„Radio astronomy with a self-built radio telescope“

verfasst von

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1 Introduction

"*With increasing distance, our knowledge fades, and fades rapidly. Eventually we reach the dim boundary – the utmost limits of our telescopes. There, we measure shadows, and we search among ghostly errors of measurement for landmarks that are scarcely more substantial. The search will continue. The urge is older than history.*" Edwin Hubble (1889-1953) [1]

At every time humans have been fascinated by the stars and other celestial bodies. They invented names for the pictures they saw in their constellations, believed them to be gods and even thought they could foresee the future by studying their orbits. Furthermore, stars were and are still observed for navigation, time reckoning and of course in the hope to learn about the reasons and processes of the universe's genesis.

However, the way, celestial bodies were studied, changed distinctly in the course of time. While the early humans just could use their naked eyes, the first telescopes of the 17th century had an approximately 30x magnification. Nowadays, modern telescopes reach much further, like the Hubble Space Telescope that observed the light of galaxies in a distance of more than 10 billion light years. Albeit people learnt a lot about the universe and its components by watching the sky, many celestial bodies also emit other kinds of radiation that cannot be detected with the human's eye. To observe these other emissions, a different kind of telescope is needed, e.g. a radio telescope, receiving signals of frequencies, which on the earth normally are used for radio, satellite reception and other commercial purposes. The observations with those differ in various aspects from the "typical" ones, e.g. several radio telescopes can be combined to gain better measurement results. Having read a short entry to this topic in my physic book, I decided to build a small one for my next "Jugend Forscht" project in the last autumn. This is an extended, altered and translated version of my related project documentary, so beside some theoretical principles about the origin of the celestial bodies' radiation and radio telescopes in general, it contains the self-built radio telescope's description and the measurement results gained with it.

2 Theoretical principles

2.1 The observed radiation and its origin

Objects, e.g. celestial bodies, are visible for human eyes if and only if they emit or reflect electromagnetic waves with a wavelength between 390 nm and 780 nm. Nevertheless, the electromagnetic spectrum consists of much more kinds of waves then these visible ones, e.g. infrared, i.e. thermal radiation or X-rays (Fig. 1).

After the end of the Second World War scientist started to try to observe those other kinds of waves to extend their knowledge about the universe. In doing so they realised, that the earth's atmosphere filters out most parts of the electromagnetic spectrum, except for the visible parts of the infrared and the radio waves [2] Those ranges of wavelength not absorbed are commonly referred to as the optical and the radio window, where the explicit limiting wavelength differs, depending on the atmosphere's exactly composition at or respectively above the observing place [3].

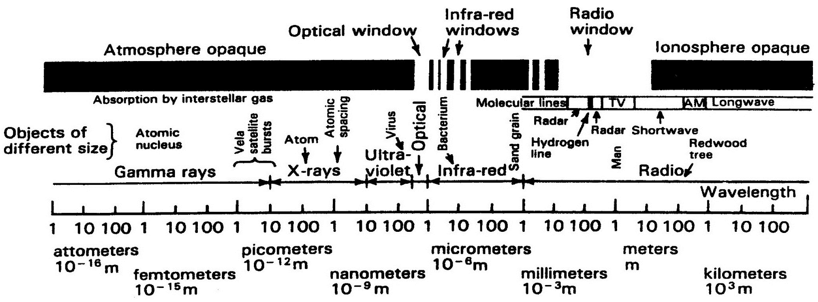


Fig. 1: The electromagnetic spectrum and the atmosphere's absorption ([3], p. 1-2, Fig. 1-1)

In general, the shorter the wavelength, the more a wave is affected by refraction and diffraction at clouds, dust particles and molecules in the atmosphere. Therefore even the best optical telescopes on the earth never achieve their theoretical very high angular resolution. Radio waves, i.e. waves between 0.1 mm and 10 km wavelength are limited to a reduced range between 1 cm and 10 m wavelength [4], but in this interval, depending on the receiver system used, even a cloudy sky would be of nearly no difference for the observations [5].

a) b)

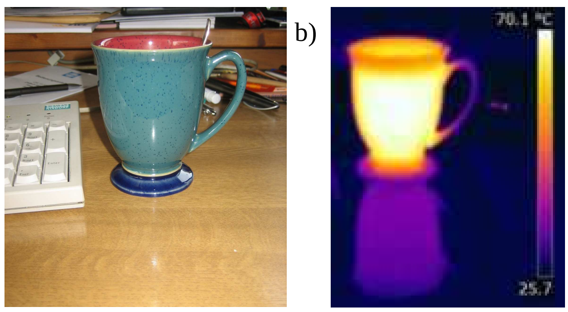


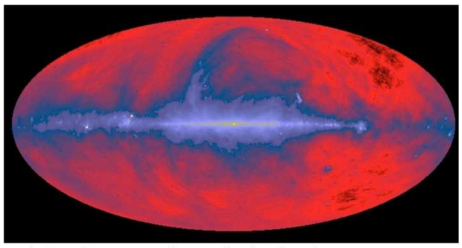
Fig. 2: A picture of a hot coffee cup, made with a) a "normal" camera and b) an infrared camera (false colour image)

From the moment the observed wavelength is changed, the measured data will differ as well. As an example Fig. 2, shows on the left side a "typical" picture of a cup and on the right side the same object as an infrared picture. Using the false colour image, the observer obtains no information about the cup's colour, but about the different areas' temperature and it can also be detected, that infrared rays are reflected even in an unpolished tabletop.

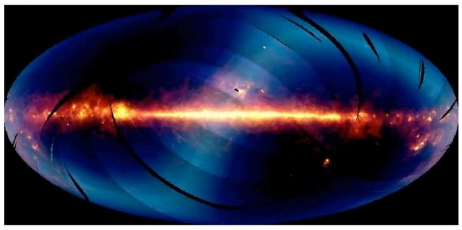
Analogous to this example a picture of the sky made with an optical telescope would correspond only at a few parts to one produced by a radio telescope. Every part of Fig. 3, made by satellites, for example the *CO*smic *B*ackground *E*xplorer (COBE)-Satellite, shows the same view of the sky. A region near the core of the Milky Way can be seen in the middle of each picture, but because of the different kinds of radiation occurring for different reasons, each picture offers different information about physical processes within this section.

The intensity of infrared rays, for example, depends on different temperatures. The free space's temperature is round about 3 K (-270°C), so strong infrared radiation indicates hot objects. It occurs e.g. near stars or in their formation regions, larger sections of high infrared radiation are gases and dust heated by near stars or strong reactions.

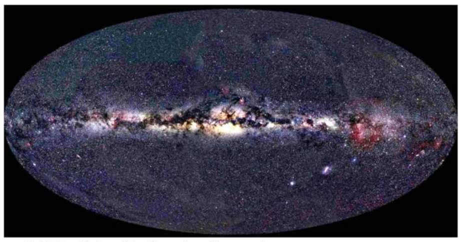
Visible light occurs as well because of temperature, but only at higher ones and in addition to that because of activity within atom's shells. In contrast, X- and gamma rays, which carry much more energy than the former ones, indicate the location of strong magnetic fields, because they arise when electrons are accelerated in those regions. The strongest source for this kind of radiation is a *neutron star*.



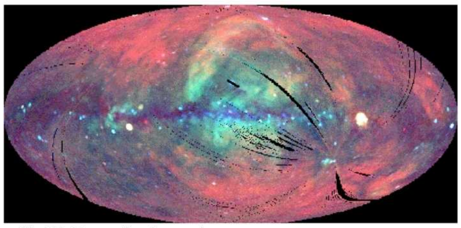
a) Radio wavelength (~ 1 m)



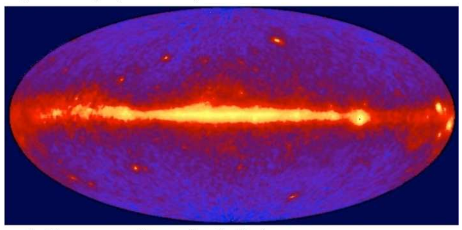
b) Infrared (~ 0,1 mm)



c) Visible light (~ 1 µm)



d) X-Ray (~ 1 nm)



e) Gamma-Ray (~ 1 fm)

Fig. 3: Pictures of the sky taken at different wavelength [6]

Because of their high energy, stars in general are like fusion reactors, they combine atoms of one element to a different one and thereby energy is released. Mostly it is hydrogen that is transformed to Helium. Stars with masses at least eight times larger than the sun's mass are able to fusion even heavier elements, e.g. carbon to magnesium. Thereby it turns into a read super giant with an extreme dense core, consisting of iron and nickel. A star is only as long stable as the fusion processes within release enough energy to counteract the gravity, i.e. the attraction between masses. Otherwise the core's density increases more and more and if its mass is larger than 1.4 solar masses, the star collapses as a super nova. While the outer particles of the star are accelerated in direction of the core's centre, it is heating up to a temperature of round about 10^9 K, at the same time radiation is released. It splits the iron-atoms of the core into helium and neutrons. Because energy is needed for this process, the core's temperature decreases. A smaller temperature equals a slower movement of the single particles, i.e. they are stronger effected by the gravity, the collapse is enhanced. In consequence, helium cores are split into protons and neutrons. In the following, protons and electrons turn into further neutrons while releasing energy. This process continues until all the protons and electrons are transformed, the core's density increases thereby up to 10^{11} kg per cm^3. Finally, the neutrons are able to counteract the gravity because they allow no further reactions, the core turns stable again. Its radius is somewhere between 9 km if its mass equals three suns ore 13 km, then it would be as heavy as the sun. Those neutron stars, as these cores are called now, occur within binary star systems or as pulsars [5]. The latter are sources for different kinds of radiation. Due to their strong magnetic field and very fast rotation, a signal can be detected periodically, just like a giant lighthouse. They emit also radio waves, which in general occur because of electrons changing their energy state.

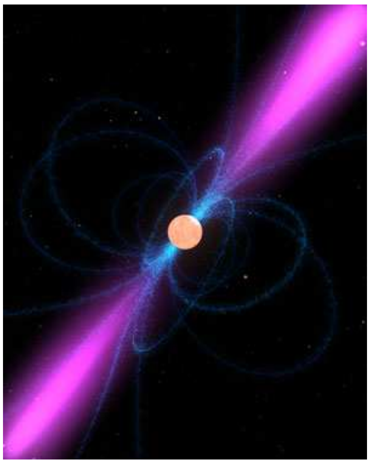


Fig. 4: A still from a pulsar animation, the jet is shown in violet and the magnetic field lines in blue [7]

Black holes, which also cannot be detected with an optical telescope, emit radio waves and as a result can be observed with a radio telescope.

In fact, Sagittarius A, the black hole in the middle of our galaxy, was the first radio source to be observed. In 1931 a radio engineer in New Jersey named Karl G. Jansky started to observe thunderstorm static to improve beam antennas for transoceanic radio-telephone circuits. Among those thunderstorm statics he discovered "*a steady hiss type of unknown origin*" [3]. In further studies he came to the conclusion that this unknown source cannot be part of our solar system, but must be located somewhere in the constellation of Sagittarius. Jansky himself never found out, what exactly he had detected, but with these early observations he laid the foundation of the radio astronomy and in his honour, this source is also known as J1 (J for Jansky-Source) [3].

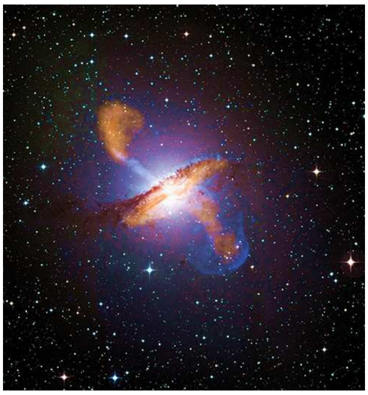


Fig. 5: An overlay of measurements of Centaurus A, the brightest object within the constellation of Centaurus [6]

Different wavelengths are interesting not only because of them offering information about the conditions and processes at a certain place; some sources could not even be detected in any other way. For example, in Fig. 3c) the visible light offers little information about the galactic centre, but infrared or radio waves arising there can pass the gas and dust on the way to the observer. To put as much information in one picture as possible, results of different observations are overlaid. For example, Fig. 5 is an image of Centaurus A, a highly active galaxy, probably even the remnant of a collision of two galaxies [4]. The picture in visible light is overlaid a false colour picture, depicting X-rays in blue and sub-mm waves in orange, i.e. radio emissions with the shortest wavelength, in the electromagnetic spectrum being located next to infrared.

2.1.1 Thermal sources

Sources are, depending on the kind of their radiation's incurrence, divided in thermal and non-thermal emitters [8].

The former contains every kind of sources emitting radiation, caused by electrons moving through gases or plasma, that means completely ionised gas with an extreme high temperature (5 000 K to 20 000 K) and a small density [4]. If an electron hits one of the gas' ions, it becomes bound again, thereby its energy decreases. The difference between the high kinetic energy and the lesser one after being bounded is emitted as an electromagnetic wave. In interaction with matter its energy can only be released completely or not at all and transfers a certain momentum, hence in quantum physics it is regarded as a particle called *photon*. The same happens, if an electron approaches a proton. Because of its positive charge it attracts and changes the electron's way, again producing radiation, releasing the so called *bremsstrahlung*. Examples for this kind of emitters are the Orion- and Rosetta Nebular and the most famous one, the cosmic background radiation, first detected in 1965 by A. Penzias (*1933) and R. Wilson (*1936) [3; 4].

Furthermore, depending on an object's temperature, its atoms and therefore electrons are moving faster or slower, thus every object emits in some way radiation, covering a certain continuous range of wavelengths.

2.1.2 Line spectra

Other radiations often observed are the specific line spectra of elements.

The energy level of an electron bound in an atomic shell can change between states of distinct energies. These are determined by the number of protons in the nucleus and the resulting occupancies allowed. If energy from the exterior is transferred to an atom's electron it is thereby forced to a higher energy level. Within a short period or after the external stimulation ends, it returns to its former lower level, emitting radiation with the according energy difference. A so called emission spectrum would show some sharp lines at special wavelengths. These wavelengths are specific for every element, because of the different energy states being quantized. A certain element's spectrum consists of multiple lines, because the transition between different energy levels causes different kinds of radiation. The same applies for different molecules. While passing a gas cloud on its way to the observer, parts of the radiation stimulate atoms and molecules of the cloud if the photon's energy is matching to their possible energy states. After this stimulation, the radiation will be released after a short while again. No longer being emitted in one single, but every direction in space, the radiation with this wavelength reaching the observer is much weaker than the rest of the gas cloud's emission. Therefore, within the resulting cloud's spectrum dark lines occur, the so called *Frauenhofer lines*. By measuring these lines, the single elements and thereby the composition of e.g. a nebular can be figured out [5]. Of special interest is especially the 21.1 cm-hydrogen-line, generated by neutral hydrogen's emissions at a frequency of 1.42 GHz, because of 98% of the universe consisting of hydrogen. A high signal at this wavelength at a special position would lead to the conclusion that in this direction a high amount of hydrogen and thereby maybe another galaxy might be located.

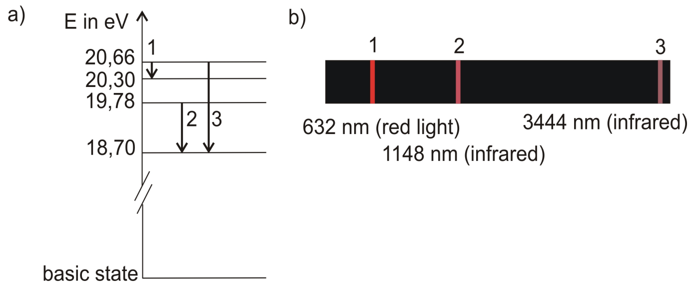


Fig. 6: a) Some of the quantized energy levels of Neon and b) the radiation caused by the three changes between these states. Altogether, Neon's line spectra consists of 28 lines only in the visible range [5]

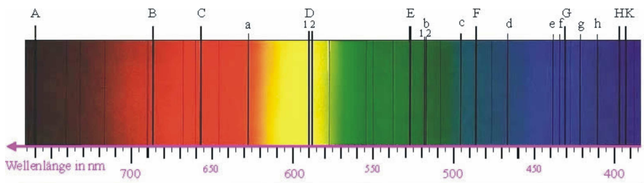


Fig. 7: The range of visible light of the sun's absorption spectrum. The Frauenhofer lines are caused by, among others, oxygen (A, B and a), sodium (D_1 and D_2)) or calcium (G, H and K) [9]

2.1.2.1 Doppler-Effect

Furthermore, if the original wavelength is known, these lines allow even statements about the velocity of an object by examining the *Doppler shift*. As shown in Fig. 9, if emitter and receiver are moving relatively to each other during the transmission, the emitted waves are stretched or compressed, resulting in lower respectively higher wavelength to be observed. The same effect, named after C. Doppler who discovered and explained it in 1842, also occurs e.g. when an ambulance with horn approaches and departs and its pitch seems to change.

A wave can be characterised as already mentioned by its wavelength λ, the shortest distance between two wave peaks, or by its period *T*, the time that it takes before the wave's shape repeats (Fig. 8). Expressed in another way does that mean, within the time *T* travels a wave with the velocity *c*, that in case of electromagnetic waves is the speed of light (approximately $c = 2.998 * 10^8 \frac{m}{s}$), the distance λ

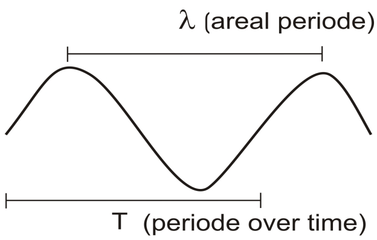


Fig. 8: Two of a wave's characteristics

$$\lambda = c \cdot T \qquad (1)$$

If the source of a wave itself is moving, the wavelength λ_R received by a resting observer would be longer or shorter, depending on the direction of the emitter's movement (Fig. 9).

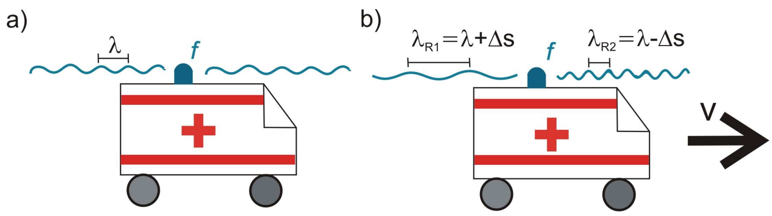


Fig. 9: a) a resting and b) a moving ambulance emitting constantly a signal with the wavelength λ (respectively the frequency f)

$$\lambda_R = \lambda \pm \Delta s \qquad (2)$$

The additional distance Δs is the way travelled by the emitter moving with the velocity *v* in the time *T* (Fig. 9). If its movement is uniform, λ_R can be written as

$$\lambda_R = \lambda \pm T \cdot v \qquad (3)$$

According to formula (1) *T* can be replaced, so the observed wavelength λ_R is

$$\lambda_R = \lambda \pm \frac{\lambda}{c} \cdot v \qquad (4)$$

$$\lambda_R = \lambda \cdot \left(1 \pm \frac{v}{c}\right) \qquad (5)$$

While talking about pitches, it is more comfortable to use frequencies, the number of complete periods within one second, than wavelengths, because a high frequency corresponds to a high pitch and the other way round.

Between both exists a simple relation:

$$\lambda = \frac{c}{f} \qquad (6)$$

where c is again the wave's velocity, i.e. in this case light speed. Because of this inversely proportional relation it has to be mentioned, that a high frequency corresponds to a short wavelength. Expressed with frequencies, formula (5) would be

$$\frac{c}{f_R} = \frac{c}{f} \pm \frac{c \cdot v}{f \cdot c} \qquad (7)$$

$$\frac{c}{f_R} = \frac{1}{f}(c \pm v) \qquad (8)$$

$$f_R \cdot \frac{1}{f}(c \pm v) = c \qquad (9)$$

$$f_R = \frac{c \cdot f}{c \pm v} \qquad (10)$$

$$f_R = \frac{f}{1 \pm \frac{v}{c}} \qquad (11)$$

Like in formula (2), the minus sign in this formula is, valid if the emitter approaches the receiver and vice versa the plus sign while departing.

2.1.2.2 Relativistic effects

Another effect that displaces lines within a characteristic spectrum can be explained by Albert Einstein's Relativistic Theory, when a source is moving with high velocities. Einstein postulated two basic principles:

First, within every inertial system, i.e. laboratory system that always shows the same results of experiments, no matter of being moved or not, all laws of nature are valid in the same way.

Second, the speed of light is a constant and has in every system the same value of approximately $2.9978 \cdot 10^8 \, \frac{m}{s}$.

To prove this, he made a gedankenexperiment, the so called *light clock.* As shown in Fig. 10a), a closed box with mirrors at opposite walls is imagined. Because of being a thought experiment only, the box can be assumed to be that big, that it takes a light beam one second to travel from one end to the other.

If a light clock is moving, a resting observer who watches the clock passing by will notice a different result than one moving together with the clock. The latter would, according to the second postulate, detect no difference; one move through the clock would take the light beam one second. The light beam's movement is uniform; those can generally be described by

$$s = v \cdot t \qquad (12)$$

where *s* is the distance travelled in the time *t* with the velocity *v*, which is, in this case, of course, the speed of light.

