Radio Receivers,

from crystal set to stereo

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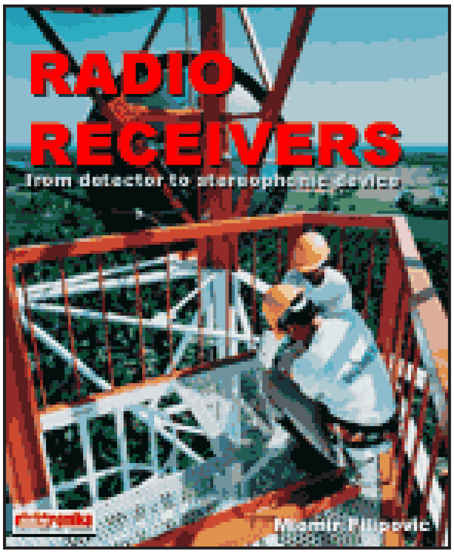
It is hard to imagine what would the modern world look like without the permanent exchange of huge quantity of information. It is being transferred by various means (newspapers, telephone, the Internet etc.), however, the fastest way of doing it, and sometimes the only one, is by radio, where transfer is being done by electromagnetic waves, traveling at the speed of light. This book covers the history and principles of radio transmission and an array of different radio receivers...



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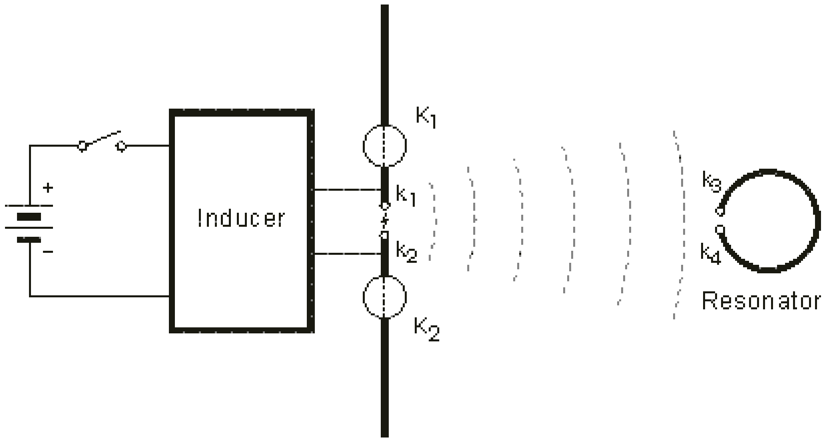
CHAPTER 1 Introduction

It is hard to imagine what the modern world would look like without the constant exchange of a huge quantity of information. It is currently disseminated by various means such as newspapers, telephone and the Internet. However the fastest way, and sometimes the only way, is by radio. This is where the transfer is by electromagnetic waves, traveling at the speed of light. In radio communication, a radio transmitter comprises one side of the link and a radio receiver on the other. No conductor of any kind is needed between them, and that's how the expression **Wireless Link** came into being.
In the early days of radio engineering the terms **Wireless Telegraph** and **Wireless Telephone** were also used, but were quickly replaced with **Radio Communication**, or just **Radio**.



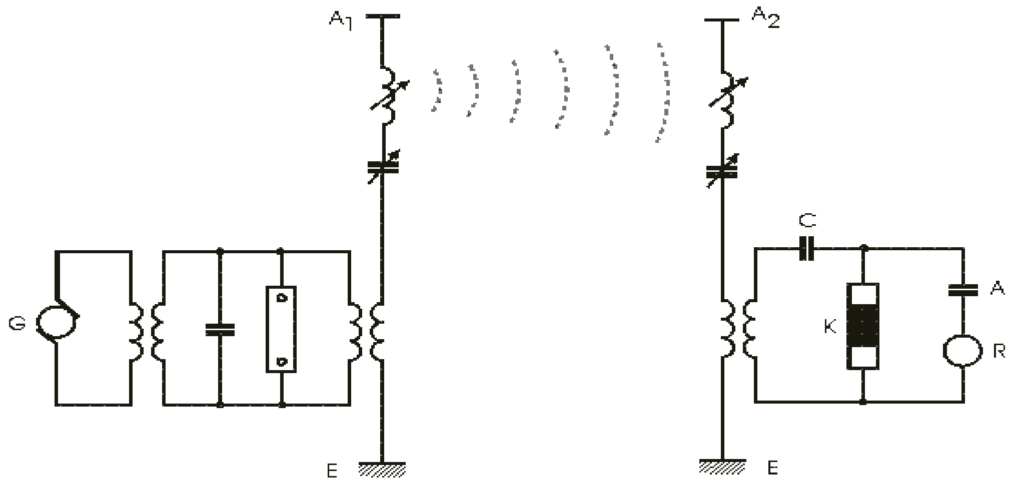
Pic.1.1. Electrical diagram of Hertz's transmitter / receiver

Radio communication is created by means of electromagnetic waves, of which the existence and features were theoretically described and predicted by James Maxwell, in 1864.
First experimental proof of this theory was given by Heinrich Hertz in 1888, ten years after Maxwell's death.
It was already known at that time that electric current exists in oscillatory circuits made of a capacitor of capacity **C** and coil of inductance **L**. It was Thomson, back in 1853 that determined the frequency of this arrangement to be:

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

Hertz used an oscillatory circuit with a capacitor made of two bowls, K1 and K2 (Pic. 1.1), and the "coil" was made of two straight conductors. The bowls could be moved along the conductors. In this way the capacitance of the circuit could be altered, and also its resonance frequency. With every interruption from the battery, a high voltage was produced at the output of the inductor, creating a spark between the narrow placed balls k1 and k2. According to Maxwell's theory, as long as there was a spark, i.e. alternating current in the circuitry, there was an

electromagnetic field surrounding the conductors, spreading itself through the surrounding space. A few metres away from this device Hertz placed a bent conductor with metal balls k3, k4 placed on the ends, positioned very close to each other.
This also was an oscillatory circuit, called the resonator.
According to Maxwell's theory, voltage induced by the electromagnetic waves should be created in the resonator. Voltage existence would be shown by a spark between the balls k3 and k4.
And that's the way it was: Whenever there was a spark in the oscillator between the balls k1 and k2, a spark would also be produced by the resonator, between balls k3 and k4.
With various forms of the arrangement in Pic. 1.1, Hertz proved that electromagnetic waves behave as light since they could also be reflected and refracted.
It was also shown that light is of electromagnetic nature, as stated by Maxwell.
Hertz, however, did not believe in the practical value of his electromagnetic waves experiments. The range of the link was no further than a few meters. The transmitted signal was very weak, therefore the signal in the receiver had a very small amplitude and it wasn't possible to detect it at a greater distance. The possibility of amplifying the signal in the receiver did not exist at the time.
Besides the short range, another shortcoming of the link was noted: If another similar transmitter was working nearby, a receiver detected all the signals at the same time. It did not have the ability of isolation.
However crude and simple these experiments were at the time, they represented the birth of a new scientific branch - **Radio Engineering**.
The pioneers of radio were Popov and Marconi, but the place of honor belongs to Nikola Tesla, who demonstrated wireless broadcasting in 1893, at the Franklin Institute.
Pic.1.2 shows the arrangement of this broadcast system.



Pic. 1.2. Electrical diagram of Tesla's radio transmitter & receiver from 1893.

Tesla's idea was to produce electromagnetic waves by means of oscillatory circuits and transmit them over an antenna. A receiver would then receive the waves with another antenna and oscillatory circuit being in resonance with the oscillatory circuit of the transmitter. This represented the groundwork of today's radio communications.

In 1904 John Flemming created the diode, and in 1907 Lee De Forest invented the triode. That year can be considered the birth of electronics, with the triode being the first electronic component used in a circuit for signal amplification.

Rapid development of radio engineering over the ensuing years produced many innovations and after the First World War a huge number of radio stations emerged.
At that time TRF (Tuned Radio Frequency) receivers were used. Compared to modern receivers they had both poor selectivity and sensitivity, but back then they fulfilled the demands. The number of radio stations was much less than today and their transmitting power was much smaller. The majority of listeners were satisfied with the reception of only local stations. However as the number of stations increased, as well as their transmitting power, the problem of selecting one station out of the jumble of stations, was becoming increasingly more difficult.

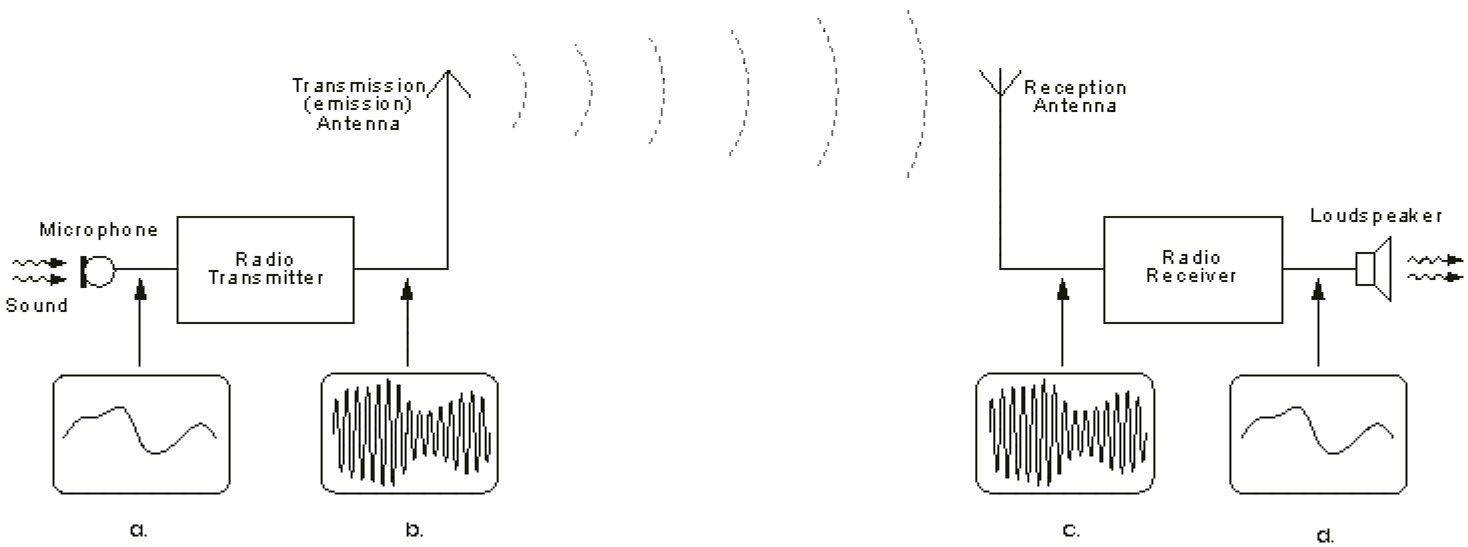
It was partially solved with an increase in the number of oscillatory circuits in the receiver and the introduction of positive feedback, but the true solution was the invention of the **superheterodyne receiver**. This was accomplished by Lewy (1917), and improved by E.H. Armstrong (1918).
An enormous impact on the world of radio was the invention of the transistor by Bardeen, Bretten & Schockley, in 1948. This reduced the size of the radio receiver and made truly portable sets a reality.
This was followed by the introduction of the integrated circuit, enabling the construction of devices that not only proved better in every way than those using values, but also new designs.
Radio amateurs' contribution to radio engineering should also be emphasized.
In the beginning, radio communication was being conducted in the LW and MW bands. But achieving long-distance reception required very powerful transmitters.
The SW band was considered to be useless for radio broadcast on long distances and was given to radio amateurs.
The were banned from using LW and MW bands by commercial radio stations.
However, something unexpected happened: Amateurs were able to accomplish extremely long distance transmissions (thousands of kilometres), by using very low-power transmitters. This was later explained by the influence of the ionosphere layer, the existence of which was also predicted by Tesla.
Modern radio receivers differ greatly from the "classical" types, however the working principles are the same.

