X-Ray Generator
B.Sc(MT) Radiography Ist Year

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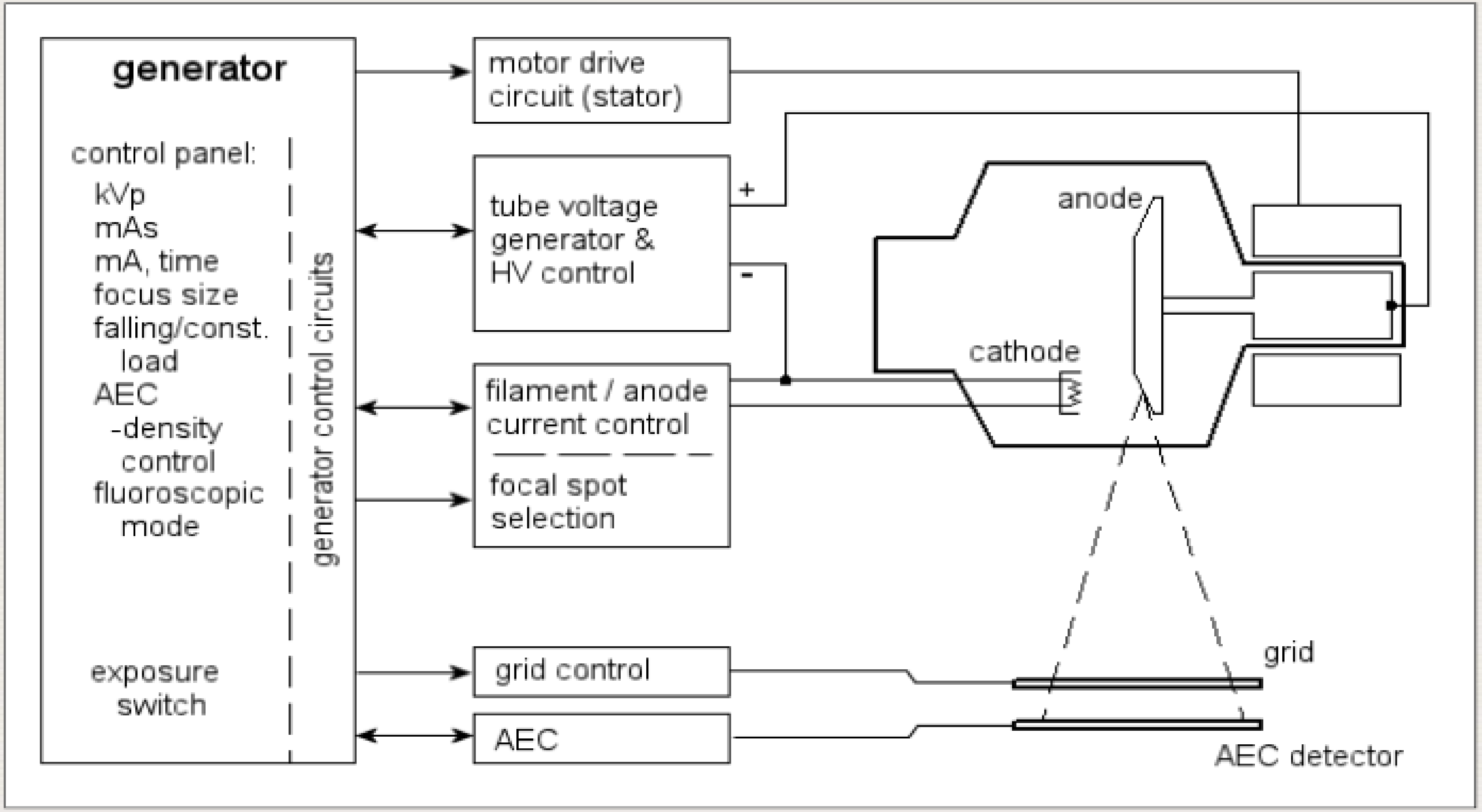
The X Ray Generator

