Nature of EM Waves

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Electricity – friend and foe?

- Modern day life is abundant with radio and electrical/electronic equipment
- It is difficult to imagine life w/o technology
- To name a few:
  - Radio and TV broadcast services
  - HIFI audio, video recording
  - Wire and wireless telecommunication

- Cellular telephone, mobile radio
- Educational and scientific electronic/ electrical equipment
- Medical & Biological apparatus
- Household appliance
- Electrical power equipment, industrial electronics
- Lights and Fluorescent lamps

- They all have one thing in common:
  - The generation of electromagnetic waves
- This EM waves may affect other systems or living cells
  - This happens if the EM waves occupy the same or overlapping EM spectra of the victim circuit

- EMC problems stems from the many possible types of EMI generators
- Can be broadly classified into two categories:
  - Natural noise
  - Man made noise

Natural Sources

- Static Noise due to precipitation
- Atmospheric noise
- Nearby and medium distant lightning
- Solar noise effects
- Cosmic radio noise

Man made noise

Switching operations **Power faults** **Electric motors** **Static and rotary converters** **Rectifiers** **Contractors**	**Arc furnaces** **Induction furnaces** **Air conditioning** **Computer and switching circuits** **Fluorescent lamps** **Neon displays** **Medical equipment**
Workshop equipment **Rolling mills** **Cotton mills** **Welders** **Rotary saws** **Compressors** **Ultrasonic cleaners**	**Radio broadcast stations** **TV stations, Radar, Mobile Telephone** **Microwave ovens, Refrigerators/ freezers, Mixers, light dimmers** **Personal computers….etc**

Continuous and Transient EMI Source

Sources of continuous EMI (sources with fixed frequency)	**Sources of Transient EMI (sources with a large frequency spectrum)**
Broadcast stations	Lightning
High power radar	Nuclear EMP
Electric motor noise	Power line faults
Fixed and mobile communications	Switches and relay
Computer, visual display units, printer	Electric welding equipment
High repetition rate ignition noise	Low repetition ignition noise
AC/ multiphase power rectifiers	Electric train power pickup arcing
Solar and cosmic radio noise	Human electrostatic discharge

Electromagnetic Environment

- Consist of EM signature of all listed equipment
- Can be sub-divided into:
  - Residential EM environment
  - Industrial EM environment
- Or by voltage supply rating
  - DC – 430Vrms = residential
  - 430Vrms upwards = industrial

- Clearly some working space consist of power distribution (i.e. Electrified railway)
- What else differentiates residential and industrial environment.

Residential	Industrial
Confined space Difficult to enforce any regulation Assume 24 hr occupancy	Employer responsible to provide safe working

	Emission Req	Immunity Req
Residential	High	Low
Industrial	Low	High

	Emission Req	Immunity Req
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(red box) = **Safety Critical Equipment**

	Emission Req	Immunity Req
Residential	High	Low
Industrial	Low	High

Very rarely used, but could apply to scientific equipment used only in a designated lab

