Peter Greil. DL7UHU

Amateur use of the optical spectrum (above 300GHz) Part 1

Nowadays, large quantities of data are transmitted in built up areas using optical directional radio links. The optical transmission technology for this is perfected and operationally reliable. Optical transmission has been used for telephone links for over 100 years. Recently radio amateurs have also devoted attention to this subject. The basic principles and the technology are described below.

1. Introduction

The optical range has been used for telephone transmissions for over 100 years, and in Germany the term "Lichtsprechen" ("optical speech") was coined for it. During the Second World War, the technology was used mainly for military purposes, and in the Cold War period it was widely utilised by agents and spies. Nowadays, enormous amounts of data are transmitted in the Gbit range in built up areas over links that are up to 5 km long, and several thousand kilometres between satellites.

Individual radio amateurs were experimenting in this field in the sixties. The level of activity increased when it became possible to use lasers.

The range that can be covered is essentially dependent on the location and, above all, on the weather. If visibility is very good, the power level is a less important factor.

National and international regulations are currently being revised, or introduced, and co-ordinated in order to provide unambiguous definitions for amateur radio in this area.

1.1. History

Alexander Graham Bell applied for a patent for his "photophone" back in 1880. This projected sunlight onto an acoustical recording diaphragm by means of a reflector and a lens system. The reception equipment was made up of a selenium detector and a telephone earpiece [16].

This process doubles the frequency at demodulation therefore meaningful understanding can only be achieved for of modulation of <20 % and then with "errors".

In Germany, the first time any practical use was made of this technology was for telephony during the First World War. The range was approximately 8km, and for telegraphy it exceeded 8km. By 1929 various types of apparatus were being manufactured in Germany and marketed under the description of "optical telephones".

The receiver cell in use was the Thallofide (Tl2S) cell, developed in 1917. This is made from partly oxidised thallium sulphide, and used in a narrow range at approximately 950nm. Thallofide is toxic with the lower toxic limit for Tl2S being 92.7µg/m³. It is a photo-resistor and is used with a screen and a red filter, and is easy to replace.

A selection from the 24 or more known types of equipment:

The OF 80, manufactured from 1934 or earlier, was the forerunner of the LiSpr 80 (supplied to the U.S.S.R. until 1939)

The OF 130, which contained only one common lens, with a diameter of 130mm, for transmission and reception, and used as a telescope objective.

The predecessor of the Li Spr 60/50 was the LiSpr a.

Whether it was deliberate or not, the descriptions of equipment and types were used for various applications (and not always correctly used) by manufacturers, users and other interested parties.

A silicon PIN diode is at least 1,000 more sensitive than the Tl2S photo-resistor [3]. Although the receiver for the equipment consisted of nothing but the Tl2S photo-resistor and a low-frequency amplifier, relatively long ranges were specified. For example, depending on the type of equipment and the diameter of the reception lens (50mm - 130mm), daylight telephony ranges for German equipment used in the Second World War period were specified as being between 2km and >15km. Messages were indeed reliably transmitted over these distances in normal weather.

Experiments in telegraphy using Italian optical telephone equipment from the Second World War period have yielded ranges of 30km or even 50km, while only 6 - 7 km. were specified, or 9km for telephony [4]. We shall discuss range specifications later.

Equipment was also manufactured that was equipped with a high-pressure gas filled lamp as a transmitter, which was directly modulated and could transmit on several channels.

Until as late as May 1951, development, manufacture and operation was prohibited in the allied zones and the subsequent Federal Republic. The author does not know when it became possible, for example, to apply for, and perhaps obtain, licenses from the Central Office for Telecommunications Technology in Darmstadt or the MPF in Berlin.

At the end of the fifties, assembly instructions for optical speech equipment began to appear in non-technical publications. They were intended for games and experiments to amuse the young. In the sixties, the “ASTRO Infraphon 6611” optical speech equipment was licensed by the Federal Post Office, and could therefore be operated without any license or fee. A permit was still required if the remote station was not on the same property.

In 1967, Conrad Electronic developed the “NORIS 6611 optical speech equipment”. It was sold in pairs for DM59.50 in kit form and for DM110 as a finished unit The “JO 4.01 optical speech equipment” was produced in the D.D.R. in 1985, it contained a “diaphragm” which could be used for recording.

With the coming of the laser, radio amateurs also began to intensify their experiments, often only in order to set up a one-way link to receive telegraphy.

No official licenses appear to have been issued, either there were simply no applications submitted, or a decision was taken on principle to issue no licenses. (Please contact the author via the publishers if you have any information on this).

At least one license was applied for in the D.D.R., the applicant being informed a year later that the application had been rejected.

In the sixties, experiments were carried out with Manfred (now DD6VGM) involving filament bulbs, which very quickly led to the conclusion that a minimum level of optical knowledge and a minimum expenditure on the mechanics is necessary to obtain consistent results.

The first fee paying licence was issued for radio experiments in the optical range of 400 to 420GHz on 10th June, 1996, to Michael Kuhne, DB6NT, and a later one to Helmut Neidel, DL1IN. On 6th January 1998 the two of them created their first link at 411GHz. Michael Kuhne did not use an LED, he used a Russian beam-lead diode, which was mounted at the focal point of a 16cm mirror. This acted as a nine times multiplier of the original quartz signal during transmission and as a mixer diode during reception. Helmut Neidel used a 51.4GHz Gunn oscillator signal in a mixer PLL, following eight times multiplication and a 4λ "long wire" the same diode illuminated a 16cm Fresnel lens.

My own attempts to gain licences in the nineties simply made no progress, although suitable provisions were made by the BAPT for commercial use.

Things really began to move forward in 1997, when a friend was found (Rainer Wilhelm, DH7RW, in BAPT Abstract 123). Links could be established at frequencies exceeding 300GHz under very good clear conditions. The first licence was issued on 22nd June 1998, and the callsign DA5FA was allocated. Following the later allocation of callsign DA5FB to Hans (DL7VJB), a two-way A2A link was established, on a lovely sunny day, on 5th June, 1999, over a distance of 680m. Since a station consisted of a separate transmitter and receiver, tuning to the remote station was very tedious. The quality of the link led me to think that there must be sufficient reserves available for greater distances.

