# 16. POINT-TO-POINT TRANSMISSION

## 16.1. Introduction

As we have seen in Chapter 1, the aim of the transmission is to pass the information from the source to the sink. Transmission systems therefore include the source, the sink and the interconnecting transmission channel. In this chapter we treat the transducers, multiplexers and A/D converters as the part of the source since their properties are irrelevant in the following discussion.

Several tasks of digital processing are carried out in the transmission channel. In fact, the design of the transmission channel is a design of digital processing operations in which two factors has to be considered: the quality requirements for the signal reaching the sink and the model of the channel. Quality requirements are usually fixed in national standards based on international standards or -what is more typical- on recommendations. The properties of the channels are essentially determined by the parameters of the transmission media but they are influenced also by the properties of the circuits and devices used in the channel.

In a transmission system, distortions have to be kept at an acceptable level, i.e. the speech must remain intelligible, the speaker's voice recognizable, the music enjoyable, etc. Interference, distortion and noise components present in the signal transmitted towards the sink are supposed to be given; we do not deal with the criteria these specifications are based upon.

With certain restrictions, analog signals may be of arbitrary waveform. In the analog signal transmission, waveform fidelity is of primer importance; to ensure a 'good' transmission, distortion components may be specified separately. In long haul transmissions, however, the noise at the output is of main importance thus the signal-to-noise ratio is the most important parameter. In digital transmission the number of waveforms is finite, sources usually send binary signals which are apriori known, hence, at the output of the channel it is not necessary to reconstruct precisely the waveform, it is enough to decide which one of the input signals was sent. This decision, of course, can be either right or wrong. Thus the most important quality parameter here is the probability of the right decision. Signal-to-noise ratio and the probability of error are influenced by all listed distortional effects (additive noise, linear distortion, etc.).

## 16.2 General Block Diagrams of Transmission Systems

As we have seen, transmission systems are built upon sources, sinks and transmission channels interconnecting the former two. The transmission channel is based primarily on the transmission media which can be wirebound or wireless. Wirebound connection is either metal or optical cable; the wireless (radio) transmission can be either terrestrial or satellite.

A part of interfacing equipment depends on the transmission media but is not depending on the properties of the signal. Firstly, let us discuss the radio transmission without dealing with the properties of the transmitted signals. In Fig. 16.1. basic blocks of a radio transmitter-receiver pair are presented. The receiver shown here is of so-called superheterodine type in which the signal is amplified by the so-called intermediate frequency (IF) amplifier. This is not the only solution but it is used almost exclusively.

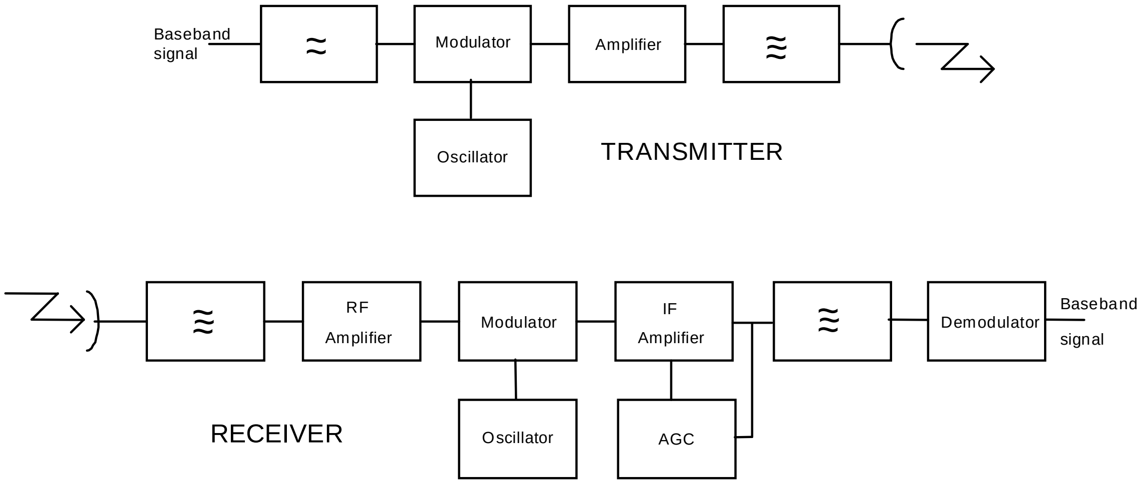


Figure 16.1 Block Diagram of a Transmitter and a Receiver

General block diagram of an optical transmission system is given in Fig. 16.2. The optical modulator is framed in the figure since it is missing in the majority of cases; the light source is modulated by the driver circuit. In the following we discuss the microwave and the optical transmission systems. Guided wave systems have already been discussed in Chapter 8.