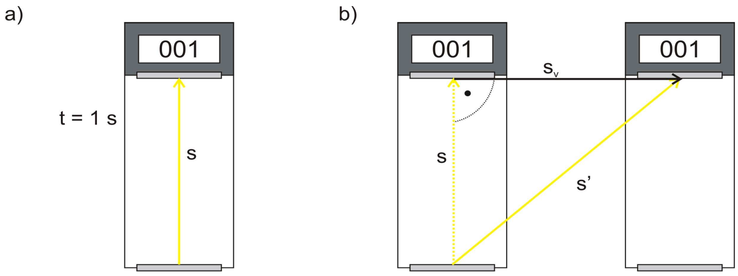


Fig. 10: a) A resting light clock, the beam travels round about $s = 2.998 \cdot 10^8 \, m$, i.e. nearly 300 000 km. b) A light clock travelling the distance s_v after the beam started.

Contrary, a resting observer would notice, that the light has travelled a longer way *s'*. Due to the postulates, *c* has to be constant in the system of the moved observer as well as in the systems of the one at rest. They study the same process in both cases described by a formula like (12), therefore the only possible conclusion is, that a greater distance *s'* means that the time *t'* in the moved system hast to be larger than *t*, the time the observer at rest would notice. Generally spoken, in a moving system time passes by more slowly than in a resting one. This phenomenon is called *time dilation.*

Fig. shows the distance *s* travelled by the beam within a clock at rest, s_v the distance the clock itself travelled and *s'* the light beam's way within a moving clock. These distances are depicted as vectors, they form a right-angled triangle, therefore their relations is, according to the Pythagorean Theorem

$$s'^2 = s^2 + s_v^2 \qquad (13)$$

These distances being, as described, covered in a uniform movement can be replaced by the right part of formula (12), so

$$(c \cdot t')^2 = (c \cdot t)^2 + (v \cdot t') \qquad (14)$$

Rearranged to *t'*, the time passing by in the resting system is

$$(c \cdot t)^2 = (c \cdot t')^2 - (v \cdot t') \qquad (15)$$

$$c^2 \cdot t = (c^2 - v^2) t'^2 \qquad (16)$$

$$t = \frac{c^2 - v^2}{c^2} t'^2 \qquad (17)$$

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad (18)$$

A frequency *f* is defined as the amount of events, e.g. oscillations, per unit of time. So, the difference of time between two observed systems causes also a displacement of expected frequencies. Although, as the last formula shows, the difference between *t'* and *t* is the smaller, the slower an object is moving, because of the radical's value being in this case very close to 1. In fact, *v* has to be at least 5% of the speed of light to make the dilation of time bigger than 0.1%.

Due to these two effects the position of a characteristic line within a spectrum will change, if a celestial body is moving or rotating. Fig. 11 shows as an example a spiral galaxy in top view that is rotating as well as departing from the observer while emitting a strong signal at the frequency f_S. The described effects are visible in the diagrams below; the flux density *S*, a measurement for the signal's strength (see "2.1.5 Flux density"), is shown as a function of different frequencies observed. If the source was not moving, just one peak would occur at the expected frequency.

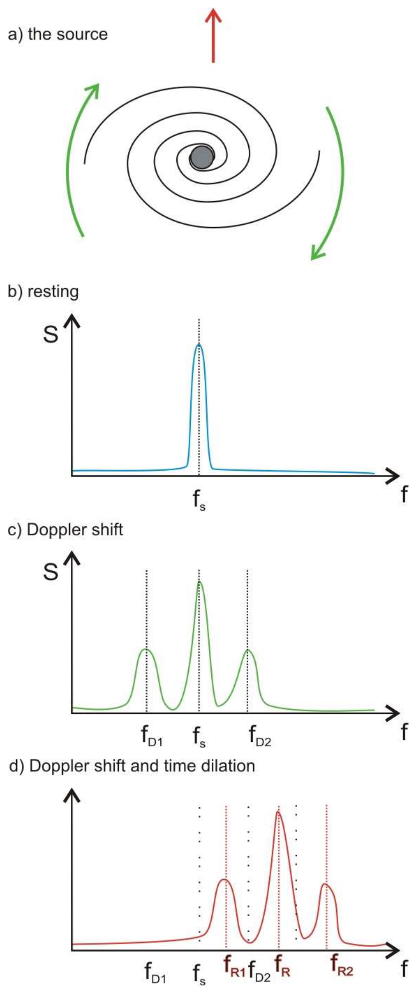


Fig. 11: Different effects to use characteristic line spectra to gain acknowledgement about a source's movement

The Doppler Effect (Fig. 11b)) causes a shift of the characteristic emissions, to the lower as well as to the higher part of the spectrum, because due to the rotation one arm of the object approaches the observer, the other departs (Fig. 11 a)). As long as it is only rotating, the core of the celestial body is not moving relatively to the observer. Therefore there is still a third peak at the expected characteristic frequency f_s. If the object is moving with a very high velocity, as explained time dilation occurs as well; in consequence all three lines would be shifted to different frequencies (Fig. 11c)).

Thus, conclusions from its distance and movement can be made only by studying the displacement of characteristic line emissions. Therefore, the bandwidth of the received signal must never be too small, otherwise frequencies displaced by these effects cannot be detected.

2.1.3 Non-thermal sources

Charged particles are not only set in motion by temperature or electric forces, but also because of magnetic fields. Contrary to electric fields, a magnetic field forces an electron on a circular path. Although they might be moving there with a constant velocity, they are accelerated steadily. Thereby, tangential to their direction of movement, radiation is released. Because of this kind of radiation also occurs in particle accelerators, especially cyclic particle accelerators, so called synchrotrons, this radiation is also commonly referred to as *synchrotron radiation* [4]. In this way the radio signals of quasars, i.e. the core region of highly active galaxies or the already mentioned pulsars, originate.

Another kind of non-thermal emission is the occurrence of the so called MASER-principle, i.e. microwave amplification by stimulated emission of radiation.

Atoms are stimulated by an exterior source and after a while one of them emits radiation while falling back to the lower energy level. This radiation makes other atoms release energy as well in the same instant and thereby the radiation increases [4].

Non-thermal sources are e.g. remains of supernovas like Cassiopeia A, the strongest emitter beyond our solar system, or the crab nebular, the result of a supernova, that was observed on July 4th 1054 [3; 4].

2.1.4 Black Holes

The reason for the origin of a black hole’s radiation is not quiet clarified; most likely it is a combination of different effects, the Blanford-Payne-scenario and the Blanford-Znajek-mechanism [6]. The former is caused by the black hole’s great mass and strong magnetic fields: Pursuant to the law of gravitation, black holes attract every other kind of objects, by friction these particles warm up. The extreme heat causes besides the light emitted radiation in the form of X- and Gamma-rays, the so called accretion disc evolves. This free energy leads to free and accelerated electrons; thereby a rotating magnetic field develops [10]. Influenced by this field, particles of the accretion disc starts to rotate as well and thereby form a particle beam. If its rotation is fast enough, this beam is accelerated and collimated and finally sent out as a so called *jet*, a subatomic beam accompanied by strong radiation at nearly every frequency [6].

The Blanford-Znajek-mechanism in contrast occurs if the black hole itself is rotating. As a result of the rotation, the different magnetic fields in the accretions disc are twisted. If magnetic field lines of different direction hit each other, redundant energy is transferred to the accretions disc's plasma. Its kinetic energy is now high enough to overcome the black hole's attraction, therefore the described jet occurs [6].

2.1.5 Radiation intensity and flux density

To compare the emissions of these different sources, a measurement for their strength is needed. Therefore, often the *radiation intensity I* is used.

It is defined as

$$I = \frac{\Delta E}{A \cdot \Delta t} \qquad (19)$$

that means, the energy ΔE that is transmitted per time interval Δt at an area A.

The energy E converted during the time interval Δt describes the power P, which is

$$P = \frac{\Delta E}{\Delta t} \qquad (20)$$

so formula (19) can be written as

$$I = \frac{P}{A} \qquad (21)$$

Its unit would be, according to that formula, $\frac{W}{m^2}$.

In the radio astronomy it is also common to use the *flux density S*, the integral of the source's brightness B

$$S = \int\int B(\theta,\phi)d\Omega \qquad (22)\ [3]$$

where Φ and θ are the vertical and horizontal opening angles of the antenna and *d*Ω, the infinitesimal *beam solid angle*

$$d\Omega = \sin\theta d\theta d\phi \qquad (23)\ [3]$$

Sources with a high flux density within our solar system are the sun, the moon, as a reflector of the sun's emission and parts of Jupiter's atmosphere. In Fig. 12 the flux density of some sources is shown as a function of the observed frequency, respectively the wavelength as indicated at the upper axis. The non-SI unit "Jansky" (Jy) given there for the flux density is named after the already mentioned founder of the radio astronomy. Among radio astronomers it is an often used measurement for the flux density. Expressed in SI-units

$$1\,Jy = 10^{-26}\,\frac{W}{m^2 Hz} \qquad (24)$$

that means, the unit "Jansky" is adapted to the mostly weak emissions of natural radio sources. The diagram's caption also has to be mentioned. The axes are labelled logarithmic, i.e. one step does not correspond to one unit, but the decimal power's exponent increasing by one. In comparison to terrestrial sources like e.g. satellites, those celestial bodies' radiation is distinctly weaker, a switched on mobile phone placed on the moon's surface would be, excluding the sun, the third-strongest source [4]. Therefore in the immediate surroundings of radio telescopes such terrestrial kinds of noise sources must be disabled as far as possible. To keep the influence of disturbing emitters as low as achievable, radio telescopes are built in remote places, e.g. within a desert or a valley, like the 100m-radio telescope in Effelsberg, Germany. Furthermore, several frequencies are protected for radio astronomy by law, i.e. terrestrial transmitters are not permitted to send at those frequencies, e.g. in the range from 89.0 GHz to 92.0 GHz, because of the characteristic emissions of different organic molecules like e.g. methanol, being located there [11].

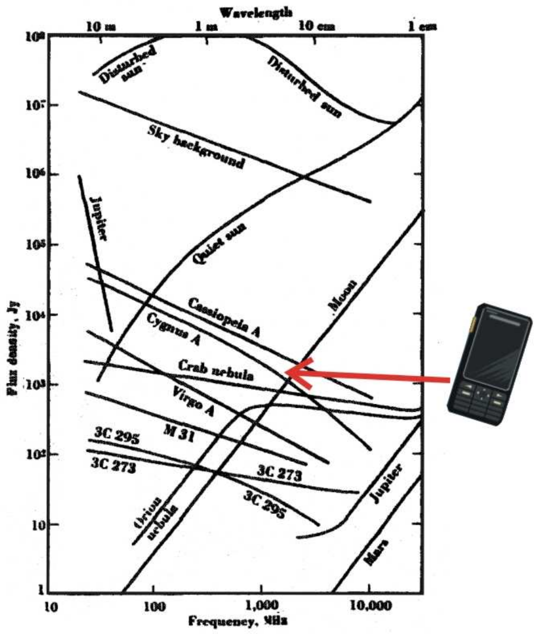


Fig. 12: Different strong sources and there signal's flux density at different frequencies (lower axis) respectively wavelengths (upper axis) [3, edited]

Having a closer look at Fig. 12 it can be detected, that the graphs are for some sources increasing, for others decreasing. These courses of the graphs allow a differentiation between thermal and non-thermal sources.

In general, as depicted in Fig. 13, the larger the observed wavelength, the "brighter" seems a non-thermal sources. Contrary to this, a thermal source has its signal maximum at shorter wavelengths, closer to the infrared rays.

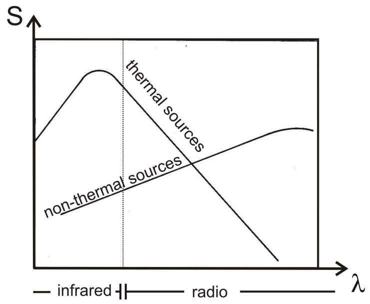


Fig. 13: The flux density at different wavelengths is one possibility to distinguish between the two major kinds of sources

To find out, whether a thermal or non-thermal emitter is studied, the observed wavelength just has to be changed and the source's flux density plotted as a function of the wavelength. It is useful to know the kind of radiation and therefore the related signal's process of its generation, to determine further conditions, e.g. the temperature, the density or the magnetic field strength. [4].

2.1.6 Polarisation

Differentiation between these two categories of sources is also possible because the emitted radiation is polarised in different ways.

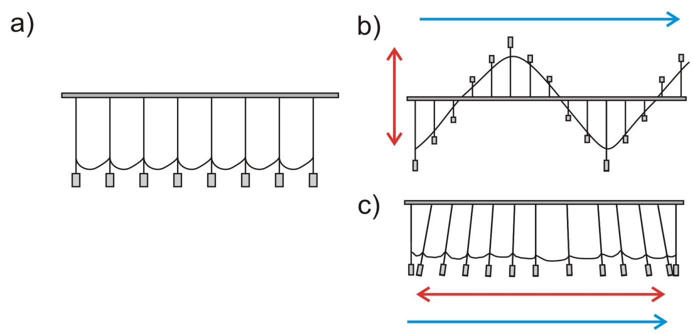


Fig. 14: a) linked pendulums as an example for a wave and them swinging as b) transverse (plan view) and c) longitudinal waves (side view), where the blue arrow is the wave's direction and the red one the swinging direction of the pendulums

Every kind of wave is defined as a linkage of singular oscillating systems. These oscillators are swinging in sequence in the same way. Waves are now divided in two kinds, *longitudinal* and *transverse* waves. The phenomenon of polarisation is only found among the former, because their oscillators are not swinging in the direction of the wave's movement, but perpendicular to it (Fig. 14b)). The arbitrary oscillators' swinging direction is called the *direction of polarisation*. Mostly, it is distinguished between *horizontal*

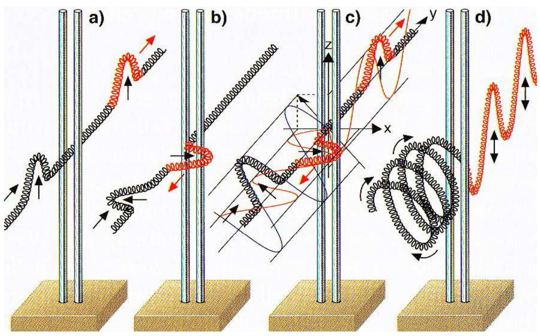


Fig. 15: a) vertical polarisation, b) horizontal polarisation erased by a polarising filter, c) a filter selecting parts of special polarisation d) circular polarisation being reduced to linear polarisation [4, p.125, Fig. 125.2]

polarisation, i.e. the vibration vector being parallel to the ground and *vertical polarisation*, perpendicular swinging oscillators. Also circular or elliptical polarisation can occur (Fig. 15d)), if a wave spreads out in a helical way. With so called *polarising filters* the kind of polarisation can be detected (Fig. 16). The first one reduces, if necessary, the wave to linear polarisation or filters out horizontal polarisation (Fig. 16a)). The second filter, aligned perpendicular to the first one, allows differing between vertical polarised and longitudinal waves. Both would pass the first filter unaltered, so the second one is needed to differ between the kinds of waves, while in cases of linear polarisation one filter would suffice to distinguish the polarisation directions.

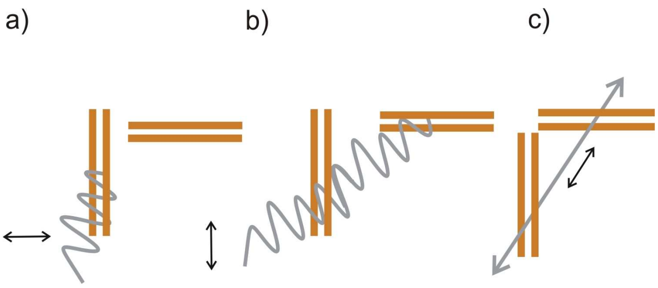


Fig. 16: Analysis of a) a horizontal polarised, b) a vertical polarised and c) a longitudinal wave

If a signal is not polarised in any way, it is of thermal origin, non-thermal, i.e. synchrotron emitters in contrast would show elliptical polarisation [4].

Another way to classify sources is there extent. First, to allow the derivation of formulas or to describe the behaviour of very small or distant emitters, the approximation of a *point source* is made sometimes, although not existing in reality. A source of larger extend up to 1° angular diameter is commonly referred to as a *localised source*, bigger ones are called *extended sources*. Although the distinction between large and extended source is in fact arbitrary, the value of 1° angular diameter is the agreed border among radio astronomers [3].

In summary, to realise meaningful measurement, a radio telescope should be able to allow the alteration of the observed frequency, to distinguish between different kinds of polarisation and to be sensitive enough to permit conclusions about a source's flux density. Furthermore, there must be a way to determine the "viewing direction" of the telescope, i.e. to identify a certain position at the sky.

2.1.7 Often used systems of coordinates

So reproducible to find a source or to observe the same points again, it is necessary to define a celestial body's explicit position in the sky. Therefore a system of coordinates is needed. Contrary to most systems used especially to identify places and distances on earth, galactic coordinates provide no length specifications, but angles.

Depending on the source observed, i.e. its distance to the observer or the period of the measurement, different coordinate systems are used. The simplest one is the horizon system depicted in Fig. 17.

The origin of ordinates equals the observer's position, the coordinates of a celestial body are therefore defined by two angles relatively to this place, one for the horizontal and one for the vertical direction. The reference plane for this location is a circle parallel to the horizon with the observer in its centre. The object's height, its *altitude* or *elevation*, is given as the angle between this plane and a line from the observer to the object. The imagined circle described by this line passing the zenith is called the *object circle*.

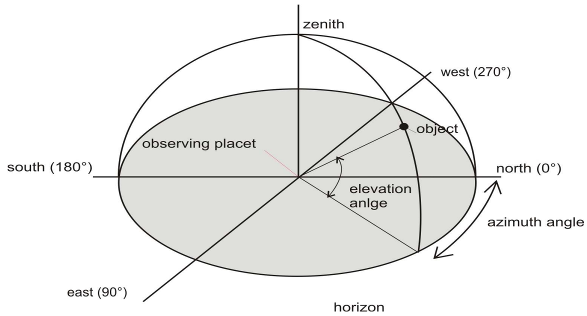


Fig. 17: The horizon system of coordinates

The horizontal coordinate, the *azimuth*, is measured clockwise from the north direction as zero point to the point of intersection of this object circle and the reference plane. It assumes therefore values between 0° and 360°. The advantage of this system of coordinates is the option of easy measurement of the coordinates, e.g. with a compass and a protractor and therefore an easily alignment. Nevertheless, the observer's position, i.e. his longitude and latitude, must be indicated, because the coordinates would be of course different at an altered place. Moreover, due to the earth's rotation and the movement of the object, its coordinates change at every time [3].

A different system of coordinates often used is the equatorial one (Fig. 18).

The earth is imagined to be in the middle of a sphere with a large radius, where the plane through the earth's equator is the plane of reference. The points of intersection between the line through the terrestrial poles and the surrounding sphere are the *celestial poles*. To ascertain a celestial body's horizontal position called *right ascension*, first a circle through the object and the celestial poles is defined,

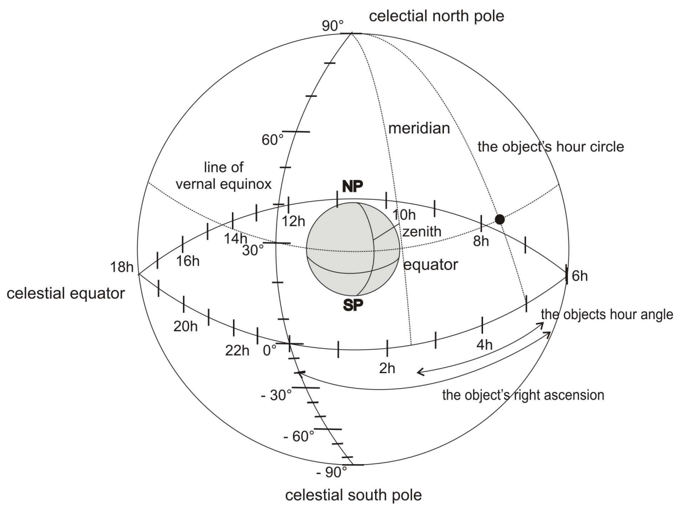


Fig. 18: The equatorial system of coordinates

called the object's *hour circle*. The right ascension is measured from this circle to an arbitrary reference, mostly the line of the vernal equinox, i.e. the circle through the celestial poles and the sun's position at approximately March 21st. Because of having been in the direction of the constellation of Aries years ago, the line of vernal equinox is commonly referred to as the *first point of Aries*. The right ascension is expressed in degrees, i.e. it assumes values from 0° to 360°, or in hours, minutes and seconds of arc, where

$$360° \triangleq 24\,\text{h} \quad (25)$$ and

$$1° \triangleq 4\,\text{min} \quad (26)$$

Furthermore, the object's *hour angle*, the angle between the hour circle, and the *meridian*, the circle through the celestial poles and the observer's zenith, can be declared to indicate an object's position. The relation between the right ascension RA_O of an object, the right ascension of the meridian as the observer's local sidereal time RA_m and the hour angle HA is

$$HA = RA_m - RA_O \quad (27)$$

Accordingly the algebraic sign of the hour angle provides the information, whether the object has already passed the zenith, in this case it is positive, otherwise it is negative.

