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Amateur Radio Exam Course — Canada, Advanced Qualification

ISED Amateur Radio Operator Certificate, Advanced Qualification: one chapter for each of the 50 topics of the official question bank.

Author, contact and licence

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Advanced Theory

A-001-001 The time constant

RC and RL circuits

$$\tau = R \times C \quad \tau = \frac{L}{R}$$

- **RC circuit:** in one time constant, the capacitor charges to **63.2%** of the applied voltage, or discharges to **36.8%** of its initial charge.
- **RL circuit:** in one time constant, the current builds up to **63.2%** of its maximum.

Time constants	Charge	Discharge
1	63.2%	36.8%
2	86.5%	13.5%

Examples (R = 470 kΩ)

C	$\tau = R \times C$
100 μF	47 s
220 μF	103 s
470 μF	221 s

Back EMF

Back EMF is a **voltage that opposes** the applied EMF.

Source: ISED official question bank, Advanced Qualification (section A-001).

A-001-002 Fields, energy and skin effect

Skin effect

As frequency increases, RF current flows in a **thinner layer near the surface** of the conductor: this is **skin effect**. A conductor's resistance is therefore **higher for RF** than for DC.

Fields and energy

- Around a wire carrying current: an **electromagnetic field**. Its direction relative to electron flow follows the **left-hand rule**.
- Between the plates of a capacitor: an **electrostatic field**.
- Energy stored in these fields is **potential energy**.

Component	Property	Unit
Capacitor	Ability to store a charge	Farad
Inductor	Inductance (energy $W = \frac{1}{2}LI^2$)	Henry

Source: ISED official question bank, Advanced Qualification (section A-001).

A-001-003 Resonance of a series RLC circuit

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

The resistance does not affect the resonant frequency. With L in μH , C in pF and f in MHz:

$$f \approx \frac{159}{\sqrt{L \times C}}$$

L	C	f
50 μH	40 pF	3.56 MHz
40 μH	200 pF	1.78 MHz
50 μH	10 pF	7.12 MHz
25 μH	10 pF	10.1 MHz
3 μH	40 pF	14.5 MHz
4 μH	20 pF	17.8 MHz
8 μH	7 pF	21.3 MHz
3 μH	15 pF	23.7 MHz
4 μH	8 pF	28.1 MHz
1 μH	9 pF	53.1 MHz

Finding C

$$C = \frac{1}{(2\pi f)^2 L}$$

At 14.25 MHz with L = 2.84 μH : **44 pF**.

Source: ISED official question bank, Advanced Qualification (section A-001).

A-001-004 Resonance of a parallel RLC circuit

The resonant frequency is found **as for a series circuit**; R plays no part:

$$f \approx \frac{159}{\sqrt{L \times C}}$$

L in μH , C in pF, f in MHz.

L	C	f
1 μH	10 pF	50.3 MHz
2 μH	15 pF	29.1 MHz
5 μH	9 pF	23.7 MHz
2 μH	30 pF	20.5 MHz
15 μH	5 pF	18.4 MHz
3 μH	40 pF	14.5 MHz
40 μH	6 pF	10.3 MHz
10 μH	50 pF	7.12 MHz
200 μH	10 pF	3.56 MHz
90 μH	100 pF	1.68 MHz

Finding L

$$L = \frac{1}{(2\pi f)^2 C}$$

At 14.25 MHz with C = 44 pF: **2.8 μH** .

Source: ISED official question bank, Advanced Qualification (section A-001).

A-001-005 The quality factor (Q)

For a **parallel** RLC circuit:

$$Q = \frac{R}{X_L} \quad X_L = 2\pi fL$$

f	L	R	X_L	Q
14.128 MHz	2.7 μ H	18 k Ω	240 Ω	75.1
14.128 MHz	4.7 μ H	18 k Ω	417 Ω	43.1
14.225 MHz	3.5 μ H	10 k Ω	313 Ω	31.9
7.125 MHz	12.6 μ H	22 k Ω	564 Ω	39
7.125 MHz	8.2 μ H	1 k Ω	367 Ω	2.73
7.125 MHz	10.1 μ H	100 Ω	452 Ω	0.221
4.468 MHz	47 μ H	180 Ω	1,319 Ω	0.136
3.625 MHz	3 μ H	2.2 k Ω	68.3 Ω	32.2
3.625 MHz	43 μ H	1.8 k Ω	979 Ω	1.84
3.625 MHz	42 μ H	220 Ω	957 Ω	0.23

(With f in MHz and L in μ H, $2\pi fL$ comes out directly in ohms.)

Why add a resistor?

A resistor across a parallel resonant circuit **decreases the Q** and **increases the bandwidth** ($B = f/Q$), without changing the resonant frequency.

Source: ISED official question bank, Advanced Qualification (section A-001).

Advanced Components and Circuits

A-002-001 Semiconductors

- **Silicon** and **germanium** have both metallic and non-metallic characteristics: they are the basic semiconductor materials.
- **Pure** silicon is an **insulator**; a **semiconductor** is sometimes an insulator, sometimes a conductor.
- **Doping** means adding small amounts of **impurities**.
- **Gallium arsenide** is used at **microwave frequencies**.

Type	Free electrons compared with the pure crystal	Majority carriers
N	More	Free electrons
P	Fewer	Holes

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-002 Special diodes

Diode	Feature	Use
Zener	Constant voltage under varying current	Regulate voltage
Varactor	Internal capacitance varies with the applied voltage	Electronic tuning
Hot-carrier (Schottky)	Fast switching, low capacitance	VHF and UHF mixers and detectors
Point contact	Very low capacitance	RF detector
PIN	Intrinsic layer between P and N	RF switch

Junction diodes

- Two structural categories: **junction** and **point contact**.
- Major ratings: **maximum forward current** and **peak inverse voltage** (PIV).
- Forward current is limited by **junction temperature**.

Zener power

- A 10 V, 50 W Zener at full dissipation: $I = 50/10 = 5$ A.
- Its power rating is given at 25 °C; as temperature rises, the usable power is **less**.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-003 Bipolar transistors: alpha and beta

Ratio	Definition	Configuration
Alpha (α)	Change in collector current relative to emitter current; forward current gain	Common base
Beta (β)	Change in collector current relative to base current	Common emitter or common collector

$$\alpha = \frac{\beta}{1 + \beta} \quad \beta = \frac{\alpha}{1 - \alpha}$$

- α is slightly below 1; the current gain in common emitter or common collector is **high to very high**.

NPN and PNP

Transistor	Conducts when the base goes...	Direction
NPN	Positive	From the negative emitter to the positive collector
PNP	Negative	From the positive emitter to the negative collector

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-004 Field-effect transistors (FET)

- The terminals of a JFET: **gate**, **drain** and **source**; two types: **N-channel** and **P-channel**.
- An FET has **high input impedance**; a bipolar transistor has **low** input impedance.

Enhancement and depletion

FET	With zero gate voltage
Enhancement mode	No channel: no current ; gate voltage creates (enhances) the channel
Depletion mode	The channel exists: current flows ; gate voltage reduces (depletes) it

In an N-channel MOSFET, **electrons** carry the current; in a P-channel, **holes**.

Static electricity

- FET and **CMOS** devices are **susceptible to damage from static charges**.
- Many MOSFETs have a built-in **gate-protective Zener diode**, which keeps static or excess voltage from puncturing the gate insulation.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-005 The silicon controlled rectifier (SCR)

- The **SCR** belongs to the **thyristor** family.
- Structure: **PNPN**; terminals: **anode**, **cathode** and **gate**, the control element.
- Two stable states: **conducting** and **non-conducting**.
- When **gated on** (positive gate), it behaves between anode and cathode like a **junction diode**: a **forward-biased silicon rectifier**.

