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Amateur Radio Exam Course — USA, Amateur Extra Class

FCC Element 4, Amateur Extra Class: one chapter for each of the 50 topic groups of the official NCVEC 2024-2028 question pool.

Author, contact and licence

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Commission Rules

E1A Band edges, special bands and operating aboard

Staying inside the band

An SSB or data signal occupies a few kHz on **one side** of the displayed carrier frequency.

Case	Rule
3 kHz USB on 14.348 MHz	Illegal: the upper 1 kHz is outside the 20 m band (14.350 MHz)
LSB near a lower band edge	Display at least 3 kHz above the lower edge
2.8 kHz USB data on 20 m (data segment ends at 14.150 MHz)	Highest carrier: $14.150 - 0.0028 = \mathbf{14.1472 \text{ MHz}}$
Answering 3.601 MHz LSB phone	No: the sidebands extend below the phone segment (3.600 MHz)

- On **60 m**, a CW signal is sent **at the center** of the channel.

LF and MF bands

Band	Maximum power
2200 m	1 W EIRP
630 m	5 W EIRP (except parts of Alaska)

Ships, aircraft and forwarding

- Aboard a US-documented or registered vessel or craft, the person in physical control must hold an **FCC amateur license** or be authorized for **reciprocal** operation; **any FCC license** works in international waters.
- Operation must be approved by the **ship's master** or the **pilot in command**.
- In a message forwarding system, the **control operator of the originating station** is accountable for a rule violation.

Source: 47 CFR §97.5, §97.11, §97.219, §97.301, §97.303, §97.305, §97.307, §97.313.

E1B Interference, quiet zones, antennas and RACES

Definitions

- A **spurious emission** is outside the **necessary bandwidth** and can be reduced or eliminated **without affecting** the information.
- An acceptable bandwidth for **digital voice or SSTV** on HF: **3 kHz**.

Protecting others

- Protect an **FCC monitoring facility** within **1 mile**.
- If a **70 cm** repeater interferes with a **radiolocation** system, its control operator must **cease operation or make changes**.
- The **National Radio Quiet Zone** surrounds the **National Radio Astronomy Observatory**.
- If an amateur station interferes with broadcast receivers of good design, the FCC may require it to **avoid transmitting at certain hours** on the offending frequencies.

Antenna structures

- Near a **public-use airport**, you may have to notify the **FAA** and register with the FCC (Part 17).
- **PRB-1** applies to **state and local zoning**: regulations must make **reasonable accommodation** for amateur radio.

RACES

- Any FCC-licensed station **certified by the civil defense organization** for the area may operate under RACES rules.
- It may use **all amateur frequencies** authorized to the control operator.

Source: 47 CFR §97.3, §97.13, §97.15, §97.121, §97.303, §97.307, §97.407; PRB-1.

E1C Technical limits, LF bands and operating abroad

Technical limits

Rule	Value
Data bandwidth on 60 m	2.8 kHz
Angle modulation index below 29.0 MHz (at the highest modulating frequency)	1.0
Spurious emissions below 30 MHz	At least 43 dB below the fundamental (mean power)
Transmission time if a remote control link fails	3 minutes

630 m and 2200 m

- Before transmitting, notify the **Utilities Technology Council** (UTC) of your call sign and station **coordinates**.
- You may operate after **30 days** unless told you are within **1 km** of power-line carrier (PLC) systems.
- **Phone** is allowed on the **entire 630 m** band.

International operation

- Messages to foreign stations: **incidental to the purpose** of the service and **personal remarks**.
- **CEPT** lets US citizens operate in many European countries and Europeans in the US; carry a copy of **FCC Public Notice DA 16-1048**.
- An **IARP** is a permit for operating in certain countries of the **Americas**.

Automatic control

Third-party traffic under automatic control is allowed **only with RTTY or data** emissions.

Source: 47 CFR §97.5, §97.115, §97.117, §97.213, §97.221, §97.303, §97.305, §97.307.

E1D Space, telemetry and telecommand

Term	Meaning
Telemetry	One-way transmission of measurements at a distance
Space telecommand station	Sends commands to start, change or stop functions of a space station; its signals may be encrypted
Earth station	Any amateur station , within the control operator's privileges

- **Telecommand** stations of a space station: any station **designated by the space station licensee**.
- A **balloon-borne** telemetry station identifies with its **call sign**.
- A station operated by telecommand on or within 50 km of the Earth's surface must post a **copy of the license** and a label with the licensee's **name, address and phone number** and how to reach the control operator.
- A **model craft** under telecommand: at most **1 W**.

Space station bands

Range	Bands
HF	40, 20, 15 and 10 m
VHF	2 m
UHF	70 cm and 13 cm

- **Space, beacon and telecommand** stations may transmit one-way communications.

Source: 47 CFR §97.3, §97.119, §97.203, §97.207, §97.209, §97.211, §97.213, §97.215.

E1E Volunteer examiners

The system

- A **VEC** (Volunteer Examiner Coordinator) is an organization with an **FCC agreement** to coordinate, prepare and administer exams; the **VECs** maintain the **question pools**.
- To be accredited, a **VEC must confirm** that the VE applicant meets the FCC requirements.
- VEs and VECs may be reimbursed for out-of-pocket expenses of **preparing, processing, administering and coordinating** exams.

At the session

- **Each administering VE** is responsible for the proper conduct of the session.
- A VE may **not** examine **relatives** listed in the rules.
- A candidate who does not follow instructions: **terminate** their exam immediately.
- If the examinee **fails**, return the application to them.
- If they **pass**, **three VEs** certify the qualification, and the VEs **submit the application to the VEC**.

Fraud

A VE who fraudulently administers or certifies an exam risks **revocation** of their station license and **suspension** of their operator license.

Source: 47 CFR §97.509, §97.511, §97.521, §97.523, §97.525, §97.527.

E1F Miscellaneous rules

Spread spectrum and amplifiers

- **Spread spectrum** is permitted only **above 222 MHz**.
- An uncertified amplifier able to work below 144 MHz may be sold only if it was **built or modified by an amateur** for an amateur station.
- To be certified, an external amplifier must meet the **spurious emission standards** at the lesser of 1,500 W or its full output.

Geography

- **Line A** runs roughly parallel to and **south of the US–Canada border**.
- North of Line A, amateurs may not transmit on **420 to 430 MHz**.

Licensing

- A **Canadian** license holder gets the privileges of their Canadian license, **not exceeding Amateur Extra**.
- The FCC may grant a **Special Temporary Authority (STA)** for **experimental** communications.
- The control operator of an **auxiliary station** must be Technician or higher.

Content

- A message to a business is allowed when neither the amateur nor their employer has a **pecuniary interest**.
- Communications **for hire** or material compensation are prohibited, except as the rules provide.
- **Encoded messages** may not be sent over an amateur **mesh network**.

Source: 47 CFR §97.3, §97.107, §97.113, §97.201, §97.303, §97.305, §97.315, §97.317; 47 CFR §1.931.

Operating Procedures

E2A Amateur satellites

Orbits

- **Keplerian elements** define a satellite's orbit.
- An **ascending pass** goes from **south to north**.
- A **geostationary** satellite seems to stay in one place in the sky.

Modes and bands

- A satellite's **mode** gives its **uplink and downlink** bands (the letters of the mode designator).
- **L band** is **23 cm** and **S band** is **13 cm**.

Linear transponders

- A linear transponder relays **FM, CW, SSB, SSTV, PSK and packet**.
- An **inverting** transponder mixes the uplink with a local oscillator and sends the **difference**: the signal position is **reversed** (USB up becomes LSB down), and **Doppler shift is reduced** because the up and down shifts are opposite.
- Limit your **ERP**: too much power **reduces the downlink power** for everyone else.

Other

- A **circularly polarized** antenna minimizes **spin modulation** and **Faraday rotation**.
- **Store-and-forward** holds digital messages on the satellite for later download.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E2).

E2B Amateur television

Fast-scan (analog NTSC)

- A frame has **525** lines, **interlaced**: odd lines in one field, even lines in the next.
- **Vestigial sideband**: AM sending one full sideband and part of the other; it **reduces bandwidth** while keeping the low video frequencies.
- On **70 cm**, ordinary TV sets can receive amateur TV on channels **shared with cable TV**.

Digital TV

- **DVB-T** uses **QAM** and **QPSK**.
- A coding rate of **3/4** means **25%** of the data is forward error correction.

Slow-scan (SSTV)

- Brightness is coded by the **tone frequency**; specific **tones** start each line.
- Color lines are sent **one after the other**.
- The **VIS code** identifies the SSTV **mode**.
- Digital SSTV with **DRM** can be received on an **SSB** receiver.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E2).

