Noise and Interference in Optoelectronic Systems

Since an electronic interface is used to modulate the signal carrier in an optoelectronic device, circuit or system, it is possible for interference phenomena to disrupt the operation.

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INTRODUCTION

Interference phenomena have been observed in devices with optoelectronic, acousto-optic or magneto-optic systems commonly used in industrial, commercial or military applications.[1] Various tests on such devices have shown the following effects, as reported throughout the literature.

In electro-optic systems the RF energy causes heating of optical waveguides, which are highly sensitive to temperature changes. The temperature changes modify the refractive index of the waveguide, disrupting its operation. [2]

Radio-frequency fields applied to a Bragg cell have resulted in three types of failures in the metal-case cell: non-linearities in the crystals and transducer, compression of its diffraction efficiency, and spreading of the diffracted beam. Further, in magneto-optic devices used for spatial light modulation, interference has caused inadvertent switching of individual pixels. In various tests, using high RF levels, up to half the pixels were switched to the wrong state. In turn, this caused severe performance degradation.

The placing of an RF source near one of the connector pins of a charged couple device (CCD) chip can produce different effects depending on whether the interference is pulsed or continuous. Pulsed effects include bars appearing on the display and loss of synchronization. Continuous effects include smearing, lightening, darkening and doubling of the image.

NOISE TOLERANCE IN OPTICAL AND ELECTRICAL SYSTEMS: A COMPARISON

In a system, the signal level is commonly referenced to some absolute value or compared to the noise level present and expressed as signal-to-noise ratio (SNR). In dealing with these values, the decibel (dB) is a commonly employed unit. However, it is important to note that when operating with optical and electrical decibel terms, a difference of a factor of two may arise due to the detection of the optical radiation. This creates an often misunderstood relationship which is explained in the following sections. A specific example is used to illustrate.

AN ELECTRICAL SYSTEM

In an electrical system the decibels of power, electrical voltage and current ratios are expressed as follows:

$$dB = \log_{10}(P_2/P_1) = 20 \log_{10}(V_2/V_1) = 20 \log_{10}(I_2/I_1)$$

Assuming a 1-ohm resistor R with a voltage across it of 3 V, the electrical power in the resistor will be $P_1 = (V_1^2/R) = 9$ W. If the voltage is increased to $V_2 = 30$ V, the power will became $P_2 = V_2^2/R = 900$ W. The dB power ratio is 10 log $(P_1/P_2) = 20$ dB. On the other hand, the dB voltage ratio is 20 $\log(V_2/V_1) = 20$ dB. Thus, the electrical voltage and electrical power dB levels are indentical for the above condition.

AN OPTICAL SYSTEM

There is a difference when comparing the optical power present in a fiber optic link or a point-to-point infrared (IR) optical link to the electrical voltage in the receiver after the detection process. Here, the optical radiation is converted to an electrical current by the photodetector. The relationship of the incident optical power P to the current I in a unit gain detector is I = Pr, where r is the responsivity of the photodetector in A/W. Typical PIN silicon photodetectors have responsivities in the range of 0.4 to 0.5 A/W in the 820 to 900 nm wavelength region. Since the photodetector current is directly proportional to the incident optical power, the decibel relationship becomes

$$dB = 10 \log(P_2/P_1) = 10 \log[(I_2/r)(I_1/r)] = 10 \log(I_2/I_1)$$

This relationship is different by a factor of two from the dB of electrical current equations and demonstrates the origin of the variation when dealing with decibel units for optical to electrical conversion. Consequently, an optical link system which experiences an additional 2-dB optical power loss due to insertion of a connector will suffer a corresponding 4-dB reduction in the voltage SNR at the detector output. On the other hand, an increase of the optical power by 2 dB would enhance the voltage SNR by 4 dB. To further clarify these relationships, the following example is given to represent a real world situation.

EXAMPLE

Figure 1 shows an optoelectronic circuit where a photodetector is combined with an operational amplifier to produce an output voltage V. Here, the output voltage is equal to the detector current I times the feedback resistance R_F, or $V = I R_F$ and $I = Pr$, where P is the optical power and r the responsivity. Combining these two equations gives $V = PrR_F$. Assuming R_F = 1 Mohm and r = 0.5 A/W, the relationship associated with two optical power levels can be considered. With P_1 = 1 μW, it gives $V_1 = rP_1R_F$ = 0.5 V, and with P_2 = 10 μW, it gives $V_2 = rP_2R_F$ = 5 V.

