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**Radio frequency electromagnetic waves
Construction of a receiver and measuring the mobile phone radiation**

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Contents

Abstract

Radio frequency radiation is used to transfer many different kinds of data. In this paper it is described how this type of data exchange works and it is discussed if it is dangerous to humans. It is also explained, how a device can be constructed, which ”sniffs” for radio frequency radiation. The mobile phone radiation is measured with this ”sniffer” and analyzed.

Because of its length and plentitude of math formulas, this whole document (except for the appendix) was created with TEX. Please excuse the author for any formatting mistakes as this program is very complex. Thank you.

1 Introduction

At the same time as the big bang blasted away the vacuum in the universe, or more precisely, after the Planck-time of $5,3912110^{-43}$ seconds, there arose one important physical phenomenon: Radiation, in other words electromagnetic waves (EMWs), filled the no longer empty space. Radiation such as radio waves, visible light, X-Rays, and even dangerous gamma rays were emitted from all kinds of stars including our sun. Billions of years later humans discovered the existence of this appearance, pressed it into physical laws (James Maxwell), and began to generate it (Heinrich Hertz). In today's time EMWs play a very big role: Experiments are running with high energy lasers, cancer is treated with X-Rays, but the most important is the use of EMWs to transfer data, which is done in the radio spectrum. The following work attends to this subject, from the principals of radio waves and the dangers of this radiation up to the specific point of mobile phone networks. In the second part it is described how a radio-frequency "sniffer" can be constructed and how it is used.

2 Radio frequency electromagnetic waves

2.1 Basics

2.1.1 The electromagnetic spectrum

The phrase "electromagnetic waves" is the umbrella term for lots of different radiations. If asked not many people would know, that radio waves have the same character as light, or even micro waves, although these different radiations got a lot in common: They consist of photons traveling without the need for an "ether" at lightning speed, just at different wavelengths. Graphic 1 should give an overview of the electromagnetic spectrum. The EMWs discussed in this paper are ultra high frequency radio waves, whose frequency range from 300MHz to 3GHz. In the following this radio frequency radiation will be abbreviated with RF. The mobile phone frequencies of 0.9GHz, 1.9GHz, and 2.1GHz are the main focus. Optical radiation has a much higher frequency, about 480THz (infrared) to 750THz (ultraviolet). Radiation at even higher frequencies than light, can ionize matter (above 2.5PHz). Table 2 gives more specific information about the different kinds of radiation.

2.1.2 General characteristics of electromagnetic waves and fundamental formulas

EMWs travel at lightning speed ($2.99792458^{8}\frac{m}{s}$ in vacuum). Through **air** the speed is commonly assumed to be the same as c because of

$$c_{\text{air}} = \frac{c}{n_{\text{air}}} = \frac{c}{1.000292} = 2.99704944^{8}\frac{m}{s} \approx c, \tag{1}$$

whereas n_{air} is the refractive index of air.
The **frequency** f of an EMW with a given **wavelength** λ can be calculated:

$$f = \frac{c}{\lambda} \tag{2}$$

As the word "electromagnetic" already reveals, that the waves travel with alternating electric- and magnetic fields through space. The electric field is at right angle and in phase to the magnetic field (in the far field[1]) and these two fields are at right angle to the direction of motion (see drawing 3). Furthermore James Maxwell proved that the field forces can be converted into each other (source: [1], page 295):

$$E = B \cdot c \tag{3}$$

[1] In the near field the electric component is shifted by up to $\frac{\lambda}{4}$.

The **intensity** I (medial radiant power per area) of EMWs is expressed in the following term (source: [1], page 267):

$$I = \frac{P}{A} = \frac{1}{2\mu_0} \cdot E \cdot B = \frac{1}{2\mu_0} \cdot E \cdot \frac{E}{c} = \frac{1}{2\mu_0 c} \cdot E^2 \quad (4)$$

With this formula it is possible to calculate the received power of an antenna, which will be important in section 3.2.1.
The electric- and magnetic field of EMWs can generally be described as transversal sinusoidal waves or as interactions of sinusoidal waves (Fourier).
In quantum physics EMWs are a big chapter, because EMWs consist of quants called photons. The energy of one photon of an EMW with a specific frequency can be calculated (source: [1], page 380):

$$E = h \cdot f \quad (5)$$

h is Planck's constant with the value of $6.6261 \cdot 10^{-31} Js$. Photons only exist in a moving state and have theoretically no mass in position of rest. Moving photons have besides a **mass character** a **wave character** as they interfere (i. e. at a grid) because of coherence, they can be reflected, form fixed waves, and be polarized.

2.1.3 Generation of electromagnetic waves

In oscillating circuits electric charges in the capacitor take turns with the magnetic flux in the inductor. When the capacitor is charged, an electric field develops, then the capacitor discharges itself as the charge flows through the inductor; this electric flow causes a magnetic flux. The capacitor is charged the opposite way and a negative electric field develops. The electric charges ar pushed the opposite way through the inductor, which causes a negative magnetic flux. These alternating magnetic- and electric fields make up an electromagnetic wave. The process repeats itself until the entire energy in the circuit is converted into EMWs and transformed at the circuit‘s resistance. The simplest oscillating circuit (with the highest resonance frequency) is an antenna. The tips of the antenna act like a small capacitor and the whole pole as a small inductor (see graphic 4b). Drawing 3 shows the oscillating process of an antenna. As for the resonance frequency of an oscillating circuit applies the Thomson-formula ($f = \frac{1}{\sqrt{LC}}$), high frequencies (from some kHz up to the several GHz) can be generated with antennas. With a Meissner'sche regeneration, the unmuted oscillating circuit generates constantly EMWs. A transistor interconnects exactly at the time when the electric flow through the inductor is biggest and charges the capacitor completely again (see graphic 4a). The energy lost through the circuit's resistor and EMWs is replaced.

2.2 Sources of electromagnetic waves

The number of sources of EMWs is countless. Here are some examples to give a small overview.

2.2.1 Unused radiation

Radiation from outer space (stars, dark material, our sun) and radioactive elements is natural. Earth's magnetic field protects us from this mostly dangerous high-energy radiation. Otherwise it wouldn't be possible for life to develop on Earth, because some radiation from space is ionizing and damages the DNA irreparable. Only specific frequencies reach Earth's ground (see graphic 5). The penetrating radiation adds to the "electro smog" created by humans.
EMWs generated through power supply lines (50Hz), railroad current lines (16Hz), monitors, electro motors, etc. are byproducts of electronic devices, and - just as the natural radiation from space - not avoidable.

2.2.2 Used radiation

Data transmission Radiation of the radio and TV broadcast, mobile phone and W-LAN connections, police-, aircraft-, army-radio, and of many more devices serve the same purpose: data transmission. This becomes more and more important in our time. The amount of data transferred grows every day and most of it is delivered through EMWs. The cable network is used less and less, because our society demands more independence; the following example supports this: Stationary phones are obsolete and that's why more mobile phones than ever are sold: "Telecommunication devices were inquired most with mobile phones pushing the economic growth with a sales growth of 9,0% (within 6 months)" [2]. Same applies for television: Who receives TV programs via cable nowadays? Only the Internet is still mostly based on cable network, but: besides the commonly used DSL connection you can surf the net by availing yourself of the UMTS net. This is especially of importance for remote villages / houses, because a DSL connection isn't worthwhile there. Also more and more people use it to access to internet sites and their emails via mobile phone.

Radio Frequency Identification Electromagnetic data transmission isn't just used by radio, TV, and mobile phones; it faces us almost everywhere in everyday life. Not many think about Radio Frequency Identification (RFID) when going shopping for example. This is how it works: A small passive electronic chip (also called RFID-Transponder) is powered by mutual inductance coupling and sends back the information the chip carries. The "Reader" creates EMWs which cause electric currents in the antenna of the Transponder and gives commands to the chip at the same time. With the inducted electric currents, the transponder gets enough power to compile a response. The Reader converts the modulated response and gets data such as serial numbers, information about a product, a person, whatever is stored on the chip. The advantage: if such a transponder is not deactivated at the cash point, then the reader sounds the alarm. In future are further uses possible, such as automatic checkouts instead of cash points, electronic identification of people, etc.

Distribution and limits of the spectrum To prevent interference, the available frequencies are divided into different nets. This way the eventualities are used at full capacity. Interference makes it impossible to decode a signal. The only limit given to the masses of data transmitted is the electromagnetic spectrum. Firstly our environment limits the available frequencies as Earth's atmosphere absorbs most of the EMWs (graphic 5). The radio frequency (RF) spectrum, which isn't absorbed, is divided up very exactly and reserved for different users. The state lays down these wave bands and sells rights. I. e. companies payed more than 8 billion Euros each for the six UTMS wavelengths. Second there is a technologically limit. Nowadays it isn't possible to use high frequencies (i e. infrared) for data transmission, but experts predict that this barrier will be broken soon.

2.3 Electromagnetic pollution and its dangers

As described in chapter 2.2, electromagnetic pollution grows permanently and we can't avoid being exposed to it, as it's everywhere around. As it seems, nobody knows for sure what impacts EMWs have on human health. The opinions on that matter range from corrupt scenarios and different kinds of health risks to no effect of EMWs on humans at all. Despite an abundance of studies and opinions (there exist about 1,390,000 entries for "electro smog" in google) no unison answer exists for questions such as "Do EMWs alter our DNA and cause cancer?" or "Do EMWs influence our psyche and health?". Here are some examples for studies and incidents about EMWs that show how contradictory science can be. **Note: In this part the author doesn't want to take sides, this should be a neutral summary of selected studies.**

2.3.1 Study 1: Mind control

Jim Keith created big fear of EMWs with his book "Mind control World control". It says, that EMWs with certain frequencies can influence the minds of the people, and that governments already use this possibility to "guide" the nation. Low frequency waves of the railway (16Hz) are such a nominee for "mind altering": The intense low frequency EMWs induct currents in nerve cells of humans and our brain can't process these nerve signals. The result are many health problems, like depressions, damage of the human visual system, damage of the nerve system and intestinal tract, hearing problems, and much more.

2.3.2 Study 2: Heating

The author asked himself, how could it be that radiation of far less energy than light[2], harms humans? The answer Dr. Gleixner had for this, explained it that way: After 3.5 billion years of evolution, organic cells could cope with light waves (and still we get skin cancer from UV-light), but humans are not used to lower frequencies. The molecules of our body react completely different to this kind of radiation. A recent study proves that: Nerve cells and synapses in our brain pass on information by electrical charged atoms. "And these ions are made to vibrate by mobile phone radiation" [3]. These vibrations cause heating and the temperature rises to a maximum of 100 degree Celsius. This happens only in the synapses, a small part of the brain tissue, and through heat conductance the synapses are cooled down again. But nevertheless a localized and temporary high temperature is possible to occur. No wonder that the brain could suffer damage under theses circumstances. Markus Antonietti, director of the Max-Planck-Institute, urges therefore to avoid mobile phone radiation as much as possible.

2.3.3 Other health risks

Other studies try to show, that RF radiation is dangerous, as it causes cancer: "Someone telephoning for extremely long times, has apparently a slightly increased risk of getting Gilom-cancer" [4]. But experts agree that the study led by Anna Lahkola has to be approved by further studies before this is used as a "proof" that mobile phone radiation causes cancer. This and other studies are telling the exact effects of EMWs on health; but all differ from each other, which makes the subject dubious. In a letter to the editor in the Toelzer Kurier [5] there is no hint for Gilom-cancer, but it says that an permanent SAR[3] of more than

- $0.0001\frac{W}{kg}$ during sleep causes extreme stress.
- $0.001\frac{W}{kg}$ under normal circumstances causes tumorigenic cell proliferation.
- $0.1\frac{W}{kg}$ increases the tumor susceptibility in the head, and increases the risks of leukemia and lymphoma.

Someone living next to an mobile phone antenna (within 150 meters), is exposed to an SAR of about 0.0002 Watts per kilogram[4] constantly, which would mean great danger. But only a few people living next to an antenna complain about stress, sleeplessness, etc.

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[2] the energy of the maximum mobile phone frequency photon is about 0.00001eV and the average energy of a light photon is 2.48eV because of (5)

[3] specific absorbtion rate; more under 2.3.5

[4] see chapter 3.2.3

2.3.4 Contradictions

If someone moans about negative effects of an antenna on his / her health, then this is often an absolute psychological cause, as the "placebo-effect" shows: Several times it occurred, that an antenna was installed and people filed for injunctive relieve because they suffered headaches, sleeplessness, and sickness. But just a red light was glowing on top of the antenna, the rest of it was not operating yet. Some studies can't show the connection between radiation and cancer either. Once more than 100,000 people were observed for years, and it was found out that people who use mobile phones very often have a *lower* risk of getting cancer than others. Why? Probably because educated people have better jobs, where they need mobile phones quite a lot, but educated people usually live more healthy at the same time, which reduces the risk of getting cancer.

