HF Linear Amplifiers

Basic amplifier concepts, types & operation

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Tube Amplifiers   **Solid-State Amplifiers**

Basic Linear Amplifier Requirements

- **Amplify the exciter's RF output (by 10 dB or more).**
- **Provide a means of correct matching to load.**
- **Amplify complex signals such as SSB with minimum distortion (maximum linearity).**
- **Transmit a spectrally-pure signal.**
- **Assure a safe operating environment.**

Basic Amplifier Types

- **Tube,** grounded-grid triode (cathode-driven) – most popular. Some designs use tetrodes.
- **Tube,** grounded-cathode tetrode (grid-driven) – less common, but growing in popularity.

- **Solid-state,** BJT (junction transistors) – 500W or 1 kW.
- **Solid-state,** MOSFET – typically 1 kW.

Grounded-Grid Triode Amplifier
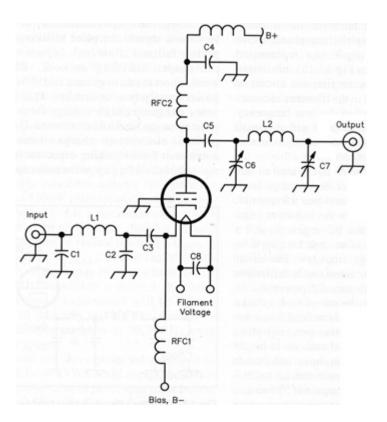## showing pi-section input & output networks

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Input network: C1-L1-C2
Plate feed circuit: RFC2-C5
Output network: C6-L2-C7
Plate tuning: C6
Loading: C7

Input impedance of grounded-grid triode amplifier
Is low, complex, and also non-linear (decreases at
onset of grid current). **Tuned input network** tunes
out reactive (C) component, and also linearizes
tube input impedance via flywheel effect.

Cathode choke RFC1 provides DC return path for
plate feed, and allows cathode to "float" at RF
potential. **Heater** (or filament of directly-heated
tube) powered via bifilar RF choke.

Pi-output network matches tube load resistance
to antenna, RF drive power added to output.

Amplifier can operate in **Class AB1** (no grid current)
or **AB2** (some grid current).

Tubes for Grounded-Grid Amplifiers

- **Directly-heated glass triode (e.g. 3-500Z, 811A, 572B)**

  - **Advantages:** Inexpensive, tough, directly-heated filament simplifies cathode circuit, simple cooling system.

  - **Disadvantages:** Very few manufacturers – limited supply & dubious quality.

- **Directly-heated ceramic-metal triode (e.g. 3CX1200A7)**

  - **Advantages:** High power output, high grid dissipation, tough, zero-bias operation possible (simplifies PSU).

  - **Disadvantages**: Fairly costly, high filament power.

- **Indirectly-heated ceramic-metal triode (e.g. 8877)**

  - **Advantages:** readily available, moderate cost, lower heater power.

  - **Disadvantages:** cathode more delicate than directly-heated; some tubes have low grid dissipation (easily damaged by overdrive). 8877 grid dissipation = 25W (OK).

Grounded-Cathode Tetrode Amplifier showing grid-swamped untuned input & pi-section output network
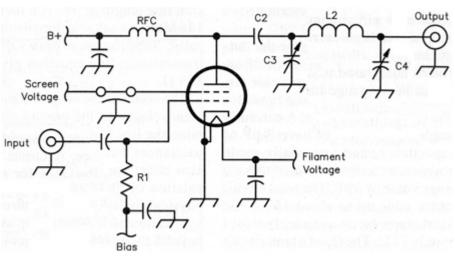
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Grid-swamping resistor: R1

Plate feed circuit: RFC-C2

Output network: C3-L2-C4

Plate tuning: C3

Loading: C4

Input impedance of grounded-cathode amplifier is high, complex, and also non-linear (decreases at onset of grid current).

Grid-swamping resistor (typ.50W) swamps tube input resistance and reactance, and eliminates effect of input-impedance nonlinearity. As input circuit is broadband, It need not be bandswitched.

Class AB1 (no grid current) most common.

Grounded-Cathode vs. Grounded-Grid

- **Input circuit:** *Grounded-grid amplifier* has bandswitched tuned input networks. Each network is broadly-tuned to cover an amateur band. Input network acts as low-pass filter, reducing harmonics from exciter. Some older amplifiers may not present 50Ω resistive load to exciter (especially on WARC bands*).

- *Grounded-cathode amplifier* has simple 50Ω resistive input circuit. As input circuit is broadband, it always matches exciter correctly, and need not be bandswitched. Note that lack of tuned input network reduces harmonic suppression, and can allow high RF energy from VHF parasitic oscillations to damage exciter.

- Use of **tetrode** rather than triode in grounded-cathode amplifier reduces grid-plate capacitance. This increases **input/output isolation,** eliminating feedback path which can cause instability.