E2C Contests, DX and remote operation

Contesting and logs

- Contests are generally excluded from **30 m** (and the other WARC bands).
- In a VHF/UHF contest, SSB and CW activity is in the **weak-signal** segment, near the calling frequency.
- **Cabrillo** is the standard format for **contest logs**; **ADIF** is for exchanging **log data**.
- **Logbook of The World** (LoTW) confirms US and non-US contacts, special events and Worked All States.

DX

- A **QSL manager** handles confirmations for a DX station.
- DX stations work **split** to keep callers off their frequency, to avoid frequencies some callers cannot use, and to hear better.
- In a pileup, send your **full call sign once or twice**.

Remote operation and mesh

- Operating remotely a transmitter located in the US: **no additional indicator** is needed.
- **Latency** is the delay between an operator's action and the change in the signal.
- Mesh networks run on **wireless routers with custom firmware**, on frequencies **shared with unlicensed** data services.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E2).

E2D VHF digital modes: meteor scatter, EME and APRS

Mode	Use
MSK144	Meteor scatter
Q65	EME (moonbounce)
JT65	Very low signal-to-noise ; multitone AFSK

- EME contacts use **time-synchronized transmissions** alternating between stations.
- In a VHF contest on FT8 or FT4, the **grid square** replaces the signal report.

APRS

- Uses the **AX.25** protocol, with **Unnumbered Information** frames for beacons.
- Data is relayed by **packet digipeaters**; the path **WIDE3-1** asks for three hops, one remaining.
- APRS tracks **balloons** in real time.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E2).

E2E HF digital modes

Modulation

- Data below 30 MHz uses **FSK**.
- **Direct FSK** shifts the transmitter **VFO**; audio FSK feeds tones through the audio input.

WSJT-X modes

Mode	Feature
FT8	15-second cycles; the narrowest of these modes
FT4	Four-tone continuous-phase FSK
FST4	Four-tone Gaussian FSK, variable periods, seven tone spacings
Q65	Averages several receive cycles (unlike JT65)
WSPR	Beacons only: no keyboard-to-keyboard

WSJT-X timing depends on **synchronized computer clocks**.

Other modes

- **PSK31** uses **variable-length** character coding.
- **PACTOR** transfers **binary files**; **PACTOR IV** has the highest throughput in good conditions.
- **ALE** stations constantly **scan** a list of frequencies and wake up when they hear their call sign.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E2).

Radio Wave Propagation

E3A EME, waves, ducting and meteors

Earth–Moon–Earth

- Two stations can be up to about **12,000 miles** apart, if both see the Moon.
- **Libration fading** is a fluttery, irregular fading.
- Path loss is lowest when the Moon is at **perigee**.

The electromagnetic wave

- The electric and magnetic fields are at **right angles**, and the wave travels at a right angle to both.
- **Circular polarization**: the fields **rotate**.
- Speed in a medium depends on its **index of refraction**.

Propagation

- When darkness lowers the MUF, switch to a **lower** HF band.
- Microwave **ducts** often form over **large bodies of water**, with a typical range of **100 to 300 miles**.
- Meteors ionize trails in the **E region**; best for meteor scatter: **28 to 148 MHz**.
- **Aurora** comes with **severe geomagnetic storms**; **CW** works best.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E3).

E3B Transequatorial, long-path and sporadic E

Transequatorial propagation (TEP)

- Between points **2,000 to 3,000 miles** apart on a path **across the geomagnetic equator**; up to about **5,000 miles**.
- Most likely in the **afternoon or early evening**.

HF paths

- **Ordinary and extraordinary** waves are independently propagating, elliptically polarized waves created in the ionosphere.
- On **160 m**, a path **entirely in darkness** gives the longest distance.
- **Long path** is most frequent on **40 and 20 m**.
- A **lower** elevation angle makes each hop **longer**.
- **Chordal hop**: successive refractions **without a ground reflection**, so **less loss** than ordinary multi-hop.

Ground wave

- Its range **decreases** as frequency increases.
- It supports **vertical** polarization.

Sporadic E

Most likely **around the solstices**, especially in summer, and **between sunrise and sunset**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E3).

E3C Space weather and propagation tools

Solar events

- **Solar flares** cause short radio blackouts; **Class X** flares are the most intense.
- A sudden rise of noise across much of HF means a **flare** or a **coronal mass ejection** impact.
- A **G5** storm is an extreme geomagnetic storm.

Indices

- A rising **A or K index** means a more **disturbed** geomagnetic field; paths **through the auroral oval** then suffer high absorption.
- **Bz** is the north-south strength of the interplanetary magnetic field; a **southward** Bz favors disturbances.
- The **304 Å** parameter measures UV emissions correlated with the solar flux.

Tools

- **VOACAP** models **HF propagation**.
- Propagation reporting networks report **digital and CW** signals.
- The VHF/UHF radio horizon is about **15%** farther than the geographic horizon.

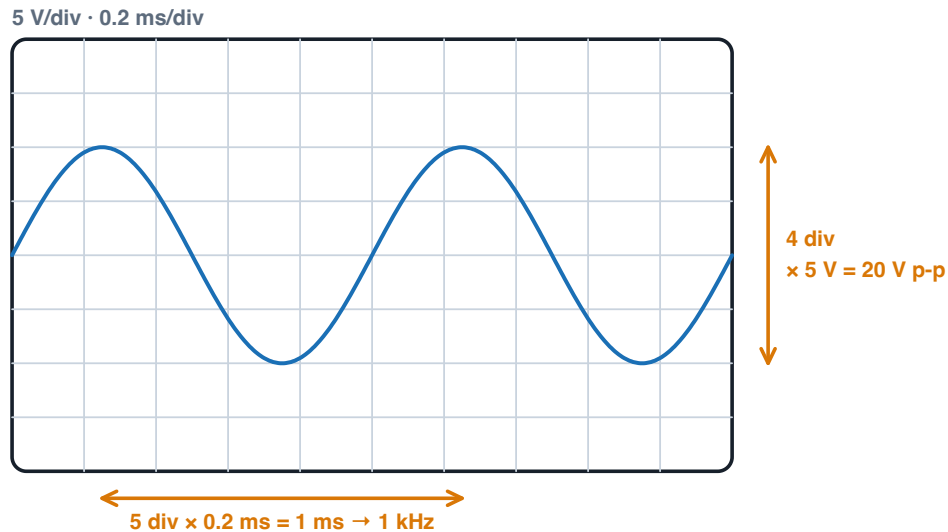
Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E3).

Amateur Practices

E4A Test instruments

Oscilloscopes

- On a digital scope, the highest frequency displayed accurately is limited by the **sampling rate** of the A/D converter; **aliasing** shows a **false, jittery low-frequency** waveform.
- **Probe compensation**: display a **square wave** and adjust until its flat parts are as **flat** as possible.
- Keep the probe's **ground lead short**.
- To measure a linear supply's ripple, use **line** triggering.



Reading an oscilloscope

Spectrum analyzer

- It displays **amplitude** (vertical) against **frequency** (horizontal).
- It shows a transmitter's **spurious signals** and **intermodulation** products.

Other instruments

- A **prescaler** divides a frequency down to a counter's range.
- SWR can be measured with a **directional wattmeter**, a **vector network analyzer** or an **antenna analyzer**.
- An antenna analyzer **computes SWR and impedance** automatically, and also measures **velocity factor**, **cable length** and the **resonant frequency** of a tuned circuit.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E4).

E4B Measurement accuracy and network analyzers

Accuracy

- A frequency counter's accuracy depends mostly on its **time base**.
- A voltmeter's **ohms per volt** times its full-scale reading gives its **input impedance**.
- The **Q** of a series-tuned circuit comes from the **bandwidth** of its frequency response.

Power

With **100 W forward** and **25 W reflected**, the load absorbs **75 W**.

Vector network analyzer (VNA)

- Calibrated with three loads: **short circuit, open circuit and 50 Ω** .
- It measures **input and output impedance, reflection coefficient** and, with two ports, a **filter's frequency response**.

S parameter	Meaning
S11	Input return loss / reflection coefficient (like VSWR)
S21	Forward gain

The subscripts give the **ports** where the measurement is made.

Intermodulation test

Modulate an SSB transmitter with **two non-harmonically related audio tones** and look at the output on a **spectrum analyzer**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E4).

E4C Receiver performance

Noise

- **Noise figure**: the ratio, in dB, of the noise the receiver generates to the theoretical minimum.
- **-174 dBm** is the theoretical noise in **1 Hz** at the input of a perfect receiver at room temperature.
- Noise floor grows with bandwidth: from 50 Hz to 1,000 Hz is $10 \log 20 \approx 13 \text{ dB}$.
- **MDS** is the **minimum discernible signal**.
- On the low HF bands, an **attenuator** reduces overload without hurting signal-to-noise: **atmospheric noise** still exceeds the receiver's own noise.