In amateur equipment, the SCR's main use is the power supply **overvoltage "crowbar"** circuit.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-006 Amplifier classes

Class	Conduction	Linearity	Efficiency
A	The entire cycle (360°)	Best	Lowest
AB	More than 180°, less than 360°	Good	Medium
B	180°	Average	Good
C	Less than 180°	Poorest , most distortion	Highest

For a **CW, RTTY or FM** transmitter (constant amplitude), **Class C** gives the best efficiency. SSB and AM need a linear amplifier.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-007 Amplifier configurations

Bipolar transistor

Configuration	Input / output phase	Feature
Common emitter	180° out of phase	High gain
Common base	In phase	Very low input impedance compared with the output
Common collector	In phase	Emitter follower

Field-effect transistor

FET configuration	Bipolar equivalent
Common source	Common emitter
Common drain (source follower)	Common collector
Common gate	Common base

In **common source**, the input impedance is set mainly by the **gate biasing network**, and the output impedance by the **drain resistor**.

The Darlington pair

High gain, **high** input impedance and **low** output impedance.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-008 The operational amplifier

An **operational amplifier** (op-amp) is a **high-gain, direct-coupled differential amplifier** whose characteristics are set by **external components**.

The ideal op-amp

Characteristic	Ideal value
Input impedance	Infinite (very high)
Output impedance	Zero (very low)
Gain	Infinite
Frequency response	Flat

- In a closed loop, **gain** is set by the **external feedback network**.
- **Offset voltage** is the potential remaining between the input terminals in a closed loop.

Circuit	Output
Inverting	180° out of phase
Non-inverting	In phase

Active filters

An op-amp RC filter shows **gain** instead of insertion loss; in amateur radio it is mainly used as an **audio filter** in receivers.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-009 Mixers and frequency multipliers

Mixing

Mixing combines two signals to produce their **sum** and **difference**. At the output: the **original** frequencies, their **sum** and their **difference**.

- **Too much** input signal generates **spurious signals**.
- Going from 5.3 MHz to 14.3 MHz (14.3 is not a multiple of 5.3): a **mixer** (with a 9 MHz oscillator).

The frequency multiplier

- It runs in **Class C**, which produces plenty of harmonics.
- Its output circuit is **tuned higher** than the applied frequency: to a harmonic.

In the typical circuit (inductance L1 and variable capacitor C2 in series between VCC+ and ground, collector on a tap of L1):

Part	Role
Input capacitor to the base	DC blocking
C2	Tunes L1 to the desired harmonic ; L1 and C2 make the multiplier
C3 (VCC+ side of L1 to ground)	RF bypass : RF ground at the supply end of L1

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-010 Logic circuits

Gate	Output
AND	"1" only if all inputs are "1"
OR	"1" if any input is "1"
NOT (inverter)	The opposite of the input
NAND	"0" only when all inputs are "1"
NOR	"0" if any (or all) inputs are "1"
EXCLUSIVE OR (XOR)	"1" when only one input is "1"
EXCLUSIVE NOR (XNOR)	"1" when the inputs are the same, for example all "1"

Flip-flops and multivibrators

- A **flip-flop** is a binary sequential logic element with **two stable states**; it is also called a **latch** or a **bistable multivibrator**.
- In a multivibrator, when one transistor conducts, the other is **cut off**.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-011 Quartz crystals

The piezoelectric effect

A crystal produces a voltage when it is **deformed**. Crystal **oscillators**, **filters** and **microphones** depend on it; **active filters** do not use crystals.

Electrically, a crystal looks like a **very high Q tuned circuit**.

Crystal oscillators

- Advantage over an LC oscillator: **much greater frequency stability**.
- They do **not** give high power output.
- An oscillator whose output is close to a multiple of the crystal frequency is an **overtone oscillator**.

Crystal filters

- Thanks to the crystal's **high Q**, they beat LC filters for narrow bandwidths.
- A **crystal lattice filter** has a narrow bandwidth and steep skirts; its response depends on the **relative frequencies of the crystals**.
- For SSB phone, a good filter is **2.4 kHz** wide.

Source: ISED official question bank, Advanced Qualification (section A-002).

A-002-012 Filter families

Three general groups: **high-pass**, **low-pass** and **band-pass**.

Filter	Pass band	Skirts
Butterworth	Maximally flat	Less steep
Chebyshev	Ripple	Steeper

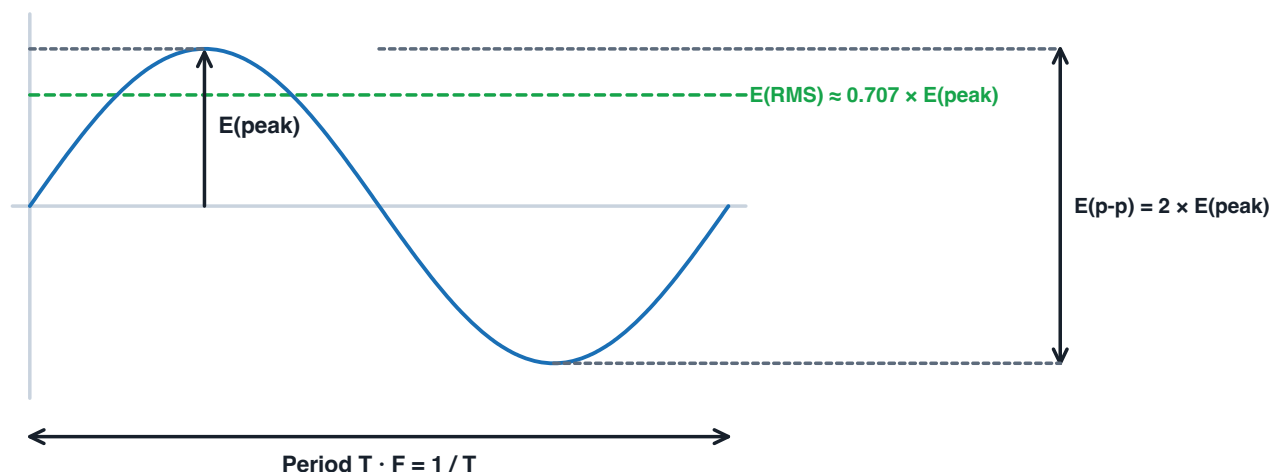
On VHF and up

- **Resonant cavities** are **narrow band-pass filters** on VHF and up; they do not suit audio or low RF (they would be huge).
- A quarter-wave cavity for 50 MHz: $\lambda = 6$ m, so about **1.5 m** long.
- A **helical resonator** protects a VHF/UHF receiver input against overload and spurious signals.
- For a bandwidth close to a TV channel, none of these filters fits.

Source: ISED official question bank, Advanced Qualification (section A-002).

Measurements

A-003-001 RMS and peak values



Sine wave: peak, RMS and period

- The **RMS** (effective) value of an AC voltage causes **the same heating** in a resistor as a DC voltage of the same value.
- For a sine wave it is **70.7%** of the peak value: $E_{RMS} = 0.707 \times E_{peak}$. Frequency plays no part.
- Ohm's law for AC uses **RMS values**; AC voltmeters are **calibrated in RMS**.
- On an oscilloscope, the easiest value to read is **peak-to-peak**: $E_{p-p} = 2 \times E_{peak}$.

Data	Result
20 V peak	14.14 V RMS
17 V peak	12 V RMS
340 V peak-to-peak (170 V peak)	120 V RMS
120 V RMS	$120 \times 1.414 \times 2 \approx 339.5$ V peak-to-peak

Source: ISED official question bank, Advanced Qualification (section A-003).

A-003-002 Measuring peak envelope power (PEP)

Peak envelope power (PEP) is the power supplied during one RF cycle at the **highest crest of the modulation envelope**.

$$PEP = \frac{(0.707 \times PEV)^2}{R_L}$$

With a voltmeter across a resistive load: $P = E^2/R$.

Oscilloscope on a 50 Ω dummy load

Peak-to-peak	Peak	RMS	PEP
200 V	100 V	70.7 V	100 W
400 V	200 V	141.4 V	400 W
500 V	250 V	176.8 V	625 W
800 V	400 V	282.8 V	1,600 W

For an **unmodulated carrier**, the envelope is constant: **PEP equals average power** (1,060 W on the wattmeter = 1,060 W PEP).

Source: ISED official question bank, Advanced Qualification (section A-003).