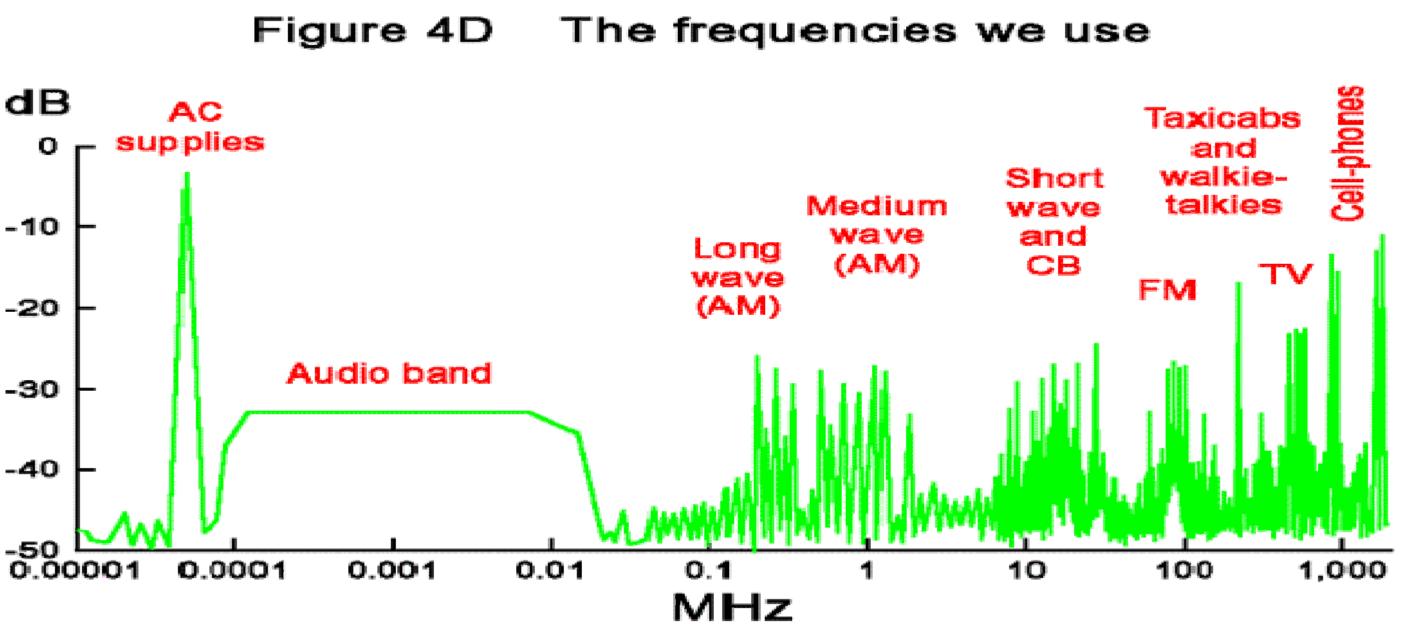


Figure 4D The frequencies we use
dB
0
-10
-20
-30
-40
-50
AC supplies
Audio band
Long wave (AM)
Medium wave (AM)
Short wave and CB
Taxicabs and walkie-talkies
FM
TV
Cell-phones
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1,000
MHz

