Receiver Fundamentals
and
The “Superheterodyne Receiver”

Chapter 23 and 24
RAE Course

2018-04-03
John Brock ZS6WL

Chapters 23 and 24
fit together

- Noise in Receivers
- Selectivity
- Sensitivity
- Dynamic range
- The TRF (Tuned Radio Frequency) Receiver
- The “Super Heterodyne” Receiver
- The Direct-Conversion Receiver

- Summary

Section Summary Receiver Fundamentals

The key attributes of a receiver are:-

- **Sensitivity**, is the ability to receive weak signals;
- **Selectivity** is the ability to distinguish between adjacent (frequency) signals;
- **Dynamic Range** is the ability to receive weak signals despite the presence of strong signals nearby (in frequency);

In the direct-conversion (DC) receiver, the incoming RF signal is mixed down to audio frequency using a **product detector/mixer** and **local oscillator**. Most of the selectivity of a DC receiver is contributed by audio filters following the **product detector/mixer**. DC receivers have much better selectivity than TRF receivers, but they suffer from an **image response** to the opposite sideband that can only be eliminated with complex designs. **The 'modern Software Designed Receiver' can easily do this in software and processing power.**

A bad DC design may also radiate some of the local oscillator, causing interference to other users. [EMC – Chapter 28]

Noise

What ‘noise’ annoys an oyster?
Sorry, I mean a Radio Amateur...

Noise is random except when restricted by **bandwidth**.
It has a power level. Usually measured in dBm.

It can mean the difference between hearing a signal or not.

It is the “**signal to noise**” ratio that defines a receiver’s **sensitivity**.

Again measured in dB as a ratio.

Sources of noise

Where does ‘noise’ come from?

- Receiver thermal noise
- Other receiver noise
- Atmospheric noise
- Electrical noise
- Ground noise
- Galactic noise
- Other signals

“Front End” Design

Synthesiser phase noise/jitter

QRN - lightning

QRM - Motors, switch-mode power supplies, faulty insulators on power lines, etc.

Those suns are not trying to communicate. They are just nuclear fusion reactors...

Adjacent channel interference is heard as noise in channel.

$$P_{Noise} = k * T * B$$

Sources of noise [2]

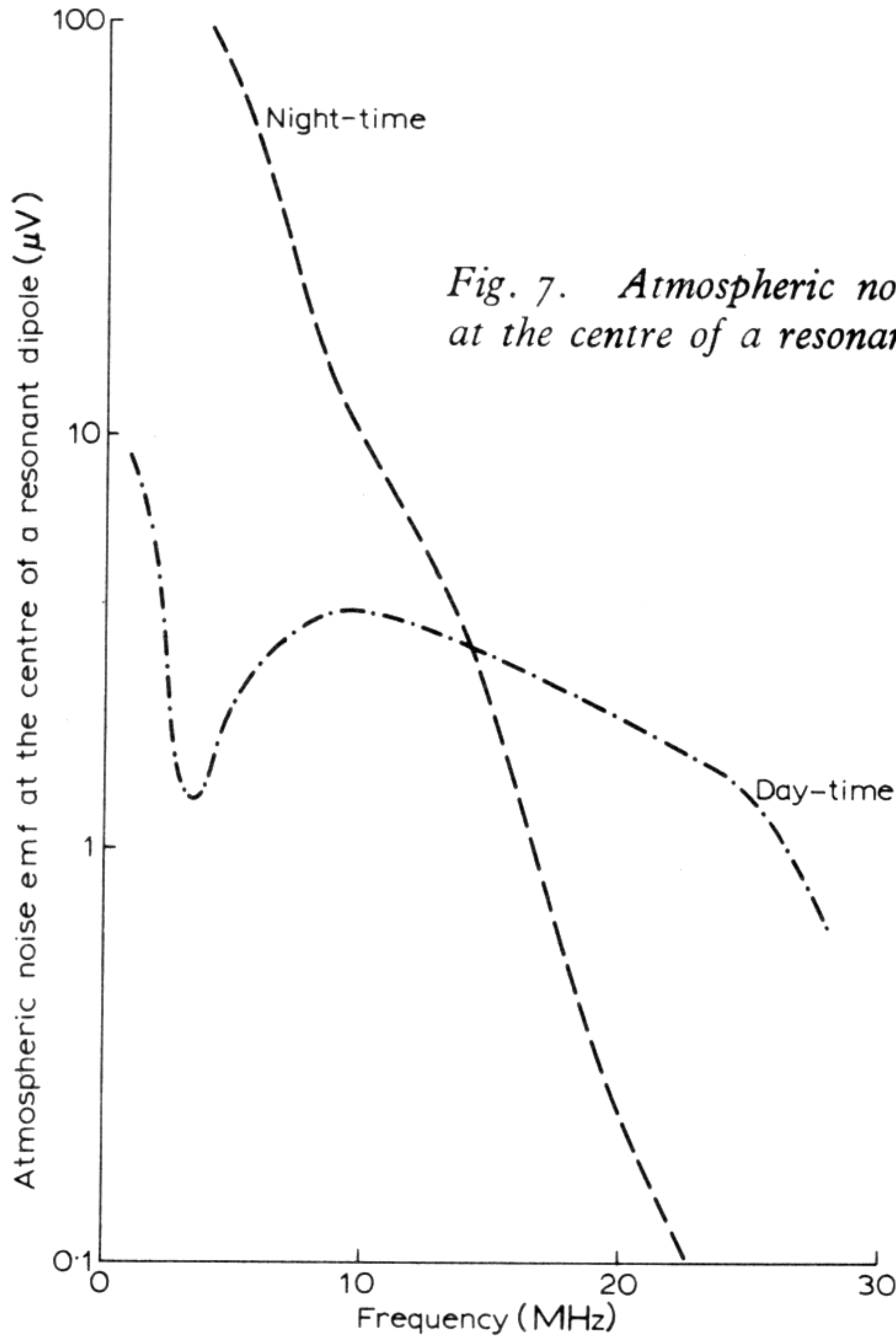


Fig. 7. ***Atmospheric noise. The e.m.f. at the centre of a resonant dipole.***

Selectivity

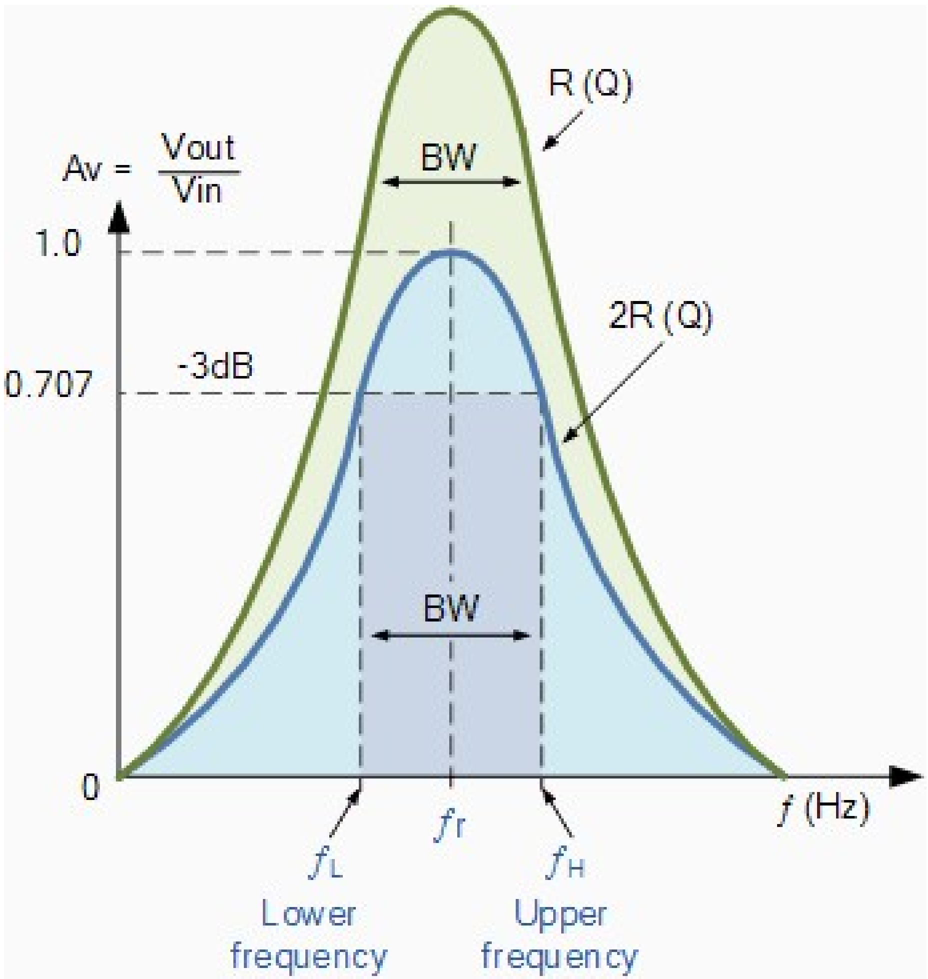
The ability of a receiver to ‘select’ a wanted signal in the presence of an unwanted signal.

A TRF receiver has very poor selectivity.

This poor selectivity led to the design of the Superheterodyne. For a variety of reasons.

Tuned circuit ‘Q’ factor wasn’t sufficient, even over several stages to suppress the “unwanted” signal.

Selectivity = Q factor = Narrow Bandwidth



Bw = fr / Q

Thus at 1MHz
A Q of 10, will give 100 kHz bandwidth
A Q of 100, will give 10 kHz bandwidth
A Q of 250, will give 4 kHz bandwidth

At 10MHz
A Q of 10, will give 1 MHz
A Q of 100, will give 100 kHz
A Q of 250, will give 40 kHz
A Q of 1000, will give 10 kHz
e.g. a Crystal Filter

Sensitivity

Sensitivity is defined by the “Signal to Noise” ratio.

How “Signal to Noise” is measured.
Signal-to-noise ratio is measured by turning on and off the modulation of a signal input to a receiver and measuring the output of the receiver under both conditions. The difference (in dB) between the two measurements gives the signal to noise ratio.

The signal input is then reduced until a specific ratio is reached.

