Transmission of Audio Signals by Infrared Light Carrier

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A recently developed technique for the wireless transmission of audio signals makes use of the invisible modulated infrared radiation. Infrared emitting gallium-arsenide luminescence diodes are used as radiators of the modulated signal. As receiver, a photosensitive diode is used. Its plastic convex lens concentrates the incident infrared radiation on the rather small photosensitive diode surface. To eliminate the action of visible light, a so-called black filter — transparent only to infrared — is interposed. Amplitude modulation of the infrared emitter is possible, but cannot be used because other ambient light sources could create interference. To overcome this obstacle, frequency modulation of an amplitude-modulated standardized carrier frequency is used. The distribution of infrared radiators in a room is touched upon, and interference levels from ambient light sources are indicated. The components of a monophonic infrared audio transmission system are discussed.

A recently developed technique for wireless audio communication is coming into greater use in a number of applications which formerly used fixed wiring, RF-links, or induction loops. This technique makes use of modulated infrared light at wavelengths just adjacent to the visible spectrum.

The transmission of signals by light has long been known. For the high quality transmission of audio signals by this method an advance in semiconductor technology was needed. Recently, suitable semiconductor luminescence diodes have been developed. By means of different substrata and dopings they can be made to emit light in the visible or near infrared range. Their efficiency of about 10% is high enough for the intended purpose.

An early application of these diodes was seen in Europe for the transmission of TV sound in the home. This was followed by remote control applications of TV and audio equipment, and subsequently by two-channel transmission with high fidelity quality.

Improvements in LED efficiency and the design of powerful light emitters have made large systems possible. They offer solutions of economical and technical superiority for the hard of hearing in churches and theaters, for monitoring in studios, for the replay of audio information to audiences in lecture halls, and in courtrooms. Ultimately, an infrared nine-channel system was developed for the simultaneous interpretation in multilingual conferences and exhibitions.

Characteristics of Infrared Components

Emitter Diodes

In an infrared transmission path, infrared LEDs are used as emitters, and the receiver contains an infrared sensitive diode. The latter are generally silicon PIN diodes. The emitter diodes in most frequent use look like small transistors. The cross section of the basic structure of an infrared emitting luminescence diode is shown in Fig. 1. By special dopings a *pn* junction is created in a gallium-arsenide crystal. This diode is used in a forward direction. When a voltage is applied, the *pn* junction produces infrared light with an efficiency — as already mentioned — of about 10%. This radiation passes through the chip in all directions. The chip is mounted in a housing similar to that of a transistor. The optical characteristics can be varied by the mechanical design and by incorporating reflectors. Some examples of packaging infrared emitting diodes are shown in Fig. 2. Their radiation patterns are shown in Fig. 3.

The light emitted by these diodes has a wavelength of 930 nm. It should be emphasized that this is neither monochromatic nor coherent radiation. This makes it possible to use an unlimited number of these diodes side by side without generating interference.

Each emitter diode delivers 10 mW of total radiated power. In order to accumulate sufficient power for good transmission quality, multiple diode arrays must be assembled (Fig. 4). The unit shown in the upper half of the figure is made up of 119 transmitter diodes; it is part of the high power radiator, model SZI 1019. The lower section shows a line array of 12 diodes as used in models SZI 1011 and SZI 1012. These radiator assemblages show the same general optical characteristics as that of the single diode.

Receiver Diodes

The receiver utilizes a photodiode biased in the reverse direction. It converts the modulated infrared light radiation into modulated electrical signals. The basic structure of a receiver diode is shown in Fig. 5. The relation between the incident illumination and the current generated by the diode is very linear. Because of the smallness of the lightsensitive area (7 mm^2), receiver diodes are often provided with a convex lens to concentrate more light on that area. This frog-eye lens has become characteristic for the surface of many infrared receivers (Fig. 6).