The dB optical power level change is $10 \log(P_2/P_1)$ = 10 dB, whereas the dB change in signal voltage level is $20 \log(V_2/V_1)$ = 20 dB.

THE OPTOCOUPLER CASE

The primary means for signal isolation in systems include transformers, coaxial cable, optocouplers and fiber optics. Optical isolation owes its higher performance to the fact that it converts the signal carrier from one physical form, electrons, to another, photons. This conversion strips away in-system and/or common-mode noise, allowing the receiver to produce a relatively pure signal. As photons have neither mass nor charge, they can pass unaffected through high-radiation environments. In addition, optocouplers constitute a particularly effective method of signal isolation in radiation-hardened systems[3].

COUPLING PROBLEMS WITHIN THE DEVICE

Isolation in optocouplers is affected by stray capacitive coupling as shown in Figure 2. Capacitance C_{CM} is only a small part of the total input-to-output capacitance C_{C1} which usually is given in data sheets as C_{I-0}. C_C is also called reverse coupling capacitance. It should be noted that C_{CM} is fairly constant and in most optical isolators is between 0.05 and 0.1 pF, whereas in the internally shielded types it is 10 times smaller.

For the unshielded single-transistor analog types, common-mode rejection (CMR) can be improved by adding a neutralizing capacitor between the collector and either of the input pins. The value of the neutralizing capacitor C_{CM} should be

$$C_{CM} = \beta C_{CM} \qquad (1)$$

Optical isolators virtually eliminate dc ground loops ($R_{ISO} \equiv 10^{12}$ ohms), but they do allow some ac ground loop current. Internal capacitance between the input and output circuits permits ac ground loop current according to

$$i_{GL} = C_c\,(de_{CM}/dt) \qquad (2)$$

where

$$C_c = C_{I-0} = C_{CM} + C_1 + C_2 \qquad (3)$$

The internally shielded optical isolators have a lower C_{CM}, but C_c does not charge appreciably. Unfortunately, there are no circuit tricks that can be done to reduce C_c or its effects. In applications where the C_c = 1 pF of most optical isolators is intolerably high, the only solution is to select a type that has a larger physical separation between the input and output circuits. Such types are usually more costly because they require lenses or fiber optics to obtain adequate optical coupling between widely separated circuits.

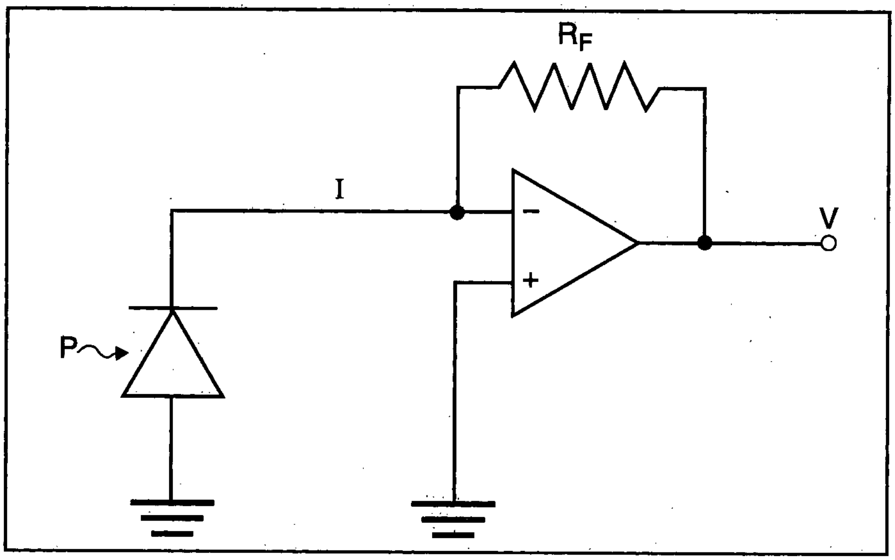

Figure 1. Photodetector Combined with Operational Amplifier.