Dynamic Range

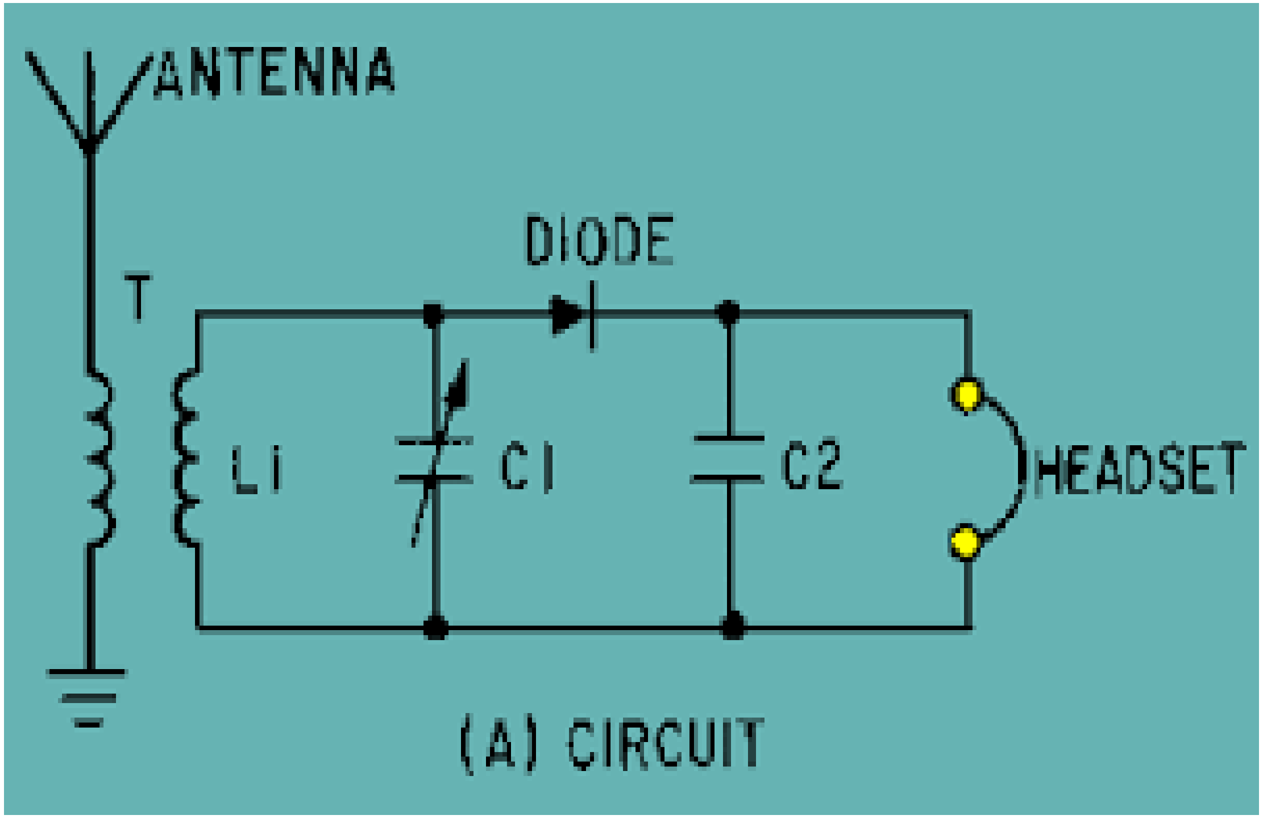
The ability to handle large signals at the input to the receiver...not necessarily at the same frequency as the signal.

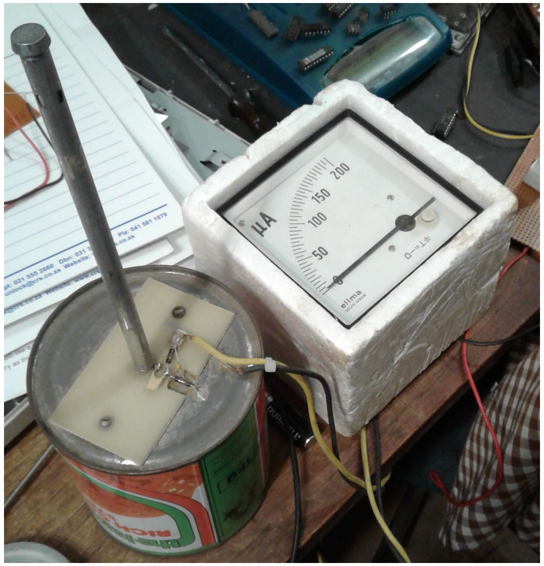
Cross-modulation, intermodulation, “Intercept Points” and IP3 are NOT part of this course.

This is one of the reasons why most modern designs use double-balanced mixer modules with +7 to +17dBm local oscillators at 50 Ohms.

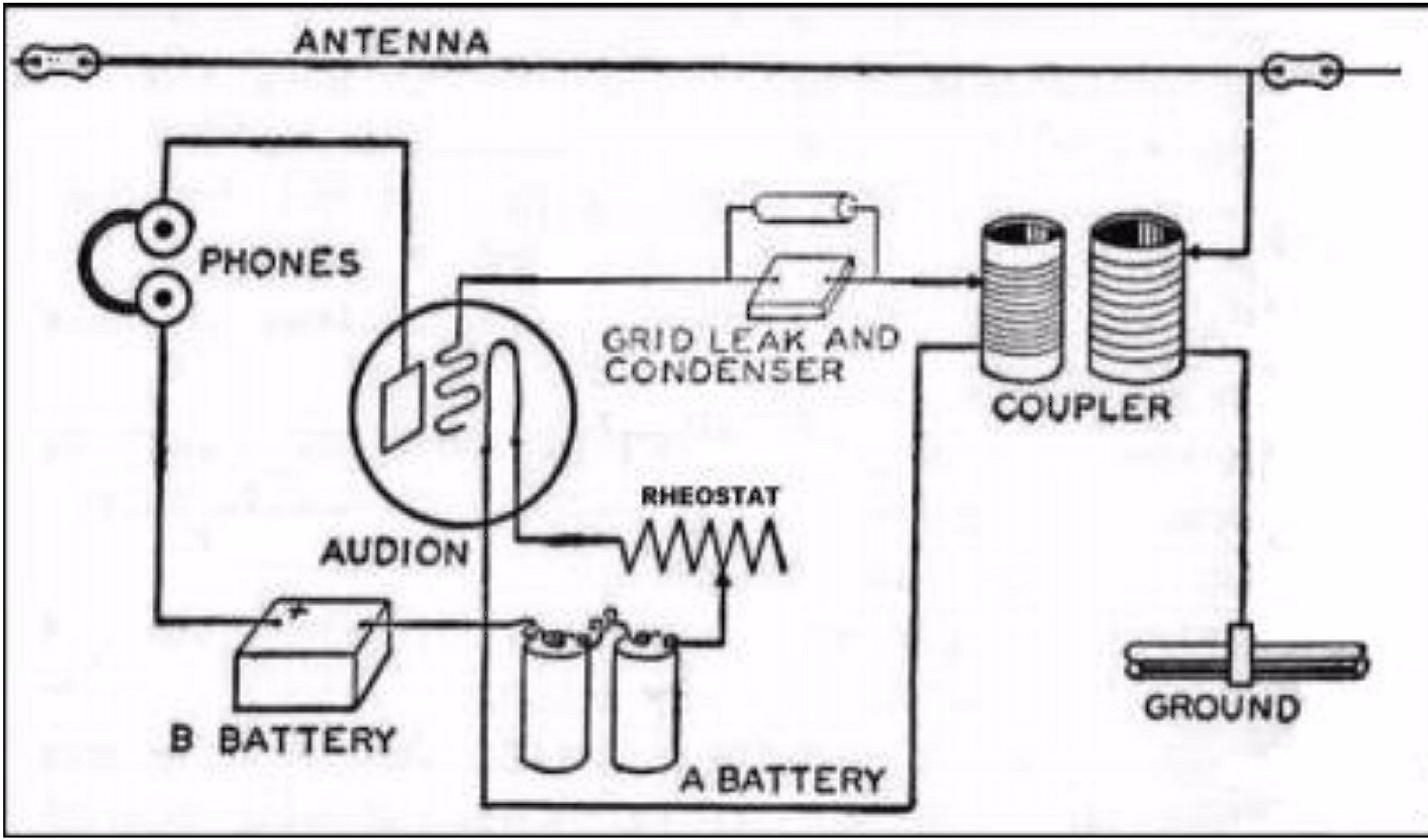
Diode detector – Crystal Set

[sorry - zero power receiver]





Very Early Receiver

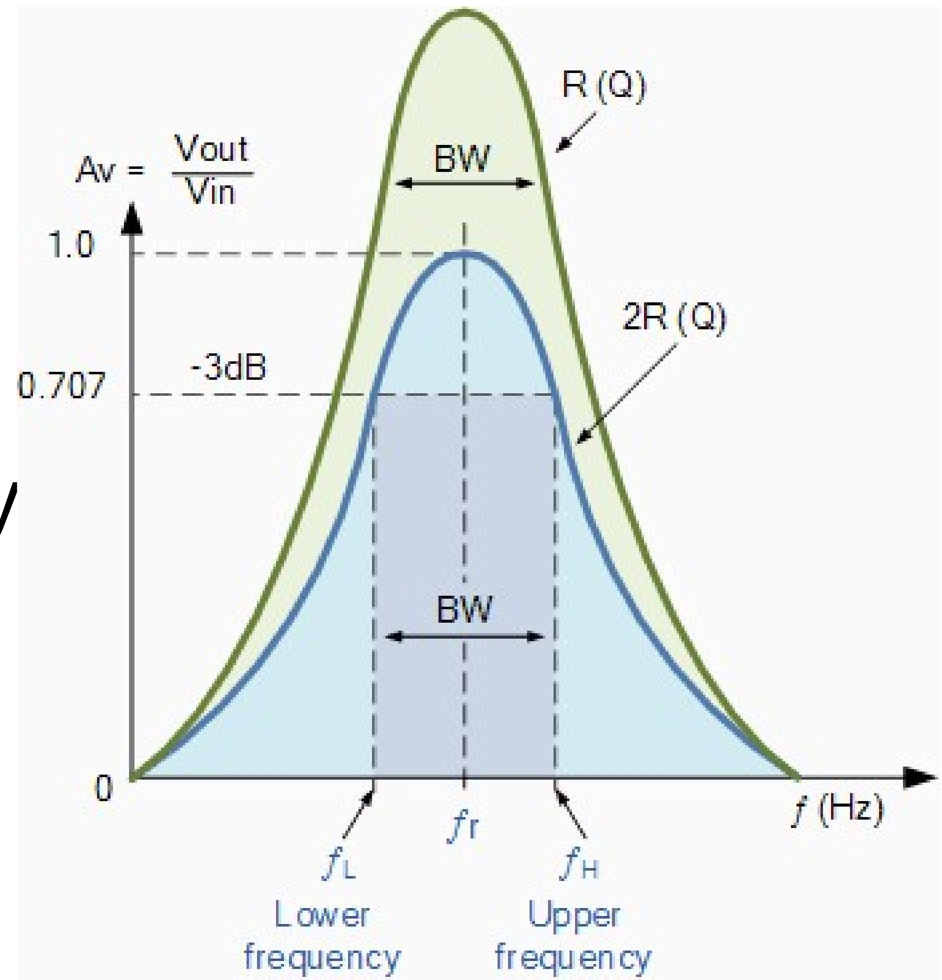


The TRF receiver [1]

Lots of valves/transistors and tuned circuits, all tuned to the desired transmission...

