHz	No phone or image
20 m	14.025 to 14.150 MHz	14.225 to 14.350 MHz
17 m	18.068 to 18.110 MHz	18.110 to 18.168 MHz
15 m	21.025 to 21.200 MHz	21.275 to 21.450 MHz (for example 21,300 kHz)
12 m	24.890 to 24.930 MHz	24.930 to 24.990 MHz
10 m	CW: the entire band ; data: 28.000 to 28.300 MHz	28.300 to 29.700 MHz

- **80, 40, 20 and 15 m** have segments reserved for **Amateur Extra** licensees; there, Generals cannot transmit.
- Generals may **not** be control operators on **7.125 to 7.175 MHz**.
- When Generals do not get a whole voice segment, they get its **upper** part.
- On 10 m, **repeaters** operate **above 29.5 MHz**.

Secondary bands

Where the amateur service is **secondary**, amateurs must **not cause harmful interference** to primary users and must **accept** their interference.

Source: 47 CFR §97.205, §97.301(d), §97.303, §97.305(c).

G1B Antennas, beacons and permitted transmissions

Antenna structures

- Away from public-use airports, an antenna structure up to **200 feet** above ground needs no FAA notification or FCC registration.
- Under **PRB-1**, state and local governments must **reasonably accommodate** amateur communications, with the **minimum practical** regulation for a legitimate purpose.

Beacons

- Purpose: **observing propagation and reception**.
- Automatically controlled HF beacons: **28.20 to 28.30 MHz**.
- Power limit: **100 W PEP**.
- Only **one beacon** per band from the same station location.

Permitted transmissions

- One-way transmissions to help people **learn Morse code**.
- **Occasional** retransmission of **weather and propagation forecasts** from US government stations.
- Abbreviations and procedural signals, if they **do not obscure the meaning** of a message.
- Contacts with amateurs in any country, except those whose administrations have **objected** to the ITU.

Good practice

The **FCC** determines "good engineering and good amateur practice" for anything Part 97 does not cover.

Source: 47 CFR §97.3(a)(9), §97.15, §97.101, §97.111, §97.113, §97.203; PRB-1, 101 FCC 2d 952 (1985).

G1C Power limits and digital protocols

Power

Power limits are measured as **PEP output** from the transmitter.

Band	Maximum power
30 m (for example 10.140 MHz)	200 W PEP
160 m, 12 m, 10 m (General)	1,500 W PEP

60 meters

- On USB, the maximum bandwidth is **2.8 kHz**.
- If you use an antenna other than a dipole, **keep a record of its gain**.

New digital protocols

Before using a new digital protocol on the air, **publicly document** its technical characteristics.

Source: 47 CFR §97.303, §97.309, §97.313.

G1D Volunteer examiners, upgrades and remote operation

Volunteer examiners (VE)

- VEs are accredited by a **Volunteer Examiner Coordinator (VEC)**.
- Minimum age: **18**.
- A General VE may administer **Technician** exams only.
- A Technician exam must be observed by **at least three VEs** of General class or higher.
- A non-US citizen can be a VE if they hold an FCC **General or higher** license.

Upgrades and credits

- A **CSCE** (Certificate of Successful Completion of Examination) is valid **365 days** for exam credit.
- With a CSCE for General, a Technician may operate on **any General or Technician segment**, identifying with "**AG**" after the call sign until the upgrade shows in the database.
- Anyone who once held a General, Advanced or Extra license that was not revoked gets **partial credit**.
- After the two-year grace period, to get a new General license, show proof of the expired license and pass the current **Element 2** exam.

Remote operation

- Operating a US station from abroad: the control operator needs a **US license**.
- Operating a station in South America from the US: only the **remote station's country** rules apply.

Source: 47 CFR §97.7, §97.9, §97.119, §97.501 to §97.509.

G1E Third parties, automatic control and special rules

Third-party traffic

- Messages to a country with a third-party agreement must relate to **amateur radio**, **remarks of a personal character**, or **emergencies and disaster relief**.
- A person whose amateur license was **revoked** and not reinstated may not be a third party.
- Third-party messages via remote control are allowed **whenever** third-party messages are allowed.

Repeaters and automatic control

- A **10 m repeater** may retransmit a 2 m signal from a Technician only if its own control operator holds at least a **General** license.
- Automatically controlled RTTY or data stations may talk to each other **anywhere on 6 m and shorter**, and in limited **HF** segments.
- Outside those segments, the station that starts the contact must be under **local or remote control**.

Other rules

- North and South America are in **ITU Region 2**.
- Take specific steps to avoid harmful interference **within one mile of an FCC monitoring station**, on bands where amateurs are **secondary**, and when transmitting **spread spectrum**.
- Amateurs may **not** communicate with unlicensed Wi-Fi stations on 2.4 GHz.
- Spread spectrum is limited to **10 W PEP**.
- Avoid **14.100, 18.110, 21.150, 24.930 and 28.200 MHz**: international **propagation beacons** use them.

Source: 47 CFR §97.13, §97.101, §97.111, §97.115, §97.117, §97.205, §97.221, §97.301, §97.303, §97.305, §97.311, §97.313; ITU Radio Regulations.

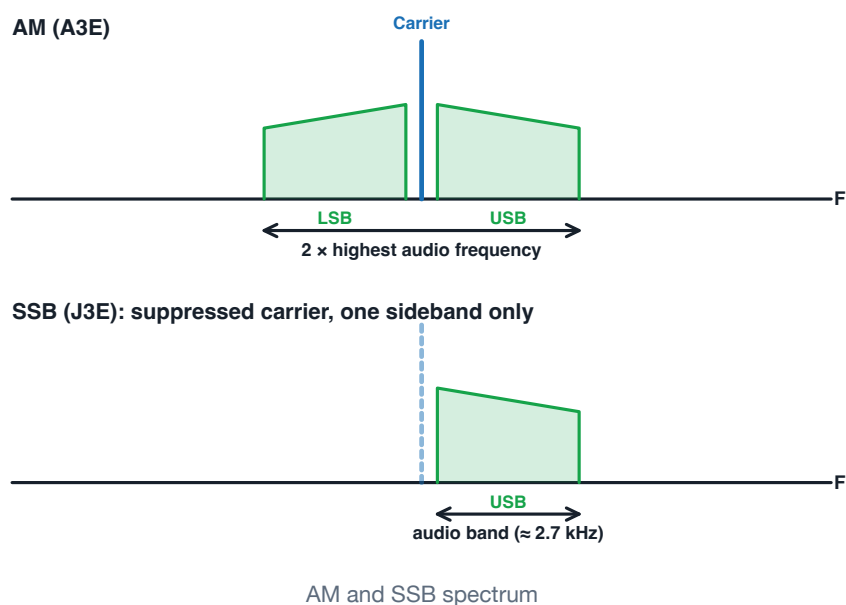
Operating Procedures

G2A Phone operation

Which sideband?