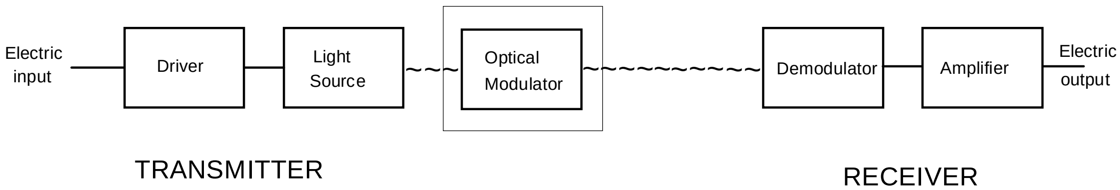


Figure 16.2 Block Diagram of an Optical Transmitter and Receiver

## 16.3. Microwave Transmission Systems

### *16.3.1. General Features*

Since long-haul transmissions require great bandwidth, the frequency range between 1 GHz and 300 GHz is used for this purpose. This range is called the *microwave* range and the region between 30 and 300 GHz is sometimes distinguished as the *millimeter wave* range. High frequency and short wavelength are the most important features of the microwaves. The microwave carrier can be thus modulated by a relatively wideband signal and small antennas can be used to produce a narrow radiation pattern. On the other hand, microwaves do not diffract on great objects such as the Earth, so that only line-of-sight propagation can be used at these frequencies.

A section of a microwave transmission link can therefore extend only to the horizon. Of course, at higher locations, the horizon is more distant, so that the microwave antennas have to be installed high, on mountain peaks, on towers, etc. Taking into account also terrestrial obstacles, the horizon is hardly farther than 50 km. To communicate to greater distances, either the signal has to be *repeated* every 50 km (i.e. received, amplified and retransmitted) or a single repeater has to be used, located on a *satellite* positioned at high altitude above the Earth. The first solution is known as the terrestrial or radio-relay system while the latter is the satellite communication system. Among the satellite systems, especially the so-called *geostationary* satellites are suitable for microwave transmission. These satellites are positioned about 36000 km above the equator and since the revolution time of the satellite is equal to the time of one turn of the Earth, the satellite seems to be "fixed" above a given point of the Earth.

The ratio of the power of the carrier ($C$) to the additive thermal noise ($N$) is of essential importance in microwave transmission:

$$SNR \triangleq \frac{C}{N} = \frac{P_a}{a_s \cdot k \cdot T \cdot B} \tag{16.1}$$

where $P_a$ is the transmitter power, $a_s$ is the free-space loss, $k \cdot T \cdot B$ is the noise power of the resistor having an equivalent absolute temperature $T$. The free-space loss is:

$$a_s = \frac{\left(4p \cdot D \cdot f^2\right)}{G_a \cdot G_v \cdot c^2} \cdot A_f \tag{16.2}$$

where $G_a$ and $G_V$ are the gains of the transmitter and of the receiver antennas, $D$ is the length of the propagation path, $c$ is the velocity of the light, $f$ is the frequency and $A_f$ is the fading attenuation (power ratio).

The signal-to-noise ratio can thus be given as follows:

$$SNR = \frac{P_a \cdot G_a \cdot G_v \cdot c^2}{(4pDf)^2 \cdot k \cdot T \cdot B} \cdot \frac{1}{A_f(t, f)} \tag{16.3}$$

where the time and frequency dependence of the fading attenuation (both random) is indicated. Statistical parameters of the fading attenuation depend on the frequency range and on the kind of the system (terrestrial or satellite), moreover, different parameters are of importance for analog and for digital transmission.

In terrestrial transmission the following frequency ranges are used : 2, 4, 6, 7, 8, 11, 13 and 17 GHz. The ranges used for the satellite communications are 4-6, 12-14, 20-30 GHz (the greater frequency is used in the Earth-satellite direction and the lower one in the backward transmission).

