Jules' Workshop

Standard

Unit 20

OP AMPS, EMC and EMI

ACMA Syllabus February 2024

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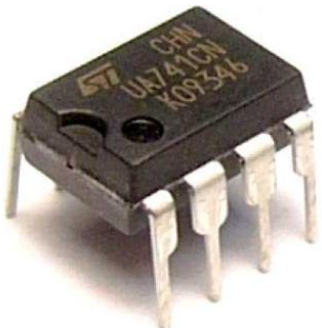
Operational Amplifiers (Op Amps)

The operational amplifier (Op Amp) is one of the most versatile devices available, and applications using this device are widespread in both the analogue and digital arenas. The vacuum tube Op Amp was invented by Karl Dale Swartzel Jr in 1941 when working at Bell Laboratories.

Looking at the Op Amp as a black box, there are usually five connections. The symbol for the Op Amp is a sideways triangle.

In some drawings, the power connections are not shown, but implied.

In this lesson, we will use the very common µA741 operational amplifier as the example.



Ideal Op Amp Characteristics

Open Loop Gain (Avo) – The ideal Op Amp has high gain of about 20,000 to 200,000. As open loop op amps have extremely high gain, they are used in this configuration for non-linear applications such as comparators, zero-crossing detectors, and basic switching circuits.

Closed-loop operational amplifier configuration is a circuit design where a portion of the output signal is fed back to the input, creating a loop to control gain and stability. Negative feedback maintains a stable operating point where the voltage difference between the two inputs is zero. This concept is often called a "virtual short" or virtual ground.

Input impedance (Z_{IN}) – The input impedance is the ratio of input voltage to input current and is assumed to be infinite.

Output impedance (Z_{OUT}) - The output impedance of the ideal operational amplifier is assumed to be zero, but the output impedance is in the 100Ω - 20kΩ range.

Bandwidth (BW) - An ideal operational amplifier has an infinite frequency response from DC to daylight, so it has infinite bandwidth. In real Op Amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifier's gain becomes one.

Common Mode Rejection Ratio (CMRR) - CMRR is the ability of the Op Amp to reject the same signal on both inputs. This is important for the cancellation of noise common to both inputs.

Offset Voltage (V_{IO}) – The Op Amp output is zero when the voltage difference between the inverting and the non-inverting inputs is zero. Real Op Amps have some amount of output offset voltage.

Rules

Op Amp ideal characteristics can be summarized by the two very important Golden Rules:

1. In a closed loop configuration, the output drives the V_{IN} + and V_{IN} – to be equal.
2. The inputs draw no current.

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Typical Op Amp

Below are a few interesting figures from the µA741 data sheet that make it a versatile device.

- Vom Output voltage swings typically +/-14 V.
- Icc No load supply current 3.3 mA
- T_A Operating free-air temperature maximum 70° C.
- CMRR Typically 90 dB. Excellent Performance: A value of 90 dB is considered excellent, meaning the device is very effective at suppressing common noise. 90 dB implies a reduction of common-mode signals by a factor of roughly 31,600 times.
- r_i Input resistance typically 2 MΩ
- r_o Output resistance typically 75 Ω

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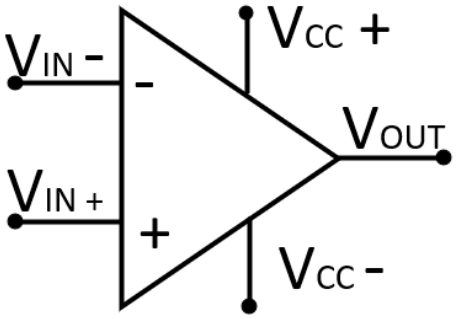
UA741

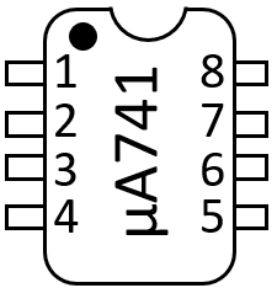
General-purpose single operational amplifier

Datasheet - production data

Go online and look for the data sheet for the uA471 op amp and peruse the parameters.

Opp Amp Connections





Pin	Description	Pin Name
1	External offset voltage.	Offset N1
2	Inverting input.	VIN -
3	Non-inverting input.	VIN +
4	Negative supply voltage	VCC -
5	External offset voltage.	Offset N2
6	Output to the next stage.	VOUT
7	Positive supply voltage	VCC +
8	Not connected	

Offset

Unavoidable mismatches in the Op Amp circuitry can cause the device to output a signal when then is no input signal. These input mismatches can be adjusted as per the datasheet for the Op Amp in use. Usually by applying an offset voltage to N1, Pin 1, and/or N2, Pin 5.