The only significant difference is in the way the receiver is tuned to a station. Classical devices used a variable capacitor, coil or varicap diode, with the frequency read from a scale with movable pointer. In modern devices, the adjustment is done with a frequency synthesizer controlled by a microprocessor and the reading is displayed on an optical readout.

The inclusion of a microprocessor enables any one of a large number of pre-tuned stations to be selected and displayed and the use of a remote control makes the receiver even more user friendly.

Chapter 2 Principles of radio transmission

Transfer of information (speech, music, image, computer data etc.) by radio can be presented in its simplest form with block - diagram as on Pic.2.1. That is a transmission realized by amplitude - modulated signal. Since, in our example, the information being transferred is the sound, the first step of such transmission is converting the sound into electrical signal, this being accomplished by a microphone. The low - frequency (LF) voltage at microphone output (Pic.2.1-a), that represents the electrical "image" of the sound being transferred, is being taken into the transmitter. There, under the effect of LF signal, the procedure called amplitude modulation is being carried out, and on its output high - frequency (HF) voltage is generated, its amplitude changing according to the current LF signal value. HF voltage creates HF current in the antenna, thus generating electromagnetic field around it. This field spreads through the ambient space, being symbolically shown on Pic.2.1 with dashed circles. Traveling at the speed of light (c=300 000 km/s), the electromagnetic field gets to the reception place, inducing the voltage in the reception antenna, as shown on Pic.2.1-c. This voltage has the same profile as the one on Pic.2.1-b, except it has much smaller amplitude. In the receiver, the amplification and detection are carried out first, resulting with the LF voltage on its output, that has the same profile as the one on Pic.2.1-a. This voltage is then transformed into sound by loudspeaker, that sound being exactly the same as the sound that acted upon the microphone. This, naturally, is the way it would be in ideal case. Back to reality, due to device imperfection as well as the influence of various disturbances, the sound being generated by the loudspeaker differs from the one that acts upon the microphone membrane. The block - diagram on Pic.2.1 (excluding the HF signal shape) is also applicable in case of radio transmission being carried out by frequency modulation. In that case frequency modulation is being carried out in the transmitter, under the effect of LF signal coming from the microphone, therefore HF signals on Pics.2.1-b and 2.1-c having constant amplitude, and their frequency

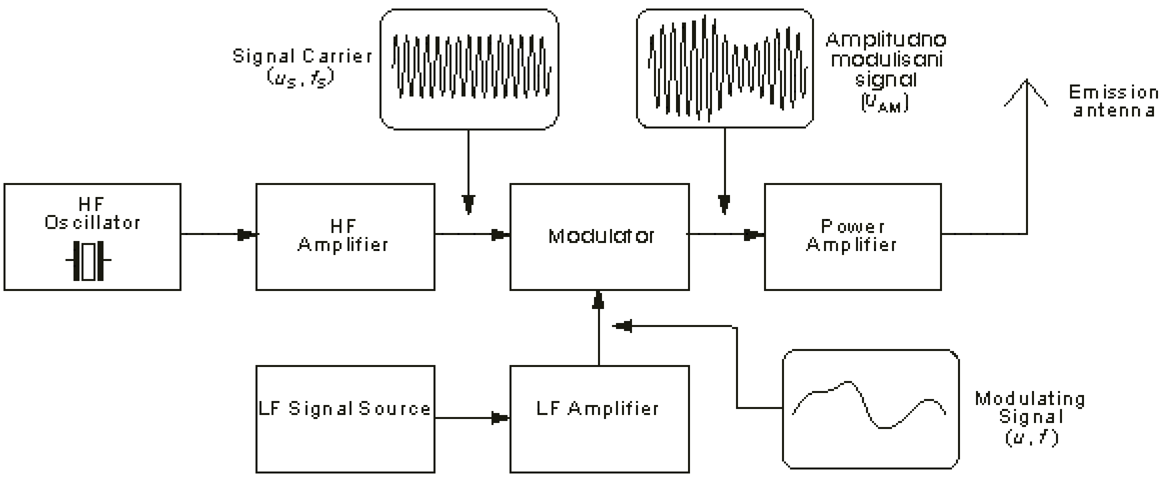


Pic.2.1. Radio Transmission Block-Diagram

being changed in accordance with the actual value of LF signal from the microphone. In fact, all types of radio transmission can be presented with Pic.2.1. First, the information being sent is always transformed into electrical signal through the appropriate converter. In telegraphy this converter is the pushbutton, in radiophony it's a microphone, in television engineering an image analysis cathode ray tube (CRT) etc. Then, with this "electrical image" of information, the modulation is being done. The modulated HF signal is being transferred into antenna and transmitted. On the reception place, the modulated signal from the reception antenna is being amplified and detected and then, again with the appropriate converter (pen recorder, loudspeaker, TV CRT etc.), the information is transformed back into its original form.

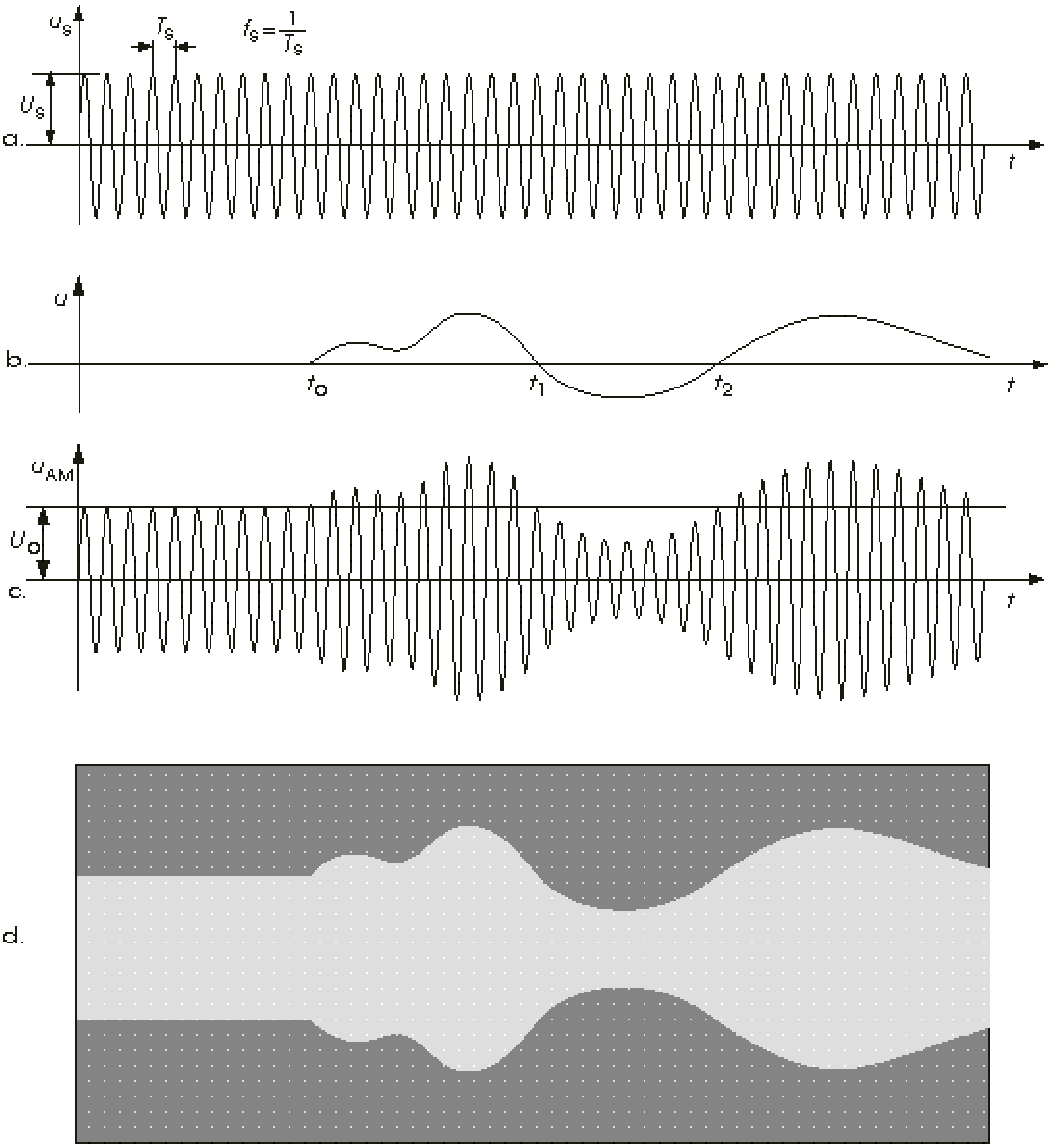
2.1 AM Transmitter

In order to better understand the way the radio transmitter works, block - diagram of a simple AM (amplitude modulated) signal transmitter is shown on Pic.2.2. The amplitude modulation is being performed in a stage called the modulator. Two signals are entering it: high frequency signal called the carrier (or the signal carrier), being created into the HF oscillator and amplified in the HF amplifier to the required signal level, and the low frequency (modulating) signal coming from the microphone or some other LF signal source (cassette player, record player, CD player etc.), being amplified in the LF amplifier. On modulator's output the amplitude modulated signal UAM is acquired. This signal is then amplified in the power amplifier, and then led to the emission antenna.



Pic. 2. 2. AM Transmitter Block Diagram

The shape and characteristics of the AM carrier, being taken from the HF amplifier into the modulator, are shown on Pic.2.3-a. As you can see, it is a HF voltage of constant amplitude US and frequency fS. On Pic.2.3-b the LF signal that appears at the input of the modulator at the moment t0 is shown. With this signal the modulation of the carrier's amplitude is being performed, therefore it is being called the modulating signal. The shape of the AM signal exiting the modulator is shown on Pic.2.3-c. From the point t0 this voltage has the same shape as that on Pic.2.3-a. From the moment t0 the amplitude of AM signal is being changed in accordance with the current value of the modulating signal, in such a way that

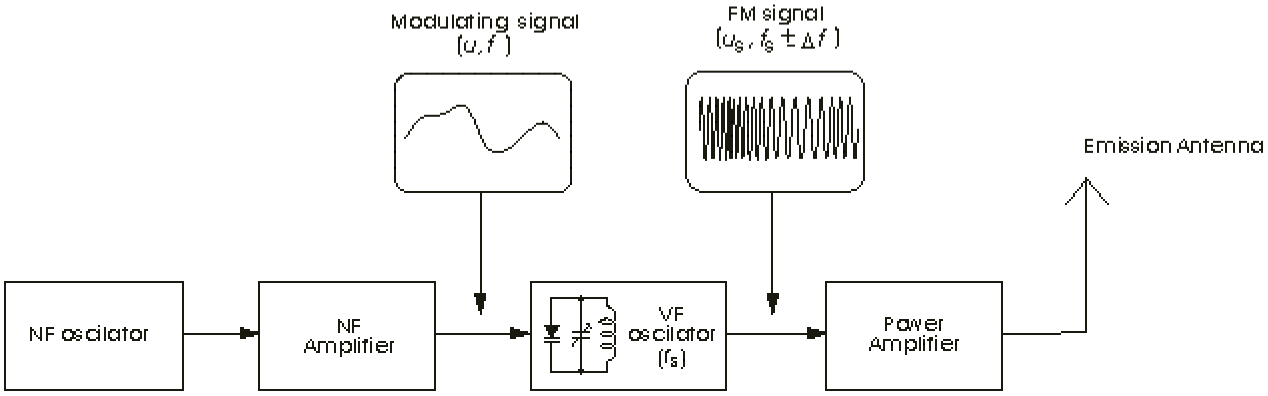


Pic.2.3. Voltage wave envelopes of an AM signal: a- The (signal) Carrier, b- The Modulating Signal (LF signal being transferred), c- AM (amplitude - modulated) signal, d- true look of the AM signal.