### *16.3.2. Digital Radio Transmission*

The cost of a radio transmission system is determined mainly by the required transmission power, by the required bandwidth, and by the complexity of the signal processing. Without going into details, let us remark that in the case of digital transmission the above factors can be freely converted among each other by choosing the appropriate modulation system. Further, frequency seems to be the most "expensive" factor, and the expenses of the signal processing strongly depend on the actual technological level. Fortunately, these expenses are continually decreasing with the new developments in technology.

First, let us examine the transmission of a single digital signal disturbed by additive Gaussian noise. Modulating a carrier with binary signals, two different signal shapes can be generated. For the amplitude, frequency and phase modulation (ASK, FSK and PSK) these signal pairs are as follows:

$$
\begin{aligned}
ASK &: s_1(t) = \sqrt{2}A \cdot \cos w_c \cdot t & FSK &: s_1(t) = \sqrt{2}A \cdot \cos w_c \cdot t \\
& \quad s_2(t) = 0 & & \quad s_2(t) = \sqrt{2}A \cdot \cos(w_c + Dw)t \\
PSK &: s_1(t) = \sqrt{2}A \cdot \cos w_c \cdot t & & \\
& \quad s_2(t) = \sqrt{2}A \cdot \cos(w_c + DF)t; \quad t \in (0, T) & &
\end{aligned}
\tag{16.4}
$$

where $T$ is the bit time, $A$ is the effective amplitude, $\omega_c$ is the angular frequency of the carrier and $\Delta w$ and $\Delta F$ are the frequency deviation and the phase deviation, respectively. The error ratio is minimum when PSK with $\Delta F = \pi$ is used, i.e. if $s_1(t) = -s_2(t)$. With an ideal receiver, the error ratio would be

$$
P_e = \frac{1}{2} erfc\left[\sqrt{E / N_0}\right] \sim \frac{1}{2}\sqrt{N_0 / p \cdot E}\, \exp(-E / N_0), \tag{16.5}
$$

where $E = A^2 \cdot T$ is the energy of one bit and $N_0 = k \cdot T$ is the noise spectral density. (Mark ~ represents the asymptotical equality.)

While the phase modulation is more or less plausible, demodulation is not so easy: to distinguish the signals ($s_2 = -s_1$), a *phase reference* has to be known. Systems requiring a phase reference for the demodulation are called *coherent*.

Not only the PSK but any other system where the phase of the carrier is important has to be transmitted coherently and the reference phase is then recovered from the transmitted signal. If there is no such reference, the transmission is called *non-coherent*.

Fig 16.3. illustrates how the decision is made in the case of PSK modulation. Since there is one frequency only, the usual vectorial presentation can be used (let us remark that it can also be used in a more general case). The absolute value of the signal vectors is equal to the square root of the energy. The vertical line is the so-called *decision threshold*.

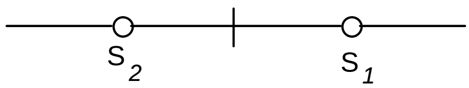


Figure 16.3. Vectorial Representation of the PSK Symbol Pair

If the phase of the received vector falls into the right half-plane it is taken as $s_1$, if it is in the left plane it is taken as $s_2$. The probability of error is determined by the probability that a transmitted $s_1$ is phase-shifted by the noise and received with a phase falling into the left half-plane.

As far as the modulation bandwidth is concerned, it can be shown that it is in the order of $1/T$ around the carrier frequency, more precisely, it is a little bit greater if a single carrier is used the amplitude and phase of which are modulated. Because of the cost of the frequency, more economical modulation methods have to be used, especially for high-speed signal transmissions. For the given source speed, the only possibility is to increase the value of $T$, i.e. to concentrate more bits into one symbol. If $n$ bits form a symbol and the carrier is not modulated then the bandwidth is reduced to $1/n$-th of its original value. On the contrary, the number of the possible states will have been increased to $M = 2^n$. It can be shown that $M$-ary PSK (MPSK) is the optimum modulation method if $M \leq 6$; for greater values of $n$, however, the simultaneous amplitude and phase modulation is a better solution. For higher number of states, $M$-ary quadrature-amplitude modulation (MQAM) is almost exclusively being used since it is close to the optimum. The MQAM signal can be expressed as follows:

$$s(t) = \mathrm{A}(a\cdot\cos\omega_c t + q\cdot\sin\omega_c t)\; a, q = \frac{\pm 1}{L-1}, \frac{\pm 3}{L-1}, \mathbf{K}, \pm 1;\; L = \sqrt{M} \qquad (16.6)$$

The vectorial representation of the four-phase PSK (QPSK) and 16QAM signals is shown in Figure 16.4. As the price to be paid for the reduced bandwidth, a much greater power has to be used to achieve the same error ratio as previously.