Spectral Characteristics

The spectral characteristics of the infrared transmission system are shown in Fig. 7. To the right, the narrow-band emission spectrum of the gallium-arsenide diode is shown. The unfiltered spectral sensitivity of the silicon photo PIN diode includes visible light in addition to its infrared sensitivity maximum. At its peak sensitivity (λ = 850 nm) an efficiency of 90% is reached. To eliminate the action of visible light, the photodiode is often used in conjunction with a so-called black filter, an optical filter which is transparent only to infrared light.

Modulation Technique

For the purpose of audio transmission, the emitter diodes must be modulated in some way. Infrared emitters, like all luminescence diodes, can be modulated only in intensity. One simple modulation technique consists in letting the current flowing through the diode follow the amplitude of the audio signal, causing direct modulation of the infrared light intensity. This technique is not practical though, because the low frequency range is already occupied by other light sources that could interfere. Fluorescent lights, for instance, emit a signal of 120 Hz with a considerable amount of harmonics. The problem can be avoided by using carrier frequencies; low frequency disturbances can thus be avoided, and even multichannel transmission becomes possible. Infrared emitter diodes can be modu-

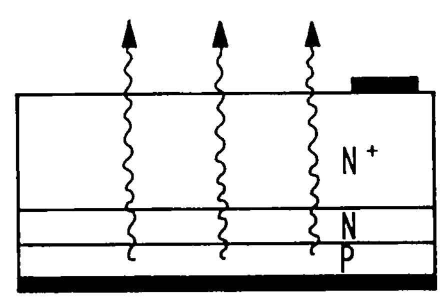

Fig. 1. Schematic cross section of an infrared emitting gallium-arsenide diode.

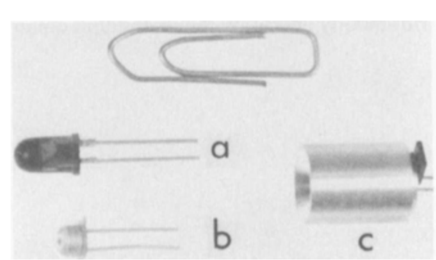

Fig. 2. Various designs of infrared emitting diodes: (a) type LD 271 in plastic encasing; (b) type LD 242 with metal encasing; (c) type LD 242 provided with reflector.

A contribution received on 17 March 1980 from Horst A. Ankermann, IPAS International Corp., 1440 Broadway, Suite 2250, New York, NY 10018.