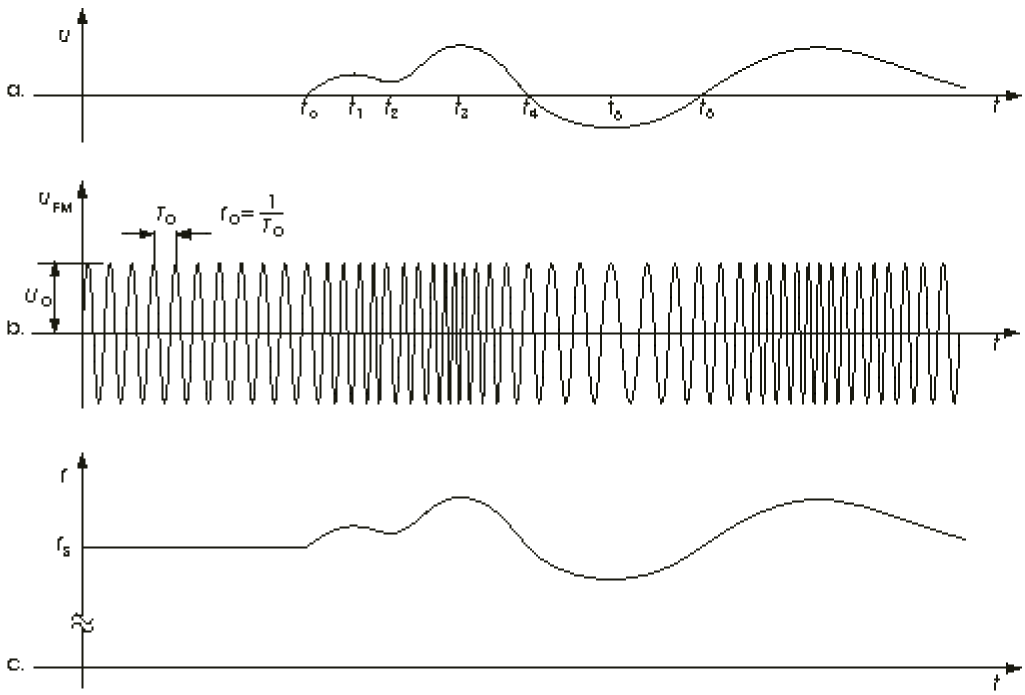
the signal envelope (fictive line connecting the voltage peaks) has the same shape as the modulating signal.

Let's take a look at a practical example. Let the LF signal on Pic.2.3-b be, say, an electrical image of the tone being created by some musical instrument, and that the time gap between the points t0 and t2 is 1 ms. Suppose that carrier frequency is fS=1 MHz (approximately the frequency of radio Kladovo, exact value is 999 kHz). In that case, in period from t0 till t2 signals us on Pic.2.3-1 and uAM on 2.3-c should make a thousand oscillations and not just eighteen, as shown in the picture. Then It is clear that it isn't possible to draw a realistic picture, since all the lines would connect into a dark spot. The true picture of AM signal from this example is given on Pic.2.3-d. That is the picture that appears on screen of the oscilloscope, connected on the output of the modulator: light coloured lines representing the AM signal have interconnected, since they are thicker than the gap between them.

Block - diagram on Pic 2.2 is a simplified schematic of an AM transmitter. In reality there are some additional stages in professional transmitters that provide the necessary work stability, transmitter power supply, cooling for certain stages etc. For simple use, however, even simpler block diagrams exist, making the completion of an ordinary AM transmitter possible with just a few electronic components.



Picture 2.4. FMtransmmiter Block diagram



2.2. FM Transmitter

Block diagram of an FM (frequency modulated) transmitter is given on Pic.2.4. Information being transferred, i.e. the modulating signal, is a signal from some LF source. it is being amplified in LF amplifier and then led into the HF oscillator, where the carrier signal is being created. The carrier is a HF voltage of constant amplitude, whose frequency is, in the absence of modulating signal, equal to the transmitter's carrier frequency fS. In the oscillatory circuit of the HF oscillator a varicap (capacitive) diode is located. It is a diode whose capacitance depends

upon the voltage between its ends, so when being exposed to LF voltage, its capacitance is changing in accordance with this voltage. Due to that frequency of the oscillator is also changing, i.e. the frequency modulation is being obtained. The FM signal from the HF oscillator is being proceeded to the power amplifier that provides the necessary output power of the transmission signal.
Voltage shapes in FM transmitter are given on Pic.2.5. Pic.2.5-a shows the LF modulating signal. The frequency modulation begins at moment t0 and the transmission frequency begins to change, as shown on Pic.2.5-b: Whilst current value of the LF signal is raising so is the trasmitter frequency, and when it is falling the frequency is also falling. As seen on Pic.2.5-c, the information (LF signal) is being implied in frequency change of the carrier.
The carrier frequencies of the radio difusion FM transmitters (that emmit the program for "broad audience") are placed in the waveband from 88 MHz til 108 MHz, the maximum frequency shift of the transmitter (during the modulation) being ±75 kHz. Because of that the FM signal should be drawn much "thicker", but it would result in a black-square-shaped picture.

2.3. Wavebands

While considering problems related to the realization of the long - distance radio links, significant differences between the electromagnetic waves of various frequencies must be kept in mind. For example, low frequency waves (below 500 kHz) can bend themselves following Earth's curvature, while the HF waves are moving in streamlines, just as light. Some waves can be reverberated from the ionosphere, others are passing through it etc. According to characteristics of their outspread, radio waves can be classified into several groups or ranges: long, mid, short and ultra-short. Limits between the wavebands are not precise, with the raise of their frequency the waves are gradually losing some features while gaining some others. This division is shown in Table 1.

Table No.1

Range	Frequency	Wavelength
Long waves (LF*)	30 - 300 kHz	10 km - 1 km
Mid waves (MF*)	300 - 3000 kHz	100 m - 100 m
Short waves (HF*)	3 - 30 MHz	100 m - 10 m
Ultra short waves:		
a. Metre range (VHF*)	30 - 300 MHz	10 m - 1 m
b. Decimetre range (UHF*)	300 - 3000MHz	100 cm - 1 cm
c. Centimetre range (SHF*)	3 - 30 GHz	10 cm - 1 cm
d. Millimetre range (EHF*)	30 - 300 GHz	10 mm - 1 mm

* LF low frequencies, MF mid frequencies, HF high frequencies, VHF very high frequencies, UHF ultra high frequencies, SHF super high frequencies, EHF extra high frequencies. Waves with wavelength smaller than 30 cm are also called the microwaves.

In the third table column the wavelengths are given. Wavelength (ë) is distance that the wave passes moving at the speed of light (c=3*103 m/s), during the period that is equal to its oscillating period (T): ë=c*T. Having in mind that the wave frequency is f=1/T, one can easily get to the well known expression that gives the relation between the wavelength and the frequency:

$$\lambda = \frac{c}{f}$$

Using this formula one can calculate the wavelength knowing the frequency and vice versa. For example, wavelength of an FM transmitter emitting at f=100 MHz frequency is L=3*108/100*106=3 m. Similar to that, wavelength of Radio Belgrade 1 is L=439 m, which makes its frequency equal to f=3*108/439=684 kHz.
Radio diffusion is being performed in certain parts of the wavebands given in Table 1, their boundary frequencies are (rounded values):

LW (long waves) 150 kHz (2km) 300 kHz (1 km)
MW (mid waves) 500 kHz (600 m) 1500 kHz (200 m)
SW (short waves) 6 MHz (50 m) 20 MHz (15 m)
FM (ultra short waves) 88 MHz (3.4 m) 108 MHz (2.78 m)

In LW, MW and SW the amplitude modulation is used, while in FM range it is the frequency modulation.

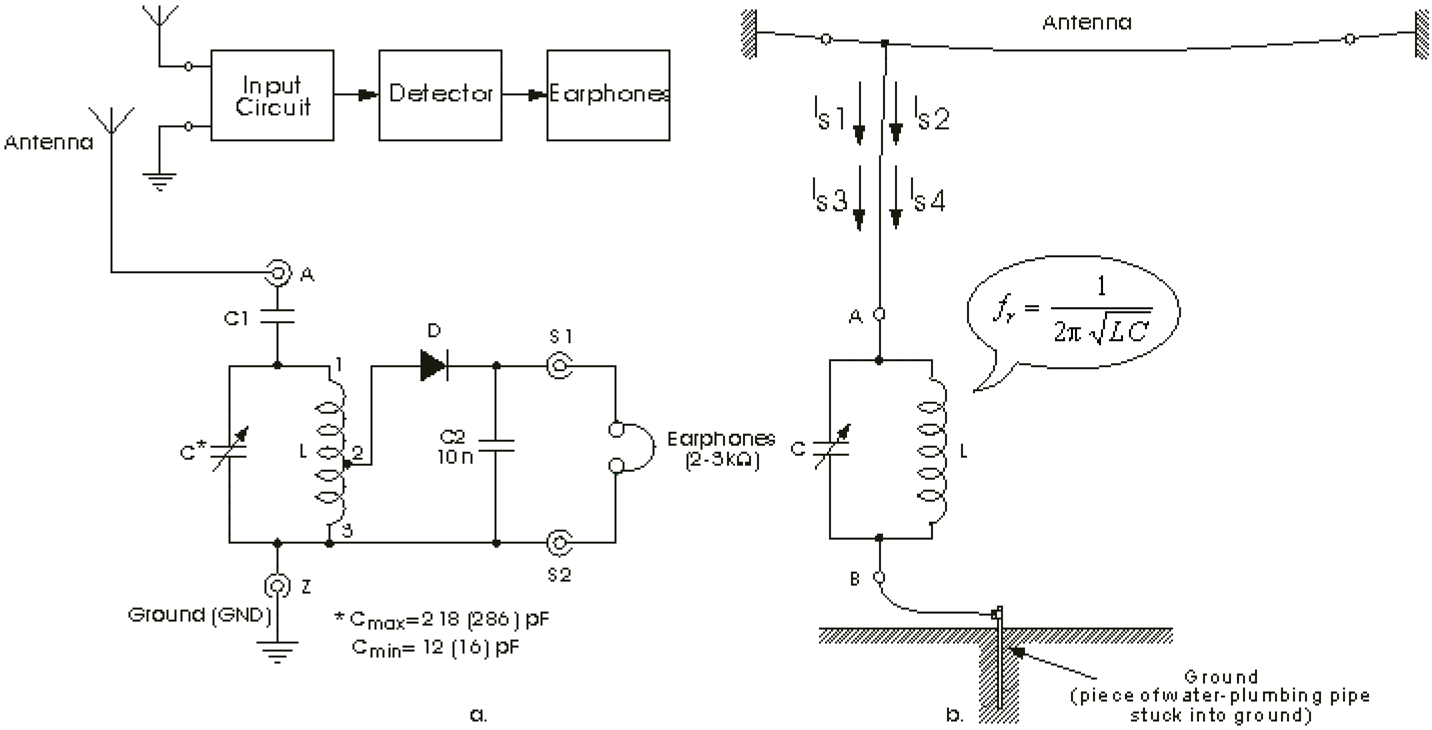
Here are the frequencies (in kHz) of some radio transmitters from the MW range, that can serve for tuning of the radio receivers being described in this issue: Timisoara 630, Belgrade1 684, Bucharest 855 .