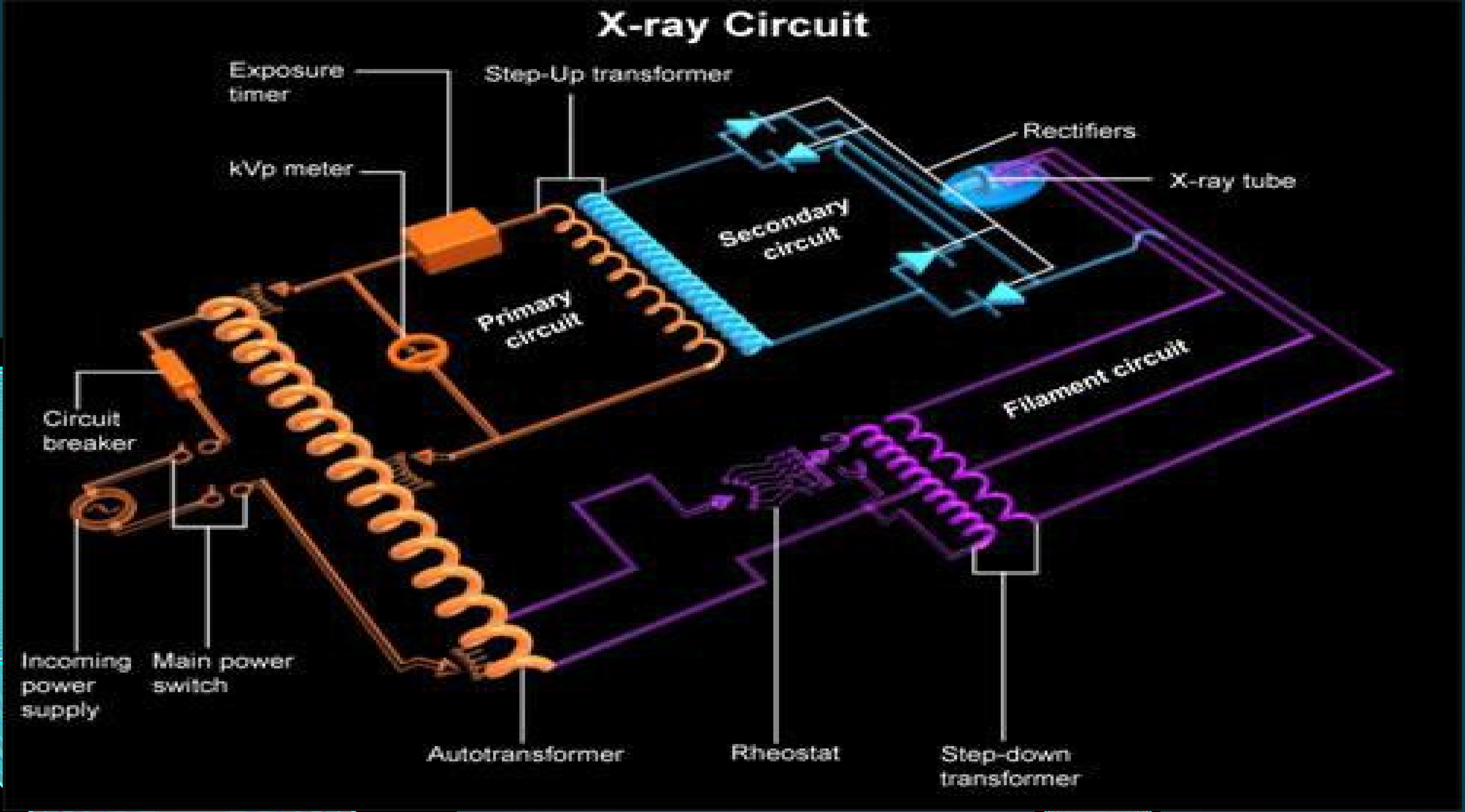
- Provides all electrical power sources and signals required for the operation of the X ray tube
- Controls the operational conditions of X ray production
- Controls the operating sequence of exposure during an exam

The essential components are:

- a **High Voltage** supply
- a **Filament Heating** circuit to determine anode current
- an **Operational Control**
- a **Motor Drive** circuit for the stator windings required for a rotating anode tube
- an **Exposure Control** providing the image receptor dose required



Schematic diagram of a basic X ray generator



Source: Lecture 10 X-Ray Circuit , KAAB

The main circuit and filament circuit are combined to form the complete basic x-ray circuit that is composed of sequence of devices to produce x-rays.

- **Main Circuit** (creates the x-rays by modifying the power from the source)

1.PRIMARY CIRCUIT–Control Panel

- **Main Switch**: The switch that generates the power to the x-ray tube.
- **Exposure Switch** : A remote control device that permits current to flow through the circuit.
- **Timer**: Device used to end the exposure at an accurately measured preset time.

2.SECONDARY CIRCUIT–high voltage transformers, rectification & x-ray tube.

- **Filament Circuit** (ensures the filament has the most suitable thermionically emitted electron cloud by using the incoming power)

1.FILAMENT CIRCUIT–varies current sent to the filament in order to provide the required mA value.