The vertical coordinate, the *declination*, is given, similar to the horizon system, as the angle between the reference plane and the line from the earth' middle to the object. The scale is the same as the earth' system of latitude, i.e. the declination assumes values between 0° and -90° south of the equator and up to +90° in the northern hemisphere. Fig. 18 shows an object at 30° declination, for an observer on the earth at 30° north latitude it would pass the zenith.

In contrast to the horizon system, an object's coordinates remain the same independent from the observing place, however, they cannot be set without requiring major effort. Nevertheless, because of the earth' axe rotating with a period of round about 26 000 years, seen over a long-term period, these coordinates change as well. Hence, together with equatorial coordinates a date of reference, the so called *epoch*, is given.

Both types are useful while observing sources within or near our solar system. Other systems of coordinates, used to describe movements and positions on a larger scale, base on a different plane of reference, e.g. the *ecliptic system*, using a plane through the earth' orbit or the *galactic system*, based on a plane parallel to our galaxy [3].

2.2 Functional principle of a radio telescope

Generally a radio telescope consists of two main components: a receiving construction to observe the radiation and a method to measure its energy, an evaluation electronic.

2.2.1 Components of a radio telescope

Put simply, to send or receive electromagnetic waves, two electric components connected in series are needed: a coil, in whose inside a magnetic field arises with current being supplied, and a capacitor, a storage for electrical charges, generating an electric field between its plates. Either of these components is able to store energy in its specific field. They are, depending on the way they are integrated within a circuit, able to transform an AC (alternating current) signal into an electro-magnetic wave or the other way round. Thereby, a decreasing electric field *E* at the capacitor causes an increasing magnetic field *B* at the coil (Fig. 19). When the capacitor is discharged completely, the process reverses, the coil's strong magnetic field induces a current that again charges the capacitor, while the magnetic field's energy is reduced. Such an arrangement is called *resonant circuit*, because of having one distinct resonant frequency f_r at which the circuit can be stimulated to nearly undamped oscillations. This frequency is defined by the coils inductivity *L* and the capacitor's capacitance *C*

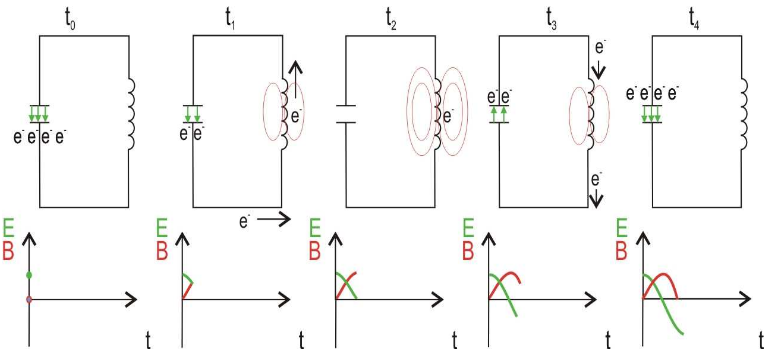


Fig. 19: Within a resonant circuit magnetic and electric field change periodically

$$f_r = \frac{\sqrt{\frac{1}{L \cdot C}}}{2\pi} \qquad (28)$$

In the simplest way, a piece of wire or a metal rod, called a Hertzian dipole, can assume the function of both, where the different fields are caused by the electrons movement within the wire (Fig. 20) [4].

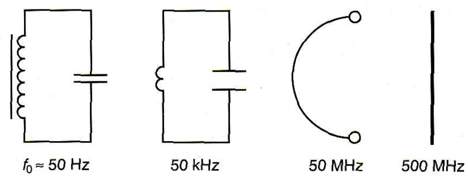


Fig. 20: Resonant circuits with increasing resonant frequencies [5, p.287, Fig. 287.1]

While studying strong sources, an antenna like shown in Fig. 21 suffices completely as transformer between the waves and a voltage signal. To observe weaker radiation, in addition a parabolic reflector has to be used to enhance the receiving area and to focus the incoming radiation. By mounting a *feed horn*, concentric metal tubes in front of the receiving dipoles, the waves are additionally concentrated; furthermore, feed horns can filter out special kinds of polarisation, so the incoming information is first reduced to a range closer to the desired one.

When the incoming radiation is strong enough to be detected, behind the Hertzian dipole first the transformed AC-Signal is amplified, whereas the system should add as little inherent noise to the signal as possible. The component's noise *N* can be described with the Nyquist formula

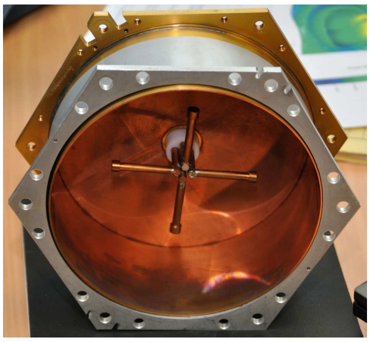


Fig. 21: A cross dipole of the MPIfR, especially made for the hydrogen's emissions at 1.42 GHz

$$N = k \cdot T \cdot \Delta f \qquad (29)$$

where Δf is the noise's bandwidth, k the Boltzmann constant ($k = 1.381 \cdot 10^{-23} \frac{J}{K}$) and T the temperature of the system, which is directly proportional to the noise. Therefore the HF-components of larger radio telescopes are refrigerated down to temperatures of ca. 15 K above absolute zero. After that a bandpass filter limits the frequency range, to reduce the influence of disturbing sources transmitting in close proximity to the desired frequencies. The lower a signal's frequency, the lower are the losses during the transmission along any conductors. Hence, an oscillator's signal with a constant frequency is mixed with the signal to decrease its frequency. If f_R is the frequency of the received signal and f_O the oscillator's, the resulting sum- and difference frequency can be written as

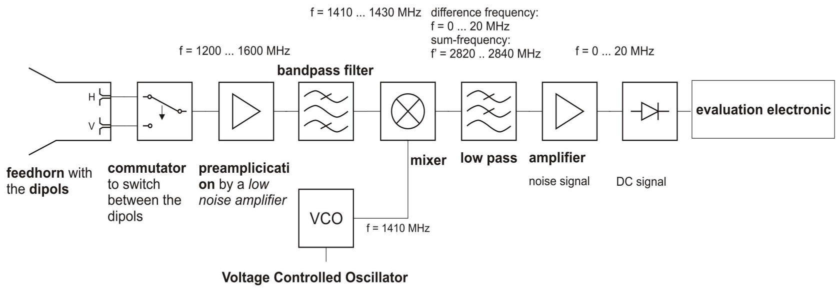


Fig. 22: general receiving technology, the values of the frequencies are examples from a LNB, a receiver used for satellite TV

$$f_S = f_R + f_O \qquad (30) \text{ (sum-frequency)}$$

and

$$f_D = f_R - f_O \qquad (31) \text{ (difference frequency)}$$

Because of the difference frequency being now very much smaller than the originally received one, only this part of the signal continues to be used. Then it is separated from the rest of the signal with a low pass filter. Generally that is combination of a resistance and a capacitor, but in this case, using high frequencies, a combination of inductances and capacitors is used. Depending on the kind of measurement the filtered signals can then either be analysed immediately or saved to do so later.

2.2.2 The angular resolution

The parabolic reflector is also crucial for the telescope's angular resolution, which equals the minimum angular distance $\Delta\alpha$ between to objects, that is required to ascertain a definitely distinction between them.

The waves that are emitted by one or multiple sources, interfere at location of the receiver, furthermore every obstacle or aperture causes diffraction. According to C. Huygens (1629-1681) every obstacle causes the arising of elementary waves, circle waves propagating in every direction (Fig. 23). Therefore we cannot observe an object, but its diffraction pattern. Those patterns should have a sufficient distance as shown in Fig. 24; otherwise the picture gets fuzzy (Fig. 24 b)). This minimum distance *R* corresponds to the length between the 0^{th} order maximum and the 1^{st} order minimum. If Fig. 25, the depiction of diffraction at a slit is considered as a simplified example, a relation for *R*, the image distance *b* and the angular distance $\Delta\alpha$ arises from geometrical considerations.

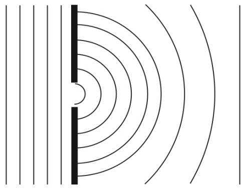


Fig. 23: Huygen's principle

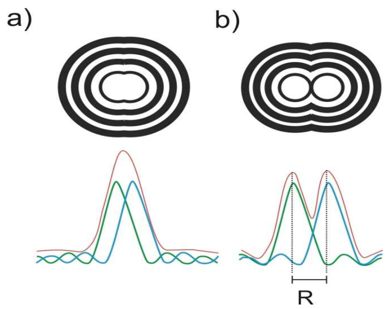


Fig. 24: Diffraction pattern of two sources that a) cannot and b) narrowly be distinguished

$$\sin(\Delta\alpha) = \frac{R}{b} \qquad (32)$$

Rearranged to *R* it shows, that

$$R = \sin(\Delta\alpha) \cdot b \qquad (33)$$

For small angles the approximation

$$\sin(\alpha) \approx \tan(\alpha) \approx \alpha \qquad (34)$$

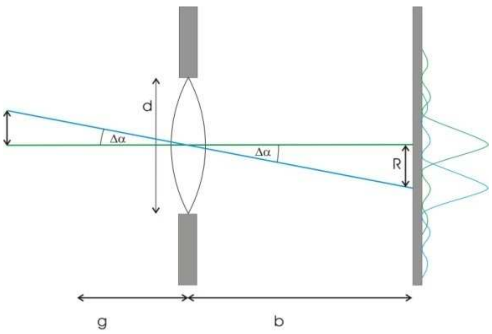


Fig. 25: Diffraction at a slit

can be made. So formula (33) can approximately be written as

$$R = \alpha \cdot b \qquad (35)$$

Now, another way to express α is searched.

While talking about interference it must be distinguished between constructive, i.e. amplifying and destructive, i.e. effacing superposition. Fig. 25 shows an arrangement that produces a picture at the screen, so constructive interference occurs. Therefore the condition

$$\sin(\Delta\alpha)\cdot d = n\cdot\lambda \qquad (36)$$

valid for constructive interference must be true. It arises from geometrical considerations, according to Fig. 26; the difference between to amplifying waves can be either expressed by

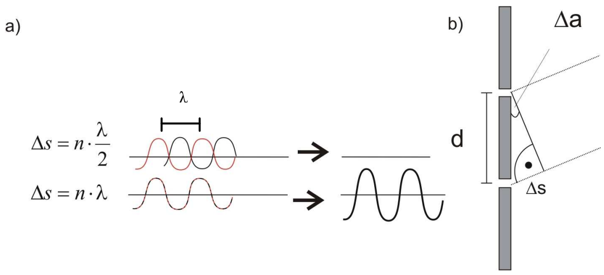


Fig. 26: a) destructive (above) and constructive (below) interference and b) interference at a slit.

$$\Delta s = n\cdot\lambda \qquad (37)$$

or

$$\Delta s = d\cdot\sin(\Delta\alpha) \qquad (38)$$

both combined yield to formula (36).

Rearranged to *sin (Δα)* respectively α, α can approximately be expressed by

$$\alpha = n\cdot\frac{\lambda}{d} \qquad (39)$$

where d is the slit's width, λ the light's wavelength and n the order of the maximum or minimum. Because the first order minimum was regarded, n would be 1. But in reality diffraction of waves seldom occurs like in Fig. 25; but similar to the diffraction at a circle aperture. The calculation of the intensity distribution, like the right part of Fig. 25; is much more laborious and complex. The first one who succeeded to do so was A. Fresnel (1788-1827), but because of its complexity this calculation is nowadays done by a computer. The circle aperture's area is divided in regular streaks. According to Huygens the assumption is made, that every one of them is the origin of elementary waves (Fig. 23). These waves' amplitude is directly proportional to the streak's acreage, i.e. the intensity is not uniform. The smaller the distance of a point to the margin of the circular aperture, the lesser is the intensity at this place. To calculate the complete intensity distribution, the horizontal and vertical components

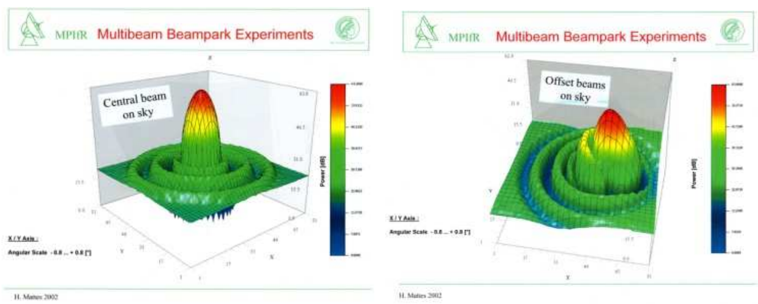


Abb. 27: The intensity distribution a) caused by direct exposure and b) if the main focus is not quiet hit [4a]

of every streak are added up for every single place and every angle of incidence. The result of these calculations looks like Fig. 27. They provide a value of approximately 1.22 for *n* for the 1st order minimum, resulting in

$$\alpha = 1.22\frac{\lambda}{d} \qquad (40)\ [5]$$

As long as *b* is known, a minimum distance *R* given in metre can be calculated with formula (33), but mostly formula (40) is of more interest. In contrast to optical telescopes or microscopes in the radio astronomy *d* does not correspond to a slit's or lens' width, but the diameter of the parabolic reflector. The it is, the smaller becomes the fraction's value, i.e. the smaller is the minimum angular distance between two objects. Therefore radio telescopes with large parabolic reflectors have a better angular resolution than smaller ones. As a negative result the tracking and control have to become more accurate to allow the precise alignment to a specific point.

Another possibility to achieve a high resolution even without big reflectors is the saving and subsequent computational interference of the signals. For Very Long Baseline Interferometry (VLBI) two or for Very Long Array (VLA) even more telescopes are pointed at the same coordinates. The signals they detect are saved with a highly precise time signature, for this purpose atomic clocks are used. Later on a computer program correlates the signals as if they had been detected by one giant reflector with a diameter like the distance between the singular telescopes [5]. By combining different radio telescopes, an angular resolution of $\frac{1}{10\,000}$ arc second could be achieved. That would mean being able to detect a tennis ball on the moon's surface. This concept is also used in the VLBI Space Observatory Programme (VSOP), a Japanese radio astronomy project started in 1997. With the help of an extra terrestrial 8 m-receiver and the correlation with radio telescopes on the earth, an effective diameter of up to 30 000 km could be achieved [4]. Its aim is among others to study AGNs, Active Galactic Nucleus, i.e. black holes respectively their jets.

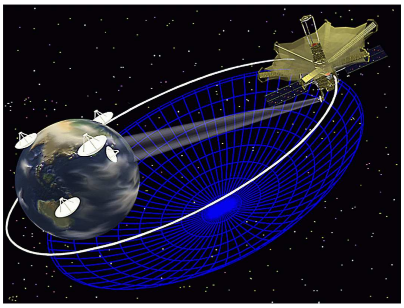


Fig. 28: The VSOP, its effective parabolic reflector is shown in blue, its diameter equals round about 2.5 times the earth' diameter [4]

However, a radio telescope can only be oriented at one only point, i.e. contrary to optical telescopes, which produce a complete depiction of the region observed, just one pixel can be obtained at any times. Nevertheless, pictures of larger areas of the sky can be taken when the parabolic reflector is moveable, just like the 100 m radio telescope of the Max-Planck-Institute for Radio Astronomy in Effelsberg, the biggest rotatable radio telescope in Europe. To alter the radiation's angle of incidence on the receiver and therefore the "viewing direction" of the telescope in a limited way, the position of the receiver relatively to the prime focus can be changed as well. That is the way e.g. the big radio telescope in Arecibo, Puerto Rico, is working, using a reflector that fills a whole valley.

Fig. 29: The 100-m moveable radio telescope in Effelsberg, Germany

While observing moving objects, the reflector can be pointed on one place on the object's path and then be fixed. Due to the inherent motion of the object the intensity distribution can be detected as well.

3 The self-built radio telescope

Being a competition entry to the "Jugend Forscht"- competition, my self-built radio telescope should be realisable with basic materials and moveable in horizontal and vertical direction. A short enquiry in the internet revealed the general possibility and several examples for such a project. Most of them use the most common possibility to receive radio radiation: a customary satellite system for television.

3.1 The receiving system

To receive satellite television, a LNB, a *Low Noise Block*, a signal converter adding very little hissing to the incoming signal, is used. In my project, I am using the type Sharp BSCS86M50 Dual that is able to receive and process frequencies between 10.70 GHz and 12.75 GHz, i.e. according to formula (6) signals from 2.35 cm and to 2.80 cm wavelength. This range is near the lower limit of the atmosphere's radio window (Fig. 1) [4].

Fig. 30: A LNB from the outside

Firstly, as already mentioned, concentric metal cylinders focus the incoming waves on two perpendicular dipoles, one for each kind of polarisation, because of satellite's signals being either horizontal or vertical polarised. By switching between a 14 V and an 18 V DC (direct current) signal for the LNB coming from the receiver, both kinds of polarisations can be used. As described (see chapter “2.1.2 Non-thermal sources”), natural sources can emit circular polarised waves; therefore both dipoles are needed to receive these signals, thereby a switching between the different amounts of both kinds of polarisation is possible.

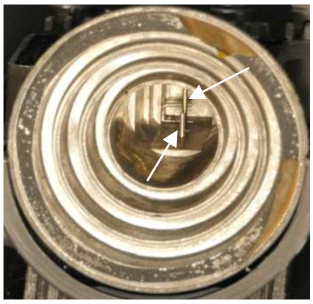


Fig. 31: The LNB’s receiving hole aperture with the two dipoles

As a protection against dirt, LNBs are equipped with a cover at their entry opening, therefore they can easily be damaged while opening. That is why the pictures shown are photographies of a broken one, the only difference between the actually used and the depicted one is the number of connectors for satellite receivers.

Afterwards, the received signals are amplified (1) and reduced to a frequency between 950 MHz and 2150 MHz by being mixed (2) with a built-in oscillator’s signal (3). This reducing is necessary because the lower a signal’s frequency, the lower are its losses while being conducted in even longer coaxial wires. Furthermore, thereby the following electronic, e.g. the satellite receiver, can handle the incoming signals and produce a TV image at a monitor. The amplifier stages are partially connected with a capacitor, a component that represents an infinitely high resistance for DC signals. Thereby the signal having been mixed with a DC signal is freed of it again. Because of the depicted LNB having four connections, amplification and decoupling of the signals happen two times on the circuit board’s front and back.

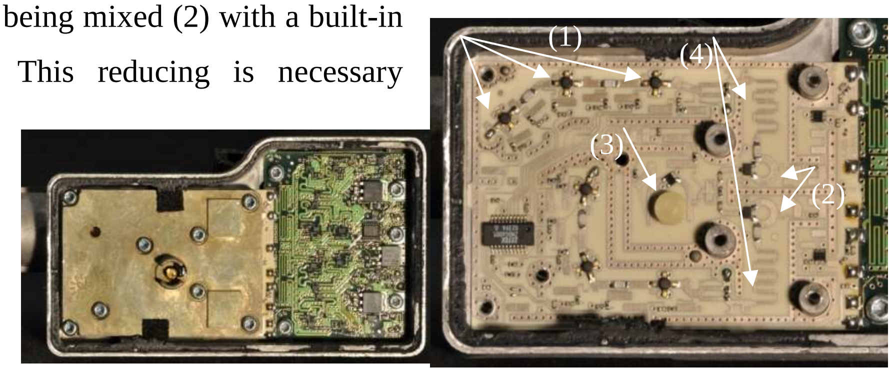


Fig. 32: The LNB’s inside with a) a covering over the high-frequency components and b) without it

This LNB (1) is mounted in an existing holder at the lower verge of the satellite dish (Fig. 33). Its effective diameter is 70 cm, so in comparison to

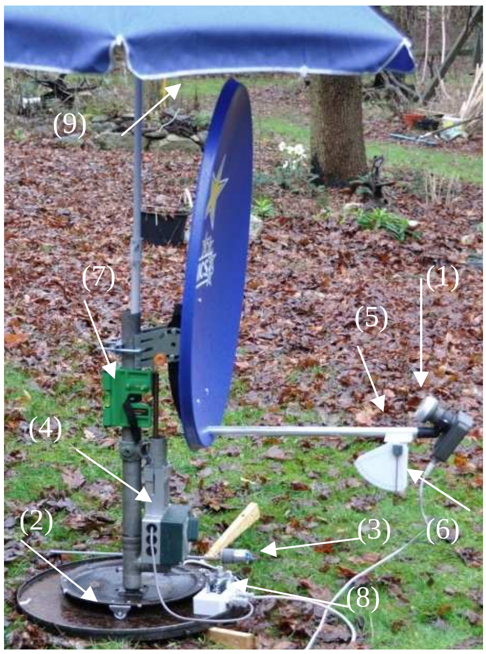


Fig. 33: The construction at the observing place

“real” radio telescopes very small, but manageable in the framework of this project. It is mounted on an old rotary plate, placed upside-down with a short steel tube. Because of this kind of fixture the dish’s easily horizontal movement is ascertained without the need for moving the whole construction. The rotatable part of the plate is also supported by four rollers (2), to prevent the steel tube from tilting and thereby distorting the elevation angle.

The reflector’ turning in horizontal direction is controlled by an electric rotating motor fixed at the plate (3). It is connected to the plate by means of a threaded rod used as a drive spindle (3a). A piece of acrylic glass, rotatable fixed at the rim of the plate and provided with a screw thread, connects the drive spindle with the plate. (3b). If the motor starts rotating, it approaches or withdraws the motor due to the spindle’s turning. This allows turning the plate by about 100° in horizontal direction.