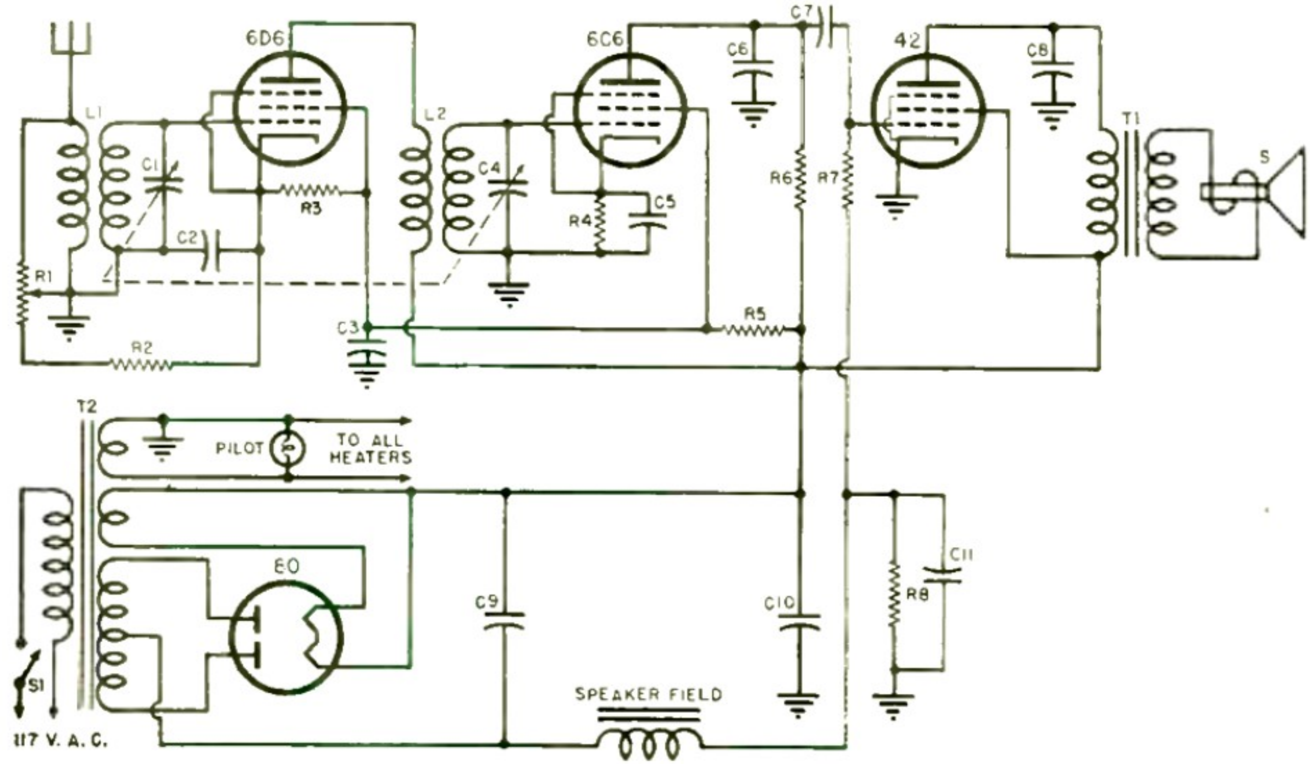
Long Wave -
Medium Wave -
Short wave --> 30MHz
The Q required now gets very high.

Very High and Ultra High Frequencies - impossible!



The TRF receiver

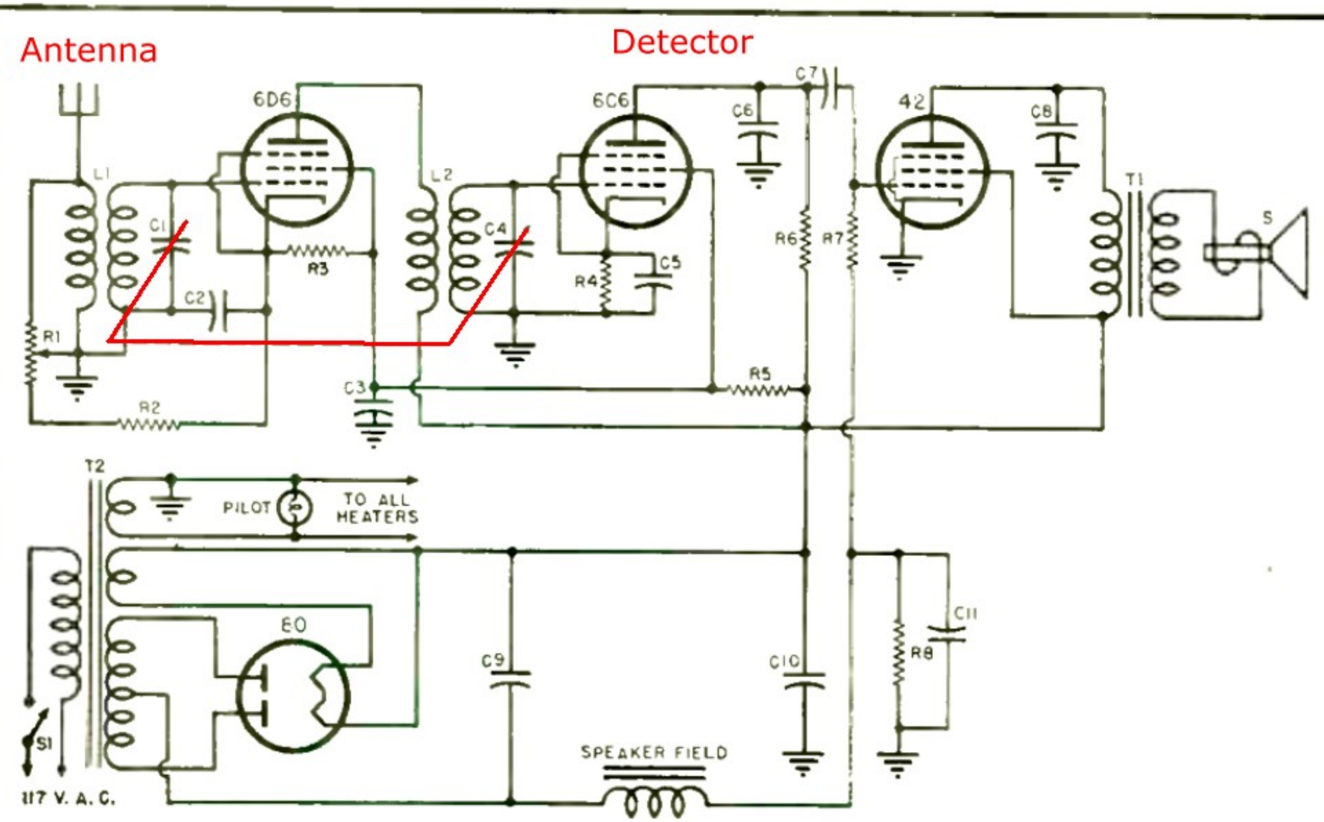
Circa 1947 [3]



R_1—10,000 ohm, wire-wound vol. control
R_2—200 ohm, ½ w. res.
R_3, R_5—50,000 ohm, ½ w. res.
R_4—25,000 ohm, ½ w. res.
R_6, R_7—500,000 ohm, ½ w. res.
R_8—500 ohm, 2 w. res.
C_1, C_4—2-gang, 365 μμfd. var. cond.
C_2, C_5—.1 μfd., 200 v. cond.
C_3—.1 μfd., 400 v. cond.
C_6—500 μμfd. mica cond.
C_7—.01 μfd., 400 v. cond.
C_8—.001 μfd., 400 v. cond.
C_9, C_{10}—8 μfd., 350 v. elec. cond.
C_{11}—10 μfd., 25 v. elec. cond.
L_1—Ant. coil (Meissner #14-1022 or equiv.)
L_2—R.f. coil (Meissner #14-1023 or equiv.)
S_1—S.p.s.t. sw. (on R_1)
T_1—Output trans. 7000 ohm plate-to-v.c.
T_2—Power trans. 250-0-250 v. @ 50 ma.; 6.3 v. @ 2 amps.; 5 v. @ 2 amps.
S—6" speaker, 450 ohm field
1—6D6 tube
1—6C6 tube
1—42 tube
1—80 tube

The TRF receiver

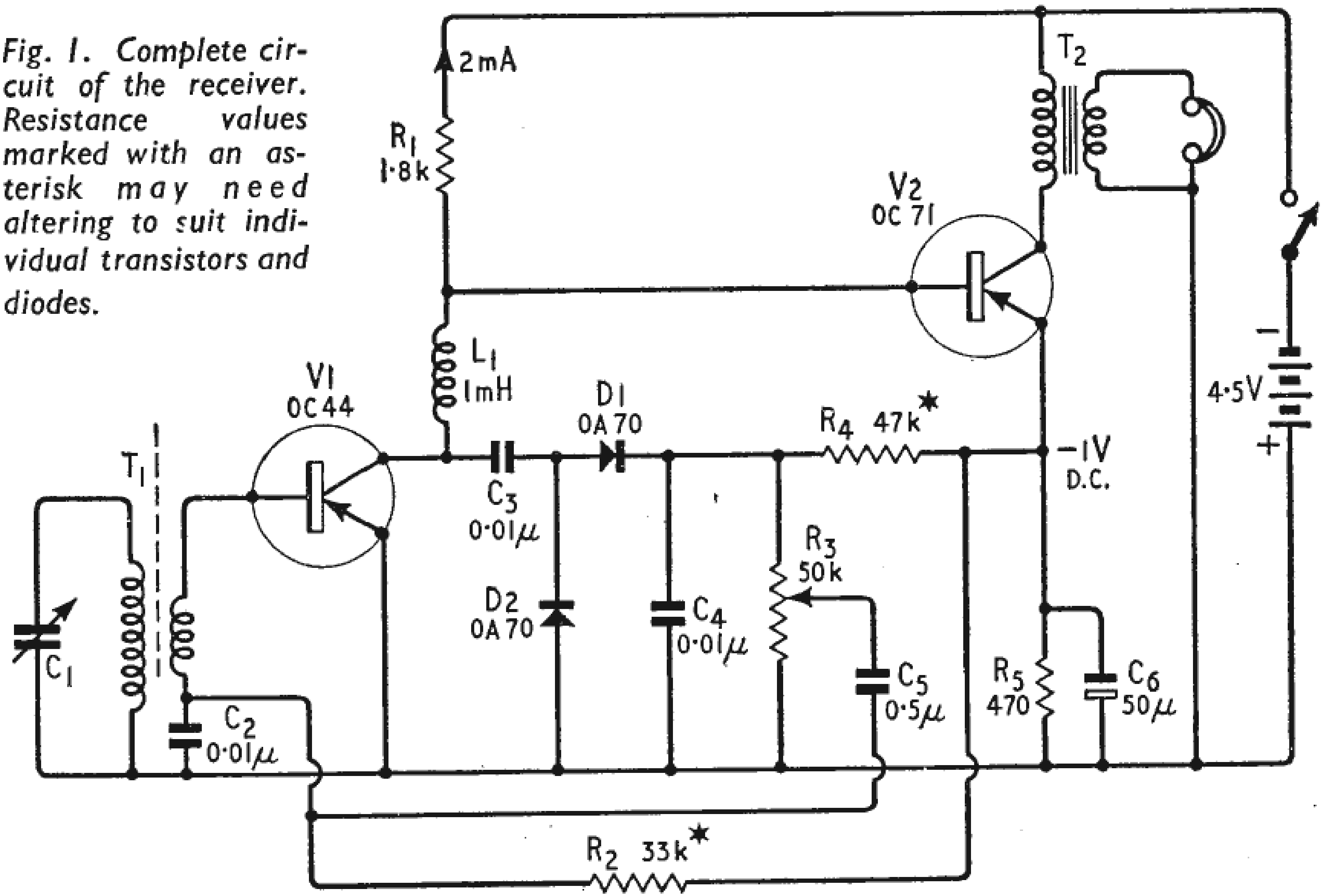
Circa 1947 [3]



R_1—10,000 ohm, wire-wound vol. control
R_2—200 ohm, 1/2 w. res.
R_3, R_5—50,000 ohm, 1/2 w. res.
R_4—25,000 ohm, 1/2 w. res.
R_6, R_7—500,000 ohm, 1/2 w. res.
R_8—500 ohm, 2 w. res.
C_1, C_4—2-gang, 365 μμfd. var. cond.
C_2, C_5—.1 μfd., 200 v. cond.
C_3—.1 μfd., 400 v. cond.
C_6—500 μμfd. mica cond.
C_7—.01 μfd., 400 v. cond.
C_8—.001 μfd., 400 v. cond.
C_9, C_{10}—8 μfd., 350 v. elec. cond.
C_{11}—10 μfd., 25 v. elec. cond.
L_1—Ant. coil (Meissner #14-1022 or equiv.)
L_2—R.f. coil (Meissner #14-1023 or equiv.)
S_1—S.p.s.t. sw. (on R_1)
T_1—Output trans. 7000 ohm plate-to-v.c.
T_2—Power trans. 250-0-250 v. @ 50 ma.; 6.3 v. @ 2 amps.; 5 v. @ 2 amps.
S—6" speaker, 450 ohm field
1—6D6 tube
1—6C6 tube
1—42 tube
1—80 tube