2.3.5 How to prevent exposure to electro smog

Let's presume that EMWs are really dangerous. How should we behave? Josef Kutt, a local scientist from Bad Heilbrunn, specialized on detecting interference maximums of cosmic- and terrestrial radiation. Sleeping or working at a interference maximum causes according to him concentration problems, blood pressure perturbation, nervousness, allergies and headaches, and he recommends to shield the radiation with "reflecting materials such as shielding wallpaper andd -paint" [6]. This way the electromagnetic pollution can be reduced at one's home, but the shielding materials arise a problem at the same time: If a radiating device (mobile phone, stationary phone, W-LAN router, etc.) is used within this shielding, then the devices radiate even more because they try desperately to set up a connection through the shielding material and adjust up the radiation. Under chapter 3.2 there will be discussed, what really helps reducing mobile phone radiation and what not. Everybody should follow these guidelines in order to protect himself from *possible* health risks. Limiting intensity values defined by the WHO are supposed to minimize possible health risks: The SAR (specific absorbtion rate) shouldn't exceed 2.0 Watts per kilogram. That means that one kilogram of your body should not absorb more than 2.0 Watts of energy while using a electronic device. In other words: Accepted that a head is filled with water (thermal capacity $c = 4.19\frac{kJ}{kgK}$), then one cubic centimeter (1g) should not be heated up more than 0.03 degrees Celsius per minute (heat conductance not considered). The calculation:

$$SAR = c_w \cdot \frac{\Delta T}{\Delta t} \Rightarrow \Delta T = \frac{SAR \cdot \Delta t}{c_w} = \frac{2.0\frac{J}{kg\ s} \cdot 60s}{4.19\frac{kJ}{kgK}} = 0.0287°C \tag{6}$$

Usually mobile phones have SARs of 0.1 to 1.6 Watts per kilogram, which is below the limit. A SAR of less than 0.6 is recommended by the Bundesamt fuer Strahlung [4].

2.4 Basics of the cellular phone network

2.4.1 How a radio cell works

The average European talks about 14 minutes per day on a phone, and 9.3 minutes of this time on the mobile device [7]. Assumed that 90% of all calls are made in the traffic hours from 7 o'clock to 22 o'clock, then about 770 thousand (!) people in Germany talk on a mobile phone at same time[5]. A call of one person will be observed in the following. Graphic 6 visualizes the explanation. The caller dials a number on the mobile phone. It sends a short signal in form of RF (radio frequency) EMWs carrying the dialed number which is received from a Base Transceiver Station (BTS). The received signal at the BTS is relayed to the Mobile Switching Center (MSC), either through a telephone cable,

[5]calculation: $0.9 \cdot \frac{82{,}310{,}000people}{\frac{15 \cdot 60minutes}{9.3minutes}} \approx 0.77 \cdot 10^6 people$

or with a beam antenna. This way radiation is reduced as much as possible. The MSC connects the call with the recipient. At the MSC this RF signal is either converted into low frequency impulses again, if the recipient uses a land line connection. If the recipient uses a mobile phone, the Home Location Register (HLR) checks where the recipient's mobile phone was registered for the last time. If the mobile phone is in the same radio cell, then the RF signal is amplified at the BST and sent in all directions; the recipient's mobile phone antenna picks up the signal. If the recipient's mobile phone is located in another cell, then the signal is forwarded to the BTS of this cell (usually via cable) and sent in all directions there. This is how the HLR knows where each mobile phone is located: When a mobile phone is turned on, it sends a signal to the next BTS, and the HLR registerers the phone in this radio cell. About every hour the mobile phone sends a short signal to the BTS in order to tell the HLR if it changed the radio cell. That means, that a standby mobile phone doesn't radiate all the time, just about one second every hour, if it is not used for making a call or being called.[6]

2.4.2 The different mobile phone networks

There are three different types of EMW frequencies used for mobile phones: The D-net (890-960 MHz), the E-net (1760-1875 MHz), and the UMTS net with 1920-2170 MHz. The D- and E-net replaced their forerunners (A, B, and C net) and work almost the same: The frequency is divided in 8 time slots, so that 8 people can use one antenna at the same time. Each time slot is about 577μs long, which means, that a BTS receives from and emits to **one** mobile phone every 0.46ms a data packet of about 500,000 electrical impulses[7]. Each time slot repeats itself 217 times a second. To prevent interference between the EMWs from the mobile phone and the BTS, the mobile phones send in the uplink-band, which is 890-915MHz for the D-net and 1725-1780MHz for the E-net; and the BTSs send in the downlink-band, which is 935-960MHz for the D-net and 1820-1875MHz for the E-net [9]. There exist 125 frequencies with a 200kHz band with for the D-net and 275 for the E-net. Different companies bought these frequencies; i.e. E-plus and O_2 have 112 each, T-mobile and Vodavone have 25 each within the E-net. With 8 time slots it would seem possible that almost 900 people could use the O_2 net in one cell at a time. But this isn't the case: In order to prevent interference between neighboring cells, the BTSs of the D- and E-net have to send on different frequencies. Thus only about 2% of all viable frequencies can be used in one cell. As now only less than 50 different mobile phones can use one BTS at the same frequency, the cells are smaller in more populated areas than in sparsely populated ones. This means that in towns a cell might be only a few hundred meters big in diameter and the radiation of the station and mobile phones is much less there, compared to the country where a cell is some kilometers in diameter and where the station and the mobile phone work with high intensities in order to build up a connection. To arise the maximum number of viable calls, up to three sector antennas can be installed at one BTS. These sector antennas radiate only in a $120°$ section of one cell.

10.5 million of all mobile phone connections in Germany use the Universal Mobile Telecommunications System (UMTS). The UMTS-net uses instead of 8 time slots 15 ones which are 0.67ms long each, which makes a repeating frequency of 100Hz [10]. Interference between neighboring UMTS cells isn't avoided by using different frequency band withs, but through coding the signals with a "cell ID". Hence each of the 6 UMTS providers can divide his whole 10MHz bandwidth into 3550 frequency bands with a range of 200kHz to transfer data in all cells; which increases the transfer rate by 200 times compared to the D- and E-net. To prevent interference of signals sent at similar frequencies within the 10MHz bandwidth, the signals are combined before being sent; this process is called "Multi-

[6] This section is based on information from [8].

[7] for the 900MHz D-net; for the E-net there are even about 1 million electrical impulses sent in one time slot

plexing”. As the UMTS uses more time slots and can send on different frequencies within the 10MHz bandwidth, it is possible, that several 100 calls can be made within one cell. It is also possible to transfer big amounts of data; i.e. pictures, e-mails, etc. This system is also assisted by satellites, which means that there are no ”dead spots”, even in remote areas.

2.4.3 Modulation

The data (telephone number, speech, SMS, etc.) is transmitted from the mobile phone to the BST like this: The low frequency signals (i. e. sounds: 20 to 16000Hz) are converted into high frequency EMWs. The electric sound-signals created with a microphone are modulated with a high frequency carrier wave into high frequency electric signals (how it works can be seen in graph 7). The modulated sound wave is afterwards commutated in addition so that a ground can be defined. Why are the signals transferred into high frequency and then low frequency again? It would have several disadvantages to transfer low frequency EMWs which comply with the sound-frequencies:

Amount of data First, the amount of data which can be transferred would be very small. It's impossible to divide a low frequency carrier wave into time slots, so only one person can use it at a time. It would also be impossible to divide an area into radio cells because a 200kHz band with can't be maintained.

Antenna length Second, the antenna would have a length way beyond any convenient size: the shortest antenna is a $\frac{\lambda}{2}$ dipole which makes at a frequency of 1000Hz (corresponding to a high c of the gamut) a length of $\frac{c}{2f} = 150km$.

Antenna coefficient And third, the coefficient of the radiating power / antenna power would be very poor. The power which antenna needs can be calculated: A charge Q flows through the antenna with the frequency f. The charge has to be moved with a angular rate of

$$\omega = 2\pi f \tag{7}$$

and as it charges the tip of the antenna one time positive and one time negative, is

$$\Delta Q = 2Q. \tag{8}$$

Because the current is defined as a charge moving per time through the antenna, follows from (7) and (8):

$$I = \frac{\Delta Q}{\Delta t} = 2Q \cdot 2\pi f. \tag{9}$$

Furthermore it can be said that the voltage between the tip of the antenna and ground is:

$$U = \frac{2Q}{4\pi\epsilon_0 h}. \tag{10}$$

This follows from the Coulumb-law; h is the height of the antenna above ground. The electric power is defined as voltage times current, so it follows from (9) and (10):

$$P_a = I \cdot U = \frac{2Q \cdot 2\pi f \cdot 2Q}{4\pi\epsilon_0 h} = \frac{2Q^2 c}{\epsilon_0 \cdot h \cdot \lambda}. \tag{11}$$

A more complicated calculation results in the energy transmitted by an antenna (source: [11], page 432):

$$P_t = \frac{1}{2} \cdot \frac{Q^2 h^2 \omega^4}{\pi\epsilon_0 c^3} = \frac{1}{2} \cdot Q^2 h^2 \cdot \frac{\pi^3 c}{\lambda^4 \epsilon_0}. \tag{12}$$

The radiating coefficient of the antenna is the fraction of (11) and (12):

$$\eta = \frac{P_t}{P_a} = \frac{h^3\pi^3}{4\lambda^3} \approx \frac{8h^3}{\lambda^3}. \tag{13}$$

This formula applies for $h < \frac{\lambda}{2}$; for $h \geq \frac{\lambda}{2}$ the coefficient is 1. Hence the height of the antenna should be preferably high and the wavelength preferably small in order to get a high coefficient. An antenna 10m above ground would have a coefficient of 3.0^{-13} for 1000Hz and 1.0 for all radiations above 37kHz. To cover an area of several kilometers, an antenna for 1000Hz at an height of 10m would summon 67 Tera Watts; for a carrier wave above 37kHz only 20 Watts.

2.4.4 Signal reception

Sight contact is not needed for a working connection, because RF EMWs are reflected and at many objects (even hills and mountains), and can penetrate many materials. To reduce radiation, the following two things are done: First, each mobile phone has a chip in it (similar to or the same as the MAX4000EUA described later) which regulates the transmitting power. The chip detects the intensity of the electromagnetic waves received from the BTS and measures that way, how strong the mobile phone has to create its signals so that they can be received from the BTS. At low radio reception (in remote areas, far away from a BTS, in shielded rooms such as cars, buildings, cellars, ...) the transmitting power is regulated up to a thousand times more than at high radio reception. The range of the emitted signals is limited to about 30 kilometers. The maximum transmitting power of mobile phones is limited to 0.125 Watt for the UMTS net and 2 Watts for the D- and E net, and this power decreases with increasing distance:

$$P \sim \frac{1}{r^6} \text{ because of } P \sim I \sim E^2 \sim r^{(-3)^2}$$

This follows from (4) and the Coulomb Law of antennas ($E = \frac{Q}{4\pi\epsilon_0 r^3}$). The second point is arranging antenna stations throughout the country in a comb shaped formation with a radius of only 10km or less. That way at almost every position it is possible to get radio reception with a mobile phone, and the mobile phones and BTSs can operate with low power levels (which means less electromagnetic pollution). More antenna stations (even though they are frowned upon so much), reduce the overall electromagnetic radiation.

3 Projects

3.1 Construction of a RF sniffer

3.1.1 Objective target

As the name already tells, a RF sniffer detects radio frequency EMWs, while ”sniffer” indicates high sensitiveness and accuracy. And this is true: RF EMWs could be detected with much simpler circuits, like an antenna connected parallel to a RF diode, but the diode can't trace weak sources at high frequencies, as the sniffer can. With the RF sniffer it is possible to see, what causes little electromagnetic smog and what the most, and how exposure to EMWs can be reduced. There are uncountable offers in stores and internet shops for devices just fulfilling the same job, with the following difference: these so called ”spectrum analyzers”, ”RF meters”, or ”electro smog detectors” might be calibrated, but despite the big assortment, the author was not able to find a device for less than 100 Euros; upper price limit several 1000 Euros. This self-made RF sniffer is at least as sensible and accurate as most offered devices of its kind. Besides some semiconductors, the inner circuits, the potentiometers and

the speaker, no components needed to be purchased, as they were already viable. The cost for the purchased parts was not more than 25 Euros total. Table 9 shows what components are needed.
The task: construct a RF sniffer with the following features:

- output of the intensity of the radiation
- output of the kind (frequency) of the radiation
- a BNC connection so that different kinds of antennas can be tested
- an output channel for an oscilloscope or a sound card in order to be able to analyze the characters of mobile phone radiation
- a low battery display
- handy size
- low cost
- sensitivity regulation

The following is a report of how this task was handled by someone without big electrical experience, but some creativity. It can also be used as a instruction if the reader wants to reproduce the device.

