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German WW2 Radio

technology, equipment & innovations

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VA7OJ

Scope of presentation

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- Component and packaging technology
- Design features
  - Frequency stability & repeatability
  - Maintainability
- Typical components
- **Luftwaffe:** MF/HF & VHF communications
- **Joint Service:** E52 'Köln' HF Receiver
- **Wehrmacht:** Portable VHF Tactical Radio

Highlights of German WW2 military radio

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- German radio industry (1930 – 1945) was extremely innovative
- Many advances in component, circuit & system design are still in use today
- Particular strengths in vacuum tubes, receivers and airborne radio systems
- Mechanical construction & packaging generally superior to comparable Allied equipment
- Pioneered deployment of tactical VHF comms *(and even SSB in fixed installations)*

Component and packaging technology

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- Use of as few tube types as possible
  - Simplify manufacture and logistics, but complicate circuit design
- US control of Brazilian quartz markets influenced design:
  - Simple MOPA-type transmitters
  - Limit use of quartz crystals to IF filters
  - Stable tunable oscillators became a fine art
  - Coils on ceramic formers with silver windings vacuum-deposited onto grooves in former. Q > 500!
  - IF coils on powdered-iron pot-cores
  - Temp. coefficient of ceramic compensated for that of metallic windings; also NTC and PTC ceramic capacitors
  - Precision tuning capacitors; plates machined from single billet on ceramic shaft
  - Solid die-cast light-alloy chassis; heat-producing components thermally coupled to chassis Link

Design for frequency stability & repeatability

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- Large, directly-calibrated tuning dials
  - resolution to 100 Hz
  - precision backlash-free dial drives
- Crystal calibrators in some sets
  - also portable, plug-in calibrators
- Dynamic compensation of transmitter MO (VFO)
  - RF current & TC/loss factor of capacitor adjusted such that key-down RF heating of capacitor offsets drift due to RF heating of coil and heat-related inter-electrode capacitance changes in MO tube
- Typical stability: ±3.2 x 10^{-4} (±1.3 kHz at 4 MHz)
  - for -50 to +50°C, 22 to 29V DC supply voltage range
- This technology was lost in the post-war years
  - synthesizers removed incentive for its retention

Design for maintainability

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- 3-dimensional construction
  - compartmentalized die-cast light-alloy chassis, with each functional circuit in its own shielded compartment wherever possible
  - tubes in recessed sockets, removable from chassis exterior
- Compact modular design, with standard interfaces
  - inter-modular connectors allowed easy assembly and disassembly
- Logical breakdown: “block diagram in hardware”
  - RX: RF/mixer, LO, IF & selectivity, demodulator, AF
  - TX: MO, buffers if any, PA, output tank, T/R switching
    - AM modulator separate
- Testability
  - each module tested individually on special test jigs prior to integration and final test
  - “BITE”: in-circuit tube check with built-in meter or plug-in test set

Typical components

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- **RV12P2000 Pentode:** widely used as small-signal RF, IF and AF amplifier etc. This is the **only** tube type used in the FuG 10 EK and EL receivers, and in the Telefunken E52 'Köln' HF receiver.

- **RL12P35:** Transmitting pentode used as PA and driver in many radio systems incl. FuG 10. 35W anode dissipation.

- **Variometer:** variable inductor used in FuG10 airborne MF/HF transmitter. L_{min} with coils 90° apart. Note sputtered-on windings.
- Image courtesy G3YNH.

- **Here are a few examples of components used in German WW2 radio equipment.**

FuG 10 (Funkgerät Typ 10)

Luftwaffe MF/HF radio system

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- Developed by Lorenz AG (now Alcatel-SEL), 1936-37
  - standardized in 1939 for all larger aircraft with crew > 2
  - RAF equivalent was T1154/R1155; US equiv. was BC-375/BC-348
- Plug-in modular component units on flight deck
  - EK (HF) & EL (MF) receivers Link 1 Link 2
  - SK (HF) & SL (MF) transmitters Link 3
  - Antenna control unit (FBG.3), modulator (TZG 10), switchbox etc.
- Remote ATU (AAG.2) – mounted in tail area, near antennas
  - Controlled from FBG3 via synchros, connected to TX/RX via 60Ω coax
- Basic specifications: Link 4
  - Freq. range: MF 300 - 600 kHz. HF 3000 - 6000 kHz.
  - Power output: 70W (A1A), 40W (A2A, A3E)
  - Sensitivity: 4 µV for $10V_{rms}$ output in 4 kΩ (A1A)
  - Selectivity: 6 dB BW = 3 kHz, 60 dB BW = 18 kHz
  - Primary DC power input: 800W max.