VIN –

The inverting input. Output will be 180 degrees out of phase with the input. The 741 can accept an input voltage of +- 15 volts.

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VIN +

The noninverting input. Output will be in phase with the input. The 741 can accept an input voltage of +- 15 volts.

Vout

The voltage output range will depend on Vcc +-.

Vcc

Positive supply maximum +15 V

Negative supply maximum -15 V

The A741 operational amplifier does not have a dedicated ground pin. The op amp uses dual power supplies—a positive supply, Vcc +, and a negative supply, Vcc -, to establish a reference voltage. This is termed a "virtual ground" or common 0-volt reference point.

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Useful Op Amp Circuits

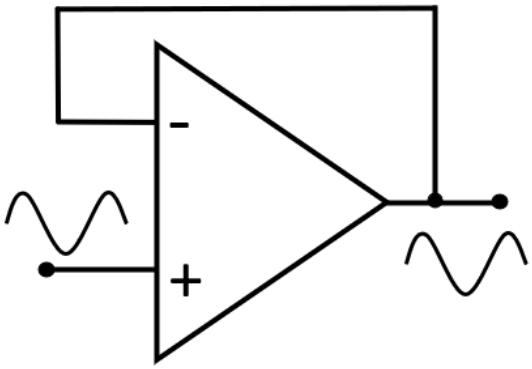
There are many circuits using the Op Amp as the primary component. I selected 10 to provide examples.

Just be aware of the versatility of op amps and some of the configurations that can be arranged.

The Voltage Follower

Also known as a unity gain amplifier, buffer amplifier or isolation amplifier.

This circuit is used as a buffer because it draws very little current due to the high input impedance of the amplifier. This eliminates loading effects on the preceding input circuit. The Op Amp has a gain of 1 so the output is the same as the input.

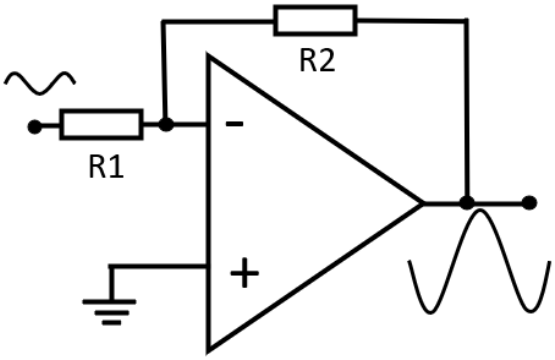


Voltage Follower

Vout = Vin

The Inverting amplifier

This configuration changes the signal by 180 degrees. The gain of the amplifier is determined by the ratio of R_1 and R_2.



Inverting Amplifier

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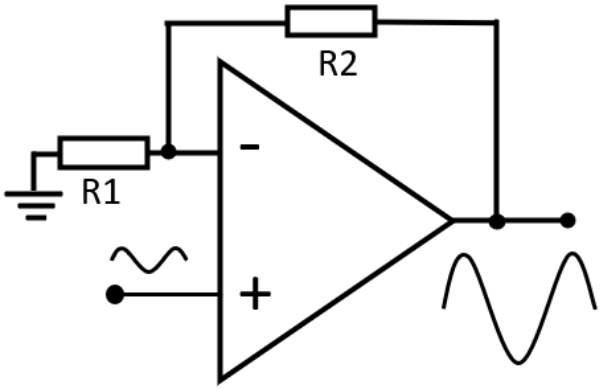
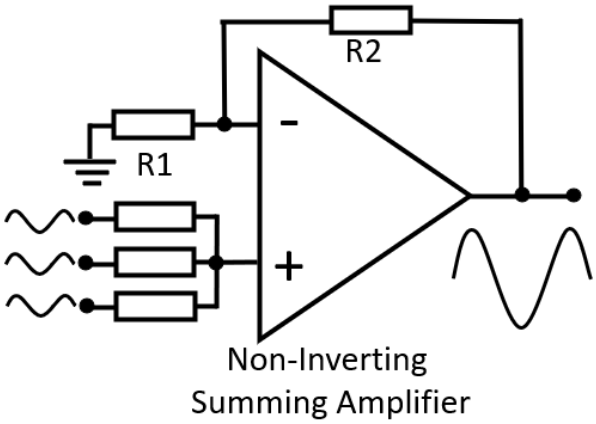
The non-inverting amplifier

This configuration is used where the input and output are in phase. The gain of the amplifier is determined by the ratio of R_1 and R_2.