3.1.2 The circuit

First the circuit has to be mapped; therefore it is useful to create a circuit diagram. After some research the author found a freeware program called BSch [12] with which circuit diagrams can be constructed on the computer. As a basis for the circuit diagram, the RF sniffer circuit from AATiS [13] seemed to be a good choice. This circuit intensifies EMWs of 0.1 to 2.5GHz and has three different outputs; the first for intensity measurement, the second for an oscilloscope or a sound card, and the third for a speaker. With the speaker a pulsed signal can be detected, and that way conclusions can be drawn about the radiation. The D- and E-net work with pulsed signals of 217Hz (see 2.4.4), so a deep crackling can be heard in the speaker. The UMTS-net has pulsed signals at 100Hz, which means that the sound should be even deeper. An Base Transceiver Station can be detected as the noise is then high-pitched: A station interrupts its transmission for only some μs between the 8 time slots. As there are 8 (15) time slots repeating themselves 217 times a second each, the "interruption frequency" is 1736Hz, which can be heard in the speaker. This way antenna stations can be found, and maybe the different nets can be distinguished. As this output is quite important, it is found in the final circuit plan, too. The second output is also adopted as there might be a chance for wanting to measure i. e. the frequency of pulsed signals with an oscilloscope or a sound card. A driver for a sound card with a voltage-frequency converter was created, but not used for measurements yet. In order to keep this text short, the explanation of how this driver is designed is left out.

Changing the display and sensitivity The third output, which is for the intensity measurement, was changed though. It is designed for a needle display, but that's inaccurate because of the needle's inertia, especially when the output voltage differs rapidly. A second disadvantage is its big size and a third the cost. A LED display would do much better. Therefore a LED-driver is needed which activates a specific number of LEDs at a specific input voltage. Such a driver is used in the SMD-version of AATiS, but no circuit diagram gives a clue about how it works. After long research a driver was found, the LM3914. Applied as described in the data sheet it displays an input voltage on 10 LEDs (more under LM3914). As this driver has - by contrast to a needle display - an infinite intern resistance, it makes no sense to use the potentiometer POT2 in series to the inner circuit (IC) LM3914 (as it is done in the AATiS circuit). Another problem: The potentiometer in the intensity output line varies only the intensity output, but not the speaker- and oscilloscope output. Solution: The potentiometer is left out in this place and built in at the amplifier LM324 (pin 1 to 2). The signal can be amplified by the factor of 3.13 to 4.17 depending on the adjustment at the potentiometer (more under LM324). Now the sensitivity of the device can be regulated.

Other changes Instead of the constant voltage source (UA78L05, IC4 in the AATiS circuit), another one, the LP2951C was used. This IC has - besides the constant voltage output - a pin to output an error, which is perfect to drive a low battery display (more under LP2951CN). Another modification made to the circuit is the antenna switch. With this switch it can be chosen between the BNC female connection and an external antenna. With a switch someone can choose between the antenna attached to the box (7.1cm long, best for detecting UMTS radiation of 2.1GHz) and the BNC connector to which all kinds of antennas with a male BNC connection can be mounted.

Result: a new circuit diagram The circuit diagram showed in graphic 8 is the achievement of all these changes. For better overview the ”supply line” of 5.20 volts is marked red and the ”ground line” of 0 volts is marked blue. Three tags show measured voltage values which can be used to check reproduced devices. The green line indicates the antenna connected to the BNC female connection.

3.1.3 The electronic parts

The next step is ordering all electric pieces needed. All components are listed in table 9. The core piece of the circuit is the IC MAX4000EUA which intensifies high frequency signals. Similar ICs such as the MAX4001/2/3, MAX2015 and AD8316 work exactly the same way, they just differ a little in the input range. It was not possible to order any of these parts at Buerklin, Conrad Electronics, Schubert, or any other big electronic company. Asking for offers for one of the ICs on an internet site was a little more successful: Dozens of mails congested the author’s email account, most of them from China. Unluckily the shipping- and bank transfer costs were resoundingly high. Contacting the manufacturer of the IC (Maxim) wasn’t successful either. Finally it was possible to purchase the needed part at AATiS. And the journal ”elektor” was so friendly to send an AD8316 for free (which wasn’t needed in the end), after the author asked for help. The other electrical parts are not much of a problem to get, but there are some things to care about:

- It is very expensive and laborious to etch a circuit board for this single device. An experiment board with conductive paths and a hole-grid of 2.54mm can be used as well, and is much cheaper.
- In this work, SMD (Surface Mounted Device) resistors and -capacitors are used. After practicing with two or three SMD parts it’s not that difficult anymore to solder them, but many people prefer bigger parts. SMDs make the device a lot smaller, but someone who can’t cope with the small size should use normal resistors and capacitors.
- If possible the ICs should be ordered in a DIP size because then they can be simply plugged to the experiment board which makes it easy to solder. The TOP size is much bigger and hard to connect to the board, and the SOP size is even harder to solder because it is so small. Unluckily the MAX4000EUA is only viable in SOP size.

- Additionally the ICs shouldn't be soldered to the board directly, but to a IC socket. That way an IC can be exchanged easily if it doesn't work. The contact clip strip are designed to be soldered upside down onto the circuit board, but as the speaker is on the backside of the board, the clips had to be soldered onto the front side of the board. To make this possible, the single clips were cut out of the plastic strip and and etched to the board; then the IC was simply plugged onto them.
- It is very useful to purchase a resistor- and capacitor (SMD-)assortment. These parts are needed in every circuit and it's cheaper than ordering every single part. And these parts are easily lost because of their small size, so it's useful to have some in reserve.
- Diodes and electrolyte capacitors have different polarity connections. The anode (+) of LEDs is indicated by the slightly longer connection. The cathode (-) of a diode is marked with a black ring. Electrolyte capacitors have, just as diodes, a longer connection at the anode and the cathode is usually marked with a bar. BUT: the bar on a SMD capacitor marks the anode, not the cathode!

3.1.4 Creating the circuit on the board

Now the electronic parts have to be arranged in a preferable expedient way. For this, a printout of the experiment's board layout in a scale of about 10 : 1 is very helpful. It saves a lot of work later if this step is done properly. After several tries, the one showed in drawing 10 was chosen. With tweezers, a soldering gun, tin-solder, and some solder-forming flux, the SMD parts and ICs are connected to the experiment board. Tin-solder is very important to make the soldering iron more fluent. Especially the ICs are vulnerable to high temperatures, so the soldering temperature should not exceed more than 300 degrees Celsius and the soldering time not more than some seconds. For the SMDs the following technique is quite successful: the part is dipped in flux, then placed with tweezers on the board, pressed with a toothpick onto the board while soldered with the soldering gun. The IC MAX4000EUA is quite a problem, because its SOP package has 4 outlines on 1.95mm, which is very hard to solder. It makes it easier to attach the pins to small cables or thin conductors first, which are then connected to the experiment board. All ground connections are soldered to a wire at the back of the experiment board; this makes the circuit clearer. The potentiometers, switches, and diodes are connected to the board with wires, too. It is useful to use wires of different colors for different connections, or to mark them with some tape. Later on broken connections can be found more easily this way. It also helps to keep the overview of the complex circuit. Jumpers between two connections are created with thin conductors. A conductor is cut to the right length and bent, so that it fits in two holes of the board; then the edges are brushed with flux and it is soldered. With desoldering braid "solder blots" and wrong connections are removed.

It is important that the connection between the antenna to the MAX4000EUA doesn't absorb any EMWs, otherwise it would act as an antenna itself, which alters the length and adulterates the measurements. So the construction should be put in a high frequency safe box, or the wire should be shortened to a length of some millimeters. As it is impossible to shorten the connection to some millimeters with the switch in between, the board is put into an old band-aid box. The box (and some additional plastic foam) protects the circuit from mechanic shocks. In the end it turned out that the box doesn't absorb the EMWs, and even additional aluminum foil wrapped around the device or grounding the device didn't help. Dr. Roman Dengler couldn't find an answer for this problem either, according to him "there might be many reasons. It is very difficult to shield off RF waves." The author's explanation is, that the box is too small. The metal of the box acts like an antenna with a length of about 12cm and even grounding doesn't help in the RF spectrum as the inducted alternating currents can't flow fast enough from / onto the box. As an improvement the author suggests to use a more massive and bigger box. Small holes have to be drilled into the metal to fasten the potentiometers, switches, LEDs, and the BNC connector. Holes are also needed for the speaker. When everything is connected and fixed in the box, it is very important to check with a multi meter if

- all resistors have the right value
- all connections work properly
- the diodes, LEDs, and capacitors are poled the right way
- the battery is charged
- if there are any unwanted electric connections.

It's better to spent some time on doing this properly than destroying an IC or other parts because of a shorting plug (even though the maximum ratings of the units are quite high). The author found two mistakes this way: A diode was poled the wrong way and a bypass existed where it shouldn't. Only afterwards the device should be switched on for the first time. If it is not working, the voltage values circuit diagram can be checked and that way some mistakes in the mounting can be found. Dr. Roman Dengler from the university of Karlsruhe was so kind to provide some voltage values, and with them a last mistake in the circuit was found.

3.1.5 How the circuit works

Theoretically the RF sniffer functions if it is built according to the circuit plan, which was developed in the section above. In this section the author analyzes how the circuit works, why and if components are needed in their place, and most important, what resistor / capacitor value is used best. This is a preferably easy explanation of the important features of the ICs and potentiometers. Further information about the ICs (i. e. maximum ratings or other possible applications) are found in the data sheets [14]. For better understanding, use the equivalent circuits in graphic 11 while reading the following descriptions.[8]

- **IC1 MAX4000EUA** (logarithmic RF-detecting controller) **and transistor T1 BC549C**
  This IC, a 2.5GHz 45dB RF-detecting controller, can be found in many devices such as mobile phones. There it controls the power at which a mobile phone emits its signals (stronger signals are needed if the connection to the next antenna is poor). The mobile phone doesn't radiate much at good reception, and adjusts up its power by a factor of 1000 or more at bad reception. Generally this IC intensifies input signals of -58dBV to -13dBV (0.001V to 0.224V)[9] and a frequency of 0.1 to 2.5GHz. Simplified it works in this application as described in the following: An EMW causes a low electric current in the antenna. This current is matched to ground with a 56Ω external resistor and connected to pin 1 of the IC, where it is decoupled with an internal capacitor. An internal resistor connects the decoupled current (point A) with V+, the supply voltage. Point A (the decoupled current) is also connected to 4 amplifiers in a row. After the last amplifier, the rectified signal is connected to OUT (pin 7). This means, that at no input signal, the voltage at OUT will be V+ (as at the beginning of the amplifier row (point A) the voltage matches V+). At

[8] In the following sections the resistor values in Ohm are shortened with numbers: i. e. 10k means 10,000 Ohm and 4k7 means 4,700 Ohm.

[9] $U_x = U_0 \cdot 10^{\frac{Level\ in\ dBV}{20}}$ with U_0 being 1.0V

an input signal, the voltage at the antenna rises slightly above ground for a short time, despite the small resistor which connects the antenna to ground, because the current can't flow through it quick enough. The voltage at antenna side of the internal capacitor rises, which causes a voltage drop on the opposite side of the capacitor. Here again, the current can't flow through the resistor connected with V+ fast enough; it flow through the amplifier row instead. There the current and lower voltage are rectified and the voltage at OUT drops. The higher the input signal, the more the voltage drops at OUT. R2 reduces the OUT voltage and adapts it to the operating point of the NPN transistor T1. At no input signal the transistor interconnects which means that point B is leveled with ground. With increasing input signal the OUT voltage drops, which increases the "resistance" of T1. This means that the voltage at B rises. Point B is connected to SET of the IC, to close a control loop in the IC. The voltage at point B (and SET) is quite proportional to the logarithmic input signal ($\frac{V_{SET}}{V_{Input}} \approx \frac{0.25V}{1dB}$). This IC works quite constant even at different supply voltages and temperature variances. But the voltage at point B (SET) should be decoupled as the MAX4000EUA supports only low load currents ($< 10mA$). The three different outputs of the RF sniffer would need too high currents which adulterates the voltage at SET.
A capacitor at pin 4 could determine which input frequency is rectified most, but as this device measures radiation of the whole RF spectrum, it is left out. Pin 2 shuts down the IC if it is connected to ground, but as the IC should operate continuous in this device and no "standby-mode" is wished, it is connected to the supply voltage. The component needs a supply voltage at pin 8 of 2.7 to 5.5V compared to ground (pin 5). A capacitor of about 100nF should be placed close to pin 8 in series so that the supply voltage is smoothed. Pin 6 is not internally connected and commonly used to adhere the IC to the circuit board.