FuG10 Overall System View

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Module Dimensions:
RX: 180mm H X 200mm W X 220mm D

TX: 220mm H X 215mm W X 200mm D

- **Upper row: MF RX (EL), HF RX (EK), Antenna Control Unit (FBG.3)**
- **Lower row: MF TX (SL), HF TX (SK), Switchbox**
- **2 antennas: fixed or trailing-wire, selectable at FBG.3. Trailing antenna is remote-controlled (12m HF, 70m MF).**
- **60Ω coax between TX/RX and remote ATU. Vacuum T/R relay in ATU.**

FuG10 Interior Views

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SK Transmitter with RL12P35 tubes (1 in MO, 2 in parallel for PA) Image courtesy LA6NCA

AAG.2 ATU showing HF variometer (left), vacuum T/R relay (centre) and MF variometer (right). Image courtesy SRS

- **Note the extremely high quality and finish.**

FuG10 Interior Views

EK Receiver, top view, showing tube sockets, IF transformers and chassis compartments.
Image courtesy Bo Samuelsson

EK front panel frame & tuning dial mechanism with 4 preset cams.
Image courtesy LA6NCA

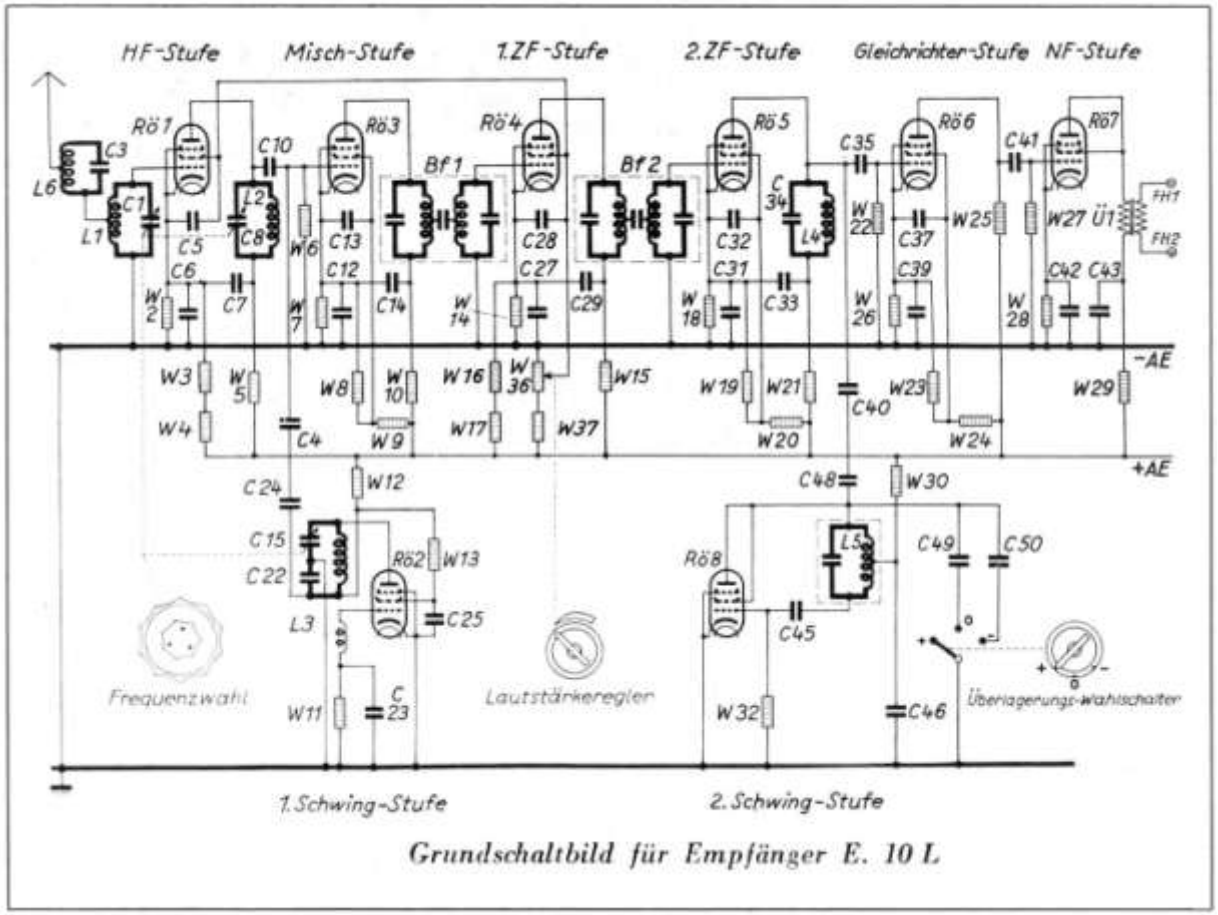
EK: Detail of main tuning capacitor.
Image courtesy LA6NCA