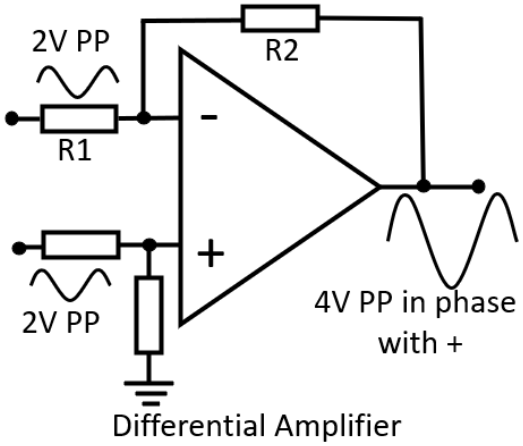
The non-inverting summing

This amplifier is used to combine the voltages present on two or more inputs into a single output voltage. As it is noninverting, the output will be in phase with the input. The gain of the amplifier is determined by the ratio of R_1 and R_2.



The Differential amplifier

This configuration is a circuit that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. The circuit has two inputs, and the output is proportional to the difference between the two voltages.



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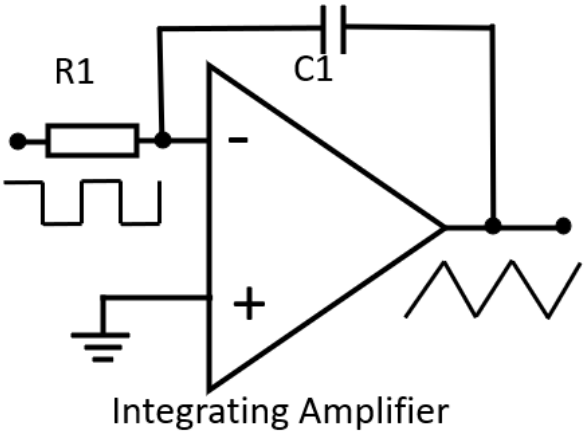
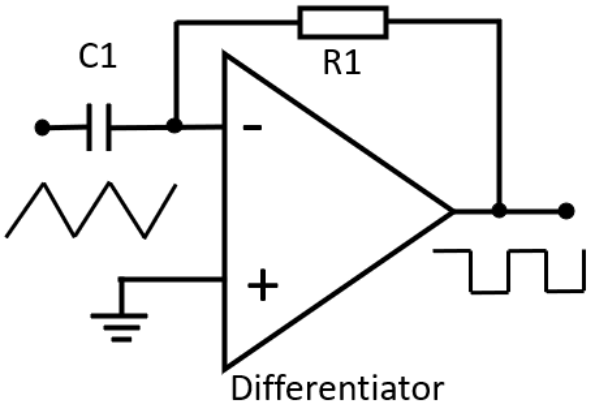
The Integrator Op Amp

This configuration performs integration with respect to time. The output is proportional to the input voltage integrated over time governed by R_1 and C_1.



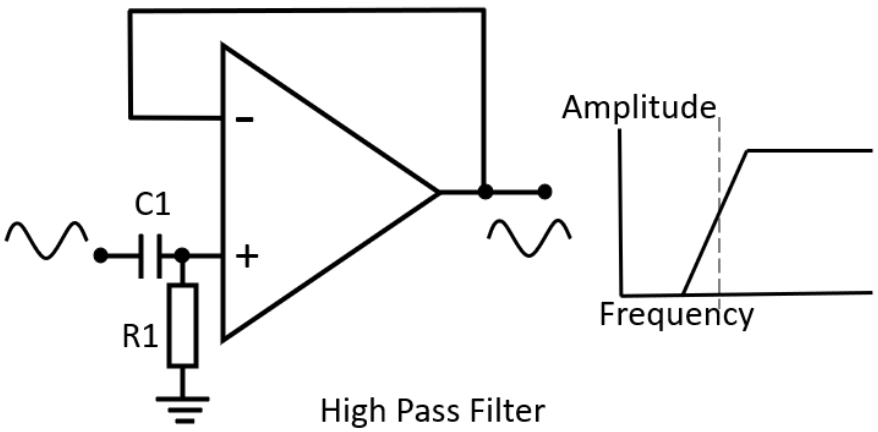
The Differentiator

This configuration is designed so the output of the circuit is proportional to the rate of change to the input. The rate of change is governed by C_1 and R_1.