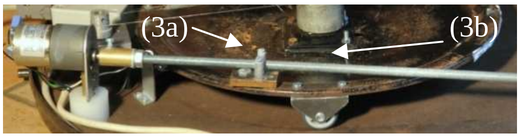


Fig. 34: The azimuth control

For the elevation control, a second motor (4), normally applied to adjust valves in a heating system, is used. By moving up and down a copper tubing (4a), which is fixed at the back of the reflector’s mounting, it alters the elevation within a range from 0° to 25°. To determine the initial telescope direction, as already described, a compass and a protractor can be used. For this purpose, a metal plate, as placement for the compass, is located next to the LNB (5). This is necessary to ascertain, that the compass, whose accuracy is round about 3°, is positioned horizontally; otherwise the measurement would be falsified. A self-built protractor (6), consisting of an angle scale and a small weight fixed at a brass rod, allows to read the elevation angle with a precision of approximately 1°. Although there is already an angle scale at the reflector’s back, this method is more accurate, because of the former being very small. To guarantee the horizontal positioning of the whole construction, a combination of three sprit-levels is mounted at the steel tube (7). With the help of these levels and three adjustable feet, the telescope can be adapted even to uneven grounds. Having been partly mounted at the outside of the casing (8), the electronic components for the motor control have to be protected against the rain. Furthermore, the plate consists of wood, so it should not get too wet either. A sunshade, being big enough to cover the whole construction, can be put in the steel tube to function as a provisional rain shelter (9).

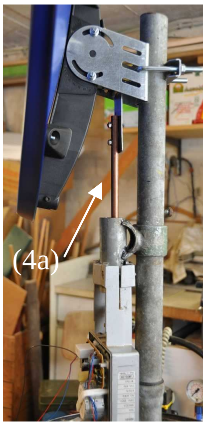


Fig. 35: The elevation control

3.1.1 The electronic control

The electronic part of the construction consists of the control circuit for the two motors, located in the immediate vicinity (Fig. 33, (8)) and the control unit (Fig. 36) that can be placed near the measuring station. The complete circuit diagrams of all self-built electronic elements can be found among the appendixes.

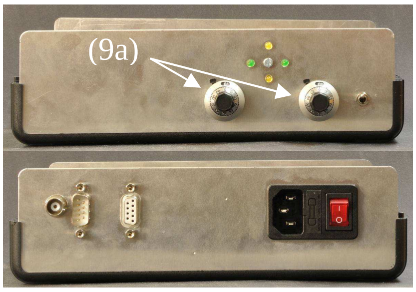


Fig. 36: The control unit's front and back

The control unit contains the source for the motors' and control's supply voltage. Its circuit diagram is "Appendix I". To provide the voltages required, a transformer (Fig. 37, TR1) and a rectifier, the combination of the capacitor C1 and the diode D1, is needed. The first one smoothes the DC voltage coming from a socket, while the diode is conductive only in one direction and hence produces the voltage polarity desired. A DC-DC-Converter (DC1) and a voltage stabiliser (IC1), provide a bipolar supply voltage from -15 V to +15 V and a stabilised 10 V supply used as reference voltage for the construction's position feedback. As a voltage being defined as a potential difference, one common reference point, ground (GND), is needed for all of them. The transformer's output of 24 V AC is connected directly to the motor control circuits. The regulation voltage that controls the two motors' movement is determined by the two potentiometers R2 and R3, adjustable resistances ((9a), blue mark Fig. 38). According

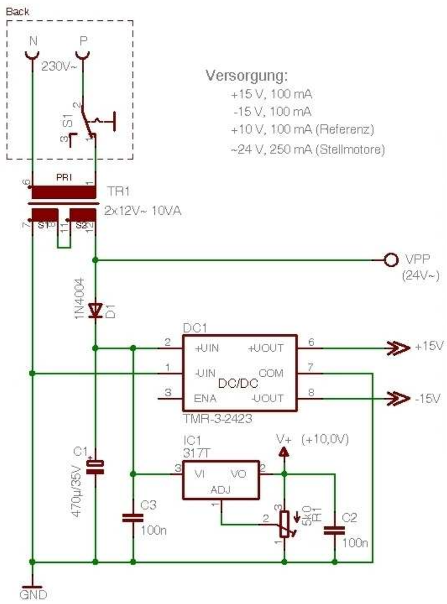


Fig. 37: The electronic components for the mains voltage transformation

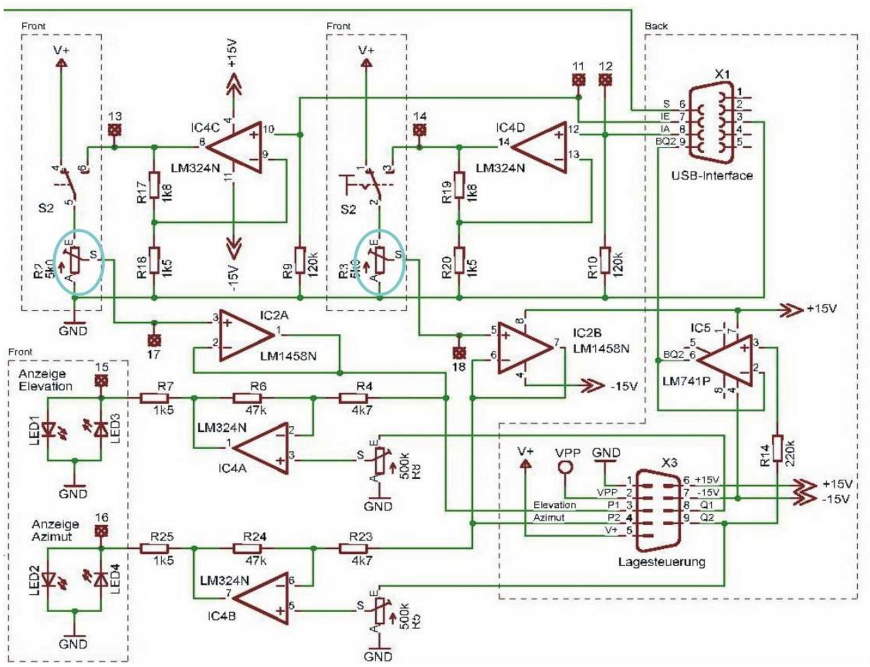


Fig. 38: The other components of the control unit

to their setting, a voltage signal is transmitted to pin 3 and 4 of the sub-D connector X3 and together with the other signals via a long shielded cable to the motors' control circuit at the rotatable plate.

The casing there has two further sub-D connectors, X4 and X5, each of them is connected to one of the motors ("Appendix II"). As it can be seen in Fig. 39, the 24 V AC signal at pin 2 of connector X4 is first applied to two diodes, D1 and D2 (blue mark). The latter is conductive for the negative portions of the AC signal, vice versa D1 for the positive ones. Thereby the incoming voltage is split in a negative and a positive signal, this arrangement of diodes is called *half wave rectifier*. The two capacitors C3 and C4 are periodically charged by the incoming supply current via the two diodes and discharged by the electric load of the following components. Thereby they smooth the otherwise pulsating DC voltage.
These supply voltages are applied to the transistors Q1 and Q2 (violet mark). Those are semiconductor devices that function as current amplifiers, controlled by the current that is applied between two of their ports, the *base* and the *emitter*. Due to the high current at their third port, the *collector* and the according power dissipation, they have to be mounted on heatsinks on the casing's outside.

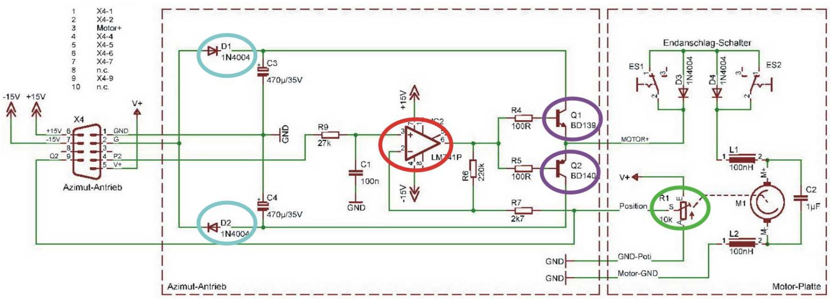


Fig. 39: The circuit diagram for the azimuth control

The algebraic sign of the arriving signal determines the direction of the motor's turning. Therefore, it is necessary to make one transistor conductive while the other stays insulating. For this purpose the second voltage from the control unit, the regulating signal is used. In case of the azimuth control it is applied to pin 4, otherwise pin 5. The combination of the capacitor C1 and the resistance R9 is a low pass filter used to free the signal from possible noise or disturbances and prevents the motor from trembling. Afterwards, it is connected to the positive input of IC2, an *operational amplifier* (red mark). Those are used in various types of circuits, e.g. for amplifying or like in this case, for regulation of a voltage signal. It contains three ports, two for input and one for output. The latter's signal U_{out} is the amplified difference between both incoming signals U_{in1} and U_{in2} *at the positive and negative inputs*

$$U_{out} = n \cdot (U_{in2} - U_{in1}) \qquad (41)$$

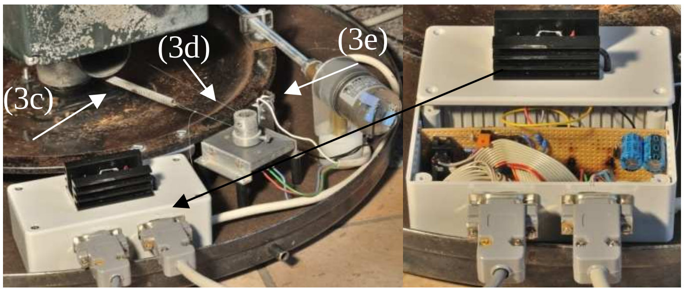


Fig. 40: The electronics for the azimuth control

If the output signal becomes negative, transistor Q2 turns conductive, otherwise it is Q1. If the desired position is reached, the motor should stop its rotating. For this purpose, the signal at the negative input port has to be raised while the motor is turning. Therefore the steel tube is connected to another potentiometer R1 (green mark, Fig. 40 (3d)) with a steel wire and a coil (3c)). By being connected in this way, it turns while the steel tube is moved, and the negative input signal increases until the output signal becomes 0 again and the motor stops. Decreasing the signal of the positive input causes the output to become negative, and the other transistor moves the motor in its opposite direction. As already mentioned, the azimuth can only be altered within a range of 100° due to the mechanic fixation. To prevent the motor from turning the reflector despite of this further on, two microswitches ES1 and ES2, demounted from an old computer mouse, are fixed at the outer edge of the plate at exactly the two end positions (Fig. 40, (3e)). If one of them is pressed, the motor stops automatically its movement, because in this case the current is stopped by diode D3 or D4. Inverting the motor current, the appropriate diode allows the motor to turn in its opposite direction again.

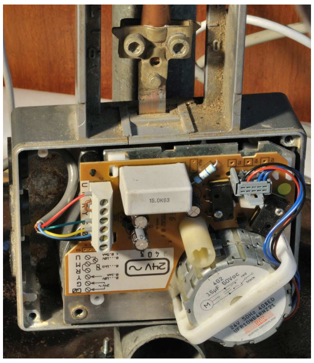


Fig. 41: The inside of the elevation motor's casing

Because of the elevation drive unit having been used for a defined purpose, its casing already contains a circuit board with such an arrangement; therefore its circuit diagram is just a pattern depicting the different sorts' assignment ("Appendix II"). It is connected with the same AC voltage supply as the azimuth motor, only the regulation signal is of course the one controlled by the other potentiometer.

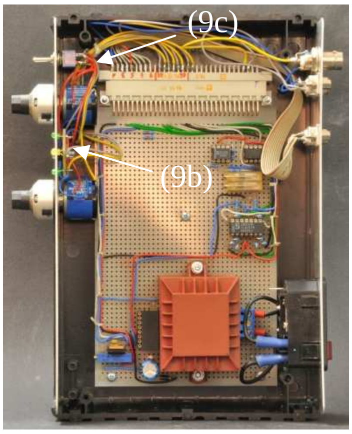


Fig. 42: The control unit's interior

To be able to realise at a remote measuring place, that the reflector has reached its desired position, four LEDs are used (LED1-4, Fig. 42, (9b)). As can be seen in Fig. 38, the nominal signal, connected to pin 3 respectively pin 4, and the current signal, i.e. the voltage changing while the turning, connected to pin 8 and 9, are applied to two other operational amplifiers, IC4A and IC4B. Just like at IC2 in the motor's control, their output signals turn negative, to 0 or positive. The connected LEDs are according to this light emitting or not. By setting the two potentiometers R5 and R8, this position feedback can be adjusted. In addition to that, the voltage determined by the motor's current position is applied to IC5, another operational amplifier. In this case it is not used to amplify, put to ascertain that the signal is not falsified. It is connected to pin 9 of the sub-D connector and used to determine the telescope's azimuth from a remote place.

Within a circuit the different currents and voltages can have influence on each other, but to ascertain that the motors stand still when the set position is reached, the control signals have to be stable. To provide the required low impedance output, two additional operational amplifiers IC2A and IC2B are placed between the potentiometers and the connectors that lead their signals to the motors. Thereby currents caused by disturbances produce only a low voltage disturbing.

As an even more comfortable and precise alternative to use the potentiometers for a manual control, the two regulating voltage signals can be replaced by analogue signals from an USB-interface. Such a one is able to send and receive analogue and digital signals from a computer and send them to a device like the control unit connected with a cable. For this purpose the device's signals have to be amplified by the operational amplifiers IC4C and IC4D from approximately 4.4 V to 10.0 V. By using switch S2 (Fig. 42, (9c)), it can be changed between the manual and the computerised control.

3.2 The evaluation electronics

To analyse the signals measured, two ways with different advantages and disadvantages are possible. Mainly a customary satellite finder, a device used to direct the satellite dish to the right position was used. An alternative is the FUNCube Dongle, a software defined receiver the size of a USB-stick.

3.2.1 The satellite finder

A satellite finder helps to find the correct position for a satellite dish by giving an optical and acoustical feedback according to the strength of the received signal. For this purpose it is inserted at one end of the cable between the LNB and the satellite receiver. The stronger the signal, i.e. the nearer the dish's focus is pointed to the satellite's position, the stronger becomes the beep signal and the

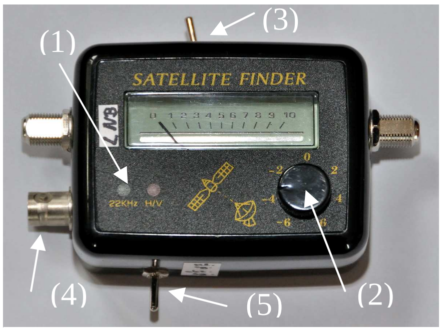


Fig. 43: The modified satellite finder

higher is the pointer setting. This characteristic indicates, that within this appliance the AC signal coming from the LNB is changed into a DC signal, that can be processed further, for example by amplifiers connected to the USB-interface and an appropriate software.

For this purpose the satellite finder depicted in Fig. 43 has been modified in several ways.

As visible in the circuit diagram (“Appendix III”), the LNB’s signal is divided. One part passes the appliance unaltered, the other part is used to supply the finder with the necessary voltage and to produce an information about the signal’s amplitude. It indicates not only the received HF signal, but also the operating voltage for the LNB coming from the satellite receiver to switch between the two possible polarisations. So, to gain its own DC voltage needed, the overlaid DC-component is filtered out by passing an inductance within the finder (Fig. 44). With the help of transistor V2 and resistance R1 it is altered to a signal of round about 8 V (VCC). Furthermore, it is applied to LED1 that lights the display. As already mentioned (see chapter “3.1 The receiving system”), the value of the DC voltage supply from the satellite receiver, either 14 V or 18 V, determines whether vertical or horizontal polarised waves are detected. If the latter is the case, the satellite finder is able to indicate this with another LED. This visualisation is controlled by transistor V5. If the voltage applied to its base and emitter is the mentioned 18 V signal, the current at the collector becomes high enough to make LED3 emit light. In addition, the receivable range of signals is divided in the low band, i.e. frequencies between 10.70 GHz and 11.70 GHz and frequencies up to 12.75 GHz, the high band. To switch to the latter, the DC voltage supply is modulated with a second signal at a frequency of 22 kHz. In this case, the satellite finder uses this part of the voltage to activate LED2.

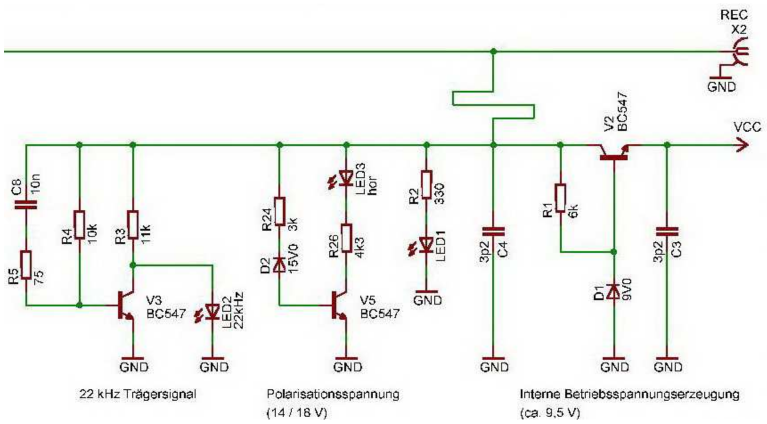


Fig. 44: The satellite finder’s component generating the operating voltage

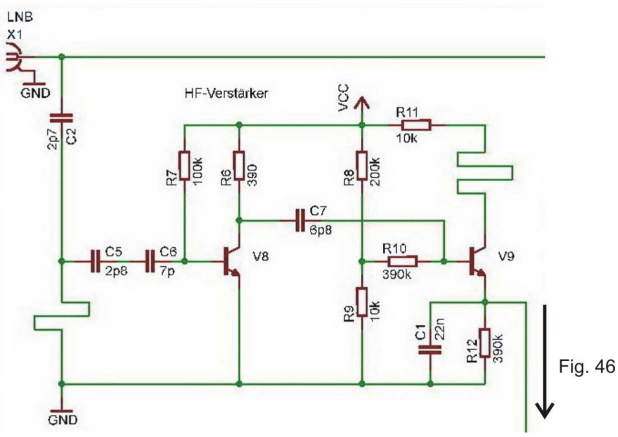


Fig. 45: The signal processing

To process the HF part of the LNBs signal, first it is freed from the DC signal and then amplified by transistor V8. Due to the capacitor C7 and the resistances R8 and R9, acting as a voltage divider, transistor V9’s signal depends on the LNB signal’s average value. It is connected to the positive port of IC1B (Fig. 46). The signal that is applied to the negative port can be altered with the potentiometer VR201 (Fig. 43, (2)), the adjuster for the finder’s sensitivity. Because of the relation between a resistance *R*, a voltage *U* and a current *I* being

$$R = \frac{U}{I} \qquad (42)$$

its high value cause a low current. This is necessary to keep the appliance’s electricity consumption low and to prevent high heat development. For processing it further, the voltage regulated by VR201 is transformed to a low-resistance signal by IC1A, another operational amplifier in this case used as impedance converter. Afterwards, it is connected to the negative port of IC1B. As already mentioned in formula (41), generally an operational amplifier’s output signal depends also on a constant *n*. This constant equals the relation between the two resistances connected to their negative port and the output port. In this case

$$n = \frac{R18}{R17} \qquad (43)$$

Therefore, the signal is amplified by nearly factor 40. Finally, this output signal is connected to the level meter M1, and there it determines the pointer’s setting. In addition to that, it is applied to IC1C. The arrangement within the red frame contains is called a *multivibrator with a voltage controlled frequency*. As already explained, the two incoming signals determine the voltage at the output port. However, this signal is connected to the input port with the two resistances R20 and R22, this is called *back coupling.* As a consequence, it influences the voltage at the input ports. Due to this, it increases first and when it reaches its maximum, the process is reversed; the output signal approaches the other maximum. Hence, the output signal swings periodically, with a frequency that is determined by the used resistances R20, R22, R25 and the capacitor C9. The resulting AC signal is then applied to the signal generator, the beep signal arises. As one

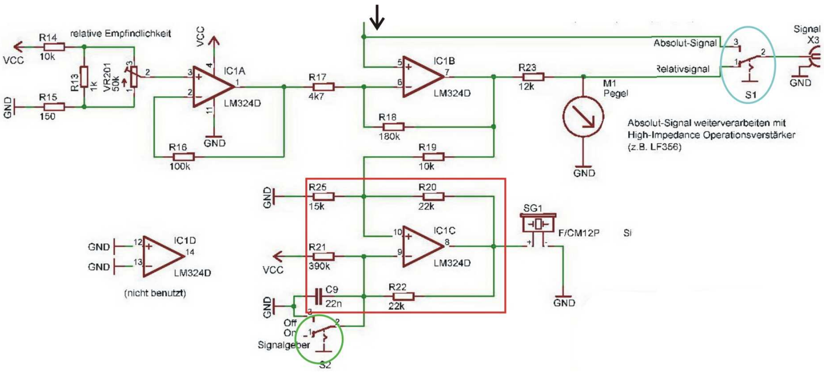


Fig. 46: The evaluation of the signal

modification, switch S1 (Fig 43, (3), Fig. 46, green mark) is integrated in this arrangement to override the capacitor and thereby disable the signal generator if desired. Furthermore, an additional bushing (X3, Fig. 43, (4)) was integrated in the satellite finder's casing and connected to the signal applied to the level meter, or respectively if the setting of switch S2 (Fig. 43, (5)) is changed, to the signal coming from transistor V5. The latter option would offer some advantages, because the output signal is independent of the potentiometer's setting, but also requires an additional circuit.