I subsequently worked alone, using house walls and, in the hours of darkness, and listened to foliage of a poplar, as at a distance of 140m. FM experiments with a modified ELV kit at 30kHz/ 60kHz and again at 30kHz, were carried out in the middle of 2000. The results were documented and were also made available as "specifications" to other radio amateurs.

Hellmuth Cuno (DL2CH) developed the FM link further, and managed to create a complete laser transceiver. My areas were the mechanics and optics required, the basic principles and regulations for contests, and the regulations for neighbouring countries.

With regard to the approval required, conditions were subsequently adjusted through practice and experience, and approval became possible without the allocation of a special callsign.

2. Basic principles

2.1. Wavelengths and frequency ranges

The optical range begins at 300GHz, which corresponds to a wavelength of 1mm. Specifying the wavelength is normal for the practical frequency specification and thus the band description do not coincide with the wavelength specification in every case. The Ångström should no longer be used as a unit of measurement. Current bands are listed in Tables 1 to 3, without reference to national restrictions.

In order to avoid any clashes that might arise, the band classification shown should be used. The gaps between 3µm and 12µm, or 760nm and 780nm, may be necessary for reasons of classification until the IARU can impose a clarification throughout Europe, or all over the world (?). They are available for amateur radio, insofar as national restrictions do not apply (Table 3).

Table 1 : Europe [5]

Frequency	**Wavelenghts**	**Description**
300GHz - 100THz	**1mm** - 3µm	Infrared C
100THz - 214THz	**3µm** - 1.4µm	Infrared B
214THz - 384THz	**1.4µm** - 780nm	Infrared A
384THz - 750THz	**780nm** - 400nm	Visible
750THz - 952THz	**400nm** - 315nm	Ultraviolet A
952THz - 1071Thz	**315nm** - 280nm	Ultraviolet B
107THz - 1667THz	**280nm** - 180nm	Ultraviolet C

Table 2 : USA [20]

Frequency	**Wavelenghts**	**Description**
300GHz - 25THz	**1mm** - 12µm	FIR (Far Infrared)
25THz - 214THz	**12µm** - 1.4µm	IR (Infrared)
214THz - 394THz	**1.4µm** - 760nm	NIR (Near Infrared)
394THz - 750THz	**760nm** - 400nm	VIS (Visible)
750THz - 3000THz	**400nm** - 100nm	Ultraviolet

Table 3 : Reception [5]

Frequency	**Wavelenghts**	**Description**
300GHz - 25THz	**1mm** - 12µm	
100THz - 214THz	**3µm** - 1.4µm	Infrared B
214THz - 384THz	**1.4µm** - 780nm	Infrared A
384THz - 750THz	**780nm** - 400nm	Visible preferred 660nm ± 15nm
750THz - 952THz	**400nm** - 315nm	Ultraviolet A
952THz - 1071Thz	**315nm** - 280nm	Ultraviolet B
107THz - 1667THz	**280nm** - 180nm	Ultraviolet C

Note for all tables: Band descriptions are in bold

Table 4 : Operating and transmission modes.

AM Telegraphy	Rx: 625Hz	Optimal low frequency bandwidth dependant on speed
	Tx: 625Hz ±1Hz	Square wave 1:1 medium power A3 modulation
AM Telephony	Rx: 350Hz - 2.7KHz	Low frequency bandwidth 2.35KHz
	Tx: 350Hz - 2.7KHz	Speech
FM Telegraphy	Rx: 32.769KHz	Fixed frequency between 32 and 38KHz
	625Hz	High frequency bandwidth 3KHz
	625Hz	Optimal low frequency bandwidth dependant on speed
	Tx: 32.768KHz	Carrier adjustable between 32 and 38KHz
	625Hz ±1Hz	Sound modulation index 2

The modulation index for telephony has not been optimised

FM Telephony	Rx: 32.768KHz	Fixed frequency between 32 and 38KHz High frequency bandwidth ?KHz Optimal low frequency bandwidth 2.35KHz
	Tx: 32.768KHz	Carrier adjustable between 32 and 38KHz
	350Hz ±2.7Hz	Speech

The verbal descriptions are a small selection from descriptions that sometimes contradict each other. In order to avoid the duplicated use of a wavelength and/or a frequency for 2 adjacent bands, the “>” sign was used.

National restrictions

The following restrictions apply in the 300GHz band, the operation of amateur radio equipment on the following frequencies will not be permitted in Germany in future, so please take this into account now:

300GHz to 444GHz
453GHz to 510GHz
546GHz to 568GHz
623GHz to 711GHz
730GHz to 732GHz
795GHz to 909GHz
926GHz to 945GHz
951GHz to 956 GHz

2.2. Modes and types of transmission

A list of the modes and sound frequencies used can be found in Table 4 below.

The 625Hz frequency was selected in order to reduce interference from the mains (50 / 60Hz) and its harmonics at (100 / 120Hz), for example, from illumination. The effect of the magnetic interference from the mains frequency with its harmonics, e.g. during experiments in buildings, is reduced.

2.3. Signal strength specification

It is not practicable to specify the input voltage for the “S-Meter” in relation to the input resistance. It is important, and helpful, to include the input power. Above 30MHz, 5µV into 50Ω corresponds to an S-Meter reading of S9. This gives an input power of 5×10^{-13}W, corresponding to 500pW.
However, specifying the input power alone still says nothing about the “field strength” present at the receiving point.

It is expedient to relate the input power to the reception area, which gives the “field strength”. Thus the remote transmitting station can determine the intensity of irradiation from itself at the receiving point. You should determine whether there may be a risk to your eyes.

So we return to what was normal in amateur radio by specifying of the received field strength, and move away from specifying the input voltage [17].