The High pass filter

This configuration is a unity gain amplifier passing the frequencies higher than that determined by R_1 and C_1.



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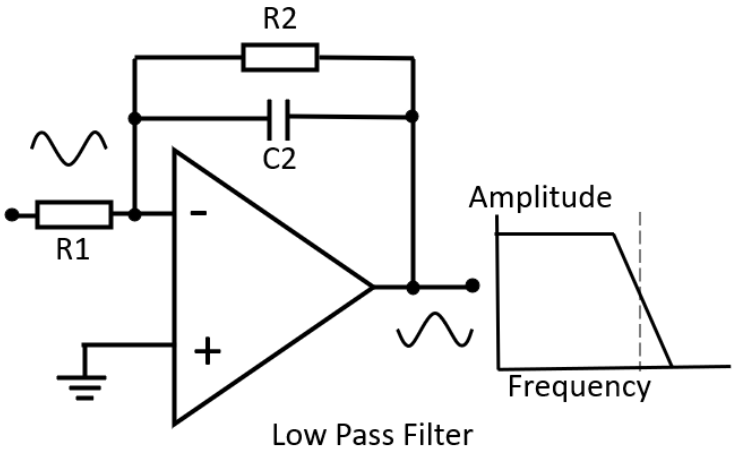
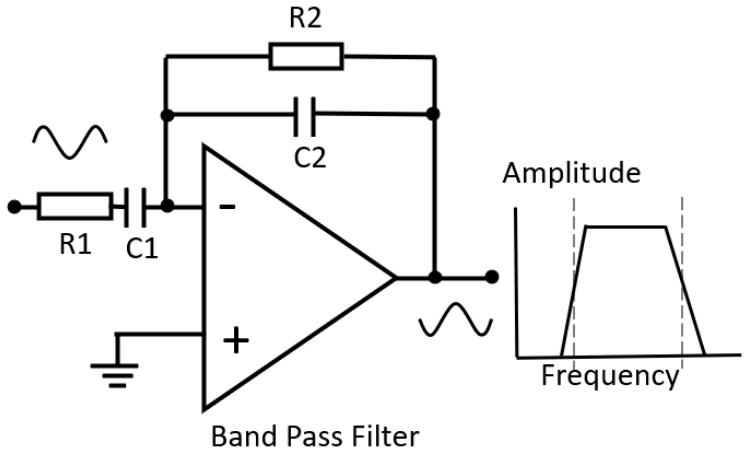
The Low pass filter

This configuration is a unity gain amplifier passing the frequencies lower than that determined by R_1 and C_1.



The Band pass filter

This configuration is a unity gain amplifier. R_1 and C_1 determine the high pass cut off while R_2 and C_2 determine the low pass cut off.



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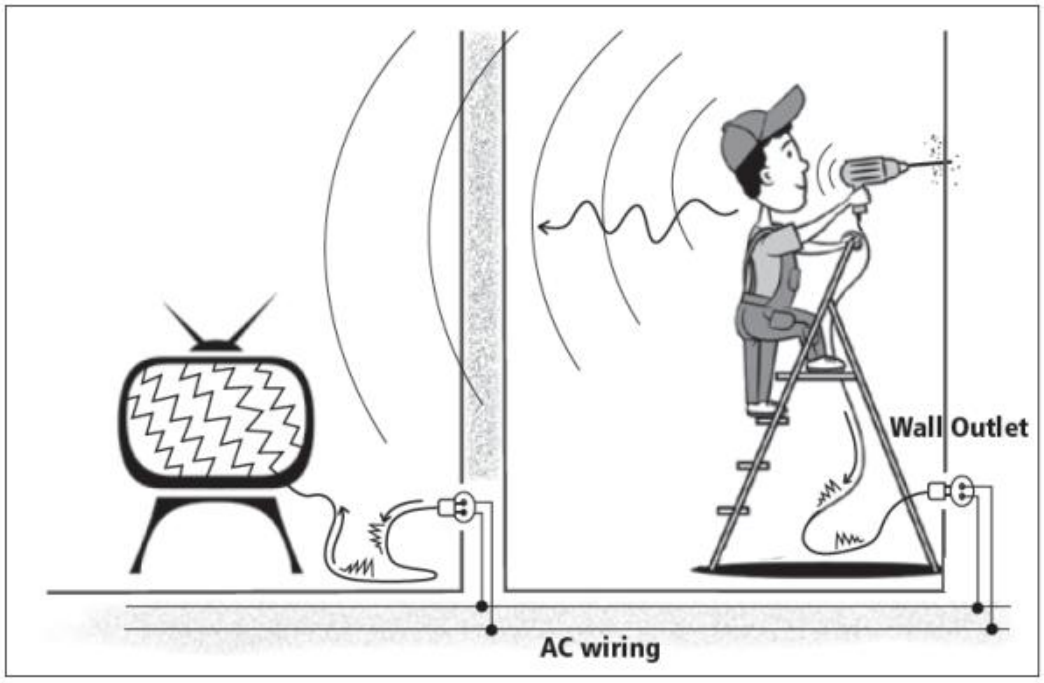
Interference And Immunity