A-003-003 Dip meter and signal generator

The dip meter

- A **variable frequency oscillator** with metered feedback current.
- It shows the **resonant frequency of a circuit** that is not powered (it supplies the RF itself): tuned circuits, **antenna traps**.
- It applies most directly to **parallel tuned circuits**.
- It should be **loosely coupled** to the circuit.
- It **cannot directly measure** capacitance or inductance.
- Its accuracy does **not** depend on transmitter power.

The signal generator

- A **high-stability oscillator** covering a wide range of frequencies and amplitudes.
- Its output attenuator reads accurately only when **properly terminated**.
- FM receiver 12 dB SINAD sensitivity: a **calibrated RF signal generator** with FM tone modulation and a **total harmonic distortion analyzer**.

Source: ISED official question bank, Advanced Qualification (section A-003).

A-003-004 The frequency counter and calibration

The frequency counter

- It **measures frequency**; its clock is a **crystal oscillator**.
- Its accuracy depends on its **time base**; its frequency response on the **speed of the logic**. To improve it: improve the time base.

Error in parts per million

The maximum error is the frequency in MHz times the error in ppm, in hertz.

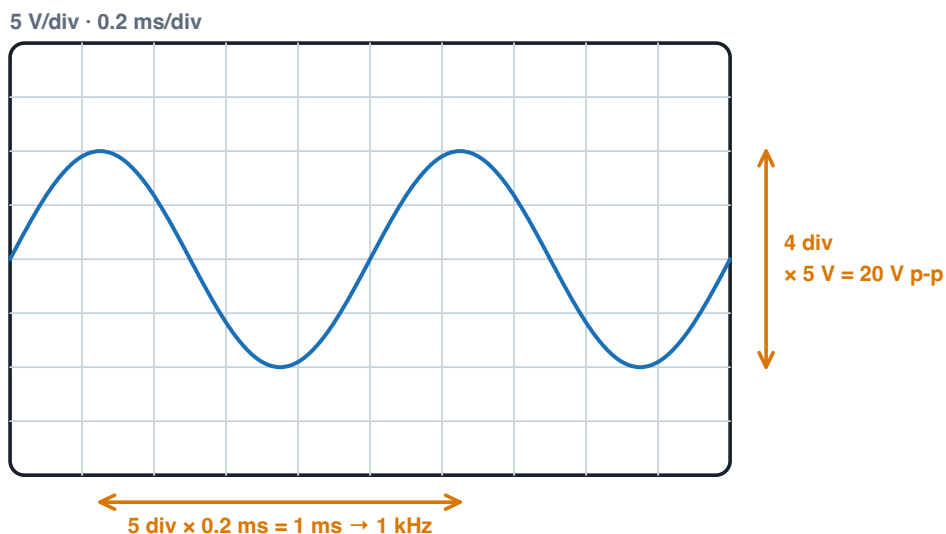
Accuracy	Error at 146.52 MHz
0.1 ppm	14.652 Hz
10 ppm	1,465.2 Hz

Reference oscillators

- High stability: TCXO (temperature compensated), OCXO (oven controlled), GPS disciplined. A **VCXO** (voltage controlled) is **not**, by itself, a high-stability oscillator.
- A **frequency-marker generator** is a stable low-frequency oscillator rich in **harmonics** for calibrating a dial.
- A crystal calibrator is checked by **zero-beating** it against a standard frequency station such as **WWV**; the beat note should be **as low as possible**.

Source: ISED official question bank, Advanced Qualification (section A-003).

A-003-005 The oscilloscope



Reading an oscilloscope

Performance

- Accuracy: the **time base**; response: the **linearity and bandwidth** of the deflection amplifiers.
- **Bandwidth** is the highest frequency the scope can display. To improve it: a faster **horizontal sweep** and a wider **vertical amplifier**.
- A **dual trace** scope shows a circuit's input and output together.
- A probe must be **compensated** every time it is used with a different scope.

Uses

- It is the best instrument to check the **quality of a CW or SSB signal**; the vertical input takes the transmitter's RF output **through a sampling device**.
- It **cannot directly** measure FM carrier deviation.

Lissajous figures

$$\frac{f_V}{f_H} = \frac{\text{horizontal loops}}{\text{vertical loops}}$$

Case	Result
100 Hz horizontal, 150 Hz vertical	3 horizontal loops, 2 vertical
100 kHz horizontal, 5 vertical loops and 2 horizontal	$100 \times 2/5 = 40 \text{ kHz}$
Phase difference of 0° or 180°	A diagonal straight line

Source: ISED official question bank, Advanced Qualification (section A-003).

A-003-006 Ammeters, voltmeters and wattmeters

Extending the range

Meter	Resistance added
Ammeter	In parallel (shunt)
Voltmeter	In series (multiplier); this is what a multimeter adds when switched to a higher range

Examples

- 40 μA , 96 Ω meter extended to 1 mA: voltage $40 \mu\text{A} \times 96 \Omega = 3.84 \text{ mV}$; the shunt carries 960 $\mu\text{A} \rightarrow$ **4 Ω** .
- 1 mA, 0.5 Ω milliammeter as a 20 V voltmeter: $20/0.001 - 0.5 =$ **19,999.5 Ω in series**.
- 150 V voltmeter of 150 k Ω extended to 750 V: **600,000 Ω** in series.

Sensitivity

- Ammeter: the **current giving full-scale deflection**.
- Voltmeter: in **ohms per volt**; 150 k Ω on 150 V = **1,000 Ω/V** ; 20 k Ω/V means a **50 μA** meter.

The RF wattmeter

Connected **at the transmitter output connector**; most work at **50 Ω** .

Source: ISED official question bank, Advanced Qualification (section A-003).

Power Supplies

A-004-001 Rectifiers

Rectifier	Ripple (60 Hz mains)	Feature
Half-wave	60 Hz	One pulse per cycle
Full-wave centre-tap	120 Hz	Uses half the secondary on each half cycle
Full-wave bridge (4 diodes)	120 Hz	No centre tap needed ; the highest average voltage, double the centre-tap circuit with the same transformer

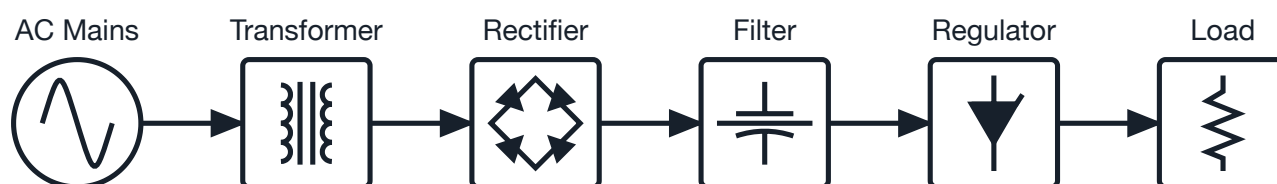
- Unfiltered, a full-wave rectifier gives **pulses at twice the mains frequency**.
- A full-wave **voltage doubler** uses **both halves** of the AC wave.

Peak inverse voltage

Circuit	Peak inverse voltage
Half-wave with capacitor input, very light or no load	2.8 times the RMS voltage
Full-wave centre-tap, any load	2.8 times the RMS voltage

Rectifier diodes

- Ratings not to exceed: **peak inverse voltage** and **average forward current**.
- In high-voltage supplies, a **resistor and capacitor** across each series diode **equalize the voltage drops** and guard against transient spikes.



Linear regulated power supply

Source: ISED official question bank, Advanced Qualification (section A-004).

A-004-002 Power supply filters

Two types: **capacitor input** and **choke input**.

Filter	Advantage
Capacitor input	Higher output voltage (close to peak)
Choke input	Best regulation (about 0.9 times the RMS voltage); with a full-wave rectifier, the best regulation of all

- A series choke **passes DC** readily and **impedes the AC component**.
- Filter chokes are rated by **inductance** and **current-handling capacity**.

The bleeder resistor

- It **discharges the capacitors** when the supply is off and **improves regulation**.
- With choke input, it ensures the **minimum current** needed.
- The capacitor must still be rated for the transformer's **peak voltage**: if the bleeder burns out with no load, it charges to the peak.

Watch for resonance

Choose the **first choke and first capacitor** with care: if they form a **series resonant circuit** near the ripple frequency, ripple, peak rectifier current and peak inverse voltage become very high.

