

Optical Infrared Communications

Once information has been “glued” onto a carrier signal—the information is used to **modulate** the carrier signal in some way—the carrier signal can be **propagated** from one point (where the transmitter is located) to another point (where the receiver is located).



This **electromagnetic propagation** can occur in one of two ways; either in a **bounded** channel (e.g., a transmission line or waveguide) or in an **unbounded** channel (e.g., in free-space).



Electromagnetic energy at frequencies **below 100 GHz** (approximately) are coupled into (at the transmitter) and out of (at the receiver) free-space using an **antenna**.

This creates a highly effective communications system, as electromagnetic propagation is **very fast**, traveling at a velocity of almost 3×10^8 meters/second—the **speed of light**!

Moreover, electromagnetic energy oscillating at (carrier) frequencies of 2 GHz (approximately) **propagate well** through objects that we think of as opaque—concrete, wood, drywall insulation, soil, etc.

To signals propagating at a frequency **less than 2 GHz**—a region loosely defined as the **Radio Frequency (RF)** region of the electromagnetic spectrum—most solid objects appear to be **transparent**.

In the RF frequency band, no one should throw stones, as everyone lives in a **glass house**!



These **two** characteristics—**fast** propagation and propagation **through solid objects**—make RF signals a great **carrier** of important information.

Q: *Is electromagnetic communications limited **only** to the RF region?*

A: Absolutely **not**! Just above the RF region of the electromagnetic spectrum is the “**microwave**” region—loosely defined as frequencies between **2 GHz and 20 GHz**.

Electromagnetic communication in the microwave region has **some advantages** over RF, but it is also hampered by the fact that solid objects don't look **quite** as transparent at microwave frequencies.



As a result, microwave communication systems are typically “**line-of-site**”. For example, most **satellite** communications occurs in the microwave region.

Q: *What happens at frequencies beyond (above) the microwave region?*

A: **Bad stuff** happens, generally speaking. The most odious of this is the fact that the Earth’s **atmosphere** does **not** even appear to be transparent at these higher frequencies. This is particularly true if the atmosphere is full of **water vapor** (i.e., clouds!).



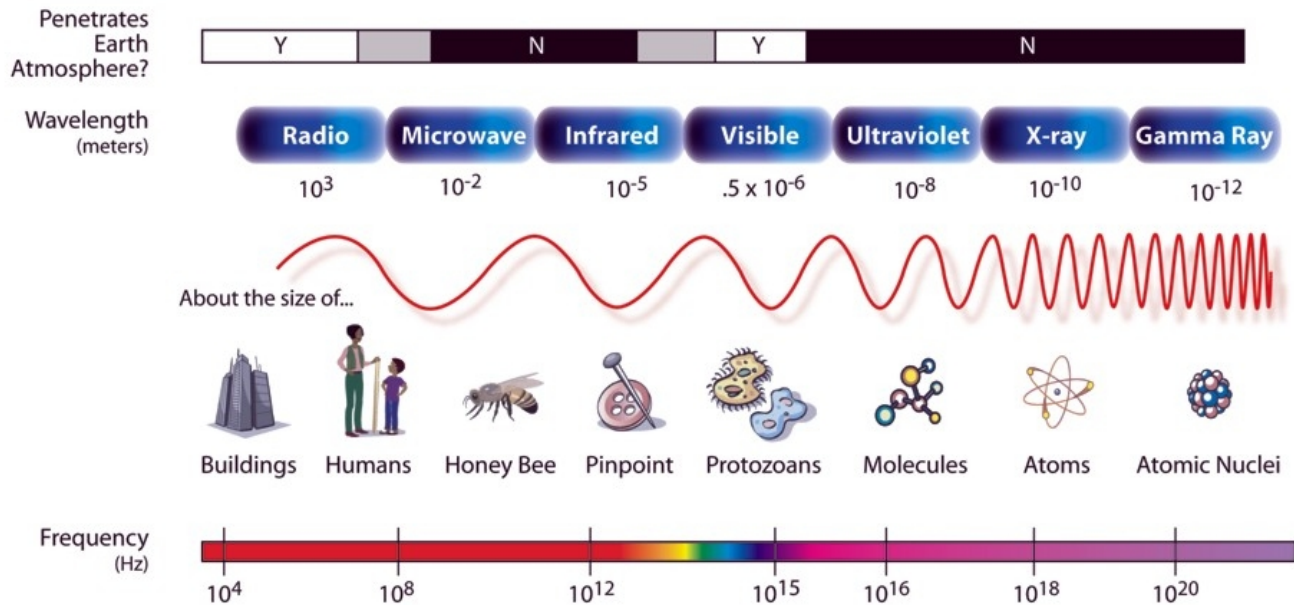
Q: *So **all** electromagnetic communication occurs at frequencies in the RF or microwave region?*