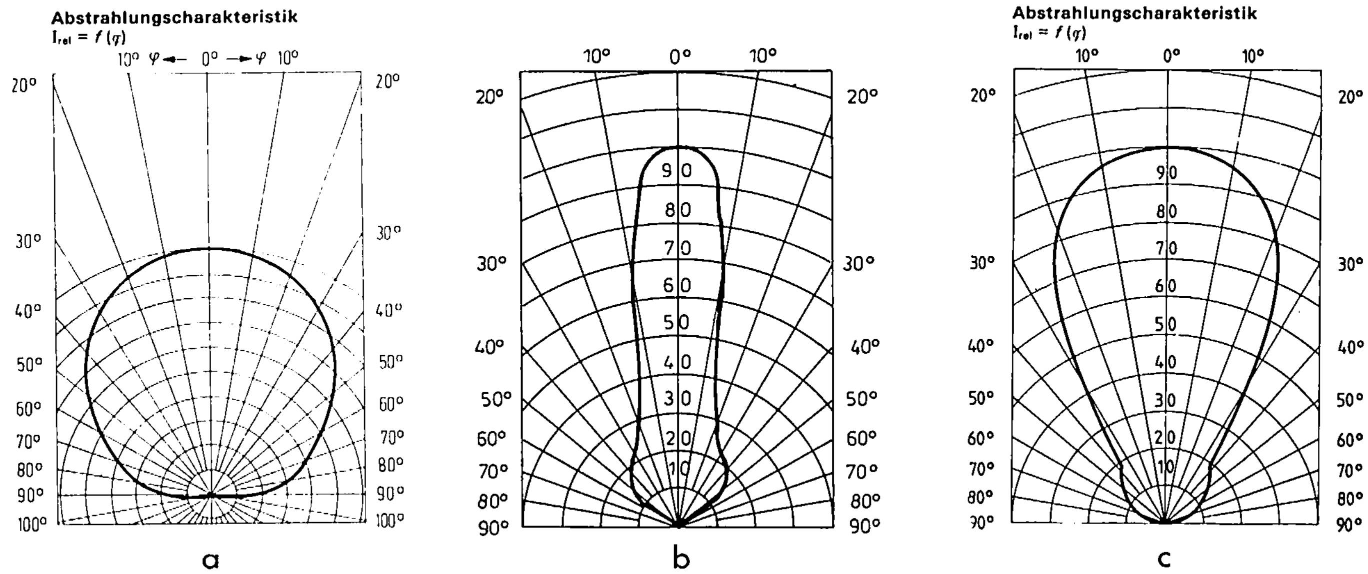

Fig. 3. Radiation pattern of infrared emitting diodes: (a) type LD 242 without reflector; (b) type LD 242 with reflector; and (c) type LD 271.

lated effectively with frequencies up to 500 kHz.

For monophonic transmission, a frequency of 95 Hz was standardized. This carrier frequency modulates the amplitude of the diode current. The carrier itself is frequency modulated by the audio signal. An AM/FM double modulation is the result (Fig. 8). For multichannel operation, a corresponding number of additional carrier frequencies must be used. To avoid channel interference in multichannel systems, the harmonic content of the carrier frequencies must be kept small. The infrared radiators contain special devices to suppress harmonics.

Distribution of Infrared Light

Because infrared and visible light do not differ greatly in wavelength, the light distribution is similar for both. Like visible light, infrared light is completely absorbed by a black velvet curtain, while it is reflected directionally by a shiny metal surface. Window panes easily transmit it and walls are completely opaque to infrared light. Except for windows or other openings, infrared light will remain confined to a room in which it has its source. This is an important advantage of the infrared system, because it permits the use of multiple transmissions simultaneously in adjoining rooms without mutual interference. With infrared-opaque curtains it is even possible to divide a large room into several independent transmitting areas.

Illuminating a Room with Infrared Light

Bright sunlight generally interferes with infrared transmission. Hence, the application of the system should be limited to enclosed areas only. As with any transmission system, the receiver needs adequate signal strength. Thus, a sufficient amount of infrared light must be provided. Also, the infrared illumination within a room should be homogeneously distributed. To achieve the relatively high power needed, the emitters of the infrared system are connected to the 110-V line. To achieve homogeneity, several radiators may be installed.

Because infrared light has many properties quite similar to visible light, normal illumination techniques are helpful for the general layout of a large room to be uniformly irradiated by a number of infrared sources. The distribution of the infrared sources will be similar to the distribution of sources of visible light that will result in uniform illumination of the room.

Receivers and radiators should be in direct sight of each other, even though the infrared light from the radiating diodes reaches the receiving diodes in two ways: by direct incidence and by indirect reflection paths. The best signals, of course, are the ones transmitted directly from transmitter to receiver. To avoid shadowing, the radiators should be installed as high up as possible. In practice, best results have been achieved by installing the radiators in the upper corners of the room, tilting them downwards like the floodlights in a football stadium.

Sources of Interference

As with other wireless techniques, the avoidance of interference is based on a

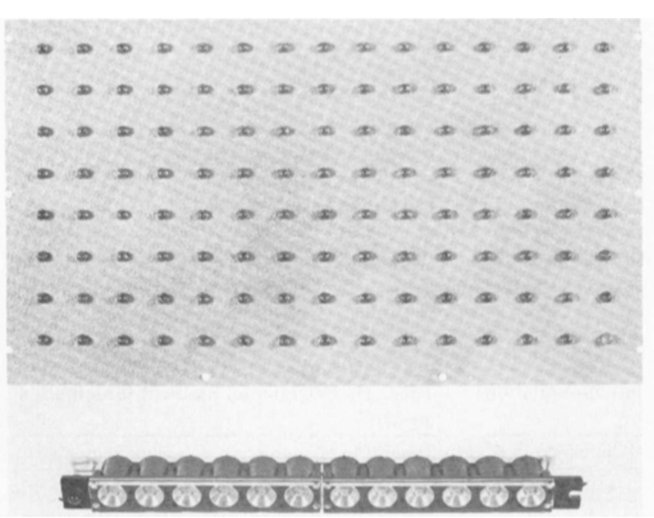
Fig. 4. Emitter arrays.