This means that specifying the signal strength for the remote station is more meaningful, and the receiving point knows the sensitivity of the receiver that is being used. To specify signal strength to two decimal places in the RST/M system, the radiation is measured in the usual 6dB steps. The description should simply be left to the RST/M system. With a high irradiation, the suffix (+ x dB) is required. The reception of weak satellite signals has been taken into account.

If we take dm² as the reception area, or a round area with a diameter of 1.13dm, we obtain the readings below. Here we are in the range of specifications S 1 to S 9 only for very sensitive receivers, and otherwise we are at S 9 + x dB.

Perhaps this will start people thinking about putting more energy into developing increasing receiver sensitivity:

S 1	7.63×10^{-16} W/m²
S 2	3.05×10^{-15} W/m².
S 3	1.22×10^{-14} W/m²
S 4	4.88×10^{-14} W/m²
S 5	1.95×10^{-13} W/m²
S 6	7.81×10^{-13} W/m²
S 7	3.13×10^{-12} W/m²
S 8	1.25×10^{-11} W/m²
S 9	5×10^{-11} W/m²

The S0 specification indicates that no meaningful data can be obtained.

The receivers S-Meter can be calibrated at no great expense see also vacuum range.

2.4. Signal generation

A laser does not have to be used as the transmitter, even if the classification refers to laser classes [5]. An LED, an LED group or another source may need to be allocated to a laser class to make the corresponding risks apparent. This also applies to transmitters that are driven by frequencies below 300GHz or generate their signals in another way.

2.5. Laser classes

If we purchase laser diodes, laser pointers or laser diode modules, we find a laser class specified on the equipment, or some other indication of possible risks. This has also begun to happen with LEDs.

The laser classes are clarified in DIN EN 60825-1, with particular reference to any possible health risk to the eye. The licence to use a laser class includes the corresponding indications regarding the safety required.

The specification of the maximum power as a limiting value, normal in amateur radio, is useful only under extreme conditions, due to the physiological effect in the optical range, and so is meaningful only in special cases for the radio amateur. Depending on the conditions, for laser class 3B, a power level of between 1.58mW and 150MW is permissible for our experiments. For an emission lasting 1ns, we can probably not carry out a QSO, but we can receive a reflection from a remote sphere in the sky.

The following numerical values do not take any modulation and/or keying into account. They are based on continuous wave power plotted against the angle of radiation, the duration and the wavelength, which is not given in full in every case. This is a simplified representation but the corresponding standard (DIN) should be utilised in every case, in order to detect the framework conditions.

Limiting value for accessible radiation, abbreviated to GZS (Grenzwert zugänglicher Strahlung), see Tables 5 and 6.

Table 5 : Old version of Laser Classes. (March 1997, expires 1/1/2004)

Laser Class 1

Sources that are safe under reasonable operating conditions

λ660nm	α < 11mrad	t 1ks	at 125µW
λ940nm	α 5mrad	t 1ks	at 360µW
λ400 - 550nm	α < 11mrad	t > 10ks - 500min	GZS 3.9µW
λ550 - 700nm	α < 11mrad	t > 10ks - 500min	GZS 3.9 - 125µW
λ700nm - 1.05µm	α < 11mrad	t > 1ks - 500min	GZS 120 - 600µW
λ 1.05 - 1.15µm	α < 11mrad	t > 1ks - 500min	GZS 600µW
λ 1.15 - 1.4µm	α < 11mrad	t > 1ks - 500min	GZS 4.8mW
λ 1.4 - 4µm	α < 11mrad	t > 10s - 500min	GZS 10mW

Laser Class 2

Sources of visible light only, in the range from 400nm to 700nm. In this range the eye is protected by natural reflex reaction.

λ400 - 700nm	α < 11mrad	t > 10s	at 1mW

Laser Clas 3A

Sources of visible light as in class 2 or other wavelenghts, viewed directly using optical aids (binoculars, telescope etc.) can be dangerous.

λ400 - 700nm	α < 11mrad	t > 10s - 500min	GZS 5mW
λ700nm - 1.05µm	α < 11mrad	t > 1ks - 500min	GZS 0.6 - 3mW
λ 1.05 - 1.15µm	α < 11mrad	t > 1ks - 500min	GZS 3mW
λ 1.15 - 1.2µm	α < 11mrad	t > 1ks - 500min	GZS 3 - 8mW
λ 1.2 - 1.4µm	α < 11mrad	t > 1ks - 500min	GZS 8mW
λ 1.4 - 1mm	α < 11mrad	t > 10s - 500min	GZS 50mW

Laser Class 3B

Sources that are usually only safe when viewed as diffuse reflections. A beam from the source is usually dangerous.

λ400nm - 1mm	α < 11mrad	t > 10s - 500min	GZS 500mW

2.6. Daytime visibility range

Meteorological visibility, as observed in weather stations, is defined as the greatest distance from which a black object of sufficient size (angle of vision 0.5° to 5°) can be seen against the horizon with the naked eye and at which it's outlines are recognisable. Telescopes and the like may not be used here.

A normal pencil at the end of an outstretched arm can be seen at an angle of vision of approximately 0.5°.
Television masts, church towers, high chimneys, monuments, etc. can be used as visual markers.
The "black object" in the above definition should not be taken too seriously. The difference in luminance is a physiological factor in visual observation. The human eye recognises a difference if the object has about 95 to 98% of the

luminance of the background (the horizon). The reference value for visibility is the horizon, even if it's luminance is changeable, e.g. for the morning sky and evening sky in the East or the West.

The range reported at a weather station is the worst visibility at any compass point on the horizon, so there should be poor visibility over approximately a 30degree sector. The code 89 in the SYNOP code for visibility (VV) means, “visibility exceeds 70km”. If we look at this critically, the very fine sub-division of visibility in the weather code is not adhered to at all weather stations. The range of visibility has no decisive significance for the weather forecast. Yet the differences in visibility are taken very seriously for visibility ranges of up to approximately 5,000m, since they are particularly important for flying (visual flight).

