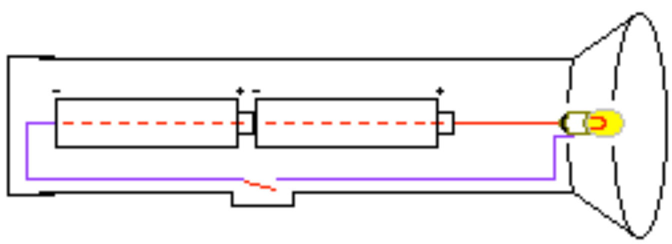
**DIRTY Electricity**

Whether in a technical community or not, the term “Dirty Electricity” has caught on. Popularized as it is by the different vendors of “filters,” or “meters” to measure it, it is now part of the informal community language. The various vendors, competing as they are, will always state that their product is “better.” In reality, they are all flinging a lot of dirt, and it’s not electric. So what does the term actually mean?

To answer that question, a bit of technology overview is necessary.

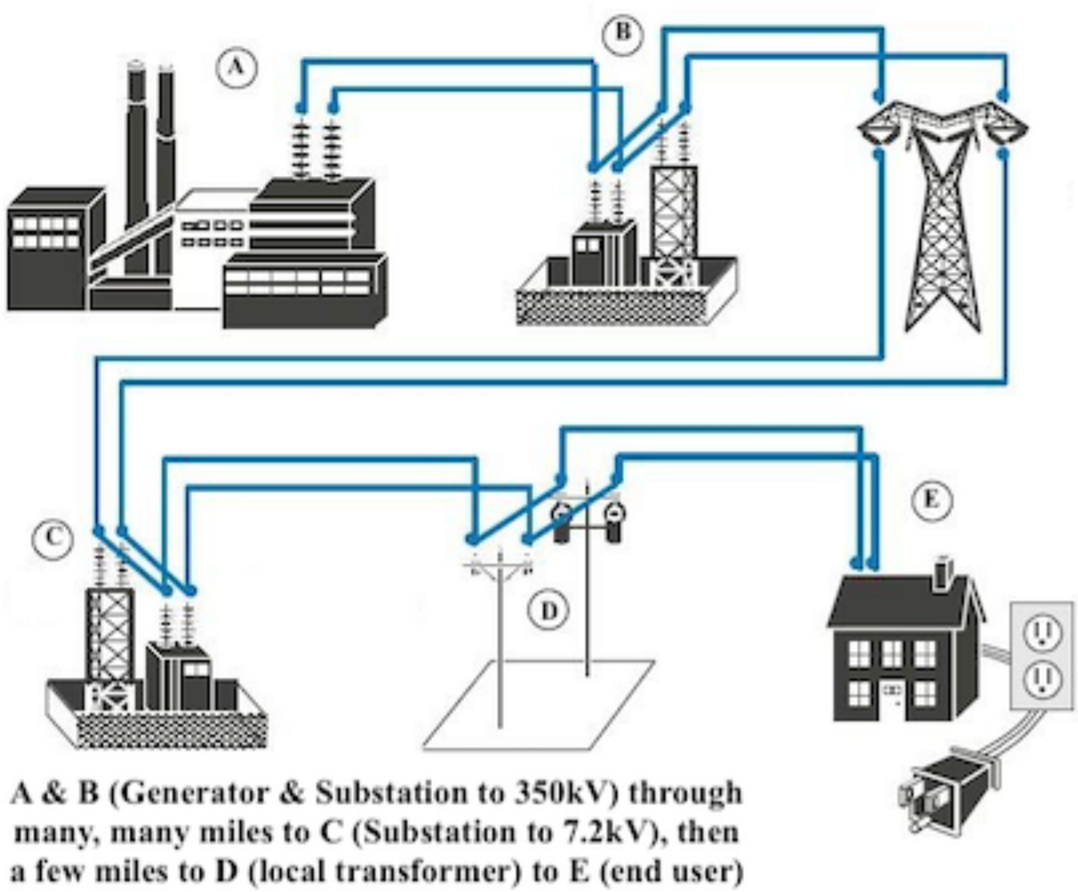
Starting with DC (*Direct Current*) systems like for an automobile, a battery provides 12 V (*Volts*). Once the engine is started, the Alternator (*and integrated Voltage Regulator*) produce about 14 V to charge the battery, and feed the necessary loads. So if the voltage were to drop to say, 10 V, or rise to 18 V, it would be out of tolerance and strange things could happen, like equipment damage, or stalling while on a highway, or some lonely country road. In that case, you could justifiably call that Electricity, Dirty, rotten, etc., while you sought the aid of a mechanic, at whatever the going hourly rate is (*yes, in this case a Mechanic is also an Electrician*).




*A simple DC circuit, a flashlight (note the batteries in Series where their Voltages add)*

For current to flow there is the necessity of a loop, as in the simplified sketch above. For DC a wire from the positive terminal to a lamp (*for example*), and another wire from the lamp’s other terminal to the battery’s negative terminal. A convenient switch to break the loop’s continuity will serve as an On/Off control.