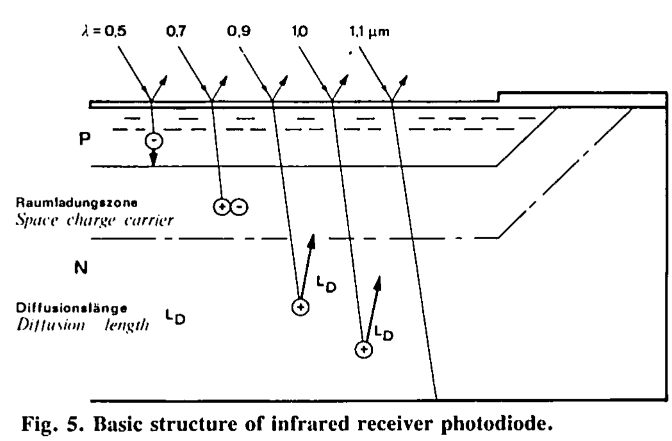

Fig. 5. Basic structure of infrared receiver photodiode.

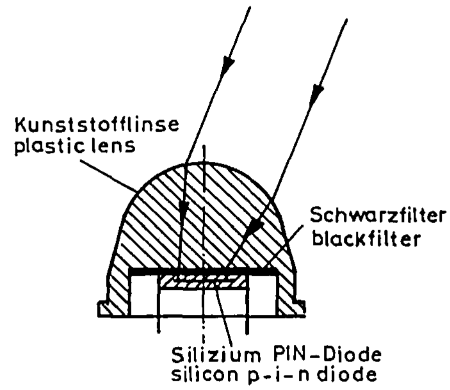

Fig. 6. Cross section of silicon PIN receiver diode with plastic convex lens and black filter.

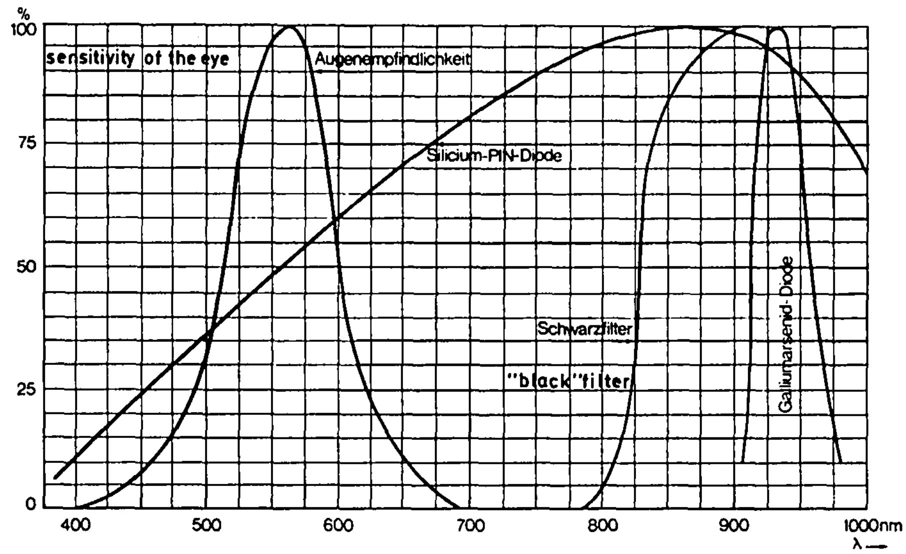

Fig. 7. Relative spectral sensitivity characteristics of the human eye (standard observer), silicon PIN diode without and with black filter, and spectral emission curve of gallium-arsenide diode (far right).