A: Not all! **Much** communication also occurs using the “**visible**” and “**infrared**” regions.

Way up at the high end of the electromagnetic spectrum is electromagnetic energy that oscillates at **fantastically high frequencies**—and thus fantastically **small wavelengths**.

We call this region the **visible region** for a very good reason—propagating electromagnetic energy at these frequencies can actually be **seen** with the human eye!

THE ELECTROMAGNETIC SPECTRUM



From: www.pol-us.net/ASP_Home/aspkids/EM-spectrum.jpg

Q: *Wow! I can I see this electromagnetic wave? **Where** do I go? **What** do I do?*

A: You don't have to **go** anywhere or **do** anything. You are seeing this electromagnetic energy **right now**—we gave propagating electromagnetic waves at these frequencies the name “**light**”.

→ Visible **light** is simply a propagating **electromagnetic wave** in the “visible” region!

Q: *Why do you call it “visible” light? Is there such a thing as “invisible” light?*



A: Actually there **is**! Just a bit below (i.e., lower in frequency) the visible region is the **infrared region**. Infrared propagation is **very** similar to visible **light**, only we humans **can't see** it with our eyes.

Q: *But I don't understand. You said that visible and infrared energy is used for **electromagnetic communication**, but I know that visible light does **not** propagate through solid objects, nor does it propagate well through **clouds**. How is this region of the electromagnetic spectrum **useful**?*

A: Typically, the visible and infrared region of the electromagnetic spectrum is used for propagating a **bounded wave**. Specifically, visible and infrared energy is propagated in a **waveguide**.



Waveguides are fundamentally different than transmission lines (e.g., a coaxial cable), but they both essentially constrain a propagating electromagnetic wave—sort of an **electromagnetic pipe**!



Microwave waveguide was developed during World War II at the **MIT Radiation Lab**—the laboratory that developed modern **radar**.

Waveguide in the electromagnetic propagation in the **optical** (i.e., visible and infrared) region was a more **difficult** technical challenge. The first successful waveguide at these frequencies was not constructed until the **1960's**.

This waveguide has a more popular moniker of "**fiber optic**" or "optical fiber". Fiber optic "cable" made possible the use of infrared and visible light for electromagnetic communications.

Visible light encounters **no clouds or buildings** as it propagates through an optical fiber!



Q: *But I don't see why we would want to use visible light in bounded electromagnetic propagation. Can't we just propagate RF or microwave energy down a **transmission line**?*



A: We can and frequently **do** (e.g., cable TV!).

However, the visible and infrared region of the electromagnetic spectrum has one gigantically important attribute that the RF and microwave regions do **not**—**bandwidth!**

The RF microwave regions of the electromagnetic spectrum spans a bandwidth of approximately **20 GHz**. In contrast, the infrared and visible region of the electromagnetic spectrum has a bandwidth of **more than 100,000 GHz**—5000 times that of the entire RF/microwave region!