Transformers

- **Autotransformer**-that contains an iron core and a single winding or wire; is used in the x-ray circuit to provide a small increase in voltage before the step up transformer.
- **Step-up transformer**-that increases voltage from primary to the secondary coil and decreases current in the same proportion. Has more turns in secondary than in primary coil. Is used to increase voltage to the kilo voltage level for x-ray production.
- **Step-down transformer**-that decreases voltage from primary to the secondary coil and increases current in the same proportion. Has more turns in the primary than in the secondary coil. Is used in the filament portion to increase current flow tot he cathode

RECTIFIERS

- A rectifier is an electrical device that converts alternating current (AC) to direct pulsating current (DC).

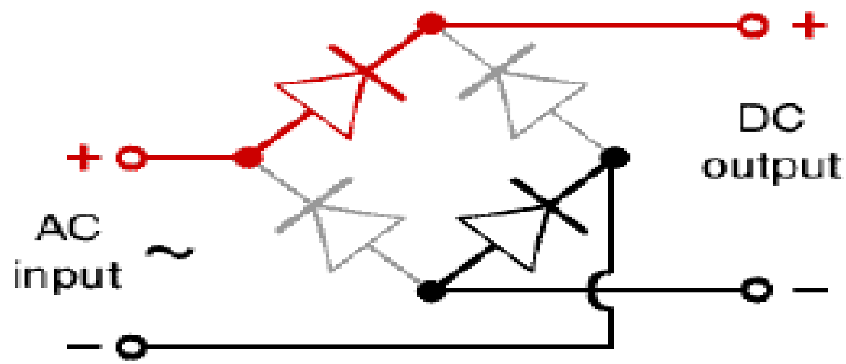
- Two Types of Rectifiers:

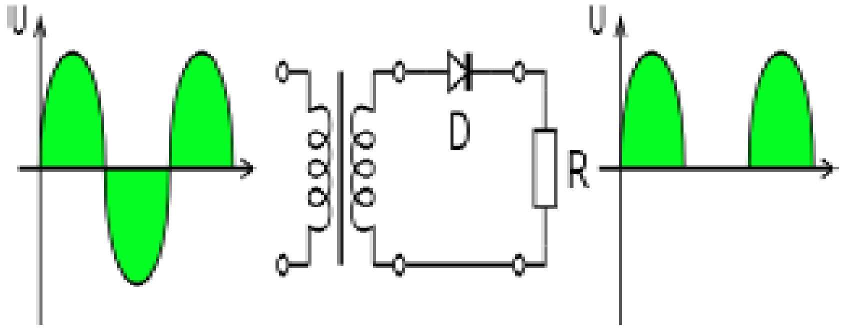
1. **Half Wave Rectifiers**

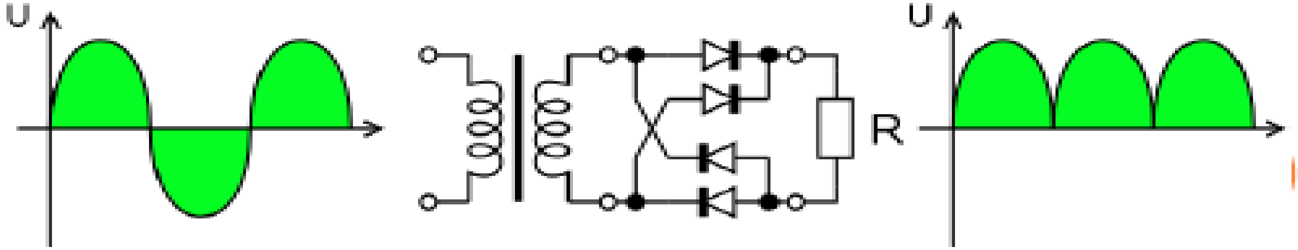
   * pass half of the alternating electrical current through one or more diodes

2. **Full Wave Rectifiers**

   * generally use four diodes to function, changing the entire current into a direct current.