Electromagnetic compatibility (EMC) and electromagnetic interference (EMI) are frequently referred to when discussing the regulatory testing and compliance of electronic and electrical products.



Electromagnetic Interference (EMI)

EMI can be defined as interference that impacts the functioning of an electronic device. Sources of EMI can sometimes be environmental events but more often the EMI source is another electronic device or electrical system. Common electronic sources are transmitters, cellphones, welders, motors and LED screens.

EMI is also called RFI (Radio Frequency Interference) however EMI is any frequency of electrical noise, whereas RFI is a subset of noise on the EMI spectrum.

There are two types of RFI.

- Conducted EMI is unwanted high frequencies that ride on the AC wave form.
- Radiated EMI is emitted through the air.

Causes of EMI

Interference occurs when an unwanted signal disrupts the use of your television, radio or cordless telephone. Interference may prevent reception altogether or may cause only a temporary loss of a signal. The interference may affect the quality of the sound or picture produced by your equipment.

The origin of any EMI may come from many sources.

- External noise – other electrical equipment nearby.
- Natural origins - electrostatic interference and electrical storms.
- Radio Frequency Interference (RFI) –radio systems signals
- Crosstalk - in cabling

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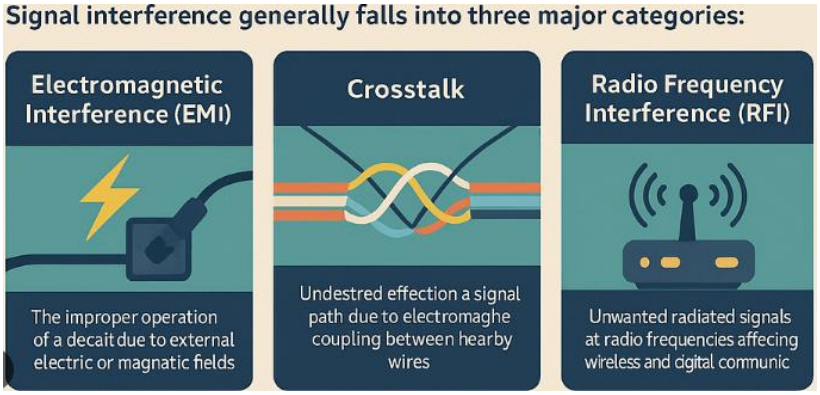


Intermodulation

Intermodulation distortion is the undesired combination of several signals in a nonlinear device which produces a new unwanted frequency. This new frequency can cause interference in adjacent receivers. Intermodulation can also be produced in rusty or corroded tower joints, guy wires, turnbuckles and anchor rods or any nearby metallic object acting as a nonlinear “mixer/rectifier” device.

Eliminating EMI Influence

Methods to reduce or eliminate EMI:

Filtering - EMI filters can suppress electromagnetic noise transmitted through conduction. These filters extract any unwanted signals while allowing desirable signals to pass. A choke is an example of a Low Pass Filter removing EMI.

Grounding - Grounding devices provide a low impedance path for EMI to dissipate and can mitigate the ill-effects of EMI.

Decoupling – Decoupling capacitors in circuits is good practice. Decoupling capacitors in power supplies reduces the possibility of EMI entering the device from the power mains.

Shielding or Blocking - EMI shielding is the practice of blocking the electromagnetic field from impacting the device. These barriers are made of conductive or magnetic materials. You will find EMI shielding in your cell phones, in the microwave oven door, as well as your computers and keyboards.