2.7. Range

In the following, daytime visibility range is understood as having the meteorological definition given above, so visibility range does not necessarily refer to seeing an object.

It makes sense to be within the visibility range to begin with. Eyesight, the lasers frequency and the frequency dependent sensitivity of the detector, the attenuation problems in the atmosphere due to water vapour, carbon dioxide and other gases in the infra red are the criteria. The atmosphere is always a non-homogenous medium as the distance increases, due to the different temperature layers. The light beam becomes “curved”, even if only the effects of this can be observed. This often happens when making measurements using a theodolite in cities, therefore these measurements are therefore restricted to short distances. For this reason, measurements over greater distances are carried out on 2 days with as much variation in the weather as possible. Links parallel to the ground at the normal distance can be extremely misleading, so please choose the right links for experiments.

If the stations are 20m above the ground, the beam is displaced, at a distance of 6km, by 1m in the course of a day. At a height of 4m, the displacement is 5.1m, and at the standard height of 1.5m. it is considerably more. The displacement changes with the distance, double the distance equals four times the displacement! As long as your eye is on the finder and your finger is on the sighting device, or as long as effective control can be exercised using a 4 quadrant detector or the like, the process can and will be stabilised.

It is usually not possible to distinguish whether the “mechanics” and/or the optics and/or the atmosphere has/have “moved”. So reliable links can be used only up to 3km (5km), but then they can be used almost permanently. As the height increases, the attenuation is reduced more and more. At a height of 4,000m, the attenuation is only 1/1000 of the attenuation at sea level. For this reason, no attempt was made to carry out precise observations concerning the weather, the height and other parameters to determine the range. This would be outside the framework and would be of little use in practice, since we are in fact working in “real time”.

It is expedient to specify the vacuum range. For a daytime visibility range of 500km, 99% of the vacuum range is obtained. If we take the equipment parameters as given and use the equipment sensibly, the range depends on the weather and the condition of the atmosphere. A pre-condition is that the sites have been sensibly selected. Information in [1] is highly recommended. It contains comprehensive basic principles, with comprehensive calculations and also measurements for Berlin, Karl-Marx-Stadt (Chemnitz), Dresden (highest attenuation), Greifswald, Leipzig and Warnemünde (lowest attenuation).

Table 6 : New version of Laser Classes (Issued November 2001, valid in Germany since 1st November 2001).

Laser Class 1

Sources that are safe under reasonable operating conditions.

λ315nm - 400nm	t 1ks - 500min	GZS 7.9µW
λ1.4µm - 4µm	t 10s - 500min	GZS 10mW
λ4µm - 1mm	t 10s - 500min	GZS 1000W/m^2

Laser Class 1M

Sources that are safe under reasonable operating conditions except when optical equipment is in use.

λ315nm - 400nm	t 1ks - 500min	GZS 7.9µW
λ1.4µm - 4µm	t 10s - 500min	GZS 10mW
λ4µm - 1mm	t 10s - 500min	GZS 1000W/m^2

Laser Class 2

Sources that are safe under reasonable operating conditions. Eye protection normally ensured by lid closing reflex.

λ400nm - 700nm	α <1mrad	t>0.25s	GZS 66.7mW

Laser Class 2M

Sources that are safe under reasonable operating conditions. Eye protection normally ensured by lid closing reflex except when optical equipment is in use.

λ400nm - 700nm	α 100mrad	t>0.25s	GZS 66.7mW

Laser Class 3R

Source that could be dangerous if anyone looks directly into the beam.

λ315nm - 400nm	t 1ks - 500min	GZS 40µW
λ1.4µm - 4µm	t 10s - 500min	GZS 50mW
λ4µm - 1mm	t 10s - 500min	GZS 5000W/m^2

Laser Class 3B

Source that are normally dangerous if anyone looks directly into the beam.

Attenuation at 920nm per km. for:

50%-70% of time attenuation <1.3dB
82%-90% of time attenuation <4dB
98%-98.5% of time attenuation <40dB

A 99.9% certainty for transmission in the open air is possible only over a few hundred metres at an acceptable cost. Equipment for serious users is commercially advertised and used only at distances of up to 3km and in exceptional cases up to 5km.

As radio amateurs, we must use the times and the weather when the attenuation is relatively small.

Range specifications for a combination of transmitter and receiver (Tx/Rx) are rarely meaningful, since the specifications for this usually do not include the weather and the attenuation required, or else they can not be reproduced.

For commercial equipment in the DDR, ranges were specified at a visual range of 5km and a signal-to-noise ratio of 10dB. For the JO 4.02 unit (specified range 5km), this gives a range of 15km for a visual range of 70km. The vacuum range is 20km for the signal-to-noise ratio mentioned. This gives a considerably greater range under amateur radio conditions. It is necessary to specify the vacuum range because this completely dispenses with the weather and thus the atmosphere. It is expedient if it is based on equipment with the same characteristics as the remote station. The vacuum range can be calculated theoretically or determined practically.

If you can not use a second transmitter, receiver or transceiver of the same type, a combination can be used. This might be a telescopic sight, LED/Laser diode module with a short length, so that you can ignore the attenuation. Good visibility is needed and it is important that the radiation cross-section of the transmitter exceeds the receiver area. It must be possible to reduce the receiver area by a defined amount, for example by means of a 3 section screen. Once contact has been made, the receiver area should be reduced while the signal received corresponds to the values expected for the signal-noise ratio and the limiting range.

At first the maximum daylight visibility range was given for VV = 89 as >500km. It is anyone's guess why it was changed down to 70km. With a daytime visibility range of 18km, for two items of equipment with different vacuum ranges of 30km and 100km, a relative range is obtained usually only a range described as being of 10km or 16km. The longer the vacuum range, the closer the relative range comes to the visibility range. If you can see the remote station, that does not always mean that you can also work with it, and vice versa.

To be continued.