Source: ISED official question bank, Advanced Qualification (section A-004).

A-004-003 Voltage regulators

Two main types: **linear** and **switching**.

Regulator	How it works
Linear	The conduction of a control element varies in proportion to the line voltage or load current
Switching	The control device is switched on and off , with the duty cycle set by line and load conditions

Linear regulators

- The stable reference is a **Zener diode**.
- **Series** regulator: the **best efficiency**.
- **Shunt** regulator: presents a **constant load** to the source.
- Remote sensing: a **feedback connection** from the load directly to the error amplifier input.

The three-terminal regulator

It contains, in one package, a **voltage reference**, an **error amplifier**, **sensing resistors** and a **pass transistor**. Its key specifications: the input voltage range, the **output voltage** and the **maximum output current**.

Source: ISED official question bank, Advanced Qualification (section A-004).

A-004-004 Regulation and protection

The pass transistor

Its dissipation is proportional to the **load current** and the **input/output voltage difference**:

$$P = (E_{in} - E_{out}) \times I_{load}$$

Regulation

- The output is cleanest and best regulated **at the point where the sampling network** (error amplifier) is connected.
- The **load resistance** is the output voltage divided by the total current, including the bleeder current.

Load changes	Regulation
Long term	Static
Short term (CW, SSB)	Dynamic : improved by increasing the output capacitor

In the regulated supply

- Four diodes in a bridge form the **rectifier**.
- The filter electrolytic capacitor feeds the **voltage regulator**.
- **Fuses** carry AC ahead of the transformer and DC ahead of the output.
- A **diode across the regulator** (input to output) protects it from **reverse voltages**.

Source: ISED official question bank, Advanced Qualification (section A-004).

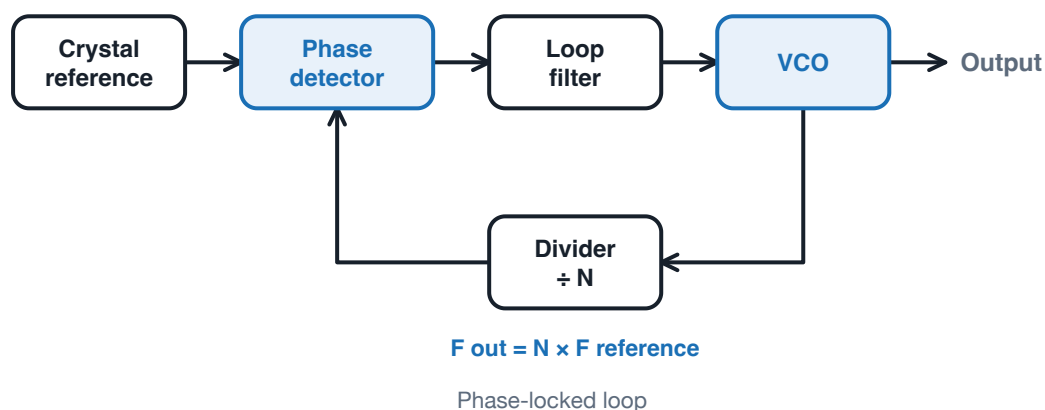
Transmitters, Modulation and Processing

A-005-001 Oscillators

An oscillator depends on **positive feedback** (for example a VFO).

Oscillator	Positive feedback
Hartley	Through a tapped coil
Colpitts	Through a capacitive divider (two capacitors in series); stable , often used as a VFO
Pierce	Through capacitive coupling : a capacitor in series with the crystal

- For high stability, the feedback capacitors are **silver mica**.
- A **phase-locked loop** synthesizer needs a very stable reference: any phase variation of the reference produces **phase noise** at the output.
- An oscillator followed by a Class C amplifier is a **two-stage CW transmitter**.



Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-002 The tube power amplifier

The grounded grid amplifier (triode)

Part	Role
Input	Applied to the cathode
Plate to the pi network	Through a blocking capacitor
Plate RF choke	Connected to B+ (high voltage)
Cathode RF choke	Connected to B- (bias)
Transformer connected to the tube	Supplies the filament voltage
Capacitors from each side of the filament to ground	By-pass

- Returning the filament through the **centre tap** of its transformer prevents the AC filament supply from **modulating the emitted wave**.
- 400 W output at 400 mA with 50% efficiency: 800 W input, so $800/0.4 = 2,000$ V of B+.

Adjustments and precautions

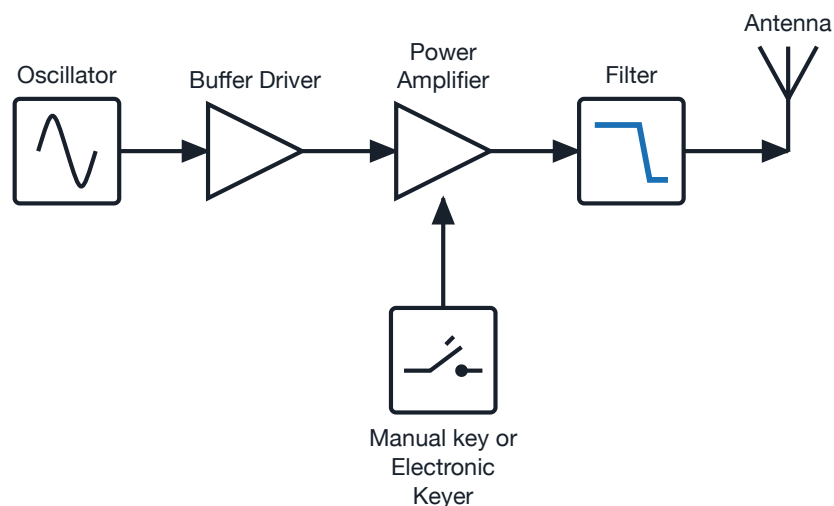
- The output tuning controls of the **pi network** allow **efficient transfer** of power to the antenna.
- **Tuned circuit coupling** between stages attenuates harmonics from early stages.
- After adjusting a VHF amplifier inside: make sure **all shielding is fastened in place**.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-003 Neutralization and parasitic oscillations

The two-stage CW transmitter

- The second transistor is the **power amplifier**.
- The RF transformer between stages is also **part of a tuned circuit**.
- The RF choke and grounded capacitors on the collector supply **form a low-pass filter** that keeps RF out of the supply.
- Keying the **buffer stage** rather than the oscillator makes **oscillator frequency changes** less likely.



Neutralization

- It **cancels positive feedback** caused by **interelectrode capacitance** (tubes) and eliminates **parasitic oscillations**.
- A well-neutralized stage shows a **minimum change in grid current** as the output circuit is tuned.

Parasitic oscillations

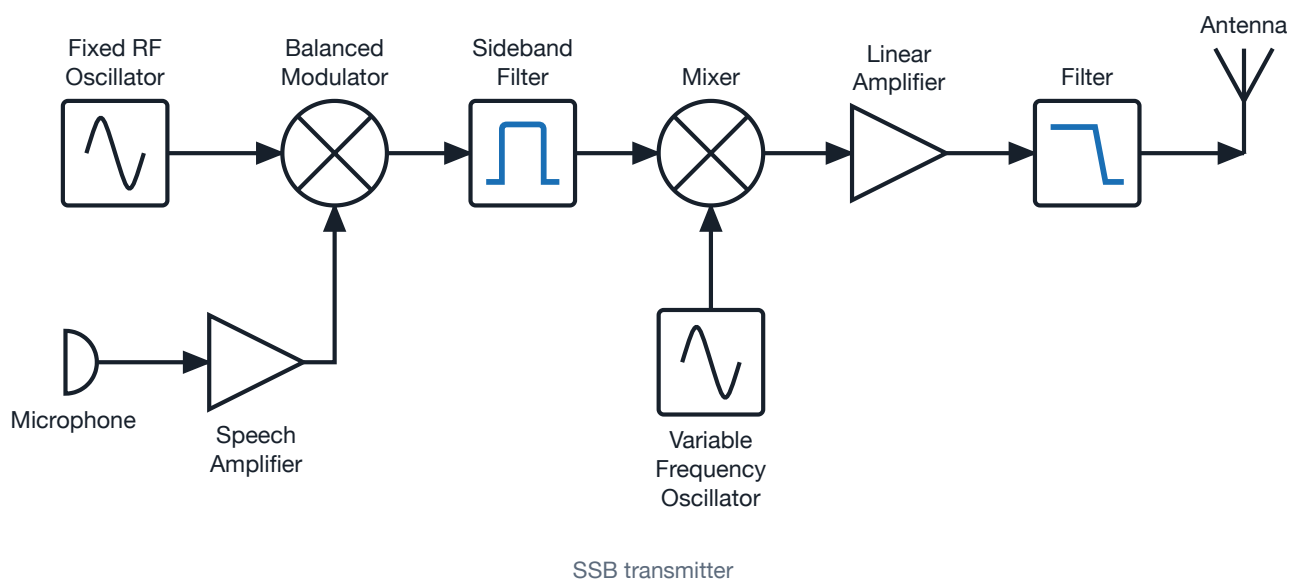
They occur mostly in **RF power output stages**, due to **accidental resonant frequencies** or a **lack of neutralization**.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-004 SSB transmitters: balanced modulator and two-tone test