Q: *What's the big deal about **bandwidth**?*

A: Bandwidth determines the **rate** at which we can reliably send information—the larger the bandwidth, the larger the “**data rate**”.

Q: *Do we really **need** such large bandwidths? I don't think I have that **much** to say!*

A: We didn't **used** to need that much bandwidth, but as you may have noticed, we humans now fling “information” back and forth in all directions with **phenomenal alacrity**.



Texting, blogging, tweeting, talking, surfing, listening, viewing, downloading, searching, sharing, networking, and podcasting (LOL!)—we communicate with a frequency and variety that was unfathomable just 30 years ago (whether we actually communicate any **better** is debatable).



Without optical fiber, and the bandwidth it provides, modern life would be **very different** from what it actually is today!



Q: *What about communication via **unbounded** propagation of light?*

A: The problem of course is that electromagnetic energy does **not propagate well** in the infrared and visible light region. As you may have noticed, light does not penetrate "stuff" like walls, furniture, doors etc.

→ For visible light and infrared, only **windows** are transparent!



As a result, communication systems involving (mainly) infrared propagation can transfer information over a distance of 15 meters or less—pretty much from **one side** of a room to the **other** side.



Q: *Transmit information **across** a room?
Why would I want to do that? I don't need
electronic communication to **talk** to
someone in the same room!*

A: True, but most unbounded infrared communications systems are **not** designed to allow for humans to communicate with other humans, they are designed to allow for humans to communicate with other "**things**".

In other words, these communication systems allow humans to control **devices** within a room.



Q: *Can't we just **walk** across the room and control them?*



A: We can, but most humans now find this to be just **too darn much work!**

Unbounded infrared communication systems are a prized possession of every **couch potato** and **channel surfer**—it is these systems that allow TVs, cable boxes, stereos and DVD to be controlled remotely—controlled remotely via a remote control!

Q: *You keep saying that these are **infrared** systems. Why don't we use light in the **visible region** for remote control systems?*

A: When you push a button on a remote, a **light turns** on at the end of the remote. If you shine this light on your TV, it will respond by **changing** the channel or **increasing** the volume.

Q: *Wait! I've never noticed any **light** shining when I use my remotes, you must be **confused!***



A: The reason that you've never noticed this light is that this light is **infrared**—it is **not** located in the **visible** region of the electromagnetic spectrum.

This is **why** infrared (and not visible light) is used in remotes—the light it produces is **invisible** to us humans!



Q: So how do we **modulate** this infrared signal? How do we “glue” information onto this carrier? Do we use Amplitude Modulation (**AM**) or Frequency Modulation (**FM**)?



A: It is exceedingly difficult and **expensive** to **frequency modulate** electromagnetic energy at infrared frequencies. In fact, it's pretty darn difficult to produce a “coherent” sine wave at these frequencies—a **laser** is typically required!

Thus, information is typically placed on the infrared signal via **Amplitude Modulation (AM)**.

Q: *So, the resulting amplitude of the infrared signal is **proportional** to some information signal?*

A: Yes and no.

It turns out that AM is no piece of cake either when applied to infrared. By far the **easiest** (and thus cheapest) way to Amplitude Modulate an infrared signal is simply to turn it “**on**” or turn it “**off**”!

Thus, the infrared lights of most remotes are simply switched between an “on” and an “off” state!

This type of amplitude modulation is known as **On-Off Keying (OOK)**

Q: *But how can we use this to **convey information**?*

A: We can modify the **rate** at which the infrared signal is turned "on" and "off"! The **rate** (i.e., frequency) at which the infrared is switched is **proportional** to the information we wish to send.

To be specific, the infrared signal of most remotes are **typically** switched "on" and "off" at a rate between **20 kHz and 150 kHz**.

This frequency is known as the "**chip rate**"; 40 kHz is a pretty standard chip rate for remote controls.