X. References

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Peter Greil, DL7UHU

Amateur use of the optical spectrum, part II

Update

If the proposed draft version of the amateur radio ordinance (Amateurfunkverordnung = AFuV) avoids any "changes" and comes into force at the end of 2003 or the beginning of 2004 as the AFuV, the situation will be as follows:

The amateur radio range starts at 444GHz, with a few gaps being reserved for radio-astronomy and earth resources radio services. From 956GHz to 1,667PHz, the optical range is then fully available without any restrictions on frequency, even for operating and transmission modes that are not yet in existence!

Once the new amateur radio ordinance comes into effect, an existing amateur radio callsign is sufficient for the "lower" laser classes, and no applications need be made for confirmations, approvals and the like.

For amateur radio operation in laser class 3B, which could involve a higher risk of personal injury, an application should be made under Paragraph 17 of the AFuV. Permission will not be granted for activities involving laser class 4.

The term "laser classe(s)" from (DIN) European standard EN 60825/1 is used here, no lasers need be used. Even in this case, they are mainly to be used for other activities (LED, copying, and the like) see also Part I in VHF Communications 1/2003, Page 19.

Continuation from Part I:

2.8. Eyes and optical instruments (binoculars)

If at least 25 photons make contact with an eye which has been acclimatised for at least 30 minutes, 8 of those photons will reach the retina and a light stimulus is registered. Changes in the light intensity in the ratio of 1:10,000,000,000 can be detected! The eye can not be beaten for individual photon detection except by very good photo multipliers and avalanche photodiodes.

So what makes a good pair of binoculars? The ratio of the objective lens diameter to the eyepiece lense diameter gives the magnification, which is specified as the first number. This means that the lens is seen as if from a shorter distance, in accordance with the lens distance/magnification ratio. For Earth observations with the naked eye, the eypiece lens diameter, which is made approximately the same size as the users pupil in mm, is specified as the second number, and defines the maximum meaningful magnification. For astronomical observations, and when only low definition is required, the value should be doubled. From low values up to approximately 125mm objective lens diameter, the definition improves linearly. Subsequently, massive increases in the diameter of the objective lens are necessary in order to increase the definition any further [30].

Unfortunately, binoculars are on sale which do not fulfil these conditions. “Magnification to spare”, “more magnification than you need” thats what the salespeople say. The effective eypiece lens diameter (Austrittspupille = AP) is obtained by dividing the objective lens diameter by the magnification. In the course of a lifetime, the maximum possible pupil diameter of a healthy person changes from approximately 7mm to approximately 2mm. A person (usually an older person) with a pupil of a maximum 2mm uses only 8% of the capacity of a pair of 7x50 binoculars, usually identified as a night glass, since the effective eypiece diameter is 7mm! Now its clear what a good pair of binoculars are!

You should just check for yourself what your maximum pupil diameter is, in the twilight hours, after at least 30 minutes.

A light filter matching the wavelength of the light to be received can be attached to the lens to heighten the contrast not only when there is interference due to external light sources with a different wavelength, but also to target prominent points. Such a filter was supplied, for example, with the ZEISS Glas 6x30 from Li Spr. It was described as a “monocular filter”. Filter combinations can also be of assistance here. Filter goggles naturally do the same job, but are uncomfortable. (Often wrongly described as “protective goggles”, suitable filter goggles are supplied with laser spirit levels. Protective goggles must naturally have green filters for this purpose). Edmund Optics (www.edmundoptics.com) is a good source of filters outside Germany - Ed.

The twilight output (Dämmerungszahl = DZ) is the product obtained if the magnification is multiplied by the lens diameter. Additional physiological factors are taken into account here, which influence night vision. The higher the product the better, but take account of the comments made on the meaningful size of the exit pupil to obtain the twilight output. So the twilight index (DI) = DZ x AP takes account of the real eye.

2.9. Received power and intensity of irradiation

To obtain a general idea of what is feasible, we can calculate the fraction of the transmitting power arriving at the receiver under ideal conditions, the received power.

See also Section (B) - Calculations

At 660nm, the background radiation under ideal conditions, on a moonless night, is approximately 7µW/m². [18]. 16kcd/m² can be taken as being the maximum horizontal luminance for a clear day [25]. The higher usable sensitivity of very good avalanche photodiodes, (APDs) and photo multipliers, (PMTs) can not be utilised except at night using the modulation processes specified here. They are less suitable for daytime use than PIN diodes.

But first we must look into standard PIN diode technology. Its a short cut to finding useful devices.

2.10. Locations and location specifications, searching for and finding remote stations

As regards specifying the location for the locator, use WGS84, and if possible use 8 digit references for short distances [8]. (Microfield, TNL enhancement) The meaning of the 7th and 8th digits is analogous to that of the 3rd and 4th digits. Logbook programs have recently been developed which can be used for the 8 digit locator and also for THz. (The Log, HAMMAP). The WGS84 height is not suitable for height specifications. It is not a working height. So dont be surprised if GPS equipment appears to give false height readings. The standard datum zero (Normalhöhennull = NHN) has taken over from the HN and NN as a working height. Even modern maps still have data taken from different reference systems, so dont be surprised [2].

With the disappearance of visible boundaries in the "undergrowth", there may be problems in the determination of the political location, the provincial boundary. Here you should refer to maps from the UTM experts or showing the UTM grid [31]. Since 1998, topographical maps have been available in bookshops and from land survey offices in WGS84 with a UTM grid! GPS equipment can also be used to call up prominent points later and read them off as UTM, locator, Gauß/Krüger and other data, which is considerably more comfortable than carrying out calculations. Displays in "mil", (compass point) are usually more accurate than those in "°", (e.g. Trex Legend GPS equipment) The UTM expert/grid data can also be used in "undergrowth" without any problems, since a fmap slide/scale with a length of 5cm. is also suitable for 1:20,000.

A map slide is better than a scale; it can always be used directly for 2 scales without any calculation. You can easily make one yourself.

In the spirit of HAM, every station should have one or more triple systems to use as remote stations. It is particularly effective to receive a sufficiently strong echo by impulse modulation with a corresponding transmitter pulse width repetition rate, it is radar with light (LIDAR). This provides more security than listening to the 625Hz tone of the normal inherent modulation.