Bands	Usual voice mode
160, 75 and 40 m	Lower sideband (common practice)
14 MHz and up (20, 17, 15, 12, 10 m)	Upper sideband
VHF and UHF SSB	Upper sideband

- **SSB** is the most common voice mode on HF: it uses **less bandwidth** and is **more power-efficient**; only one sideband is sent, the carrier and the other sideband are suppressed.



On the air

- To break into a phone contact: say your **call sign once**.
- **VOX** allows **hands-free** operation.
- A station in the lower 48 calling "**CQ DX**" wants stations **outside** the lower 48.
- Set **ALC** with the **microphone gain** (transmit audio).

Source: NCVEC 2023-2027 General question pool (subelement G2).

G2B Operating courtesy and emergencies

Frequencies

- Except in emergencies, **no station has priority** on any frequency.
- If propagation brings interference, try to resolve it **with the other stations** in a mutually acceptable way.
- Follow the **voluntary band plan** when choosing a frequency.
- On 50.1 to 50.125 MHz, stations in the 48 contiguous states contact only stations **outside** the 48 states.

Mode	Minimum separation
CW	150 to 500 Hz
SSB	2 to 3 kHz

- Before calling CQ: send "**QRL?**" and your call sign on CW, or **ask if the frequency is in use** on phone.

Distress and nets

- If a station in distress breaks in: **acknowledge** it and find out what help it needs.
- A net should have a **backup frequency**.

RACES

- Only a person holding an **FCC amateur license** may be the control operator of a RACES station.
- RACES drills and tests: **no more than 1 hour per week** without special authorization.

Source: 47 CFR §97.101, §97.407.

G2C CW operation and Q signals

- **Full break-in** (QSK): the transmitting station hears **between code characters and elements**.
- Answer a CQ at the **fastest speed you copy comfortably**, but **no faster than the CQ**.
- **Zero beat**: matching your transmit frequency to a received signal.
- A "C" after an RST report means a **chirpy** or unstable signal.

Signal	Meaning
KN	Listening only for a specific station
AR	End of a formal message
QRS	Send slower
QRL?	Are you busy? Is this frequency in use?
QSL	I have received and understood
QRN	I am troubled by static
QRV	I am ready to receive

Source: NCVEC 2023-2027 General question pool (subelement G2).

G2D Monitoring, logs and contacts

Volunteer Monitor Program

- Amateur volunteers **formally enlisted** to monitor the airwaves for rule violations.
- Goal: encourage amateurs to **self-regulate** and comply.
- To find a station holding a repeater on, monitors **compare beam headings** on the repeater input from several locations.

Contacts

- General call on HF: "CQ" a few times, "this is", your call sign a few times, then **pause to listen**.
- **Signal reports** at the start of a contact let each station adapt to conditions.
- In a contest, identify **according to normal FCC rules**.
- **QRP** means **low-power** operation.
- The **NATO phonetic alphabet**: Alpha, Bravo, Charlie, Delta...

Maps and logs

- An **azimuthal projection** map shows **true bearings and distances** from a given location.
- For a **long-path** contact, point the antenna **180°** from the short path.
- A **station log** helps you answer if the FCC asks about your station.

Source: NCVEC 2023-2027 General question pool (subelement G2).

G2E Digital mode operation

RTTY

- Sent as AFSK with an SSB transmitter: **LSB**.
- Common shift on HF: **170 Hz**.
- If it will not decode: mark and space may be **reversed**, the **baud rate** may be wrong, or you may be on the **wrong sideband**.

FT8 and WSJT modes

- JT65, JT9, FT4 and FT8 with AFSK use **USB**.
- FT8 needs the **computer clock accurate to about 1 second**.
- On 20 m, FT8 is around **14.074 to 14.077 MHz**; most digital modes are between **14.070 and 14.100 MHz**.
- To answer a CQ, pick a clear frequency in the **alternate time slot**.

Winlink, PACTOR and VARA

- **Winlink**: an amateur radio network for **email**, a form of packet radio, on **VHF and HF**. Its Remote Message Servers are **gateways**; connect by sending a **connect message** on the published frequency.
- **VARA** is a digital protocol used with Winlink.
- **PACTOR** links are limited to **two stations**: you cannot join.
- Interference on PACTOR or VARA causes **retries, long pauses** or **failure to connect**.

Mesh networks

AREDN mesh networks provide **high-speed data** during emergencies or community events.

Source: NCVEC 2023-2027 General question pool (subelement G2).

Radio Wave Propagation

G3A The sun and HF propagation

Sunspots and the solar cycle

- **Higher sunspot numbers** mean a better chance of good propagation on the **higher frequencies**.
- In low solar activity, **15, 12 and 10 m** are the least reliable for long distance.
- **20 m** supports worldwide daytime propagation **at any point** of the cycle.
- Conditions vary on a **26 to 28-day** cycle because of the **rotation of the Sun's surface**.
- The **solar flux index** measures solar radiation at a wavelength of **10.7 cm**.

Solar events

Event	Delay to Earth	Effect
Solar flare (UV and X-rays)	About 8 minutes	Sudden ionospheric disturbance : disrupts lower frequencies more than higher ones
Coronal mass ejection	15 hours to several days	Geomagnetic storm
Coronal holes (charged particles)		HF disturbed

Geomagnetic activity

- A **geomagnetic storm** is a temporary disturbance of the Earth's magnetic field; it **degrades high-latitude HF** propagation.
- High geomagnetic activity creates **auroras** that can reflect **VHF** signals.

Index	Measures
K-index	Short-term stability of the geomagnetic field
A-index	Long-term stability of the geomagnetic field

Source: NCVEC 2023-2027 General question pool (subelement G3).

G3B MUF, LUF and skip distances

Term	Meaning
MUF	Maximum usable frequency between two points
LUF	Lowest usable frequency between two points

- Between the LUF and the MUF, waves are **refracted back to Earth**.
- Below the LUF, they are **attenuated** before reaching the destination.
- If the LUF exceeds the MUF, ordinary sky-wave propagation is **not possible** on that path.
- The least attenuation is **just below the MUF**.
- The MUF depends on **path distance and location, time of day and season, and solar radiation and disturbances**.

Distances

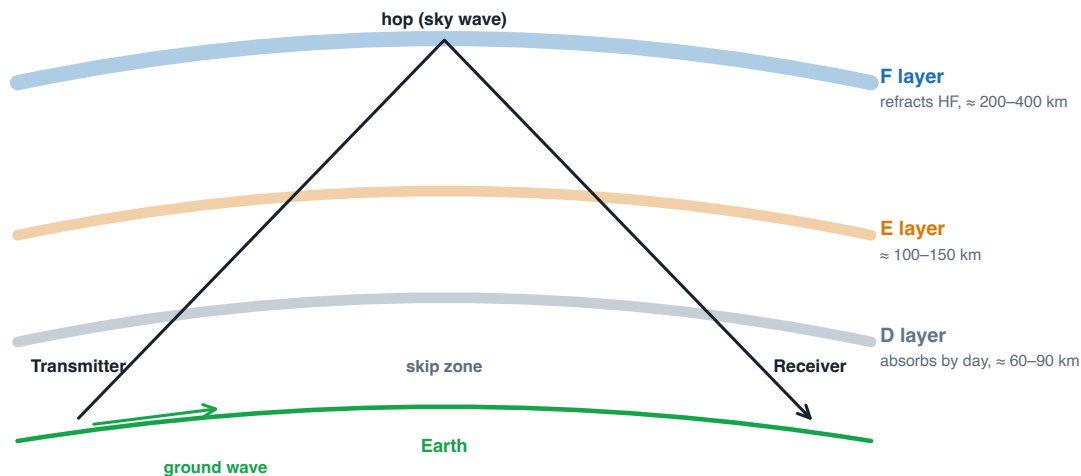
Region	Maximum single hop
E	About 1,200 miles
F2	About 2,500 miles

Practical tips

- Signals arriving by both short path and long path may give a slightly **delayed echo**.
- To check current propagation from your station, use an internet network of **automated receiving stations** (reverse beacons).
- Summer brings **high static** on the lower HF bands.