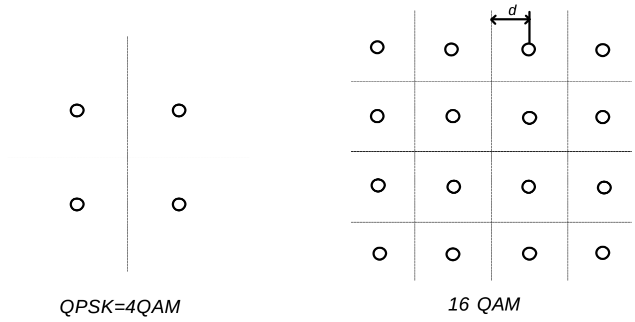


Figure 16.4. Representation of the QPSK and 16QAM Signals

Comparing Fig. 16.4. with Fig. 16.3., it can be seen that while in PSK noise greater than $\sqrt{E}$ could only cause faulty decisions then in 16QAM the decision threshold is closer so even a smaller noise level ($d$) may cause errors. It can be shown that if $M > 2$ then the error ratio is approximately

$$P_\mathrm{E} = \frac{1}{2}\cdot\mathrm{erfc}\left[\sqrt{d^2 / N_o}\right] \qquad (16.7)$$

where $d$ is the minimum distance out of the distances of the individual signals from the decision threshold.

It can be shown that for the same error ratio the power ratio of QAM and PSK signal is

$$\frac{P_\mathrm{MQAM}}{P_\mathrm{PSK}} = \frac{2\left(2^{n/2}-1\right)^2}{n}; \qquad M = 2^n \qquad (16.8)$$

i.e. for the linear reduction of the bandwidth the power has to be increased nearly exponentially. QPSK is used for low-speed transmissions while 64QAM, 256QAM and even 1024QAM systems are used in high-speed communications (for bit rates higher than 100 Mbit/s). Let us notice that QPSK is a certain kind of optimum: the bandwidth is the half of that used by the PSK while the power is the same.

As we have seen in Chapter 12., a so-called Nyquist-filter is used to avoid intersymbol interference. In some cases additional linear distortion is caused by the transmission medium itself.

Since the amplitude of the MPSK signal is constant, the nonlinear distortion of the amplifiers does not increase the error ratio. In MQAM transmission, however, the distortion has to be kept at a low level. As it can be seen from Fig. 16.5. that either the gain or the phase shift depend on the input amplitude, and the signal vectors are shifted closer to the decision threshold ($d' < d$) so that the error ratio increases. This can be reduced if the signal is *predistorted* so that the resulting response of the amplifier and the predistortion unit are approximately linear.

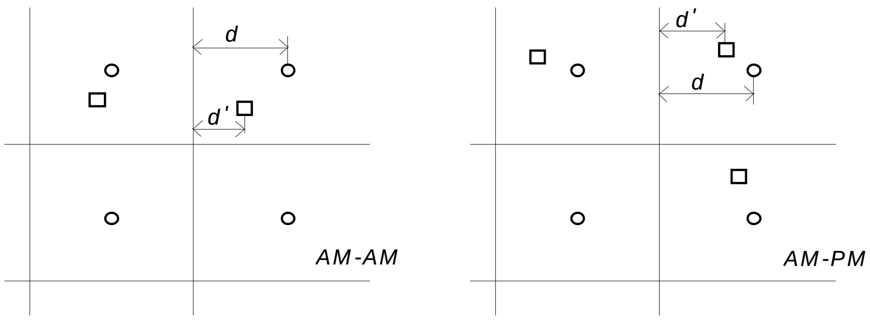


Figure 16.5. Influence of the Nonlinear Amplifier on 16QAM
(o: original vector; □: distorted vector)

As it was mentioned, a phase reference is needed for coherent demodulation. Since the carrier is suppressed in all modulation systems discussed above, it cannot be simply recovered from the received signal by a linear filter, a nonlinear operation has to be used instead. As an example, carrier recovery used in QPSK system is shown in Figure 16.6.