Producing SSB

- The **balanced modulator** produces **double sideband, suppressed carrier**; this is where the carrier is suppressed.
- A **filter** then removes the unwanted sideband.
- The carrier should be at least **40 dB** below peak output.
- Compared with AM, SSB gives about **6 dB of gain at the transmitter** and **3 dB at the receiver** (half the bandwidth).



The two-tone test

- Feed **two audio sine waves**, within the transmitter's audio passband and **not harmonically related**, and watch the output on an **oscilloscope**.
- It measures the amplifier's **linearity**.
- Peak power is **twice** the power of either tone.

Flat topping

Signal distortion caused by excessive drive: the envelope peaks are flattened.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-005 Frequency modulation

Modulation index and deviation ratio

$$m = \frac{\Delta f}{f_{mod}}$$

Deviation	Modulating frequency	Result
3 kHz	1 kHz	Index 3
6 kHz	2 kHz	Index 3
±5 kHz	3 kHz maximum	Deviation ratio 1.66
±7.5 kHz	3.5 kHz maximum	Deviation ratio 2.14

The **deviation ratio** uses the **maximum** deviation and the **maximum** modulating frequency.

Properties

- With no modulation, the carrier sits on its **centre frequency**.
- Deviation depends **only on the amplitude** of the modulating signal.
- An FM wave with single-tone modulation has an **infinite number of sidebands**.
- Bandwidth (Carson's rule): $2 \times (5 + 3) = \mathbf{16 \text{ kHz}}$.

Multiplication

Deviation is multiplied along with frequency: from 12.21 MHz to 146.52 MHz ($\times 12$), the oscillator needs $5,000/12 \approx \mathbf{\pm 416.7 \text{ Hz}}$.

Deviation meters

Some work on a **carrier null**: you need the **modulating frequency and the modulation index**.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-006 FM, repeaters and intermodulation

Phase modulation

- Varying the tuning of an amplifier's resonant circuit: a **phase modulator**.
- What sets a phase modulator apart from a frequency modulator: **pre-emphasis**.
- **Pre-emphasis** attenuates the low audio frequencies (boosts the highs).
- The compressor and clipper go **between the audio amplifier and the modulator**.
- Three parameters to verify: **power**, **frequency deviation** and **frequency stability**.

Intermodulation between repeaters

- Two repeaters in **close proximity**: their signals mix in a **power amplifier** and create signals at the sum or difference of their frequencies.
- Cure: a **terminated circulator** (ferrite isolator) in the transmitter or duplexer line.
- Third-order products: $2f_1 - f_2$. For a receiver on 146.70 MHz and a transmitter on 146.52 MHz: 146.34 MHz and 146.61 MHz.
- Intermodulation is **not** typically associated with an **intermediate frequency stage**.

The duplexer

For a 2 m repeater, the best duplexer filter is a **cavity filter**.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-007 Speech and signal processing

Compression and ALC

- **Automatic level control** (ALC) keeps the peak RF output fairly constant; it is **RF compression**.
- **Speech compression** gives full amplification to low-level signals and reduces it for strong ones.
- **AF clipping** increases **harmonic distortion**. An RF clipper distorts less, but it is **not** easier to build.
- Ways to limit peaks: RF clipping, compression, AF clipping; "frequency clipping" is not one.
- **Frequency division** is not an analog signal processing principle.

Digital signal processing (DSP)

A **digital signal processor**: **analog-to-digital** converter, **mathematical transform**, **digital-to-analog** converter and **low-pass filter**. (There is no "aliasing amplifier".)

Bits	Levels
8	$2^8 = 256$

Each bit added to the converter adds about **6 dB** of dynamic range.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-008 Digital codes and protocols

Code	Information bits	Feature
Baudot	5	Upper case only
ASCII	7	Upper and lower case
ISO-8859 extended ASCII	8	Accented characters
Varicode (PSK31)	Variable	Elements of unequal length

Error detection and correction

- The **CRC** (cyclic redundancy check) is for **error detection**; it is created with a **hash function**.

AMTOR	Method
Mode A (ARQ)	The receiving station requests repeats automatically
Mode B (FEC)	Each character is sent twice

Networks

- AX.25** is the **packet** protocol.
- In the **OSI** model, the TNC-to-computer connection belongs to the **physical** layer.
- APRS** does **not** provide automatic link establishment.

Source: ISED official question bank, Advanced Qualification (section A-005).

A-005-009 Spread spectrum

In **spread spectrum**, the carrier varies according to a predetermined **pseudo-random sequence**, over a wide band.

Technique	Principle
Frequency hopping	The carrier frequency changes very rapidly, many times per second, following a pseudo-random list of channels
Direct sequence	A very fast binary bit stream phase-shifts the carrier

- Hard to monitor: the receiver must be **synchronized** with the transmitter.
- Resistant to interference: signals not using the spreading algorithm are **suppressed** in the receiver.

Source: ISED official question bank, Advanced Qualification (section A-005).

Receivers

A-006-001 Frequency conversion and double conversion

The superheterodyne

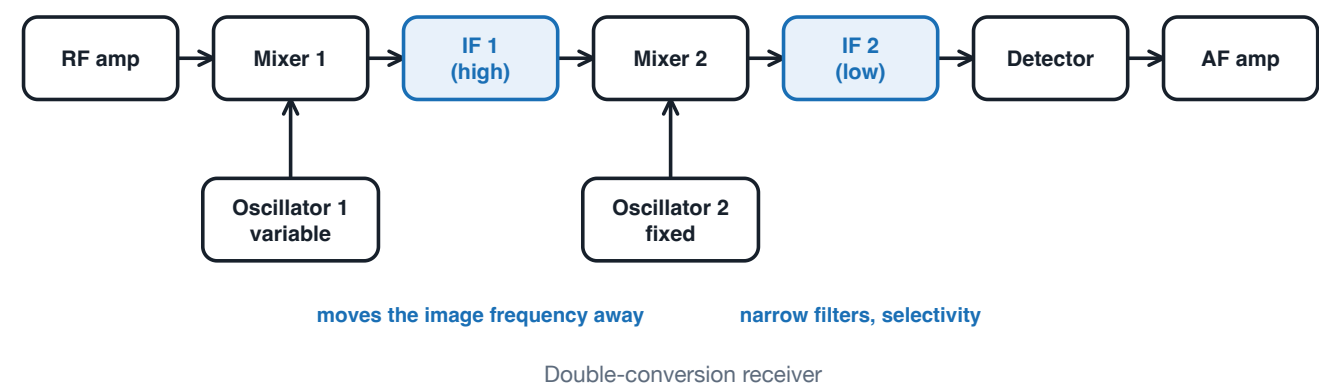
Frequency conversion gives **increased selectivity** and **optimal tuned circuit design**: the filters work at a fixed **intermediate frequency (IF)**.

- Choosing the IF means weighing **image rejection** and **responses to unwanted signals**.
- The **crystal filter** sits in the **IF circuits**.
- The **RF amplifier** has its input and output tuned to the received frequency.
- The **mixer** lies between a tunable stage and a fixed-frequency stage.
- LO at 16 MHz, 9 MHz IF: the received frequency is $16 - 9 = 7$ MHz.