Source: NCVEC 2023-2027 General question pool (subelement G3).

G3C Ionospheric regions, critical angle and scatter



The ionosphere, ground wave and sky wave

Regions

- The **D region** is closest to the Earth; by day it **absorbs** signals below 10 MHz, which makes long distance on **160, 80, 60 and 40 m** harder in daytime.
- Skip via the **F2 region** is the longest because it is the **highest**.

Critical frequency and angle

Term	Meaning
Critical frequency	The highest frequency refracted back to Earth at a given incidence angle
Critical angle	The highest takeoff angle that returns a wave to Earth under given conditions

Scatter and NVIS

- **Scatter** lets you hear signals in your own **skip zone**; the signals are **weak** (only a small part of the energy is scattered), **distorted** (several paths) and **flutter**.
- **NVIS**: short-distance MF or HF propagation at **high elevation angles**.

Source: NCVEC 2023-2027 General question pool (subelement G3).

Amateur Radio Practices

G4A Transceiver and amplifier controls

Receiving

Control	Purpose
Notch filter	Removes interference from carriers in the passband
Reverse sideband on CW	May reduce interference from other signals
Noise blanker	Reduces gain during each noise pulse
Noise reduction	Too much distorts signals
Attenuator	Prevents overload from strong signals
Dual VFO	Transmit on one frequency, listen on another

Transmitting

- **ALC** prevents **excessive drive** to an amplifier; it must be **inactive** for AFSK data, because it **distorts** the signal.
- An **antenna tuner** increases power transfer from the transmitter to the feed line.
- An **electronic keyer** generates dots and dashes automatically.
- Delaying RF output after keying an external amplifier gives it time to **switch its antenna relay**.

Tube amplifiers

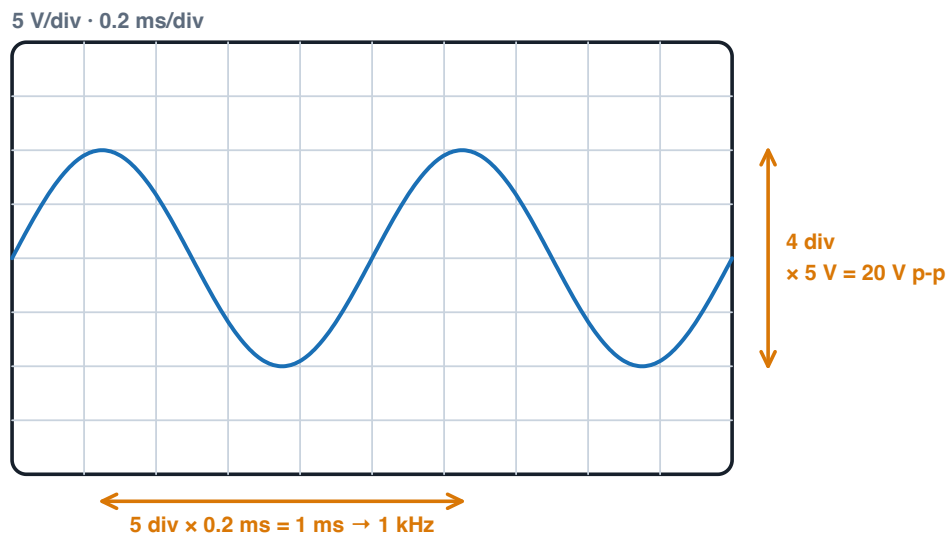
- The correct **TUNE** setting gives a **pronounced dip** in plate current.
- **LOAD** (coupling) is set for the **desired output** without exceeding the maximum plate current.

Source: NCVEC 2023-2027 General question pool (subelement G4).

G4B Test equipment

Oscilloscope

- It has **horizontal and vertical channel amplifiers** and can show **complex waveforms**, unlike a digital voltmeter.
- It is the best tool to check a **CW keying waveform**; the vertical input takes the **attenuated RF output** of the transmitter.
- A **two-tone test** (two non-harmonically related audio signals) checks **linearity**.



Reading an oscilloscope

Meters

- Voltmeters have **high input impedance** to **reduce loading** on the circuit.
- A **digital** multimeter has **higher precision**; an **analog** one is better for adjusting to a **maximum or minimum**.
- A **directional wattmeter** gives the **SWR**.

Antenna analyzer

- For SWR, connect it to the **antenna and feed line**.
- It can also measure the **impedance of coaxial cable**.
- Strong nearby transmitters can **disturb** its readings.

Source: NCVEC 2023-2027 General question pool (subelement G4).

G4C Interference, grounding and bonding

Interference

- A **bypass capacitor** reduces RF interference to audio circuits.
- A **ferrite choke** on a cable reduces common-mode current.
- **Arcing** at a poor connection causes interference over a wide range of frequencies.

Interfering transmitter	Sound in an audio device
SSB phone	Distorted speech
CW	On-and-off humming or clicking

RF burns and ground loops

- RF burns can come from a ground wire with **high impedance** on that frequency; a **resonant** ground puts **high RF voltage** on equipment enclosures.
- **Bonding all equipment enclosures together** minimizes RF hot spots and **ground loops**.
- A ground loop in audio connections shows up as **hum** on your signal.

Safety grounding

- All metal enclosures must be grounded so **hazardous voltages** cannot appear on the chassis.
- Do not **solder** lightning ground connections: a strike's heat would destroy the joint.

Source: NCVEC 2023-2027 General question pool (subelement G4).

G4D Speech processing, S meters and band edges

Speech processor

- It increases the **apparent loudness** of your voice: it **raises the average power** of an SSB signal.
- Badly adjusted, it causes **distorted speech, intermodulation** and **excessive background noise**.