- **IC2 LM324** (operational amplifier)
This IC is a simple operational amplifier (OA). The special feature about it is that this single piece consists of four independent amplifiers (pins 1-3; 5-7; 8-10; 12-14). Pin 11 is connected to ground and makes up the power supply with the supply voltage at pin 4. To understand how it works, some facts about operational amplifiers in general: This component's function is to level the voltage at its negative input pin to the voltage at the positive input pin at any time. With two resistors the component can be used to amplify a voltage signal as shown in drawing 11; this application of the OP is named "electro meter amplifier" (also "non-inverting amplifier"). As the voltage at pin 2 is adjusted to the level of U_{in}, it can be said that the voltage at the resistor R5 is $U_5 = U_{in}$. The potentiometer POT1 connected in series with R5 to ground is disregarded, as it is insignificantly small. This means that at resistor R5 the voltage U_5 is accumulating and thus the current flowing through R5 can be calculated:
$$I_5 = \frac{U_{in}}{R_5} \tag{14}$$
This follows from the definition of the resistor. Through R6 flows the same current I_5, as in the ideal case no current should flow through the operational amplifier (in reality little currents flow through the OA, which is the reason for a slight difference in the theoretically calculated amplifying factor and the real measured factor). The voltage at resistor R6 mounts up to:
$$U_6 = R6 \cdot I_5 = U_{in} \cdot \frac{R6}{R5}. \tag{15}$$
U_{out} is the sum of U_5 and U_6 (Kirchhoff's voltage law):
$$U_{out} = U_5 + U_{in} \cdot \frac{R6}{R5} = U_{in} \cdot (1 + \frac{R6}{R5}). \tag{16}$$

In the RF sniffer circuit the pins 1-3 of the LM324 are used as described above. R6 is in this case a 147k resistor in series with a 47k potentiometer, so the total value of R6 can be varied between 147k and 194k. As for R5 a 47k resistor is used, the voltage at SET is amplified by a

- minimum factor of $(1 + \frac{147k}{47k}) = 3.13$
- and a maximum factor of $(1 + \frac{194k}{47k}) = 5.12$

Measurements show that U_{out} is 2.68 to 4.52 times as high as U_{in}. This is below the ideal value calculated above, probably because of leak currents in the OA and because of the 10M resistor R10, which connects the output signal to ground. This resistor is important though, because it allows the charge which is "pumped" by the LM324 into the wire to outflow. The other three OAs of the LM324 (pins 5-7; 8-10; 12-14) are used as impedance converters. The negative input is directly connected with the output pin, which means that the output voltage is always the same as the input voltage. The voltage isn't changed here, but the application of the OA as a impedance converter is important, in order to decouple the circuit (the importance of decoupling is described under the section "IC1 MAX4000EUA").

- **IC3 LP2951C** (constant voltage supply)
The IC MAX4000EUA has to be driven with an input voltage of 3.0V to 5.5V and the battery voltage of 9V has to be set down on this level. The goal is to supply a constant voltage of about 5 volts, so that the MAX4000EUA isn't damaged because of too high voltages and that the other ICs (LM324, LM3914CN, and LM386) still work. The constant voltage reference (U_{ref}) of 1.235 volts between pin 7 and ground of this IC makes it possible to create almost any output voltage. If pin 7 is connected to ground with a resistor (in this case R15), then the voltage at the resistor is always 1.235V. As no current should flow through the IC in the ideal case, the same current flowing through R15 flows through R14. The voltage at resistor R14 is then:

$$U_{14} = I_{15} \cdot R_1 4 = \frac{U_{ref} \cdot R14}{R15} \tag{17}$$

This is a simple series connection. That makes a total voltage of

$$(U_{15} + U_{14}) = U_{ref} + U_{ref} \cdot \frac{R14}{R15} = (1 + \frac{15k}{4k7}) \cdot 1.235V \approx 3.94V \tag{18}$$

at pin 1, which is the supply voltage for IC1, IC2, and IC4. The measured value is 5.20V, which is above the calculated value. U_{ref} is really 1.23V and the resistors differ less than 5% from the given value, so the variance has to be caused by something else. A possible explanation is that a small leak current between the voltage reference (pin 4 and 7) adds to the current through R14, which increases the voltage at R14.
This IC has another feature, the ERROR flag output which indicates a dropping output voltage, the result of weak batteries. A drop of more than 5% of the output voltage (registered via a dropout in the reference voltage) activates pin 5, which generates a voltage of 5V above ground (given that the input voltage is still higher than 5 volts - which is the case with a weak 9V battery). As this output is not designed for any load current, the ERROR output has to be decoupled. R13 reduces the 5V output to the operating point of the PNP transistor T2. Only when the ERROR output connected to the base of T2 is activated, then T2 interconnects; R18 limits the current to about 10mA and the LED11 glows.
Pin 3 of this IC is the shutdown (just as the MAX4000EUA), only that it has to be connected to ground for normal operation. At pin 8 the battery voltage is connected. Pin 2 and 6 are not used in this application.

- **IC4 LM3914CN** (LED-driver)
  This IC drives the 10 LED-display. It relates the input voltage to 10 output pins (pin 1 and 18-10). The maximum input voltage is 12V, but the IC should be used in a way to output voltage differences in the limits of 0V to 5.20V as the LM324 can't trigger a higher voltage signal than its supply voltage. A internal voltage reference of 1.25 volts between pin 7 and 8 makes it possible to "program" the highest voltage at which the last LED will turn on. This is done the same way as the output voltage of the LP2915C was defined. A resistor between pin 7 and 8 defines a current:
  $$I_{16} = \frac{U_{ref}}{R16} = \frac{1.25V}{1k2} \tag{19}$$
  Here again it can be said that almost no current (maximum of $120\mu A$ according to the data sheet) can flow through pin 8; most of the current has to flow through resistor R17. Now we get the following voltage at R17:
  $$U_{17} = I_{16} \cdot R17 = \frac{U_{ref}}{R16} \cdot R17 \tag{20}$$
  The total voltage above ground at pin 7 (and also pin 6) makes therefore:
  $$U_7 = U_{ref} + U_{17} = U_{ref} + \frac{U_{ref}}{R16} \cdot R17 = (1 + \frac{3k9}{1k2}) \cdot U_{ref} \approx 3.4V. \tag{21}$$
  This is way below the aimed 5.20V, but the leak current described above varies the value; and the measurement with the multi meter shows, that the maximum input voltage is defined with R16 and R17 to 5.10V. The variance could be minimized by using smaller resistor values, but this is not possible as R16 determines the current through the LEDs: according to data sheet is
  $$I_{LED} = 10 \cdot I_7 = 10 \cdot \frac{1.25V}{R16} \approx 12.5mA. \tag{22}$$
  This is a acceptable LED current value, but a smaller resistor must not be used as the LEDs can be destroyed when currents exceed 20mA.
  The maximum input voltage U_7 is divided by ten internal 1k series connected resistors. That means that at the first 1k resistor accumulates a voltage of $\frac{1k}{10k} \cdot U_7$, at the second $\frac{2}{10} \cdot U_7,\ ...,\ \frac{10}{10} \cdot U_7$. Ten comparators in the IC "compare" the input voltage to this ten voltage steps and matche it with the one closest to it. The output pin belonging to this voltage step is activated. Inactivated pins are leveled with the supply voltage, and at activated pins the voltage drops to almost ground. Therefore the LEDs have to be connected between the supply line and the pins of the IC. The polarity has to be minded. A series resistor is not needed here, even though the voltage at the LEDs is about 5V, as the current through the LEDs is limited by R16.
  The LED-driver works in dot mode if pin 9 is left open. A "fade" of about 1mV between the comparator segments ensures that at least one LED is activated at all times when the dot mode is used. If bar mode is preferred, pin 9 hast to be connected to the supply voltage (V+ at pin 3). The supply voltage may range between 3V and 15V, so it is can be connected to the supply voltage line. Pin 2 is connected to ground.

- **IC LM386**
  This IC is designed to drive a speaker with a low supply voltage. It amplifies the input voltage between pin 2 and 3 by a factor of about 10 corresponding to 20dBV. With the 10k potentiometer POT3 and the 4k7 resistor R12, the input voltage can be regulated between 33% and 100% of the decoupled signal from the MAX4000EUA. This means that the volume of the speaker can be regulated with POT3 (R12 is the cause for the lower limit of 33%). At pin 5 the amplified signal is outputted, which is connected over a big capacitor to the speaker. The maximum voltage at the speaker is $5V \cdot 10 = 50V$, which makes at the $1k\Omega$ speaker a maximum power of 50mW.

- **Potentiometer P1** (zero point setting)
  This potentiometer is used as an alterable resistor in this application. The voltage difference U_{in} between pin 2 and 3 of the LM324, which is amplified, can be regulated. The MAX4000EUA causes even without an RF signal (just as almost any other IC) some output noise, according to the data sheet 0.35V at SET, measured 0.34V. This means that at pin 3 of the LM324 a voltage of 0.34V exists at no input signal. So pin 2 of the LM324 and therefore pin 1 of POT3 would have to be on 0.34V, too. As it is very inconvenient to open the box and measure the voltage at POT1 each time until it is adjusted to these 0.34V, the zero point (complies to zero radiation) is defined when the first green LED barely lights up. Now only POT1 has to be adjusted at no input signal, until this LED glows. For the first LED to light up, a positive voltage of about 0.51V is needed at the LP3914, that means an voltage difference of $U_{in} = \frac{U_{out}}{amplifying\ factor} = \frac{0.51V}{2.68} = 0.19V$.[10] So R4 and POT1 have to divide the supply voltage at exactly $0.34V - 0.19V = 0.15V$ above ground. The potentiometer POT1 has to be adjusted until this voltage is achieved. Calculation of the estimated value of the potentiometer:

  $$U_{POT1} = \frac{U_{supply}}{POT1 + R4} \cdot POT1 = 0.15V \tag{23}$$

  Solved for POT1:

  $$POT1 = \frac{U_{POT1} R4}{U_{supply} - U_{POT1}} = \frac{0.15V \cdot 12k\Omega}{5.20V - 0.15V} \approx 356\Omega \tag{24}$$

  As it is impossible to find resistor values for R4 and POT1 that divide the 5.20V very exactly at 0.15V, the exact value should be regulated by hand with a potentiometer. The potentiometer's value should be somewhere around 500Ω; a $2k5\Omega$ potentiometer is used as no other one was viable. This big value demands a steady hand when being adjusted, but that's nothing impossible. The potentiometer should be adjusted over again before each measurement, because environmental factors such as temperature affect the electronic components in the device.

- **Potentiometer P2** (esthesia)
  As described under LM324, this potentiometer regulates the enthesia by altering the amplifying factor.

- **Potentiometer P3** (volume)
  As described under LM386; it controls the volume of the speaker. Before taking measurements, it should be adjusted so that a hushed swoosh can be heard.

- **LED display**
  The 10 LEDs display the intensity of the radiation. It is difficult to say though, how strong the electromagnetic field is, if a certain LED lights up. In chapter 3.2.1 the value is calculated approximately; the exact correlation of the number of the LED and the intensity of the electromagnetic field needs to be experienced out in a laboratory. The RF sniffer can be calibrated in rooms concealed of any radiation from the outside and with equipment which generates defined electromagnetic fields. But this is too expensive and costly for just one device of its kind. The calculated values should be accurate enough for the author's measurements anyway.

- **Diodes D1 and D2**
  The diode D1 is very important, because it protects the circuit against false polarity. If a battery is connected the wrong way by chance, then the circuit would be destroyed, but D1 prevents this. D2 commutates the signal for the LED driver.

[10] To simplify the measurements, all calculations are based on the measured amplifying factor of 2.68 at the lowest sensitivity.

The circuit needs a power of about 40mW at no input signal and up to about 100mW at input signal (depending on bar / dot mode and the volume of the speaker).