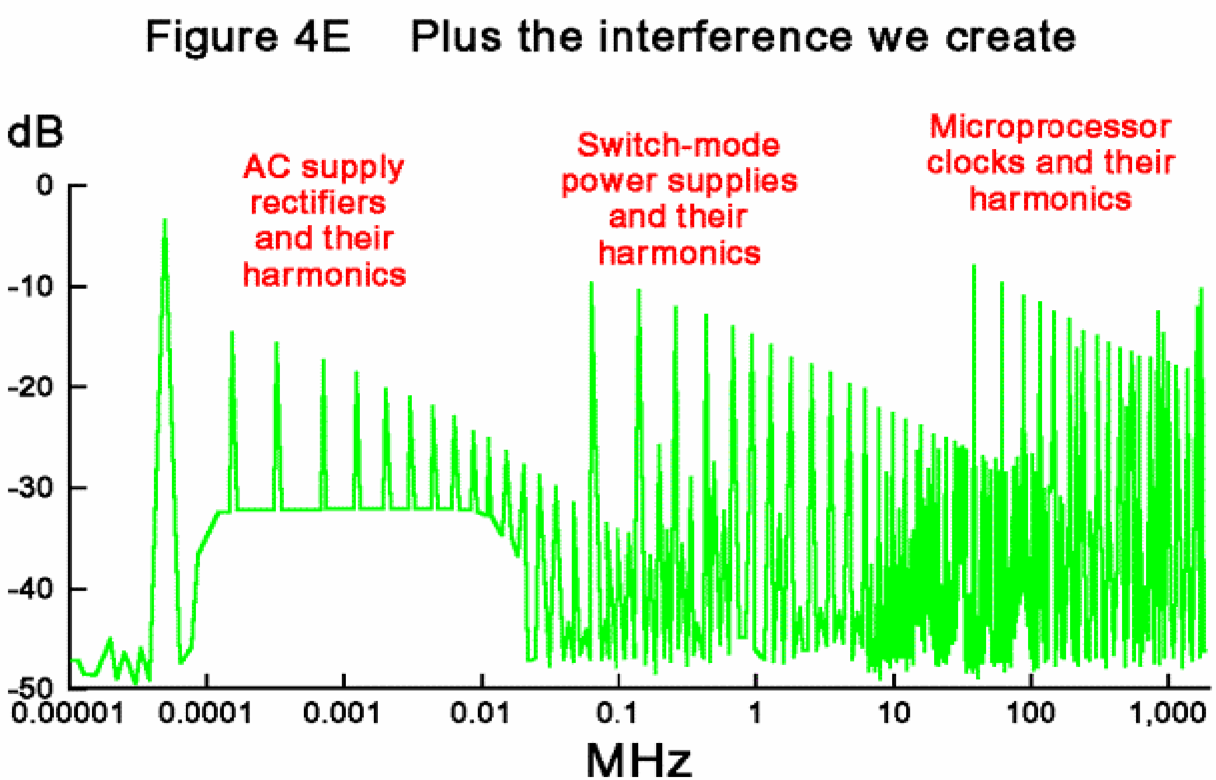


Figure 4E Plus the interference we create
dB
0
-10
-20
-30
-40
-50
0.00001
0.0001
0.001
0.01
0.1
1
10
100
1,000
MHz
AC supply rectifiers and their harmonics
Switch-mode power supplies and their harmonics
Microprocessor clocks and their harmonics

EMC - Definition

- The ability of a device or system to function satisfactorily in its intended electromagnetic environment without introducing intolerable EM disturbance to anything in that environment.

- Function as Intended = adequate immunity
- Intolerable EM disturbance = Emission level under control

- It is important to ensure electrical/electronics equipment operates satisfactory in its intended environment
  - System must be self compatible (intra-system EMC)
  - System must not interfere with neighbor
  - System must have adequate immunity to neighboring interference

Some Real life examples of EMI

- Computers used in a room close to a door fitted with a high-technology (magnetic) cat flap caused the latches on the cat flaps to rattle continuously whenever Windows was loaded or a Windows application run. (From the New Scientist magazine, 7th May 1997)

- Medical technicians taking a heart-attack victim to the hospital in 1992 attached her to a monitor/defibrillator. Unfortunately, the heart machine shut down every time the technicians turned on their radio transmitter to ask for advice, and as a result the woman died. Analysis showed that the monitor unit had been exposed to exceptionally high fields because the ambulance roof had been changed from metal to fibreglass and fitted with a long-range radio antenna. The reduced shielding from the vehicle combined with the strong radiated signal proved to be too much for the equipment. (An article in the Wall Street Journal reported in Compliance Engineering Magazine's European edition September/October 1994.)

- Quote from an article in the IEE’s Control and Computing Journal, April 1998 (page 52): “High intensity radiated fields (HIRF) guns and electromagnetic pulse transformer (EMPT) bombs are already easy to build from off-the-shelf components. The effects of even hand-built HIRF or EMPT weapons can damage microprocessors at ranges of hundreds of metres. Possibly, in a few years, a van equipped with suitable electronics could cruise down Wall Street (or through Canary Wharf - ed.) and disrupt the information processing capability of thousands of computers without being detected by the local police.”

- Around 1990 Alan Little leased a derelict arch under the railway line in Camberwell from British Rail. He borrowed money to convert it into a two-level mix of recording and rehearsal studios. The total cost was pushing £50,000. Up until November 1991 it was popular with up-and-coming bands needing somewhere to rehearse and record. Then, one fateful Saturday morning, with three bands booked for the morning and three for the afternoon, disaster struck. All the studio equipment, and the bands' amplifiers, started warbling. The bands and studio crew thought at first that they had an equipment fault. Then other studios in other railway arches in the area began phoning each other. They all had the same problem.

- Alan Little phoned British Rail and on the Monday morning a BR engineer came round, listened and said the cause was a new signalling system installed by BR. BR controls its track lights by feeding electric current through its rails. When a train runs over the rails it provides a short-circuit between them, triggering a red light behind the train. Recently BR has begun changing to the use of alternating current. The long rails act as a highly efficient aerial, radiating a powerful AC magnetic field (this was actually around 1 Amp/metre over much of the studio - editor). The AC is at audio frequency, using tones of between 1 kHz and 4 kHz. The tones are complex warbles, to safeguard the system from outside interference.

- The effect was heard through the mixing desk, with pick-up from mains and connecting leads. It was even heard through unpowered loudspeakers (even when they were disconnected from their cables and their terminals shorted - editor). It was worst when an electric guitar is plugged into an amplifier. Guitar pick-ups are designed to convert their magnetic fields, modulated by the movement of the steel guitar strings, into sound. They cannot distinguish between magnetic fields from a BR signalling system and those from vibrating strings. (Extracted from an article by Barry Fox in Studio Sound Magazine, June 1992)

Other Engineering Reasons

- Engineers are always under pressure to save costs, and the costs of preventative measures are easy to quantify. However, many engineers are uncomfortable with estimating the risks of infrequent and unpredictable events such as thunderstorms so do not effectively communicate the actual risk/cost and safety implications to their managers.