S meter

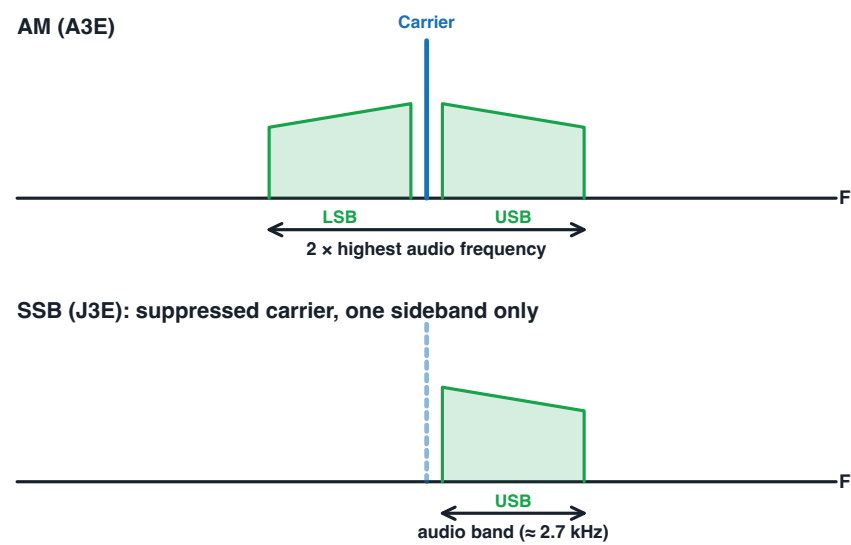
- It measures **received signal strength**; one S unit is about **6 dB**.
- 20 dB over S9 is **100 times** more power than S9.
- To go from S8 to S9, raise power about **4 times**.

Staying inside the band

An SSB signal is about 3 kHz wide, on one side of the displayed carrier frequency.

Sideband	Displayed frequency	Occupied
LSB	7.178 MHz	7.175 to 7.178 MHz
USB	14.347 MHz	14.347 to 14.350 MHz

- With LSB, stay **at least 3 kHz above** the lower edge of the phone segment.
- With USB, stay **at least 3 kHz below** the upper edge.



AM and SSB spectrum

Source: NCVEC 2023-2027 General question pool (subelement G4).

G4E Mobile and solar power

Mobile antennas

- A **capacitance hat** electrically lengthens a short antenna.
- A **corona ball** reduces RF discharge from the antenna tip.
- The **efficiency of the short antenna** is the main limit of an HF mobile station; a shortened antenna also has a **narrow bandwidth**.

Mobile power

- Power a 100 W HF transceiver **directly from the battery** with heavy-gauge, fused wire.
- Not from the **auxiliary power socket**: its wiring may not carry the current.
- Interference in a vehicle can come from the **charging system**, the **fuel system** and the **control computers**.

Solar power

- Solar cells are wired in **series-parallel**; a silicon cell gives about **0.5 V** open circuit.
- A **series diode** keeps the battery from **discharging through the panel** in the dark.
- A **lithium iron phosphate** battery needs a **charge controller**.

Source: NCVEC 2023-2027 General question pool (subelement G4).

Electrical Principles

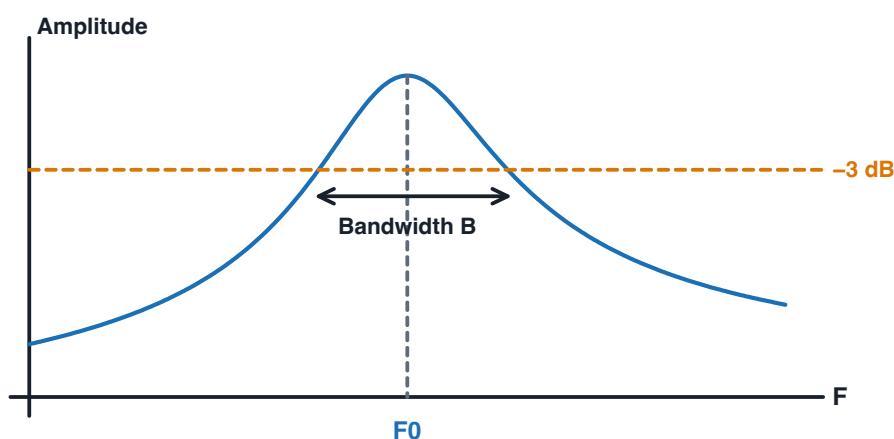
G5A Reactance, impedance and resonance

Term	Meaning	Symbol / unit
Reactance	Opposition to AC caused by capacitance or inductance	X , in ohms
Impedance	The ratio of voltage to current	Z , in ohms
Admittance	The inverse of impedance	Y

Component	As frequency increases
Inductor	Reactance increases
Capacitor	Reactance decreases

Resonance

- At resonance, inductive and capacitive reactance **cancel**.
- In a **series** LC circuit, the impedance at resonance is **very low**.



$Q = F_0 / B$: the higher the Q, the narrower the curve

Resonance curve

Impedance matching at RF

A **transformer**, a **pi network** or a **length of transmission line** can match impedances.

Source: NCVEC 2023-2027 General question pool (subelement G5).

G5B Power, decibels and RMS

Power

$$P = E \times I = I^2 \times R = \frac{E^2}{R}$$

Data	Result
400 V DC on 800 Ω	$400^2 / 800 = 200 \text{ W}$
12 V DC, 0.2 A	2.4 W
7.0 mA through 1,250 Ω	$0.007^2 \times 1250 \approx 61 \text{ mW}$
1,200 W in 50 Ω	$E = \sqrt{1200 \times 50} \approx 245 \text{ V RMS}$

- In parallel resistors, the **total current** is the **sum** of the branch currents.

Decibels

- **3 dB** is a factor of **2** in power.
- A **1 dB** loss is a power loss of about **20.6%**.

RMS and PEP

- The **RMS** value produces the same heating as a DC voltage of the same value.
- 120 V RMS $\rightarrow 120 \times 1.414 \times 2 \approx 339.4 \text{ V peak-to-peak}$; 17 V peak $\rightarrow$ **12 V RMS**.

$$PEP = \frac{(0.707 \times E_{peak})^2}{R}$$

Peak-to-peak on 50 Ω	PEP
200 V	100 W
500 V	625 W

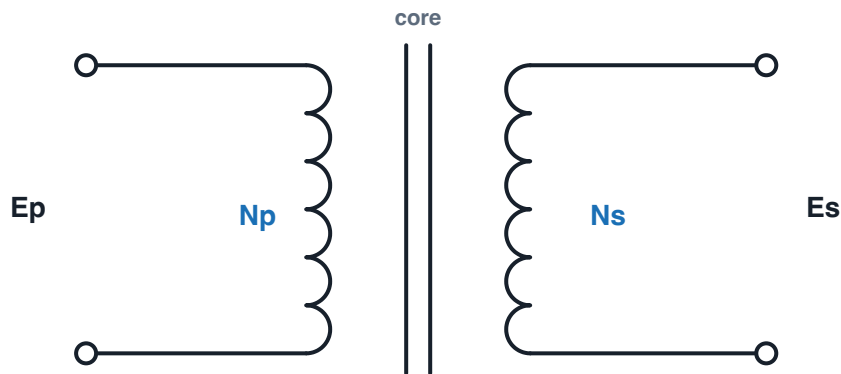
- For an **unmodulated carrier**, PEP = average power (ratio **1.00**): 1,060 W average = 1,060 W PEP.