Thus, the **infrared** signal is effectively **Amplitude Modulated** by a **40 kHz square wave**. When the square wave is in its high state, the infrared light is switched "on". When the square wave is in its low state (i.e., zero), the infrared light is switched "off"

Q: *But how does **information** get placed on this flashing light?*

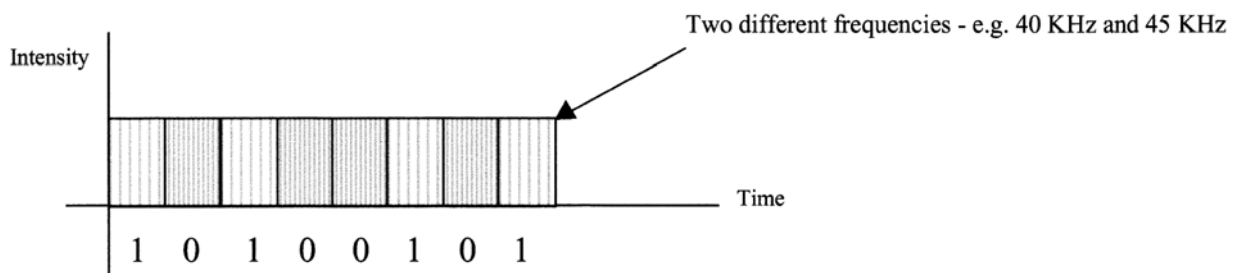
A: There are various means, but typically information is placed on the signal by **altering the chip rate** in a manner that is **proportional** to the information signal.

For example, say we wish to transmit a **digital stream** of data (i.e., "ones" and "zeros"). This is typically what remotes do—the **binary** word tells the TV what button has been pushed!

We can convey this information by changing the **chip rate** from, say, **40 kHz** for a binary "0", to **45 kHz** for a binary "1".

Of course, once we change the chip rate, the square wave must **remain** at that frequency for some significant amount of time (i.e., **several cycles** of the square wave), before it can change back to the other value.

This time is known as the "**chip interval**" and is typically some **integer** number of square wave cycles. Thus, the **data rate** (in bits/second) of a remote is always **less** than the chip rate.



For example, say we use a **chip rate** of 40 kHz, and a **chip interval** of 33 cycles (i.e., 33 chips/bit). Since the **period** of a 40 kHz is 25 micro seconds, the **chip interval** is $33 \times 25 = 825$ microseconds.

Thus, a new "bit" of information is sent every **825 microseconds**. The inverse of this value gives us the **data rate**— $1/825 = 1200$ bits/second.

Q: *Wow! That seems like an exceedingly **slow** data rate. Do these thing really work?*



A: A data rate of 1200 bits/second is **plenty** fast, considering **all** you are trying to do is tell the TV to "go to channel 457"!

Q: *Changing the "chip rate" frequency sounds a lot like **Frequency Modulation (FM)**. Is that what we are doing?*

A: Absolutely! Changing the frequency of a signal between two (or more) fixed values is known as **Frequency Shift Keying (FSK)**. FSK is a very popular **FM technique** for communicating digital information.

The 40 kHz square wave is also referred to as a **sub-carrier**.

Communication via infrared light is thus accomplished in a **two step** process:

- 1.** Information is used to **Frequency Modulate** a square-wave **subcarrier**.
- 2.** This modulated square-wave sub-carrier is then used to **Amplitude Modulate (OOK)** an **infrared light**!