- As someone said recently: Doctors kill people in ones, but engineers do it in hundreds. Careers and personal liability are also at stake here too, so it is always best to make an informed cost/risk case and get a written decision from management.

The EMC Coupling Problem

$$d < \frac{\lambda}{10}$$

- Low and High Frequencies
- Low Frequencies
  - Circuit Theory Approach
- High Frequencies
  - EM Approach
  - Use of Vectors (**E** and **H**)
- Coupling has a frequency dependence

Other Topics

- Require Fourier Analysis
  - Both Conducted and Radiated Signals have wideband content, generally.
  - Low Frequency fundamental can cause high frequency coupling (interference)
- Antennas
  - Used for measurements
  - Start from same point as EM coupling

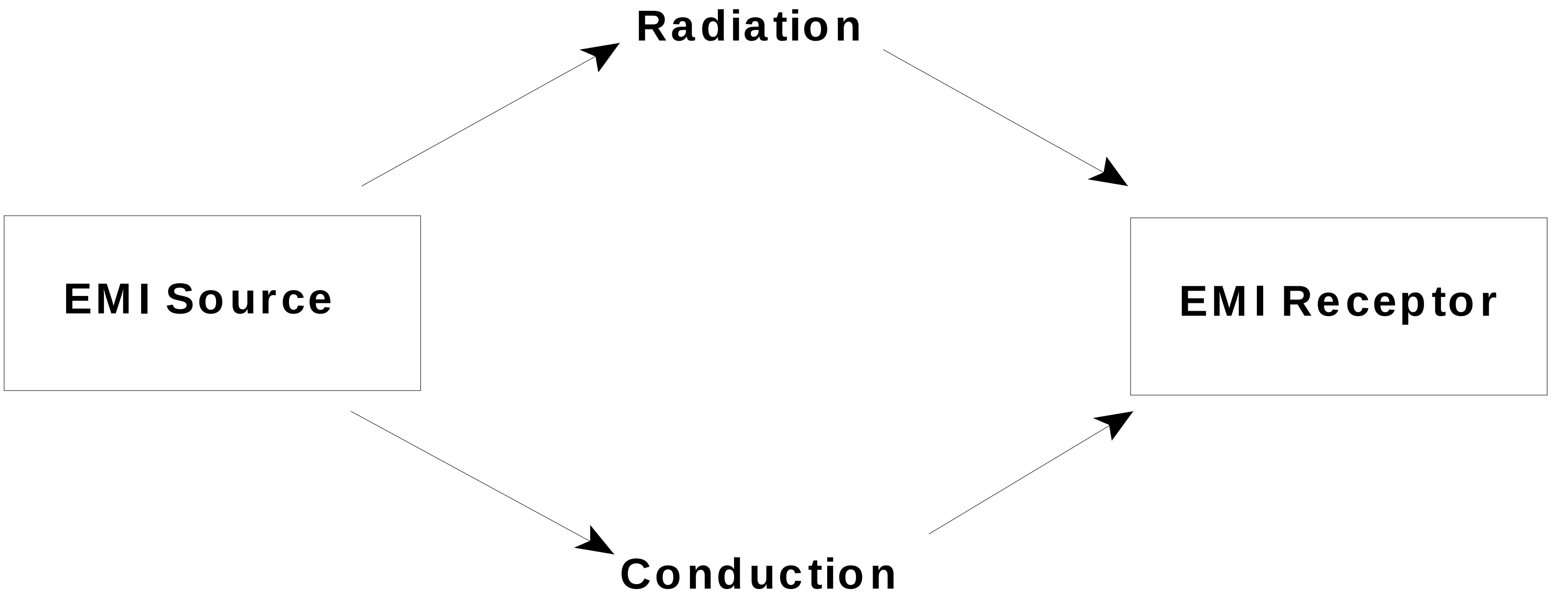
Some Definitions

EMI	Electromagnetic Interference; Environmental EM pollution
Noise	Any undesirable signal
Interference	Undesirable effects of coupling, noise
Susceptibility	Ability of a device to respond to an unwanted electromagnetic signal
RFI	Radio Frequency Interference