Chapter 3 Direct (TRF) Radio Receivers

3.1. The Simplest Radio Receiver

Each radio receiver must have a reception antenna. It is an electrical conductor, where voltages of various frequencies and amplitudes are being induced, under the influence of electromagnetic fields from various radio transmitters. Besides these voltages, those induced by EM fields that are created by various disturbance sources (such as electrical motors, various household appliances spark-plugs of an automobile and all other devices where electrical current is being switched on/off during work) are also present in the antenna, as well as those from fields originating from outer space or the Earth's atmosphere. Basic roles that a radio receiver has are:
a. To separate the signal (voltage) of the radio station that it is tuned at from the multitude of other voltages, whilst suppressing (weakening) all other signals as much as possible,
b. amplifies the extrapolated signal and take out information from it and
c. reproduces that information, i.e. restores it into its' original shape.
Even the simplest radio, the one we are discussing in this chapter, must be able to accomplish all these tasks. The electronic diagram of one such device is given on Pic.3.1. It is the famous (years ago) Detector Radio Receiver or shortly, Detector. The signal selection (separation) and voltage amplification are performed in the oscillatory circuit that is made of the capacitor C and coil L, the separation of information (speech or music) from the AM station signal in the detector that comprises the diode D, capacitor C2 and resistance of the headphones, and information restoring in the very headphones.
Main advantages of this device lie in its extreme simplicity and the fact that it

requires no additional energy sources for its' operation. All the energy required it draws from the antenna, which therefore has to be at least a dosen metres long for proper operation. It is also useful to have a good ground. One can do without it but the reception with it is truly better, especially considering the distant and small-power transmitters.



Pic.3.1- a-Block diagram and electronic diagram of a detector radio receiver, b-operating principle of input circuit

3.1.1. Input Circuit

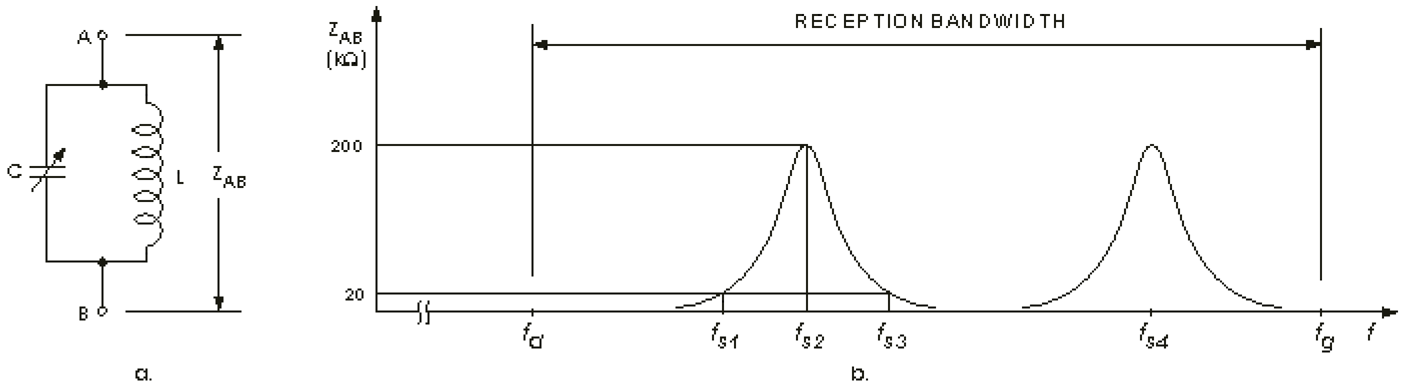
The capacitor that takes the signal from the antenna (so-called coupling capacitor) C1, variable capacitor C and coil L form the input circuit of the radio receiver. Its main role is to separate the signal of station the receiver is tuned at from multitude of voltages (having various frequencies and amplitudes) existing in the antenna, amplify that signal and turns it over to the detector.
In order to better understand the requests that are to be fulfilled during the practical realization of input circuit, it is necessary to know basic characteristics of circuit made of capacitor C and coil L. It is called 'The oscillatory circuit' and is shown on pic.3.2-a. The amount of its impedance (resistance to AC current) between points A and B, which is marked with , depends on the frequency, as it is shown on the diagram on pic.3.2-b. The most important characteristic of this circuit is its resonance frequency, being given by the Thomson's formula:

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

As one may notice, the resonance frequency depends on the capacitance of the capacitor C and inductivity of coil L, and changes if one of them change. In our receiver, a variable capacitor is used, that can change its capacitance from Cmax to Cmin, therefore changing the resonance frequency in boundaries from

$$f_d = \frac{1}{2\pi\sqrt{LC_{max}}} \quad \text{to} \quad f_g = \frac{1}{2\pi\sqrt{LC_{min}}}$$

The area between fd (lower boundary frequency) and fg (upper boundary frequency) is the reception area of the input circuit, as shown on pic.3.2-b. On this picture, carrier frequencies of four radio transmitters are being marked with fs1, fs2, fs3 and fs4. The resonance frequency of the oscillatory circuit is set (by means of C) to be equal to the carrier frequency of the second station: fs2. In that case, the impedance ZAB - frequency dependance is shown in continuous line. As one can see, the impedance ZAB for all received signals whose carriers have frequencies less than fs1 and greater than fs3 is less than 20 kOhms, while for the station that is tuned it is equal to 200 kOhms. Let us now imagine that the parallel oscillatory circuit is connected with the antenna and ground, as shown on pic.3.1-b. Imagine, also, that there are (only) four voltages in the antenna, that have the same amplitude and are created by four radio transmitters, having carrier frequencies of fs1, fs2, fs2 and fs4. Since these voltages spread between the antenna and the ground, four currents will flow through the oscillatory circuit:



Pic.3.2 a-parallel oscillatory circuit, b-ipedance - frequency dependence of the parallel oscillatory circuit

Is1, Is2, Is3 and Is4. The voltages that are created by them in the oscillatory circuit, between points A and B, are equal, acc. to Ohm's Law, to the product of current and impedance: UAB=I*ZAB. Acc. to pic.3.2-b, for Is2, impedance of the circuit is ZAB=200 kOhms, and for currents Is1 and Is3 it is 10x smaller. That means that the voltage that is being created in the oscillatory circuit by the station that transmits on frequency fs2 will be ten times greater than the voltages being created by stations transmitting on frequencies fs1 and fs3. This is how selection of one station is performed, by means of the oscillatory circuit. Transition to some other station is performed by changing the capacitance of capacitor C, as long as the resonance frequency of the oscillatory circuit does not become equal to the carrier frequency of that station. If its frequency happens to be fs4 (acc. to pic.3.2-b), the impedance of the oscillatory circuit for that case is shown in dashed line, which causes that on the circuit output voltage of the station that transmits on frequency fs4 is acquired, while other stations' signals are suppressed.

At first glance, everything is just the way it should be: Parallel oscillatory circuit extrapolates one and suppresses all other stations. Unfortunately, the reality isn't so simple. First of all, radio transmitters operate with various output (emission) powers and on various geographic distances from the receiver, therefore making the voltages that their signals create in the reception antenna very different in amplitude. It is clear that stronger signals will “cover” the weak ones, thus disabling their reception. E.g. if radio transmitter that emits on the frequency fs1 is geographically much closer to our radio receiver that the transmitter operating on fs2, the voltage the former creates in the reception antenna can be even 200 times greater than the one created by the latter. The oscillatory circuit will do its job as previously described, but on its ends the voltage of the first transmitter will still be greater (20x) than that of the transmitter the receiver is tuned at, and normal reception won’t be possible. There are also other problems whose solving will not be discussed herein, and readers that are interested in those can read a book “Radio Receivers”, written by Momir Filipovic, issued by the National Textbook Publishing Company from Belgrade, Yugoslavia.

To conclude this chapter, we may say that the simplest radio receiver can cover only signals of the local and powerful radio transmitters.

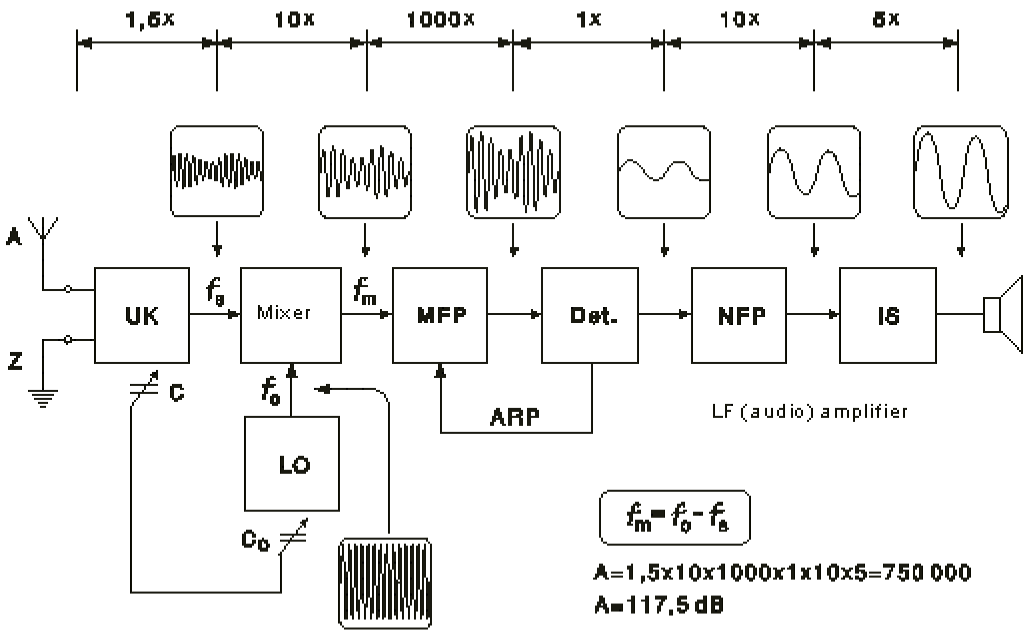
Chapter 4 Superheterodyne Radio Receivers

As far as the professional manufacturers are concerned, the direct (TRF) receiver has "played out his tune". After half-century struggle on the market, it has been replaced by the superheterodyne receiver, that was patented in 1918 by Edwin Armstrong. In that time, commercially speaking, its main advantage was its substantially easier tuning to the station. It requires only one button for this, comparing to the TRF receiver that needs two buttons to be intermittently adjusted for optimal reception, and also it requires much of the knowledge, skill and patience, which the average buyer does not have. The superheterodyne receiver is, however, also more complex than the TRF, and setting of its stages during its production requires some special instruments, that the average radio amateur does not possess. Nevertheless, it is not impossible to build such device in the amateur environment, and when the operating principles are known, the necessary adjustments can be done "by hearing".