Selectivity

- A **front-end filter** (preselector) removes strong out-of-band signals.
- A **narrow roofing filter** improves **blocking dynamic range** by attenuating strong nearby signals.
- **IF shift** reduces interference from adjacent stations.
- Matching the bandwidth to the modulation **maximizes signal-to-noise**.
- A **high IF** makes it easier to reject **images**.

Oscillators and SDR

- **Reciprocal mixing**: **LO phase noise** mixes with strong nearby signals and creates interference; in an SDR, phase noise of the **master clock** does the same.
- An SDR overloads when signals exceed the **A/D converter's reference voltage**.

FM

Capture effect: a stronger signal suppresses a weaker one on the same frequency.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E4).

E4D Dynamic range, intermodulation and link budgets

Dynamic range

- **Blocking dynamic range:** the dB difference between the **noise floor** and the signal that causes **1 dB of gain compression**.
- Poor dynamic range causes **cross modulation** and **desensitization**.
- **Desensitization:** loss of sensitivity from a strong nearby signal; **attenuation before the first RF stage** helps.
- The **preselector** rejects signals outside the band received.

Intermodulation

- Caused by **non-linear** circuits.
- **Odd-order** products of two in-band signals also fall **in band**, which makes them troublesome.
- A **third-order intercept** of +40 dBm: two +40 dBm signals would, in theory, create a third-order product as strong as either of them.
- Between two nearby repeaters, the signals mix in a **final amplifier**; a **terminated circulator** at the transmitter output cures it.

Link budget

Work in dBm: 0 dBm = 1 mW, +40 dBm = 10 W, -100 dBm = 0.1 pW.

Example	Calculation	Result
Received level	$+40 + 6 + 3 - 100$	-51 dBm
Link margin	Received $+40 + 10 - 3 - 136 = -89$ dBm; needed $-103 + 6 = -97$ dBm	+8 dB

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E4).

E4E Noise and interference suppression

Receiver tools

Tool	Action	Drawback
Noise blanker	Removes impulse noise	Strong signals may be distorted and seem to produce spurious emissions
Digital noise reduction	Reduces white noise, ignition noise and power line noise	
Automatic notch filter	Removes carriers	May remove the CW signal too

Sources of interference

Source	Symptom or cure
Car charging system	Ferrite chokes on its leads
AC motor	A brute-force AC-line filter in its power leads
Computer network equipment	Unstable signals at specific frequencies
Switch-mode power supplies	Carriers at regular intervals across a wide range
Arcing thermostat contacts, faulty doorbell transformers	Loud roaring or buzzing
Corroded metal connections	Mix AM broadcast signals into spurious signals on MF/HF

Cables

- **Common-mode current** flows equally on all conductors; on a shield, it makes the cable **radiate or pick up** interference.

Surge protection

- Install the AC **surge protector** on the **single-point ground panel**, which makes all **lightning protectors act together**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E4).

Electrical Principles

E5A Resonance and Q

At resonance

Circuit	Impedance	Current
Series RLC	About R (minimum)	Voltage and current in phase
Parallel RLC	About R (maximum)	Minimum at the input; maximum circulating in L and C

- In a series circuit, resonance can make the voltage across L or C **higher** than the applied voltage; raising Q **raises these internal voltages**.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

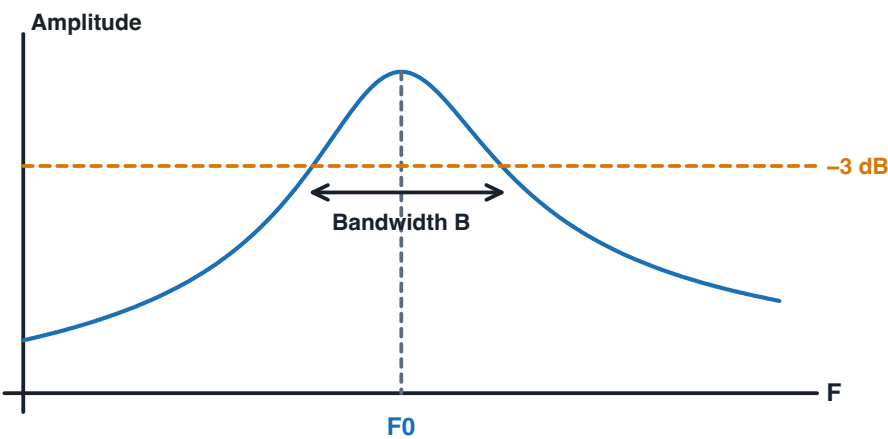
L	C	f
50 μH	40 pF	3.56 MHz
50 μH	10 pF	7.12 MHz

Q and bandwidth

- Parallel circuit: $Q = R/X$ (X of the inductor or capacitor).
- Half-power bandwidth: $B = f/Q$.

f	Q	Bandwidth
7.1 MHz	150	47.3 kHz
3.7 MHz	118	31.4 kHz

- A higher Q in a matching circuit means a **narrower matching bandwidth**.



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

Resonance curve

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E5).

E5B Time constants, admittance and phase angle

Time constant

- One **time constant** charges a capacitor to **63.2%** or discharges it to **36.8%**: $\tau = R \times C$.
- Two 220 μF capacitors and two 1 $\text{M}\Omega$ resistors, all in parallel: $440 \mu\text{F} \times 0.5 \text{ M}\Omega = \mathbf{220 \text{ s}}$.

Admittance

- **Admittance** (Y) is the inverse of impedance; **susceptance** (B) is its imaginary part, the reciprocal of reactance.
- From polar impedance to admittance: take the **reciprocal of the magnitude** and **change the sign of the angle**.

Phase

- In a **capacitor**, current **leads** voltage by 90° ; in an **inductor**, voltage **leads** current by 90° .
- In a series RLC circuit, $\theta = \arctan \frac{X_L - X_C}{R}$: voltage leads if $X_L > X_C$, lags otherwise.

X_C	R	X_L	Phase
500 Ω	1 $\text{k}\Omega$	250 Ω	14.0°, voltage lagging
300 Ω	100 Ω	100 Ω	63°, voltage lagging
25 Ω	100 Ω	75 Ω	27°, voltage leading

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E5).

E5C Impedance on rectangular and polar coordinates

Notation

- Rectangular: $R + jX$; $+j$ is inductive, $-j$ capacitive. A pure $100\ \Omega$ capacitive reactance is $0 - j100$; $50 - j25$ is $50\ \Omega$ in series with $25\ \Omega$ of capacitive reactance.
- Polar: **magnitude and phase angle**; a pure inductive reactance has a $+90^\circ$ angle. Polar coordinates are often used to show the **phase angle**.
- On rectangular coordinates, **resistance** is on the **X axis**, **reactance** on the **Y axis**; a pure resistance sits on the horizontal axis.
- A **phasor diagram** shows the phase relationship between impedances; frequency response graphs use a **logarithmic Y axis**.

Figure E5-1

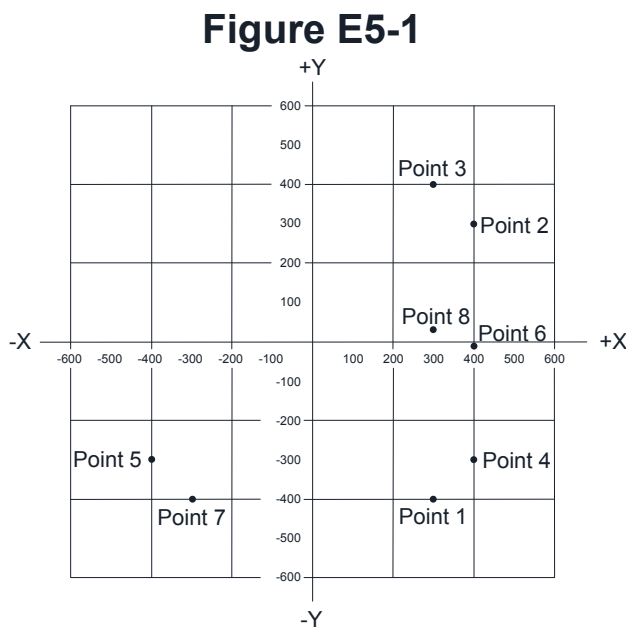


Figure E5-1

Compute the reactance, then place $R \pm jX$:

Circuit	Reactance	Point
400 Ω and 38 pF at 14 MHz	$X_C \approx 300\ \Omega$	4 ($400 - j300$)
300 Ω and 18 μ H at 3.505 MHz	$X_L \approx 396\ \Omega$	3 ($300 + j400$)
300 Ω and 19 pF at 21.2 MHz	$X_C \approx 395\ \Omega$	1 ($300 - j400$)

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E5).