3.2 Data interpretation and measurements

With the right antenna connected to the RF sniffer, all electronic devices working between 100MHz and 2.5GHz can be detected and compared. It would be very interesting to try out different kinds of antennas, but the author confines the measurements to one antenna-kind for the sake of shortness. The external antenna used for measurements is a $\frac{\lambda}{2}$-dipole antenna made of model railway tracks, which can be plugged together and extended.

3.2.1 Data interpretation

How can the measurements be analyzed? How much radiation does a LED indicate? To answer this question, several formulas are needed which will be accepted as they are and won't be proved in this work:

- The intensity per area: (see also chapter 2.1)

$$I = \frac{1}{2\mu_0 c} \cdot E^2 \tag{25}$$

- The effective area of an antenna: [15]

$$A = \frac{\lambda^2}{4\pi} \tag{26}$$

  Electromagnetic fields in this area induce a current in the antenna.

- The gain G of antenna:

$$G = D \cdot \eta \tag{27}$$

  The coefficient η can be assumed to be 1 for frequencies in the GHz band (see (13)). The directivity D is the quotient of the antenna's area of radiation and the area of a globe. An ideal isotropic antenna would radiate in all directions, but every antenna is limited in its radiation angle. EMWs emitted from an antenna can't be received everywhere, but the intensity of the signal increases within the radiation angle instead (see also graphic 12). Therefore D is always above 1 for antennas, for dipole antennas about 2.14dBi which corresponds to a factor of 1.64.

- The power absorbed by the antenna is the product of the effective area, the gain and the intensity (source: [15]):

$$P_a = A \cdot G \cdot I = \frac{\lambda^2}{4\pi} \cdot 1.64 \cdot \frac{1}{2\mu_0 c} \cdot E^2 \tag{28}$$

  Solving the equation for E:

$$E = \sqrt{\frac{P_a \cdot 8\pi\mu_0 \cdot f^2}{c \cdot 1.64}} \tag{29}$$

  With a measured input power P_a at a given frequency, the electric field could be calculated now.

- The SAR-value (source: [16]):

$$SAR(\omega) = \frac{\sigma(\omega) \cdot E^2}{\rho} \tag{30}$$

$\sigma(\omega)$ is the electrical conductivity of human tissue contingent upon the frequency and ρ is the density of the tissue. $\sigma(\omega)$ can be calculated for different materials with the following formula (source: [17]):

$$\sigma(\omega) = i \cdot \omega \cdot \epsilon(\omega) \cdot \epsilon_0 = 2\pi f \cdot \epsilon(\omega) \cdot \epsilon_0 \tag{31}$$

This formula is very difficult to solve as it consists of an real- and imaginary part, and depends on the relative permittivity $\epsilon(\omega)$, which is also hard to get. Values such as the relaxation time which are needed for the relative permittivity, are only viable for water and not human tissue. Instead being calculated, the electrical conductivity of muscles is read off a logarithmic diagram (source: [18]). The exact value can't be determined as the diagram has a poor resolution, but approximately it can be said that for 900MHz the electrical conductivity is $1.2\frac{S}{m}$, and for 1800MHz and 2100MHz it is $2.0\frac{S}{m}$. The density ρ of muscle tissue is approximately $1050\frac{kg}{m^3}$ [19]. These values and formula (29) inserted in (30) make for

- $SAR(900MHz) = 59\frac{P_a}{kg}$
- $SAR(1900MHz) = 396\frac{P_a}{kg}$
- $SAR(2100MHz) = 540\frac{P_a}{kg}$.

The only unknown value now is the received power P_a. And this is how it is appraised: The LM3914CN divides 5.10V on 10 LEDs. At an input voltage of $n \cdot 0.51$, the next higher LED n starts to light (see chapter 3.1.5 LM3914). The input voltage corresponds to the signal at SET of the MAX4000EUA, amplified by the LM324. The amplifying factor is 2.68 for the smallest sensitivity adjusted at POT2 (see chapter 3.1.5 POT2). As the MAX4000EUA has a leak voltage of 0.34V at no input signal, 0.34V have to be added to the voltage; and as at no input signal the first LED lights up, 1 has to be subtracted of n. So the voltage at SET was originally

$$U_{SET} = (n-1) \cdot \frac{0.51V}{2.68} + 0.34V = (n-1) \cdot 0.19V + 0.34V. \tag{32}$$

In graph 13 the SET voltage is shown versus the input power in dBm for an antenna connected with a 50Ω resistance to ground. Only a 56Ω resistance was viable, but with the following formula the real input power can be adapted:

$$P_a = n \cdot U_{SET} \cdot I = \frac{n \cdot U_{SET}^2}{R_{56}} = 0.89 \cdot \frac{n \cdot U_{SET}^2}{R_{50}} = 0.89n \cdot P_{Graph}. \tag{33}$$

The power is given in dBm in the graph; it has to be converted into Watts:

$$P_a = 0.89n \cdot P_{Graph} = 0.89n \cdot 10^{\frac{1000 \cdot P_{Graph\ in\ dBm}}{10}}. \tag{34}$$

$P_{Graph\ in\ dBm}$ has to be read off graph 13 for each SET voltage. These values inserted in (34) result in the SAR-value. In table 14 all SAR-values of the three mobile phone frequencies are calculated for each LED. The calculated values can only be used as estimations, as the calculation contains approximations and the measuring error of the sniffer has to be minded.

3.2.2 Measuring different mobile phones

In table 16 the maximum SAR-values of different mobile phones are listed. Measurements were taken at the top-front of the phone (ear), the top-back (usually antenna), the low-front, and the low-back. Although most mobile phones radiate much less than the limiting SAR-values, sometimes the radiation is too strong for the MAX4000EUA. This IC intensifies signals at maximum SAR-values

of $0.08\frac{W}{kg}$ (for 900MHz), $0.07\frac{W}{kg}$(for 1900MHz), and $0.24\frac{W}{kg}$ (for 2100MHz). SAR-values printed bold in the table are above measurement possibilities. It can only be said, that the SAR-value is here above $0.08\frac{Watts}{kg}$. If the author could construct a second RF sniffer, then another IC would be used instead of the MAX4000EUA. The MAX4000EUA is too sensitive in order to measure the radiation of mobile phones; the MAX4003 would do much better as it intensifies higher input powers. Generally some conclusions can be drawn though: Some phones shield the radiation from the front almost perfectly, and others don't shield the radiation at the front at all. Of course nobody really does it, but when purchasing a new mobile phone, the customer should measure first how much the radiation is shielded from the ear. The SAR-values given in the instruction sheets alone don't tell enough. A remarkable thing is, that new phones such as the Sony Ericsson W880i radiate above-average. Some old phones radiate not as much (as it is commonly assumed). The measurement shows also, that clamshell phones are not an advantage: even though the antenna is placed further away from the ear (usually in the low back), the radiation is not much less at the ear (probably because of poor shielding). Phones using the E-net have smaller SAR-values than phones using the D-net. If this is coincidence though cannot be said. Unluckily no phone was found that radiates on the UMTS net, so this net can't be compared to the others.
As further measurements, studies, and information-flyers show, the radiation can be reduced a lot by following these hints:

- Don't cover the antenna with your hand while using a mobile phone. The fingers absorb quite a big part of the radiation from the antenna, and the mobile phone has to increase it's transmitting power unnecessarily.
- If possible, telephone only if the mobile phone has good reception and shows 4-5 bars. At bad reception the transmitting power is up to 1000 (!) times higher than at good reception.
- If possible, go outside for making a call. There the SAR-value is usually 0.1 to $0.7\frac{W}{kg}$; in buildings and in cars the SAR-value is often more than $1.2\frac{W}{kg}$.
- When using a mobile phone inside, go to a window or a door. There the reception is a lot higher.
- Using a headset reduces exposure of the head to radiation.
- When carrying a mobile phone in a pocket, always turn the front side to your body. The front side is shielded from radiation and radiates much less than the backside.
- In the underground and underground parking lots there is no need for turning the mobile phone off, because it doesn't radiate. When the mobile phone can't receive any signal from the Base Transceiver Station, then it only ”hears” for a signal.
- A mobile phone in standby mode sends only every 20 minutes to 4 hours a short signal to the Base Transceiver Station to tell in which radio cell it is located. Otherwise it only emits signals if it is requested to do so (i. e. when a call is coming in). So the mobile phone doesn't need to be turned off when it is not used.

These hints were copied several times and given to students and parents at open house at the Gymnasium Penzberg in 2006.

3.2.3 Measuring the radiation at an antenna station

On the Strassberg, a small mountain nearby the author's home, there is a Base Transceiver Station. With the RF sniffer the radiation was measured at different distances. Because it is difficult to count the steps or to measure several hundred meters in another way, the author delineated the spots where a higher LED lighted up, and measured the distance from the station in Google Earth afterwards. It was difficult to take measurements as the RF sniffer detected different signals if held in different angles and different heights. The values measured at less than 100m have to be interpreted with care, as the antenna stands high upon a farm building and the full signal can't be received on the ground. As at this BTS there were four antennas total (two for the D-net and two for the E-net) it could be possible that interference maximums adulterate the measurements a little. The author talked to the people living in the house and couldn't measure any radiation in the house at all. Therefore the antenna on the roof has to be a beam antenna and radiates only away from the house (whereas the shielding to the backside is very good). A high pitched sound in the speaker indicated that many people were using the Base Transceiver Station when the measurements were taken. The measured SAR-values were:

- for 279m: 2nd LED; corresponding to 0.00004 SAR
- for 140m: 3rd LED; corresponding to 0.00018 SAR
- for 82m: 4th LED; corresponding to 0.00070 SAR
- for 53m: 5th LED; according to 0.00353 SAR
- for 19m: 6th LED; corresponding to 0.01768 SAR

The station works for the D- and E-net. Accepted that the antenna was only operating on the E-net frequency, then the SAR-values and the intensity of the electromagnetic field can be read off table 14. At no location the SAR-value exceeded 0.018 Watts per kilogram, which is way below the limit. According to the SAR-values in chapter 2.3.3, someone living next to this antenna within 53m is in danger of getting tumorigenic cell proliferations, and someone living within 140m would suffer extreme stress. It has to be said though, that someone living directly under an antenna station, is exposed to zero radiation, as an antenna doesn't radiate in all directions (see graphic 12). Also living behind an beam antenna is completely innocuous as there no radiation can be detected.
Also it can be noticed that the radiation decreases logarithmic with increasing distance (compare to 2.4.4).

4 Conclusion

"Electromagnetic waves" - this is an important chapter in physics and an even more important one in society. No other subject is so controversial, whereas it connects people at the same time through data transmission. It was very hard work to accomplish this paper, even harder was the experimental part. But looking back now, all this time spent for it was used well. Never the author learned this much about a subject so interesting and never the author gained more practical experience. A work like this is never complete and there are many improvements that can be carried out. This work did not only drive the author to attend to this subject, but also inspired him to enter the world of communications and electronics. The next planned project is the construction of an high power, high efficiency, and low voltage LED driver.

Appendix

- Graphic 1: Electromagnetic spectrum
- Table 2: Electromagnetic spectrum
- Drawing 3: Oscillating antenna; near and far field
- Graphic 4: Meissner'sche regeneration and oscillating circuit becoming an antenna
- Graphic 5: Absorbed frequencies
- Drawing 6: Radio cells
- Graphic 7: Modulation
- Graphic 8: Circuit diagram
- List 9: Component list
- Drawing 10: Experiment board layout
- Graphic 11: MAX4000EUA, LM324, and LM3914CN
- Graphic 12: Directivity
- Graph 13: Input power
- Table 14: SAR-values
- Table 15: Measurements of mobile phones

References

[1] author: J. Grehn, J. Krause, title: Metzler Physik, 4. Auflage, 2007, Schroedel Verlag

[2] author: unknown, title: Handys, translated out of Sueddeutsche Zeitung 14./ 15.08.2007, Wirtschaft Gefragt

[3] author: Max Rauner, title: Heisse Gespraeche, translated out of Die Zeit Wissen, Mai 2006, page 102

[4] author: Christopher Schrader and Patrick Illinger, title: Wenn das Ohr heiss wird..., translated out of Sueddeutsche Zeitung 02.02.2007, Panorama

[5] author: Marcus Neumann, title: Bezug zum Grenzwert ist irrefuehrend, Toelzer Kurier 9./10.06.2007

[6] author: unknown, title: Kosmische Strahlung aufspuehren, translated out of Gelbes Blatt 16.05.2007,

[7] domanske.de/2007/11/zeitraeume/

[8] Mobilfunk und Technik, Projektheft, April 2005, Informationszentrum Mobilfunk e. V.