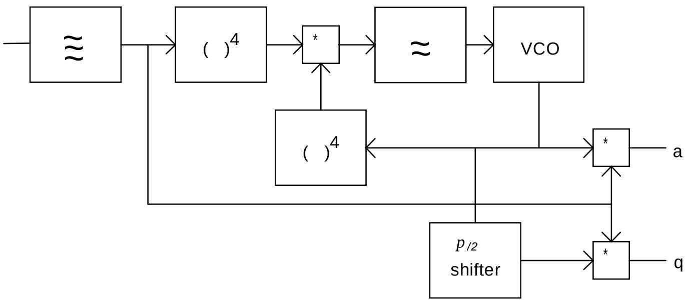


Figure 16.6. QPSK Carrier Recovery and Demodulation

As it turns out from Fig. 16.6., the fourth multiple of the four vectors points to the same direction (π). Multiplying the received signal by the reference, the demodulated baseband signal is obtained. The decision is applied to the demodulated signal. Following the decision, the shape of the original baseband signal is regenerated by the *regenerator*. *Timing* information needed for the regeneration is recovered -like the carrier recovery- by a nonlinear clock-recovery operation.

A part of the channel encoding, e.g. the conversion of the binary signals to multiple states, is done by the so-called line codec which definitely belongs to the transmission equipment.

To summarize the considerations made throughout this chapter, a digital radio section is shown in Fig. 16.7.

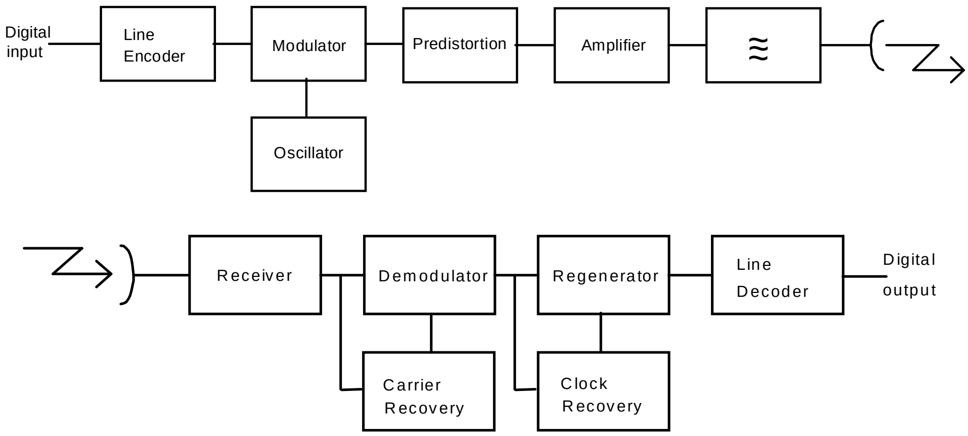


Figure 16.7. Digital Radio Section

### *16.3.3. Digital Radio Relays*

As it was mentioned above, terrestrial radio-relay systems are realized by chains of repeater stations. Factors which have to be considered in such system are as follows:

- kind of the signal to be repeated (RF, IF or baseband),
- choice of the carrier frequencies,
- compensation mode of the disadvantageous properties of the transmission medium (i.e. of microwaves propagating close to the ground).

Since the subsequential repeaters are independent of each other, the noise powers of individual receivers are summed when the signals received and amplified by nearly linear receivers are retransmitted. It can be seen from equations (16.6) and (16.7) that the error ratio strongly depends on the signal-to-noise ratio. For instance, if the signal-to-noise ratio is reduced by 3 dB, the error ratio increases by about three orders of magnitude. Therefore, it is more advantageous to regenerate the signal at each repeater since in this case only the erroneous decisions are summed up.

When the frequency plan of a radio-relay system is being designed, it has to be taken into account that receiver-transmitter pairs operate together, i.e. that very high and very low level signals are simultaneously present. Because of the finite backward attenuation of the receiver and the transmitter antennas, there is a danger of feedback between the transmitter output and receiver input. To avoid the self-oscillation of the repeater, the transmitting and the receiving frequencies should not be too close to each other. In this case, filters tuned to each other's carrier can provide sufficient selectivity to reduce the loop gain of the unwanted loop.