But DC, used where wire lengths are usually short, is unusable for long-distance power cartage (*due to Voltage Drop / Loss over long distances due to the wires’ Electrical Resistance to Current flow*), and not everyone is equipped with a generator in their back yard, nor do they want to. Along came AC (*Alternating Current*) thanks to Mr. Nikola Tesla, whereby Transformers are used to raise voltage levels to very high values for long-distance power cartage, and similar Transformers are used to lower voltage levels for domestic consumption.

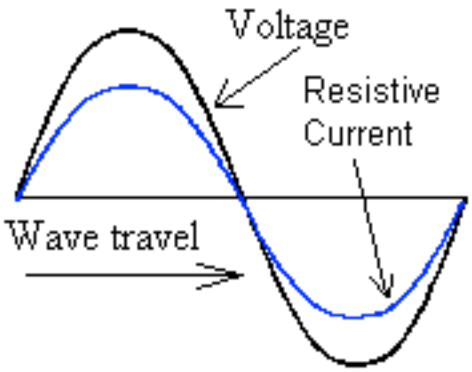



*A very simplified AC power system. Similar variants used worldwide*

A lot of interim steps are necessarily omitted here, and part of the necessity of very high voltages for long-distance power cartage is to reduce Voltage Drop due to Current Flow. As an extreme analogy, if the generator 100 miles away was producing 120 V, and by the time it reached your point of use it was down to 12 V, it would be useless to power 120 V loads. ***The voltage drop occurs due to current flow, and the wires' electrical resistance to current flow, minimal though it be, which over long distances becomes painfully relevant.*** The classical formula is Current x Resistance = Voltage. For the same amount of power, if you raise the voltage, the current can be reduced (*thus reducing voltage drop*). So if we can raise that 120 V with a transformer at the generator to say, 120,000 V for long-distance power cartage, then drop it back down to 120 V with a transformer near the point of use, we can make use of almost 100% of the generator's output.

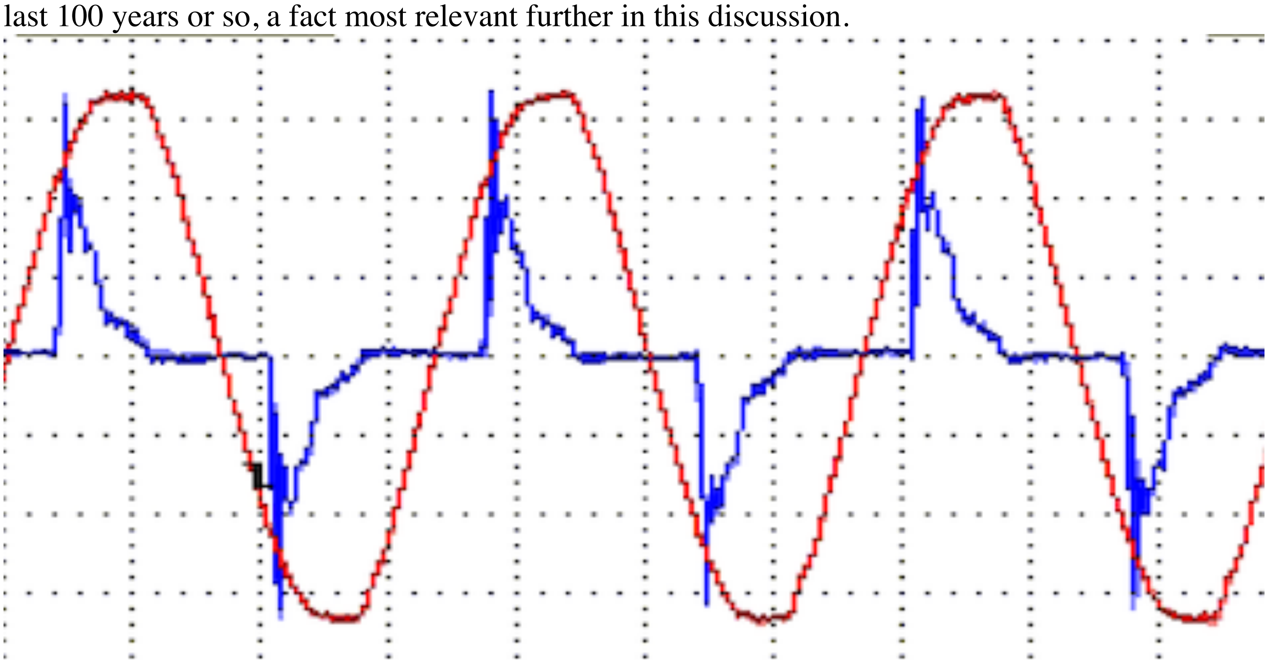
North America uses 120 V at 60 Hz (*Hertz, or cycles per second*) domestically. Many other regions use 240 V at 50 Hz. For aircraft, owing to their necessity to travel light, they use 400 Hz, which allows a substantial transformer size reduction (*transformers are usually quite heavy*).