[9] http://www.pulsstrahlung.de/frequenztabelle.htm

[10] http://www.elektronik-kompendium.de/sites/kom/0910231.htm

[11] author: H. Vogel. title: Gerthsen Physik, 19. Auflage, 1997, Springer Verlag

[12] http://www.suigyodo.com

[13] Arbeitskreis Amateurfunk und Telekommunikation in der Schule; circuit diagramm at: http://www.bausatz.aatis.de/Tipps/AS644-Tipps_HF-Sniffer/AS644B_S-a.gif

[14] www.datasheetcatalog.com

[15] http://www.ihe.uni-karlsruhe.de/download/AAS-Skript-2007.pdf

[16] http://de.wikipedia.org/wiki/SAR_%28Physik%29

[17] http://deposit.ddb.de/cgi-bin/dokserv?idn=96664882x&dok_var=d1&dok_ext=pdf&filename=96664882x.pdf

[18] http://cds.comsol.com/access/dl/papers/1927/Koch.pdf

[19] novafeel.de/koerperfett/muskelnsind-schwerer-als-fett.htm

[20] For backgournd information: Facharbeit aus dem Fach Physik, Messung von Mobilfunkstrahlung, von Regina Spichtinger, 22.12.2006

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- elector for supplying the IC AD8316 and an article about an ”electro-smog-tester”.

Word count: 12312

Ich erkläre hiermit, dass ich die Facharbeit ohne fremde Hilfe angefertigt und nur die im Literaturverzeichnis aufgeführten Quellen und Hilfsmittel benutzt habe.

Bichl, den 20.01.2007 ....

Ort, Datum Alexander Dörflinger

Graphic 1: Electromagnetic spectrum

source: http://kingfish.coastal.edu/marine/Animations/

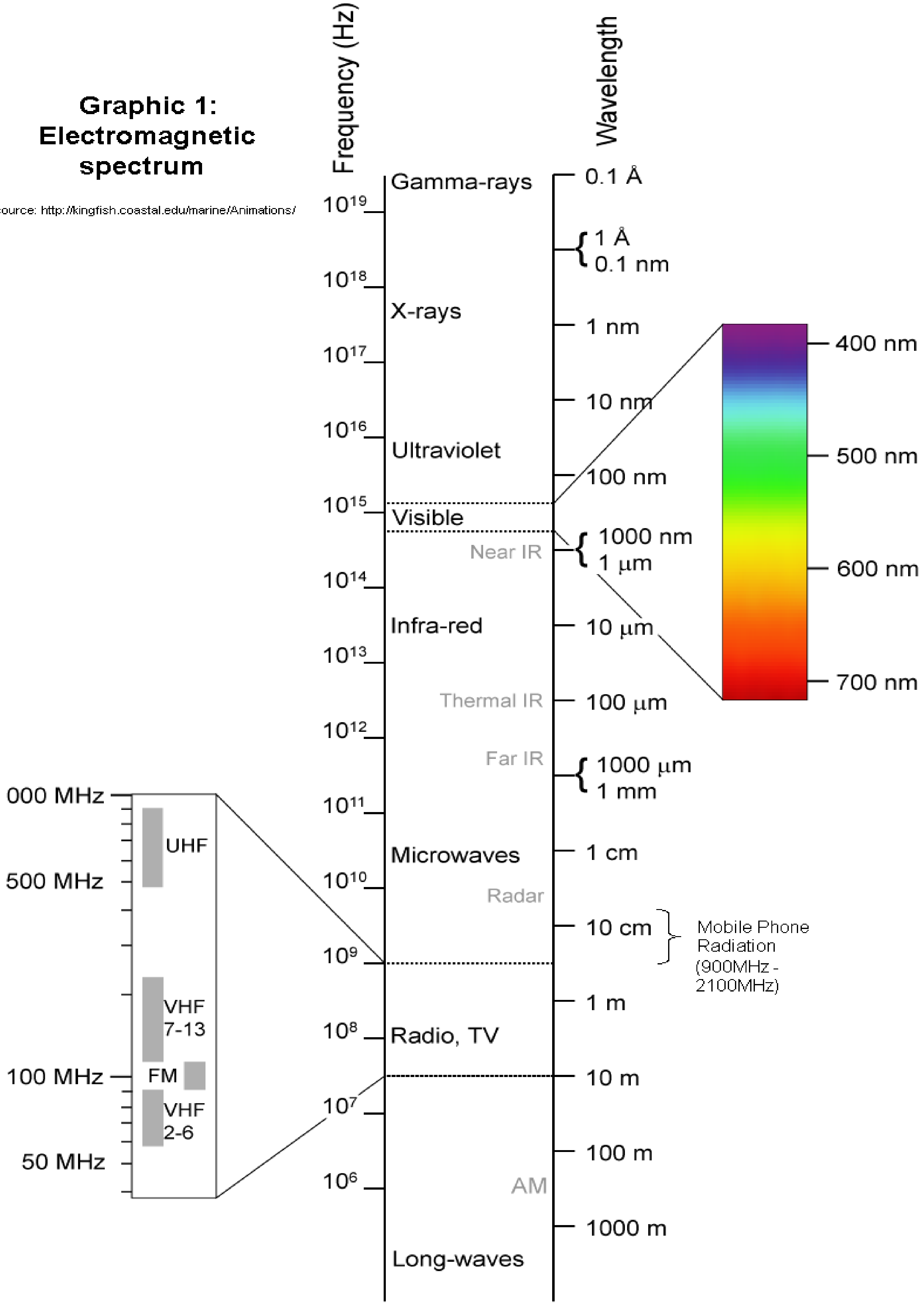


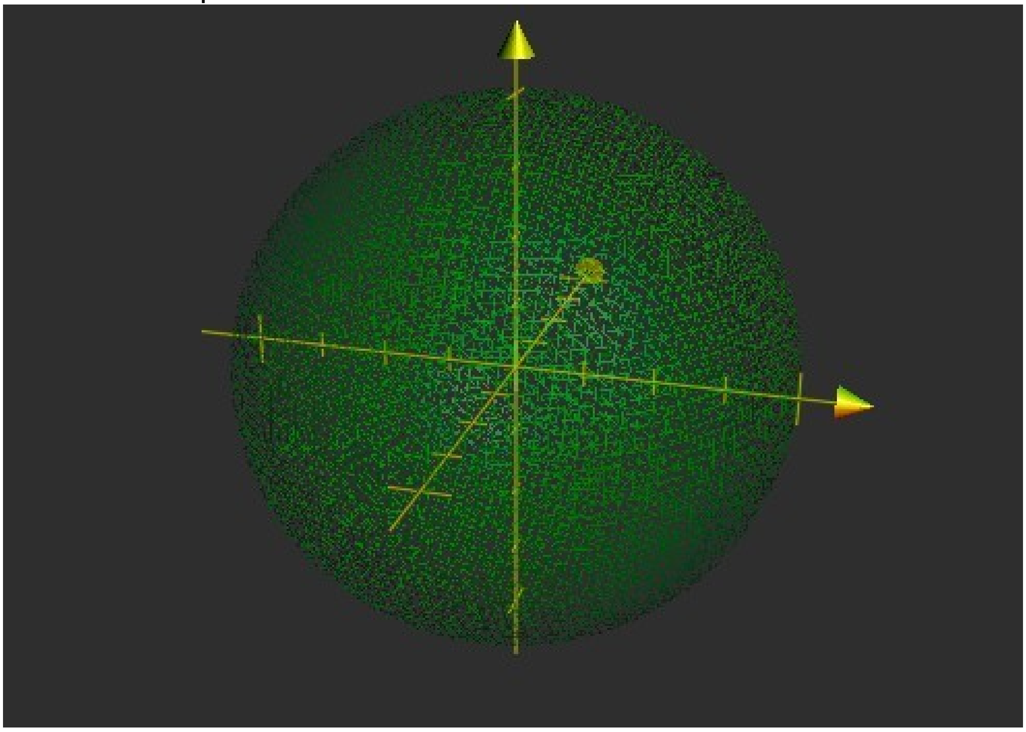
Table 9: Component List

Description	Value
Resistors	
R1	56
R2	22k
R3	2k7
R4	12k
R5	47k
R6	147k
R7	27k
R8	10k
R9	1k
R10	1M
R11	100
R12	4k7
R13	100k
R14	15k
R15	4k7
R16	1k
R17	330
R18	500
Potentiometers	
POT1	2k5
	Better: 500
POT2	47k
POT3	10k
Capacitors	
C1	10n
C2	1u
C3	1u
C4	47u
C5	220u
C6	47n
C7	1u
C8	100n
C9	10u

Description	Value
Semiconductors	
T1	BC549C (NPN)
T2	BC857C (PNP)
D1	1N4004
D2	1N4148
LED1	Green
LED2	Green
LED3	Green
LED4	Yellow
LED5	Yellow
LED6	Yellow
LED7	Red
LED8	Red
LED9	Red
LED10	Red
LED11	Red
Inner circuits	
IC1	MAX4000EUA
IC2	LM324
IC3	LM386
IC4	LP2951C
IC5	LM3914CN
Other	
Metal box	
Thin wires	
Soldering iron	
Desoldering braid	
Soldering flux	
Conductors	
High impediance speaker	

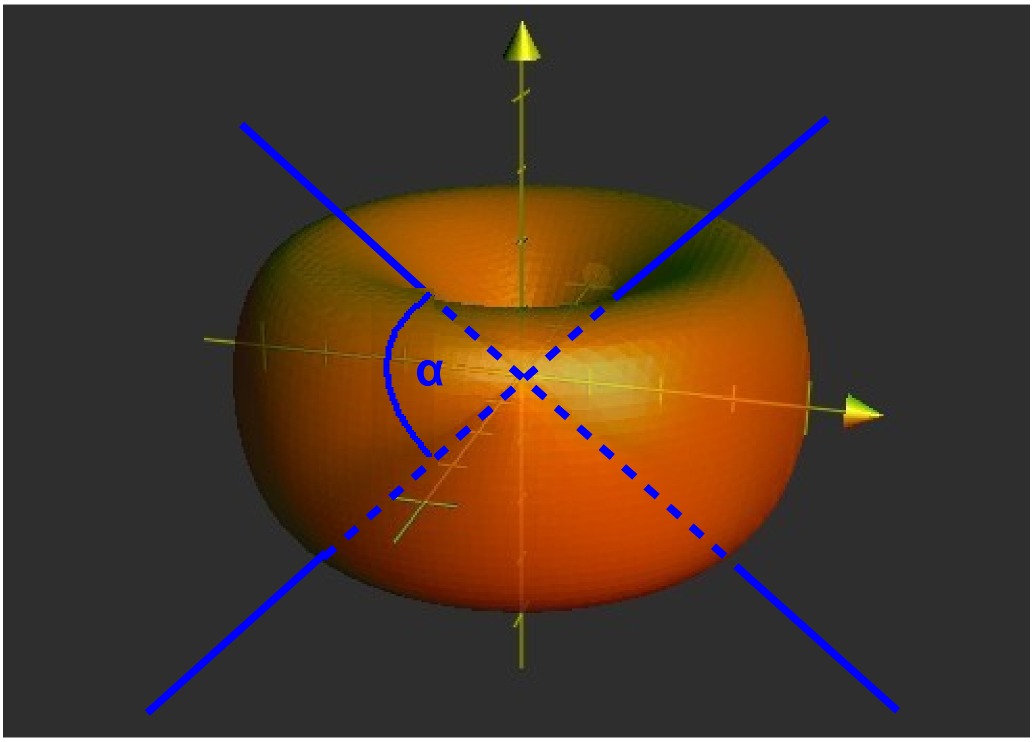
Graphic 12: The directivity of dipole antennas

An ideal isotropic antenna radiates in all directions:



The surface area of the globe is: 4 π r²

An dipole antenna radiates in a limited direction:



The outer surface area of the ring is about: α/180° x (4 π r²)

= 1/1.64 (4 π r²) for dipole antennas.

source: http://images.google.de/imgres?imgurl=http://wiki.unikonstanz.de/wiki/pub/Wireless/SendeLeistung/iso_dip_gr.jpg&imgrefurl=http://wiki.unikonstanz.de/wiki/bin/view/Wireless/SendeLeistung&h=359&w=495&sz=42&hl=de&start=2&um=1&tbnid=LLkx1DAzWcB1nM:&tbnh=94&tbnw=130&prev=/images%3Fq%3Ddipolantenne%2Bstrahlung%26svnum%3D10%26um%3D1%26hl%3Dde%26client%3Dfirefoxa%26rls%3Dcom.google:de:official%26sa%3DG