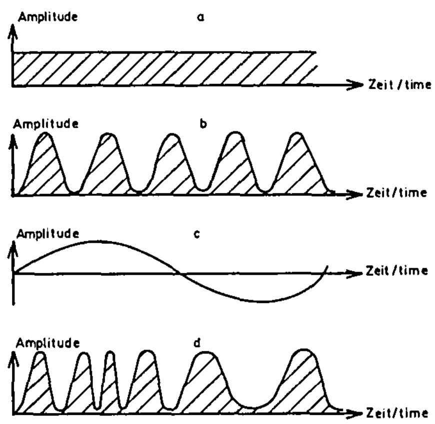

Fig. 8. Modulation technique used for infrared audio transmission. (a) Unmodulated infrared radiation; (b) infrared radiation amplitude-modulated at a fixed carrier frequency; (c) an audio-frequency modulating waveform; (d) frequency-modulated output signal of the frequency carrier shown in (b).

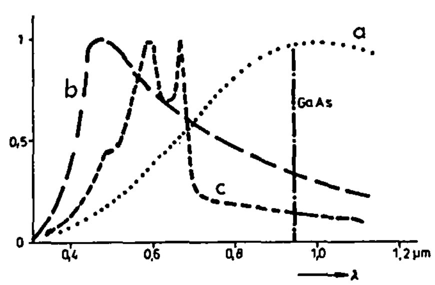

Fig. 9. Relative spectral energy distribution of various kinds of light sources. (a) Incandescent lamp; (b) daylight; (c) fluorescent light; and Ga As shows the spectral center position of the gallium-arsenide diode.

good signal strength at the location of the receiver. In the first place, there is the noise generated by the receiver itself. If, in the absence of other disturbing sources, a high noise level is heard in receivers at certain locations within a room, either the location of the radiators is incorrect or more radiators are needed.

A second important factor is given by the existing ambient light conditions in a given room. Here we have to distinguish daylight, incandescent illumination, and fluorescent lamps. All of these sources of visible light contain different amounts of infrared light that may generate a current in the photodiode of the receiver (Fig. 9).

Incandescent light contains a great deal of infrared light. Therefore, this type of illumination is particularly prone to interference. Daylight contains less infrared radiation, but outdoors the intensity of bright daylight or direct sunlight may reach extreme values that make infrared transmission impossible. Fluorescent light, on the other hand, includes only a small amount of infrared radiation.

We have to distinguish between intensity levels of visible ambient light which merely interfere with infrared audio transmission, and intensity levels which make infrared transmission quite impossible. In the latter case, the infrared portion of the ambient light overloads the photodiode of the receiver and drives it beyond its proper operating range. Table I shows ambient illumination levels at the receiver's location that do not noticeably interfere with the infrared transmission system. Such high illumination levels, however, are seldom found in typical locations. If the values of Table I are exceeded and the signal-to-noise ratio decreases, the interference may be overcome by doubling the number of infrared radiators. However, extremely high ambient illumination intensities (see Table II) make infrared audio transmission impossible.

In television studios, the illumination level from incandescent spotlights can reach 350 fc. In this special case, the design of the infrared receiver can be altered to make it *less* sensitive to light. Naturally, the number of radiators must then be increased.

Table I. Tolerable ambient illumination levels.

Type of light source	Illumination in fc
Incandescent light	40
Daylight	200
Fluorescent lamps	100

The daylight illumination level can exceed 1000 fc indoors if sunlight comes through the windows and falls directly on the lens of the receiver. In practice, curtains will be drawn in such cases. Fluorescent desk lamps can also cause interference if too close to the receiver.

A different source of interference consists in very strong alternating electric fields, especially if their frequency falls within the frequency range of infrared audio transmission. If mixed operation with inductive loop systems is desired, overlap of the frequency ranges of both systems should be avoided.