- **Note the extremely high quality, precision and finish.**

Basic Schematic of E 10 L MF Receiver (300 - 600 kHz)

Source: Fritz Trenkle

Note: No AGC in E 10 L. Later HF RX E 10a K had AGC circuit.



Grundschaltbild für Empfänger E. 10 L

Basic Schematic of E 10a K HF Receiver (3000 - 6000 kHz)

courtesy Bo Samuelsson

Note: Rö10 is AGC circuit. “10a” denotes AGC.

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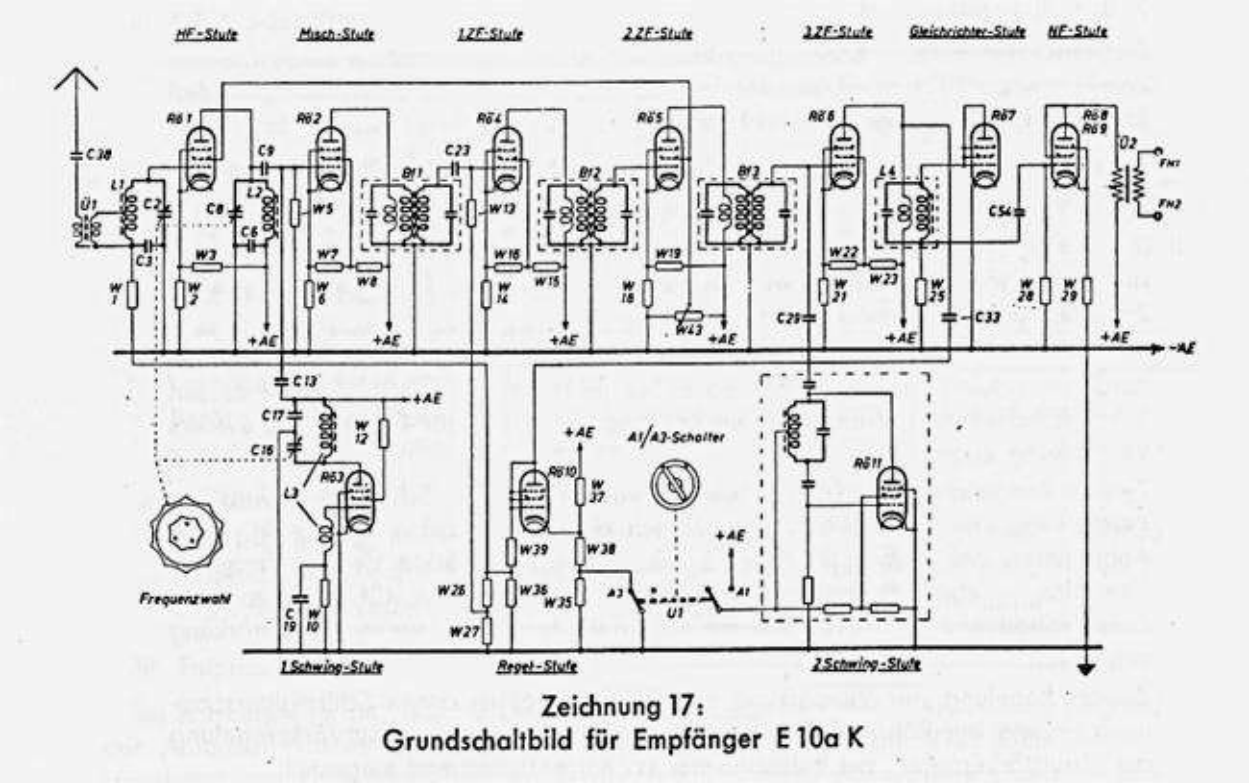
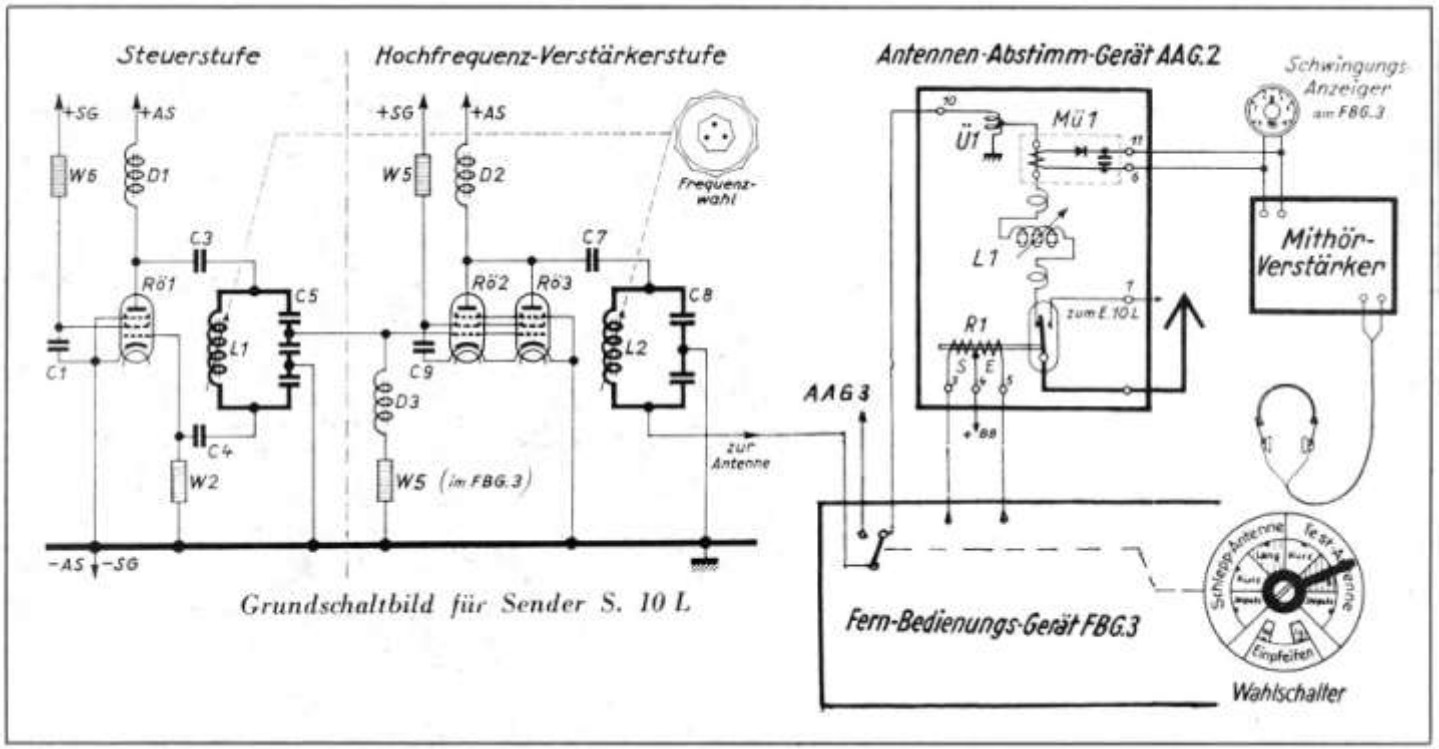


Zeichnung 17:
Grundschaltbild für Empfänger E 10a K

Basic Schematic of S 10 L MF Transmitter (300 - 600 kHz)

Source: Fritz Trenkle



Note 1: Connections from TX and RX via Ant. Control Unit (FBG.3) to ATU (AAG.2) are 60Ω coax.
Note 2: Monitor amplifier (Mithör-Verstärker) and RF power meter (Schwingungs-Anz.) coupled via current transformer Mü1.
Note 3: Later auto-ATU tuned fixed antenna at low power. Matched when rate-of-change of RF current approached zero.
Note 4: S 10 L and S 10 K transmitters used grid-block keying.