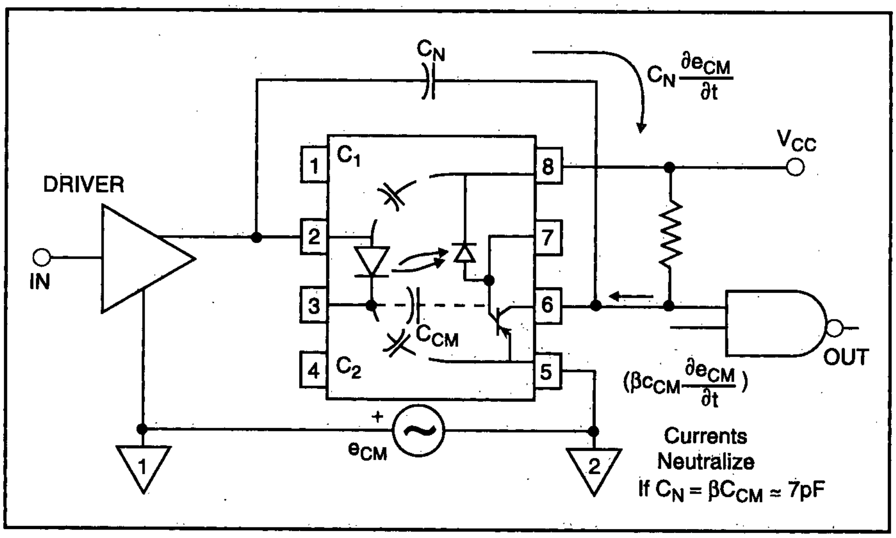

Figure 2. Basic Scheme for Neutralization. Neutralizing capacitor must have adequate voltage rating.

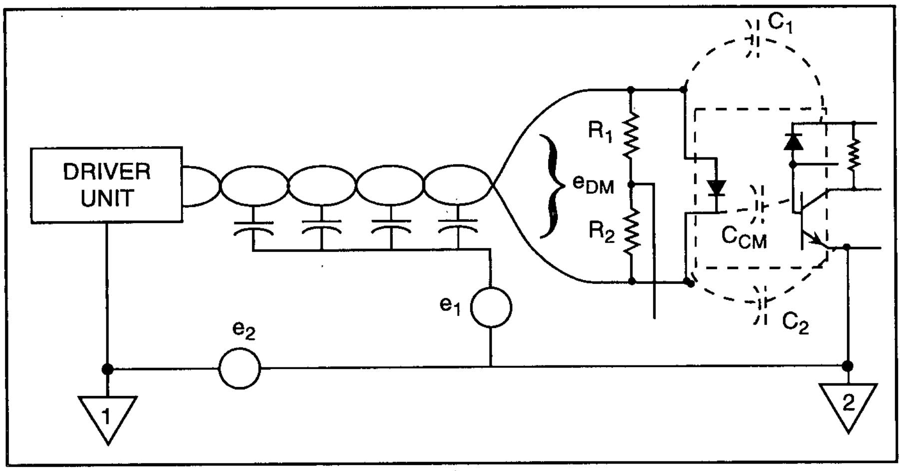

Figure 3. *Capacitive Coupling from External Signal Lines.*

COUPLING FROM EXTERNAL SIGNAL LINES

Capacitive coupling from adjacent electrical power lines to input lines for an optocoupler creates an additional input leakage current. Instances have been observed where 10 V root mean square (RMS) of common-mode ac voltage has been coupled into the open input lines to an optocoupler. This additional voltage/current can upset a threshold level design. A larger threshold voltage or current would have to be determined to detect the desired signal level.

Figure 3 shows the driving of an optocoupler where an unshielded twisted pair line is used. Common-mode voltage e_{CM} consists of an included (e_1) and inherent voltage (e_2).[4] A twisted-pair line lowers induced e_{CM}. Since both lines vary simultaneously, no voltage difference should appear at the terminators. In general, methods of reducing the effects of EMI include using a twisted-pair line, a shield, good printed circuit-board layout and carefully designed circuits.

THE FIBER OPTIC CONNECTION

Compared with metallic cable, optical fiber offers low signal loss, immunity to electromagnetic interference (EMI), huge savings in cross-sectional area and weight, inherent security (lack of radiation and resistance to tampering), and exceptionally wide bandwidth.