E5D Parasitics and reactive power

RF effects in components

- **Skin effect:** resistance rises with frequency because RF current flows near the surface; it is the main loss in **film capacitors** at RF.
- At VHF and up, keep leads **short** to **minimize inductive reactance**; at microwaves, also to reduce **phase shift**.
- Electrolytic capacitors have too much **inductance** for RF.
- An inductor self-resonates because of its **inter-turn capacitance**: nominal and parasitic reactances combine.
- A **thicker** conductor has a **longer** electrical length.

Reactive power

- In reactive power, current and voltage are **90°** out of phase; it is **wattless**, nonproductive power.
- Ideal inductors and capacitors **store** energy in their fields but **dissipate nothing**.
- Only resistance consumes real power: 1 A through 100 Ω in series with 100 Ω of reactance → **100 W**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E5).

Circuit Components

E6A Semiconductor materials and transistors

Materials

- **Gallium arsenide** is used in **microwave** circuits.
- **N-type** material has **excess free electrons**; an **acceptor** impurity adds **holes** (P-type).
- A reverse-biased PN junction does not conduct: the applied voltage pulls holes and electrons apart and **widens the depletion region**.

Bipolar transistors

- **Beta**: change in collector current relative to the change in base current.
- A silicon NPN transistor is on when its base-emitter voltage is about **0.6 to 0.7 V**.
- **Alpha cutoff frequency**: where the grounded-base current gain has fallen to **0.7** of its 1 kHz value.

FETs

- An FET has a **higher DC input impedance** than a bipolar transistor.
- A **depletion-mode** FET conducts between source and drain **with no gate voltage**.
- **Zener diodes** between a MOSFET's gate and source or drain protect it from **static**.

Figure E6-1

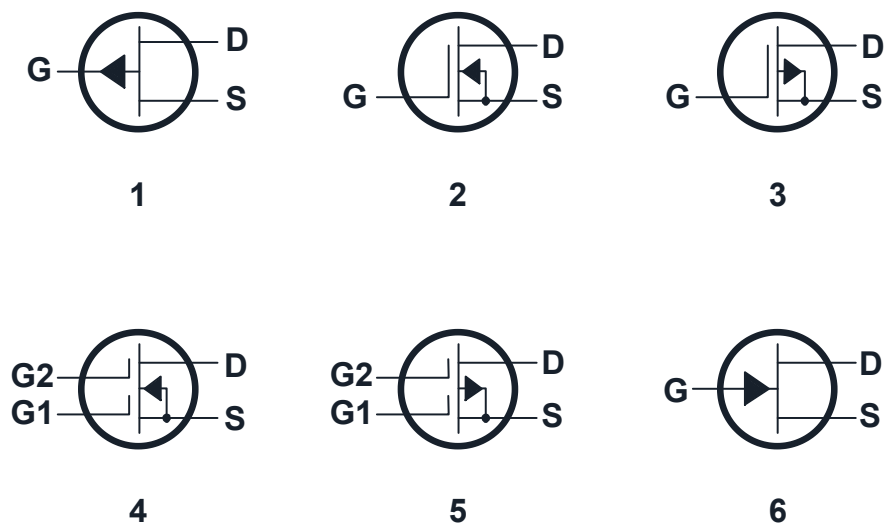


Figure E6-1

Figure E6-1	Symbol
1	P-channel junction FET
4	N-channel dual-gate MOSFET

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

E6B Diodes

Diode	Feature	Use
Zener	Constant voltage under varying current	Voltage reference
Schottky	Metal-semiconductor junction, lower forward drop	Power rectifier; VHF/UHF mixer or detector
Varactor	Voltage-controlled capacitor	Electronic tuning
PIN	Low junction capacitance	RF switch ; attenuation set by the forward DC bias current
Point contact		RF detector
LED	Forward drop set by the material's band gap	

- Excessive current kills a diode through **excessive junction temperature**.

Figure E6-2

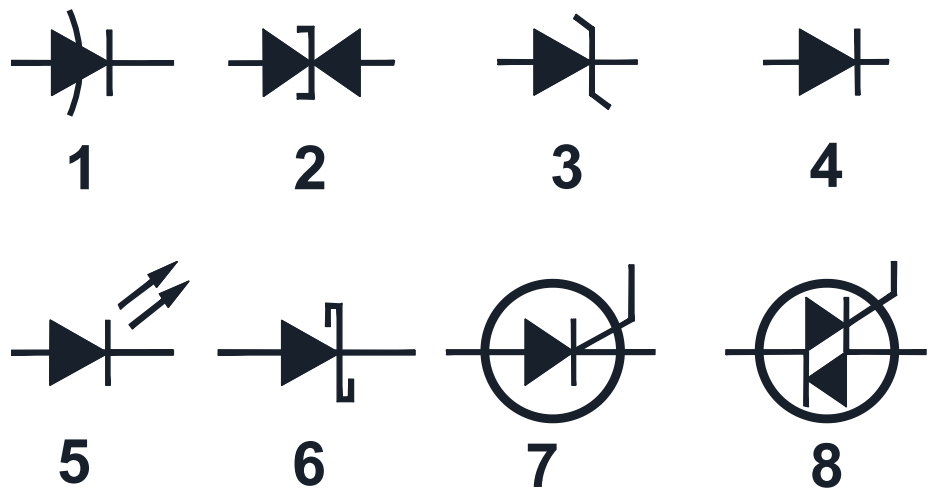


Figure E6-2

In figure E6-2, the **Schottky** diode is symbol **6**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

E6C Digital logic and comparators

Comparators

- When the input crosses the **threshold**, the output **changes state**.
- **Hysteresis** keeps input noise from causing an **unstable output**.

Logic families

Family	Feature
CMOS	Lowest power ; good noise immunity, because its input threshold is about half the supply voltage
BiCMOS	High input impedance of CMOS, low output impedance of bipolar
Tri-state	Outputs 0, 1 or high impedance

- A **pull-up or pull-down resistor** sets a defined level when an input or output is open.
- An **FPGA** is configured with a **hardware description language** (HDL).

Figure E6-3

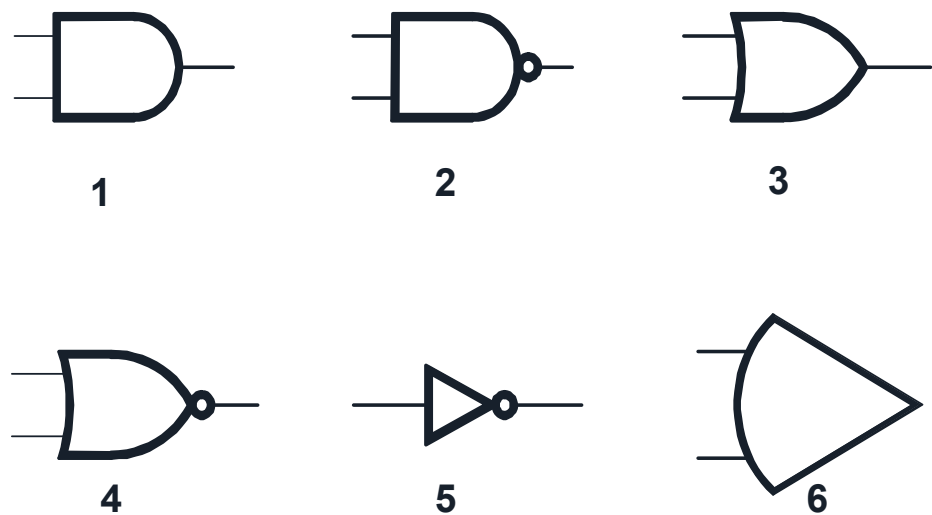


Figure E6-3

Figure E6-3	Gate
2	NAND
4	NOR
5	NOT (inverter)

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

E6D Crystals and magnetic cores

Piezoelectricity

- Materials that **produce a voltage when stressed** and **flex when a voltage is applied**.
- A quartz crystal's equivalent circuit: a **series RLC** in parallel with a **shunt capacitance** (electrodes and strays).

Cores

- Inductance depends on the core's **permeability**.
- **Laminations** reduce **eddy current** losses.
- **Ferrite** needs **fewer turns** than powdered iron for a given inductance; **powdered iron** has the best **temperature stability**.
- A **toroid** confines most of the magnetic field in the core.
- A **brass** core **decreases** inductance.
- **Saturation** comes from **excessive magnetic flux**.
- **Ferrite beads** suppress VHF/UHF parasitics on the terminals of HF transistor amplifiers.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

E6E MMICs and component packages

MMICs

- **Gallium arsenide** has **higher electron mobility**, which suits UHF and up; **gallium nitride** supports the highest frequencies in MMICs.
- MMICs offer **controlled gain**, **low noise figure** and a **constant impedance**, typically **50 Ω** .
- A low-noise UHF preamplifier has a noise figure around **0.5 dB**.
- MMICs connect through **microstrip** lines and are powered through a **resistor and/or RF choke** on the **output** lead.