Telefunken E52b 'Köln' HF Receiver - the most advanced RX of its era

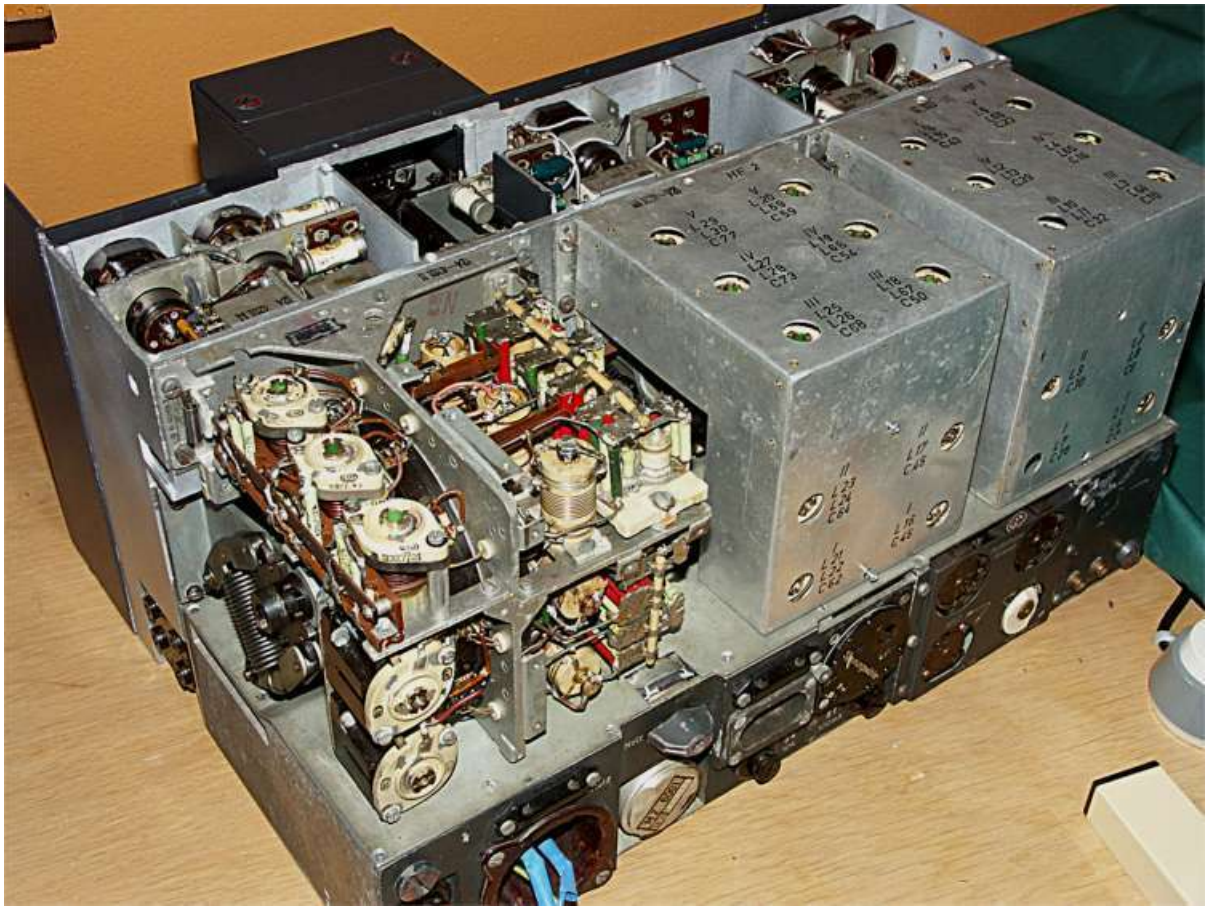
Image courtesy Bo Samuelsson

Link 1 Link 2

E52 'Köln' HF Receiver

Interior View *(courtesy Bo Samuelsson)*

Modules (l-r): mixer/LO (shield removed), RF 2, RF 1



E52 'Köln' HF Receiver

Interior Details *(courtesy LA6NCA)*

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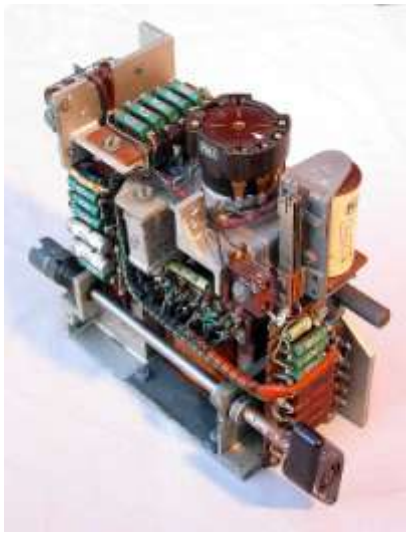