As we have seen, fading (caused by the multipath propagation and by the rain-attenuation at frequencies above 10 GHz) is the most significant disturbing factor. For low bit rate transmissions (below 40 Mbit/s) fading can be considered to be wideband, i.e. the transmission medium is supposed to be a time variant attenuator independent of frequency. Fortunately, the chance of very high attenuations is very small. The attenuation caused by normal fading is compensated by the so-called *fading margin*, i.e. the power of the transmitter has to be determined in such a way the error-rate specifications are satisfied even in the case of fading. More precisely, the percentage of time is specified during which the signal-to-noise ratio may be degraded by the fading so that the error ratio be higher than $10^{-3}$. Under these conditions, the communication will be of excellent quality for the greater part of time and will be unacceptably bad only during short (specified) intervals.

In high-speed transmissions, the fading cannot be considered to be independent of frequency, it becomes *selective* thus causing linear distortion. As a consequence of this distortion, the error ratio increases and even more, if the distortion is too great, the error ratio can be unacceptably high even in the absence of noise, merely because of the intersymbol interference. Of course, increasing the transmitted power can not compensate this effect.

*Adaptive equalization* or the so-called *diversity* system (or the combination of the two) is used to eliminate the selective fading. In adaptive equalization, the actual state of the channel is 'measured' in some way, then the response of the adaptive equalizer is adjusted so that the resulting response shall be close to the optimum. The most effective solution is the so-called *decision-feedback* loop containing a FIR and an IIR filter with variable weighting factors.

In the diversity system, the same information is transmitted in two different channels. Two methods can be used: in the *space diversity* system, the signal is received from two directions by two antennas and by two receivers while in the *frequency diversity* system two signals are transmitted simultaneously on two different frequencies. The principle of both systems is that the probability of having bad propagation conditions in both channels is much smaller than the probability that one of the channels will be useless.

### *16.3.4 Digital Satellite Communications*

Since a great part of the hemisphere is visible from a geostationary satellite, it can be used as a repeater even between two very distant points on the Earth. Yet there are some differences between the terrestrial and the satellite radio communications:

a.) the waves from the satellite travel only a short path through the atmosphere thus fading is much smaller (below 10 GHz), and it can be neglected altogether,

b.) a satellite is capable to establish communication with several pairs of terrestrial stations, i.e. the satellite can be used for *multiple access,*

c.) the distance to be bridged is considerably long so that the path attenuation and the *propagation delay* are very great. The entire delay of the Earth-satellite-Earth link is about 250 ms; for this reason, not more than one satellite section may be used in one communication.

Generally, QPSK is used for the satellite systems. The on-board satellite repeater is called the *transponder, which* in fact may consist of a single linear amplifier. In more sophisticated systems, the transponder is a signal processing equipment which can restore and regenerate the baseband signals as well. A general block diagram of a transponder is shown in Figure 16.8. Here $f_1$ stands for the uplink frequency and $f_2$ for the downlink frequency.

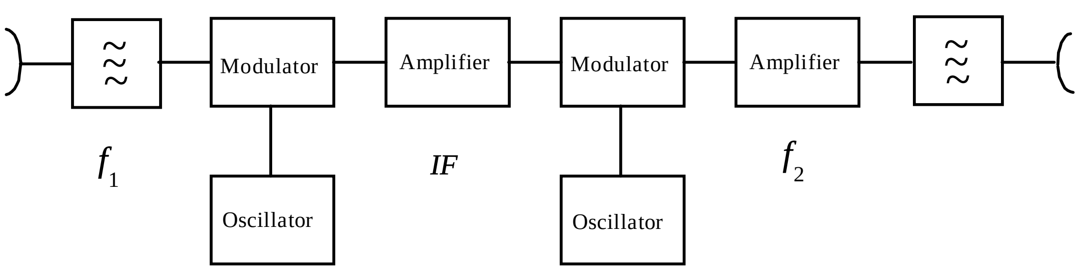


Figure 16.8. Block Diagram of an On-Board Transponder

Both frequency and time division multiple access are used in satellite communications. In the first case, the Earth stations transmit at different frequencies while in the second case different time-slots are used in the transmission. Moreover, *space division* may be used if the transponder antenna has several sidelobes. Space division can be also combined either with

FDMA or with TDMA. The multiple access may be fixed, i.e. the time slots may be assigned to individual Earth stations or it may be variable in accordance with the actual demands.

### *16.3.5. Analog Radio-Relay Systems*

Analog systems operate mostly with FDMA channels using NBFM modulation. In accordance with the central limit theorem, FDM signals are modeled by Gaussian noise.

Besides the thermal noise, *intermodulation noise* caused by nonlinear distortion is the main source of the noise. E.g. intermodulation in telephone channels results in crosstalk among the channels. Because of the Gaussian distribution of the modulating signal, the intermodulation has the same effect as the thermal noise thus the equipment have to be design so that *sum* of the thermal and intermodulation noises should be minimal.