Some Definitions

ESD	Electrostatic Discharge
EMP	Electromagnetic Pulse
NEMP	Nuclear Electromagnetic Pulse
Emitter	Source of Noise
Susceptor	Receiver, or victim

Coupling Mechanisms



Some Definitions

- Emitters
  - high power equipment.
  - Equipment with pulsing waveforms
  - Any signals with high frequency components.
  - Natural phenomena such as lightning.
  - Anything that contains good radiators and is unshielded

Some Definitions

- **Susceptors**
  - Low power electronics
  - Communications equipment
  - Computers etc.
- Movement to lower power and lower Voltage systems exacerbates the problem

Some Definitions

- **Conducted Interference**
  - Signal travels through metallic pathways.
  - Includes wires, cables, ground planes and metalwork.
  - Generally dominates at lower frequencies, normally up to about 30MHz.
  - Units normally expressed in terms of voltages or currents as dBV or dBA.

Some Definitions

- **Radiated Interference**
  - non-metallic path via electric, magnetic or electromagnetic fields.
  - Typically, occurs above 30MHz.
  - Generally, either the electric or the magnetic field dominate.
  - Can be modelled as coupling through a reactive element.
  - May, sometimes, be analysed using circuit theory, which is desirable.
  - Fields quoted in V/m, A/m or as radiated power in dBW or dBpW

Some Definitions

- **Interference Characteristics**
  - Sources may be
  - functional (intentional generators) or
  - non functional where the unwanted signal is a by-product.

Some Definitions

- Noise Waveforms
  - Periodic (Regular waveform)
  - Aperiodic (well defined but irregular waveform)
  - Random (varying and unpredictable).
  - Continuous
  - Discontinuous

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Some Definitions

- Periodic Noise Waveform

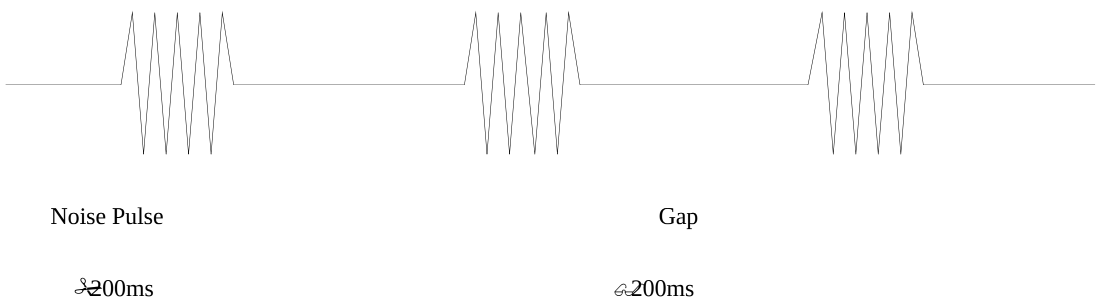
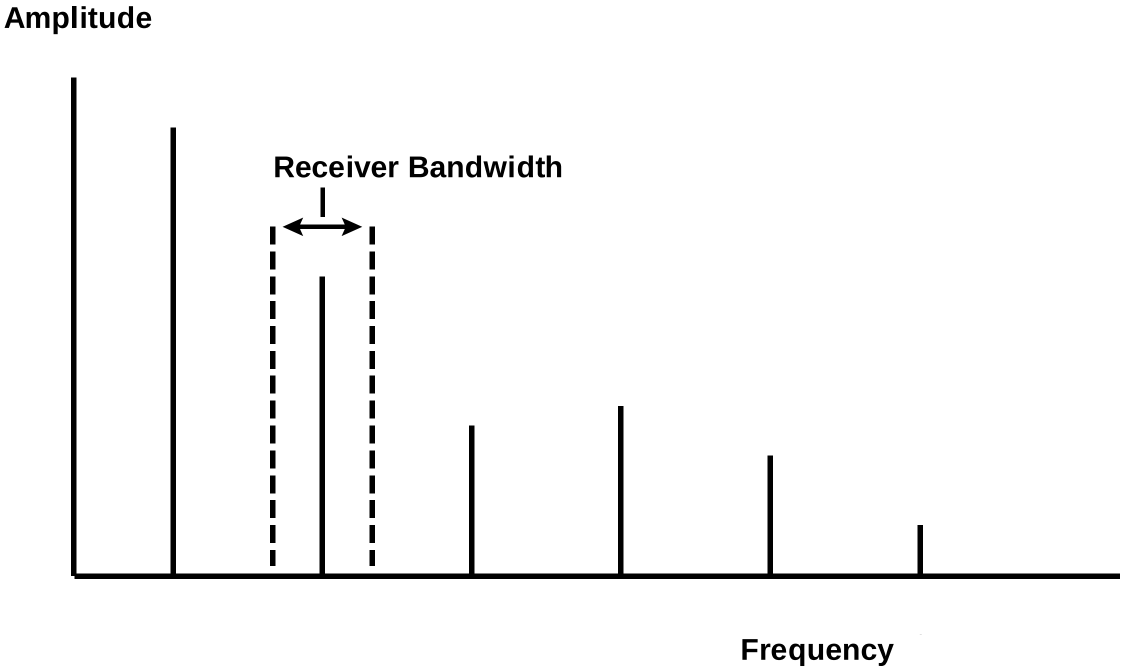