Double conversion

Conversion	Role
First (high IF)	Image rejection
Second (low IF)	Selectivity

- Advantage: **less image interference** for a given front-end selectivity.
- Drawback: more **spurious responses**, because of the extra oscillators and mixing frequencies.
- For SSB it has **two IF stages and two local oscillators**, plus the BFO.



Source: ISED official question bank, Advanced Qualification (section A-006).

A-006-002 The receiver mixer and oscillators

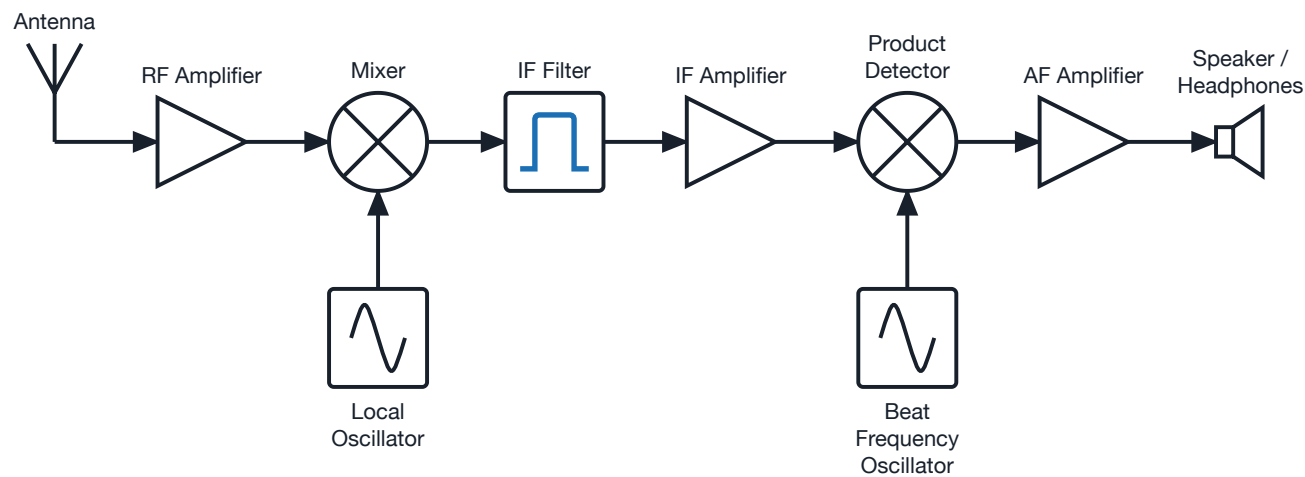
- The **mixer** changes the frequency of the incoming signal to the **IF**.
- Incoming 3,600 kHz, 9 MHz IF: the local oscillator runs at $9,000 - 3,600 = 5,400$ kHz.
- 14.250 MHz combined with 13.795 MHz gives 455 kHz: the **mixer**.
- The RF amplifier and the **first mixer** are tuned to the same frequency.
- Oscillators must be **stable and spectrally pure**.

Tuned circuits

LC circuit with a variable capacitor	Role
Before the IF amplifier, with a trimmer	Tunes the local oscillator
At the mixer input, with no RF amplifier	Tunes the preselector

The BFO

- On SSB, it replaces the **suppressed carrier** for detection.
- Offset by 500 to 1,500 Hz, it **beats with the incoming signal** (the CW tone).



Superheterodyne SSB/CW receiver

Source: ISED official question bank, Advanced Qualification (section A-006).

A-006-003 Noise, sensitivity and dynamic range

Term	Definition
Noise floor	The weakest signal detectable above the receiver's internal noise
Dynamic range	The dB difference between the largest tolerable signal and the weakest detectable one; the amplitude of nearby signals accepted without degradation
Preselector	The tuned circuits at the input and output of the RF stage

The RF amplifier

- Its main purpose: **improve the receiver noise figure**.
- It needs **just enough gain** for weak signals to overcome the **mixer noise**.
- In a good receiver, noise comes from the **RF amplifier and mixer**.
- The lower the noise figure, the greater the **sensitivity**. On HF it matters little: **external noise** exceeds internal noise.

The IF amplifier

It improves **selectivity** and **gain**.

UHF FM sensitivity

Expressed as the **RF level for 12 dB SINAD**.

Source: ISED official question bank, Advanced Qualification (section A-006).

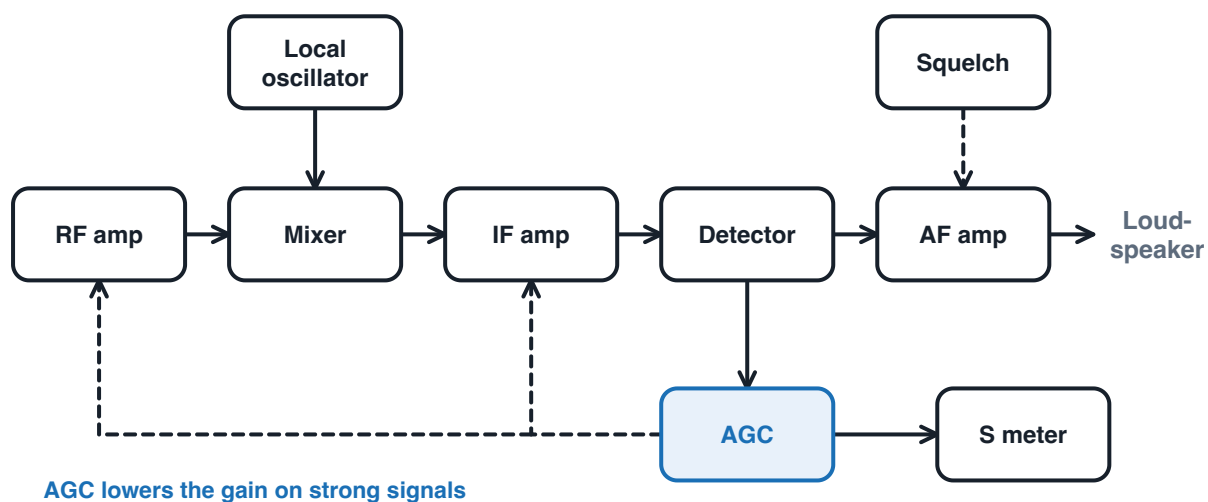
A-006-004 Detection and automatic gain control

After the IF

- The amplified IF goes to the **detector**; the detector output goes to the **AF amplifier**.
- The **product detector** mixes the incoming signal (IF) with a **locally generated carrier** (the BFO) to produce audio.
- On FM, a **de-emphasis** network restores the low frequencies cut by pre-emphasis.

Automatic gain control (AGC)

- As the signal gets stronger, it **reduces the gain**.
- Its voltage is **IF derived or audio derived** and is applied to the **RF and IF amplifiers**.
- Its two main variables: **threshold** and **decay time**.
- Distortion only on **strong signals** points to a fault in the **AGC**.



Receiver: AGC, S meter and squelch

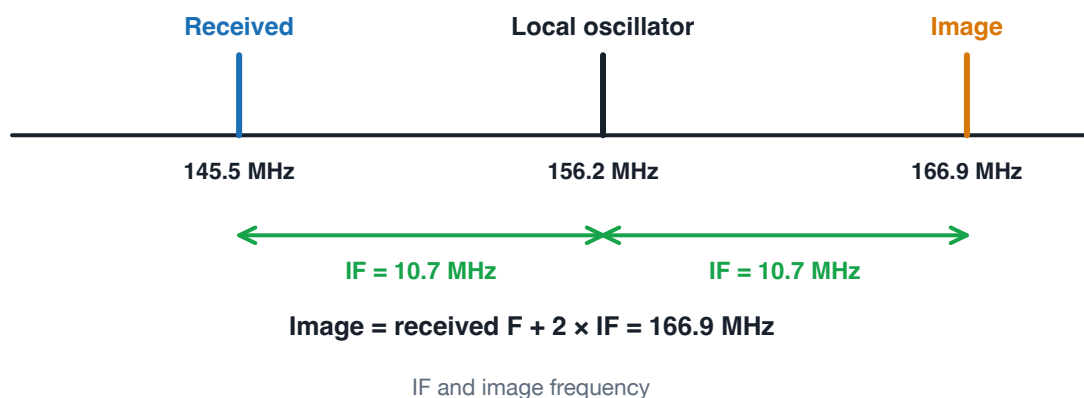
Source: ISED official question bank, Advanced Qualification (section A-006).