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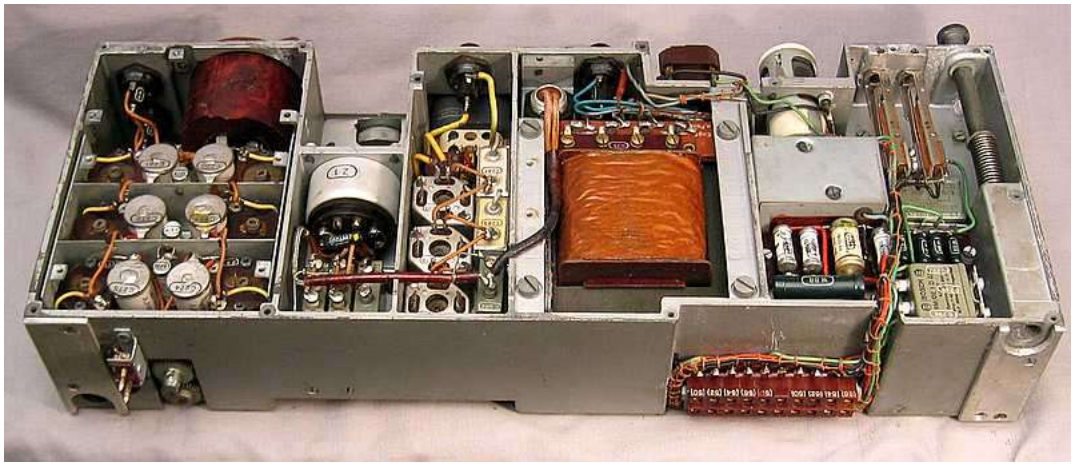

1 Tuning capacitor detail
2 IF/crystal filter module
3 AF amplifier module
4 Mains/12V PSU module

E52 'Köln' HF Receiver

Module Details *(courtesy Bo Samuelsson)*

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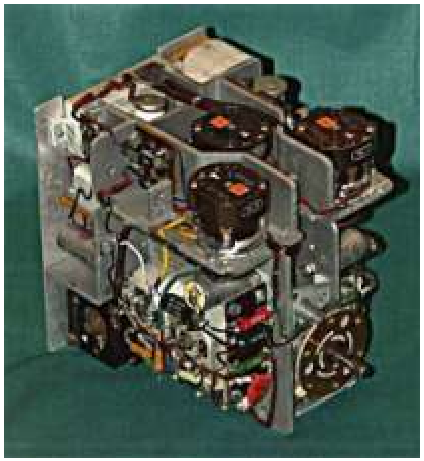

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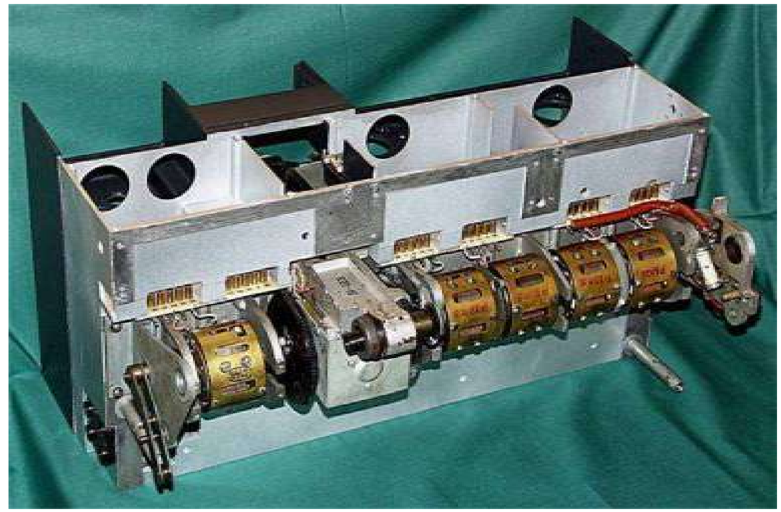