Therefore, the relative signal from the level meter is processed further. With a BNC cable it is transmitted to the control unit. Never assuming values higher than 0.5 V there it first has to be amplified by factor 10 by IC3, before being transmitted to pin 6 of the sub-D connector and the interface. Afterward the signals strength is evaluated and saved using a computer.

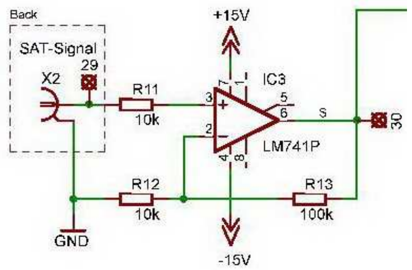


Fig. 47: The amplification of the signal from the satellite receiver

The complete measurement arrangement can be seen in Fig. 48. Due to the cables length, the receiving system can be located up to 10 m away from the evaluation electronics. The motors' control unit is connected to the control unit (1) and the LNB with the satellite receiver (2) with the satellite (3) inserted. The USB interface transmits its signal as described to the USB interface (4) that allows further evaluation with the computer, as well as the remote control of the mechanical construction. As long as television satellites are observed, a small TV screen (5) represents a second way to visualise the received signals.

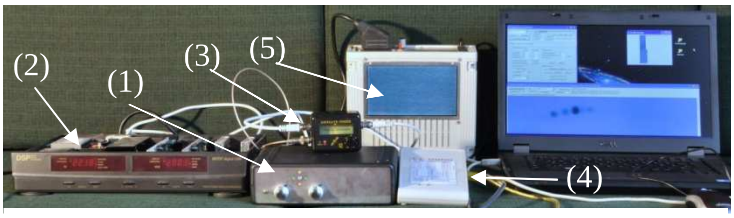


Fig. 48: The complete evaluation electronics

3.2.2 The FUNcube Dongle

2009 a group of British radio amateurs and astronomers started the "AMSAT-UK's FUNcube"-project under the motto "Fun in space with Amateur Radio". Their aim is to interest primary and secondary school children in science and especially radio communications [12; 13]. For this purpose, even a small satellite, emitting signals at two distinct frequencies measurable with relatively simple methods, will be sent into space this summer [14]. Among other projects this initiative covers the development of a software defined receiver (SDR), the *FUNcube Dongle*.

This appliance has the size of a USB stick (Fig. 49), nevertheless it contains all the components needed for processing received signals like depicted in Fig. 22.

Fig. 49: The FUNcube Dongle

It is directly connected to a computer. There the values for the LNAs, the voltage controlled oscillator and the related mixers and further amplifier and filters can be adjusted to a certain extend by a corresponding program (Fig. 50). There the received frequency can be set within a range from 64 MHz up to 1.7 GHz, signals with at least a value of 0.15µV can be detected within this range. A second program can be used to visualise and save the received data as well.

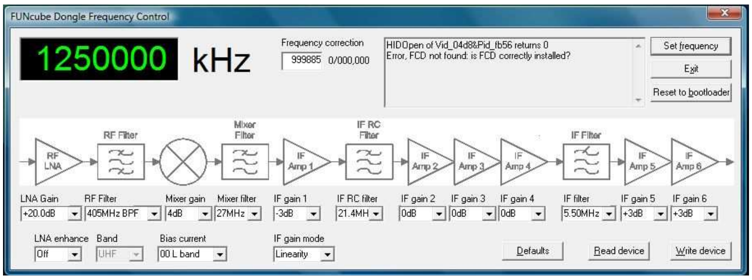


Fig. 50: A screenshot of the program used to set the FUNcube's characteristics

In contrast to the satellite receiver, the FUNcube cannot provide the DC supply voltage request by the LNB. As a consequence an external power supply is needed ("Appendix IV"). Within this appliance shown in Fig. 51, mains voltage is transformed into the required 14 V and 18 V DC supply. It could be chosen between both voltage levels via the computer if this appliance was as well connected to an interface; otherwise the switch S2 is used. The DC signal is then inserted to the arrangement with a bias tee (Fig. 52), a kind of adapter that is equipped with two jacks for HF cables and mixes the signals with the desired DC signals applied to the third jack.

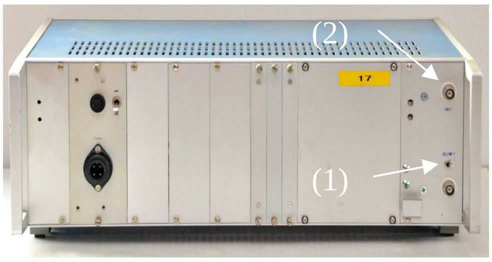


Fig. 51: The power supply unit

Fig. 52: The bias tee used for DC voltage supply of up to 12V

For increasing the sensitivity of the complete system, additional amplifiers (Fig. 53) can also be inserted between the receiver and the FUNcube, respectively the satellite finder. Thereby the signals of weaker sources can be detected; e.g. studying the sun's emission would not be possible without them. In case of

a) b)

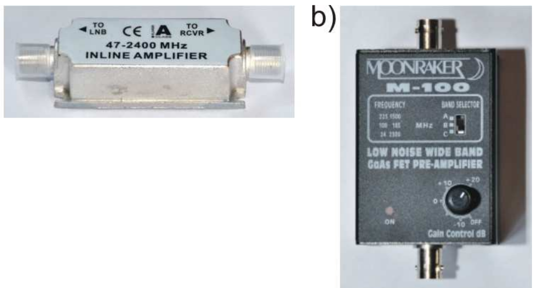


Fig. 53: a) a LNA used for receiving satellite TV at remote places and b) another amplifier with a an amplification between -10 dB and +20 dB

the satellite finder, the LNA's amplification might be too strong; as a result any meaningful measurements would not be possible. To regulate the amplification more properly, an attenuator (Fig. 54) can also be placed in front of the evaluation electronics. To provide the LNA with its operating voltage, the power supply unit also contains another jack for a 12 V DC voltage (Fig. 51).

Fig. 54: An attenuator with a value of 0.5 dB up to 20 dB

All this components can be connected with different adapters in various arrangements; Appendix V shows a complete overview about the possible combinations.

3.3 The Programs

To control the mechanical construction and to evaluate the received data, two programs were written. The programming language used is „Visual Basic", the complete program code supplemented with short comments can be seen in Appendix VI. As already mentioned, the data received with the FUNcube requires a different kind of evaluation program, hence the basic functions of the enclosed freeware "SpectraVue" will be explained as well.

3.3.1 The control program

When being started, the program for the position control automatically searches for connected interfaces, results are listed in the combo box in the upper left corner (Fig. 55). With the "Verbinden"-button a connection is established, now the program has access to the motor control and the unit connected to the satellite finder. The current signal received from the latter is now visualised in the progress bar labelled as "Signal", the numeric value given in the textbox "aktuell" below. The value of the box named "Counts" indicates the number of the interfaces analog channel read outs within the measurements time interval, "Mittelwert" the average between all these signal values. Below the progress bar the information about the parabolic reflector's actual position is listed. It is given as relative ("Rel.") and as absolute position ("Abs."). As already described, it can only be altered within two distinct ranges of

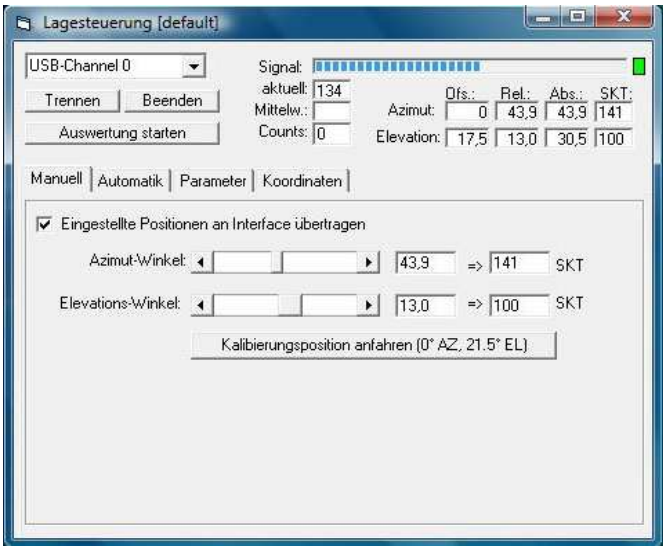


Fig. 55: Control via sliders

angles, so the relative position assumes values between 0° and 100° for the azimuth. As already mentioned, the signal from the potentiometer moved by the steel tube's turning is also applied to the interface. By reading out the corresponding analogue channel, a value for the current azimuth is obtained. It is entered in the textbox below the sliders. The fixture at the steel tube requires a minimum of 16° for the elevation, moreover, the elevation motor needs a minimum voltage signal to start moving; therefore the relative elevation allows for angles between 17° and 41°. For using the horizon system of coordinates, the absolute position has to be determined once. Before it is measured with a protractor and a compass as already described, the reflector has to be driven to the minimum azimuth angle and to an elevation of 21.5° to put the compass' placement in a horizontal position. This can be achieved by pressing the "Kalibrierungsposition anfahren"-button. When the desired position is reached, the coordinates can be determined as described. The result of this measurement is then placed in the "Offset"-textboxes and the program adds these values to the relative position indicating the absolute position. After this initial alignment, the construction can be directed to an arbitrary position by moving the sliders. This function can be found in the same tab page, called "Manuell", where the button for the coordinate's calibration is located (Fig. 55). If the hook in its upper left corner is set, a signal according to the slider's position is transmitted to the interface immediately and thereby to the motor control unit. The actual angle is shown in the left textboxes. The interface's accuracy being 8 bit, it can process 2^8 different numbers assuming values between 0 and 255, that correspond to the sliders' scale divisions. The relation between these values and the angle not being uniform, a numeric function has to be found, to allow adjusting certain angles, while scale divisions are send to the interface. For this purpose, the sliders' position was changed in defined intervals and the angles the reflector moved listed. Evaluating this measurement series with "Excel", a polynomial of third degree for the elevation angles and a linear function for the azimuth could be determined.

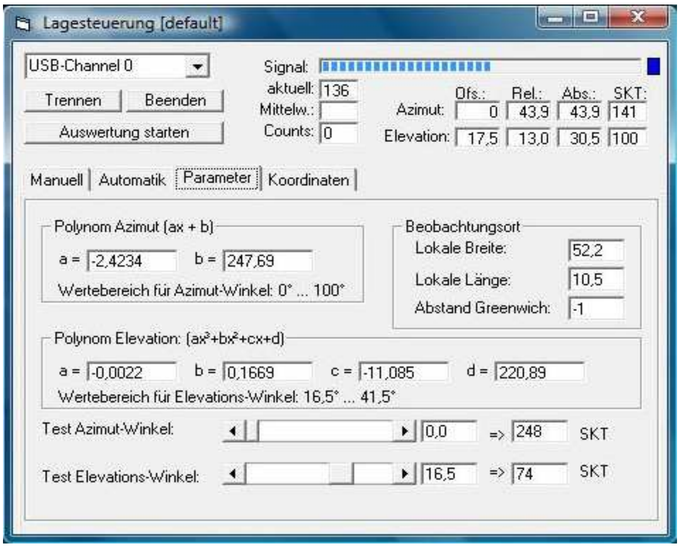


Fig. 56: The tab page „Parameter“

Their coefficients are written in the provided textboxes within the tab page "Parameter" (Fig. 56). In entering different values, modifications of the mechanical adjustment can be made, that would yield to deviating coefficients, without requiring altering the program code. With the sliders below it can be tested, whether the coefficients produce correct values without moving the reflector. The geographical location is also entered there, as well as the time interval between the measuring place and Greenwich. This information is crucial to use the function of the fourth tab page "Koordinaten" (Fig. 57).

3.3.1.1 Coordinate transformation

Like mentioned in chapter 2.1.7 "Often used systems of coordinates", celestial coordinates are not given uniform, but according to different systems. A conversion between both systems mentioned can be useful because e.g. some books and programs only use one system. Horizontal coordinates can be entered in the provided textboxes and the program converts them in equatorial ones.

The declination *D* that corresponds to the elevation is calculated by

$$D = \frac{180°}{\pi} \cdot \arcsin\left(\sin(el) \cdot \sin(lat) + \cos(el) \cdot \cos(el) \cdot \cos(az)\right) \qquad (44)$$

where *el* is the elevation, *az* the azimuth and *lat* the telescope position's latitude given in radian measure. The conversion between both angular measurements is made within the program code, thus the measured values can directly be entered in the textboxes. The result is then output in hours, minutes and seconds of arc.

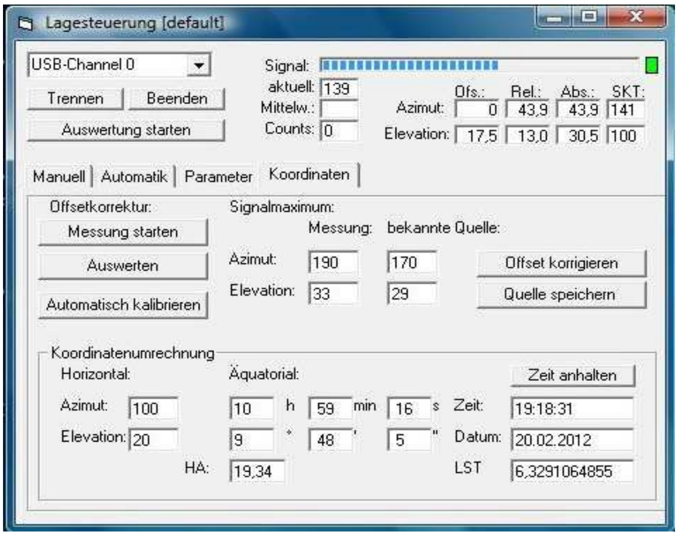


Fig. 57: The conversion between systems of coordinates and the automatic offset correction

In comparison the calculation of the right ascension *RA* is a bit more laborious, requiring first the determination of some other items, the *local sidereal time LST* and the *hour angle HA*, which are output in two additional textboxes (Fig. 57). According to formula (27) they yield

$$RA = LST - HA$$

The hour angle is given by

$$HA = \frac{180}{\pi} \cdot \arccos\left(\frac{\sin(el) - \sin(lat) \cdot \sin(D)}{\cos(lat) \cdot \cos(D)}\right) \qquad (45)$$

The calculation of local sidereal time requires the *Greenwich sidereal time GST* and the telescope's longitude *lon*

$$LST = GST + \frac{lon}{15} \qquad (46)\ [15]$$

For the GST in turn it is necessary to determine the *Julian Time* and the UTC, the *coordinated universal time* and two additional items containing these (see Appendix VI). Because of the latter items depending on the time and date, both are given in the lower right corner. By default this textboxes contain the current values, they are updated by a timer with every second. This timer can be interrupted with the "Zeit anhalten"-button, afterwards every arbitrary time or date can be entered in the textboxes.

3.3.1.2 Automatic scans

To make a measurement, the second tab page "Automatik" is used (Fig. 58). It provides setting and performing automatic measurement of a predetermined area, i.e. the reflector scans a section of the sky, while saving a value for the received signal after every step. First, the ranges for the azimuth and the elevation are determined by filling the textboxes in the upper left corner with relative initial and final values. In addition, the step range for both directions, i.e. the angle that is passed before measuring again, is set. Because of the elevation control motor requiring a minimum signal, this value must not be smaller than 0.5.

The right part of this tab page allows setting certain time intervals, used throughout the scanning process. The first entry "Positionierungszeit" determines the time in seconds that it takes to move from one position to the next one. Its value depends mainly on the angle step values "Schrittweite" and has to be increased with larger step sizes. Because of the feedback for the azimuth movement being added very lately in this project, the constructions' velocity was never tried out; therefore this value is only estimated. Nevertheless, the azimuth motor being slower than the one for the elevation,

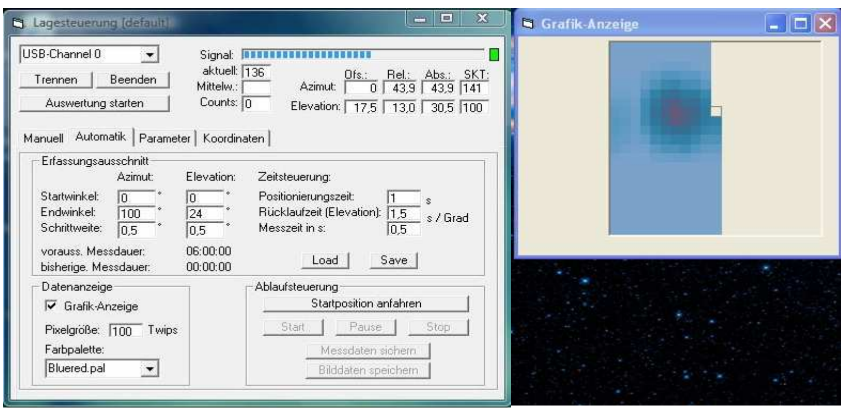


Fig. 58: The tab page for automatic scans during a measurement

the reflector turns one step in azimuth direction, than scans the whole range of angles for the elevation. While the reflector turns at the end down again, the azimuth is increased by on step. The time it takes the elevation motor to make it pass one degree is the second entry, named “Rücklaufzeit (Elevation)”. A value of 1.3 seconds per degree is sufficient. The last entry “Messzeit” sets the actual time interval to acquire the signal desired. During this interval, the analogue-digital-converter of the USB-interface will sample as much values as possible; the actual number is used to determine the average signal amplitude to be saved. The total time for a scan of a certain area amounts from the number of distinct positions and theses time settings. The estimated time is displayed below the angles settings. During a measurement, the time that already has passed can also be found there. All this presets can be saved with the “Save”-button, in this case a text file, containing the numeric values for the parameters, is created and a Windows dialog opened, where the storage location can be chosen. The same is happening the other way round if the “Load”-button is pressed, the parameters are read out from a chosen initialisation file and written in the textboxes. If the program is closed, the values for the telescopes last position are saved in another file named “position.ini” as well as the parameters of the last automatic scan. They can be reloaded by pressing the “last”-button, the next time the program is started. When finally all presets are set as desired, the “Startposition anfahren”-buttons is pressed to move the antenna to the position at the lower left end of the determined area. With the “Start”-button the scan starts. In this moment, a text file not visible for the observer is created, containing all the parameters, covering presets and all values determined in the tab page “Parameter” as well as the initialising file’s name (Fig. 59). A timer with the interval of the time it takes to pass one step (timerAuto, see Appendix VI) starts a second timer (timerMess), that reads out the interface’s analogue channel for the satellite finder’s signal. The average value of these results is added to the text file, combined with the current date, time, azimuth and elevation. Because of the accuracy of the interface’s channel used for this again being 8 bit, the signals assume values between 0 and 255. The values for azimuth and elevation

```
Initialisierungsdatei:  (default)
Lokale Länge:   52,2000
Lokale Breite:  10,5000
Polynom Azimut, a =     -2,4234
Polynom Azimut, b =     247,6900
Polynom Elevation, a =  -0,0022
Polynom Elevation, b =  0,1669
Polynom Elevation, c =  -11,0850
Polynom Elevation, d =  220,8900
Azimut-Bereich:
Offset: 76
Startwinkel:    9,0000
Endwinkel:      99,0000
Schrittweite:   1,0000
Elevations-Bereich:
Offset: 15,5
Startwinkel:    0,0000
Endwinkel:      24,0000
Schrittweite:   1,0000
Positionierungszeit:    1,0000
Rücklaufzeit (Elevation):       1,2000
Datum   Uhrzeit Azimut  Elevation       Data
04.02.2012      17:02:53        85,0000 15,5000 50,3194
04.02.2012      17:02:55        85,0000 16,5000 50,0000
04.02.2012      17:02:58        85,0000 17,5000 48,9583
04.02.2012      17:03:00        85,0000 18,5000 43,9388
04.02.2012      17:03:01        85,0000 19,5000 37,5278
04.02.2012      17:03:02        85,0000 20,5000 30,0417
04.02.2012      17:03:04        85,0000 21,5000 20,2778
04.02.2012      17:03:05        85,0000 22,5000 6,8889
04.02.2012      17:03:06        85,0000 23,5000 0,7500
```

Fig. 59: An excerpt from a measurement file

printed in this file correspond to real horizon coordinates, because the offset written in the provided textboxes is added to them.