Having very, very briefly introduced power systems, we can now consider types of use. It is known that if a wire is too thin to carry a given current, it will melt. Thus the development of fuses (*and later circuit breakers*) to limit the passage of current to safe values for the intended use. It is also known that if this thin wire of a certain resistance is in an enclosure whose air has been vacuumed out, it can be caused to glow substantially for a long amount of time (*thus the development of the Incandescent Light Bulb*) before it melts.



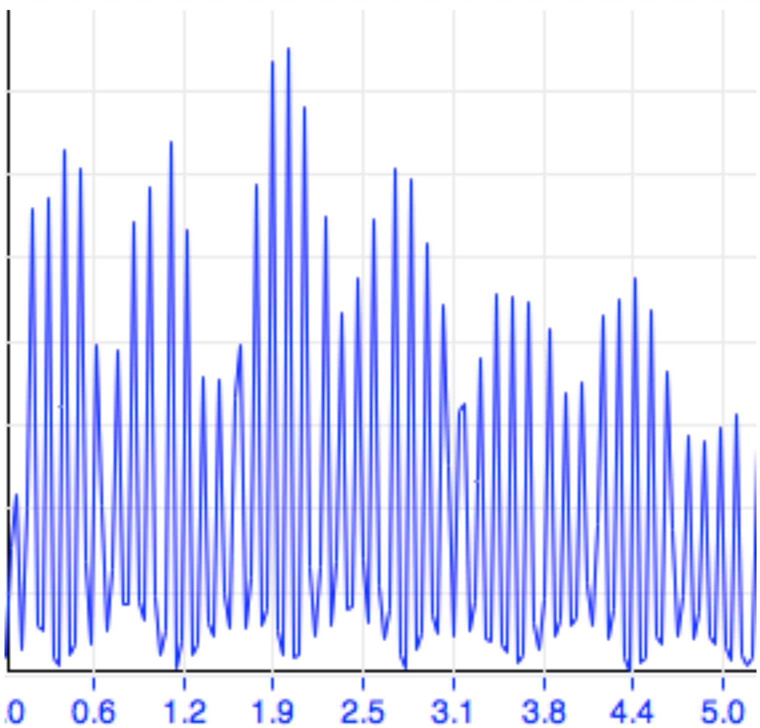

*Sketch of voltage and current flow for an incandescent lamp.* ***The waveform and frequency spectrum applied to the lamp (60 or 50 Hz) is the same as that of current used.*** *If the frequency spectrum applied to the lamp has other frequencies present, they will also occur in the current drawn.*

Along those lines of development for ambient lighting **Arc lighting** was developed, where current can be caused to flow within a vacuumed envelope emitting a great amount of light, much more so than an incandescent lamp. A refinement of an Arc lamp is a **Fluorescent lamp**, whereby a vacuumed envelope can have a small amount of mercury added, and when the mercury is heated it becomes a vapor that is electrically conductive. However, the mercury vapor fluorescent lamp produces a dismal output (*from a human visual perspective*), but if you coat the inside of that vacuumed envelope with a phosphor, which then becomes electrochemically excited by the mercury vapor emissions, the phosphor's secondary emissions can be reasonably pleasant and bright. From sweat shops to factories, fluorescent lighting has been in use for the last 100 years or so, a fact most relevant further in this discussion.



*Sketch of Voltage waveform (*Red*) and Current flow (*Blue*) above for an Arc lamp. Note the Fluoro is initially off each time the voltage crosses the Zero horizontal axis. As the voltage increases beyond a certain threshold, in either + or - direction, the fluoro instantaneously turns on, then decreases current demand to that limited by its circuitry.*

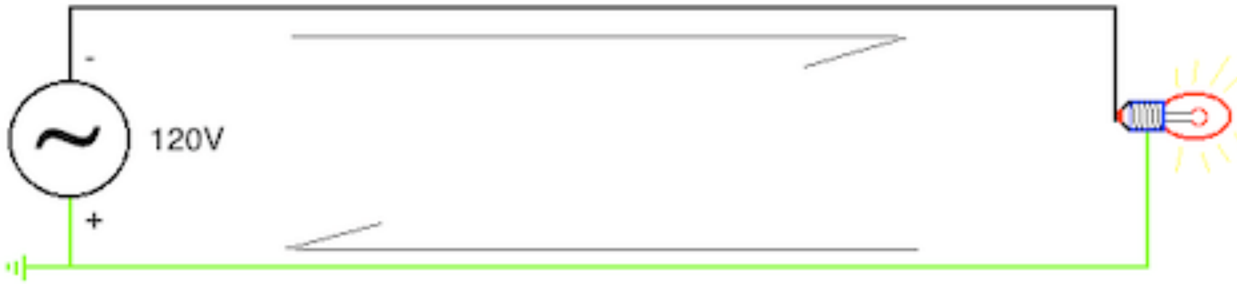
*This non-smooth / nonlinear Current demand is composed of a wide range of Harmonics (*faster echoes of 60 Hz, whose Frequency Spectrum is shown below to 22 kHz (kHz = *kiloHertz = 1000 Hz*), the 60 Hz being at far left*) **that was not previously present in the applied voltage**. The current drawn imparts some of the produced Harmonics onto the supply voltage. These were acquired using a laptop computer and a few simple and inexpensive attachments.*