Table 14: LED number versus SAR-value

(for the smallest sensitivity)

For 0.9 Ghz

LED (n)	U_LED In volts	U_SET In volts	P graph In dBm	P absorbed In watts	E In V/m	SAR In W/kg
1	0,51	0,34	0	0	0	0
2	1,02	0,53	-37	0,0000002	0,10	0,00001
3	1,53	0,72	-29	0,0000011	0,24	0,00007
4	2,04	0,91	-23	0,0000045	0,48	0,00027
5	2,55	1,10	-14	0,0000354	1,36	0,00211
6	3,06	1,29	-7	0,0001776	3,04	0,01056
7	3,57	1,48	2	0,0014106	8,57	0,08388
8	4,08	1,67	No values (radiation is too high;			
9	4,59	1,86	the MAX4000EUA can't output any			
10	5,10	2,05	voltage higher than 1.6V at SET)			

For 1.9 Ghz

LED (n)	U_LED In volts	U_SET In volts	P graph In dBm	P absorbed In watts	E In V/m	SAR In W/kg
1	0,51	0,34	0	0	0	0
2	1,02	0,53	-39	0,0000001	0,15	0,00004
3	1,53	0,72	-33	0,0000004	0,30	0,00018
4	2,04	0,91	-27	0,0000018	0,61	0,00070
5	2,55	1,10	-20	0,0000089	1,36	0,00353
6	3,06	1,29	-13	0,0000446	3,05	0,01768
7	3,57	1,48	-7	0,0001776	6,08	0,07040
8	4,08	1,67	No values (radiation is too high;			
9	4,59	1,86	the MAX4000EUA can't output any			
10	5,10	2,05	voltage higher than 1.6V at SET)			

For 2.1 Ghz

LED (n)	U_LED In volts	U_SET In volts	P graph In dBm	P absorbed In watts	E In V/m	SAR In W/kg
1	0,51	0,34	0	0	0	0
2	1,02	0,53	-33	0,0000004	0,36	0,00024
3	1,53	0,72	-27	0,0000018	0,71	0,00096
4	2,04	0,91	-22	0,0000056	1,26	0,00303
5	2,55	1,10	-16	0,0000224	2,52	0,01206
6	3,06	1,29	-9	0,0001120	5,63	0,06046
7	3,57	1,48	-3	0,0004461	11,24	0,24069
8	4,08	1,67	No values (radiation is too high;			
9	4,59	1,86	the MAX4000EUA can't output any			
10	5,10	2,05	voltage higher than 1.6V at SET)			

Table 2: The electromagnetic spectrum

Unless otherwise stated, all specifications apply to DIN standards (i.e. DIN 5031)

Umbrella term	**Acronym**	**Name**	**Frequency (/Hz)** (upper limit)	**Wavelength (/m)** (lower limit)	**Energy (/eV)**	**Applications (Examples)**	**Generation**
		Static electromagnetic fields	0	∞	0	Earth's magnetic field	
Low-frequency Waves	VLF	Very Low Frequency	3,00E+00	1,00E+08	1,24E-14		
	ELF	Extremly Low Frequency	3,00E+01	1,00E+07	1,24E-13		
	SLF	Super Low Frequency	3,00E+02	1,00E+06	1,24E-12	Submarine communication	Ground antennas
	VF	Voice Frequency	3,00E+03	1,00E+05	1,24E-11		Oscillating circuits, antennas
Radio waves	VLF	Very Low Frequency	3,00E+04	1,00E+04	1,24E-10		Oscillating circuits, antennas
	LF	Low Frequency	3,00E+05	1,00E+03	1,24E-09	Broadcasting (long wave)	Oscillating circuits, antennas
	MF	Medium Frequency	3,00E+06	1,00E+02	1,24E-08	Broadcasting (medium wave)	Oscillating circuits, antennas
	HF	High Frequency	3,00E+07	1,00E+01	1,24E-07	Broadcasting (short wave)	Oscillating circuits, antennas
	VHF	Very High Frequency	3,00E+08	1,00E+00	1,24E-06	Radio and television, radar	Oscillating circuits, antennas
	UHF	***Ultra High Frequency***	**3,00E+09**	**1,00E-01**	**1,24E-05**	***Mobile phone, GPS, WLAN***	**Antennas**
Micro waves	SHF	Super High Frequency	3,00E+10	1,00E-02	1,24E-04	Satellite television	Magnetic resonance
	EHF	Extremly High Frequency	3,00E+11	1,00E-03	1,24E-03	Radio astronomy	Magnetic resonance
Infrared	FIR	Far Infrared	2,00E+13	1,50E-05	8,27E-02	Radio astronomy	Kylstron- and magnetrom tubes
	MIR	Middle Infrared	2,14E+14	1,40E-06	8,86E-01	Infrared spectroscopy	Laser
	NIR	Near Infrared	3,90E+14	7,70E-07	1,61E+00	Remote controls, CD-laser	Laser and diodes
Visible region		Red*	4,84E+14	6,20E-07	2,00E+00		Light bulb, laser
		Yellow*	5,45E+14	5,50E-07	2,26E+00		Light bulb, laser
		Green*	6,25E+14	4,80E-07	2,58E+00		Light bulb, laser
		Blue*	7,50E+14	4,00E-07	3,10E+00	Blue ray disk lasers	Light bulb, laser
Ultraviolet	NUV	Near Ultraviolet	1,50E+15	2,00E-07	6,20E+00	Disinfection	Synchrotrons
	FUV	Far Ultraviolet	3,00E+16	1,00E-08	1,24E+02		
	EUV	Extreme Ultraviolet**	3,00E+17	1,00E-09	1,24E+03		
X-Ray	SX	Soft X-Rays**	3,00E+17	1,00E-09	1,24E+03	Medical applications	X-Ray tube
	HX	Hard X-Rays	3,00E+18	1,00E-10	1,24E+04		X-Ray tube
Gamma-Rray		Gamma-Rays	∞	0	∞		Nuclear decay

* these values are estimated and read off diagrams

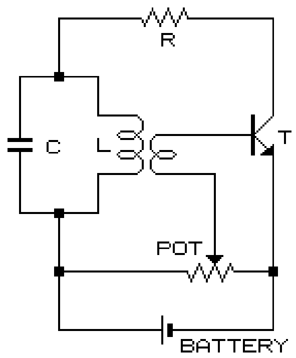
** overlapping spectra

Sources: http://en.wikipedia.org/wiki/Electromagnetic_spectrum
http://leifi.physik.uni-muenchen.de/web_ph12/umwelt_technik/06spektrum/
http://unihedron.com/projects/spectrum/downloads/spectrum_20060222.pdf
http://www.uni-regensburg.de/EDV/Misc/CompGrafik/Script_5.html

Graphic 4

Undamped oscillating circuit

a)



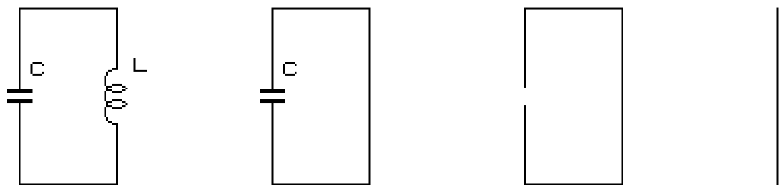
C and L makes up the oscillating circuit

R limits the current

POT sets the operating voltage of T

An oscillating circuit becomes an antenna

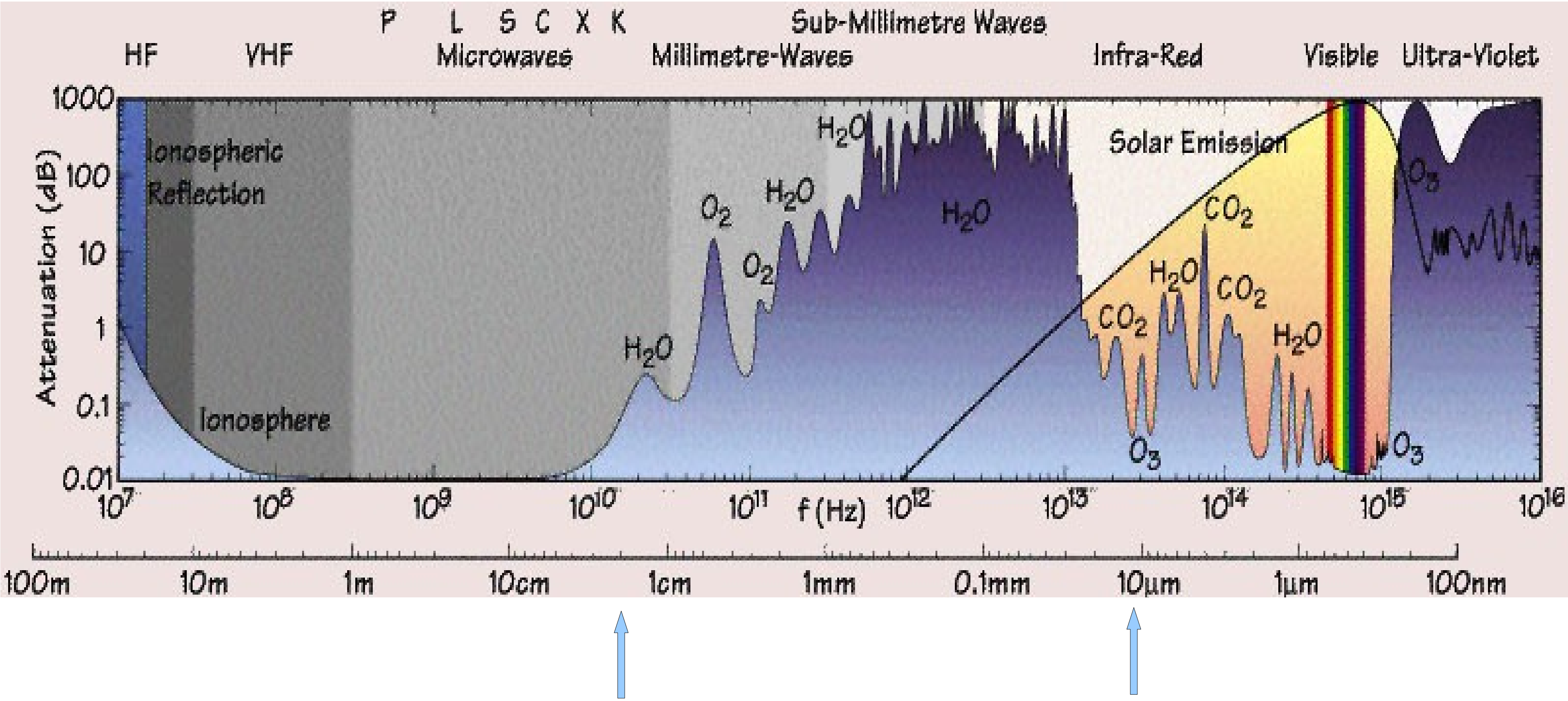
b)



Graphic 5: Absorbtion rate of electromagnetic waves according to their frequency

source: http://www.geographie.ruhr-uni-bochum.de/agklima/vorlesung/strahlung/spektrum-atmosphaere.jpg

Different molecules in the air absorb electromagnetic waves. This graph shows, which molecules absorb which frequency.