## 16.4. Light-Wave Communication Systems

Signals with frequencies falling into the visible or near infrared range are transmitted almost exclusively by means of dielectric waveguides since the properties of dielectric transmission lines are very good, the attenuation and dispersion of optical waveguides are much smaller than those of the free span. So the light can be used for wide band and long-haul communications.

Almost exclusively digital signals are transmitted by optical fibers in long-haul communications. In short-haul communication, analog signals are also used, e.g. in cable TV systems, in microwave signal transmission, in interconnections among the parts of an equipment, in personal communication, etc. In the following, only the long-haul communication will be dealt with.

### *16.4.1. Intensity Modulated Optical Transmission*

The most simple and nowadays almost exclusively used method of optical transmission is the modulation of the light intensity by a binary signal. In fact, this corresponds to the ASK modulation: zero intensity is assigned to `0' bit and a finite intensity of the light to the binary '1'. The average power of the light emitted by a laser diode is proportional to the current flowing through the diode, thus the current of the diode has to be switched corresponding to the values assigned to '0' and '1'.

This method is called the *direct intensity* modulation, which works well up to frequencies of some GHz so that it can be well used practically in all systems operating at present. If the modulating frequency is higher than the so-called *relaxation oscillation* frequency, the light intensity can be varied by means of an *optical modulator*. In both cases a photo diode or an avalanche diode is used for demodulation. The noise properties of photo diodes are better. In a photo diode the number of electrons corresponds to the number of photons, more precisely, it is the $h$-th multiple of that, where $h < 1$.

In light-modulation systems, -provided the other factors are ideal- an erroneous decision might be caused only by the shot noise due to the quantum nature of light. More precisely, when a '0' bit is being transmitted, the received signal will be zero since no additive noise is present. The optimum decision rule is thus as follows: decide on '0' if the number of the received photons is zero, and decide on '1' if the number of the received photons is greater than zero.

The probability of error can be expressed then as follows:

$$P_{\mathrm{E}} = \frac{1}{2}\cdot\mathrm{P}[n \geq 1|0] + \frac{1}{2}\cdot\mathrm{P}[n = 0|1] = \frac{1}{2}\cdot\mathrm{P}[\, n = 0|1] \qquad (16.11)$$

where P[.] is the probability of the event put in the bracket and $n$ is the number of detected photons; the condition is given by the binary value of the actually transmitted bit. The number of photons in a light impulse is given by the Poisson distribution:

$$P_{\mathrm{E}} = \frac{1}{2}\, e^{-\mathrm{n}'} = \frac{1}{2}\cdot e^{-2\mathrm{n}} \qquad (16.12)$$

where n′= 2n is the average number of the photons when a binary '1' is received, while $n$ is their average. Furthermore

$$\overline{n}' = E_1 / h\cdot f_c = 2\cdot P\cdot T / h\cdot f_c$$

so that

$$P_E = \frac{1}{2}\cdot\exp\left[\; -2\cdot P\cdot T / h\cdot f_c \;\right] \qquad (16.13)$$

where $E_1$ is the energy received with binary '1', $P$ is the average received power and $T$ is the bit time. It can be seen that the optical power required to suppress the error ratio below a given limit is proportional to both the optical frequency and to the bit frequency. For instance, 10 photons should be received on the average (i.e. 20 for each '1') to have the error ratio less than $10^{-9}$. This is the so-called *quantum limit*; in practice a power greater by about 15-25 dB is needed because of the noise of the photo diode and that of the following amplifier.

If such a long distance has to be bridged that the optical receiver cannot be provided with sufficient signal (e.g. this is the case of maritime optical cables) then repeater stations have to be inserted. At present, the optical signal has to be converted to an electrical one, regenerated and converted again to an optical signal. Solutions for the pure optical regeneration are being developed. A common drawback of both solutions is that the repeaters have to be supplied with DC power so that additional copper wires have to be included in the optical cable.

### *16.4.2 Coherent Optical Transmission*

In optics, all demodulation procedures based on mixing the optical signal with the signal of a local oscillator are called *coherent*. Furthermore, *homodine* or *heterodine* receivers are distinguished depending on whether the frequency of the local oscillator is the same as that of the transmitter or not. The block diagram of a heterodine receiver is shown in Figure 16.9. The only difference in the homodine receiver is that it does not have a demodulator since the intermediate frequency is zero so that the signal is mixed directly to the baseband.