Packages

- **Surface-mount** parts have the **least parasitics** above HF: smaller area, shorter traces, less parasitic inductance and capacitance.
- A **DIP** (dual in-line package) is **through-hole**, with two rows of pins; its **long leads** make it unsuitable at UHF.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

E6F Optoelectronics

Photovoltaic cells

- The **photovoltaic effect** converts light to electricity; **electrons** absorb the light energy.
- Most power cells are **silicon**, about **0.5 V** open circuit when fully lit.
- **Efficiency**: the fraction of light converted to current.

Other devices

- **Photoconductive** material (a crystalline semiconductor) has **lower resistance** in light.
- An **optoisolator** is usually an **LED and a phototransistor**; it **isolates** a control circuit from a 120 V AC circuit.
- A **solid-state relay** does a relay's job with semiconductors.
- An **optical shaft encoder** detects rotation with a patterned wheel interrupting a light.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E6).

Practical Circuits

E7A Digital circuits

Flip-flops and multivibrators

Circuit	Behavior
Flip-flop	Bistable ; divides a pulse train by 2
Astable multivibrator	Alternates between two states without a clock
Monostable multivibrator	Switches to the other state for a set time , then returns
Decade counter	One output pulse for every 10 input pulses

- Dividing by 16 takes **4 flip-flops** ($2^4 = 16$).

Gates

Gate	Output
NAND	0 only if all inputs are 1
OR	1 if any input is 1
Exclusive NOR	0 if one and only one input is 1

- A **truth table** lists the outputs for every input combination.
- **Positive logic**: high voltage is 1, low voltage is 0.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7B Amplifiers

Classes

- Each device of a push-pull **Class AB** amplifier conducts **more than 180° but less than 360°**.
- A **Class A** common-emitter amplifier is biased **halfway between saturation and cutoff**.
- **Class D** (switching) amplifiers are efficient because the device is **saturated or cut off** most of the time; they need an output **filter** to remove harmonics.
- A **Class C** amplifier on SSB gives **distortion and excessive bandwidth**.

Configurations

- **Grounded grid**: low input impedance.
- **Emitter follower** (common collector): input and output **in phase**.
- Prevent unwanted oscillation with **parasitic suppressors** and/or **neutralization**.

Figure E7-1

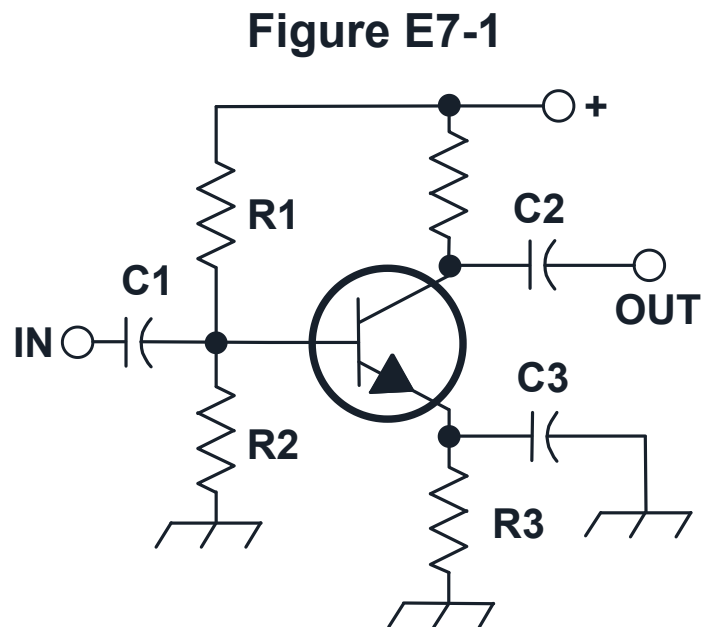


Figure E7-1

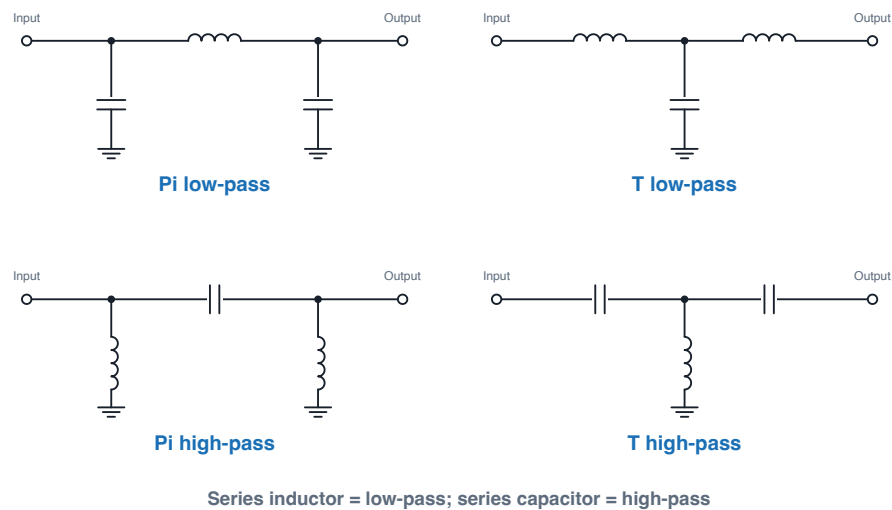
- The circuit is a **common emitter** amplifier.
- R1 and R2 form a **voltage divider bias**; R3 provides **self bias**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7C Filters and matching networks

Networks

- A low-pass **pi network**: a capacitor from input to ground, a capacitor from output to ground, and an **inductor** between input and output.
- A **T network** with **series capacitors** and a **shunt inductor** is **high-pass**.
- A **pi-L network** adds an **output series inductor** for **greater harmonic suppression**.
- A matching network **cancels the reactive part** and **changes the resistive part** to the desired value.



LC filters

Filter types

Filter	Feature
Chebyshev	Ripple in the passband, sharp cutoff
Elliptical	Extremely sharp cutoff, with notches in the stop band
Crystal lattice	For low-level signals, made with quartz crystals
Helical	Band-pass or notch in VHF/UHF transceivers
Cavity	2 m repeater duplexer

The **shape factor** measures a filter's ability to reject adjacent channels.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7D Power supplies and regulators

Regulators

Regulator	How it works
Linear	Varies the conduction of a control element to keep the output constant
Switchmode	Varies the duty cycle of pulses into a filter
Shunt	Loads the unregulated source
Three-terminal	A series regulator

- A **Zener diode** is the stable voltage reference.
- **Dropout voltage**: the minimum input-to-output voltage needed to regulate.
- Series regulator dissipation: $(E_{in} - E_{out}) \times I_{out}$.
- Switching supplies are **cheaper and lighter**: high frequency allows **smaller transformers and filters**.

Figure E7-2

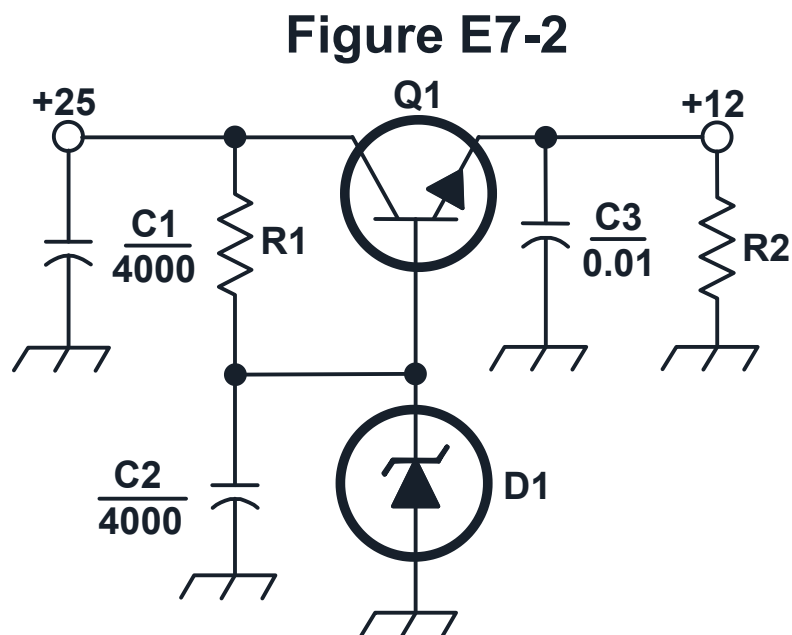


Figure E7-2

- It is a **linear voltage regulator**.
- **Q1** controls the current to keep the output **constant**; **C2** bypasses rectifier ripple around D1.