4.1. Superheterodyne AM Receivers

On Pic.4.1 you can see the block diagram of a radio-broadcast superheterodyne receiver The input circuit (UK) refines the signal of the tuned station from all the voltages created in the antenna (A) by various radio transmitters and sources of disturbances. In our example, it's an AM signal that has the carrier frequency fs, and is modulated by a single tone, as seen in the rectangle above its label. This signal is being led into the stage called the mixer. Another voltage is also led into it, the voltage from the local oscillator that has the frequency of f0, and a constant amplitude. Under the effect of these two signals, the phenomenon called the outbreak takes place in the mixer, and an AM signal appears on its output, its frequency being fm=455kHz. This signal is called the inter-frequency (IF) signal, and its frequency fm the interfrequency. The IF signal has the same envelope as the station signal entering the mixer. That means, that the information from the transmitter to the mixer is carried by the signal frequency fs, and in the mixer it is being assumed by a new carrier, that has the frequency fm. When transferring to another station, the user changes the capacitance of the variable capacitor C by turning the knob, setting up the resonance frequency of the input circuit to be equal to that station's one. Another variable capacitor, Co, is located on the same shaft as C, so its capacitance changes simultaneously to that of C. This capacitor is located in the local oscillator and that is how it gets the new oscillating frequency, having such value that the difference of the oscillator and station frequencies is again equal to the inter-frequency value.
Here's one numerical example. The interfrequency is being adopted by the constructor of the device, and it is mostly fm=455 kHz. When the receiver is set to the station that has the frequency of fm=684 kHz, the frequency of the local oscillator shall be fO=1139 kHz, therefore making there difference be 1139 kHz-684 kHz=455 kHz=fm.
When tuning to a station that operates on the frequency of fS=1008 kHz, the

listener will change the capacitances of the two capacitors until the resonant frequency of the input circuit becomes fS=1008 kHz, and the oscillator frequency fO=1463 kHz, therefore yielding
1463 kHz-1008 kHz=455 kHz=fm.
If the receiver has more wavebands (LW, MW, SW1, SW2…) it is being constructed to have the same inter-frequency value for all of them.
What do we gain with this change of the carrier frequency? So far we haven't mentioned one very important thing, that is that the input circuit can never be selective enough, to extrapolate only the signal of the tuned station, from all the signals that exist in the antenna. On the output of this circuit, besides the station signal, also signals of strong and local transmitters are obtained, especially the signals from the neighbouring channels (their frequency being very close to the one of the tuned station). All these signals are receiving new signal carriers in the mixing stage, with their frequencies deviating fm as much as their carrying frequencies differ from fS. E.g., if the input circuit is set on the station whose frequency is 1008 kHz, another two signals from the neighbouring channels can also emerge on its exit.



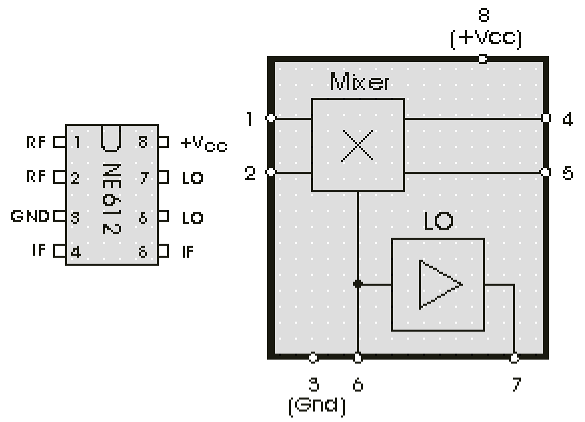
Pic.4.1. Block diagram of a superheterodyne AM receiver

Their frequencies would be 999 kHz and 1017 kHz. The ordinary TRF receiver would in this case be totally incapable of suppressing those signals, which is not the case with the superheterodyne receiver. These 3 signals are entering the mixer, which gets the 1463 kHz voltage from the oscillator. The outbreak occurs, and 3 AM signals are exiting the stage, their frequencies being 455 kHz, 464 kHz and 446 kHz. All 3 signals go to the IF amplifier (MFP), which has several amplifying stages with oscillatory circuits set to 455 kHz, making it very selective, so it amplifies only the 455 kHz signal and suppresses the others enough not to disturb the reception.
the signal exiting the IF amplifier is led onto the detector (Det.), the LF voltage amplifier (NFP) and the output stage (IS), the circuits we spoke about in the previous projects.
The ARP signifies the circuit that turns back the DC component of the detected signal into the IF amplifier, to obtain the automatic amplification regulation.
Above every block on the picture you can see the signal shape exiting that block,

as seen on the oscilloscope, in case the modulation in the transmitter is done by the single, sinusoidally-shaped tone. The upper part of the picture contains the average voltage amplifications for each block, for the mass-production devices. Total voltage amplification, which is the ratio of the voltage on the loudspeaker to the voltage in the antenna is A=750000. The amplification in decibels is therefore: A(dB)=20logA=117.5

4.1.1. The Simplest Superheterodyne AM Receiver

The author presumes that most of the readers, especially those just entering the world of radio with this book, are somewhat scared by the block diagram from Pic.4.1. Their question probably is: Can an amateur build such a receiver? Yes, he can. The author has a friend that succeeded in this some 40 years ago, when all had been done with the electronic tubes, making the practical realization of a receiver much harder than it is today, with semiconductors (its radio amateur call sign is YT1FA, and those who doubt it may contact him). However, he was doing this in the premises of YU1EXY Radio Club, in the attic of the Electrotechnical Faculty in Belgrade, using the club (more less trophy) instruments and, more important, he had help of Sasa Piosijan, Radivoje Karakasevic and Kiro Stojcevski, who knew all about the radios, especially Sasa.
The main problem in making a superheterodyne device is not the circuitry complexity but its setup, which requires lot of practical experience and some special instruments, that our readers probably don't possess. But they are much better than the TRF receivers, both regarding the sensitivity and selectivity, so we made simpler devices that are simple to set, with no instruments necessary than your ears. They are realized around the NE612 IC, whose pin description, block diagram and main features are given on Pics.4.2-a & b.
This IC comprises the critical stages of an AM superheterodyne receiver, the mixer and local oscillator. the station signal is led either on pin 1 or on pin 2 (or on both of them, in case of symmetrical coupling with the previous stage), and the IF signal is obtained on the pin 4 or 5 (or on both of them, in case of symmetrical coupling with the next stage). An oscillatory circuit, that determines the frequency of the local oscillator and the positive feedback circuit are connected between the pins No.6 and 7. Pin 3 is connected to Gnd, i.e. the minus pole of the DC supply voltage. Pin 8 receives a positive DC supply voltage which can, acc. to the table given on Pic.4.2, vary between 4.5 V to 8 V. The value of this voltage is not critical, but it is extremely important for normal operation of the receiver that this voltage is stable, therefore urging for it to be separately stabilized (with special care), as seen in some projects in this chapter and in the Appendix, that involve the NE612.
In the text that follows 3 simple superheterodyne receivers made with NE612 will be described.

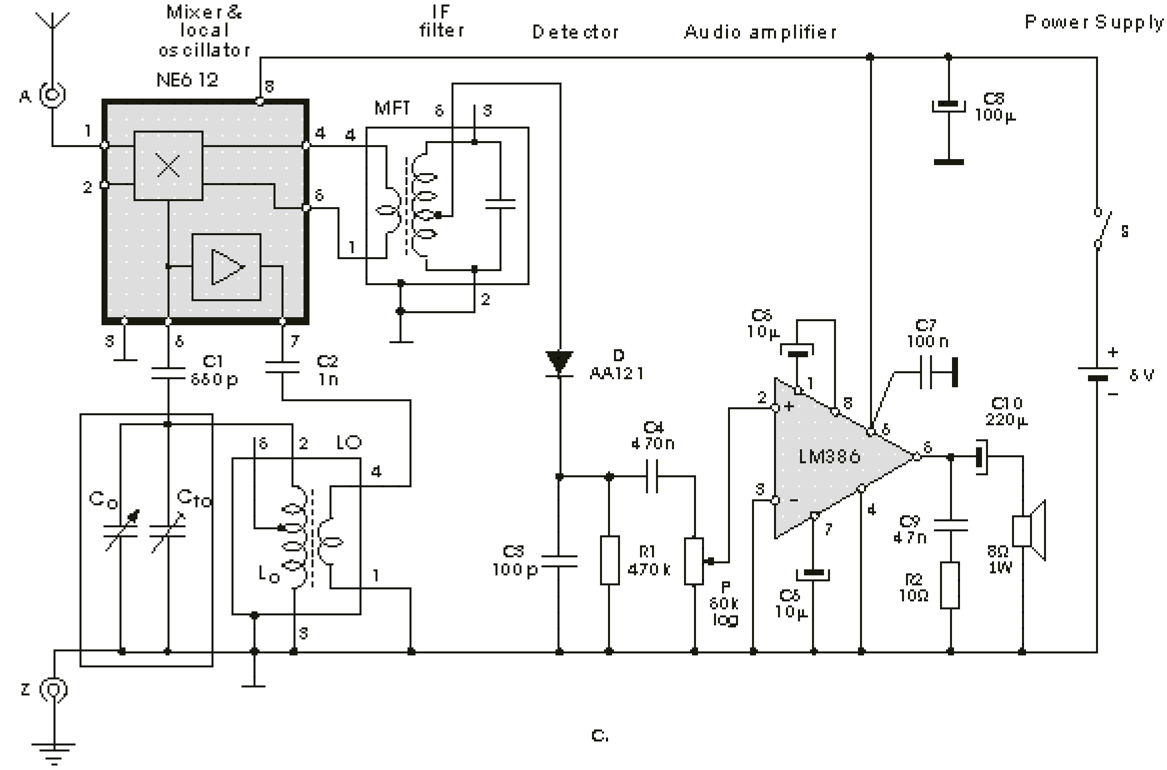


a.

NE612 IC Characteristics (NE602, SA612, SA602)

Parameter	Symbol	Range	Unit
Supply Voltage	V_{CC}	4,5 ··· 8	V
Supply Current	I_{CO}	2,4 ··· 3	mA
Input resistance (between 1& 2 & Gnd)	R_{in}	1,5	kΩ
Output resistance (between 4 & 5 & Gnd)	R_{out}	1,5	kΩ
Mixer amplification	A_{mix}	14 ··· 17	dB
Maximum oscillator frequency	f_{omax}	200	MHz
Maximum mixer frequency	f_{Mmax}	500	MHz
Outside oscillator votage	U_O	200	mV

b.



c.