In both receiver types the local laser is voltage (or current) controlled. In the homodine receiver the phase is controlled by an optical PLL so that a coherent system is created in the original sense of the word. In the heterodine receiver, only the frequency of the optical oscillator is controlled and the reference phase is generated at the electrical intermediate frequency.

It can be shown that in coherent optical systems the error ratio of the two-state PSK is (under ideal conditions)

$$P_{\mathrm{E}} = \frac{1}{2}\mathrm{erfc}[(2\mathrm{n}\alpha)^{0.5}] \qquad (16.14)$$

Comparing (16.18) with (16.11), it can be seen that for $a$ = 1 the error ratio of the coherent and the intensity modulation systems is the same while for $a$ = 0.5 a 3 dB higher optical power is needed for the same error ratio.

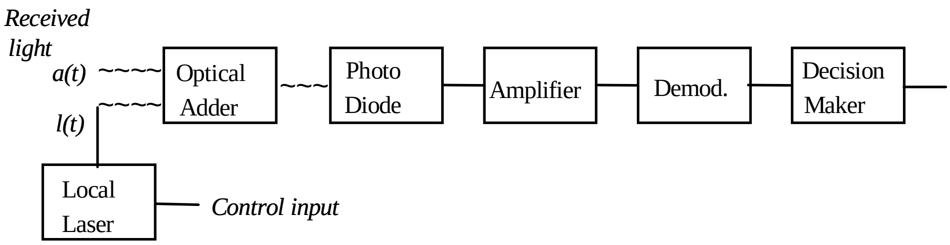


Figure 16.9. Coherent Optical Demodulator (Heterodine)

Finally, let us make some interesting remarks:

- the homodine system is 'better' by 3 dB than the heterodine one; on radio frequencies the two systems are equivalent;
- from the point of view of the average power, the quality of an ideal PSK coherent optical transmission is hardly better than the quality of an intensity modulated system; the required power, however, is 3 dB less.
- the difference is greater if real conditions are considered; it can be seen from equation (16.16) that the signal current is proportional to the local oscillator power. If the power of the local laser is chosen sufficiently high, the noise generated by the photodiode and by the preamplifier can be neglected.
- it can be assumed that optical systems of the future will apply more complex modulation procedures, similarly to today's microwave transmissions; coherent methods are necessary for such solutions.

## Control questions

1. How can the factors determining the task of a transmission system be specified?
2. Draw the block diagram of a radio transmitter and receiver.
3. What are the main properties of microwaves from the aspect of transmission? What are the consequences of these properties? What is selective fading and how can it be eliminated?
4. What are the main cost factors of a digital radio system? How can the required bandwidth be reduced? What is the price of the reduction?
5. What is a coherent system and what is a non-coherent system? How can the information necessary for the coherence be obtained? What is the coherence in optical transmission?
6. What is the quality of an intensity-modulated optical transmission system determined by under ideal conditions?

## Exercises

1. A microwave signal has to be transmitted with 2 Mbit/s on 2 GHz to 50 km. The diameters of both antennas are 2 m each, the noise factor of the receiver is 5 dB and 35 dB is supposed as fading margin. What shall be the transmitting power if the error ratio has to be kept below $10^{-3}$? (k = 1,38. $10^{-23}$ V A sec/K).

2. A 25 MHz band is available for the transmission of a 155 Mbit/s signal. What kind of modulation has to be used? What should be the receiver bandwidth and the $P_{MQAM}/P_{PSK}$ ratio?
3. A 2 Gbit/s signal is transmitted by means of intensity modulated light with 1.5 μm wavelength. What should be the peak power of the laser diode if the optical losses are about 10 dB and the noise caused by the photo diode and the preamplifier is 15 dB? ($h = 6{,}62 \cdot 10^{-34}$ VAsec$^2$.)
4. What should be the power of the transmitter laser for a heterodine PSK system?

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## Abbreviations

| | | | |
|---|---|---|---|
| FIR | Finite Impulse Response | IIR | Infinite Impulse Response |
| IF | Intermediate Frequency | RF | Radio Frequency |
| NRZ | Non-Return to Zero | QPSK | Quaternary Phase Shift Keying |
| PM | Phase Modulation | QAM | Quadrature Amplitude Modulation |