Other

- Equal resistors across series filter capacitors **equalize voltages, discharge** the capacitors and provide a **minimum load**.
- A **step-start** circuit lets filter capacitors **charge gradually**.
- Battery time = **amp-hours ÷ average current**.
- An **inverter** turns a solar panel's **DC into AC**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7E Modulators, detectors and mixers

FM

- **Reactance modulation** of an oscillator produces **FM or PM** by varying a capacitance.
- **Pre-emphasis** boosts the higher audio frequencies; **de-emphasis** in the receiver keeps compatibility with **phase-modulated** transmitters.
- A **frequency discriminator** detects FM.

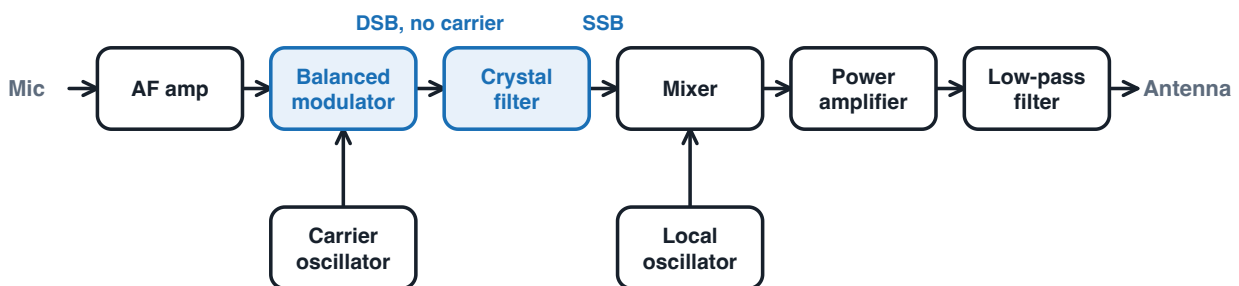
SSB and AM

- SSB: a **balanced modulator** followed by a **filter**; demodulated by a **product detector**.
- A **diode envelope detector** works by **rectifying and filtering** RF (AM).

Mixers

- Output: the two input frequencies plus their **sum and difference**.
- Input levels too high produce **spurious products**.

Baseband is the frequency range of the message **before modulation**.



SSB transmitter

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7F Digital signal processing and SDR

Sampling

- Sample at **at least twice** the highest frequency component (Nyquist).
- 1 V range at 1 mV resolution: 1,000 levels, so **10 bits** ($2^{10} = 1024$).
- **Direct sampling**: RF is digitized **without mixing** with a local oscillator; the **sample rate** sets the maximum bandwidth, and the **reference voltage and number of bits** set the minimum detectable signal.

Processing

- An **FFT** converts signals from the **time domain to the frequency domain**.
- **Decimation** lowers the sample rate by **removing samples**; an **anti-aliasing filter** first removes components that would fold down.
- **Taps** are incremental delays; **more taps** give a **sharper** filter.
- **FIR** filters can delay all frequencies by the **same amount**.

Uses

- An **adaptive filter** removes noise from SSB audio.
- A **Hilbert-transform** filter generates SSB, combining signals in **quadrature**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

E7G Operational amplifiers

The op-amp

- A **high-gain, direct-coupled differential amplifier** with **very high input impedance** and **very low output impedance**.
- An ideal op-amp's gain **does not vary** with frequency; in practice, the **gain-bandwidth** is the frequency where open-loop gain equals **one**.
- **Input offset voltage**: the differential input needed to bring the open-loop output to zero.
- Limit **gain and Q** in op-amp audio filters to prevent ringing.

Figure E7-3 (inverting amplifier)

Figure E7-3

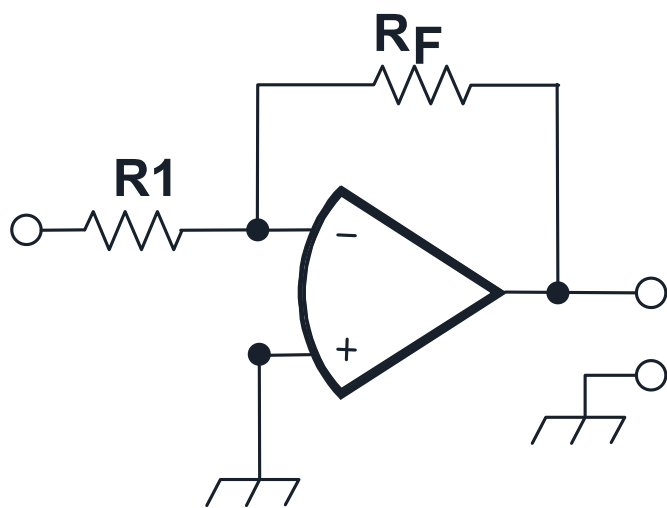


Figure E7-3

$$\text{Gain} = -\frac{R_F}{R_1}$$

R1	RF	Gain or output
10 Ω	470 Ω	47
1,800 Ω	68 kΩ	38
3,300 Ω	47 kΩ	14
1,000 Ω	10,000 Ω, 0.23 V in	-2.3 V out

- A capacitor across the feedback resistor makes it a **low-pass filter**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

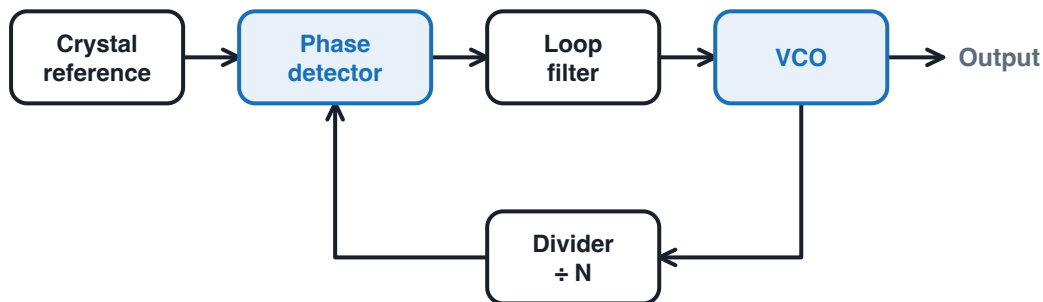
E7H Oscillators and synthesizers

Oscillators

- Three common circuits: **Colpitts** (feedback through a **capacitive divider**), **Hartley** and **Pierce** (feedback through a **quartz crystal**).
- **Microphonics**: frequency changes from **mechanical vibration**; reduce them by **mechanically isolating** the oscillator.
- **NP0 capacitors** reduce thermal drift in crystal oscillators.
- A crystal runs on its specified frequency when given its specified **parallel capacitance**.
- For microwaves: **GPS** reference, **rubidium** oscillator or **temperature-controlled dielectric resonator**.

Phase-locked loop

- A servo loop with a **phase detector**, a **low-pass filter**, a **VCO** and a **stable reference**.
- It performs **frequency synthesis** and **FM demodulation**.



$$F_{\text{out}} = N \times F_{\text{reference}}$$

Phase-locked loop

Direct digital synthesis (DDS)

- A **phase accumulator**, a **lookup table** of waveform **amplitude** values, a **D/A converter** and an anti-alias **low-pass filter**.
- Its main impurities are **discrete spurious signals**.

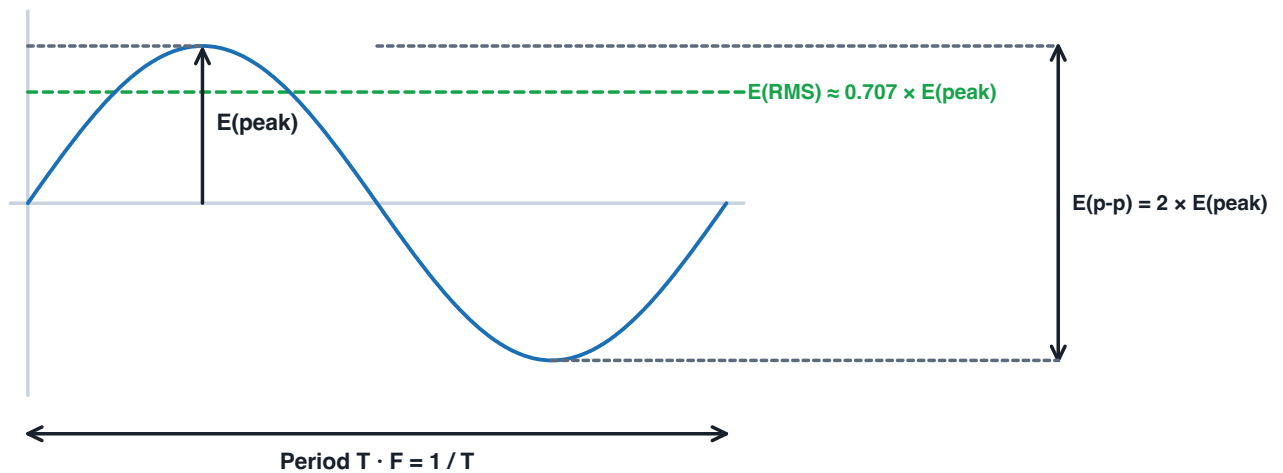
Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E7).