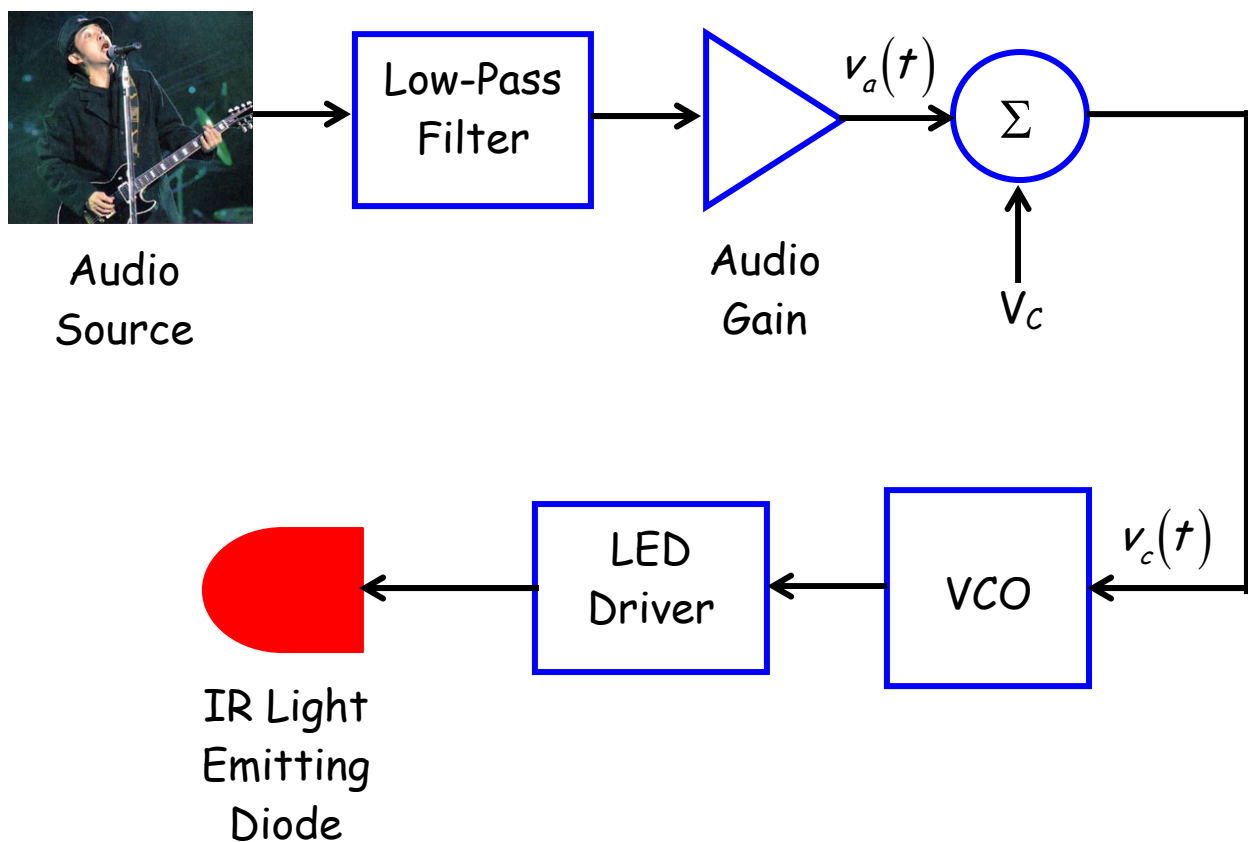
Q: ***Must** we use **FSK** to modulate the sub-carrier? Could we use (for example) an **audio** signal to **Frequency Modulate** the sub-carrier?*

A: Absolutely! In this case the subcarrier frequency would increase or decrease **proportionally and continuously** from its nominal value (e.g., 40 KHz), in response to an analog signal representing an **audio** pressure wave.

We of course could use a **VCO** (with a square wave output) to provide this Frequency Modulation.

So, let's put all the **pieces together** for an audio communications system using infrared light.