For the next position, according to the preset's value, the scale divisions are calculated and transmitted to the motor control via the interface. If the hook "Anzeige" is set, a second screen window containing a picture box is opened. A picture box is an element provided by Visual Basic, that allows displaying graphical elements, i.e. pictures saved on the computer or the creation of own images. To indicate the actual position of the reflector, a small rectangle is displayed, whose position corresponds to the current position of the reflector within the scanned area. The value for "Twips" in the lower left corner of the scan tab page determines the pixel's size within the picture box and hence the total size of the window to be displayed with (Fig. 58). According to the signals strength at this position, the rectangle is coloured. For this purpose, colour palettes normally used for visualising the results of measuring with an infrared camera, are utilised. With another program such files could even be created, but to represent the results of a scan in a graphical way, the existing ones suffice completely. When the program is started, it is searching for palettes within the current directory, i.e. the folder in which the programs EXE-file is located. For certain investigations, other palettes can be chosen as well. If the search should not return any colour palette entries, the signals are depicted in gray scale. A mouse click on an arbitrary position of this picture box displays the absolute coordinates of this position respectively the corresponding signal below the upper edge of the window (Fig. 58). If the "Pause"-Buttons is pressed during a measurement, the timer responsible for the movement is stopped as well as the motors themselves, but the process can be continued with a second click. To stop the measuring definitely, the "Stop"-button can be pressed. In this case, all timers are cancelled and the buttons for saving the text file and the picture as a bitmap are enabled.

3.3.1.3 Correction of the offset

This automatic scan also allows another option controlled in the tab page "Koordinaten". The function "Offsetkorrektur" provides a possibility for verifying the offsets that determine the values for the real position without using a compass or protractor. The idea behind this method is scanning a small area near a source with known coordinates, to determine thereby the coordinates of the received maximum signal and compare both of these values. The difference is added to the current offsets and thereby they are corrected. For this purpose it is only necessary that the scanned area is small enough to ascertain, that the measured maximum signal belongs to the known source only.

With pressing “Messung starten” the chosen tab strap switches to the “Automatik” page. There the textboxes for the presets are automatically filled with values that allow a quick scan of an area of 10° azimuth and 8° elevation, starting from the current position. If desired, these presets can be altered; subsequent the measurement has to be started by the observer. If it is finished, the window for saving is automatically opened. By pressing the “Auswerten”-button the coordinates of the highest signal within this file or any arbitrary other one are determined and written in the textboxes under “Messung”. The real coordinates of the source are placed in the other textboxes. The “Offset korrigieren”-button adds the difference between the real and the measured coordinates to the offsets and thereby they are corrected. The coordinates of such sources of reference can be saved with the “Quelle speichern”-button. The option “Automatisch kalibrieren” provides presets for a quick scan as already described, covering a certain surrounding region of the coordinates of the source of reference, respectively the place it is supposed to be. The only attendance by the observer is pressing the two buttons required for setting the telescope in motion, because the time passing until the start position is reached actually cannot be determined automatically. After having finished the measurement, the program asks again where to save the file; afterwards the already described operations are performed, but this time without requiring further clicks. The textbox for the scale divisions next to the signal’s progress bar might show then a value that is not within the range of 0 to 255, but will be actualised the next time the telescope’s position is changed.

3.3.2 The evaluation program

The evaluation of these measurements takes place in a second program that can be opened directly from the control program with the “Auswertung starten”-button, or as an additional executable program (Fig. 58). There a measurement file, chosen after pressing the “Datendatei öffnen”-button, can be read out.

According to the data contained, the described false colour images are created, where the choice between different palettes is possible again (Fig. 60). By setting the hook next to “Signal strecken”, the

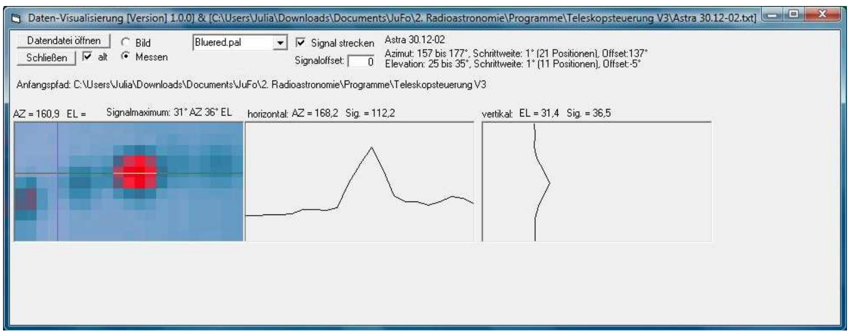


Fig. 60: A screenshot of the evaluation program’s mode for analysing the data

possible colours of the palette are not assigned to all the values between 0 and 255, but only to the range of values for the signal, that really occurr in the measurement. Thereby, e.g. the colour for the strongest signal, in this case red (Fig. 60), does not only occur if the signal assumes a value of 255, but depicting the place of highest signal. As a result the picture becomes more differentiated (Fig. 61).

As used for the correction of the offset, the signal maximum is determined. Its coordinates are shown above the picture together with the folder path of the opened file, the range of angles being measured and the offset used. Next to the false colour image two additional picture boxes are placed. If the former is clicked on at a distinct position, these boxes are filled with graphs depicting the signal's curve alongside the crosshair outgoing from the point that was clicked on.

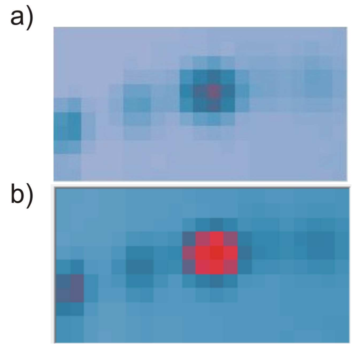


Fig. 61: A picture of the satellite Astra 1 a) without and b) with the spread colour palette

By clicking on them the coordinates corresponding to that position are written above the boxes (Fig. 60). In this way it is possible to detect points with a relatively high signal that might be not visible on the false colour image and to get their related coordinates without searching the measurement file. These three pictures can be saved using the measurement file's name supplemented by an "A" respectively the coordinates of the click in case of the two graphs in the current directory, by clicking the window using the right mouse button.

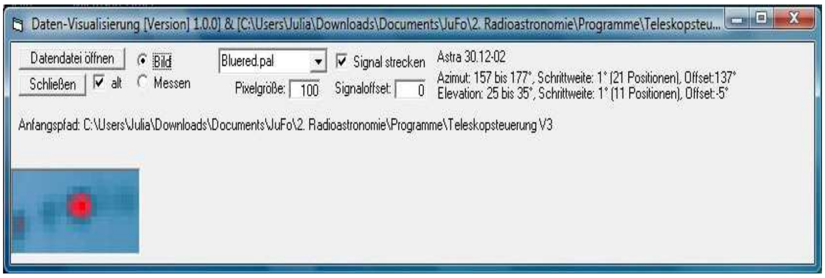


Fig. 62: A screenshot of the evaluation program's second mode "Bild"

A way to adapt the false colour images itself is provided by clicking at the option button "Bild" instead of the preset "Messen" (Fig. 62).

The number written into the textbox for the signals offset is added to the value of the signal while creating the image. Thereby, as depicted in Fig. 63, more or less details are added to the picture. Furthermore, the image size can be changed by changing the value written in the textbox for the pixel's size.

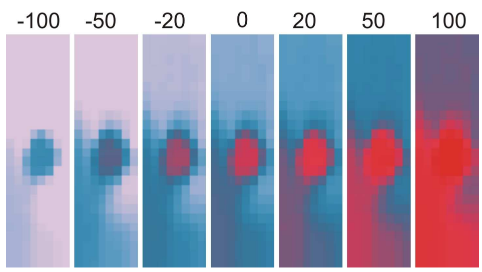


Fig. 63: A picture of another satellite adjusted by different offsets, i.e. the minimum value occurring

3.3.3 “SpectraVue”

The FUNcube in contrast provides other kind of data; therefore its evaluation requires a different program. For this purpose, the official FUNcube website can be found, providing several documents such as information about the FUNcube itself, possible applications and helpful programs. Among these recommendations was a link for the freeware “SpectraVue”.

It is used for transforming digital data into a frequency domain spectrum. Wave files, data from a soundcard or SDRs software defined receivers, like the FUNcube Dongle, are read in and after submitting a FFT, a *fast Fourier transformation* displayed in different possible ways [16]. According to Fourier’s theory, every function can be expressed as a sum of sine and cosine functions. If a program performs a FFT, it calculates the frequency and amplitude of harmonic oscillations that have to be superposed to form the incoming signal [5]. By doing so, the incoming signal’s frequency spectrum, the amplitude as a function of the frequency, can be issued.

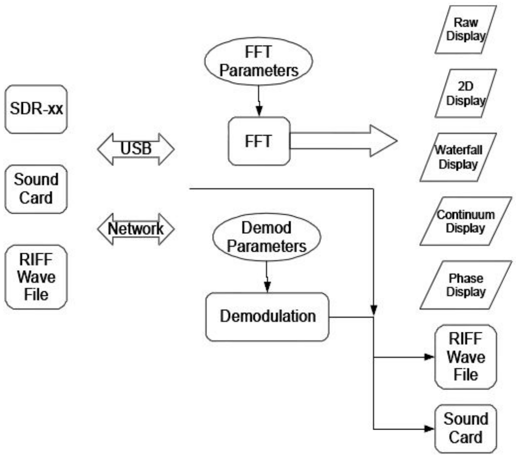


Fig. 64: The operating principle of “SpectraVue” [16, Fig. 1]

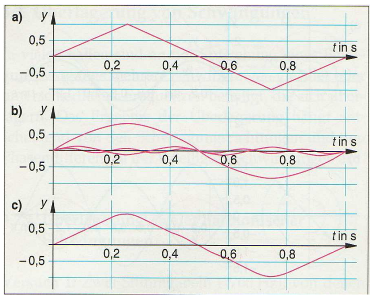


Fig. 65: a) a wave and b) the waves found by a FFT that must be superposed to form the approximation c) [5, p.116, Fig. 116.1]

Before using “SpectraVue” the first time with the FUNcube Dongle, the “SoundCard Input Setup” window has to be opened. There the current soundcard that is read out has to be changed to “FunCube Dongle V0.0”. This window provides also further presets, covering among others the sample rate that in case of the FUNcube is 96000 Hz, and the centre frequency. The latter is the frequency that will later be shown in the analysis spectrum in the middle of the screen (Fig. 66). The next step that has to be made is to assess the settings for the data output. Opening “Data Output Selection”, it can be chosen

Fig. 66: “SpectraVue “showing the raw data received

between different recording modes. It can be chosen between a 30 minutes lasting measurement with manual set adjustments or several preset proposals. The program is also able to demodulate the incoming signal, i.e. make it audible by transmitting a transformed version to the computer’s soundcard. Hence, the provided combo box should be assigned with the right appliance. Further adjustments can be made in the “General Program Setup” window, covering mainly settings concerning the display. All these presets can be saved as an initialising file within the “File” window [17].

By pressing the “Record”-button or the F12 key, recording is started; the screen shows a picture similar to Fig. 66. “SpectraVue” provides several different options for visualising the analysis results, selected by clicking at one of the tab pages below the screen (Fig. 66). The first provides a line showing the raw data per time unit, the second the FFT’s result as a graph depicting the amplitude as a function of the frequency. Frequencies of high amplitude are thereby highlighted by coloured marks. By clicking on the third tab page such a graph is shown as well, but instead of being overwritten, the last graph is shifted up and to the right, resulting in a 3D plot. The “waterfall” tab pages combine information about all three items mentioned in one continually complemented picture, where time and frequency are the axis and the amplitude is depicted in false colour. Graphs and such a waterfall can be shown at the same time within the tab page “Combo”. “Continuum” displays the total power of the entire frequency span versus time. To gain better results, e.g. with a lower signal offset or less noise, additional different settings can be made. As an example, the “SDR-IP Setup” provides some possibilities to give further information about the receiver used.

The analysis results can not only be displayed, but also saved as a graphic file of .jpeg, .bmp or .png format, or as a comma-separated text file containing the frequency, the corresponding amplitude and if desired a time stamp. The latter provides a possibility to combine the self-built telescope and this kind of evaluation electronic. The measuring file would be gained as described by the self-written programs, but the values for the signal’s strength could be replaced by the data received and processed with the FUNcube according to the time stamp contained in both files. For this purpose an additional program to process the different files and merge their data would have to be written [16].

4 Measurements

The aim of this project was to build a working radio telescope that is able to receive the emissions of sufficient strong sources. To find out the possible limitations, several measurements were made, first of television satellites, later of the sun and it was even tried to detect the radio rays reflected by the moon.

The measurement's execution was thereby similar every time. The rotary plate was positioned at a place that offers a free view to the area of the sky to be observed. Using the spirit-levels and the adjustable feet below the plate, the construction was levelled horizontally. At the measurement station the reflector was moved to the calibration position and the offsets determined by using the compass and the protractor. Afterwards, as already described, automatic scans of several parts of the sky were made.

4.1 The satellites

Before trying to measure the emissions of any celestial body, the construction, the electronics as well as the programs used had to ascertain that they are working together correctly. For this purpose, a strong source with known coordinates, emitting waves within the range detectable by the LNB, was needed. Because of the latter being a receiver for satellite television, the idea to use a television satellite as test source was obvious. The place of the measurements providing the freest view in the southern direction, the only satellites that could first be detected were the Astra 1 group located at 158° azimuth and 29.2° elevation. So, the Astra satellite was targeted during the process of developing the telescopes parts several times and often ahead of a measurement for correcting the offsets.

Fig. 67 shows the very first picture that was gained with the construction, an image of Astra. Because the program first scanned line by line in horizontal direction and did not produce a reproducible movement at the end of every line, the picture looks a bit fuzzy. Therefore, it was necessary to change the order of movements. The elevation movement being more reproducible; now one vertical line is scanned before moving one step in azimuth. Afterwards, the image shows a much improved picture (Fig. 68). Being now able to obtain reproducible results, further functions of the program could be tested, e.g. the influence of the used step size. As shown in Fig. 69, similar to a digital camera, the picture becomes the sharper, the higher the number of pixels. So,

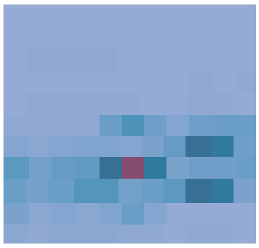


Fig. 67: First wave

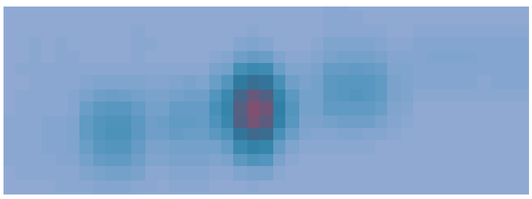


Fig. 68: The four Astra satellites

a) b)

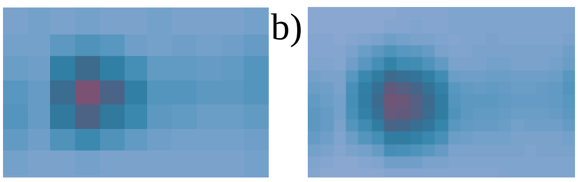


Fig. 69: Images of Astra 1 made with a) 1° and b) 0.5° step size

measurements with a small step size might require a higher amount of time, but in return the results are giving more evidence.

As mentioned in chapter “2.2.2 The angular resolution” the telescopes resolution is always of interest for the observer. To determine the opening angle, the reflector was moved until the image on the TV screen was clear. Then one direction was altered until the first position, where the image disappeared in the background noise. By moving the reflector back until the image reappeared a further to the opposite verge, the opening angle could be determined. The result was approximately 3° for both directions, the value that is normally assumed by television dishes [18]. For a mathematical verification formula (39) is used

$$\alpha = 1.22\frac{\lambda}{d}$$

Using a parabolic reflector with a diameter of 0.70 m at an observed wavelength between 0.0235 m (12.75 GHz) and 0.028 (10.70 GHz) leads to

$$\Delta\alpha = 1.22\frac{0.0235}{0.70} \approx 0.0410$$

$$\Delta\alpha = 1.22\frac{0.0280}{0.70} \approx 0.0488$$

These values are given in radian, converted in degree the result is 2.3° respectively 2.8°. Within the precision achievable with the compass and the protractor these values are agreeable to the measured one of 3°.

To determine the probable influence of the direction of polarisation, one scan of the complete possible range was made for each direction. The result is shown in Fig. 70. Although the pictures seem to differ significantly on first sight, it has to be mentioned that it takes round about 8 hours to make such a scan.

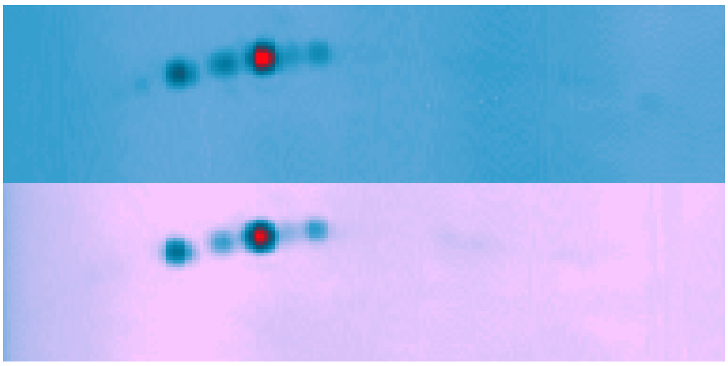


Fig. 70: A of the complete possible area (125° to 220° azimuth and 17,5° to 41,5° elevation) with the setting for a) vertical and b) horizontal polarisation

Because of being acquired one immediately after the other, the first measurement took place during daylight, while the second measurement was started in the night, at 9.54 pm on a day in December. According to formula (29), the temperature is direct proportional to the noise. Therefore, due to the fact that the construction was placed in the outside at night for several hours, the low ambient temperature has reduced the noise within the electric components as well as in the outside itself. As a result, in the second picture even some structures in the background can be seen, which are reflections in trees.

The same measurement was started a third time one month later, this time with an additional LNA with an amplification of 20 dB between the LNB and the receiver. The result is shown in Fig. 71. Again the reflections of trees and the satellites of the Astra group are visible, but in addition al lot of further satellites which seem to be located on a circular arc.

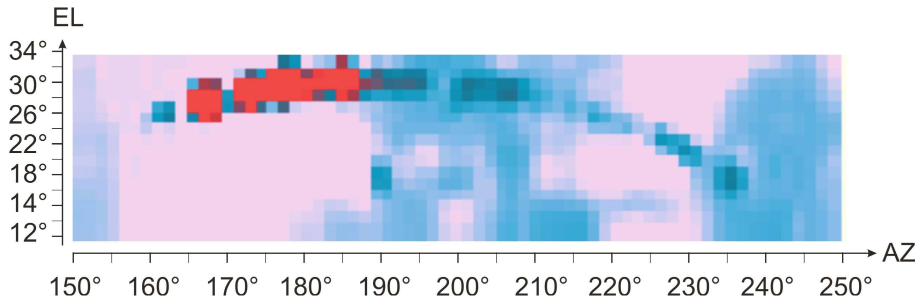


Fig. 71: A complete scan with one additional LNA showing Astra again (red) and further geostationary satellites

Satellites to be used for TV-communication must have a fixed celestial position, in order to use receiving dishes mounted in a certain direction. Such satellites are called geostationary. After having been send into space, two main forces influence the satellites position: First, because of still being near to the earth, the gravitational force F_G which is

$$F_G = \gamma \frac{m_S \cdot m_E}{r} \qquad (47)$$

where m_S is the satellite's mass, m_E the earth' one, r the distance between there centres and γ the gravitational constant (approximately $\gamma = 6.673 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}$). This force is in every case attractive. Therefore, the satellite would fall down to earth immediately. This is not the case in reality, because the satellite is moving around the earth. Its orbit can be supposed to be circular, as a result a centripetal force F_C also affects the satellite, thereby it represents the second force that is opposed to the gravitational one. It can be expressed by

$$F_C = m_s \cdot \omega^2 \cdot r \qquad (48) \quad [5]$$

where ω^2 is the satellites angular velocity. To prevent the satellite from departing as well as from approaching the earth, both forces must be equal, therefore to find the only radius r that allows that, both formulas equated with each other and afterwards rearranged to r, that yields to a distance of approximately 35 800 km between the earth' surface and the satellite. So every one of the depicted satellites has the same distance to the earth' surface, the apparent arc is the consequence.

4.2 The sun

Having tested whether all components are working properly, the next aim was to measure the emissions of a natural radio source, more specifically, the sun's.

For this purpose, a little mirror was fixed on the parabolic reflector's surface. It is small enough to not to disturb the incoming waves, but it reflects the sun's beams as well. Therefore, if the sun's position is reached by the reflector, a small point of light is visible on the LNB's covering. In addition, the program "CyberSky", simulating the starlit sky to any arbitrary time at every place, was used to list the sun's coordinates during the estimated time of measurement. The sun reaches its highest position during the day in the south around noon, achieving an elevation less than 20° during January 31st. Hence, to be sure, that the sun might not be covered by any obstacles, first trials to measure it were made at 12.50 pm respectively 12.30 pm. Within a quarter of an hour, the sun moves 15°, so moving the azimuth is redundant. Its presets were adjusted to produces no movement, whereas the elevation was changed within the complete possible range. Nevertheless, all these measurements led to results similar to Fig. 73.