A-006-005 Image, desensitization, intermodulation and stability

The image frequency

- Image rejection is set by the **RF amplifier preselector**.
- A **VHF IF** in an HF receiver moves the image response far from the filter passband.

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



Desensitization and intermodulation

- **Desensitization** is a loss of sensitivity caused by **strong signals on a nearby frequency**; a **cavity filter** reduces it.
- **Intermodulation** comes from **non-linear circuits or devices**: two or more signals mix in the **front end**.
- Poor dynamic range causes desensitization, intermodulation and cross-modulation, but **not** feedback.
- On VHF, behaviour with strong out-of-band signals is shown by the **two-tone third-order IMD dynamic range** at 10 MHz spacing.

Stability

- Poor stability usually comes from the **local oscillator** and the **power supply**.
- **Dial display accuracy** is not a cause of instability.

Source: ISED official question bank, Advanced Qualification (section A-006).

Feedlines and Antennas

A-007-001 Matching networks

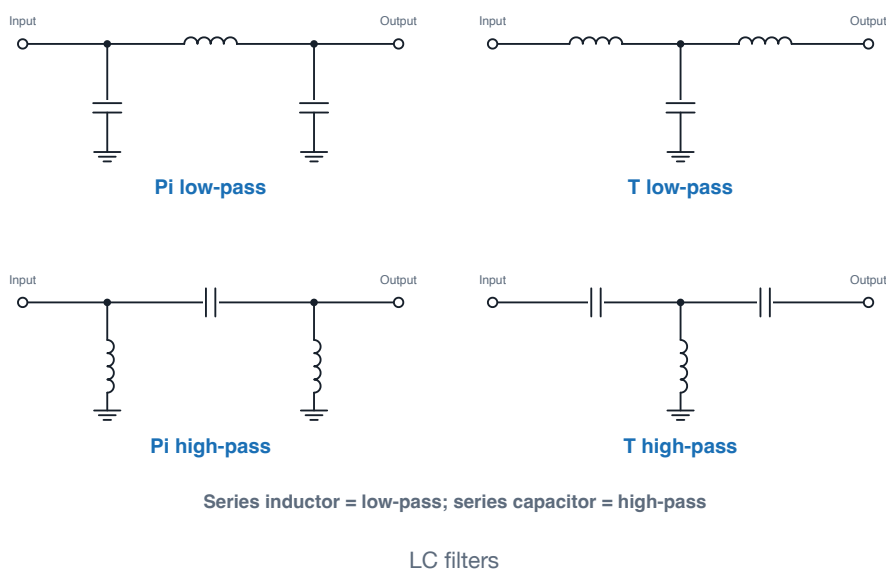
A network **cancels the reactive part** of an impedance, then **changes its resistive part**.

Network	Feature
L	Two elements: matches only a small impedance range
Pi	One inductor and two capacitors, or two inductors and one capacitor; the widest matching range
Pi-L	An extra output inductor: greater harmonic suppression

- "Transformer", "series" and "pi" tuners have a 50 Ω input and match high or low impedances; a series or transformer tuner is **not** a pi tuner, and the reverse.
- An L tuner that steps 50 Ω up to a high impedance (end-fed wire) is **not** suited to a ground-plane vertical, which is low impedance.

The Smith Chart

It **simplifies the mathematical operations** on impedances (lines, matching).



Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-002 Quarter-wave and half-wave lines, velocity factor

Resonant lines

Line	Far end	Impedance seen at the input
Quarter wave	Shorted	Very high
Quarter wave	Open	Very low
Half wave	Open	Very high
Half wave	Shorted	Very low

A quarter-wave line **inverts** the impedance; a half-wave line **repeats** it.

Velocity factor

- The **velocity of the wave on the line divided by the velocity of light** (in free space).
- It depends on the **dielectric**: $V = 1/\sqrt{\epsilon_r}$. **Polyethylene** coax: **0.66**.
- RF moves **more slowly** in coax than in air: the physical length is **shorter** than the electrical length.

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-003 Matching the antenna: gamma, T and stub

Match	Description
T match	The line (high impedance) connects to the driven element at two points , symmetrical about the centre
Gamma match	Unbalanced feed connected to the centre of the element and to a point on one side only; one adjustable mechanical and capacitive device
Stub match	A short section of line connected in parallel at a set point on the feed line

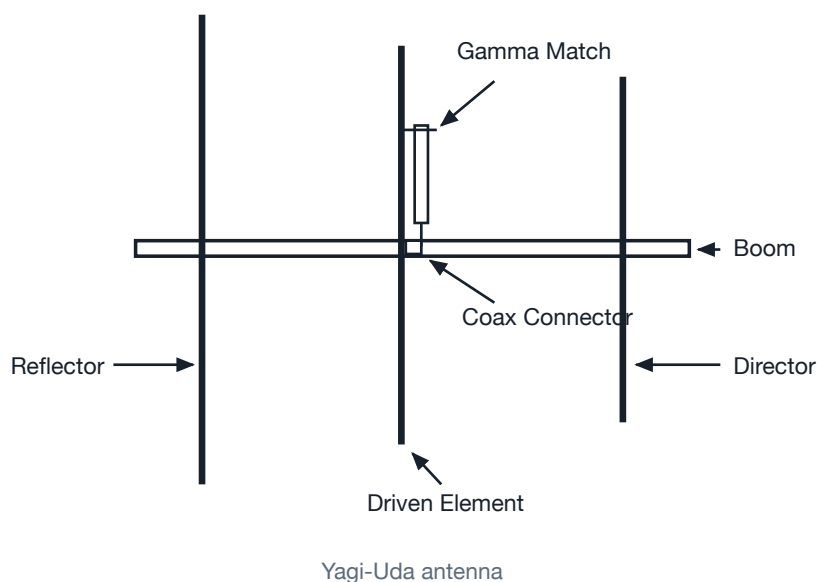
The gamma match on a Yagi

- The coax **braid** goes to the **centre** of the driven element.
- The **centre conductor** goes through the **variable capacitor**, connected to the **adjustable gamma rod**.

Physical length of a quarter-wave line

$$L = \frac{300}{F} \times \frac{1}{4} \times V$$

Frequency	Velocity factor	Length
14.100 MHz	0.66	3.51 m
15 MHz	0.8	4 m

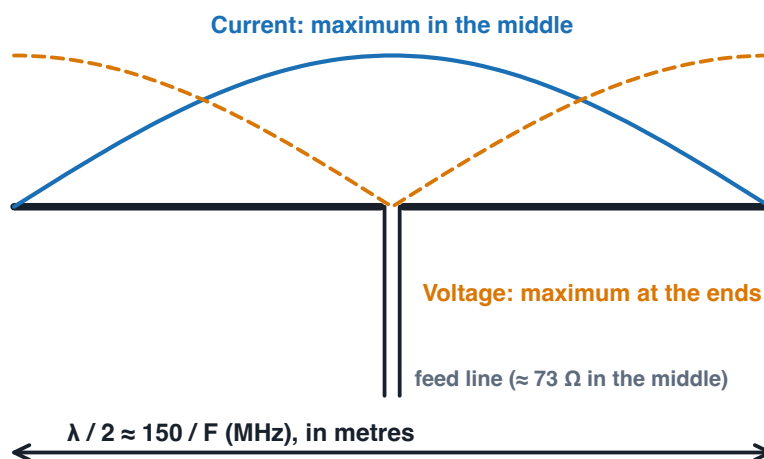


Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-004 Voltage and current along a dipole

Position	Voltage	Current	Impedance
Centre	Minimum	Maximum	Minimum (about 73 Ω)
Ends	Maximum	Minimum (zero)	Very high

- A half-wave dipole is fed where the **current is maximum**: at the centre.
- The centre impedance is low because the **voltage is low and the current is high** ($Z = E/I$).