Monophonic Systems

General Layout

Infrared monophonic audio transmission systems use a standardized frequency of 95 kHz. They are FM wideband systems with ±50-kHz deviation and 50-µs preemphasis/deemphasis. The typical commercial monophonic system comprises the following components: (1) a monophonic model SI 1011 transmitter; (2) one or several model SZI 1019 radiators; (3) several model HDI 406 receivers (or alternative models); (4) cables to connect the transmitter to the radiators; and (5) an additional dc power supply.

Table II. Detrimental ambient illumination levels.

Type of light source	Illumination in fc
Incandescent light	200
Daylight	1000
Fluorescent lamps	1000

Mono Transmitter SI 1011

The transmitter is powered by the 110-V ac line. It converts the audio signal into a frequency-modulated RF signal which is fed to the radiators by cable. The radiators convert the electrical signals into infrared signals and radiate them into the rooms. Because the transmitter and the radiators are separate units, it is possible to install many radiators at different points in a room. The transmitter has two unbalanced audio inputs: one for line level with an adjustable sensitivity of 60 mV to 3 V at 10 kΩ and the other input for dynamic microphones. The two inputs cannot be used simultaneously. A switch selects one or the other.

An LED is used as a visible modulation indicator. An automatic gain control prevents overmodulation when the input is overdriven. Because the AGC circuit is of a high quality, it can also be used for dynamic range compression by overdriving the input as desired.

In addition to the RF signal, the radiators need dc power. The transmitter contains a dc power supply sufficient for driving one SZI 1019 radiator. A maximum of 1.2 A at 32 V dc is available. When using additional power supplies, the number of radiators that can be driven is nearly unlimited. The transmitter has two identical 4-pin outlets, each of which provides dc current as well as the RF signal. The dc pins of both outlets are connected in parallel. Therefore, each outlet is capable of supplying the maximum output current.

High Power SZI 1019 Radiator

The high power radiator is equipped with 119 transmitter diodes. It is equally well suited for mono, stereo, and multichannel applications. It is equipped with a switch which increases the infrared output by 25% in the mono mode. The increase in harmonics at the higher output is not troublesome during monophonic operation. The radiator draws a current of 1.1 A, and needs a voltage of between 29 and 34 V. A single radiator is directly connectable — by means of connection cable MC 62 — either to an SI 1011 transmitter or to an SI 1019 transmitter.

The radiator has a built-in RF-limiting amplifier which always delivers an optimum level, independent of the number of channels transmitted. The unit works with input voltages between 0.8 V_{pp} and 5 V_{pp}. The input impedance is 5 kΩ. The radiator is equipped with an output socket next to the input socket, and thus several radiators can be connected in series.

The radiator is provided with a gimbal-type bracket and can be easily adjusted in any direction. For mobile applications, it may be fixed to floor stands with a 3/8-in thread. For permanent installation, swivel mount GZG 1019 is available.

Monophonic Receivers

The standard monophonic receiver is the HDI 406 stethoscope headphone. With a maximum audio output of 106 dB SPL (sound pressure level) it is useful for people with normal hearing as well as for those with slightly impaired hearing. For the hard of hearing, the special HDI 406 S version with 112 dB SPL output can be used. For people with a more profound hearing loss, the HDI 407 L receiver is available. This model is provided with an induction coil to couple the signal magnetically into an existing hearing aid, switched to its telephone position.

Within the range of an infrared audio transmission system any number of receivers may be used. All monophonic receivers are powered by a plug-in battery that can easily be detached from the unit and recharged from a 110-V ac outlet.

Conclusion

An audio transmission system has been described that uses infrared radiation as the transmitting medium. It is useful for monophonic, stereophonic, and multichannel operation. Among its many applications stand out its use for the hard of hearing in motion picture theaters, and the use as an internal communications system in places where RF interference might be a problem, such as in television studios. Many other applications suggest themselves.