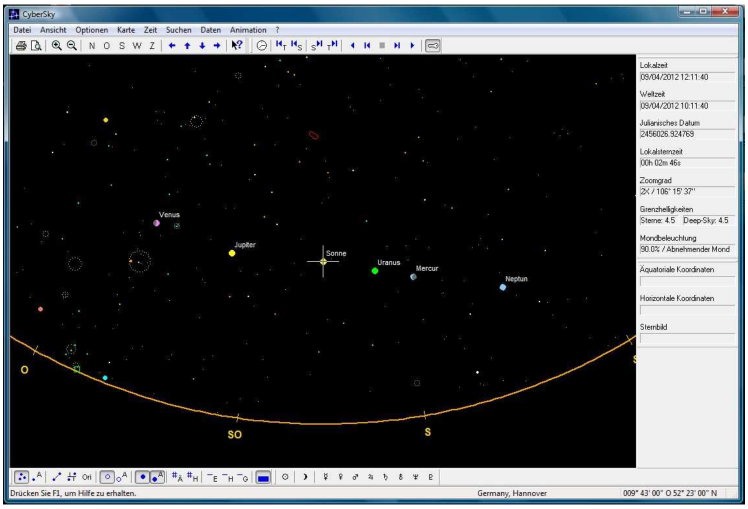


Fig. 72: A screenshot of "CyberSky"


Fig. 73: An example for a failed measurement

The sun could not be detected until an additional LNA was used (Fig. 74). The elliptical shape is a result of the sun's movement towards west, while the changing of the azimuth's angle was about ten times faster. However, this stretched shape as well as the fact that the source moved relative fast towards west indicates, that the detected object is actually the sun. Due to the reflection of

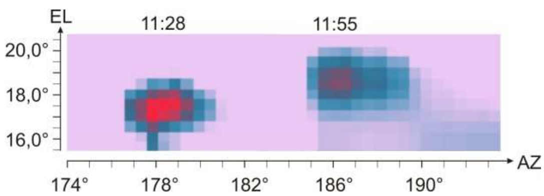


Fig. 74: The result of two measurements started one after another

sunlight in the blank rod that holds the LNB, an area with a higher signal occurred in the lower right part of the image. This reflection was not detected before, because the sunlight's angles of incidence on the reflector changed while the sun moved. That is why the sun seems to be emitting a weaker signal, visible at the darker red, at 11.55 pm.

To ascertain that it really was the lesser sensitivity that caused the first measurement's failure the same area was scanned again without the LNA, resulting in a picture like Fig. 73.

4.3 The moon

Having access to two other LNAs, the sensitivity was further increased by connecting them to the telescope, in the hope to be able to detect the emissions of the next strong source after the sun: the moon.

To be precise, the moon is no emitter, but a reflector for the waves emitted by the sun. Therefore, the highest chance for detecting its signals is a night of full moon.

Fig. 75: Result of the first trial, in the right part the Astra satellites are visible

The first trail made at the usual measuring place in February resulted in Fig. 75. In the right part, the Astra satellites are visible, but the moon's signal perished in the strong reflections of a tree.

Therefore, the next trial was made at a different place, where a free view to the east was provided several weeks later. In spite of measuring in a night of full moon and clear sky, the arising picture showed no significant source. Moreover, during the measurement a part of the power supply unit broke, therefore it had to be interrupted.

Due to the changed position of the moon in April, for the last trial the usual measuring place was relocated to a position that allows a free view to the west.

At this time, 53% of the part of the moon's surface that is visible from earth was lit by the sun. First, to be sure, that no other sources disturb the measurements, a complete scan of the area was made. The result offered no big disturbing source but further satellites, so the arc of geostationary satellites could be complemented (Fig. 76). Furthermore, these satellites provided additional points of reference on the earlier measurements. Nevertheless, despite scanning several times, the measurement resulted again

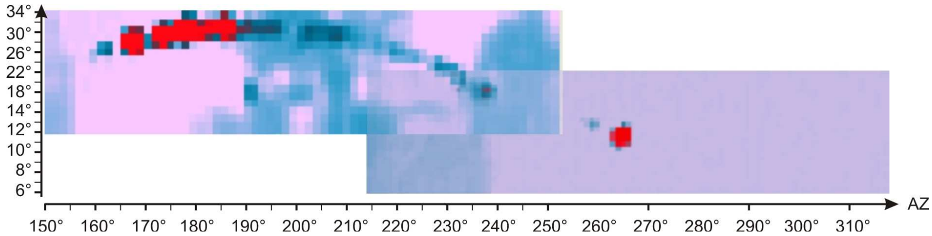


Fig. 76: A complete depiction of all satellites that were detected

in no detection of the moon (Fig. 77), where the moon should have to be visible in the right half.

Fig. 77: The result of the westwards directed measurement, the source in the left part is the satellite at the right end of the arc

There are several reasons possible. First, as depicted in Fig. 12, the moon is distinctly weaker than the sun, so even the usage of two LNAs might not lead to a sensitivity high enough to detect its radiation. Second, the last trial might furthermore have failed because the reflected intensity was too small. Another reason could be the high amplification of the LNAs having enhanced the background noise at such a degree, that the moon's signal was overcast by this noise.

4.4 Measurements with the cross dipole

Because of a very friendly donation from the Max-Planck-Institute in Bonn, the "Jugend Forscht" study group owns a cross dipole constructed for measuring the 21.1 cm-hydrogen line (Fig. 21). Albeit, a suitable reflector that would be able to detect these emissions does not still exist, some other measurements could already be done with it.

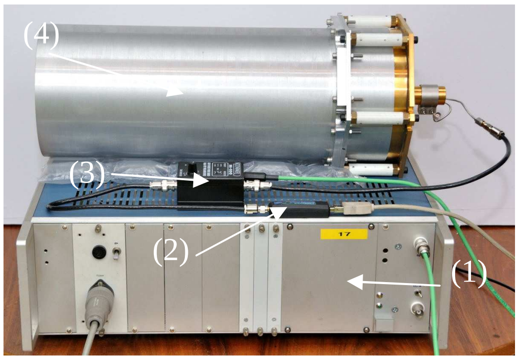


Fig. 78: measuring arrangement for the cross dipole

As depicted in Fig. 78, for this purpose the power supply unit (1), the FUNcube (2) and at least one LNA (3) for amplifying the signals are needed. The latter is necessary because the normally used parabolic reflector is too small to focus the radiation for the cross dipole, therefore the measurements must be done without it. The only wave guide is in this case the feedhorn (4), that similar to the LNB's focuses the waves on the dipoles. Furthermore, their shape prevents disturbing currents caused by electromagnetic induction in the metal from occurring.

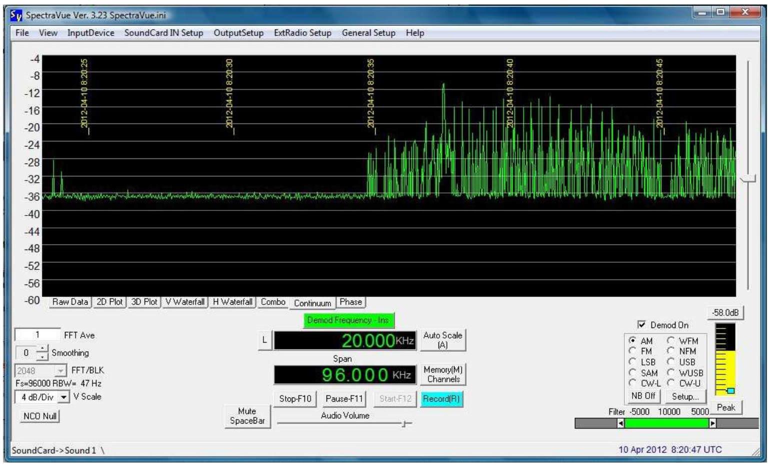


Fig. 79: Analysis of a WLAN transponder's signal with the "Continuum" mode

For example, using this special antenna was a good method to test the FUNcube and the basic functions of “SpectraVue”.

The FUNcube covers a larger range of frequencies; hence a simpler detectable source than the satellites could be used for this purpose, a transmitting mobile or better a WLAN transponder. The latter is not emitting continuously, but only during special actions, e.g. if a browser window on a laptop is updated as visible in Fig. 79. To analyse the exchanged signals, the “Continuum” mode, was used, i.e. the program visualises the signal’s amplitude within the set frequency range versus the time. Thereby this mode functions as power meter, depicting clearly the difference between no signal at the beginning (left part) and the transponder’s emission (right part).

a

b

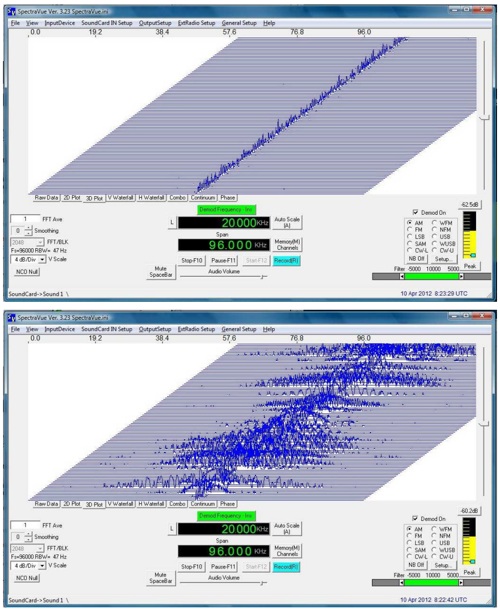


Fig. 80: The “3D plot” mode depicting a) no and b) the transponder’s emission

As already described, another way to combine information about time, frequency and the amplitude that corresponds to them is the “3D plot” mode (Fig. 80). To gain information about the amplitude of a distinct frequency, i.e. to see the complete result of the FFT, the “Waterfall” respectively the “Combo” mode is more likely (Fig. 81).

In this way the emissions of sun could also be detected, simply by pointing the cross dipole on it, but the corresponding data were not saved.

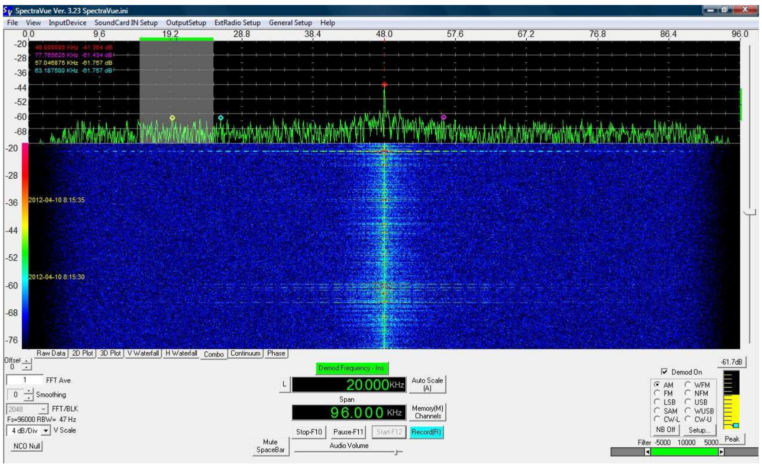


Fig. 81: The “Combo” mode showing the analysed data with false colours, the bright line depicts the transponder’s signal a centre frequency of 48 MHz

5 Results

The evaluation of all these measurements revealed the border of radio sources that can be detected with the self-built radio telescope, and furthermore different aspects that have to be considered.

5.1 Influencing factors

As the measurements showed, several factors can influence the results gained by a radio telescope, mainly divided in ambient conditions and problems concerning the telescopes components themselves.

As already hinted, e.g. in chapter “4.1 The satellites” while commenting Fig. 70, the ambient temperature can change the telescope’s sensitivity distinctly by influencing its component’s noise. A refrigeration of the electronically components is therefore standard among bigger telescopes, but the effect was also already detected at the self-built one. Nevertheless, the relation between temperature and noise, respectively radiation, can also have negative consequences. Objects with a high temperature represent sources of disturbance, therefore it has to be ascertained, that no hot items are placed near the LNB or in its viewing direction. The same is of course valid for sources emitting radio waves purposely, e.g. WLAN transponders. The higher the telescope’s sensitivity, the more tend other celestial bodies to be disturbing noises. For that reason, radio astronomical observations, e.g. with the 100 m-telescope in Effelsberg are mostly made at night, to prevent the sun from falsifying the measurements results. Another important factor is reflection. For further measurements the rod holding the LNB was wrapped in a black spiral hose, to reduce the radiation that is reflected in it. By holding ones hand in front of the LNB during an observation of the sun, the heat focussed there by the dish can be detected. For using bigger reflectors it would be necessary to cover its surface with something that absorbs the infrared rays, maybe a black foil.

The components used for the telescope itself are as crucial for the measurement’s results as the surroundings. As already mentioned, the receiver determines the range of frequencies that can be observed, while the parabolic reflector defines the angular resolution and in some way the border of the weakest signal that can be detected, because a bigger reflector of course can focus more radiation. The direction of polarisation was not crucial for detections with the self-built one, but it is useful to distinguish between the different kinds of sources.

The evaluation electronics determine the information that can be won from the received data, e.g. whether just its strength is found out, or a complete picture for the spectral distribution is gained. In the case of the self-built radio telescope, it is the satellite finder that has to be mentioned, because of the adjustment for its sensitivity not being definitely reproducible. Therefore the accurate minimal value for the signal is different in every measurement. Nevertheless, it determines the accuracy of the gained results. If its sensitivity is too small, weaker emissions cannot be detected, nevertheless, the background noise and a source cannot be distinguished if the sensitivity is too high. Hence, it is adjusted at a value that assigns a pointer deflection to the second scale division to the free sky. Thereby, the resulting picture showed mostly enough details while the strongest sources measured, the satellites, did not cause an overflow. In contrast, the LNA overdrove the satellite finder if its sensitivity was not set near the lowest possible value while measuring the satellites. Two of them can only be used together with the attenuator; otherwise the signal's offset was too high. So, the telescope's sensitivity and the method used for measuring the signals strength have to match otherwise it cannot be used properly.

5.2 Calculation of received power and voltage

As described within the elevation electronic a voltage corresponding to the received signal is produced. This voltage's strength could be calculated before to create own ore alter existing evaluation circuits, if the received power is known. In addition, if the relation between both is known, it would be possible to draw conclusions from the voltage measured to the source's transmission power.

As the letters in the brackets indicate, these items are not given in their normally used SI-unit, but in *dB* respectively *dBW*. Generally while talking about amplification and attenuation, it is more comfortable to use this unit.

An amplification *n* of for example a power is normally expressed by

$$n = \frac{P_{out}}{P_{in}} \qquad (49)$$

where P_{in} is the incoming signal and P_{out} the power after the amplification with the factor *n.*

Hence, amplifications or attenuations require multiplications or divisions. To ease those calculations the transformation in dB can be made by

$$n(dB) = 10 \cdot \lg\left(\frac{P_{out}}{P_{in}}\right) \qquad (50)$$

As a consequence, to calculate an amplification, the signal's value in dB and the amplification factor in dB can be added or subtracted. To transfer an item from its SI-unit value into a dB value, the same operation as depicted in formula (55) are made. The fraction's denominator would in this case be a reference with the value 1 in the item's unit [19]. As an example, a voltage V of 5 V would equal

$$V(dB) = 10 \cdot \lg\left(\frac{5V}{1V}\right) \approx 10.7dB$$

Of course a division with 1 does not change the value within the brackets, but contrary to maths, in physics the item’s units are as well written in a formula. Nevertheless, mathematical operations like logarithms cannot be applied to units, writing “the logarithm of volt” would make no sense in reality. By division with 1 V the units can be cancelled, thereby the bracket’s content turns into a number without any unit.

For powers the denominator would usually be 1 mW, but for the items used in formula (53) 1 W was used.

For this purpose, first the reflector’s gain *G* is calculated. It is defined by

$$G = \eta \cdot D \qquad (51)\ [3]$$

where η is the reflectors efficiency and *D* the so called *directivity.* The latter is given by

$$D = \frac{4\pi}{\lambda^2} A_e \qquad (52)$$

where λ is the wavelength observed, and A_e the effective aperture of the reflector. Between both and the *beam solid angle* Ω exists the relation

$$\lambda^2 = A_e \cdot \Omega \qquad (53)\ [3]$$

The beam solid angle is approximately the arithmetic product of the horizontal and vertical opening angle given in radian; therefore it is given in steradian, i.e. rad^2. Combining all three formulas yields to

$$G = \eta \cdot \frac{4\pi}{\Omega} \qquad (54)$$

or

$$G(dB) = 10 \cdot \lg\left(\eta \cdot \frac{4\pi}{\Omega}\right) \qquad (55)$$

The aerial’s efficiency corresponds to the ohmic losses, it can be assumed to have a value of 1. Thereby of course a strong approximation is made, but it eases the calculations now. The result has to be regarded as an upper limit value.

The received power *P(dBW)* can then be calculated by

$$P(dBW) = G(dB) + EIRP(dBW) - A(dB) \qquad (56)\ [20]$$

where *EIRP(dB)*, is the *effective isotropic radiated power*, the power that an isotropic, i.e. uniformly in every direction sending, emitter have to transmit to gain the same radiation intensity as an emitter transmitting with an aerial with the gain G. The Astra satellite for example has an EIRP of round about 50 dB. *A(dB)* is a value for the losses that occur while a wave is transmitted from an emitter to the receiver.

The third item of formula (53), the signal's losses is a combination of the so call *free space loss* FSL, caused by the distance between receiver and emitter and an arbitrary value between 1dB up to a maximum of 10 dB, representing factors like the weather, i.e. as an example the strength of the cloud cover.

The FSL can be calculated by

$$\mathrm{FSL(dB)} = 10 \cdot \lg\left(\frac{4\pi\,\mathrm{r}}{\lambda}\right)^2 \qquad (57)$$

According to logarithm's laws this can also be written as

$$\mathrm{FSL(dB)} = 20 \cdot \lg\left(\frac{4\pi\,\mathrm{r}}{\lambda}\right) \qquad (58)$$

Because of the relation between a wavelength and a frequency this equals

$$FSL(dB) = 20 \cdot \lg\left(\frac{4\pi\, r\, f}{c}\right) \qquad (59)$$

This can be further rewritten to approximately

$$FSL(dB) = 20 \cdot \lg\left(\frac{4\pi\, r\, f}{3 \cdot 10^8 \, \frac{m}{s}}\right) \qquad (60)$$

$$\mathrm{FSL(dB)} = 20 \cdot \lg\left(\frac{4\pi\ \mathrm{r}}{0.3 \cdot 10^3\ \mathrm{m} \cdot 10^6\ \mathrm{s}^{-1}}\right) \qquad (61)$$

$$FSL(dB) = 20 \cdot \lg\left(\frac{4\pi}{0.3}\right) + 20 \cdot \lg\left(\frac{r}{10^3 m}\right) + \lg\left(\frac{f}{10^6 s^{-1}}\right) \qquad (62)$$

$$FSL(dB)) = 20 \cdot \lg\left(\frac{4\pi}{0.3}\right) + 20 \cdot \lg(r)[km] + \lg(f)[MHz] \qquad (63)\ [20]$$

Being located as already mentioned at a geostationary orbit, the Astra satellite has a distance of approximately 36 000 km above the equator. Nevertheless, measured from another place at the earth surface, this value would be different. As a result of geometrical considerations, the distance between the satellite and an observer at 51° latitude can assumed to be 37 700 km. Emitting at an average frequency of 11.7 GHz, Astra's FSL would be round about 205.3 dB. Measurred by an aerial with the gain *G*

$$G = 10 \cdot \lg\left(\frac{4\pi}{0.0524 rad^2}\right) \approx 36.6 dB$$

the power received yields according formula (54) to

$$P(dBW) = 36.6\ dB + 50\ dBW - (205.3\ dB + 2\ dB) = -120.7 dB$$

with an additional loss of 2 dB. According to an rearrangement of formula (Def dB) does this corresponds to a power of 0.85 pW. Between a power *P* and a voltage *V* exist the relation

$$V = \sqrt{P \cdot R} \qquad (64)$$

where in this case R has a value of 50 Ω due to the cables and amplifiers' impedances. Therefore, the voltage corresponding to the received power is round about 6.5 µV.

6 Conclusions and possible modifications

The aim of this project was to demonstrate the basic principles of a radio telescope by means of a self-built one. The construction can be used to demonstrate the components needed and the factors that could influence a measurement. By using relative simple and low cost parts, observations of several geostationary satellites are possible. Furthermore, with an additional LNA even the sun's radio emissions could be detected. At the moment the measurement of sources weaker than the sun, like the moon, are not possible. Despite the cross dipole delivering the best results at the frequency it was constructed for, some other emissions could be studied with it.

Nevertheless, different improvements can be achieved by some alterations of the components used. First of all, to gain a better angular resolution a larger parabolic reflector should be used. This would also increase weak signals so far, that they can be detected and processed with the evaluation electronic.

Using a LNB, one possible alteration of the latter was already described in chapter "3.2.1 The satellite finder": A self-built arrangement that allows using the satellite finder's absolute signal. Thereby the strength of different sources could be compared independent from the actual gain setting.

For measuring at other wavelengths, the components contained in the LNB have to be constructed anew, covering in especially filters and mixers. A spectrum analyser could then be used to create frequency spectra basing on the data gained.

To improve the programs used, as described an additional function for processing the data that were analysed by "SpectraVue" could be added and the graphic representation adapted to it. Furthermore, the controlling program could be improved to allow converting equatorial to horizontal coordinates.

By altering the way the reflector is moved, e.g. constructing a different kind of connection between the plate and the motors, the telescope could be driven to any arbitrary position without manual interventions of the observer. Furthermore, to study the emissions of a moving source during a longer interval, an automatically tracking could be added, but this would require a possibility to calculate a celestial body's orbit.