ADVANTAGES OF INSTALLING OPTICAL CABLES ON POWER LINES

The main advantage of installing optical cables on a power transmission and distribution network is the avoidance of the expense and legal problems of burying the fibers. Another advantage, particulaly in cases where

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there are long distances between towns or where the environmental conditions are extreme, is that one team installs power and optical networks together. Although optical fibers have been installed on overhead power networks for little more than a decade, the operational demands of high-power distribution lines mean that the technology is well proven.

As a case history, voice, data and image services are provided by optical fibers installed in a 400-kV electricity distribution network in England in September 1994. The 200-km network is possible because of deregulation in telecommunications and the optical links developed by electricity companies to ensure safe power supplies.The pylons that distribute the UK's electricity typically carry seven overhead wires or bundles in a triangular arrangement: one ground wire, to protect the network against lightning or fault currents, strung above three pairs of live wires. Engineers wrap optical cables, containing 40 single-mode fibers, around the ground wire or string up a metallic optical ground wire (OPGW) that contains optical fibers.

MAGNETIC FIELD LEVELS AND THEIR EFFECTS

Optical cables installed on power lines experience magnetic field levels higher than their buried counterparts. In both cases, the fields are normal to the direction required to produce perturbations. Most of the likely effects caused by electrical and magnetic fields change the polarization state.

Polarization is becoming an issue in telecommunications. Research by telephone companies shows that erbium-doped fiber amplifiers in long haul links are prone to polarization-dependent gain, and scientists are looking at cryptography based on the polarization of individual photons.

Capacitative coupling at the live wires induces electrostatic voltages of up to several tens of kilovolts on the surface of the optical cable. These changes are benign if the cable is clean and dry. When the cable is dirty or wet, small earth-leakage currents begin to flow to the pylon. Usually harmless, these currents reduce the induced potential on the cable. They are stronger where the cable meets a pylon; weakest at the center of the span. Problems with induced currents begin when the cable dries off. Drying usually starts as a spot in the top of the cable and moves around the circumference to leave a narrow dry band which prevents leakage currents from flowing.

If the potential on the side of the band closest to the pylon falls to zero while the potential on the other side shoots up, low-current arc may leap across the dry band. This process, known as dry-band arcing, can severely damage the sheaths of all-dielectric self-supporting cables, usually close to a support pylon where the leakage currents are greatest. Dry-band arcing is avoided by attaching or wrapping an optical cable to an overhead power line.

THE INFRARED WIRELESS LINK

Infrared (IR) links can be used indoors or outdoors when designed for point-to-point applications or exclusively indoors when they operate on diffuse IR light propagation (Figure 4). In the latter, an important factor affecting the system's design is the ambient light condition.[5]

NOISE SOURCES IN AN IR LINK

Bright sunlight can interfere with an infrared transmission system operating in indoor working areas. Another important factor is the ambient conditions in a given room. This light can come from incandescent illumination, fluorescent lamps or other special lamps whose spectral output of light can be enhanced over a selected wavelength range by various additives. Infrared signals can be largely affected by background and extraneous light interference signals coming from the sources listed above.

For ease of reference, Table 1 shows part of the electromagnetic (EM) spectrum that represents the light spectrum. It should be noted that the spectral limits indicated in Table 1 have been chosen as a matter of practical convenience. There is a gradual transition from region to region. In various fields of science, the classification may differ due to the phenomena of interest. Of particular interest is the near infrared region of Table 1, within which the light-emitting diodes (LEDs) used in a diffuse light channel operate[6].

The limiting sensitivity of an incoherent detector, such as a photodiode (PIN), is determined by random fluctuations, i.e., noise, which has its origin in a number of phenomena, one of which is ambient light. In an IR diffuse-light channel using LEDs as light sources (800-950 nm), the photodiodes at the receiver are exposed to the ambient light, introducing additional noise to the input circuit of the receiver amplifier. This is in contrast to fiber optic receivers, where the ambient light has no effect on the receiver.

OPTICAL FILTERING IN IR SYSTEMS

A significant part of the incident ambient light at the receiver end may be blocked by optical filtering as discussed below. Two types of optical filters are discussed: absorption edge filters mainly blocking the visible part of the spectrum, and interference filters with a passband corresponding to the LED-source array bandwidth.