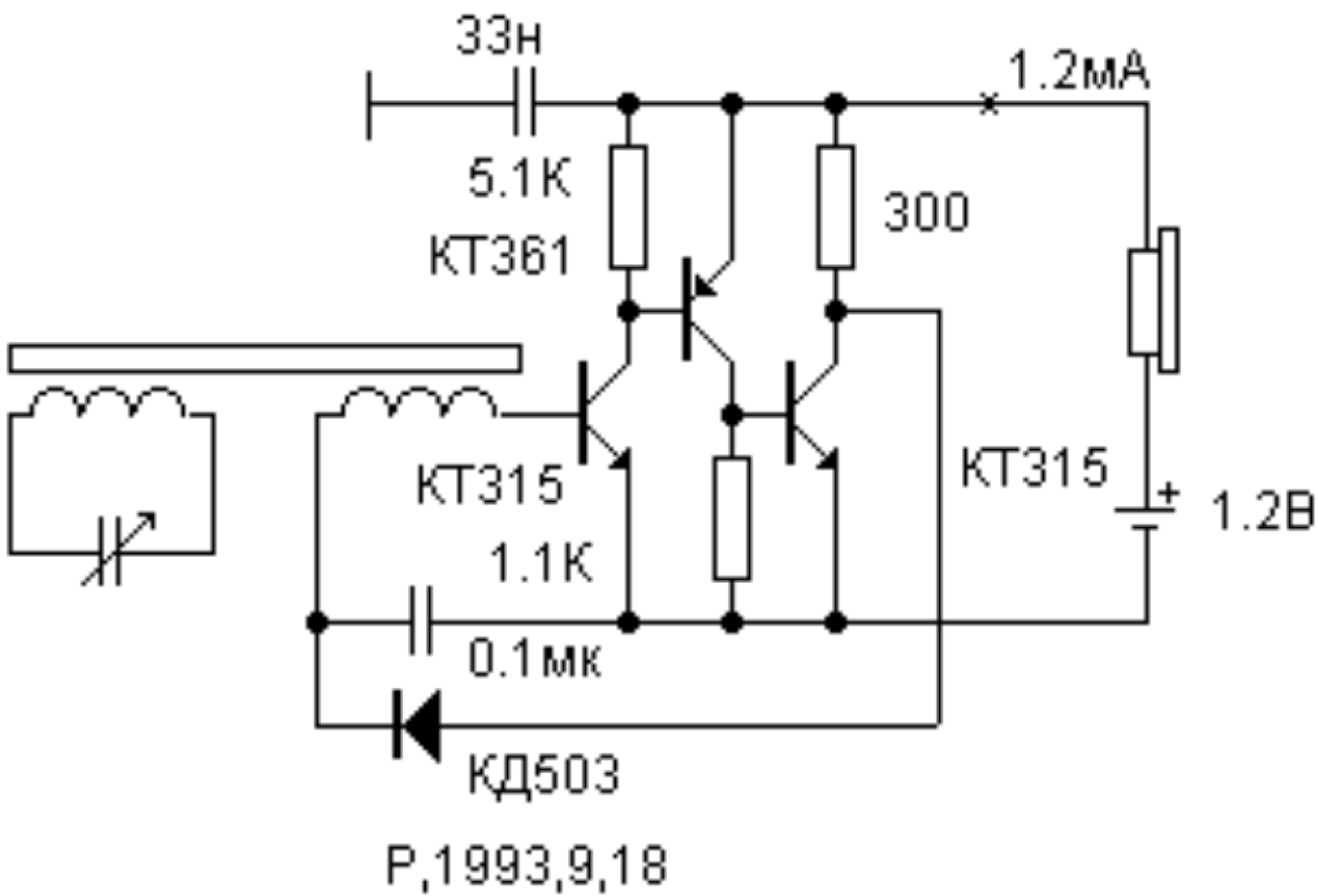
The TRF receiver 2

Fig. 1. Complete circuit of the receiver. Resistance values marked with an asterisk may need altering to suit individual transistors and diodes.

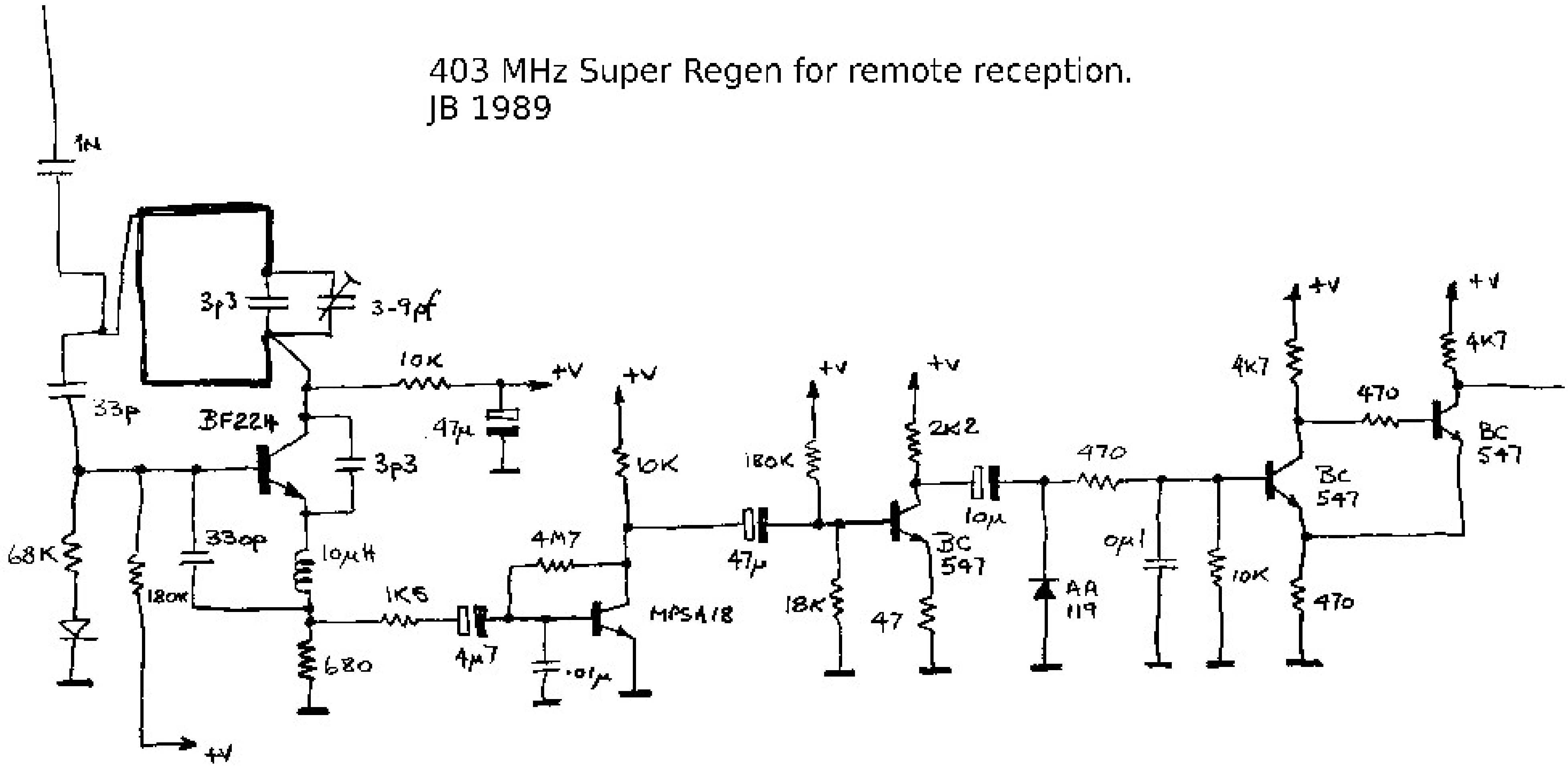


Reflex Receiver

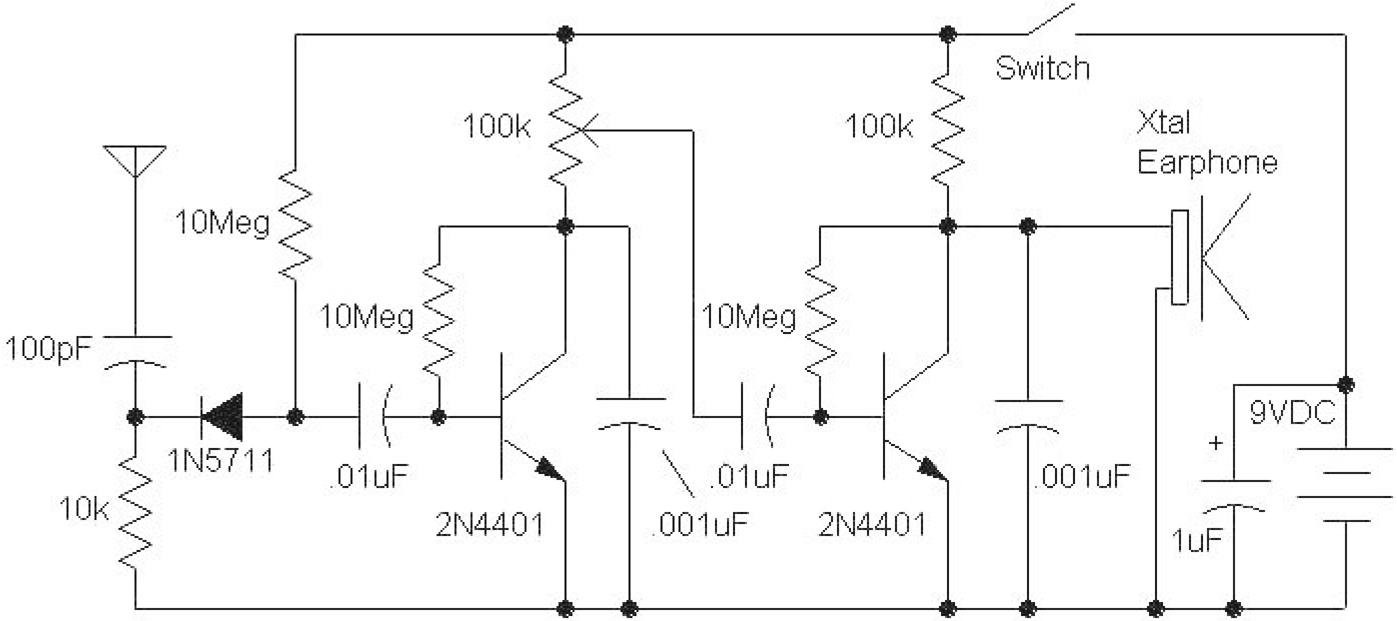
[uses ferrite rod aerial]



How about improving the design?