Figure 2. Definition of a Discontinuous Signal

Some Definitions

- **Narrow Band Interference**
  - measured **without** reference to the receiver bandwidth



Some Definitions

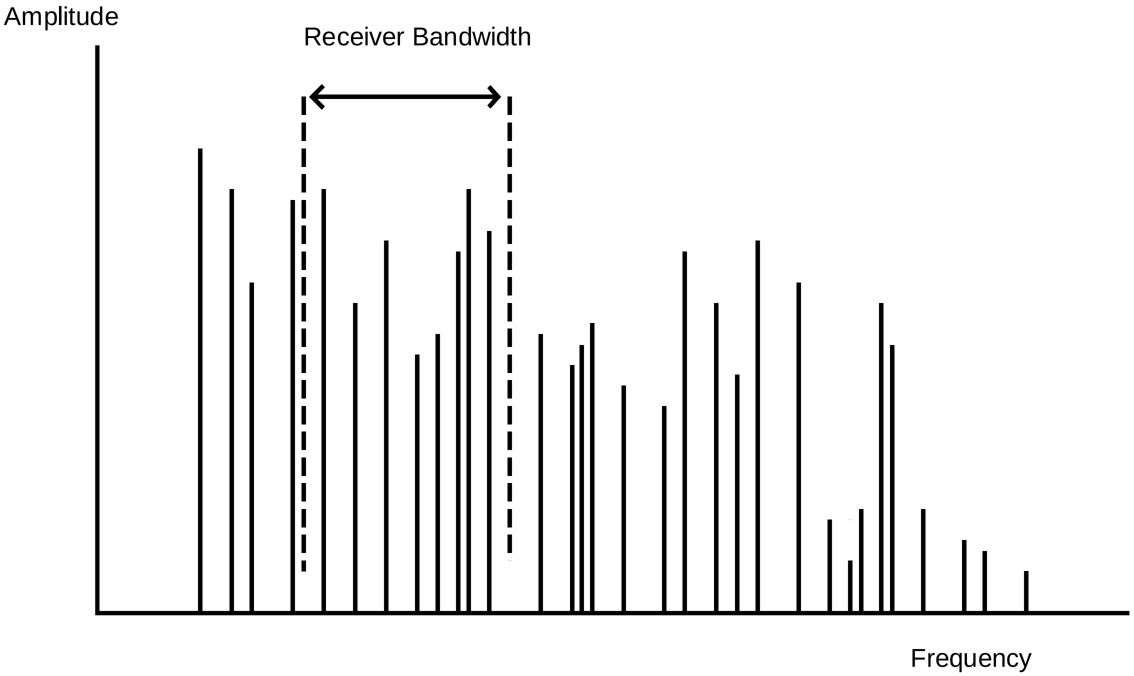
- **Broad Band Interference**
  - 3dB bandwidth of the EMI is greater than that of the measurement system
  - Coherent
    - Components related in Amplitude and Phase
  - Non-coherent
    - No Magnitude and Phase relationship between components

Some Definitions

- What type of Interference?
  - 1. Tune receiver up or down its 3dB Bandwidth
    - If change of measured value > 3dB then it is Narrow Band Interference
  - 2. Vary Receiver Bandwidth e.g. by -3dB
    - Measured value reduces by more than 3dB we have Broad Band Interference

Some Definitions

- Checking Interference Bandwidth



Coupling Mechanisms for Interference

- Radiated coupling includes Near and Far Field Coupling