EDGE OPTICAL FILTERS

An edge filter is characterized by abrupt change between a region of transmittance and a region of rejection. Long-wave-pass (LWP) filters reject the shorter wavelengths and transmit the longer wavelengths. Short-wave-pass (SWP) filters reject the longer wavelengths. An effective and inexpensive filter is obtained by developing an unexposed color film. Owing to the different source spectra, the filter is able to block ambient light to a varying degree of effectiveness. Figure 5 shows the parameters of a typical edge filter. One important parameter is the slope, which is a measure of the wavelength interval required to traverse, ranging from 5%

absolute transmittance cut-on/off point to the 80% of peak transmittance point. It is given by

$$0\%\ \text{SLOPE} = \frac{\lambda(80\%T_{pk}) - \lambda(5\%T_{abs})}{\lambda(5\%T_{abs})} \times 100\% \qquad (4)$$

BANDPASS FILTERS

A bandpass filter has a specifically defined region of transmittance bounded on both sides by specifically defined regions of rejection. It allows isolation of a band of wavelengths from the total spectrum without the use of dispersing elements such as prisms or gratings, while at the same time enabling higher energy throughput and greater out-of-band rejection. Bandpass filters have various uses in spectral radiometry, medical diagnostics, chemical analysis, colorimetry, astronomy, lasers and a multitude of other applications where spectral isolation is required. In a bandpass optical filter, the center wavelength is $\lambda_0 = \lambda_1 + (\lambda_2 - \lambda_1)/2$ and the bandwidth is $BW = \lambda_2 - \lambda_1$.

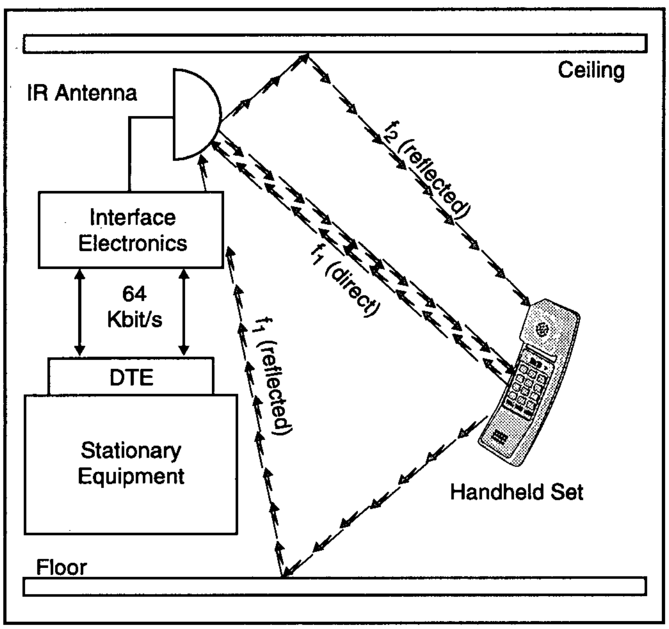

Figure 4. *Block Diagram of Two-way Wireless IR Communication System.*

EFFECTS OF ADJACENT IR SYSTEMS

General coexistence of different infrared (IR) transmission systems is possible with the application of optical wavelength multiplexing. Narrowband systems can coexist with other narrowband systems if their channel allocations (frequency-division multiplex) are chosen accordingly. Different pulse systems will coexist if the required time slots (time-division multiplex) are coordinated. The nature of wideband transmission does not allow non-correlated, non-directional systems with the same or similar optical wavelength to be operated simultaneously in one room without interference, one criterion for noise being the duration of operation. It is conceivable that a system operating in continuous mode will be subject to only minor interferences from briefly occurring control pulses of another IR system. Furthermore, optical interference with other devices emitting IR light may occur, e.g. illumination systems. Therefore, the equipment should be designed in such a way as to use the appropriate channel or bandwidth allocation for the particular application area as provided by the applicable standard.

The technical data of devices emitting infrared which is intended to be used for information transfer should list all those channels where the emitted infrared energy is above the permitted noise levels for the specific applications. This information allows the user of different infrared systems to evaluate in advance whether the intended parallel use of different systems will be reliable. If different systems share channels, a possible misfunction must be taken into account. Care has to be taken if equipment outside a certain standard is used at the same location, like security systems or other industrial applications such as measurement or automation equipments.