Pic.4.2. The simplest superheterodyne AM receiver: a-pin layout and block diagram of the NE612, b-IC technical data, c-electronic diagram of the receiver

More will be discussed in the chapter dedicated to NE612 IC, and the reader should pick one of these, or make the receiver that suits him best by combining these diagrams with earlier described HF amplifiers and input circuits.
The electronic diagram of the simplest superheterodyne AM receiver in the world, with reproduction over the loudspeaker, is shown on Pic.4.2-c. The device has got only one oscillatory circuit in the IF amplifier (being marked as MFT), whose frequency does not need to be set to some specific value (meaning the receiver will work OK even if its frequency is bigger or smaller than standard 455 kHz). Further simplification was done by omitting the input circuit, therefore avoiding the problems with quite complex adjustments between the input circuit and the local oscillator. All these simplifications do have their price: this device is less sensitive and selective than the complete superheterodyne, and is also more

prone to disturbances. Even so, it has better both the selectivity and sensitivity than the TRF.
Signals of all the stations are being led directly from the antenna onto the pin no.1, i.e. the mixer. On the other hand, the mixer also receives the HF voltage from the local oscillator, whose frequency is equal to the resonance frequency of the parallel oscillatory circuit made of CO, CtO, and LO. This frequency, if neglecting the parasite capacitances, is:

$$f_o = \frac{1}{2\pi\sqrt{L_o(C_o + C_{to})}}$$

On the mixer exit the signals from all the stations are obtained, but now they have new carrier frequencies, that are equal to the difference of the oscillator frequency and their original one. Nevertheless, only one of these signals will have the frequency that is equal to the resonance frequency of the MFT, and it will be the only one to appear on the ends of this oscillatory circuit. Here's a numerical example.

Let us assume that we have (only) 3 MW signals in the antenna, having the frequencies of fS1=711 kHz (Nis), fS2=855 kHz (Bucharest) and fS3=1008 kHz (Belgrade 2). The IF transformer frequency could be fm=455 kHz. If we set the frequency of our oscillator on fm=1166 kHz (with CO), the following signals, modulated by the radio stations' programs, will exit the mixer:

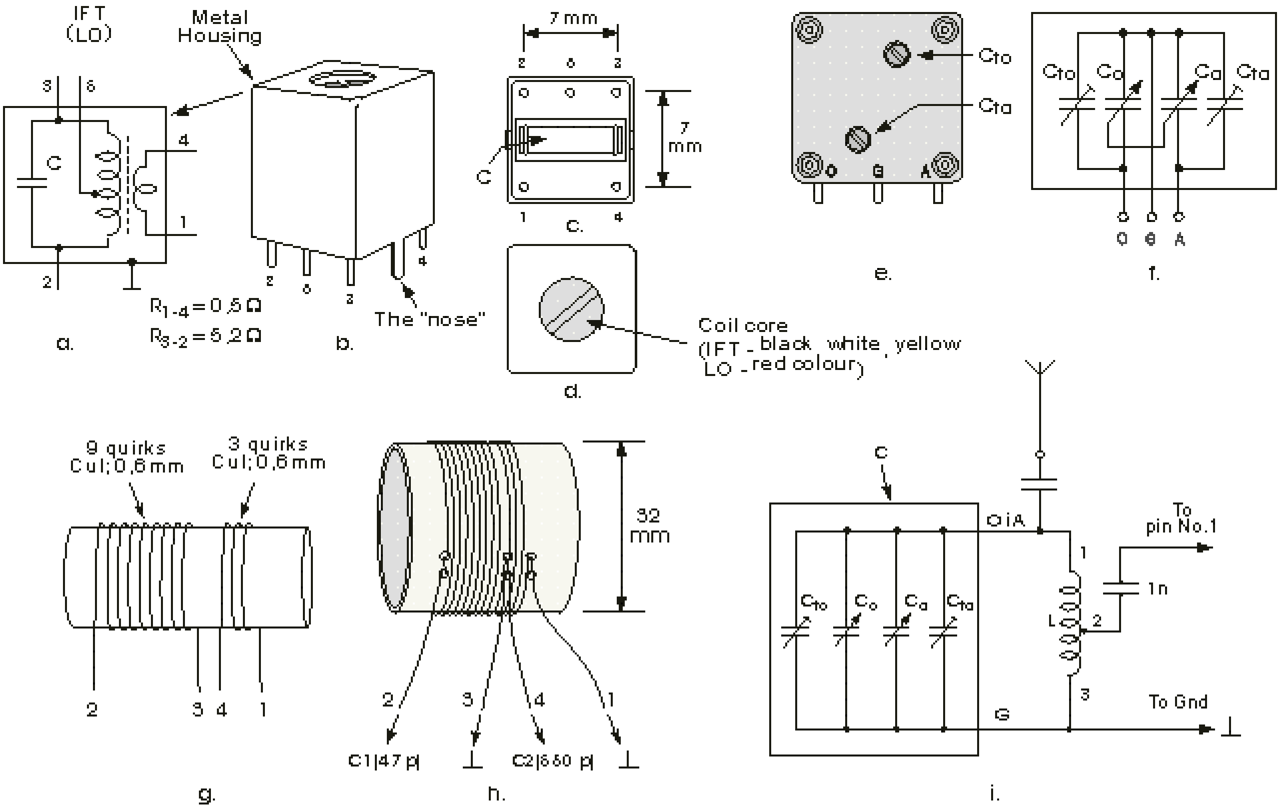
fm1=f0-fS1=1166-711=455 kHz,
fm2=f0-fS2=1166-855=311 kHz and
fm3=f0-fS3=1166-1008=158 kHz.

Since the oscillatory circuit on the mixer exit (MFT) is set to 455 kHz, we will have Radio Nis's signal from it, others will be suppressed. If we wish to hear Bucharest, the oscillator frequency should be set to 1310 kHz, and for Belgrade 2 1463 kHz. Of course that the listener doesn't need to know all these frequencies, he will just turn the knob of CO until hearing the desired station's broadcast.
The IF signal is led from the pin 3 to the detector with AA121 diode. The LF signal is taken from the R1 resistor and over the capacitor C4 it is led to the volume potentiometer P and the audio amplifier.

* the MFT is also being called the inter-frequency transformer. It is a special type component that is hard to find in the ordinary electronic shops, therefore the radio amateurs are usually obtaining them from disused factory-made devices. The IF transformer is shown on Pics.4.3-a,b,c & d. As you can see it on 4.3-a, the MFT is, in fact, a parallel oscillatory circuit with a leg on its coil. The coil body has a ferrite core (symbolically shown with single upward straight dashed line) that can be moved (with screwdriver), which allows for the setting of the resonance frequency of the circuit, being mostly fm=455 kHz. The same body contains another coil, with less quirks in it. Together with the bigger one it comprises the HF transformer that takes the signal from the oscillatory circuit into the next stage of the receiver. Both the coil and the capacitor C are placed in the square-shaped metal housing that measures 10x10x11 mm (Pic.4.3-b). From the bottom side of the housing you can see 5 pins emerging from the plastic stopper, that link the MFT to the PCB, being connected inside the MFT as on Pic.4.3-a. Besides them, there are also two noses located on the bottom side, that are to be

soldered and connected with the device ground. Japanese MFT's have the capacitor C placed in the cavity of the plastic stopper, as shown on Pic.4.3-c. The part of the core that can be moved with the screwdriver can be seen through the eye on the top side of the housing, Pic.4.3-d. This part is coloured in order to distinguish the MFT's between themselves, since there are usually at least 3 of them in an AM receiver. The colours are white, yellow and black (the coil of the local oscillator is also being placed in such housing, but is being painted in red, to distinguish it from the MFT).
Un-soldering the MFT isn't that simple and is to be performed very carefully. The iron is not to be kept leaned too long on the pins, since there's danger of melting the plastic stopper. All the tin from the pins and noses has to be removed first, by the aid of the iron and the vacuum pump (or a piece of wire stripped from the antenna coaxial cable). You can then safely remove the MFT from its original PCB.

* Pics.4.3-a, b, c & d almost fully apply for the oscillator coil as well (LO). The only difference is that LO doesn't have the capacitor C. looking from the outside, LO and MFT can be distinguished only by the marking colour, until they're lifted from the PCB.



Pic. 4.3. Components of the receiver from pic.4.2: a,b,c,d-IFT and LO; e,f-variable and trimmer capacitors of the local oscillator, g,h-SW oscillator coil; i-independent input circuit

LO's have red colour, while MFT's (IFT’s) are white, black or yellow. During the PCB design, absolute care must be taken that pins 1 & 4, as well as 2 & 3, do not permute. If that would happen, the feedback would be negative (instead of positive) and the oscillator wouldn't function. However, if you conclude during the design phase that it would be more convenient to connect pin 4 to Gnd (instead of pin 1), do have in mind that it can be done only if you connect also pin 2 to Gnd (instead of pin 3).

* Fine tuning (if necessary) of the LO's and MFT's inductance values is done by adjusting the position of the ferrite core with screwdriver.

* With CO and CtO, variable capacitor and the trimmer capacitor in the oscillator are labelled. Acc. to Pic.4.3-e & f, which shows the capacitor we spoke about in the connection with Pic.3.7, the abovementioned capacitors are connected with the circuitry over the legs O and G (Ca and Cta are not used), with G connected to Gnd.

* The receiver from Pic.4.2 can be utilized for the reception of AM stations in the SW waveband. All there is to be done is to make a new oscillator coil, acc. to Pic.4.3-g & h. It is being made of 0.4 mm CuL wire (a thicker one can also be used), on the 32 mm diam. carton body, the same one used for making coils on Pics.3.6 & 3.28. Number of quirks on the picture is 9, but other combinations should also be tried, say, 12 quirks, or somewhat less than 9. The feedback coil has 3 quirks and is spooled along the oscillator coil (as shown on picture), or over it. If you have already accomplished the reception of SW stations with some of the previously described TRF devices, you will be surprised with much bigger selectivity of the receiver from Pic.4.2. in the evening hours you'll be able to perform the receipt of huge number of stations on the radio-broadcast, professional and amateur wavebands.
For the reception of SW stations smaller capacitances for C1 should also be tested, say, C1=33 pF and similar, since it affects the oscillator frequency.

* In the previous numerical example we saw that tuning is done by setting up the frequency of the local oscillator and that fm=455 kHz, Radio Nis will be heard when the oscillator frequency is fO=1166 kHz. The story is not over, though: What will happen if there is a station that operates on 1621 kHz? Mixing its signal with the voltage from the local oscillator the modified signal is made, its frequency being
1621 kHz-1166 kHz=455 kHz.
We now have two signals on the MFT. They both have the same carrier frequency (455 kHz), one of them is program of Radio Nis, and the other comprehends the program of the station transmitting on 1621 kHz. Both of them are being heard in the loudspeaker, the interference occurs. Speaking in expert language, the obstruction because of the symmetrical station occurred. That is a station whose frequency fSS iz greater than fm for the value of the oscillator frequency:
fSS=fO+fm
Suppressing the symmetrical station signal must be done before the mixing stage. In the radio-broadcast receivers this is being done over the input circuit, and in the professional devices, by input circuitry and the HF amplifier. If you have experienced disturbances while using the receiver from Pic.4.2 (mixing of stations or, more common, whistling or squeaking tone) try changing the MFT's oscillation frequency (by turning the ferrite coil), then re-tune the receiver.