- Availability of relatively inexpensive **Russian** ceramic-metal tetrodes (e.g. 4CX800, 4CX1600) offsets additional cost of regulated screen supply, and is driving popularity of moderately-priced grounded-cathode designs.

- Grounded-cathode amplifier can have slightly higher power gain than grounded-grid.

when transmitting on 17m with 15m selected on amplifier, or on 12m with 10m selected.

ALC (Automatic Level Control) & Grid Protection

- **ALC has 3 tasks:**
  - ◆ Prevent overdrive of amplifier and resulting nonlinearity.
  - ◆ Level power output at a preset value.
  - ◆ Protect tube(s) from excessive grid dissipation.
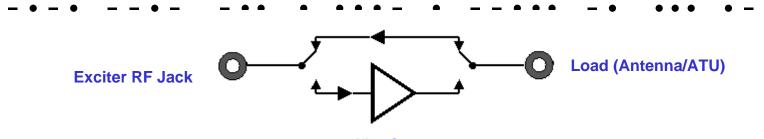
- **Basic ALC operation:**
  - ◆ ALC samples RF envelope at amplifier input, or detects grid current.
  - ◆ ALC circuit develops negative-going DC voltage (typ. 0 to -4V), which is fed back to exciter via ALC line (closed-loop) to control drive.
  - ◆ ALC pot on amplifier is adjusted for desired power output into 50Ω load.
  - ◆ Time constants of ALC are fast-attack, slow-decay. Decay time > syllabic rate (speech must not "modulate" ALC line.)

- **Grid Trip (Grid Protection):**
  - ◆ Switches amplifier into standby mode when grid current reaches preset threshold, to prevent grid over-dissipation.

Transmit/Receive (T/R) Switching
and amplifier/exciter interconnections

Exciter RF Jack
Load (Antenna/ATU)

Amplifier Stage

- Input and output T/R switches:
  - **Open-frame** relay
  - **Vacuum** relays (high speed for QSK CW)
  - **PIN diodes** (highest speed, but can burn out with high load SWR)

- Other amplifier/exciter interconnections:
  - **Keying (PTT)** – may require auxiliary relay if voltage/current rating of amplifier keying line exceeds that of exciter PTT output
  - **ALC**
  - **RF ground**

Solid-State HF Linear Amplifiers

- Push-pull, transformer-coupled broadband topology most common.
- Basic 2-device, 250W PA modules are combined for increased output, using hybrid splitter & combiner.
- Bandswitched low-pass filters at combiner output suppress harmonics.
- DC supply voltage: typ. 40 to 50V. PSU is regulated for best linearity.
- Two RF power device types:
  - **BJT** (Bipolar Junction Transistor)
    - Relatively inexpensive & rugged.
    - Typ. 10 dB power gain, rolls off to 8 dB at 28 MHz. Unusable at 50 MHz.
  - **MOSFET** (Metal Oxide Field-Effect Transistor)
    - Slightly more costly, very rugged.
    - Typ. 13 dB power gain, fairly constant up to 54 MHz.
    - DC-to-RF conversion efficiency slightly higher than BJT.
    - Linearity slightly better than BJT.

Typical Solid-State Amplifier Module (250W MOSFET)
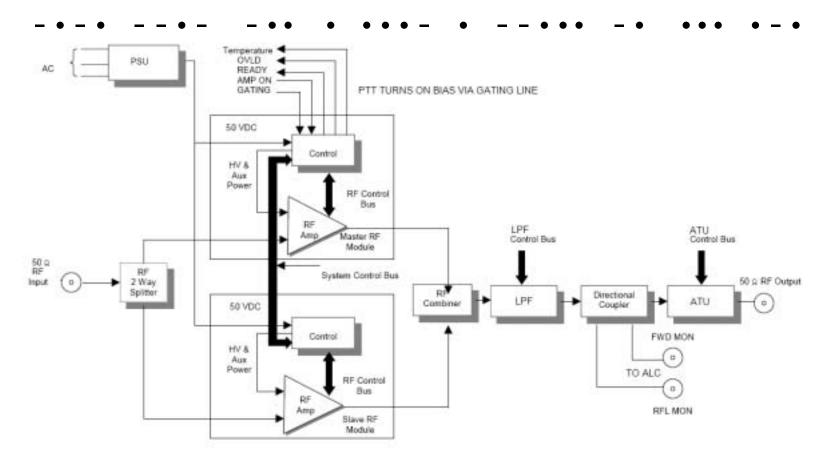