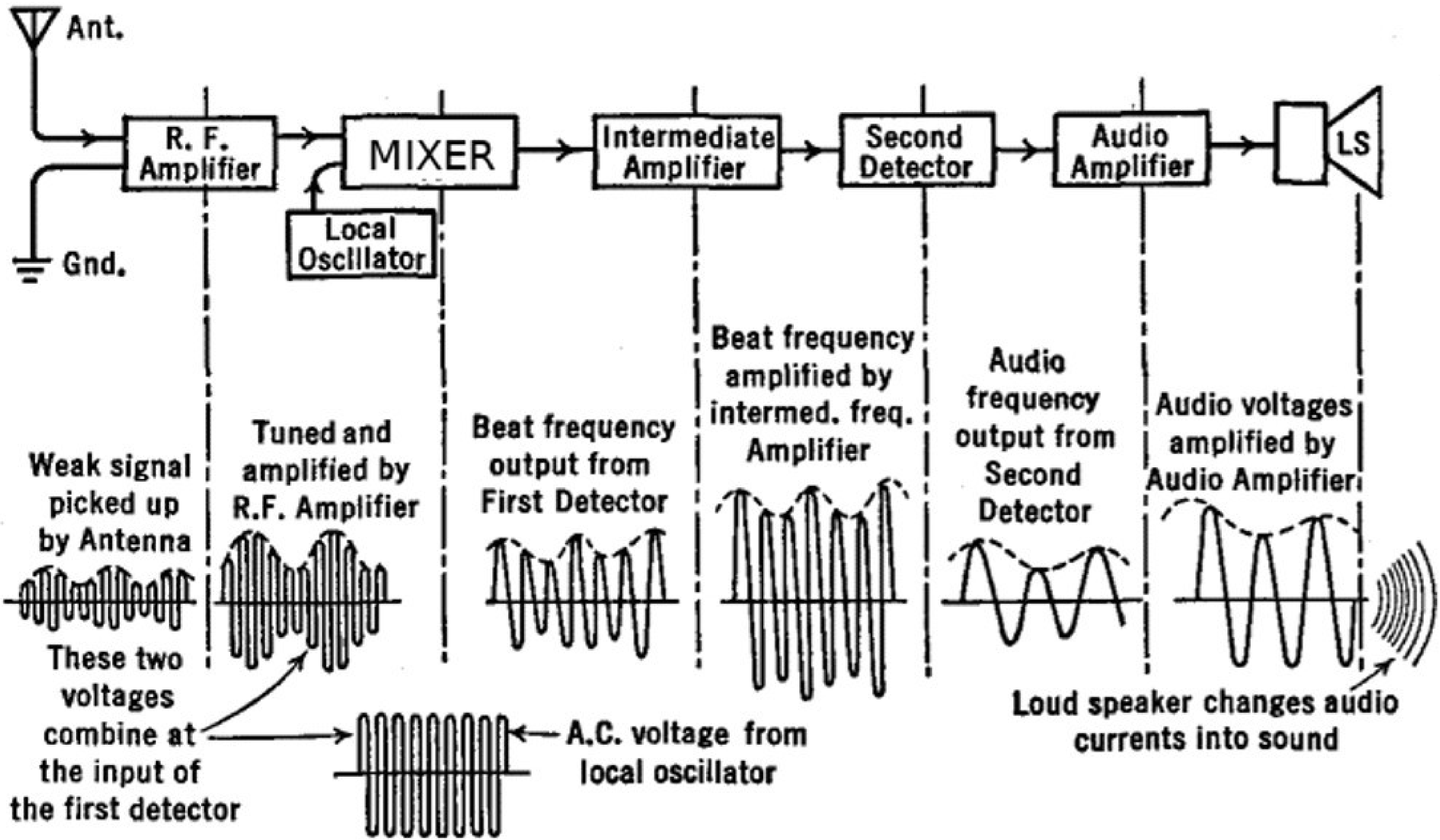
How about improving the design?



Section Summary
The Super-Heterodyne Receiver

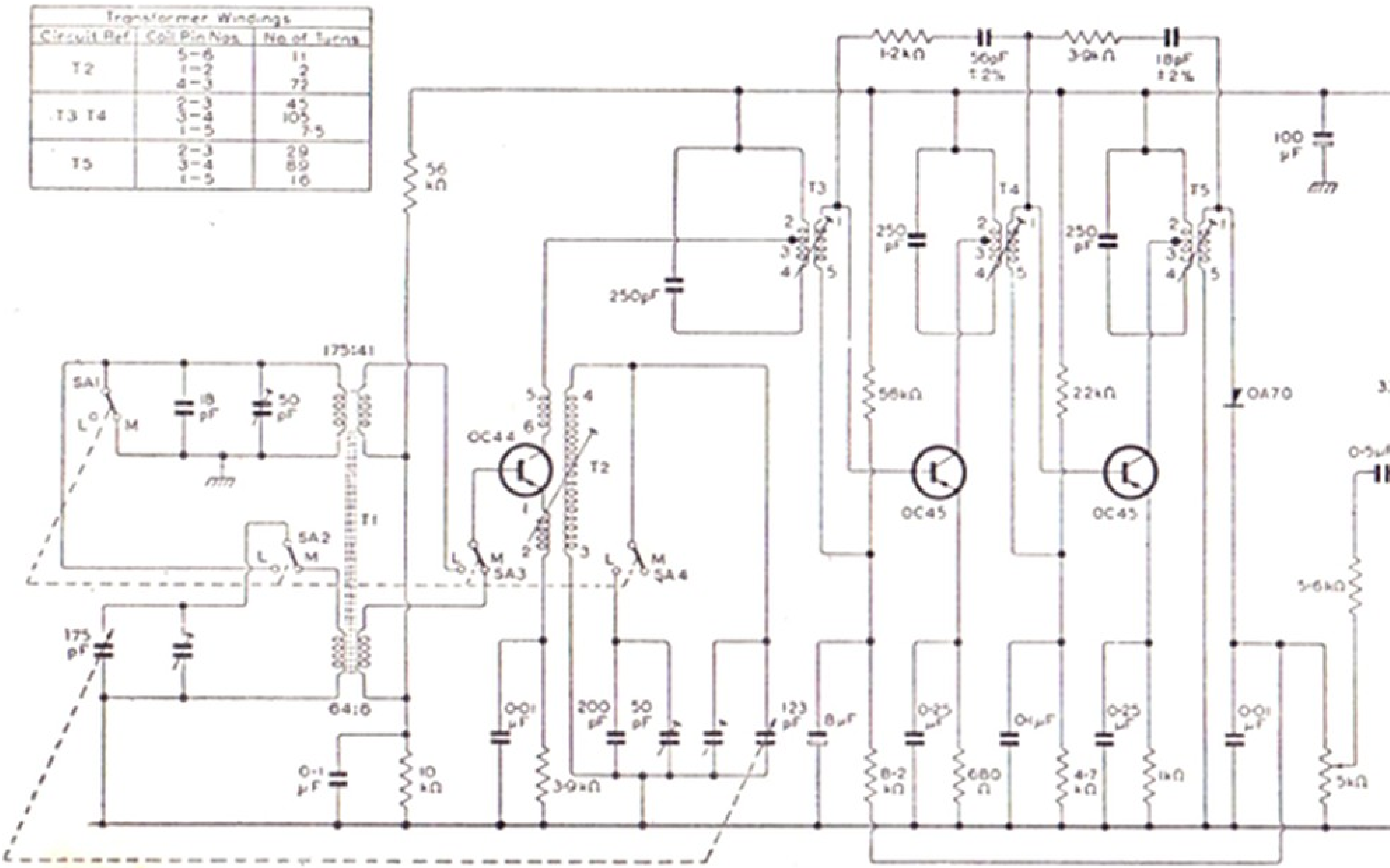
- The superhet receiver converts the incoming RF signal to one or more **intermediate frequencies** before demodulating it. Superhet receivers have an **image frequency** that when mixed with the local oscillator will also generate the same IF as the desired receive signal.
- The **image frequency** will be either the sum of, or the difference between, twice the IF frequency and the desired receive frequency. The role of the **preselector** is to reject incoming RF signals at the **image frequency**, preventing them from causing a spurious (unwanted) response in the receiver. The choice of intermediate frequency is a trade-off between selectivity (better at L.F.) and image rejection (better at high IF).
- **Noise limiters** limit the amplitude of pulse noise, reducing the effect on the receiver.
- **Noise blankers** mute the audio output for a short time (a few milliseconds) when the higher amplitude associated with pulse noise is detected.
- FM signals are detected using a Foster-Seeley discriminator or ratio detector. The discriminator should be preceded by a **limiter** to prevent it from being affected by variations in the amplitude of the signal. Weak FM signals have a characteristic hiss on them, and as the signal strength increases and the limiter becomes effective the hiss goes away, a process known as **quieting**. Most FM receivers incorporate a **squelch** function, which mutes the audio output when there is no received signal to avoid the annoying hiss.

A Superhet Receiver



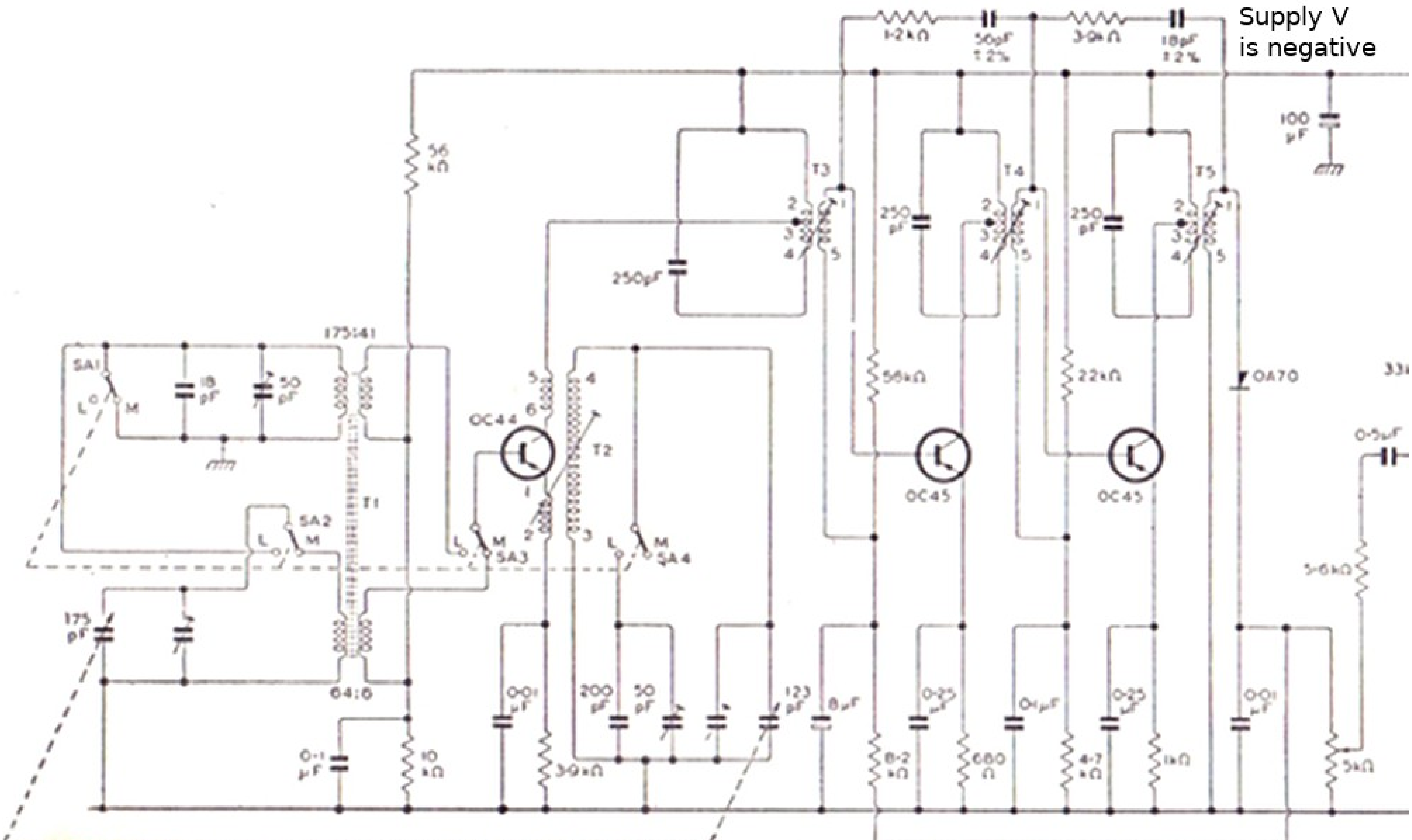
The ‘simple’ Superheterodyne

Transformer Windings		
Circuit Ref	Coil Pin Nos.	No of Turns
T2	5−6 1−2 4−3	11 2 72
T3 T4	2−3 3−4 1−5	45 105 7·5
T5	2−3 3−4 1−5	29 89 16



Tolerance of resistors marked with an asterisk (*) should be 5%. Tolerance of all other resistors shoul

The ‘simple’ Superheterodyne



Dual 'ganged' capacitors - one for input frequency, one for local oscillator frequency.