* If the receiver from Pic.4.2 is power-supplied from the battery (or adaptor) whose voltage is over 6 V, a voltage stabilizer should be inserted in the plus (+) line of the power supply for NE612, as it was done with the receivers on Pics. 4.4, 5.7 and 5.9.
If you cannot receive the signal of some station transmitting on 1500 kHz, not even with the capacitor CO knob in the rightmost position, start reducing the CtO capacitance (turning the trimmer with screwdriver) until you hear the signal. similarly, if you can't hear some station you're fond of, that transmits on 500 kHz (e.g. Radio Budapest), try increasing the LO inductance (by turning the core towards inside with screwdriver). If this doesn't succeed, change a little the MFT frequency, then try again.

* The reception can be significantly improved if input circuit (UK) is added to the receiver. In order to avoid problems with attuning the UK and the LO, the UK with special variable capacitor can be used, as on Pic.4.3-i. It is "our" capacitor from Pic.3.7, with all the capacitors connected in parallel, and "our" coil from Pic.3.6. Station tuning is now being done with two buttons, which isn't "a job for everyone". The receiver is first roughly tuned to the station using these two buttons, and then the optimum reception is carefully searched.

* If you omit the amplifier with 386 IC on the Pic.4.2, and connect high-resistance headphones instead of R1, it is the truly the simplest superheterodyne receiver in the world.

Chapter V Appendix

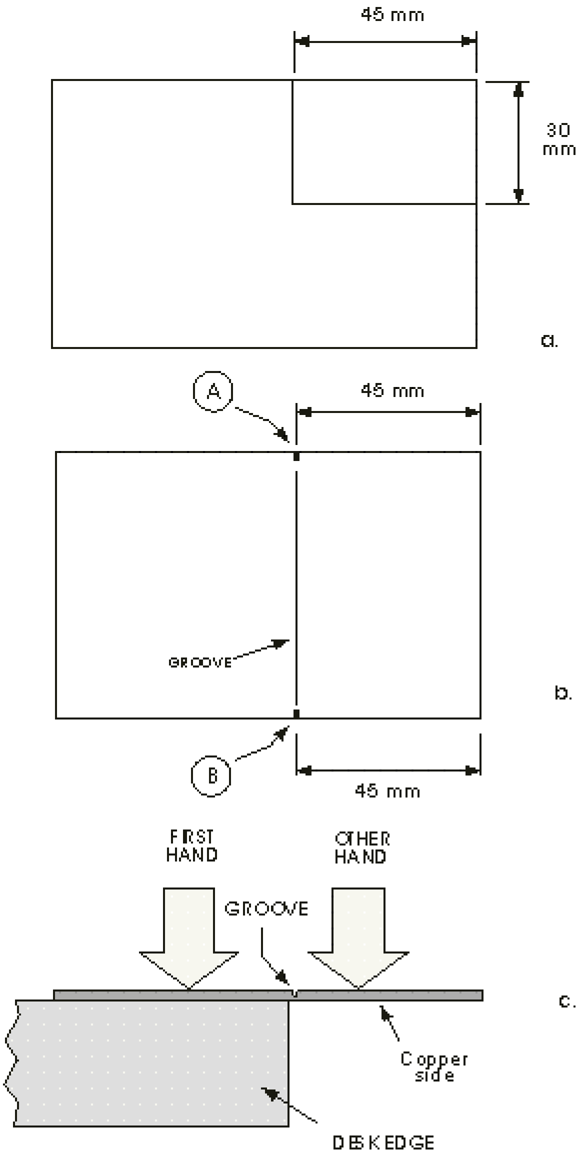
5.1. Making PCB’s

Design and manufacturing of the PCB’s has been explained in detail in the second issue of P.E. Here, we’ll consider how to make a PCB whose drawing is already done. As an example, we’ll take a drawing of the board of the receiver from pic.3.19, which measures 45 mm x 30 mm.

a. The PCB is being made of pertinax or vitroplast, i.e. a thin plate (about 1.5 mm) made of isolation material, which has a lean layer of copper put on one side. From the plate you buy in some electronic components’ shop, a 45 mm x 30 mm piece should be cut. In amateur conditions, this means refracting. First, points A and B are marked on the non-copper side of the plate, acc. to pic.5.1-b. A ruler is placed over them and a groove is made by pressing with a screwdriver or a bodkin along it. Its depth should be about 0.5 mm (on picture it is shown in dashed line). When this is done, the plate is placed on the edge of the table, with copper facing downwards. With one hand the plate is pressed firmly to the table, and with the other, the piece that has to be refracted. And - it cracks just along the groove.

On the refracted piece, a new groove, measuring 30 mm from the edge, is made, and the procedure is repeated. In this way we finally have our 45 mm x 30 mm plate.

b. All of the copper has to be clean and shiny, since only in this case the etching and, later, soldering is performed quick and easy and well. If it seems to you that the copper you have just bought is clean enough, you’re probably wrong. The plate must have spent some time in the shop, and the copper surface is certainly more-less corroded. The cleaning is most efficiently done with some abrasive powder (VIM or similar) which is otherwise used for cleaning of the cookers, bathrooms etc, but also the sodium bicarbonate, laundry detergent and even plain salt can well serve the purpose. Take a piece of cloth, wipe it with water, extract the water well and muss it to be ball-shaped. Dip it then in the powder, and scrub the copper until it “shines like the shiny sun”. After that rinse the plate,



Pic.5.1. "Cutting" of the plate: a-pertinax plate, b-marking, c-cracking

and pay attention not to touch the copper with your fingers, since that will make it dirty again.
c. Put the plate, facing the copper up, beneath the sheet that contains the PCB layout, right under this drawing. In our example, that would be the one on the pic.5.2-a. With the pike of a bodkin the holes are made through the centers of all the contacts, and in the centers of two bigger holes that are placed sidewise, taking care not to move the plate. The bodkin has to be pressed firmly, in order to obtain good prods on the copper. When this is finished, the plate should look as on pic.5.2-b. i.e. it has to contain as much prods as there are contacts, plus

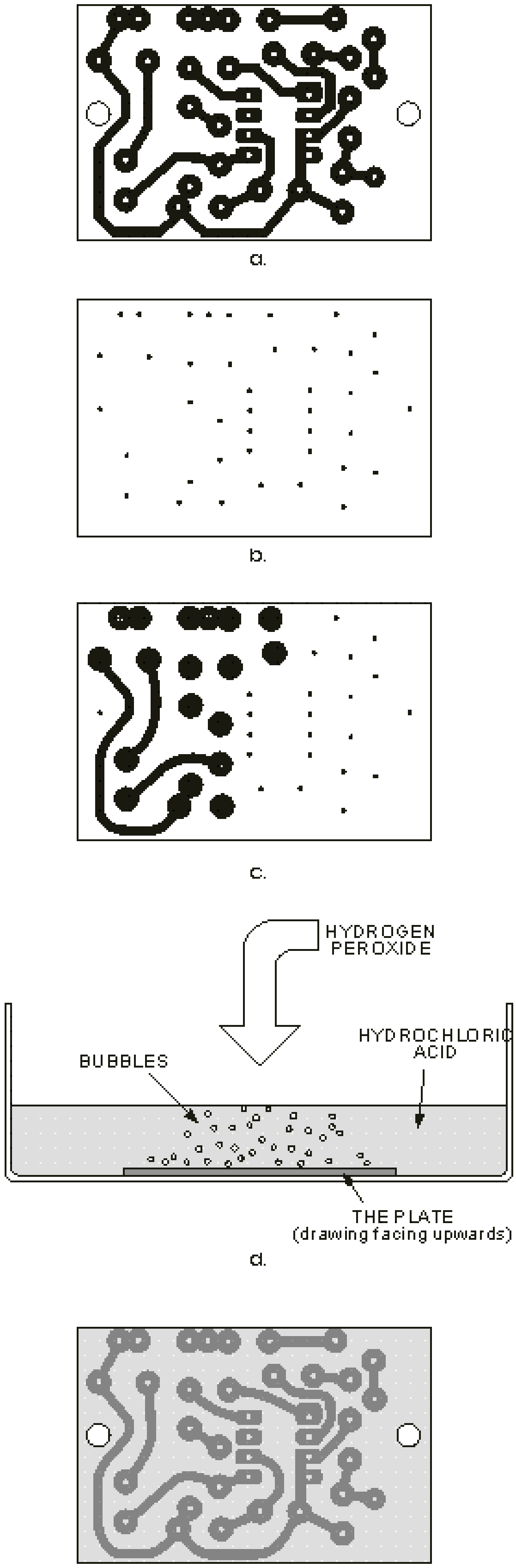
two. If the drawing contains many contacts, the plate can be easily dislocated, and the procedure is to be done all over again. It is better practice then to make a copy of the picture, cut it out, and attach it to the plate with two pieces of scotch tape.

d. Drawing the contacts and lines on the plate is done with the acid-resistant marker paintstick. It can be recognized by its characteristic "alcohol smell", and is being sold in bookstores as a marker for "writing on glass". You can test it: write in the store (it will be later afterwards) something on the glass, piece of plastic and similar, wait for a couple of seconds, then try to wipe it out with your fingertip. If the paint remains - the marker is OK. Nevertheless, this test isn't 100% certain, it is much better to buy the marker in the electronic components store (you have to accent to the salesman that you need a marker for drawing lines on PCB's). With the tip of the marker draw a circle around every prod (except those two that are for bigger holes), measuring 2-3 mm in diameter. Move the marker slowly, in order to leave a thick layer of paint on the plate. Take care to leave a small copper isle around every hole. Then,

you should, carefully and slowly, draw all the lines, by looking at the pic.5.2-a. They do not need to have the same shape as on the picture, especially they don't have to be that "chamfered". Line thickness should be about 1 mm, but that either is not obligatory, they can be somewhat thinner or a lot thicker (where applicable). The important thing is not to connect the nearby lines or contacts during the drawing, i.e. not to make junctions that do not exist on the drawing. If that happens anyhow, remove the paint surplus with a razor or a small, sharp screwdriver. Pic.5.2-c shows the beginning of drawing, several contacts and 3 lines are drawn. The drawing is finished when you have a pic.5.2-a on the copper foil.

e. Next step is etching, i.e. removing the copper that is not covered with marker paint. For this purpose, a mixture of hydrochloric acid (HCl), hydrogen peroxide (H2O2) and water (H2O). Pure hydrochloric acid is not used, but its 35% solution, that is being sold as a household cleaning agent. Hydrogen peroxide is being sold in drug stores and cosmetic stores. It is being sold as 30% solution, or even more diluted, 8-12%.

Hydrochloric acid and hydrogen peroxide are very aggressive media, especially for the eyes and skin, therefore care should be exercised when working with them. It would be the best for you to work with them in the bathroom, or some other place close to the running water supply. If some of these liquids spills on your skin, metal tool or clothing, wash them down with water immediately.