*An enlargement above of the previous sketch shows the discrete Harmonics, typically the odd multiples of 60 Hz (*the first peak (*60 Hz*) at the extreme left*), with a few being 180, 300, 420, 540 (*as shown between 0 and 0.6 on the lower axis*). <u>The frequency range to 5 kHz is used for normal speech. Dirty Electricity meters completely disregard this portion of the spectrum.</u>*

The discussion will now briefly cover the split-phase residential power system used in North

America. It consists of two of the loops described previously, connected so that they have one wire in common.

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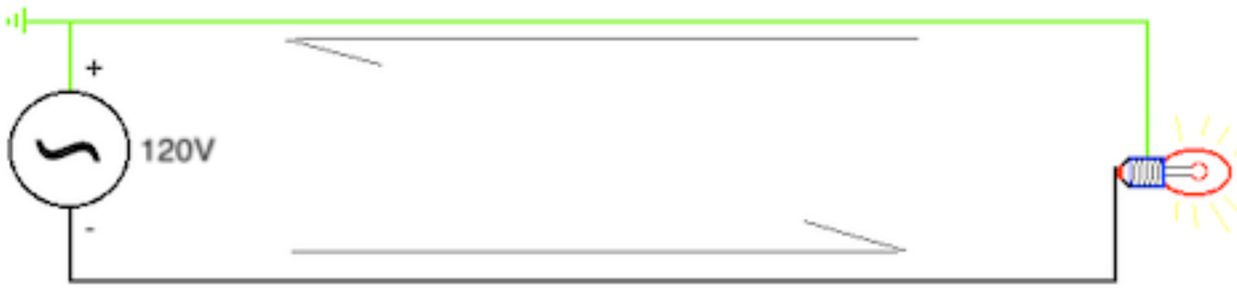