This 'feedback' is the AGC - Automatic Gain Control.

The 'simple' Superheterodyne
"issues"

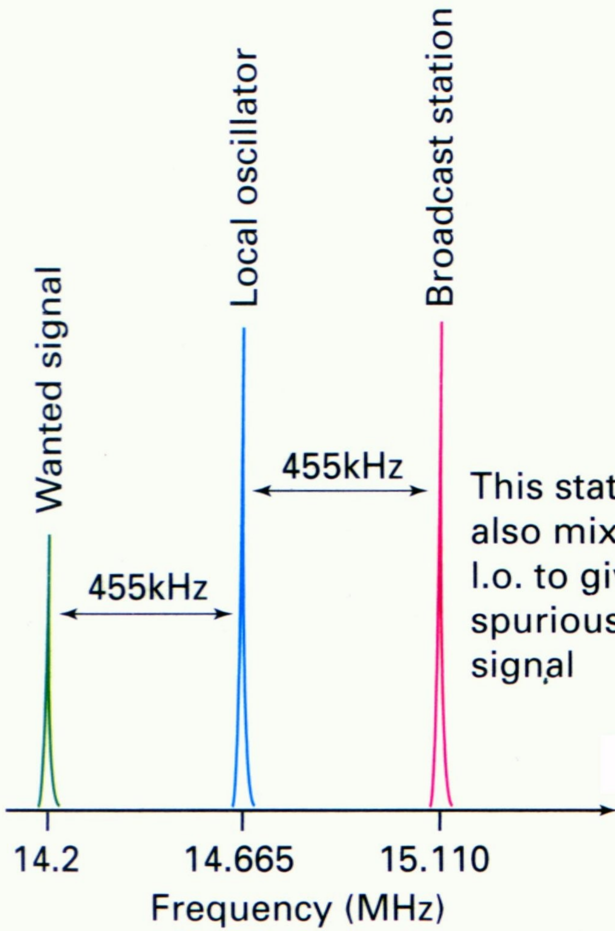


Fig. 7.1: Showing how a broadcast station in the 19m band can appear to be within the 14MHz amateur band with an i.f. of 455kHz.

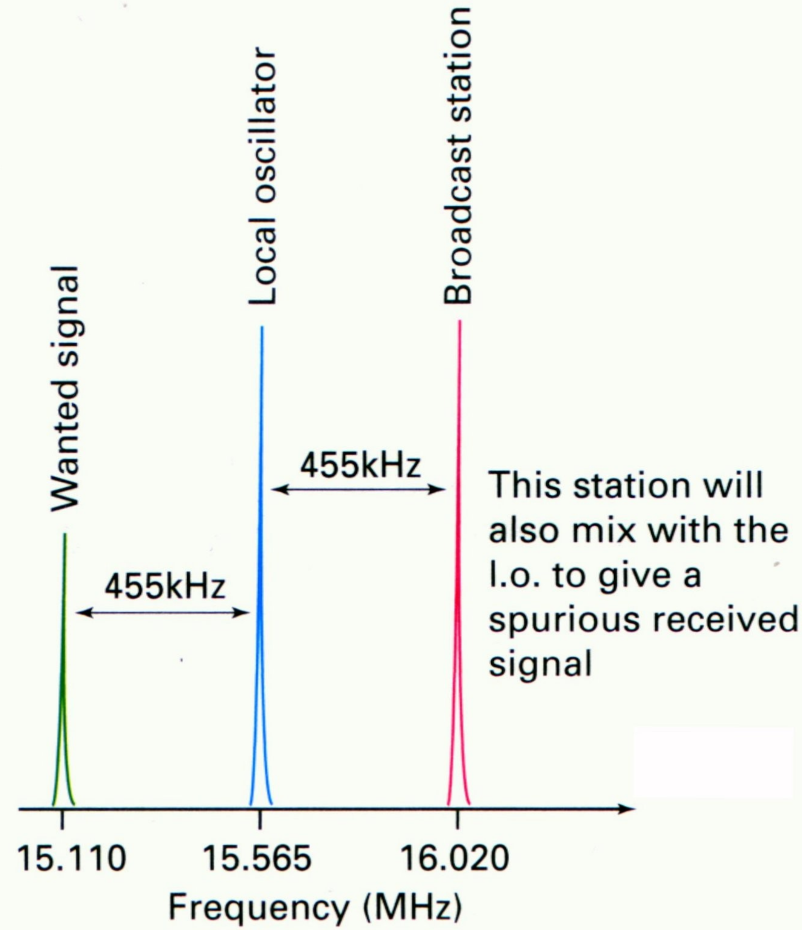
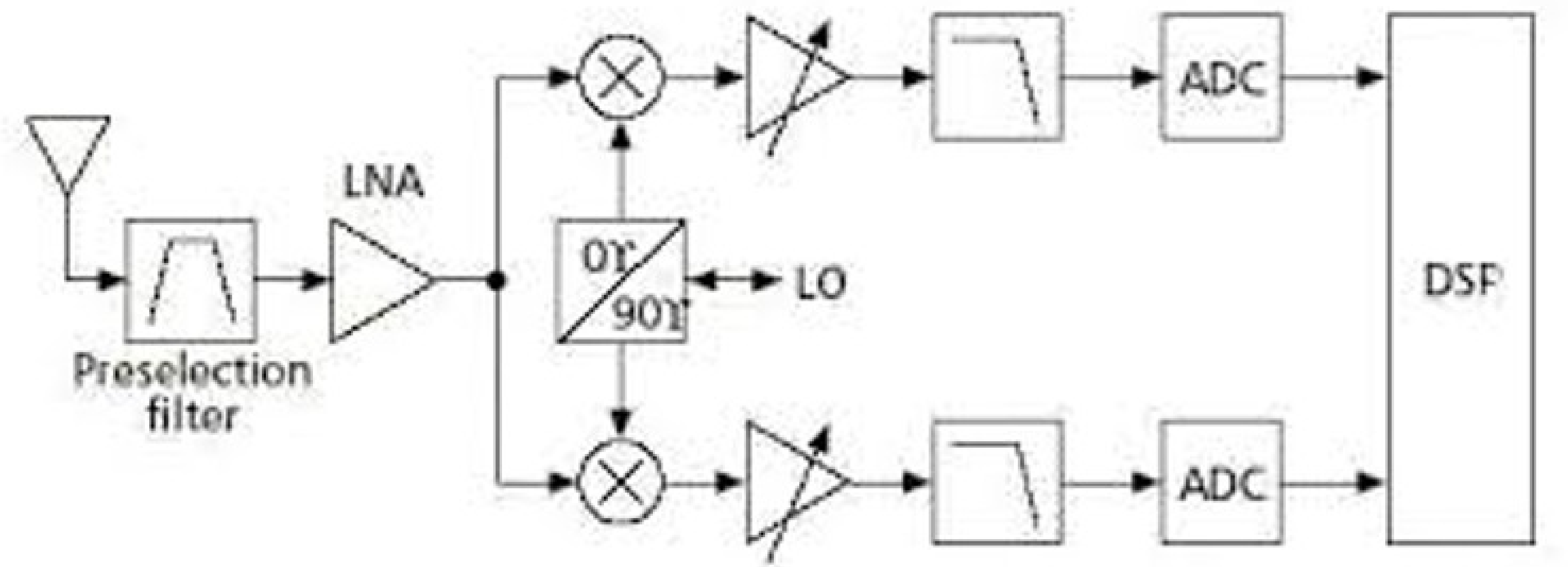


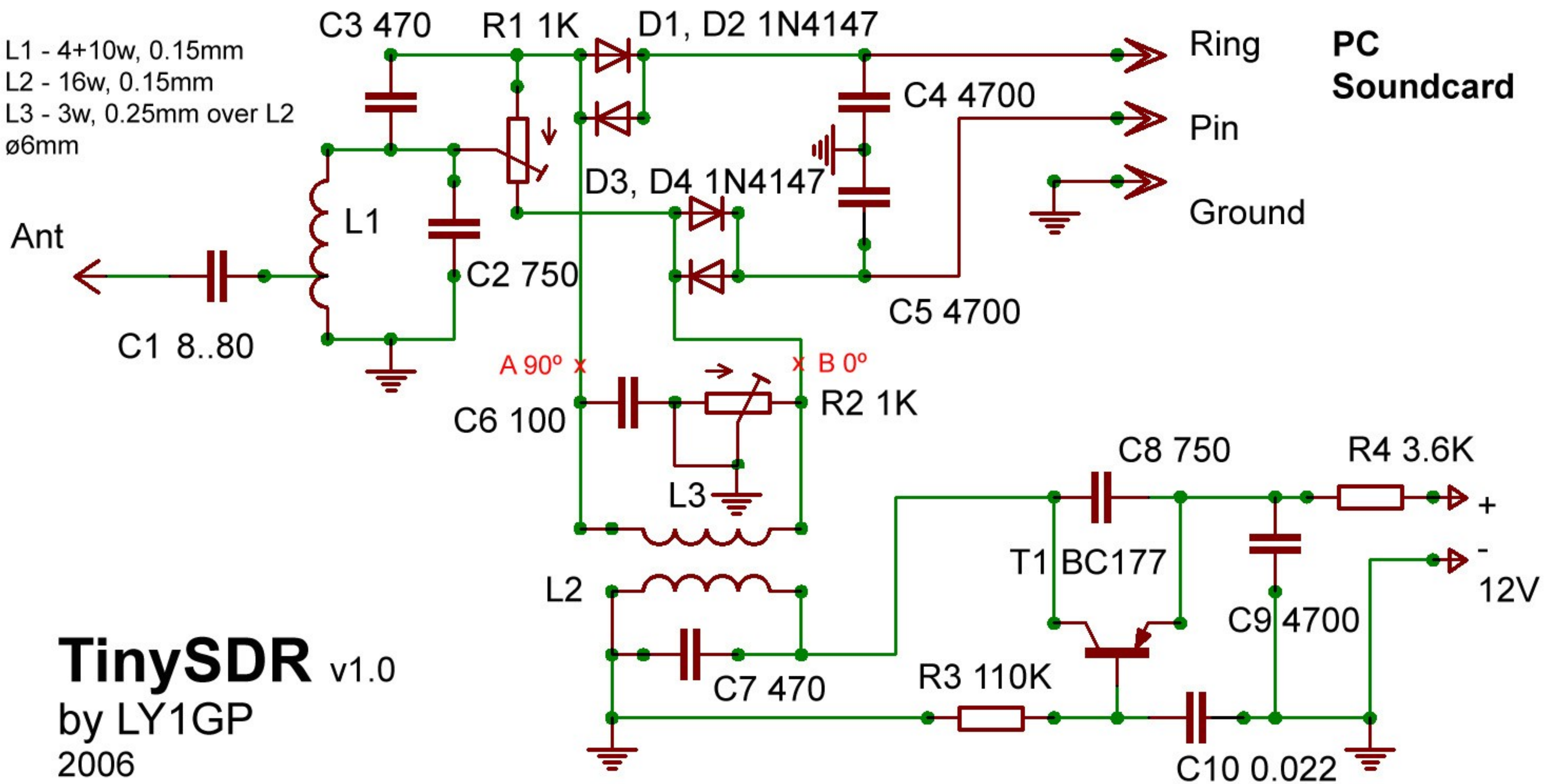
Fig. 7.2: The same receiver i.f. can allow two broadcast stations to appear to be using the same frequency.