Pic.5.2. Making a PCB: a-drawing, b-plate with bodkin prods, c-drawing contacts and lines, d-etching in the hydrochloric acid while adding the hydrogen peroxide, e-finished plate

The etching mixture is being made directly before the etching, and is CERTAINLY being disposed of, right after the process. The plate is put at the bottom of a plastic, glass or porcelain dish, with copper facing upwards, and the acid is poured, in quantity enough to fully cover the plate (pic.5.2-d). Hydrogen peroxide is then added, being poured from the container directly over the plate. The amount of peroxide depends on its concentration, as well as on the concentration of the acid. So, put some peroxide, raise a little left end of the dish, then the right one, to allow a liquids to mix, and observe the plate. The mixture is transparent, and if the copper starts changing the colour after a dozen seconds - the etching has begun. During this process, the bubbles are formed in the mixture, in the amount somewhat more than in a glass of mineral water. If too little bubbles are present, add some more peroxide. Be careful, however, not to exaggerate, since if you happen to have too much bubbles, the mixture is going to heat up and the marker paint can be destroyed. From time to time, you should raise one end of a plate with a pointed wooden or plastic stick, in order to remove the old liquid from its surface, and allow for fresh mixture to take its place. Etching is finished when there is no more uncovered copper on the plate. Raise one plate end with the stick, wait for the liquid to decant, take a plate with a laundry clip and wash it thoroughly in a jet of running water. You can then remove the paint by scrubbing, as previously described, with a wet cloth dipped in some powder. The copper contacts and lines will emerge on the plate.
f. If you were careful enough to leave a uncovered isle of copper in the centre of every contact, after etching this will be a small cavity, in the centre of the contact. Through these cavities, that will guide your drill, a 1 mm holes should be drilled (it is better if the holes are 0.8 mm in diameter, but such drills are harder to find, and a lot easier to break). Two holes for the fixing screws are usually about 3 mm in diameter. While drilling, a piece of thicker plywood or some flat hard-wood plank (beech, oak) should be put beneath the plate, and not a piece of polystyrene or something similar. Do not press the drill too hard, since the tool will be plucking tiny pieces of plastic on the other side of the plate.

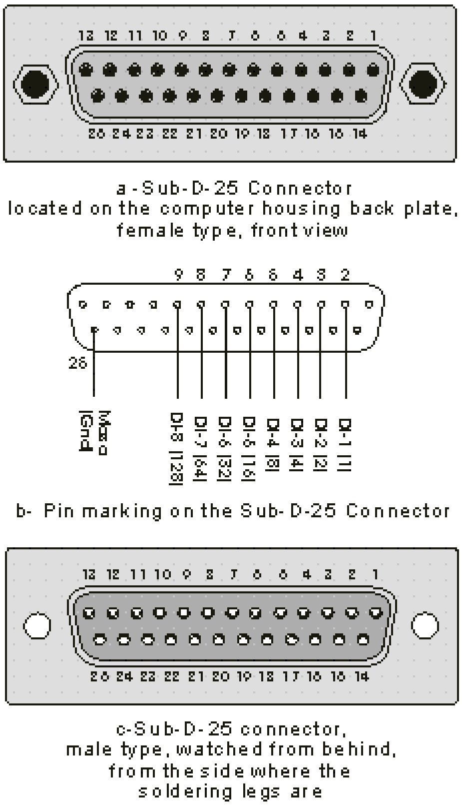
5.2. Computer-Aided Radio Receiver Control

In Book 7/8 of Practical ELECTRONICS methods for simple control of various electrical devices by computer were discussed. Practical realization of various interface circuits and sensors was described, by which the computer is being connected with the outside world, so that it can turn on/off the heater, light, fan, TV set or some other electrical device at the desired moment, based on data comprising temperature, light intensity, humidity etc. In this chapter we shall present, in short terms, one of the projects from the aforementioned book, that deals with simple computer-aided turning on/off of the radio receiver at the desired moment.
The radio is connected with the computer via parallel port, the one where the printer is also being plugged. It is a 25-pin female connector, called Sub D-25, which is given on Pic.5.3.
With appropriate programme, logical ones (voltage +3.6 V) and zeroes (0 V) can be sent to the outputs marked as DI-1, DI-2,...DI-8, that are located on the legs marked with numbers 2 to 9. Electrical devices that are being controlled are connected to these outputs over the interface circuit that is given on Pic.5.4. Two connected devices are shown on the picture, their maximum number is 8.
Pic.5.5-a shows the electronic diagram of an extremely simple interface circuit, which can serve to connect to computer the radio receiver, that can then be switched on or off at certain time, with adequate programme. The low-power transistor BC547 can be used for the consumers that use the current from the battery that is not greater than 100 mA. In case you have bigger power consumers, some stronger transistor or two transistors in Darlington junction can

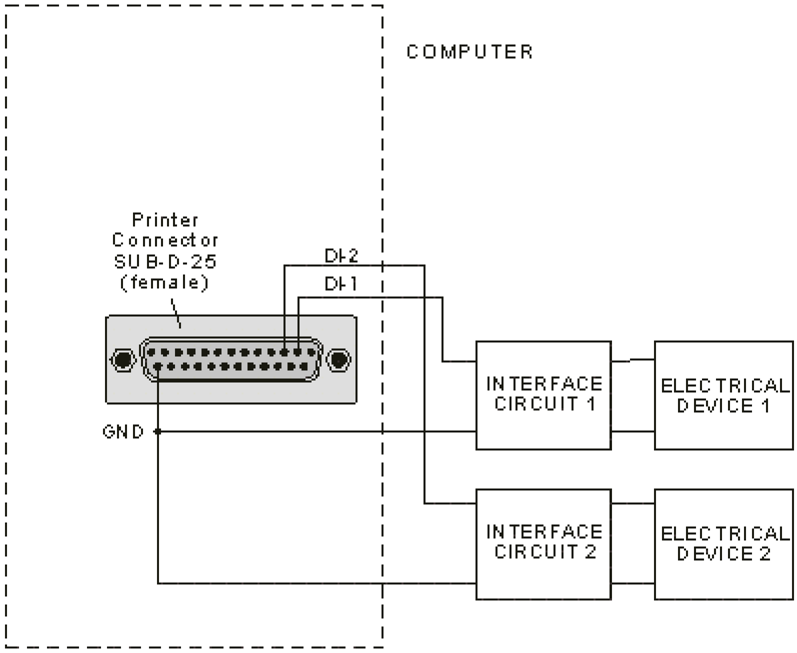
be used instead of BC547. The transistor bas is connected to the pin No.9 of the mail Sub D-25 connector over the R1 resistor, while the emitter and minus pole of the battery are connected to the pin No.25, i.e. to the computer ground. As long as there's a logical zero on the DI-8 output, the base voltage is zero and the transistor is locked and no current runs through it, therefore also through the consumer. When a logical one emerges on the DI-8, the transistor goes to the saturation regime, the voltage between collector and emitter becomes very small (practically zero) and the transistor behaves as if the collector and emitter are short-circuited. In that way almost the entire battery voltage is available on the receiver power supply input.

The PCB layout is shown on Pic.5.5-b: The component side is in the upper part, and the soldering side in lower part of the picture.

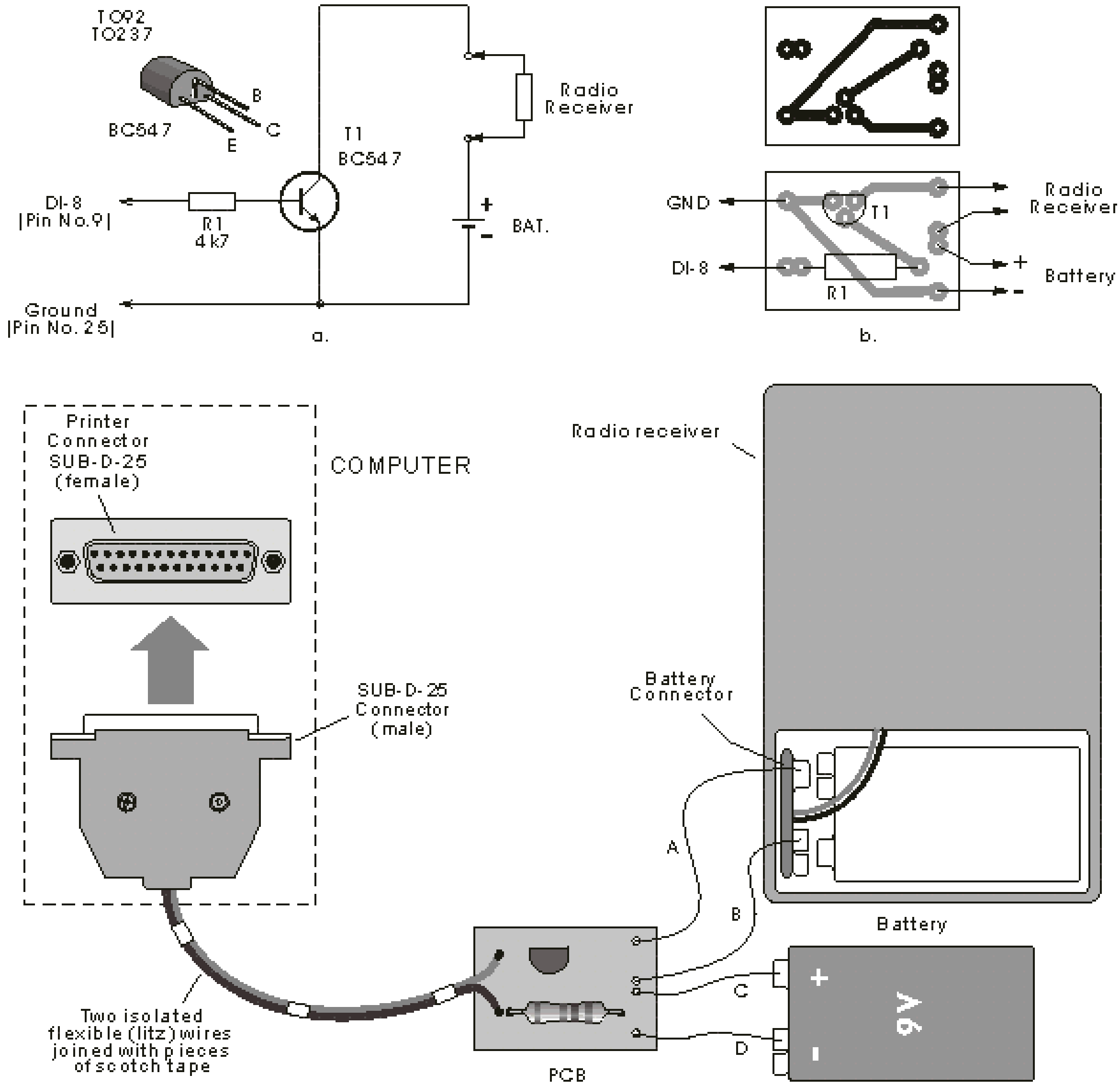
Pic.5.5-c shows how a small transistor radio receiver, powered by a 9 V battery, is connected to the parallel port, over the interface from pic.5.5-a. The plate is connected with clamps via the cables A and B, and with the battery over C and D.



Pic.5.3. Parallel Port



Pic.5.4. Connecting electrical devices onto the parallel port



Pic. 5. 5. Connecting the Radio Receiver to the Parallel Port: a-Ellectronic diagram of the Interface Circuit, b-PCB, c-Connecting the Computer, Interface Circuit, Receiver and the Battery