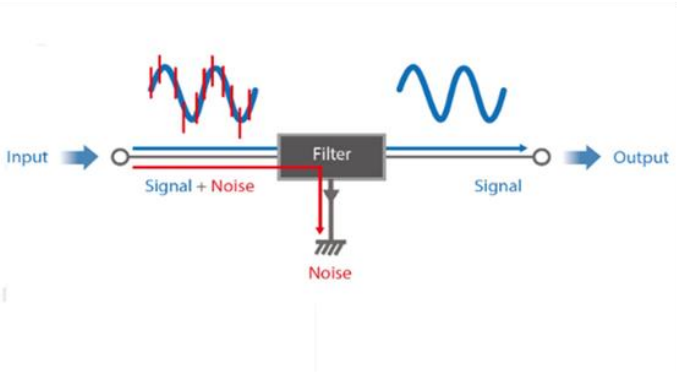
A Faraday shield is a good example of blocking EMI.

Electromagnetic Compatibility (EMC)

It is rare for electronics devices to operate in isolation as they are usually engineered to function in the presence of some form of EMI. This is particularly important in military-grade, medical and avionics equipment.

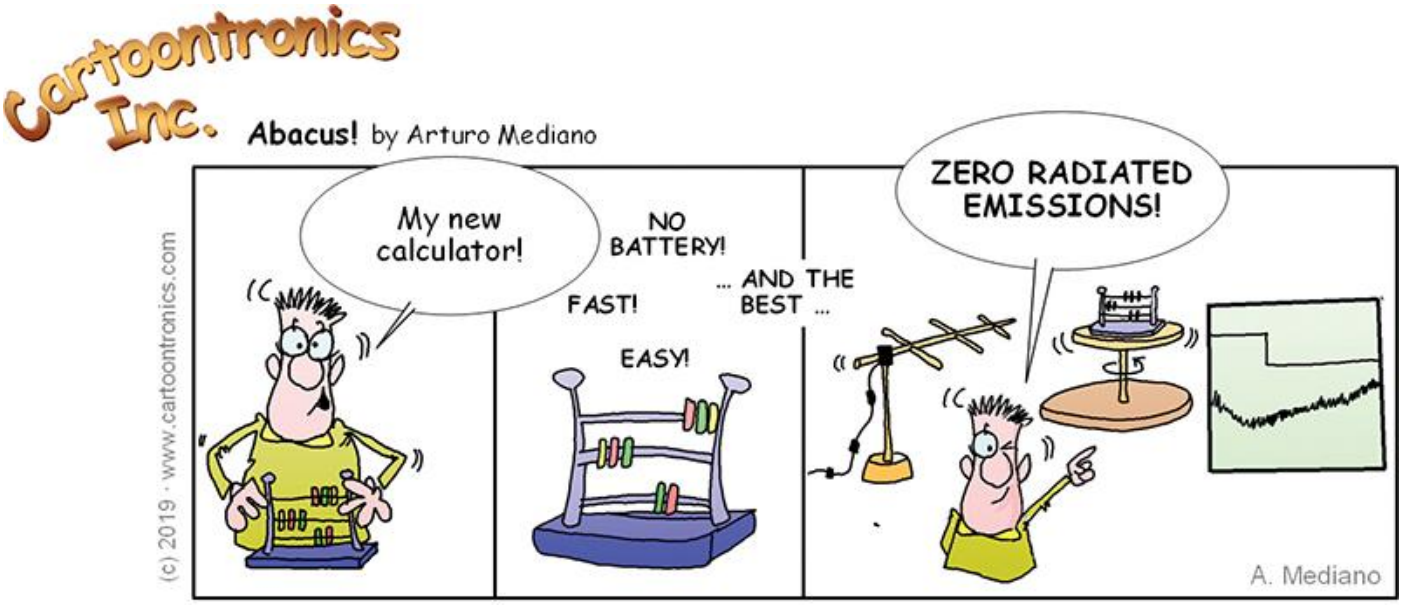
EMC is a measure of a device's ability to operate as intended in its shared operating environment while not affecting the ability of other equipment within the same environment to operate as intended. They must all play together.

Testing how a device will react when exposed to electromagnetic energy is known as immunity (or susceptibility) testing. Measuring the amount of EMI generated by the device's internal electrical systems is known as emissions testing.



Reducing Interference

- Monitor and moderate power output.
- Site your antenna away from neighbour's antennas e.g. TV
- Avoid any frequencies that are known to cause interference in your area.
- Fit a balun to the antenna.
- Conducted interference can be removed by placing chokes on affected cables.
- Install a mains filter to prevent interference getting into the mains lines.
- Show goodwill to neighbours if problems occur.



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