Generating the Tube Voltage

- Irrespective of the waveform the tube voltage is defined as the **Peak Voltage**, kVp, of the voltage train
- The **Voltage Ripple**, R, is given as the relative difference of the minimum voltage, kVmin, from the peak voltage:

$$R = (kVp - kVmin) / kVp$$

- The tube voltage is supplied **Symmetrically** to the tube, i.e. a net potential difference of 150 kV is achieved by feeding -75 kV to the cathode and +75 kV to the anode
- This is electrically accomplished by **Grounding** the centre tap of the secondary coil of the high voltage transformer(Requirements for electrical isolation are less stringent then)
- In **Mammography** with tube voltages <40 kV and with some high performance tubes one electrode is kept at ground potential

Single-Phase Generators

- Single-phase generators use a single phase mains supply and a **Step Up Transformer** with a fixed winding ratio
- The high voltage is set by a variation of the primary voltage with a switched **Autotransformer**
- **Half-Wave Rectification** of the transformed voltage gives a **1-Pulse** waveform where a pulse is a half-wave per period of mains frequency (50 or 60 Hz)
- Some low-power X ray units use the tube as a **Self Rectifying Diode** with current only flowing from the cathode to the anode but reverse current flow, as a result of a **Hot Anode** is a limiting factor
- Today **Solid-State Diodes** are used as rectifiers
- A **Full-Wave Rectification** yields two half-waves per period (**2-Pulse** waveform)
- **Voltage Ripple** of 1- and 2-pulse waveforms is **100%**

Three-Phase Generators

- With a three-phase mains supply three AC-voltages each with a **Phase-Shift** of 120° are available
- **Full-Wave Rectification** gives then 6 half-waves per period (**6-Pulse** waveform) with a nominal ripple of 13.4% (Due to imbalances in transformer windings and voltages the ripple might in practice approach **25%)**
- Adding another **Secondary Winding** to the transformer gives two secondary voltages
- Combining the full-wave-rectified secondary voltages using **Delta**- and **Wye-Connections** yields a total of 6 phases with a phase shift of 60° each
- Full-wave rectification then gives a total of **12 Pulses per Period** with a nominal ripple of 3.4% (in practice <10% is achieved)
- Three-phase generators are **More Efficient** and allow for much higher tube output than single phase

High-Frequency Generators

- This type of generator includes a **Stabilized Power Supply** in the front end of the device
- First the **Mains** supply is rectified and filtered to produce a DC-supply voltage needed for an **Inverter Circuit**
- The **Inverter** generates pulses which are transformed, rectified and collected in a capacitor to give the high voltage for the tube(The inverter **Pulse Rate** is used to control the tube voltage
- The actual voltage on the tube is sensed by the generator and compared with the voltage set on the console
- The difference then is used to change the **Pulse Rate** of the inverter until the set voltage is achieved.(Similarly a separate inverter system is used for the tube current)

High-Frequency Generators

- The **Pulse Shape** of a single X ray exposure pulse resembles a fundamental frequency of several tens of kHz giving rise to the generator's name
- Transformers for such frequencies are much **Smaller** than for 50/60Hz voltages reducing the size and weight substantially

(In low-power generators the whole generator could be included in the tube housing avoiding any high-voltage cabling)