Homodyne detector



This is the ‘modern’ way of doing things. The ADC and DSP are the sound card and processor of a personal computer.

A Direct-Conversion Receiver



Summary

The key attributes of a receiver are **sensitivity**, **selectivity** and **dynamic range**.

Sensitivity is the ability to receive weak signals; **selectivity** is the ability to distinguish between adjacent signals; and **dynamic range** is the ability to receive weak signals despite the presence of strong signals nearby.

In the tuned radio frequency (TRF) receiver all signal filtering is done at **radio frequencies**.

As a result they have poor selectivity. **Regeneration**, which consists of feeding some of the output signal back to the input of the RF amplifier, can increase both the sensitivity and selectivity of the TRF receiver, but makes it prone to oscillation. The oscillation, if well-controlled, can be used to facilitate CW and SSB reception. This is **Positive Feedback** and should NOT be used!

In the **direct-conversion** (DC) receiver, the incoming RF signal is mixed down to audio frequency using a mixer and local oscillator. Most of the selectivity of a DC receiver is contributed by audio filters following the product detector. DC receivers have much better selectivity than TRF receivers, but they suffer from an image response to the opposite sideband. This image can be rejected using In-phase and Quadrature signals or local oscillators.

A bad DC design may also radiate some of the local oscillator, causing interference to other users. That is why you would use a single or double balanced mixer.

Signal to noise ratio (SNR) determines whether a signal is readable or not. Noise can originate within the receiver or on the band. The receiver has a **noise figure** (in dB), which can also be expressed as a noise temperature (in Kelvin). At HF and below, band noise normally limits the SNR. At VHF and above, receiver noise is normally the limiting factor. Expensive semiconductors, feedlines and techniques are required to minimise receiver noise at these frequencies.

Frequency Modulation Receivers

- Deviation
- Input Frequency
- Sensitivity
- Capture Effect
- Squelch
- Detectors/Discriminators

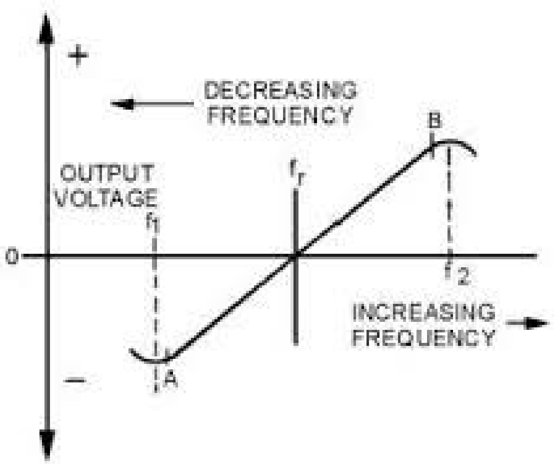
FM Detection

The basic superhet design can also be used to receive frequency modulated (FM) signals. However in this case, the product detector is replaced by a **Foster-Seeley discriminator** or a **ratio detector**.

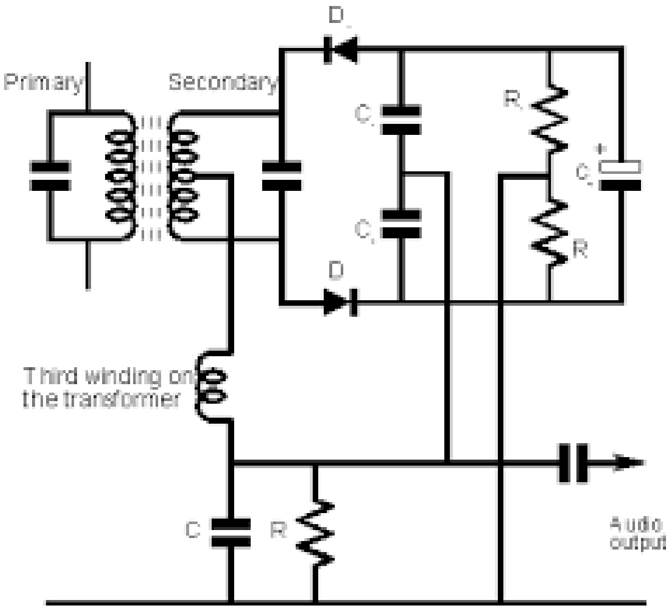
[OK, This is no longer the case. Most modern FM discriminators use a simple 90 degree phase shifting circuit.]

These are circuits that convert frequency variations into a varying output voltage, so recovering the modulation from an FM signal.

How to detect F.M.

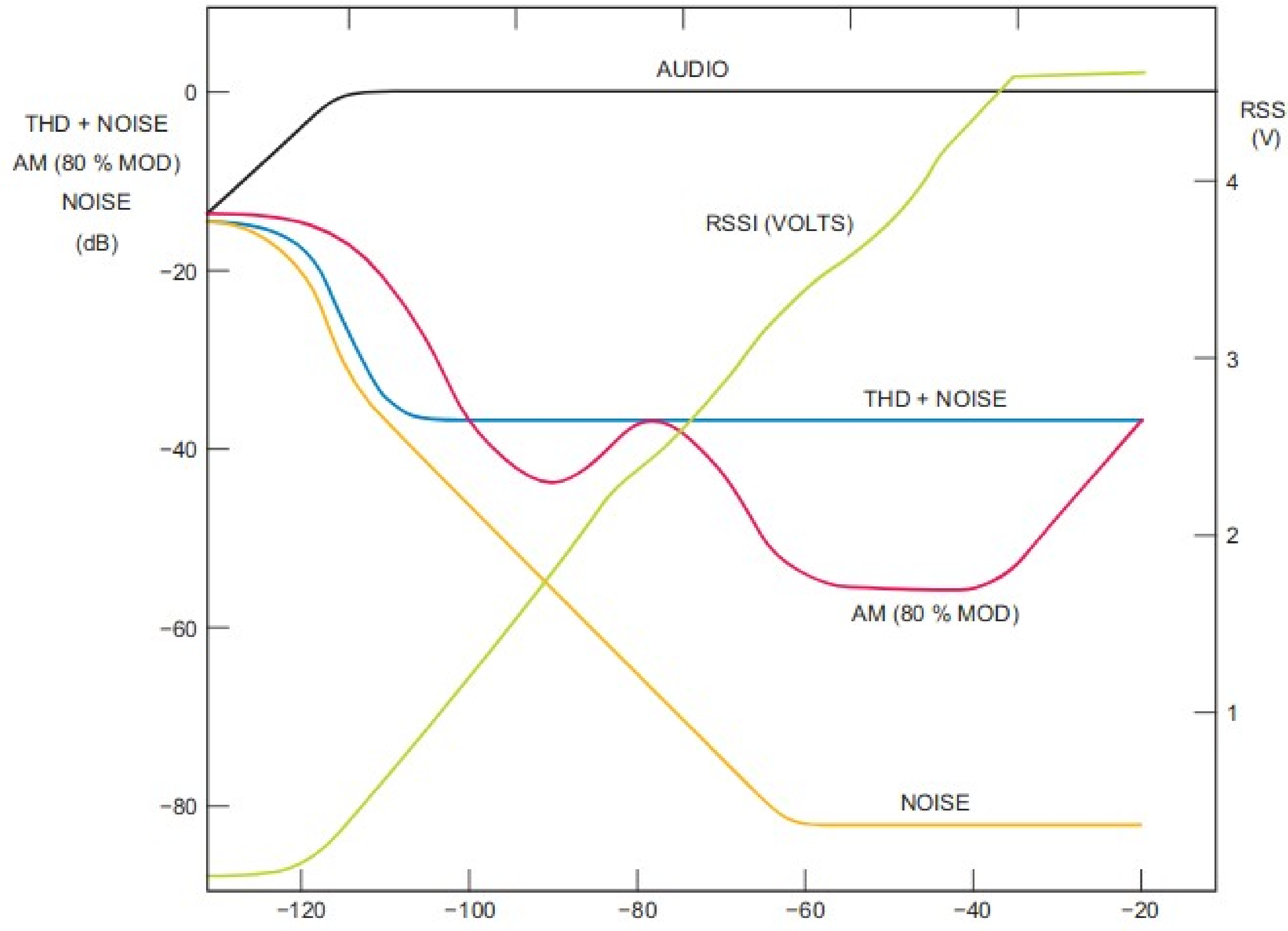


Output Voltage vs Frequency



Ratio Detector

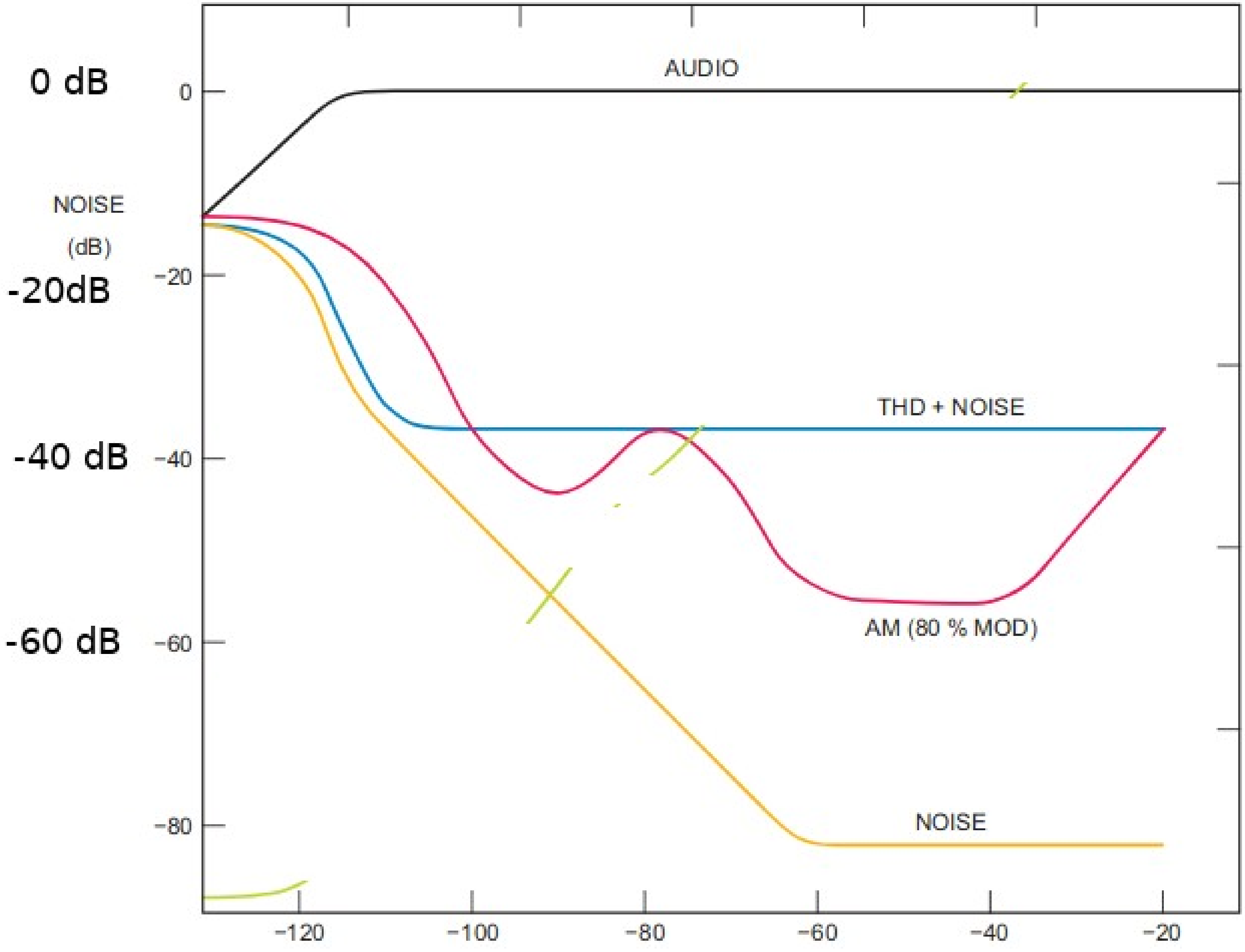
How to detect N.B.F.M.
[What advantage does FM have over AM?]