Source: NCVEC 2023-2027 General question pool (subelement G5).

G5C Transformers and combining components

Transformers

- **Mutual inductance** produces the secondary voltage.
- Voltage follows the turns ratio: 500 turns primary, 1,500 secondary, 120 V → **360 V**.
- A 4:1 step-down transformer fed on its **secondary multiplies** the voltage by 4.
- The primary of a step-up transformer uses **thicker wire** for its **higher current**.
- Impedance ratio = turns ratio squared: matching 600 Ω to 50 Ω needs $\sqrt{600/50} \approx \mathbf{3.5:1}$ turns.



$$E_s / E_p = N_s / N_p \cdot I_s / I_p = N_p / N_s \cdot P_p = P_s \text{ (ideal)}$$

The transformer

Combining components

Combination	Result
10, 20 and 50 Ω in parallel	5.9 Ω
100 and 200 Ω in parallel	67 Ω
Two 5.0 nF and one 750 pF in parallel	10.750 nF
Three 100 μF in series	33.3 μF
20 μF and 50 μF in series	14.3 μF
Three 10 mH in parallel	3.3 mH
20 mH and 50 mH in series	70 mH

- To **increase capacitance**, add a capacitor **in parallel**; to **increase inductance**, add an inductor **in series**.

Source: NCVEC 2023-2027 General question pool (subelement G5).

Circuit Components

G6A Components: batteries, diodes, capacitors and tubes

Batteries

- A 12 V lead-acid battery should not be discharged below **10.5 V** for maximum life.
- **Low internal resistance** allows a **high discharge current**.

Diodes and transistors

Diode	Forward threshold voltage
Germanium	About 0.3 V
Silicon	About 0.7 V

- A bipolar transistor used as a switch works between **saturation and cutoff**.
- In a **MOSFET**, the gate is separated from the channel by a **thin insulating layer**.

Capacitors, resistors and inductors

- **Electrolytic** capacitors: **high capacitance** for their size.
- Low-voltage **ceramic** capacitors: **low cost**.
- Wire-wound resistors have **inductance**: avoid them in RF circuits.
- Above its **self-resonant frequency**, an inductor becomes **capacitive**.

Vacuum tubes

- The **control grid** regulates the electron flow from cathode to plate.
- The **screen grid** reduces **grid-to-plate capacitance**.

Source: NCVEC 2023-2027 General question pool (subelement G6).

G6B Ferrites, integrated circuits and connectors

Ferrites

- Ferrite performance at different frequencies depends on the **mix** of materials.
- A ferrite toroid gives **large inductance** values, can be **optimized** for a frequency range, and **contains** most of the magnetic field.
- A ferrite bead on a coax **creates an impedance** to common-mode current on the shield.

Integrated circuits

Term	Meaning
MMIC	Monolithic microwave integrated circuit
CMOS	Low power consumption compared with TTL
Op-amp	An analog device

- An LED emits light when **forward biased**.

Connectors

Connector	Feature
BNC	Low SWR up to about 4 GHz
Type N	Moisture resistant , useful to 10 GHz
SMA	Small, threaded , up to several GHz
RCA phono	Low-frequency or DC connections

Source: NCVEC 2023-2027 General question pool (subelement G6).

Practical Circuits

G7A Power supplies and schematic symbols

Rectifiers and filters

Rectifier	Feature
Half-wave	One diode; converts 180° of the AC cycle
Full-wave (center-tapped transformer)	Two diodes; converts 360°

- Unfiltered, a full-wave rectifier gives **DC pulses at twice the AC frequency**.
- Power supply filters use **capacitors and inductors**.
- The **bleeder resistor** discharges the filter capacitors when power is removed.
- A **switchmode** supply runs at high frequency, so its components are **smaller**.

Figure G7-1

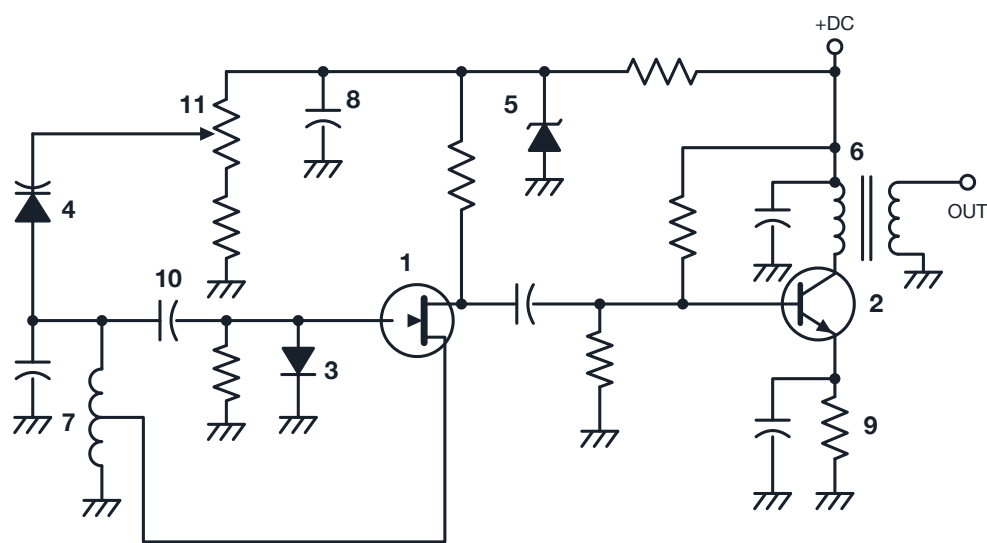


Figure G7-1

Symbol	Component
1	Field-effect transistor
2	NPN junction transistor
5	Zener diode
6	Solid-core transformer
7	Tapped inductor

Source: NCVEC 2023-2027 General question pool (subelement G7).

G7B Amplifiers, oscillators and logic

Amplifiers

Class	Feature
A	The device conducts 100% of the time
C	The highest efficiency ; fine for FM , which has a constant amplitude

- A **linear** amplifier's output **preserves the input waveform**.
- **Efficiency** = RF output power ÷ DC input power.
- **Neutralizing** an amplifier eliminates **self-oscillation**.

Oscillators

- A sine wave oscillator is a **filter and an amplifier in a feedback loop**.
- An LC oscillator's frequency is set by the **inductance and capacitance** of its tank circuit.