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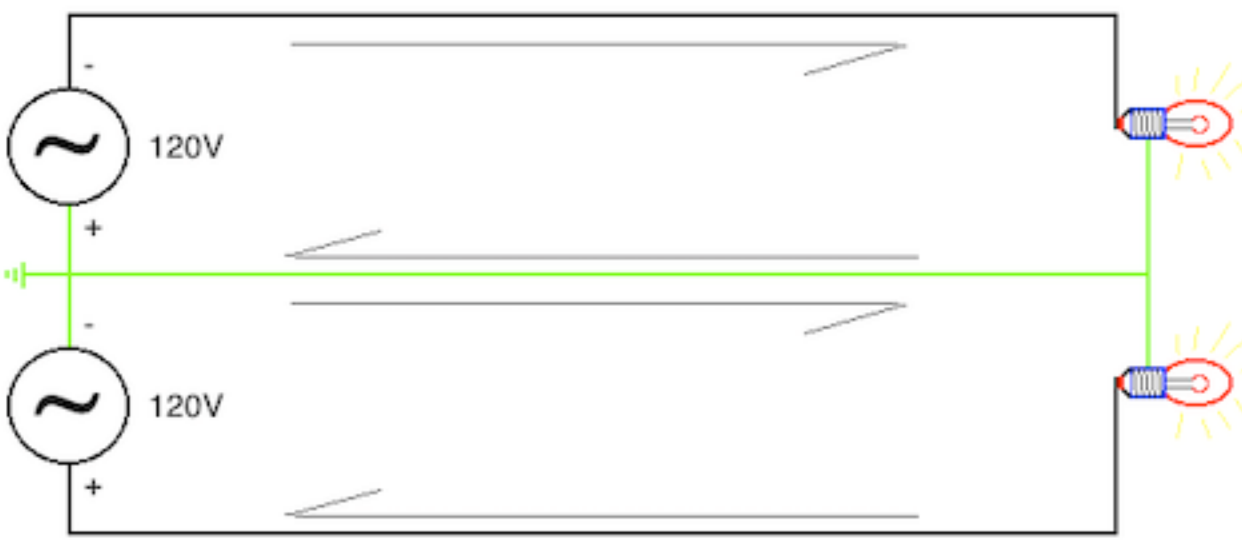
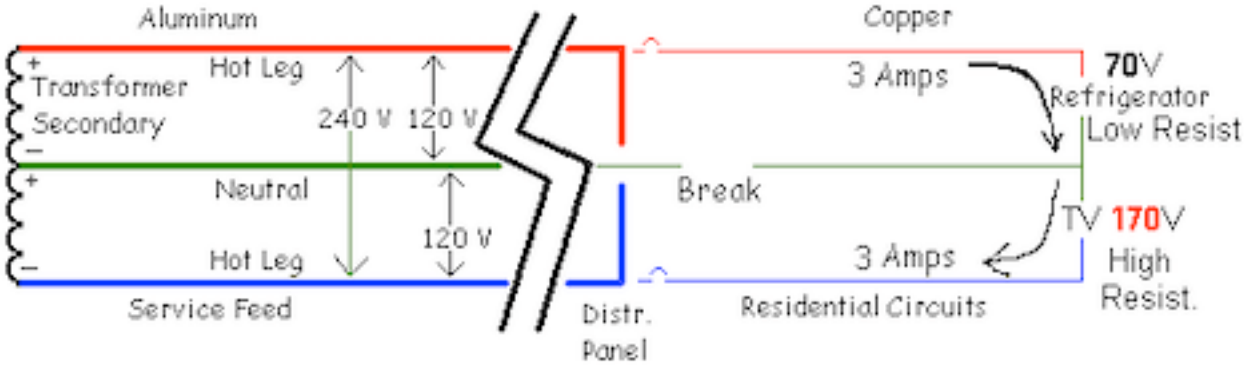
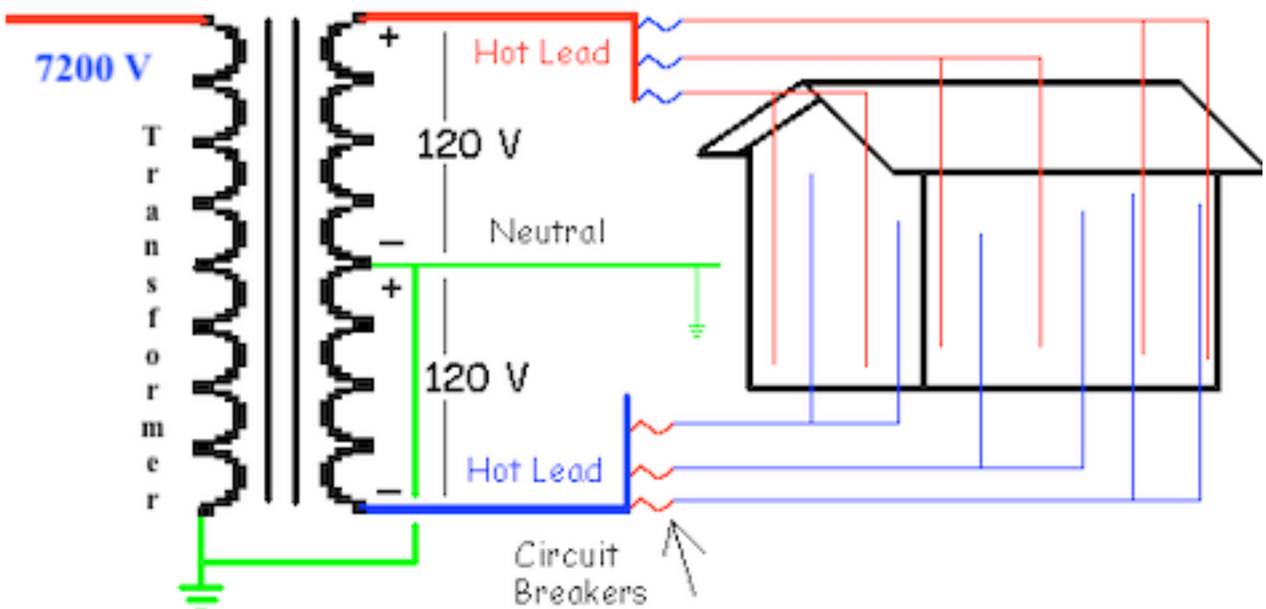



This split-phase power system has elegant beauty, and an Achilles' heel. The beauty is that you have essentially three power system with three wires (+*120, -120, 240*), and the Achilles' heel is that if the common wire (*the Neutral*) fails, voltages become unstable and a fire hazard. Note in the above sketch that the common wire has opposing currents. If they are equal, they cancel and current flows only in the outer loop. If the Neutral is removed and the loads on each leg differ, the load voltages will differ, posing an immediate fire hazard, as shown below.




This has resulted in much regulation and workarounds to preclude physical harm, with several unintended consequences. Discussion of regulation of this arrangement will be saved for another day, but biological effects of its consequences will be conducted now.