4

1 IF/crystal filter module
2 BFO module
3 Main tuning capacitor
4 Tuning dial detail

E52 'Köln' HF Receiver

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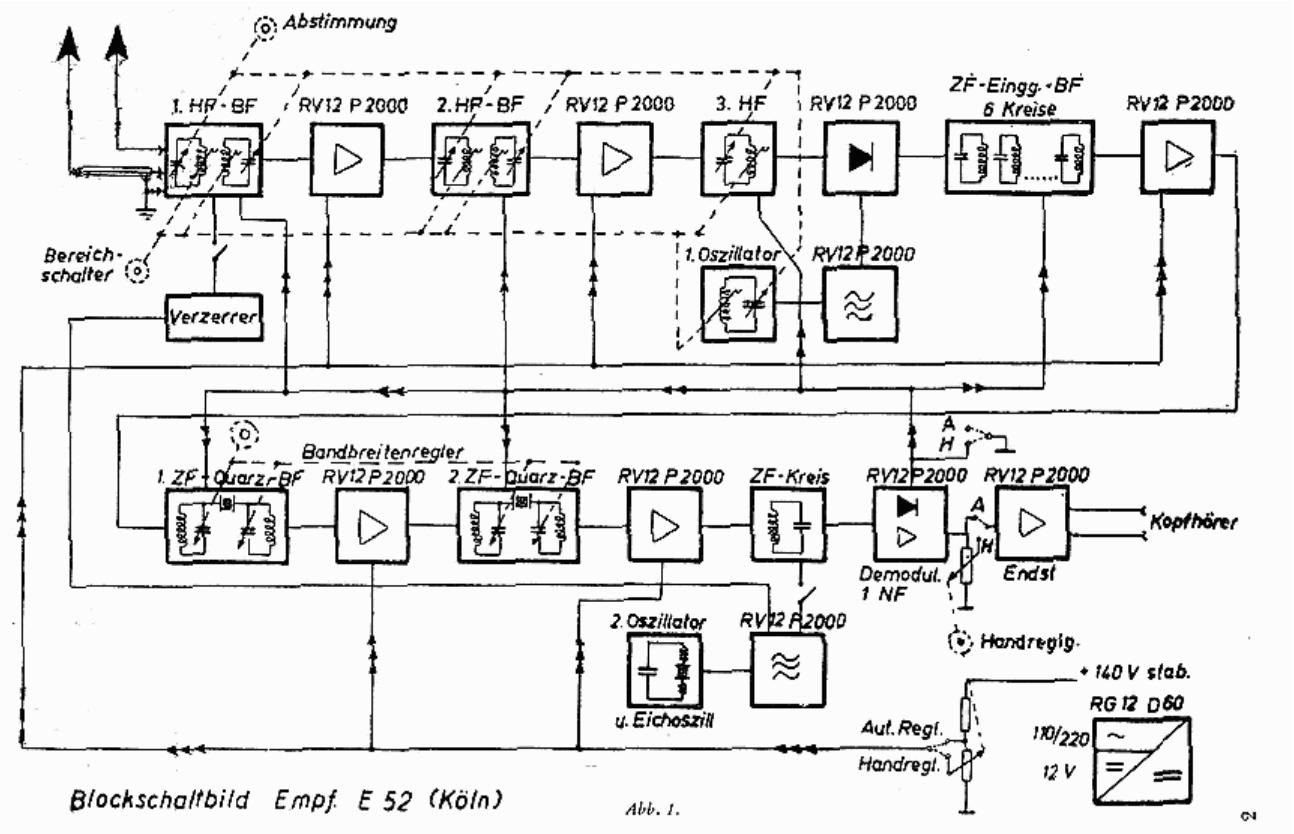
- Single-conversion HF superhet communications receiver
  - Developed 1941 by Telefunken for Luftwaffe; adopted later by all services. Used by German merchant marine until early 1960's
  - 5-pole active tunable RF preselector with 2 RF amps: superb image rejection, IF rejection, front-end protection and sensitivity
  - 1 MHz IF; crystal filter with continuously-variable bandwidth
  - Supported emissions: A1A, A2A, A3E
    - SSB/ISB adapter available for J3E, B8E
  - Die-cast chassis with shielded modules plugged into backplane
  - Unique precision geared tuning mechanism with optical projection readout (window above main dial). Resolution 1 kHz
  - Motorized tuning drive on E52a version, omitted on E52b
  - AGC on all RF and IF stages
  - Crystal-controlled BFO with +900 Hz offset
  - Built-in power supply for AC mains and 12V DC operation