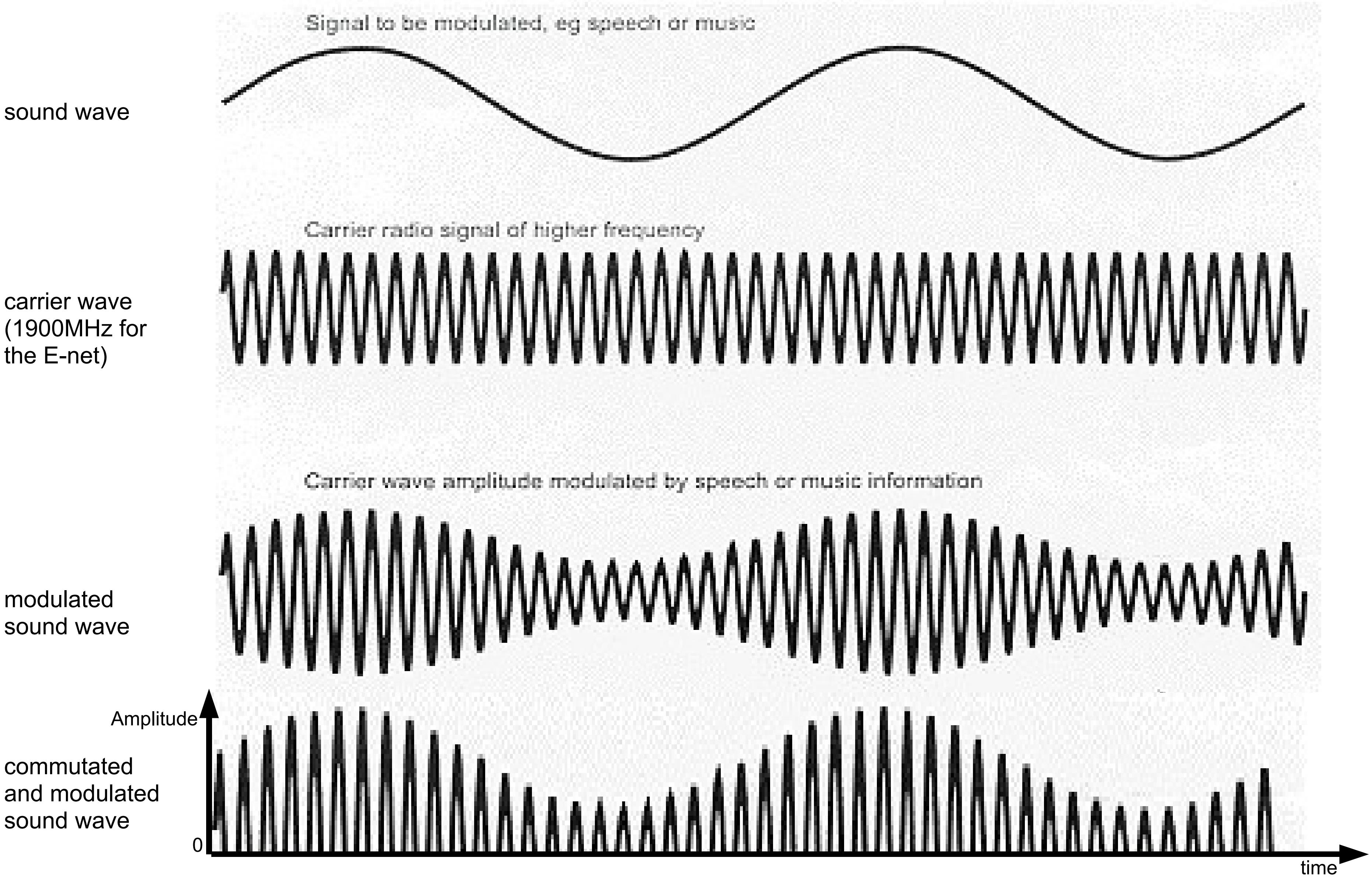


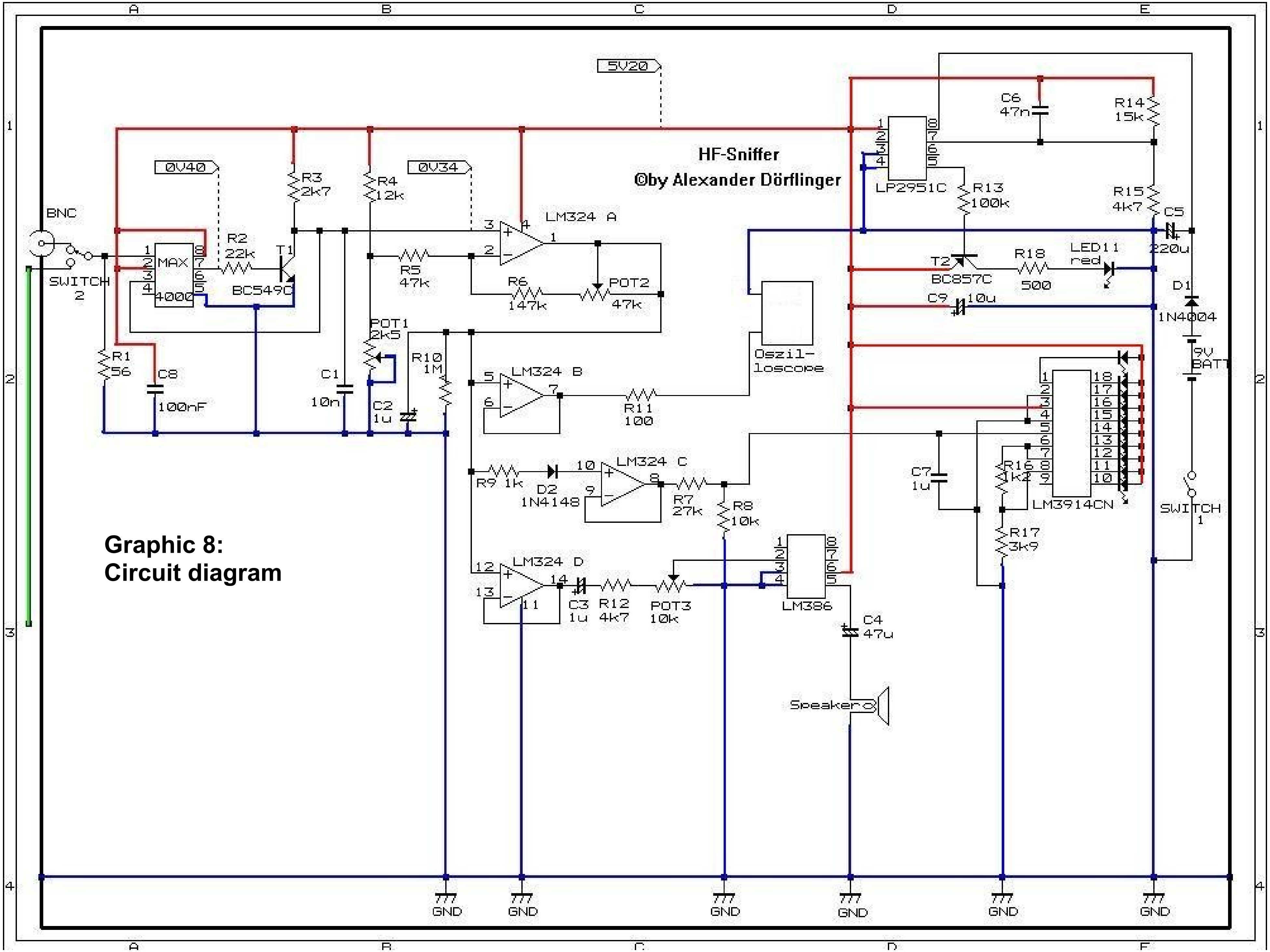
upper frequency limit:
signals can't be sent at higher
frequencies, as they are absorbed

new frequency band:
with new technology it might be possible
to use this band for transmitting signals

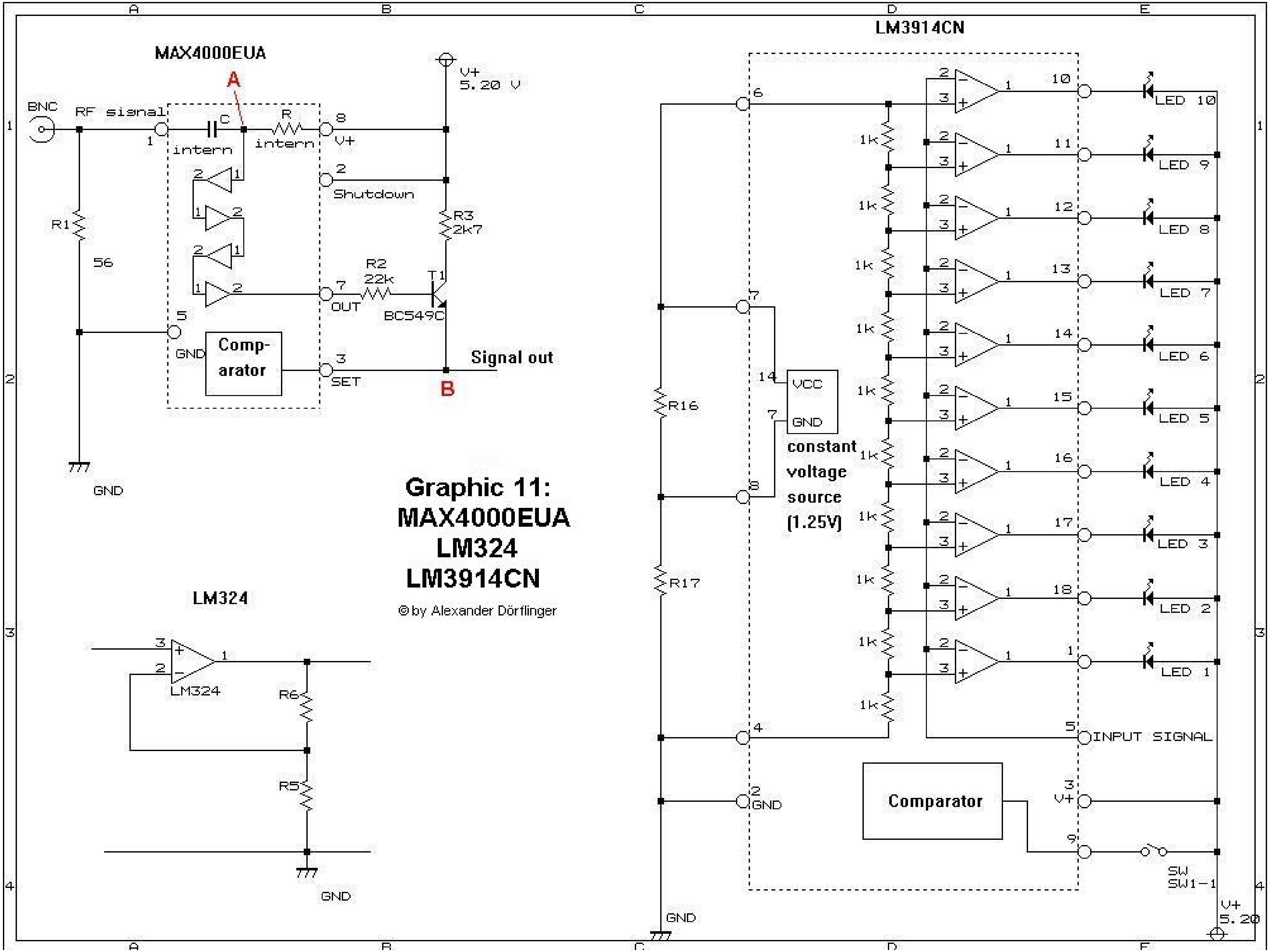
Graphic 7: Modulation of soundwaves with a carrier wave

source: http://www.ofcom.org.uk/static/archive/ra/topics/mpsafety/school-audit/mobileimages/fig1.gif





Graphic 8:
Circuit diagram



Graphic 11: MAX4000EUA LM324 LM3914CN

© by Alexander Dörflinger

Table 15: Measurements of differnt mobile phones

Manufacturer	Type	Reception (of 5)	Net	Upper Front	Lower Front	Upper Back	Lower Back	Average	Comment	Approx. SAR (W/kg)
			900MHz							
Sony Ericsson	W880i	5	D1	6	7	7	7	6,75		**0,08**
Nokia	2610	5	D2	7	7	7	7	7,00		**0,08**
Nokia	6131	5	D1	5	7	7	6	6,25	Clamshell	0,01
Nokia	611	5	D2	6	7	7	7	6,75	Clamshell	**0,08**
Sony Ericsson	Unknown	5	D1	5	6	7	7	6,25		0,01
Samsung	Unknown	3	D1	6	7	7	7	6,75	Clamshell	**0,08**
Sony Ericsson	K700i	5	D1	4	5	7	7	5,75		0,01
Samsung	D600	4	D2	6	5	6	7	4,75	Clamshell	0,003
Sony Ericsson	W800i	5	D1	7	7	7	7	5,75		0,01
Sony Ericsson	W880i	5	D1	7	7	6	7	6,75		**0,08**
			1900MHz							
Siemens	CX65	4	E	5	4	5	2	4,00		0,001
Sony Ericsson	V800	4	E	4	5	5	5	4,75		0,004
Sony Ericsson	W880i	5	E	5	5	7	5	5,50		0,02
Nokia	N73	5	E	4	4	7	5	5,00	Good shielding	0,004
Sony Ericsson	Unknown	4	E	7	4	7	4	5,50		0,02
Nokia	Unknown	5	E	7	6	7	7	6,75		**0,07**
Nokia	Unknown	4	E	4	5	7	4	5,00	Good shielding	0,004