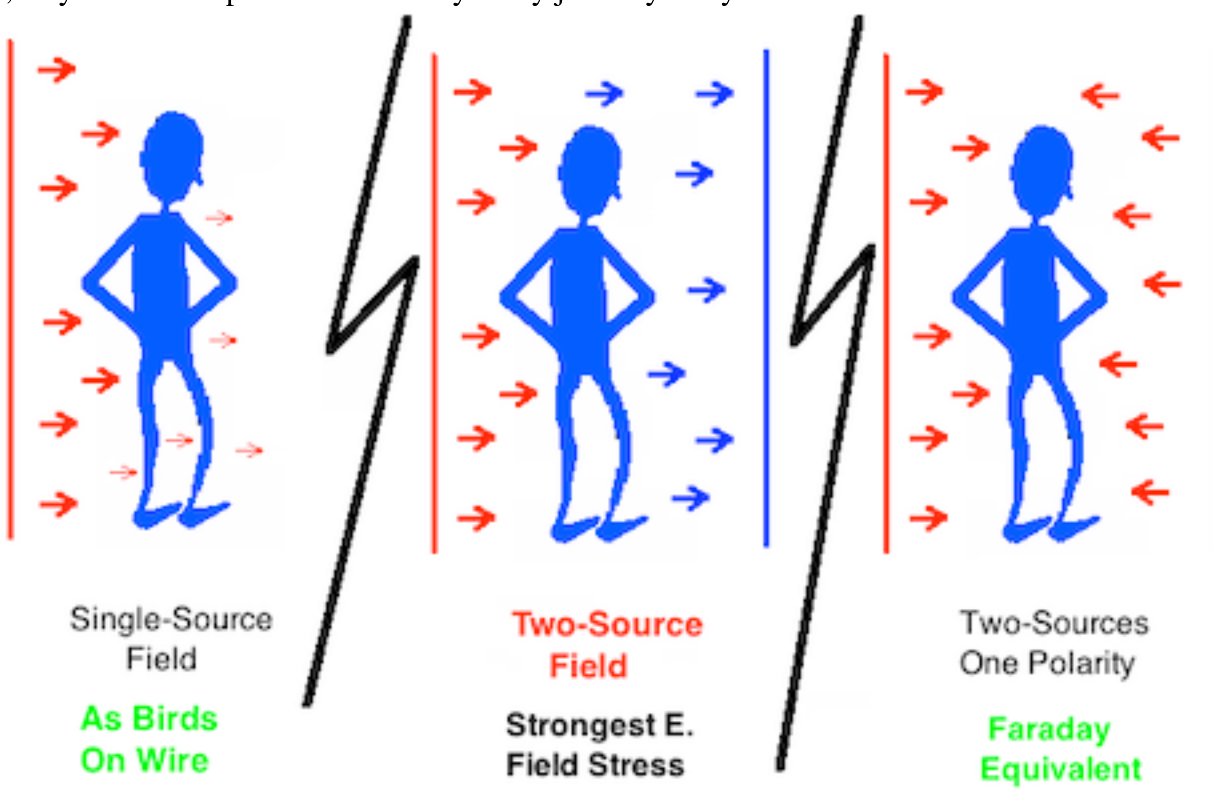



Since the electric system is a mechanical assemblage of parts, it is subject to failure, and requires a minimum of ongoing maintenance to preclude failure, despite the fact that this is Not what the typical user is aware of. Since either leg / bus of the North American system can fail, known as "part power," the two legs / buses are interspersed about a residence, to provide lighting as a minimum, everywhere, should such unlikely failure occur. This exposes the user to Electric fields everywhere from the installed wiring, without even considering the power cords plugged in at various locations, that vary in intensity due to proximity. If say a person is in a hallway, and there exist wires in each nearby wall of opposite polarities, the **differential** electric field strength is in the order of 120 V/m (*volts per meter, one of the size descriptors for electric fields*). If on the other hand the wires are of identical polarities, there is no differential field, and the person is simply elevated to the strength of the field from the wires, or about 60 volts (*the difference* *between 120V and 0V of two wires immediately next to each other in the same cable*), similar to a bird perched on an energized wire. The two situations will provide a markedly different exposure response from the individual.

When a bird is perched on an energized wire, its entire body is elevated electrically to the *same* potential of the wire. Almost.