Q1, Q2: MRF150
T1: Ferrite binocular (4:1)   T2: Large ferrite binocular 4:1 (Fig. 6.87, 2001 ARRL Handbook)
C1: 100pF Dipped Mica   C2: 330pF×2 Dipped Mica
C3, C4: 4700pF, 100V Chip Cap.
R1: 100Ω, 1/4W   R2, R3: 18KΩ, 1/4W
R4, R5: 18Ω, 1/4W   D1, D2: 10D1, 1N4002 or equivalent

Simplified Block Diagram of Solid-State HF Amplifier

SIMPLIFIED BLOCK DIAGRAM OF TYPICAL SOLID-STATE HF LINEAR AMPLIFIER (2 MODULES)
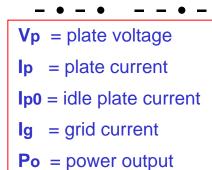
Solid-State HF Amplifier Features

- ■ **Microprocessor controller is amplifier's "brain"**
  - ◆ **Receives band information from exciter & detects drive frequency**
  - ◆ **Controls:**
    - ▶ **T/R switching & bias gating**
    - ▶ **LPF (low-pass filter) bandswitching**
    - ▶ **ALC line** *(fwd/refl power and other parameters determine ALC voltage)*
    - ▶ **Automatic ATU (if fitted)**
    - ▶ **Metering**
    - ▶ **Forced standby if preset limits exceeded**
    - ▶ **Fans**
  - ◆ **Monitors:**
    - ▶ **Forward & reflected power; calculates VSWR**
    - ▶ **Power output & drive; power gain**
    - ▶ **Balance between modules**
    - ▶ **DC supply voltage & current**
    - ▶ **PA temperature**
  - ◆ **Protects:**
    - ▶ **Reduces drive via ALC, then**
    - ▶ **Forces amplifier to standby**

Tuning a Tube Amplifier
(typical tuning procedure)

Vp = plate voltage

Ip = plate current

Ip0 = idle plate current

Ig = grid current

Po = power output

1. Power up and select desired band. Select CW at exciter. Note **Ip0**.
2. Apply sufficient drive to double **Ip0**. With **LOAD** at minimum, tune **PLATE** for **Ip** dip.
3. Adjust **ALC SET** for 50% of recommended **Ig**.
4. While increasing drive, alternately adjust **PLATE** and **LOAD** for **Ip** dip & max. **Po**.
5. Increase drive , and peak up **PLATE** and **LOAD** until **Po** no longer increases. *Do not exceed recommended Ig or Ip.*
6. Increase **LOAD** control until **Ig** drops by approx. 30% (overcoupling).
7. Increase **ALC SET** to reduce **Po** to rated value. Note ALC meter reading.
8. Select SSB at exciter. Adjust **ALC SET** for reading obtained in 7. on voice peaks.
9. Note: If amplifier has selectable **Vp**, retune when changing **Vp** setting.
10. **Retuning is required** when changing frequency, even within same band.

"Tuning" a Solid-State Amplifier
(typical procedure shown)

1. Power up. Set **METER** switch to **PRO** (ALC CAL). Select CW at exciter. Set **ALC** pot (on rear panel) to minimum. Set **BAND** to AUTO (assuming Icom exciter).
2. Select desired band. **BAND** LED for selected band will light. Apply 60W drive. Set **ALC** pot to bring meter pointer to **ALC ADJ** mark on **PRO** scale.
3. Set **METER** switch to **Po**. Meter will read 500W (rated output).
4. Select desired mode (e.g. SSB). Amplifier is now ready for operation.
5. The Icom **IC-2KL** 500W amplifier is shown here. If the compatible **IC-AT500** autotuner is connected, it will also automatically track the selected band and match the load to the amplifier's 50Ω output. The amplifier itself is broadband, and does **not** require tuning.

HF Amplifier Performance Criteria (tube & solid-state)

- **Power Output** *(PEP SSB and CW)*
  - Tube: 1.5 to 2 kW (ceramic-metal), 0.5 to 0.8 kW (glass)
  - Solid-state: 0.5 to 1 kW

- **Power Gain** *(ratio of output to drive power)*
  - Tube: 13 to 15 dB
  - Solid-state: 10 to 13 dB

- **Conversion Efficiency** *(ratio of RF output to DC input at PA stage)*
  - Tube: 50 to 70%
  - Solid-state: 45 to 50%

- **Third-order Intermodulation** *(a measure of linearity)*
  - Tube: -35 to -40 dB relative to PEP
  - Solid-state: -30 to -33 dB relative to PEP

- ***Note: 240V mains supply recommended for best efficiency and linearity.***

Switch to Safety!

- **Tube amplifiers contain lethal DC voltages > 2 kV.**
  - ◆ **Disconnect mains supply and allow all filter capacitors to discharge before opening amplifier case.**
  - ◆ *Do not defeat interlocks!*
- **Solid-state amplifiers use high DC current > 50A.**
  - ◆ **Keep metallic objects out of interior.**
- **High RF voltages can cause serious burn injuries.**