7 Acknowledgements

This document was written in British English that in some cases differs from the American version. These differences cover mainly single letters in word, e.g. "therefore" is written with an "e" at its end in British English, while the Americans skip this. Another example is the use of "z" and "s". Words like "analysis" are written with a "s" in the British version, whereas in the American version has a "z" at this place (analyze). In some cases not just the writing but also the whole word might differ, e.g. an object called "antenna" in American English would be "aerial" in Britain.

It might seem strange to see words like "bremsstrahlung" or "gedankexperiment" because them looking like German words, nevertheless, no other literally translations can be found. There are only analogous verbalisations, like e.g. "thought experiment" for "gedankenexperiment". In some cases technical terms seem to be not unambiguously, e.g. several ways to express the words "Strahlungsfluss" or "Strahlungsintensität" can be found. In some cases also the meaning of abridgments is not clear. "EIRP" can so be described as "equally" as well as "effective" isotropic radiated power.

I would like to thank all the people that made this project possible, in especially Thomas Biedermann, who invested a lot of time in helping and supporting me in many ways and Susanne Biedermann, who allowed me to come that often and reminded us to make a break. The satellite dish and a second LNB was a donation from the store "Kaiser", so I would also like to give thanks to them. Furthermore I thank my farther for "playing taxi" many times. Last but not least, special thanks to Dr. Keller and Prof. Dr. Fürst from the Max-Planck-Institute for supporting us in several ways and for intending to do so in the future.

8 Tools

Several programs were used in the scope of this project. As already mentioned, the programs were written with "Visual Basic 6.0". "EagleWin" is a program that provides the creation of circuit diagrams, therefore it was used for the ones required by the self-built appliances. During the measurements the position of the sun and the moon was determined with the simulation program CyberSky and “Microsoft Office Excel 2007” to find the function parameters as needed for the control program. This document was written with the according “Word” version. Pictures used within it were either drawn with “CorelDraw 12.0” or taken as screenshots with the “Windows snipping tool” and later on processed with “Corel Photo Paint” or “ACDsee 3.0”.

9 References

All drawings and pictures are produced by the author, unless otherwise mentioned.

(In case of references from the internet see the appended CD for the complete texts. If one site was quoted several times, respectively different parts of it, the explicit links are each time given in the upper right part of the pdf-documents.)

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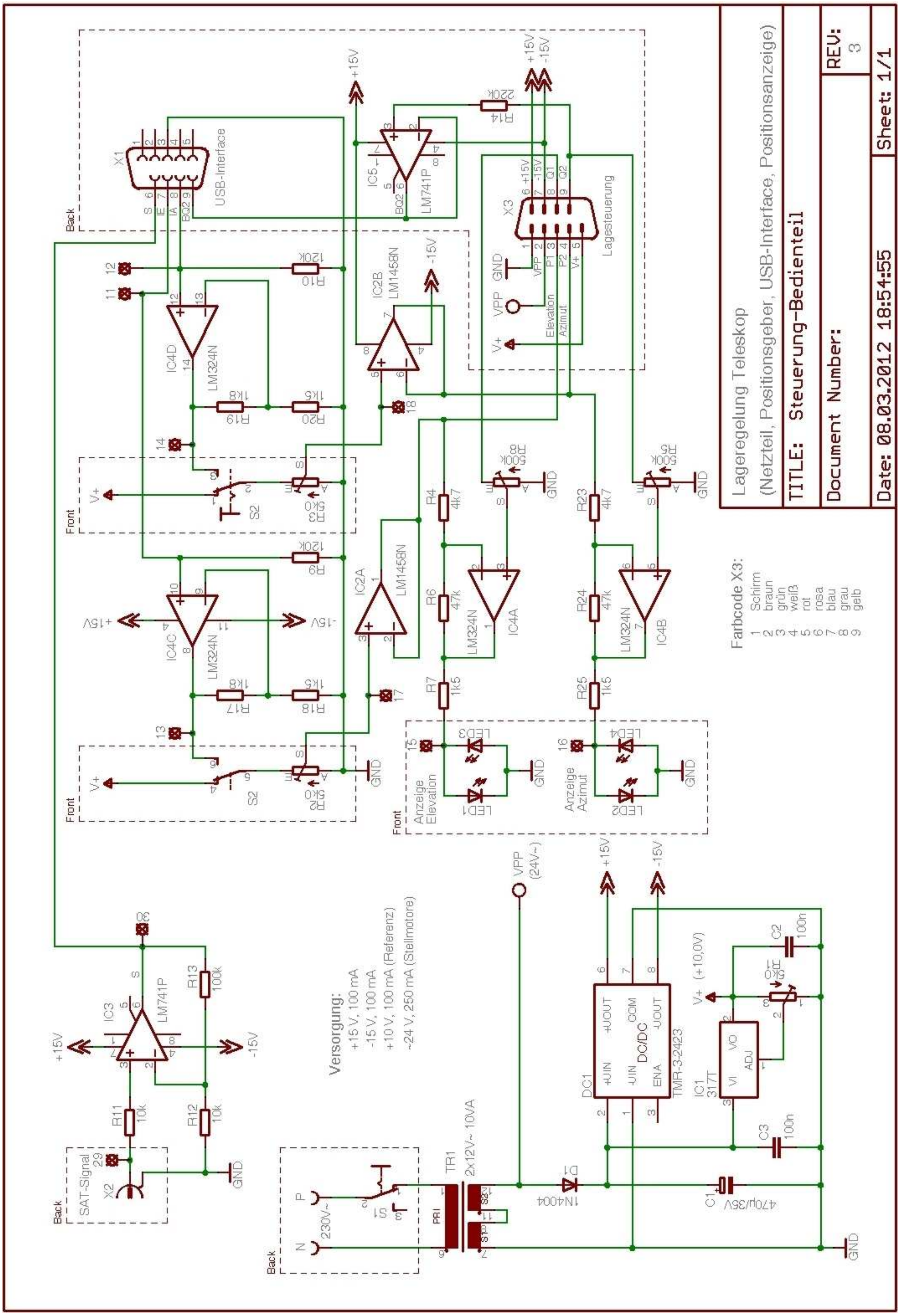
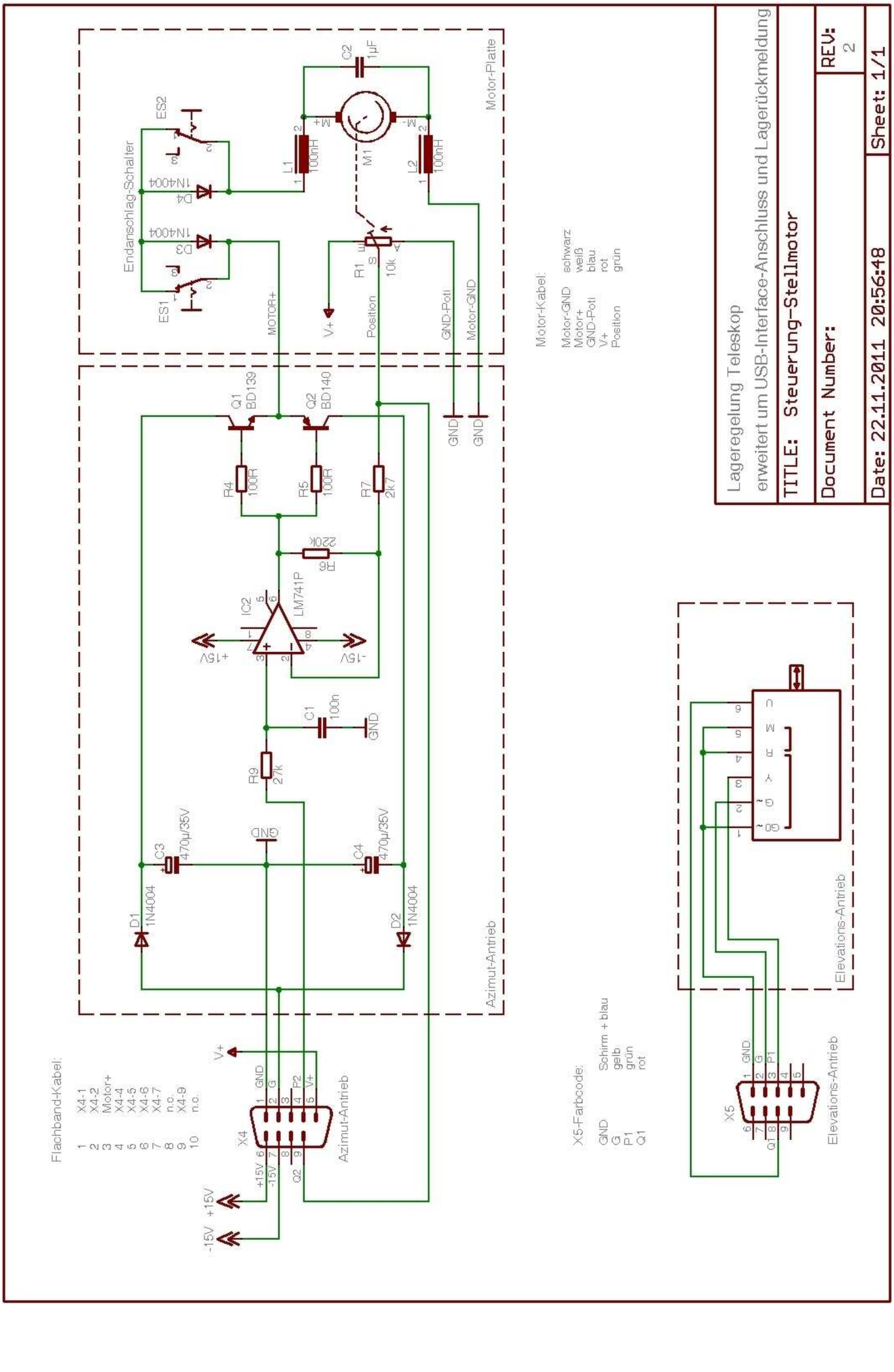
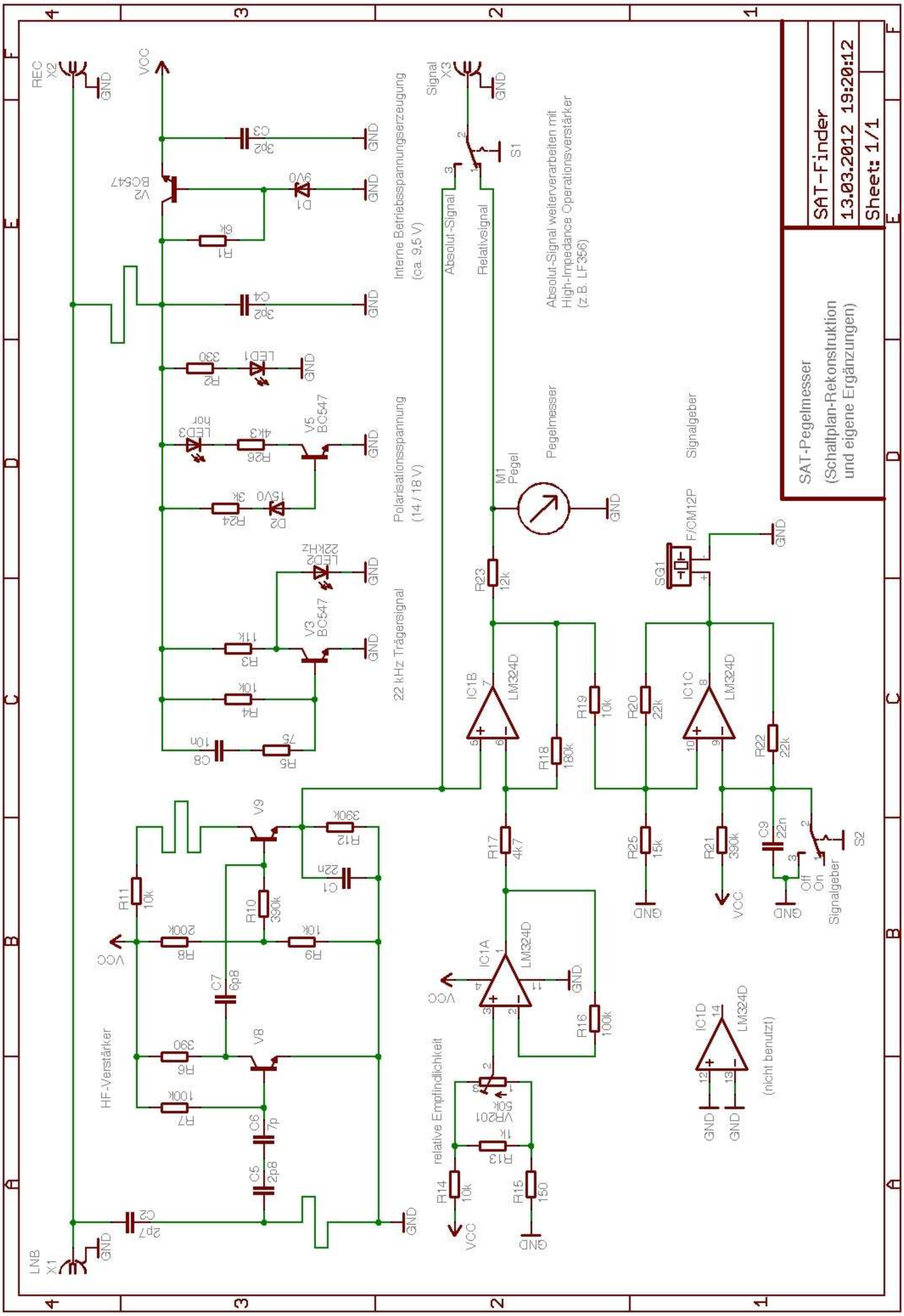
Appendix I: Circuit diagram of the control unit



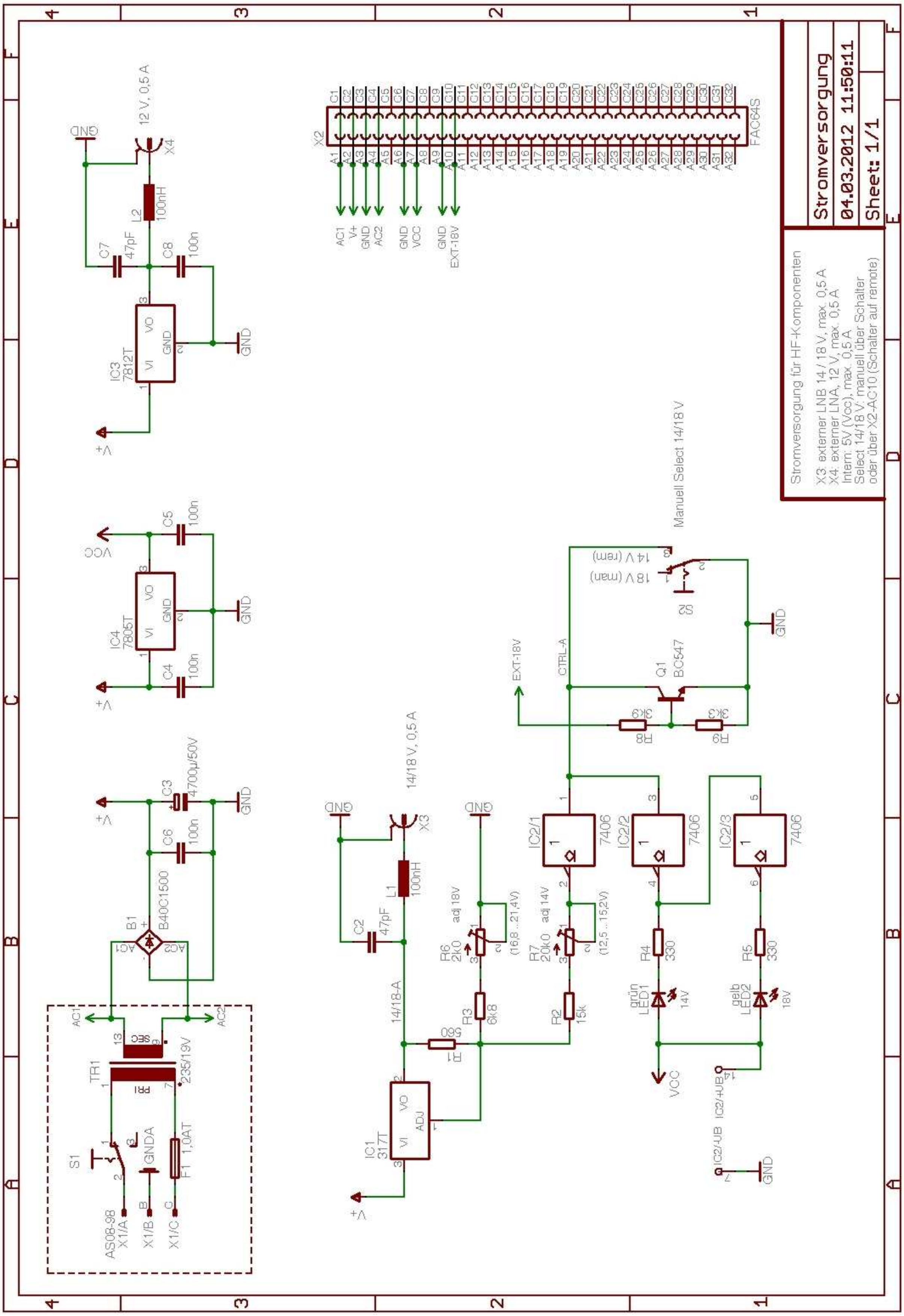
Appendix II: Circuit diagram of the motors' control



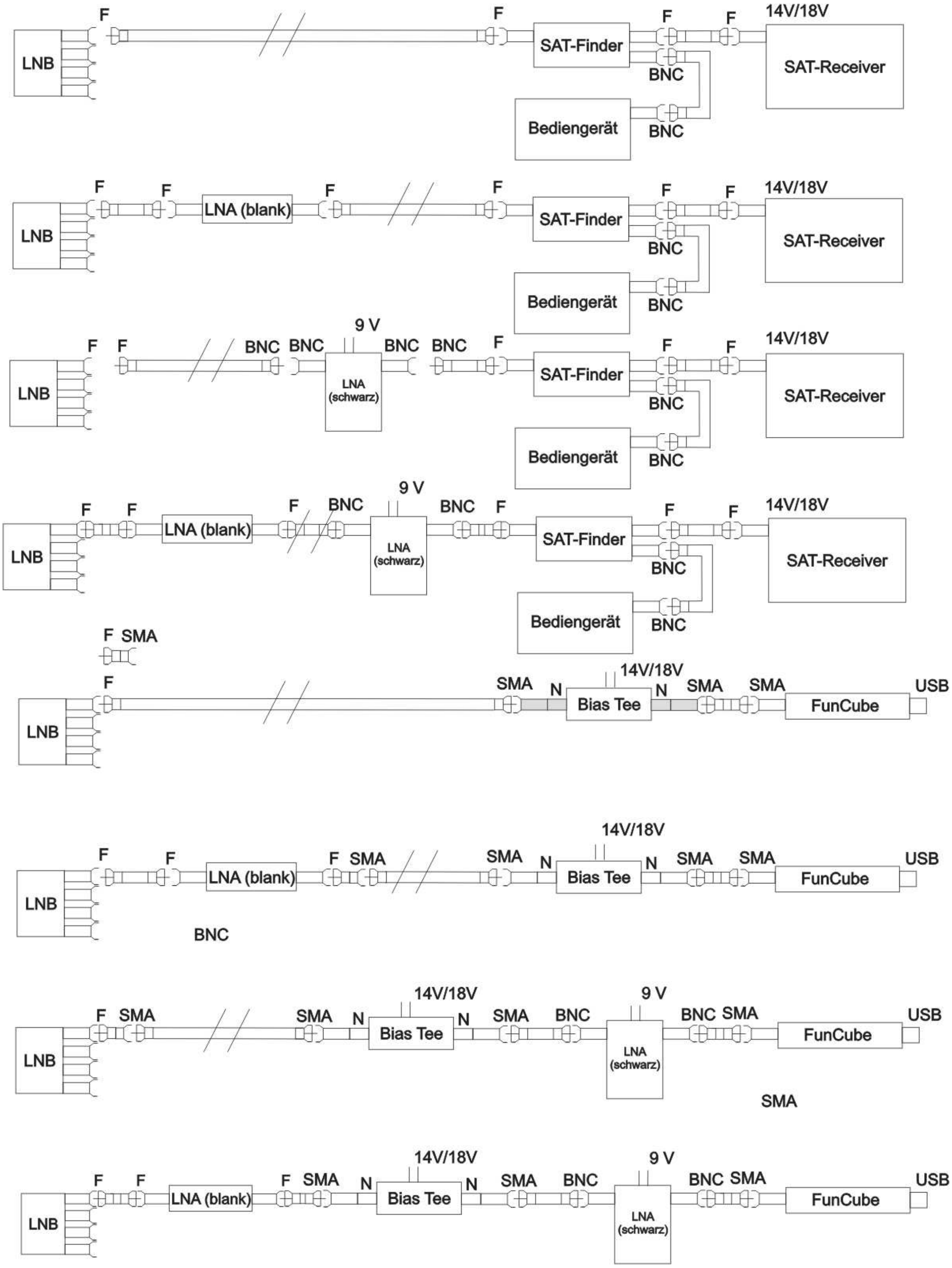
Appendix III: Circuit diagram of the modified satellite finder



Appendix IV: Circuit diagram of the power supply unit



Appendix V: Possible measurement setups (SAT-LNB)



Appendix V: Possible measurement setups (cross dipole)