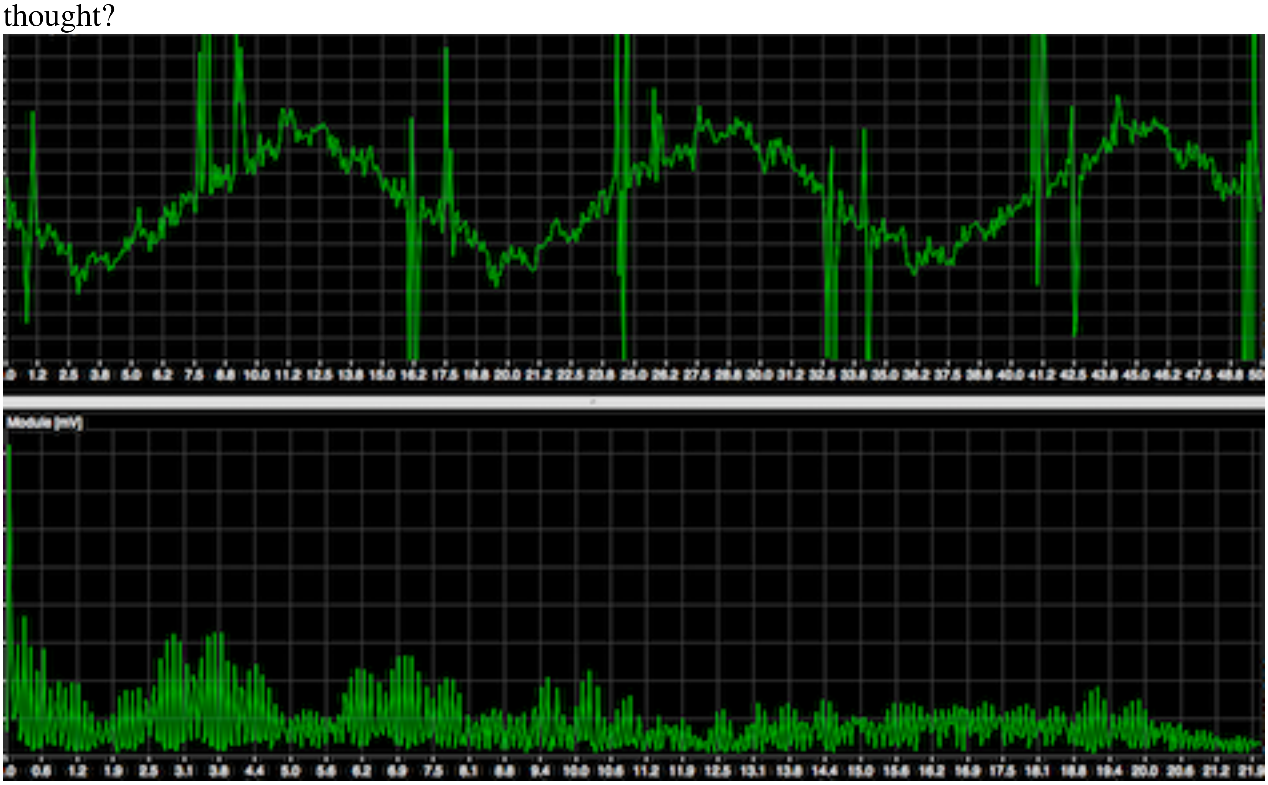
*Shown is a bird with instantaneous polarities based on the variation in **time** of the voltage on the wire, and **space** of the electric field extending out into space nearby.*

Birds seem unfazed by voltages up to about 4800. Above that (*in the common 7200V*), they may momentarily perch, but soon fly off. On the major transmission voltages, typically 120,000 and up, they don't even perch momentarily. They just stay away.




*Shown above are the various exposure to a human, from a plugged in power cord (*excluding everything else*) at left; from differing polarities at center; and from identical polarities at right.*