E52 'Köln' HF Receiver

Block Diagram *(courtesy LA6NCA)*



E52 'Köln' HF Receiver

Technical Specifications

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- **Frequency ranges:** 1.5 – 3 MHz, 3 – 6 MHz, 6 – 10 MHz, 10 – 17.7 MHz, 17.6-25.2 MHz
- **Modes:** A1A, A2A, A3E. Optional F3E, J3E, B8E
- **Power requirement:** 110-230VAC 50-60Hz, or 12VDC
- **Dimensions:** 245 x 446 x 350 mm
- **Weight:** 40.8 kg
- **Sensitivity:** A3E (wide) 3.5µV; A1A (wide) 1µV; A1A (narrow) 0.3µV
- **Image rejection:** > 94dB at 20MHz
- **IF rejection:** > 100dB at 1.5 MHz
- **Antenna inputs:** 60/150 Ω
- **IF:** 1000 kHz
- **BFO:** 1000.9 kHz
- **Bandwidth:** continuously variable from 10 kHz (-3dB)/*26 kHz (-60dB)* to 200 Hz (-3dB)/*4 kHz (-60dB)*
- **Frequency stability:** < 30 x 10^{-6} per °C
- **Tuning dial resolution:** 1 kHz

Mobile VHF Tactical Radio

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- German and Dutch radio industries had found VHF line-of-sight (LOS) propagation ideal for urban mobile radio comms. **Link**
- This led to VHF R/T systems in the 27 - 55 MHz band – rapidly adopted by Wehrmacht and Luftwaffe in late 1930's.
  - "Equipping armoured troops with VHF radio enabled individual units to be tied into the command network. The control over fast-moving combat forces gave the army operational advantages."
- Tactical VHF radio was the "central nervous system" of the Blitzkrieg
  - Allowed integrated command and control of infantry, armour and close air support
- Mobile VHF transmitters had 10 to 15W output
  - portables such as "Kleinfunksprecher d" (1944) had 0.25 to 0.5W output **Link**
- Frequency ranges 20 - 33 & 30 - 55 MHz; A3E emission (AM)
  - US Army deployed 27 - 55 MHz F3E (FM) tactical radio only in late 1943/early 1944
- British Army resisted VHF adoption almost until war's end
  - "NIH factor" and concerns about LOS propagation in congested areas were obstacles
  - Low-power AM radio sets in 2 – 4 MHz range with short antennas contributed to disastrous comms. breakdowns (e.g. "Market Garden")

Portable VHF Tactical Radio:
Kleinfunksprecher d "Dorette"

image & data courtesy LA6NCA

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KlFuSpr.d Specifications

Frequency range: 32 – 38 MHz
Power output: 200 mW
Power input: 1.4V, 150V
Battery life: 25 hrs. (80% RX, 20% TX)
Antenna: Tape antenna, 1.6m long
Tubes: Two RL 1 P 2, one DDD25
Size, transceiver:130 x 70 x 200 mm
Size, battery box: 110 x 100 x 170 mm
Weight, transceiver: 1.6 kg
Weight, battery box: 1.5 kg

Portable VHF Tactical Radio:
Kleinfunksprecher d "Dorette"

images courtesy LA6NCA

Above: Interior view, showing tuning dial
Left: Side view. Note tuning dial window

Future Presentations on German WW2 RF Topics

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- **COMINT/SIGINT:** Intercept receivers & test equipment *(e.g. spectrum analyzers!)*
- **ECM**: Comms and radar jamming, ECCM
- **Radar systems:** Ground, airborne and naval

Links for further study

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- Helge Fykse LA6NCA Website
- Bo Samuelsson's Vintage Radio Site
  - *Sincere thanks to Helge and Bo for graciously allowing me to use their superb photos*
- LA8AK Radio Communications Resource Page
- Foundation for German Communications
- VA7OJ/AB4OJ Military Radio Page
  - Also see Military Radio Links