Logic

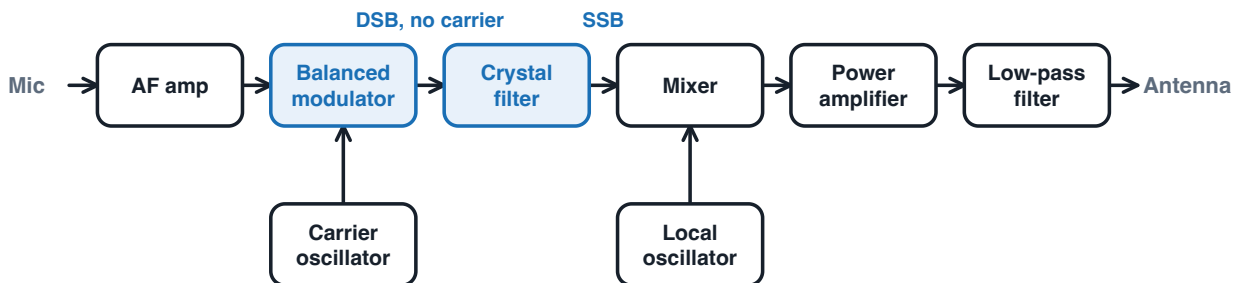
- A two-input **AND** gate: output high only when **both inputs** are high.
- A 3-bit counter has $2^3 = 8$ states.
- A **shift register** is a clocked array that passes data **step by step**.

Source: NCVEC 2023-2027 General question pool (subelement G7).

G7C Transmitter and receiver circuits, SDR and filters

SSB

- A **balanced modulator** produces **double-sideband** RF; a **filter** selects one sideband.
- A **product detector** extracts the modulation in an SSB receiver.



SSB transmitter

Other circuits

- An **impedance matching transformer** at the transmitter output presents the desired impedance to the transmitter and the feed line.
- A **direct digital synthesizer** (DDS) gives a **variable frequency** with **crystal stability**.
- Receiver sensitivity depends on the **input amplifier gain**, its **noise figure** and the **demodulator bandwidth**.

Software-defined radio (SDR)

- **I and Q** signals are **90°** apart; with I-Q processing, **any type of modulation** can be produced.
- The software does the **filtering, detection and modulation**.
- A **DSP filter** can have a **wide range of bandwidths and shapes**.

Filter terms

Term	Meaning
Cutoff frequency	Where a low-pass filter's output drops below half the input power
Insertion loss	Attenuation inside the passband
Ultimate rejection	The maximum rejection outside the passband
Bandwidth of a band-pass filter	Between the upper and lower half-power points

Source: NCVEC 2023-2027 General question pool (subelement G7).

Signals and Emissions

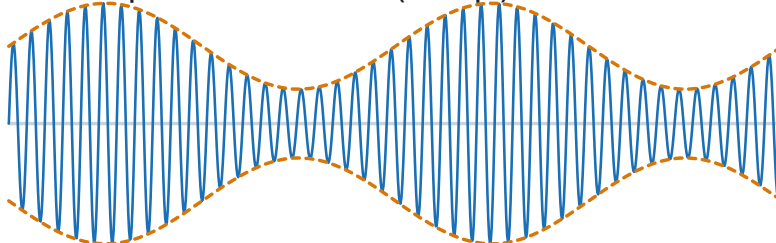
G8A Modulation and link budget

Types of modulation

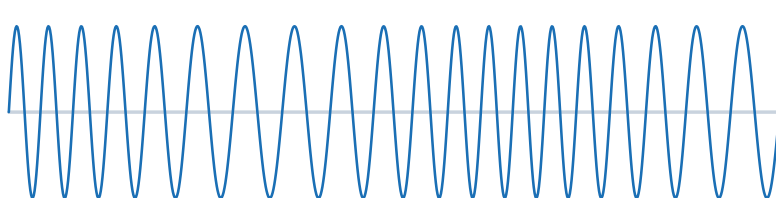
Modulation	What varies
Amplitude modulation	The instantaneous power of the RF signal
Frequency modulation	The instantaneous frequency
Phase modulation	The phase angle ; a reactance modulator on an RF amplifier produces it
Direct binary FSK	An oscillator's frequency changed directly by a digital signal
FT8	8-tone FSK
QPSK	Phase shifts of 0, 90, 180 and 270° for pairs of bits

- **QPSK31** is sideband sensitive, has error correction and about the same bandwidth as BPSK31.
- **SSB** is the narrowest phone emission.

AM: the amplitude follows the audio (envelope)



FM: the frequency follows the audio, the amplitude stays constant



AM and FM

AM details

- The **modulation envelope** connects the peaks of the modulated signal.
- **Overmodulation** gives **excessive bandwidth**; **flat-topping** is distortion from **excessive drive** or speech level.

Link budget

Term	Meaning
Link budget	Transmit power plus antenna gains minus losses , as seen at the receiver
Link margin	Received power minus the minimum signal the receiver needs

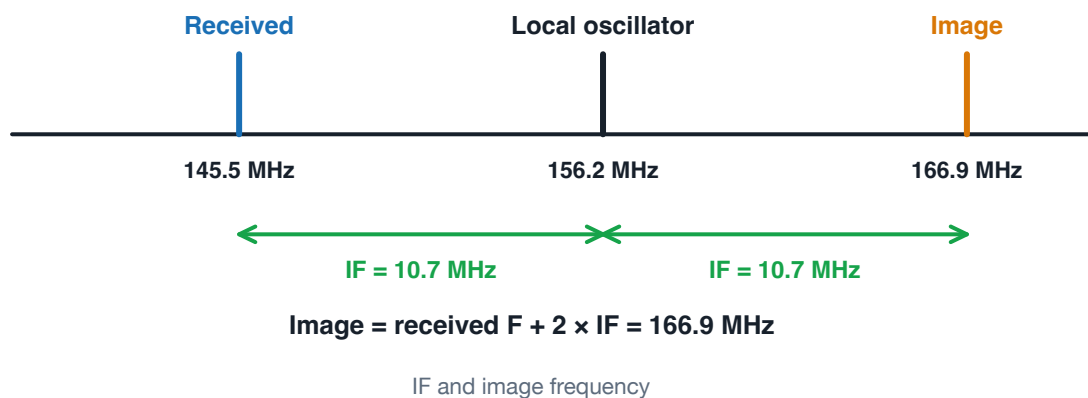
Source: NCVEC 2023-2027 General question pool (subelement G8).

G8B Mixing, multiplication and bandwidth

Mixers

- Mixing two RF signals is **heterodyning**; the output contains the **sum and difference** of the LO and RF frequencies.
- The **local oscillator** is tuned to bring different signals to the IF.
- **Image response**: interference from a signal **two IFs** away from the wanted one.

The image is the mirror of the received frequency about the local oscillator



Intermodulation

- **Intermodulation** combines signals in a non-linear circuit and produces spurious outputs.
- **Odd-order** products (such as $2F_1 - F_2$) are closest to the original frequencies.

FM

- A **multiplier** stage produces a harmonic to reach the operating frequency, and multiplies the deviation too: for 5 kHz at 146.52 MHz with a 12.21 MHz oscillator ($\times 12$), the oscillator deviates **416.7 Hz**.
- Bandwidth (Carson): $2 \times (5 + 3) = 16 \text{ kHz}$.

Bandwidth and duty cycle

- Higher **symbol rates** need **wider bandwidth**.
- Matching receiver bandwidth to the mode gives the **best signal-to-noise ratio**.
- High **duty cycle** modes may exceed the transmitter's **average power** rating.

Source: NCVEC 2023-2027 General question pool (subelement G8).