With regard to radio stations in urban areas and "on the flat", we usually quickly get to the point where these can no longer be seen and thus located, since the roofs "all look the same".

An opaque balloon filled with balloon gas, helium or hydrogen is quickly lifted by the wind. Normal balloons are unsuitable, since insufficient contrast is present when light shines through them. So its better to inflate them with air; a suitable visual target is (for example) a group of balloons providing a contrast, fastened to the end of a long fishing rod. The tip can be more securely anchored using an attached "truncated pyramid" of material, with an additional fastening, in addition to the visual target.

Its not only on stony mountains that there are problems determining the direction using a magnetic compass. It may be possible to solve the problem by taking a bearing on at least one prominent object (in Berlin and the surrounding area this is usually the television tower).

However, if you do not mount the optical transmitter on one of the types of equipment below it is preferable to use a Protractor (on a stand), or a bearing plate, a levelling instrument with a horizontal (Hz) circle, or, if things are really difficult, a theodolite. An illuminating device (also for the cross-lines of the telescope) can be fitted and it makes sense to use one even in daylight. Equipment that is too precise may be too complicated in its operation. By calculating in "paces", like the artillery used, discrepancies in the determination of the angle can be eliminated, providing there is a not inconsiderable distance between the optical transmitter unit and the position finding device.

Flak telescopes make an excellent starting point. They have a horizontal circle, a full circle of (360°/400g) /6000 or 6,400 compass points or the like, and an almost 90° vertical circle, together with an illuminated bearing plate.

N.B. Depending on the date of manufacture and the province/military organisation, 6,000 or 6,400 compass points are used for the full circle.

North seeking gyro-compasses are in use

for mobile radar equipment. Their accuracy is relatively high, even for our purposes.

To make the “manual labour” easier, Erich, HB9MIN proposed a beam scanner [19], among other things, which can be used from a station located at a prominent visible point. Provided both stations have a triple system, they can both also use a beam scanner (simultaneously, of course) if neither station is visible. It should then be possible to locate the optimal alignment in adequate comfort, and sufficiently fast and accurately.

The first stage is to find the possible locations using the “Radiomobile” 17 program. Help for the first steps was compiled by Michael Oetjen, DH6XS, for this procedure. The precision work can then be carried out in an excellent manner using “TOP 50” or “TOP 25”.

The “Top50” program is on sale in bookshops for everyone in Germany. In the “Top 25” ‚Baden/Württemberg is there on a 1:25,000 scale, 360 maps with UTM. In the “TOP50”, from version 3 onwards, gradient diagrams can also be entered and, naturally, printed out. From the location specifications, the position of the cursor displays details of the location each time (with an appropriate setting) and allows the angles between the locations and between the locations and the prominent object to be read off on the screen and/or calculated more precisely. The automatically displayed angle unfortunately has a resolution of 1°. So it is a simple matter to align the optical transmitter approximately with the remote station, even when this is not visible.

(Errors in TOP50: Brandenburg/Berlin, Version 3, at 1:50.000 printed out values of minutes after decimal point in representation in degrees and minutes without seconds can be wrong please switch to representation showing degrees, minutes and seconds!)

Since WGS84 is used for the locator, it makes sense to calculate the angle from the WGS84 co-ordinates of 3 locations. Include length and width in degrees/(minutes) or values for UTM with the associated heights in m. But it may be necessary to use elements of spherical trigonometry for this, in a transformation or during the actual calculation process.

In order to get by without spherical trigonometry, you can use the co-ordinates of the locations in UTM. The angle can quickly be determined with the normal angle references for flat surfaces, using the top values and right hand values of 3 points. If the height is not taken into account, an additional error can arise. Only the angle is correct. The North direction, however, the paths/distances, and thus the areas on the map, are wrong.

The top value is the distance to the Equator, the right hand value is the distance from a specific meridian which lies to the left.

The program in HAMMAP18 makes it possible, not only to integrate the Top50 maps and the re-calculation of various co-ordinate systems, but also to calculate the locator (2 to 12(14) places), the angle and the precise distance, among other things.

3. Assemblies in an optical transmitter

We suggest the following:

Receiver, consisting of the detector head and the optical section (if applicable, sighting device), in theory can function on its own;

Transmitter, consisting of transmitter head, laser or LED module with mechanism (if applicable, sighting device), in theory can function on its own;

Sighting device, if not present on transmitter or receiver;

Operating element, size of a hand microphone, includes sound selection, amplifier, microphone, key, modulator with sound generator, possibly with internal power supply, and can operate with various receivers and transmitters.

Power supply external, optional;

Accessories can be attached to operating element, such as headphones, microphone (transmit receive combination), key;

Basic mechanism, adjustment option for side and height, seat for stand screw, connection between receiver and transmitter.

Stand, stand rail, fastening for theodolite

3.1. Receiver

The detector head includes the detector with pre-amplifier, and is replaceable. It can be advantageous to combine it with screen, tube and filter(s).

The actual detector usually receives from behind as well, please fasten it from below! If the sensitivity of the photodiode in short circuit mode is set to 1, it is 7 x less when idling and 50 x less in diode mode [13]. This does not exclude the possibility of using idling and diode mode as well. The option of receiving constant light may not be provided for not even for measuring purposes as it will destroy the optimal layout. A2 and A3 do not really get into their stride below 350Hz, while FM certainly lies considerably higher.

The NEP (Noise equivalent power) can be determined from the data sheets of the diodes or calculated.

See also Calculations section (C)

The dark current, IR , is given for a specific blocking voltage. With a small active area, the dark current is lower. It is recommended that diode measurements are carried out. This is advantageous if the noise is mainly determined by the diodes. Often the subsequent amplifier plays too great a part in this if it is not designed correctly. For our purposes, the bias currents must be low. (LF 356, LT 1028, OP 27, OPA 111, OPA 627) N.B.! The maximum permissible blocking voltage for photodiodes is often smaller than 1V which gives a risk of destruction.