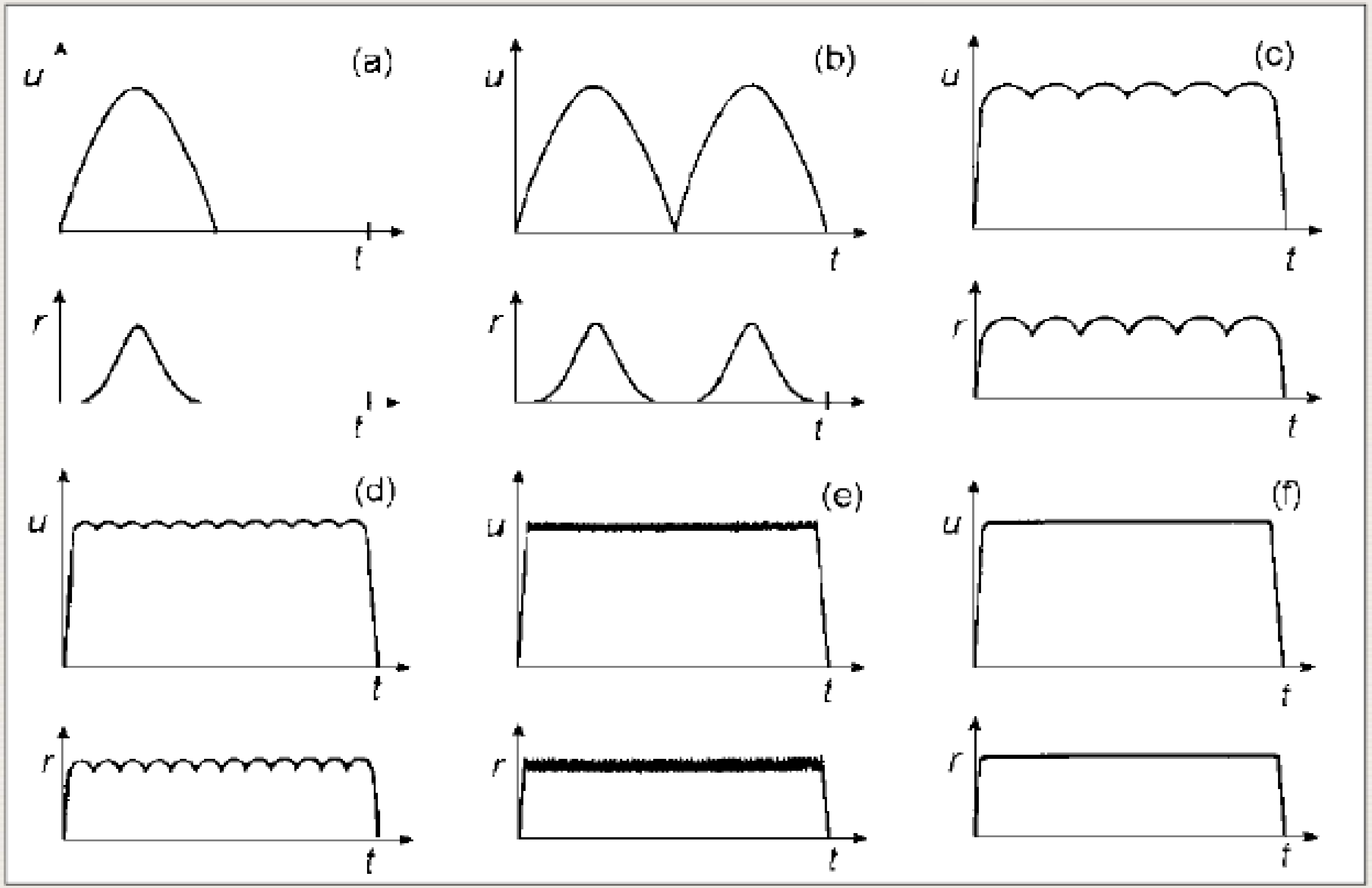
- The **Voltage Ripple** depends on many technical factors but for low-power applications is typically **~13%**, dropping to **~4%** at higher currents
- The **Time Constants** relevant for voltage and current control are typically **<250 µs** enabling better timing control of the exposure than with single and three-phase generators

Capacitive Discharge Generators

- In places with inadequate mains supply or in remote locations capacitor discharge generators are helpful
- A capacitor is **Charged** to a high voltage just before an exposure
- The capacitor is connected to the XRT with the start and length of exposure controlled by a **Grid**
- High tube currents and short exposure times can be obtained
- However, discharging a capacitor implies a **Falling Tube Voltage** during exposure
- Typically **Voltage Drops** of ~1 kV per mAs are usual
- As kerma drops with voltage the appropriate exposure of thick body parts can be problematic

Constant Voltage Generators

- Constant voltage generators achieve a DC-high voltage with minimal ripple through the use of a **Closed Loop Linear Voltage Controller** (e.g. high-voltage triodes) in series with the tube
- High frame rates and voltage stability are achieved
- Constant potential generators use a **Complex** technology with high costs of investment and operation, and consequently have lost popularity



Voltage waveforms **u** and associated tube output (dose rate) **r** for

(a) 1-pulse

(b) 2-pulse

(c) 6-pulse

(d) 12-pulse

(e) high-frequency

(f) constant voltage generators

IAEA

Filament Circuit

- An **Isolated Transformer** supplies the filament heating current
- The generator is **Programmed** to set the heating current according to the tube characteristics
- Heating currents range up to 10 A with voltages of <15 VAC
- To minimize thermal stress and increase durability, the filament is **Permanently Preheated** to a temperature for which thermionic emission is negligible
- The **Thermal Inertia** of the filament limits the speed of change in tube current (e.g. falling load)
- **Thermal Time Constants** range from 50-200 ms
- For a frequency of heating currents of 100 or 120 Hz some tube current **Ripple** is due to the temperature variations induced
- For high frequency generators the thermal inertia of the filament suppresses **Fluctuations** of thermionic emission

Operational Control

- The **Operational Control** is often accomplished by a microprocessor system but electromechanical devices are still in use
- Modern generators provide control of the **Anode Temperature** by
  - **Monitoring** the power applied to the tube and
  - **Calculating** the cooling times required according to the tube rating charts