Audio output: C message weighted; 0 dB reference = recovered audio for 8 kHz peak deviation (dB)

How to detect N.B.F.M.

[What advantage does FM have over AM?]



How we do it today
F.M. Detection...

Figure 5. Input Limiting Voltage

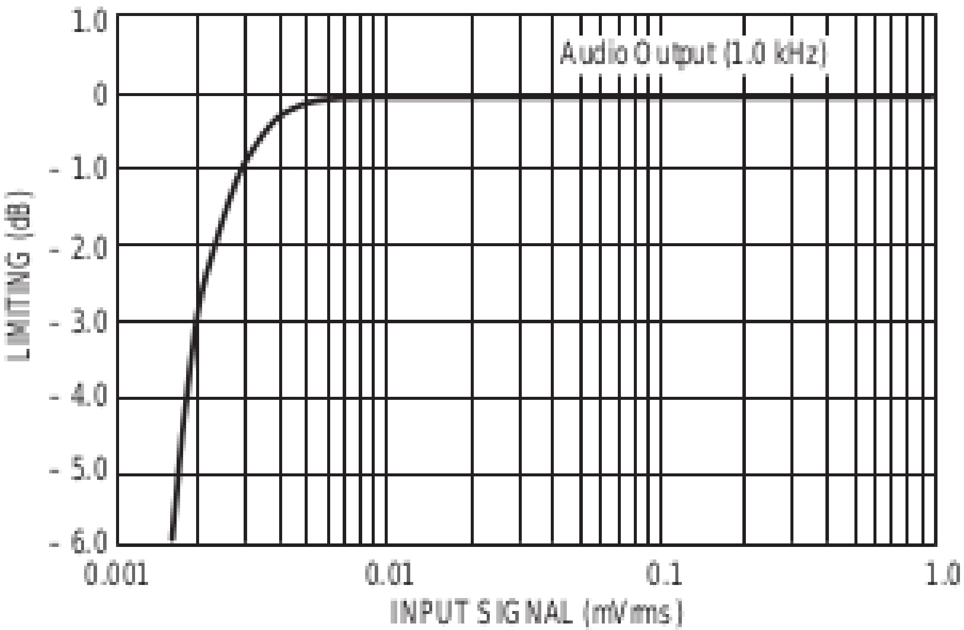
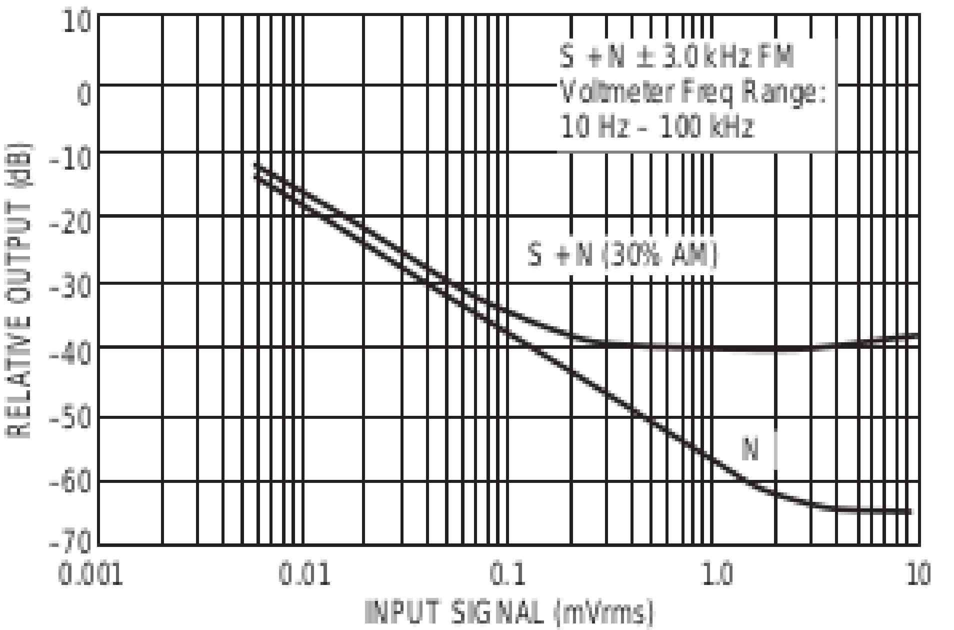
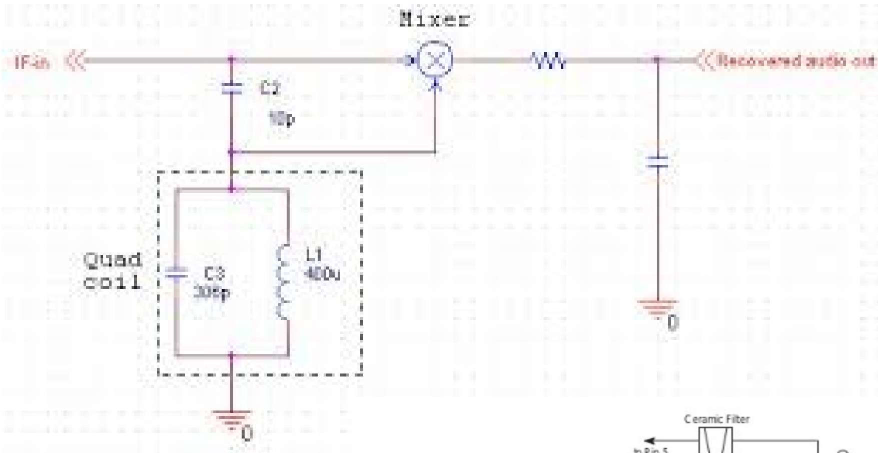


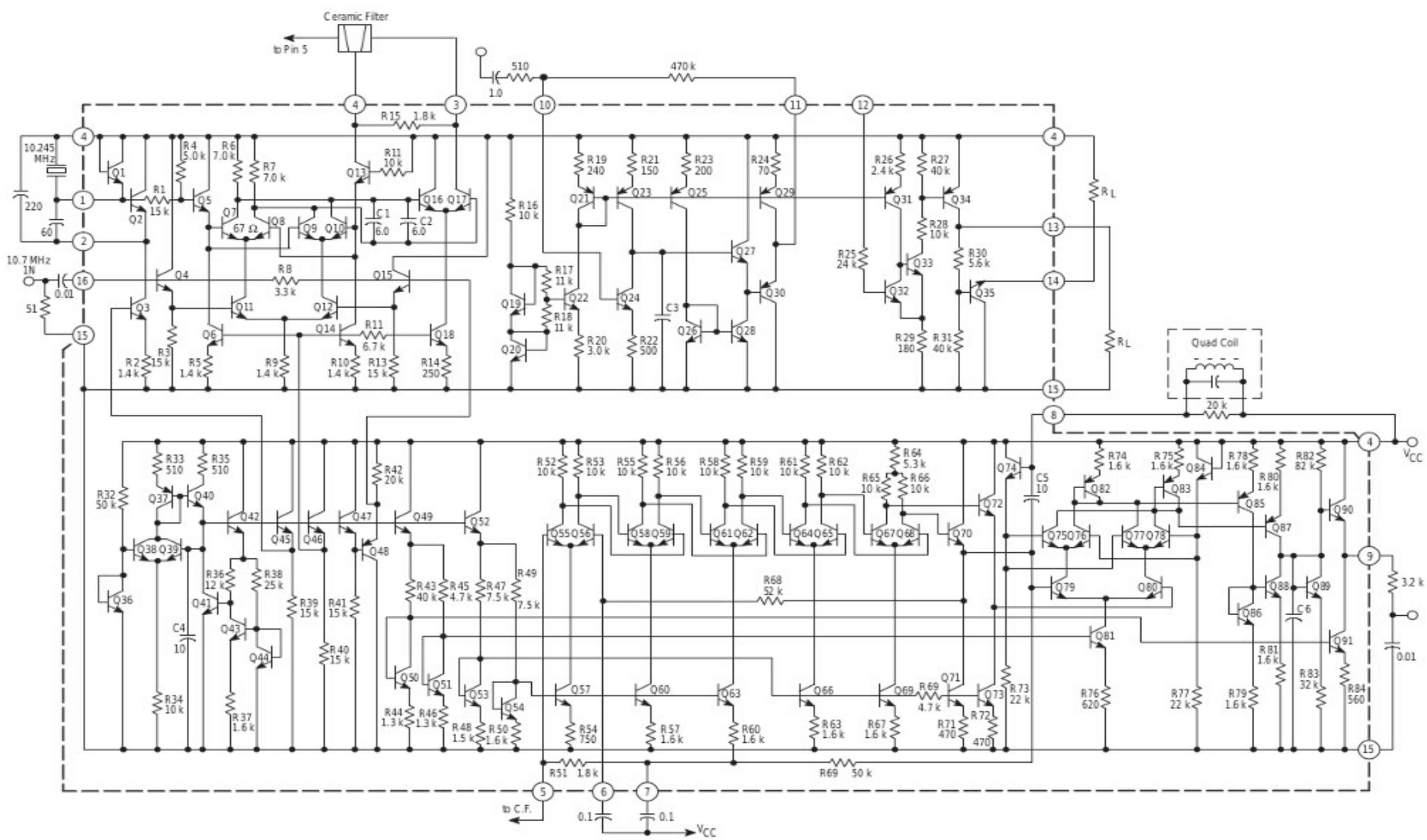
Figure 6. Overall Gain, Noise and AM Rejection



How we do it today

F.M. Detection...





FM Detection reminders

Don’t forget the ‘squelch’ !
Don’t forget the ‘limiter’ !
Don’t forget “phase noise” = jitter (in loop)
Don’t forget “Reciprocal Mixing”
Don’t forget “tracking”

Summary

The 'superhet' receiver converts the incoming RF signal to one or more intermediate frequencies before demodulating it. Superhet receivers have an image frequency that when mixed with the local oscillator will also generate the same I.F. as the desired receive signal.

The **image frequency** will be either the sum of, or the difference between, twice the IF frequency and the desired receive frequency. The role of the **pre-selector** is to reject incoming RF signals at the **image frequency**, preventing them from causing a spurious (unwanted) response in the receiver. The choice of **intermediate frequency** is a trade-off between **selectivity** (better at low frequencies) and **image rejection** (better with a higher frequency I.F.).

If a single IF cannot give adequate selectivity and image rejection, then a **dual conversion** design may be employed, with a higher first I.F. to give good image rejection, and a lower second I.F. to give good selectivity.

Noise limiters limit the amplitude of pulse noise, reducing the effect on the receiver. **Noise blankers** mute the audio output for a short time (a few milliseconds) when the higher amplitude associated with pulse noise is detected.

FM signals are detected using a Foster-Seeley **discriminator** or **ratio detector**. The discriminator should be preceded by a **limiter** to prevent it from being affected by variations in the amplitude of the signal. Weak FM signals have a characteristic hiss on them, and as the signal strength increases and the limiter becomes effective the hiss goes away, a process known as **quieting**. Most FM receivers incorporate a **squelch** function, which mutes the audio output when there is no received signal to avoid the annoying hiss.

Now for the Questions...

By the way that small red thing - it is an antenna!