Using a trans-conductance amplifier, the degeneration resistance is increased and the bandwidth is decreased, with a simultaneous increase in the amplification [9].

The slope resistance should be at least 10 x greater than the diode resistance. This can rarely be achieved with silicon diodes. So maximum sensitivity can always be attained, depending on the upper limiting frequency required. Changeover should be carried out in the detector head, preferably through a relay. One side effect is the associated change in the amplification. One range for AM, 350Hz to 2.7kHz and one for FM and other modulation processes (30kHz) … 32.768kHz ... (40kHz).

There are well-priced solutions available for remote control systems, photodiodes, trans-conductance amplifiers and band pass filters, for a frequency between 30kHz and 40kHz. Most have infra red filters, all integrated in one housing. Unfortunately these are mainly suitable for telegraphy, and apparently only for the 214THz band Using the Burr Brown OPT101 and OPT210 is simple photodiodes and trans-conductance amplifier, with access to bandwidth and sensitivity in one housing.

Replaceable at any time thanks to the mechanical separation of the operating element, and/or another operating element can be used for amplification and de-modulation via cable permanently fastened to detector head with pin-and-socket connector

Make sure that the frequency response of the system is appropriate for the transmission mode. A series circuit of

560Ohm at 47nF sets the lower limiting frequency at 6kHz and is thus not suitable for AM, but is OK for FM.

Things are different in the "basic optical path". It is not necessary to make trial systems with small lenses or other limitations. This wont change the laws of optics, although it may mean simpler equations can be used. If you are working in the sunshine for a range exceeding 2km, the limiting sensitivity means that the receiver's area diameter must be >58mm to reduce interference. These occur due to atmospheric turbulence effects which arise because we are using a wavelength of 660nm, corresponding to >80mm diameter at 920nm. For use during snow, rain and hail, the receiver area should also be large. Multiple reception is better, with several "small" receiver apertures being used instead of one "big" one. Two optics/lenses with a diameter of, for example, 80mm, are usually cheaper than one optic/lens which has a diameter of 113mm but have the same total area.

As the effective area of the light collector increases, for lenses (or lens systems) and mirrors (or mirror systems) the sensitivity theoretically increases. There are losses due to reflections on the air/glass surfaces and/or air/plastic surfaces. These can be reduced by an anti-reflection coating of approximately 8% on 1% of each contact surface. Additional losses occur if the light does not strike the photo sensitive surface vertically, details are usually given in the data sheets for the detectors. Thus concentrating reflectors are normally not able to make very good use of the light source provided, since only a very small cross-section can be used. I know of only one such system used in practice.

Please do not forget that no stray light should enter the receiver diode, a small reception angle should be aimed for. If this is not be possible, a screen usually helps.

The receiver (transmitter) angle for the receiver area (transmitter area) is determined by the areas size and by the focus.

See also Section Calculations (D)

Reputable commercial equipment (JO 4.02, -03) has the same angle on receive and transmit sides for illumination/imaging.

Optical systems which, for example, illuminate a small image measuring 24mm x 36mm, are thus naturally not needed; systems lighting up only a few mm² are sufficient, as for television cameras with small chip areas.

Some flea markets still have objective lenses with long focal lengths from DDR observation cameras, some simultaneously corrected for 546nm and 850nm and are usable in the 394THz and 214THz bands.

You should keep it in mind that the source of the remote station images should image a diameter in the nm/µm range under ideal conditions. Anything more on the detector reduces the signal/noise ratio and thus the range!

It is also important to use a screen and to keep the focus wide. A screen may sometimes be dispensable, but only for small area photodiodes.

For detectors with optical waveguides, the lenses are selected in accordance with the aperture number.

See also Section Calculations (E)

This is applicable if one end of an optical waveguide is fitted at the focal point of a lens (even a large one) as the receiver. By using an additional lens/optic, the active diameter of the optical waveguide, which measures only a few tenths of a mm, can be increased to even out tolerances (see above equation with note). There are highly sensitive broadband receiver modules which can be used for this.

Photographic objective lenses can have excessively high losses, compared to mirror objectives, because they have several contact surfaces, particularly old ones which have not been coated. High quality optical corrections are usually not necessary, since the laser and the LED are emitting radiation on almost the same wavelength. Simple lenses, telescope lenses, telescope (air) achromatic lenses and telescope mirrors can be more suitable as high quality lens photographic objectives. Newtonian systems use a paraboloid reflector (with a plane mirror), Cassegrain systems use a concentrating reflector with a convex hyperboloid mirror. The Maksutow mirror system uses a meniscus lens instead of the Schmidt plate. Fresnel lenses (for continuously corrected lenses) and, if applicable, simply constructed projection objectives can be suitable. Favourably priced magnifying glasses may contain lenses that are more suitable for us than magnifying glasses from well known manufacturers; these are constructed for the magnifying glass application and are then not suitable for us. The effective aperture, the ratio of the diameter to the focus, is usually large. Both factors combine to prevent the focussing of radiation from infinity. Thus an efficient screen can not be used, because the radiation can not be focussed sharply, in order to make optimal use of small area screens and detectors.

The only error in a lens that can cause problems is the aperture error, also known as spherical aberration. The intersection of the edge radiation, zone radiation and central radiation forms a focal surface (caustic surface, which can become visible in a round white cup full of coffee!). The radiation lying further out (edge radiation) is more intensely refracted (prismatic effect), in contrast with the radiation lying further in (zone and central radiation). The focus is nearer to the lens. When the sine condition is met, the error is eliminated.

If the receiver lens is only illuminated by radiation of a wavelength that is parallel to the axis, other lens errors have no negative influence.

Detectors that are very interesting for us have light sensitive areas with a diameter of 0.3mm and below! Thanks to the small diameter of the light sensitive area, in the same way as with the large area detectors with a screen, the influence of stray light is very much reduced.

If a large area detector, e.g. OPT 101, is used without a screen or a tube, this means that you can only work well at night. The bandwidth obtainable by day is too low.