The interference of different IR applications with each other may be shown in a matrix as indicated in Table 2.[7] As mentioned above, lighting technology may lead to interference. Besides the already known interference near 60 kHz and its harmonics, newly developed induction gas discharge lamps are generating modulated IR signals mainly concentrated at about 5.3 MHz.

VACUUM ULTRAVIOLET	MIDDLE & NEAR ULTRAVIOLET	VISIBLE	INFRARED
• Extreme Ultraviolet 10-100 nm • Far Ultraviolet 100-200 nm	• Middle Ultraviolet 200-300 nm • Near Ultraviolet 300-380 nm	380-770 nm	• Near (short wavelength infrared 770-1,440 nm • Intermediate infrared 1,400-5,000 nm • Far (long wavelength infrared) 5,000-1,000,000 nm

Table 1. *Light Regions from the EM Spectrum.*

CONCLUSION

There have been several convincing cases about the effects of electromagnetic interference and noise in the susceptibility of optoelectronic systems. Since an electronic interface is used to modulate and detect the light of beam or a diffuse infrared carrier in an optoelectronic device, circuit or system, it is possible for interference phenomena to disrupt the operation of a photonic element.

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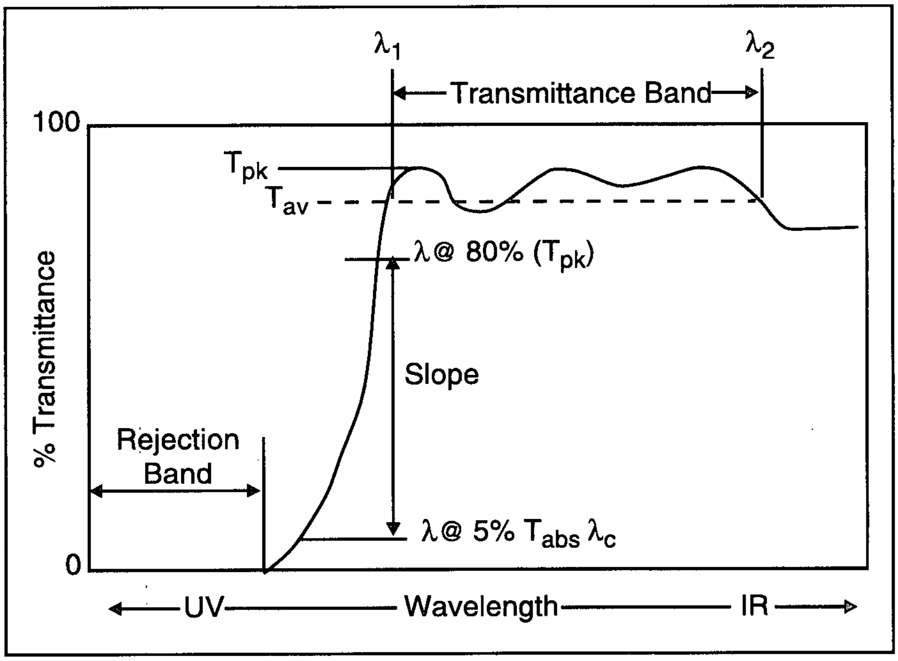

Figure 5. *Parameters of Typical Edge Optical Filter.*

From \ To	Remote Control	Audio Transmission	Data Transmission
Remote Control	No problem: modulation and decoders different to different systems	Disturbance/interference acceptable (moderate) (short and long pauses in the received signals)	Attention required for future systems -household -office
Audio Transmission	Continuous modulation: no problem. Pulse modulation: may cause problems	Depends on the choice of modulation and frequencies	Depends on the choice of modulation and frequencies
Data Transmission	Systems may fail (data confuses the remote control code)	Different grades of interference due to modulation and frequency range	Failure in unsynchronized systems and with inadequate coding
Light	No problem with adequate coding and pulse rate	Daylight: mostly not disturbing. RF artificial light: of variable influence	No problem with proper frequencies and coding

Table 2. *Interference Between IR Sources and Systems.*[7]