Signals and Emissions

E8A Waveforms and conversion

Waveforms

- **Fourier analysis** shows that a square wave is a sine wave plus its **odd harmonics**.
- A signal in the **time domain** is its amplitude at different times.
- A **true-RMS** meter measures RMS for both **sinusoidal and non-sinusoidal** signals.
- An unprocessed SSB voice signal has a PEP-to-average ratio of about **2.5:1**, set by the **speech characteristics**.



Sine wave: peak, RMS and period

Analog-to-digital and back

- **Successive approximation** is a type of A/D conversion; **direct (flash)** converters are **very fast**, which suits SDRs.
- An 8-bit converter encodes **256** levels.
- **Dither** adds a little noise to reduce **quantization noise**.
- **Total harmonic distortion** measures A/D converter quality.
- A **low-pass filter** after a D/A converter removes **sampling artifacts**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E8).

E8B Modulation index and multiplexing

FM and PM

- **Modulation index:** frequency **deviation** ÷ **modulating frequency**; for PM it **does not depend** on the carrier frequency.
- **Deviation ratio:** **maximum deviation** ÷ **highest audio frequency**.

Deviation	Modulating frequency	Result
3,000 Hz	1,000 Hz	Index 3
±6 kHz	2 kHz	Index 3
±5 kHz	3 kHz (highest)	Ratio 1.67
±7.5 kHz	3.5 kHz (highest)	Ratio 2.14

Multiplexing

Technique	Principle
FDM	Separate frequency bands , each with its own data stream
TDM	Signals share time slots
OFDM	Subcarriers chosen to avoid intersymbol interference; used for digital modes

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E8).

E8C Digital signals and bandwidth

Symbols

- The **symbol rate** is how fast the waveform changes; it equals the **baud** rate.
- **QAM** modulates the amplitude of **two carriers 90° apart**; a **constellation diagram** shows the possible phase and amplitude states.
- **Gray code** changes only **one bit** between successive values.
- A more **efficient code** raises the data rate without more bandwidth.

Bandwidth

Signal	Bandwidth
CW at 13 WPM	About $13 \times 4 = 52$ Hz
FT8	50 Hz
9,600-baud FSK with 4,800 Hz shift	$9600 + 1.2 \times 4800 = 15.36$ kHz

- CW bandwidth depends on **keying speed** and **rise and fall times**.
- Changing PSK phase at the **zero crossing** and using **sinusoidal pulses** (PSK31) **minimize bandwidth**.

Error control and networks

- **ARQ** asks for a **retransmission** when errors are found.
- Mesh network nodes have **IP addresses** and form the network through **discovery and link establishment** protocols.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E8).

E8D Spread spectrum, keying and codes

Spread spectrum

- **Direct sequence**: a fast bit stream **shifts the phase** of the carrier.
- **Frequency hopping**: the frequency changes rapidly following a **pseudorandom sequence**.
- Signals not using the algorithm are **suppressed** in the receiver.

Keying

- Very short **rise or fall times** cause **key clicks**; **lengthen** them to reduce clicks.

AFSK

- Too much **transmit audio** overmodulates AFSK; distortion is measured as **IMD**.
- An idling PSK signal should have IMD of **−30 dB** or better.

Codes

Code	Feature
Baudot	5 bits , with letters/figures shift codes
ASCII	7 or 8 bits , upper and lower case, no shift codes

Parity bits detect some errors.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E8).

Antennas and Transmission Lines

E9A Gain, ERP and efficiency

References

- An **isotropic radiator** is a hypothetical, lossless antenna radiating equally in all directions: the reference for gain.
- $\text{dBd} = \text{dBi} - 2.15$: $6 \text{ dBi} = \mathbf{3.85 \text{ dBd}}$.
- A lossless antenna with gain radiates the **same total power** as an isotropic radiator; gain only redistributes it.

ERP and EIRP

ERP takes into account all gains and losses (antenna gain in dBd); **EIRP** uses dBi.

Station	Total	Result
150 W, -2 -2.2 dB, +7 dBd	+2.8 dB	ERP 286 W
200 W, -4 -3.2 -0.8 dB, +10 dBd	+2 dB	ERP 317 W
200 W, -2 -2.8 -1.2 dB, +7 dBi	+1 dB	EIRP 252 W

Efficiency and ground

- **Efficiency** = radiation resistance ÷ total resistance.
- A ground-mounted vertical's losses depend on **soil conductivity**; a **radial system** improves efficiency.
- **Ground gain**: more signal from **ground reflections** around the antenna.
- Feed point impedance depends on **antenna height**.
- The higher the frequency, the smaller the **Fresnel zone** (smallest at **5.8 GHz** in the choices).

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9B Radiation patterns and antenna modeling

Reading patterns

Figure E9-1

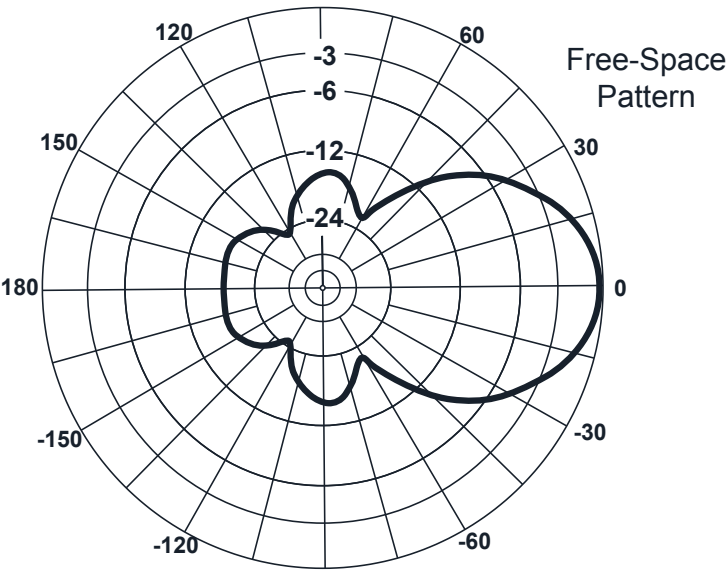


Figure E9-1

In figure E9-1 (azimuth pattern):

Measure	Value
3 dB beamwidth	50°
Front-to-back ratio	18 dB
Front-to-side ratio	14 dB

Figure E9-2

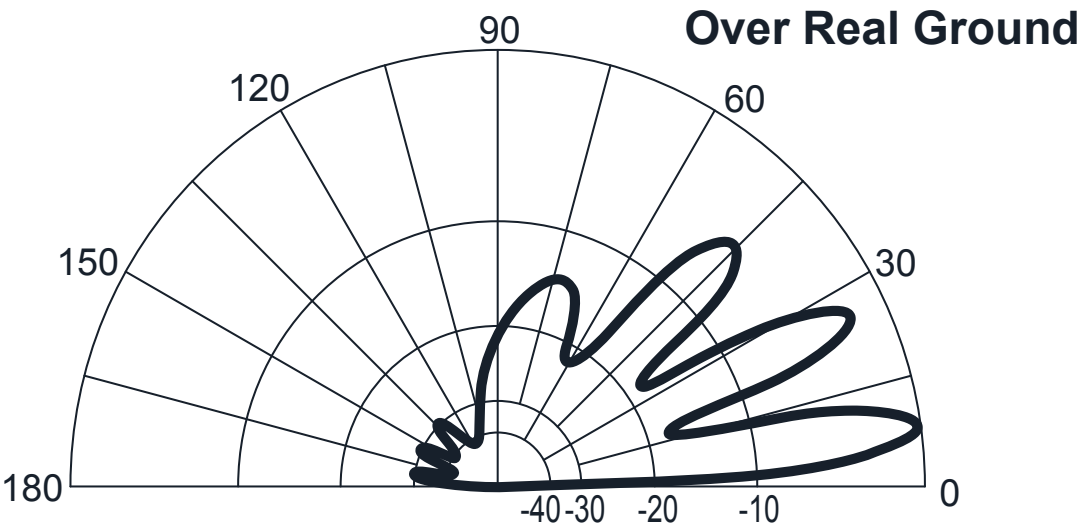


Figure E9-2

Figure E9-2 is an **elevation** pattern: peak response at **7.5°**, front-to-back ratio **28 dB**.

Far field

The **far field** is where the pattern's shape **no longer changes** with distance.