So my advice is always to check the focusing characteristics by imaging a distant object (e.g. the Moon) if the focusing characteristics are not known. A reflex camera can be used to carry out some excellent tests here.

This can not be done quickly, since you must make sure that the lens/optic and the white reception area are parallel to one another, the imaging takes place in the centre of the reception area, and the correct side of the optic/lens must be selected. To make sure there is enough contrast, a piece of tube, or better two, should be used. It is only in special cases that you can determine the aperture via the imaging of the Sun. If you image an object 1:1, and divide the distance between the object and the image by 4, that is the aperture. A suitable object might be the writing on the cap of a lit incandescent bulb.

As regards simple lenses, an aspherical lens for minimal aperture error at the wavelength in use would be ideal. A very suitable lens is the “best form lens”, also known as “the lens with the most advantageous shape”. Here one surface is convex and one only slightly curved or plano-convex. The surface which is more curved points to the remote station!

Some good results have been obtained using spherical, plano-convex spectacle lenses. If material is available with the right refractive index (refractive index 1.685 at the corresponding wavelength for thin lenses), the aperture error is minimum. Modern, point focal lenses are not at all suitable and bi-convex lenses, in which both surfaces are equally convex, are not suitable for large apertures.

Obtaining plano-convex spectacle lenses from ZEISS with minimal aperture errors, aperture approximately 300mm, diameter 70mm/75mm, has not been practicable because they are very expensive. It can be more advantageous to get hold of telescopes from a junk shop and to extract the lens. Standard optical multilayer anti-reflection coatings for visible light are almost always useless in the infra-red, as their dimming effect is too great.

The fact that lenses (lens systems) and back lens mirrors (mirror systems) (as opposed to surface mirrors) usually image different wavelengths in different planes can have advantages and disadvantages. There is less interference from undesirable wavelengths if they are not imaged in the plane. If various wavelengths are received as well as the wanted signal, it may be necessary to re-adjust the focus.

In practice, a screen can be necessary during the day if the active area of the detector is larger than the area derived from the screen diameters below, and interference irradiation can occur. It is the plane on which imaging takes place. Imagine that the remote station must be in the open air on a mountain, with the Sun almost behind it... The screen should have a diameter small enough to give the desired reception angle and the material must be very thin. The minimum possible diameter is determined by the mechanical stability and the imaging characteristics of the lens and the aperture error. The diffraction occurring with very small screen apertures is nothing to worry about in practice.

See also Section Calculations (G)

Fitting a filter is necessary in order to keep light with interference wavelengths away from the detector (usually in the daytime), provided that the detector does not have a suitable filter of its own. A few mm² is sufficient if it is attached to the screen, and the filter can be replaceable if applicable. Metal interference filters (Dielectric filters) are very small approximately 0.3nm to 25nm but the mean transmission is only 40%, for composite interference filters the mean figure is only 20%, whereas "normal" filters can have transmission levels exceeding 95%. Inclining the interference filter displaces the transmission range into longer wavelengths. Graduated filters utilise this effect. So for a metal interference filter to become fully efficient in terms of its data, the light must travel parallel to it. With high aperture lenses, then, it is better if the filter is positioned in front of the lens. If the filter is positioned near the detector, the basic optical qualities no longer play any role. Gelatine filters can be used. Since the wavelength of the laser diodes alters in response to changes in the current and the temperature, filters that are too small can cause problems. The laser runs out [19].

The coloured "cover surfaces" of the 7 segment displays can be very suitable, but they <u>must</u> be measured in advance. If applicable, they are tested by being brought into the beam. The variation is observed on a power output meter. They have the characteristics of a low pass filter, based on the wavelength.

Undesirable infra red radiation should be attenuated using infra red stop filters made for CCD cameras and heat protection filters. Heat protection filters are usually fitted as glass strips in slide projectors. They heat up through the heat radiation of the bulb and protect themselves by dissipating the heat to the slide mounting. In practice, lens and mirror systems are also used which consist of tinted glass or "Woods glass". They are optically effective as low pass filters, and there is usually no need for an additional filter.

Reputable dB specifications relating to

the improvement of the signal/noise ratio through the use of filters for a specific case can be calculated, provided that the interference radiation is emitted by the sun. Taking into account the location for the background radiation and the influence of the time of day takes a lot of effort. If the latter influencing variables are disregarded, an improvement of 6dB was obtained in a specific case by means of a metal interference filter (compared to a normal low pass filter).

Nevertheless, almost all measured specifications published are very subjective and can tell us nothing unless the weather conditions and other environmental conditions are specified. There can be an improvement only in the case of incidence of external interference light. But since its intensity can usually not be predicted and can usually not be reproduced, the results remain unclear. On an ideal night, a filter scarcely provides an advantage but in daylight it is usually advantageous.

To reduce scattered interference light, it is necessary to position a “tube” in front of the detector; this is a complement to the tube in front of the lens, which is absolutely necessary. The best dimensions can be determined graphically and/or by calculation, depending on the receiver angle and the aperture of the lens, as a tube length and a tube diameter.

(See Section Calculations (D))

Metal should be used, or some material combined with metal, if you dont know the materials’ infra red properties, since many materials are very infra red permeable. The detectors are usually particularly sensitive in the infra red, there may be problems. Coatings that are effective in visible light can be ineffective in the invisible spectrum and vice versa.

The surface of surface mirrors and the like can be made damaged even by a very soft paint brush or by breathing on them.

Some of the above instructions can not be applied to the infra red range at present. The use of night vision aids/image converters and/or IR cameras/CCD cameras/camcorders with IR stop filters turned off (NIGHTSHOT) can be advantageous.

To be continued.

X.
Literature, references (continued)

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Note from the editor:

This article has been difficult to translate and edit because it is in “note” form and the technology is not in my field. I have had some assistance from Carl Lödstrom with the terminology, while emailing copies of his article for approval and he kindly offered to help. I hope that the end result is acceptable for those interested in the optical bands.