G8C Digital protocols and modes

Mode or code	Feature
WSPR	Low-power beacon for checking HF propagation
FT8	Receives signals at very low signal-to-noise; a report of +3 means +3 dB SNR in 2.5 kHz
PSK31	Uses Varicode ; upper case letters have longer codes and slow it down
Baudot	A 5-bit code with start and stop bits
DMR, D-STAR, System Fusion	Digital voice modes

Error control

- In a packet frame, the **header** holds routing and handling information.
- In ARQ, a **NAK** asks for **retransmission**; too many attempts **drop** the connection.
- **Forward error correction** sends **redundant information** with the data.

FSK and waterfalls

- The two FSK frequencies are **mark and space**.
- A **waterfall** shows frequency horizontally, strength as intensity and time vertically; vertical lines on either side of a signal mean **overmodulation**.

Mesh networks

If one node fails, packets can still reach their target **through another node**.

Source: NCVEC 2023-2027 General question pool (subelement G8).

Antennas and Feed Lines

G9A Feed lines and SWR

Characteristic impedance

- A parallel-conductor line's impedance depends on the **distance between conductor centers** and the **conductor radius**.
- **Window line** is nominally **450 Ω**.

Loss

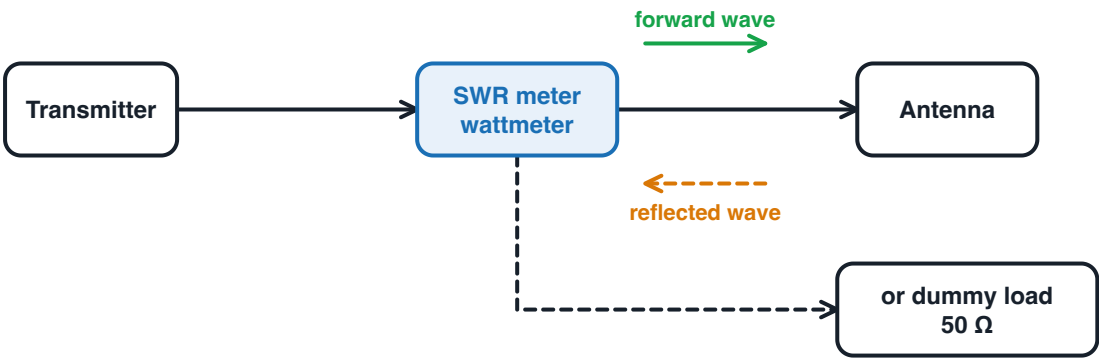
- Feed line loss is given in **dB per 100 feet**; coax attenuation **increases with frequency**.
- **High SWR increases loss** in a lossy line.
- Line loss **lowers** the SWR measured at the line input.

Standing waves

- Reflected power comes from a **mismatch** between the feed line and the antenna feed point; to prevent standing waves, **match** them.
- With resistive loads, SWR is the ratio of the larger to the smaller impedance:

Feed line	Load	SWR
50 Ω	200 Ω	4:1
50 Ω	10 Ω	5:1

- A tuner at the transmitter end shows the transmitter 1:1, but the SWR **on the feed line stays the same** (5:1 stays 5:1).

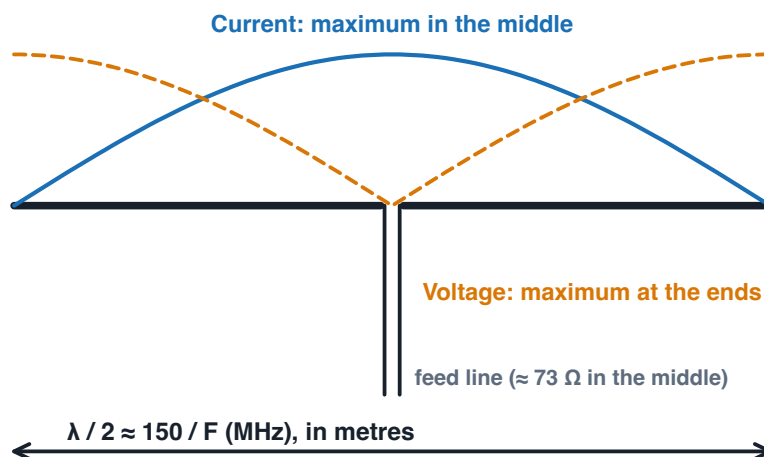


SWR = 1: antenna perfectly matched, no reflected wave

Measuring SWR and power

Source: NCVEC 2023-2027 General question pool (subelement G9).

G9B Dipoles, verticals and wire antennas



Half-wave dipole: current and voltage

Lengths (feet)

$$\text{Half-wave dipole} \approx \frac{468}{f \text{ (MHz)}} \quad \text{Quarter-wave} \approx \frac{234}{f \text{ (MHz)}}$$

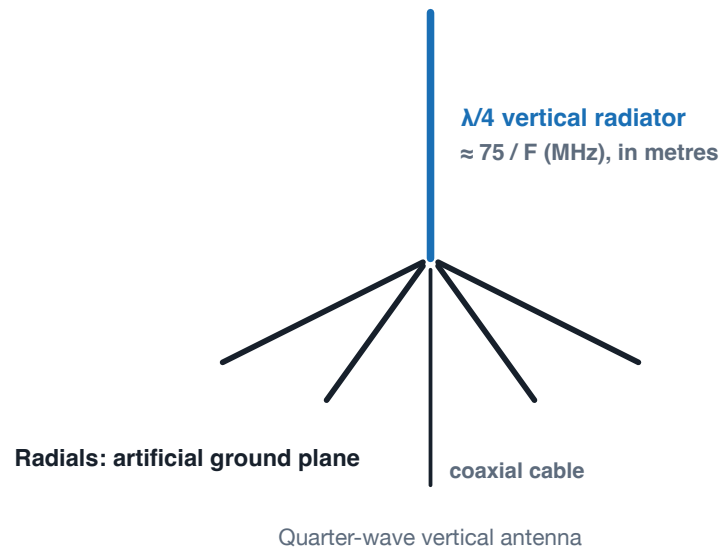
Antenna	Frequency	Length
Half-wave dipole	14.250 MHz	33 ft
Half-wave dipole	3.550 MHz	132 ft
Quarter-wave monopole	28.5 MHz	8 ft

Dipole patterns and impedance

- In free space, in the plane of the wire: a **figure eight** at right angles to the antenna.
- Below $1/2$ wavelength high, the pattern at high angles is **almost omnidirectional**.
- Lowering the dipole toward $1/10$ wavelength **decreases** its feed point impedance; moving the feed point from the center toward the ends **increases** it.
- Horizontal HF antennas have **lower ground losses** than verticals.

Verticals

- A quarter-wave ground plane is **omnidirectional** in azimuth; **sloping the radials down** brings its impedance near 50Ω .
- Radials of a ground-mounted vertical go **on the surface or a few inches below**.