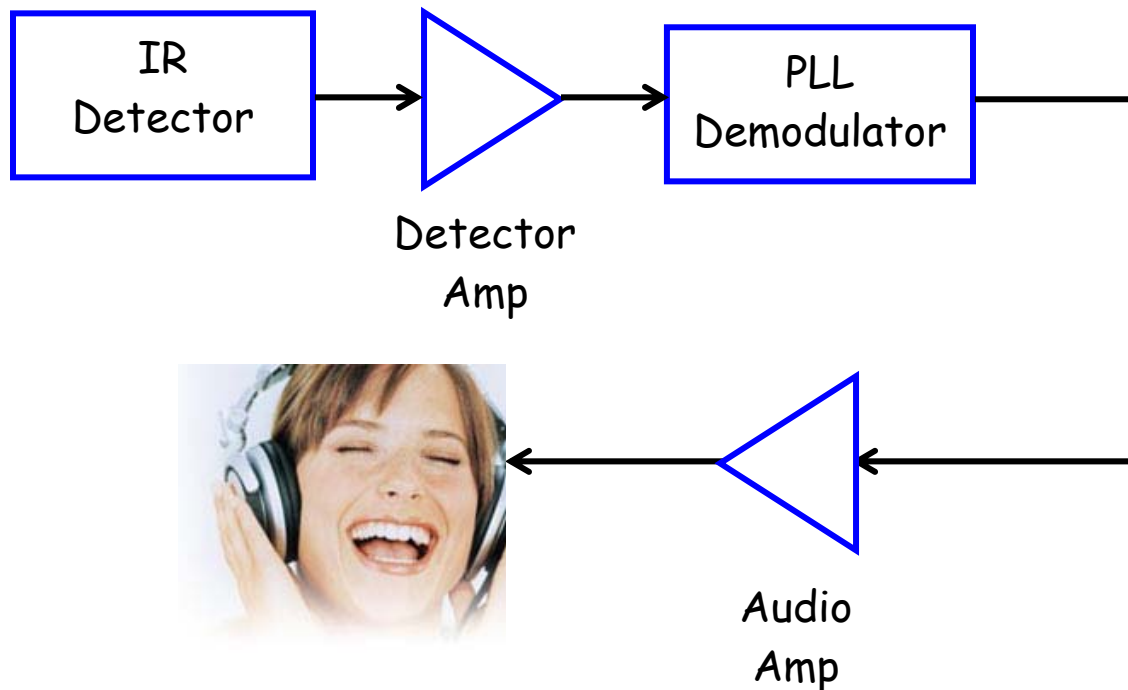
First we have a **transmitter**:



1. The **low-pass filter** simply limits the signal bandwidth to audio frequencies; typically a value much less than 20 kHz.
2. The **audio gain stage** sets the peak-to-peak audio at the correct value to generate the desired modulation bandwidth.
3. The **DC bias** value V_C sets the VCO carrier frequency—in this case the chip rate.
4. The **summer** combines the AC audio signal and the DC bias voltage.
5. The **VCO** of course creates the FM signal. In this case a Frequency Modulated square wave, centered the desired chip rate.
6. The **LED Driver** is essentially the switch circuit that turns the IR LED on and off (i.e., OOK) at the proper rate.
7. The **IR LED** is simply a Light Emitting Diode that emits light at some invisible IR frequency.

Note that elements 2,3, and 4 can be **combined or rearranged**.

Now for the **receiver**:



1. The **IR Detector** is essentially an electronic “eye” that “sees” infrared energy. Its output put is proportional to the amplitude of IR light shining on it at any given time.

Thus the output of this device will be proportional to the square wave that is driving the LED on the transmitter. This device is thus an IR Amplitude **Demodulator**!

2. The signal out of the detector, however, is very small. As a result, we require a very **high gain amplifier** to create the requisite square-wave signal into the PLL demodulator.

There are IC amplifiers made for this very purpose!

3. The output of the Detector Amp becomes the reference signal for the **PLL demodulator**. The PLL “locks” onto this

signal, and so the control voltage of the PLL VCO should be proportional to the audio signal at the transmitter.

→ The signal is thus **demodulated**!

4. This demodulated audio is typically too small to be audible; it might require some significant **audio amplification**!