Modeling

- Antennas are usually modeled with the **Method of Moments**: each wire is cut into **segments** carrying a uniform current.
- With fewer than **10 segments per half wavelength**, the computed **feed point impedance** may be wrong.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9C Arrays, wire antennas and ground effects

Two-element vertical arrays (quarter-wave verticals)

Spacing	Phasing	Pattern
$1/2 \lambda$	180°	Figure eight along the array axis
$1/2 \lambda$	In phase	Figure eight broadside to the axis
$1/4 \lambda$	90°	Cardioid

Wire antennas

Antenna	Description
Folded dipole	A half-wave dipole with a parallel wire joining its ends; about 300 Ω
Off-center-fed dipole	Similar impedance on several bands
G5RV	Center-fed through a set length of open-wire line , then a balun and coax
Zepp	End-fed half-wave dipole
Extended double Zepp	Center-fed 1.25-wavelength dipole
Long wire, unterminated	Longer wire: more lobes , aligned with the wire
Rhombic or long wire with a terminating resistor	Unidirectional

Ground effects

- Over **seawater**, a vertical radiates more at **low angles**.
- A horizontal antenna **higher** above ground has a **lower** takeoff angle; over a **downhill slope**, the main lobe angle **decreases** downhill.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9D Yagis, loading and Q

Yagis

- The driven element is about **1/2 wavelength**.
- Parasitic elements are longer or shorter than resonance to **control the phase shift**.
- Two-element Yagis usually use a **reflector**, for **higher gain**.
- Two Yagis on the same boom, **perpendicular**, driven elements at the same point and fed **90° apart**, give **circular** polarization.

Short antennas

- A **loading coil** resonates a short antenna by **cancelling its capacitive reactance**; it should have a high **reactance-to-resistance** ratio for efficiency.
- On a short whip, the best place for the coil is **near the middle** of the radiator.
- **Top loading** improves **radiation efficiency**.
- Below resonance, a base-fed whip's **radiation resistance decreases**.
- Loading coils **reduce SWR bandwidth**; a **higher Q** does the same.

Dishes

Doubling the frequency adds **6 dB** of gain to an ideal parabolic reflector.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9E Matching systems

Match	Description
Gamma	Coax shield to the center of the element, conductor a fraction of a wavelength to one side ; its series capacitor cancels inductive reactance ; also used to shunt feed a grounded tower
Beta (hairpin)	Needs the driven element insulated from the boom and capacitive (shorter than $1/2 \lambda$)
Stub	A short line in parallel with the feed line, near the feed point
Quarter-wave Q-section	Impedance $Z = \sqrt{Z_1 Z_2}$: 100 Ω to 50 Ω needs 75 Ω line

- The **reflection coefficient** describes how a load and a line interact.
- A **Wilkinson divider** splits power equally between two 50 Ω loads with a 50 Ω input.
- Several driven elements with **phasing lines** control the **radiation pattern**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9F Transmission lines

Velocity factor

- The wave's speed in the line divided by the **speed of light**; it depends mostly on the **dielectric**.
- Waves are **slower** in coax, so its electrical length is **longer** than its physical length.
- Air-insulated parallel line, $1/2 \lambda$ at 14.10 MHz: $300/14.1/2 \approx 10.6 \text{ m}$.

Line sections as impedances

Length	Far end shorted	Far end open
$1/8 \lambda$	Inductive	Capacitive
$1/4 \lambda$	Very high	Very low
$1/2 \lambda$	Very low	Very high

Line types

- Parallel conductor line has **lower loss** than plastic-dielectric coax.
- Foam coax has **lower loss**, **higher velocity factor** and a **lower maximum voltage** than solid coax.
- **Microstrip**: printed conductors above a ground plane for constant-impedance microwave connections.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9G The Smith chart

Figure E9-3

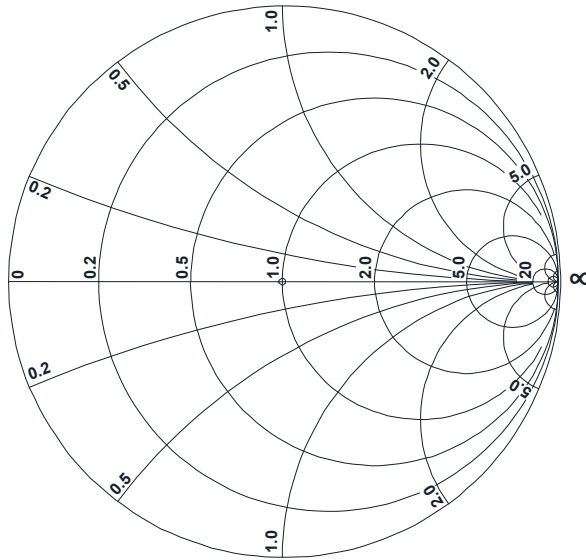


Figure E9-3

- It is made of **resistance circles** and **reactance arcs**; the arcs are points of **constant reactance**.
- The large outer circle is the **reactance axis**; the only straight line is the **resistance axis**.
- **Normalizing** means reassigning the impedance of the **prime center**.
- **Constant-SWR circles** are often added when designing matching networks.
- The wavelength scales are in **fractions of the line's electrical wavelength**.

Uses

It gives **impedance along transmission lines**, **SWR** values, and the **length and position of a matching stub**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

E9H Receiving and direction-finding antennas

Low-band receiving antennas

- On 160 and 80 m, atmospheric noise is so high that **directivity matters more than losses**.
- **Receiving directivity factor** (RDF): peak gain compared with the **average gain** over the hemisphere above.
- A **Beverage** antenna should be **at least one wavelength** long; its **termination resistor absorbs** signals from the rear, and the right value gives the **least SWR variation** over the band.
- A single-turn terminated loop (**pennant**) has a **cardioid** pattern.

Direction finding

- A small loop has a **bidirectional null**; a **sense antenna** leaves a null in **one direction** only.
- An **electrostatic shield** removes unbalanced capacitive coupling and **deepens the nulls**.
- A **cardioid** pattern is useful for DF because of its **single null**.
- More **turns** or a larger **area** raise a receiving loop's output.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E9).

Safety

E0A RF exposure and tower safety

RF exposure

- **SAR** measures the rate at which the **body absorbs** RF energy.
- FCC limits are most restrictive from **30 to 300 MHz**.
- Below 300 MHz there are separate **E** and **H** field limits: the body reacts to both, ground reflections make field strength vary with location, and E and H peaks may be in different places.
- At a neighbor's home, keep your signals below the **uncontrolled** MPE limits.
- With several transmitters, each one producing **5% or more** of its MPE limit where the total limit is exceeded shares the responsibility.
- **Microwaves**: high-gain antennas can create **high exposure** levels.
- An 80 m station must **always** be evaluated; **hand-held transceivers sold before May 3, 2021** are exempt.

Grounding and towers

- An external ground rod mainly **dissipates lightning charges**.
- **100% tie-off**: at least one lanyard attached to the tower **at all times**.
- Attach lanyards to the **tower legs**; a shock-absorbing lanyard goes **above your head**.

Source: NCVEC 2024-2028 Amateur Extra question pool (subelement E0); 47 CFR §1.1307, §1.1310; FCC OET Bulletin 65.

Formulas

The formulas used in the Amateur Extra question pool.

Circuits

Quantity	Formula
Resonant frequency	$f = \frac{1}{2\pi\sqrt{LC}}$
Q of a parallel circuit	$Q = \frac{R}{X}$
Half-power bandwidth	$B = \frac{f}{Q}$
Time constant	$\tau = R \times C$ (63.2% after one)
Phase angle of a series RLC circuit	$\theta = \arctan \frac{X_L - X_C}{R}$
Admittance	$Y = \frac{1}{Z}$: reciprocal magnitude, opposite angle
Inverting op-amp gain	$-\frac{R_F}{R_1}$
Series regulator dissipation	$(E_{in} - E_{out}) \times I_{out}$

Signals

Quantity	Formula
Modulation index	$\frac{\Delta f}{f_{mod}}$
Deviation ratio	$\frac{\Delta f_{max}}{f_{audio\ max}}$
CW bandwidth	About WPM $\times$ 4 (Hz)
FSK bandwidth	Baud rate + 1.2 $\times$ shift
Sampling (Nyquist)	At least twice the highest frequency
Levels of an n-bit converter	2^n
Noise floor	-174 dBm in 1 Hz; +10 log (bandwidth ratio)

Antennas and lines

Quantity	Formula
dBi and dBd	dBi = dBd + 2.15
ERP / EIRP	Power $\times$ gains $\div$ losses (in dB, then a factor)
Antenna efficiency	$\frac{R_{radiation}}{R_{total}}$
Quarter-wave matching section	$Z_0 = \sqrt{Z_1 \times Z_2}$

Quantity	Formula
Physical length of a line	$\frac{300}{f} \times \text{fraction} \times V \text{ (meters)}$
Parabolic dish	+6 dB when the frequency doubles

Link budget

Quantity	Formula
Received level	Power (dBm) + antenna gains – losses – path loss
Link margin	Received level – (MDS + required SNR)

Source: NCVEC 2024-2028 Amateur Extra question pool.

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