Half-wave dipole: current and voltage

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-005 Circular polarization, dishes and Doppler

Circular polarization

- Waves with a **rotating electric field**.
- **Crossed dipoles** fed **90° out of phase** produce it; so does a **helical-beam** antenna. A **loaded helical-wound** antenna (shortened whip) does **not**.
- A helix with **right-hand** polarization best receives **right-hand** polarized signals.
- A helical-beam antenna responds to both **horizontal and vertical** signals.

Polarization loss

Between two linear antennas **crossed at 90°** on a fixed VHF/UHF path: **20 dB or more**.

The parabolic dish

- Efficient because **all the received energy is focused** on the point where the pick-up antenna sits.
- Its gain depends on its **diameter in wavelengths**.
- Surface error should not exceed **0.1 λ** .
- Feeds: focal point, offset or Cassegrain; "Newtonian" is not a dish feed.

Doppler shift

It becomes significant for contacts **via satellite**.

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-006 Effective radiated power (ERP)

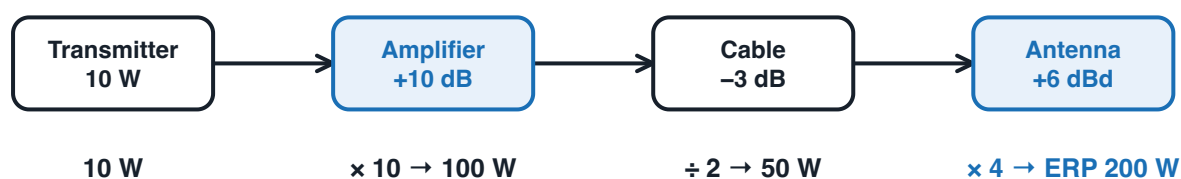
ERP is the transmitter output power, **minus line losses, plus the antenna gain relative to a dipole** (dBd).

Method

1. Add the gains and subtract the losses, in dB.
2. Turn the total into a factor: +3 dB = $\times 2$, +6 dB = $\times 4$, +9 dB $\approx \times 8$, +10 dB = $\times 10$.
3. Multiply the transmitter power.

Transmitter	Losses	Antenna	Total	ERP
100 W	3 dB	6 dBd	+3 dB	200 W
200 W	3 dB	9 dBd	+6 dB	800 W
100 W	1.3 + 0.2 dB	4.5 dBd	+3 dB	200 W
125 W	0.8 + 0.2 dB	10 dBd	+9 dB	1,000 W
1,000 W PEP	1 dB	10 dBd	+9 dB	8,000 W PEP
2,000 W PEP	1 dB	10 dBd	+9 dB	16,000 W PEP

- Losses in watts: 200 W – 5 W = 195 W, then +3 dBd → **390 W**.
- +3 dB **doubles** the ERP; going from a 3 dBd to a 9 dBd antenna multiplies it by **4**.



$$\text{Total: } +10 - 3 + 6 = +13 \text{ dB} = \times 20$$

Working out ERP in decibels

SWR and loss

High SWR increases line loss through **dielectric and conductor heating**.

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-007 Antenna height and radiation angle

Height above ground

- The **higher** a horizontal antenna (Yagi, dipole), the **lower** the radiation angle of the main lobe.
- A simple horizontal antenna only has marked directivity at **half a wavelength** or more above ground; lower down, ground reflections **distort** its pattern.
- A dipole at $\lambda/2$ above ground: **upward radiation is effectively cancelled**.
- The effective ground plane lies **several centimetres to 2 m below ground**.
- More than 3λ above ground, a dipole's centre impedance is close to **75 Ω** .

Radiation angle

- For long distance, the angle should be **less than 30°**; lowering the vertical angle lengthens each hop.
- A **ground-mounted quarter-wave vertical**, in the clear, radiates at a **lower angle** than a dipole at $\lambda/4$: better for DX.

Short range and NVIS

- A **low** horizontal antenna helps on the lower HF bands: the **ground acts as a reflector**.
- For **NVIS**: a horizontal antenna **less than a quarter wave** above ground, and a frequency **below the critical frequency**.

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-008 Radiation resistance, efficiency and beamwidth

Radiation resistance

- The **equivalent resistance** that would dissipate the same power as the antenna radiates.
- Knowing it lets you **match impedances** for maximum power transfer.
- It depends on the antenna's **location relative to nearby objects** and the conductors' **length-to-diameter ratio**.

Efficiency

Total resistance = **radiation** resistance + **ohmic** resistance.

$$\eta = \frac{R_{\text{radiation}}}{R_{\text{total}}} \times 100$$

Antenna	Calculation	Efficiency
Dipole: 72 Ω and 2 Ω	72/74	97.3%
Miniloop: 50 m Ω and 2 m Ω	50/52	96.15%

Beamwidth

The angle between the two points where the main lobe is **3 dB** down (half power).

Source: ISED official question bank, Advanced Qualification (section A-007).

A-007-009 Waveguides and printed circuit lines

Waveguide

- Used **above 3,000 MHz**.
- Its cross-section must be at least **half a wavelength**.
- It **acts as a high-pass filter**: low loss **above** its cut-off frequency, huge loss below.
- Its advantage over coax at microwaves: **very low loss** (radiation, dielectric, copper). **Hysteresis** loss does not apply to it.
- Before repairing a horn or waveguide: transmitter **off and power disconnected**.

Printed circuit lines

- A transmission line made on a printed circuit: **microstripline** or **stripline**.
- Microstripline has **poorer shielding** than coaxial cable.

Source: ISED official question bank, Advanced Qualification (section A-007).

Formulas

The formulas used in the Advanced Qualification calculations.

Circuits

Quantity	Formula
RC time constant	$\tau = R \times C$
RL time constant	$\tau = \frac{L}{R}$
Charge after 1 and 2 time constants	63.2%; 86.5%
Inductive reactance	$X_L = 2\pi fL$
Capacitive reactance	$X_C = \frac{1}{2\pi fC}$
Resonant frequency	$f = \frac{1}{2\pi\sqrt{LC}}; f \approx \frac{159}{\sqrt{L \times C}}$ (MHz, μ H, pF)
Q of a parallel circuit	$Q = \frac{R}{X_L}$
Bandwidth	$B = \frac{f}{Q}$
Alpha and beta	$\alpha = \frac{\beta}{1 + \beta}; \beta = \frac{\alpha}{1 - \alpha}$

Measurements

Quantity	Formula
RMS value of a sine wave	$E_{RMS} = 0.707 \times E_{peak}; E_{p-p} = 2 \times E_{peak}$
Peak envelope power	$PEP = \frac{(0.707 \times PEV)^2}{R_L}$
Frequency counter error	Frequency in MHz $\times$ error in ppm, in Hz
Voltmeter sensitivity	$\Omega/V = \frac{1}{I_{full\ scale}}$
Lissajous figures	$\frac{f_V}{f_H} = \frac{\text{horizontal loops}}{\text{vertical loops}}$

Modulation and digital

Quantity	Formula
FM modulation index	$m = \frac{\Delta f}{f_{mod}}$
Deviation ratio	$\frac{\Delta f_{max}}{f_{mod\ max}}$
FM bandwidth (Carson's rule)	$B = 2 \times (\Delta f + f_{mod})$
Third-order intermodulation	$2f_1 - f_2$

Quantity	Formula
Levels of an n-bit converter	2^n ; about 6 dB of dynamic range per bit

Lines and antennas

Quantity	Formula
Velocity factor	$V = \frac{1}{\sqrt{\epsilon_r}}$; 0.66 for polyethylene
Physical length of a line	$L = \frac{300}{F} \times \text{fraction of a wave} \times V$
Effective radiated power	Power – losses (dB) + antenna gain (dBd)
Antenna efficiency	$\eta = \frac{R_{\text{radiation}}}{R_{\text{radiation}} + R_{\text{ohmic}}}$

Decibel landmarks

dB	Power ratio
3	$\times 2$
6	$\times 4$
9	$\times 8$
10	$\times 10$

Source: ISED official question bank, Advanced Qualification.

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