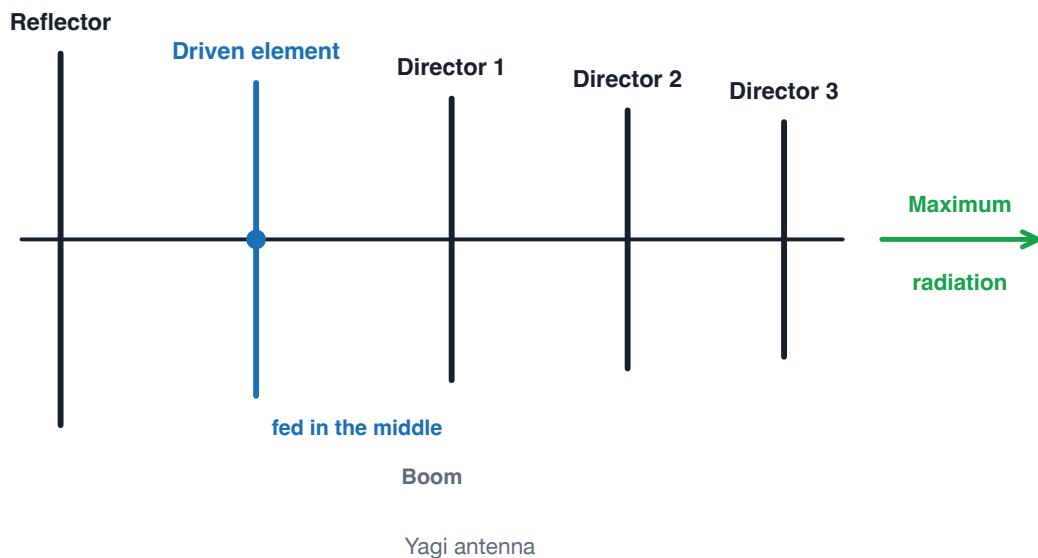


Random wire

Connected directly to the transmitter, it may put **RF current on the station equipment**.

Source: NCVEC 2023-2027 General question pool (subelement G9).

G9C Yagi antennas



- The driven element is about **1/2 wavelength**; the **reflector is longer** and the **director shorter**.
- A **longer boom** with **more directors** increases **gain**.
- **Larger-diameter elements** increase **bandwidth**.
- Gain, front-to-back ratio and SWR bandwidth are tuned with the **boom length**, the **number of elements** and their **spacing**.

Gain and pattern

- Gain in **dBi** is **2.15 dB higher** than in dBd.
- The **main lobe** is the direction of maximum radiation.
- **Front-to-back ratio**: power in the main lobe compared with the opposite direction.
- Two Yagis stacked 1/2 wavelength apart vertically gain about **3 dB**.

Matching

- A **beta (hairpin) match** is a **shorted stub** at the feed point.
- A **gamma match** does **not** require the driven element to be insulated from the boom.

Source: NCVEC 2023-2027 General question pool (subelement G9).

G9D Special antennas

Antenna	Feature
NVIS antenna for 40 m by day	A horizontal dipole 1/10 to 1/4 wavelength high
End-fed half wave	Very high feed point impedance
Halo (VHF/UHF)	Omnidirectional in the plane of the halo
Traps	Allow multiband operation
Log-periodic	Wide bandwidth ; element length and spacing vary logarithmically
Screwdriver mobile	Adjusts by varying the base loading inductance
Beverage	Directional receiving antenna for MF and low HF
Small loop (under $1/10 \lambda$ around)	Nulls broadside to the loop
Inverted V	A dipole with a single central support

- Vertically stacking horizontal Yagis **narrows the main lobe in elevation**.
- Multiband antennas have **poor harmonic rejection**.

Source: NCVEC 2023-2027 General question pool (subelement G9).

Electrical and RF Safety

G0A RF exposure

Effects and evaluation

- RF energy **heats body tissue**.
- Exposure depends on the signal's **duty cycle**, **frequency** and **power density**.
- **Time averaging**: the total exposure averaged over a period. A **lower duty cycle** allows more power.
- Stations with a time-averaged transmission of **more than 1 mW** are subject to the rules.

Compliance

- Show compliance **by calculation** (FCC OET Bulletin 65 or computer modeling) or **by measurement** with a **calibrated field strength meter and antenna**.
- If your station does not meet the exemption criteria, do an **evaluation per OET Bulletin 65**.
- If limits could be exceeded: **prevent human exposure**; do routine evaluations and **prevent access** to high-exposure areas.
- If a neighbor could be in the main lobe of a beam: make sure the antenna **cannot point at them** when they are there.
- Indoor antennas: keep **MPE limits** in occupied areas.

Source: 47 CFR §97.13(c); 47 CFR §1.1307(b); FCC OET Bulletin 65.

G0B Electrical and tower safety

Wiring

- In a four-conductor 240 V circuit, only the **hot wires** get fuses or breakers.
- National Electrical Code: **AWG 12** minimum for a **20 A** breaker; **AWG 14** wiring takes a **15 A** fuse or breaker. The NEC covers the **electrical safety** of the station.
- A **GFCI** trips when current flows from a hot wire **directly to ground**.
- A power supply **interlock** removes dangerous voltages when the cabinet is opened.

Lightning

- The lightning protection ground system goes **outside the building**; arrestors where the **feed lines enter**.
- Ground rods must be **bonded** together with all other grounds.

Towers

- Check that the harness is **rated for your weight** and within its **service life**.
- Before climbing a tower with powered devices, **lock out and tag** all circuits.

Other hazards

- Run a generator in a **well-ventilated** area.
- **Lead** from solder can contaminate food: wash your hands.

Source: NCVEC 2023-2027 General question pool (subelement G0).

Formulas

The formulas used in the General question pool.

Electricity

Quantity	Formula
Ohm's law	$E = I \times R$
Power	$P = E \times I = I^2 \times R = \frac{E^2}{R}$
Resistors in parallel	$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$
Capacitors in series	$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
Inductors in parallel	$\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \dots$
Transformer voltage	$\frac{E_s}{E_p} = \frac{N_s}{N_p}$
Transformer impedance	$\frac{Z_p}{Z_s} = \left(\frac{N_p}{N_s}\right)^2$

AC and RF

Quantity	Formula
RMS value	$E_{RMS} = 0.707 \times E_{peak}; E_{p-p} = 2 \times E_{peak}$
Peak envelope power	$PEP = \frac{(0.707 \times E_{peak})^2}{R}$
SWR with a resistive load	Larger impedance ÷ smaller impedance
FM bandwidth (Carson's rule)	$B = 2 \times (\Delta f + f_{mod})$
Odd-order intermodulation	$2F_1 - F_2$

Antennas (feet)

Antenna	Formula
Half-wave dipole	$L \approx \frac{468}{f \text{ (MHz)}}$
Quarter-wave vertical	$L \approx \frac{234}{f \text{ (MHz)}}$
dBi and dBd	$\text{dBi} = \text{dBd} + 2.15$

Decibels

dB	Power ratio
1	Loss of about 20.6%

dB	Power ratio
3	$\times 2$
6 (one S unit)	$\times 4$
20	$\times 100$

Source: NCVEC 2023-2027 General question pool.

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