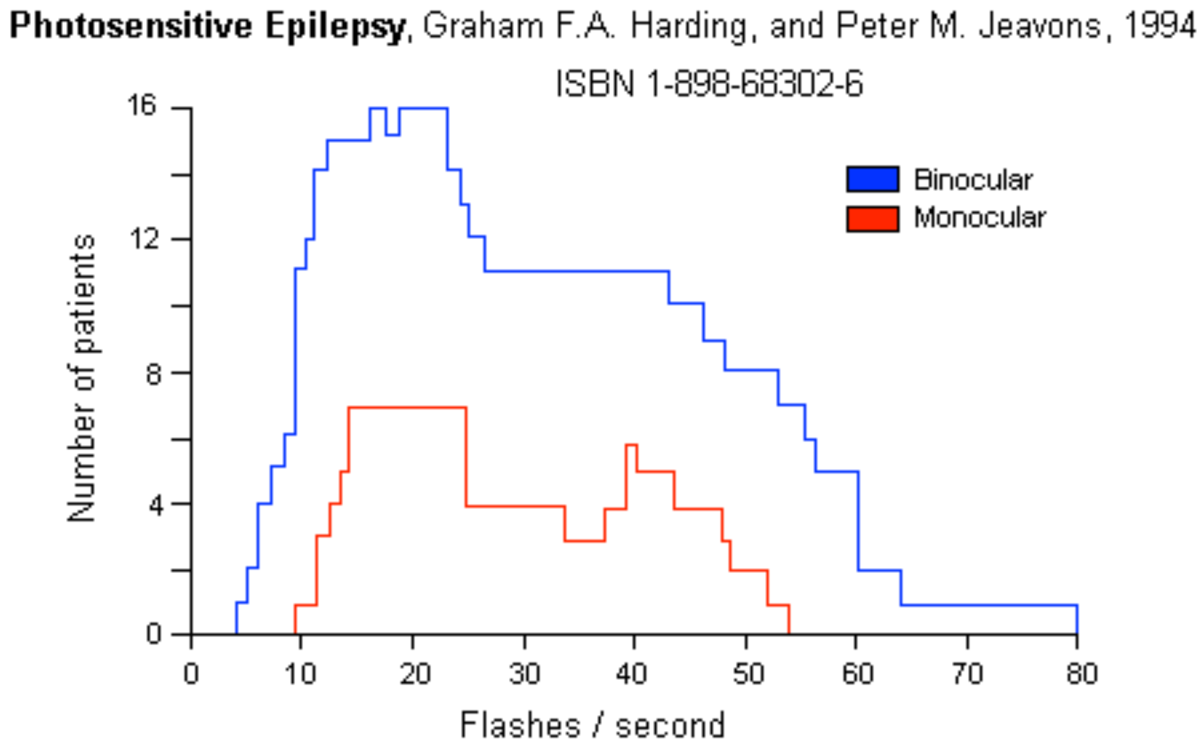
Faraday suits are regularly used by utilities personnel for live work on high voltage power lines. Energizing the entire body to the same instantaneous potential (*since Faraday suits offer almost zero electrical resistance, compared to human (*or bird*) skin*), precludes harm to the individual. In residential environments, however, the human is typically exposed to the strongest Electric Field stress from differing polarities. When a human is exposed to a differential electric field stress, the electrical entities external to the body gain access to the internals of the body, much more so when the entities' waveforms have a sharp / short rise time, not unlike TENS (*Transcutaneous Electrical Nerve Stimulators*) instruments' waveforms. When a waveform has instantaneous demand features, such as those of fluorescent lighting, dimmer switches, switching power supplies, etc., penetration of the skin boundary is eased substantially. Since the sharp / short rise time waveforms are a rich compendium of harmonics required to produce that waveform, those additional frequencies find themselves also within the body. Considering that the strongest harmonics in the power system are in the audio range, and more specifically within the region occupied by normal speech, the human is exposed to frequencies that would normally be heard, but which are **em** (*electromagnetic*) entities. It's far from abnormal for an individual so exposed to "hear" some of those frequencies, Tinnitus, some may call it. Remove the exposure, allow time for the human to adjust, and the "tinnitus" goes away. "Taos hum," some may call it, from Taos NM, one of the first places where people began to complain en masse. I fondly recall a newspaper photo in a related article, showing an individual sitting on the edge of a bed, with the bed flanked by nightstands with light fixture on them. Differential exposure? Who could have thought?




*Shown above is the BV (*body voltage*) waveform at top, and frequency spectrum at bottom, present on a young lady who was most stressed (*screaming in her head, I believe was the connotation*), in her living spaces. Turning off two circuit breakers to fluorescents, the frequency spectrum all but disappeared, and the waveform normalized to a much smoother 60 Hz. These were acquired using a laptop computer and a few simple and inexpensive attachments.*

I do not know the mechanism of the translation within the human of **em** frequency to audio, but the phenomenon has been consistently repeated over my 20+ years of **em** field assessment. When observed in real time, a frequency spectrum display can be seen to wobble up and down. Since the human eye persistence is about 0.030 seconds / 30 ms (*milliseconds*), anything slower than that, or 1/0.030 = 33 Hz will be visible to the human eye. This is concerning.

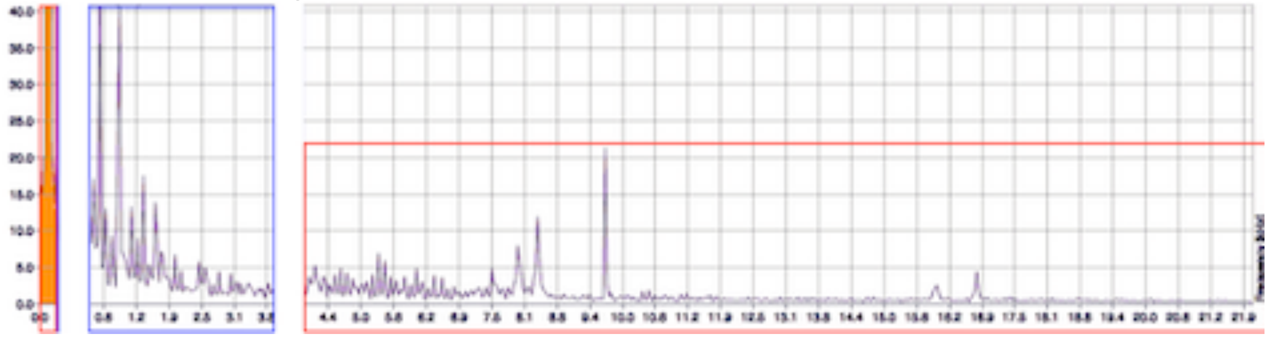
Frequencies around 1 Hz and 10 Hz are associated with earthquakes. Some clients submit that they feel their dwelling, or things within it, “shaking,” and I have been prompted with a glass of water on a table to observe the water “moving.”



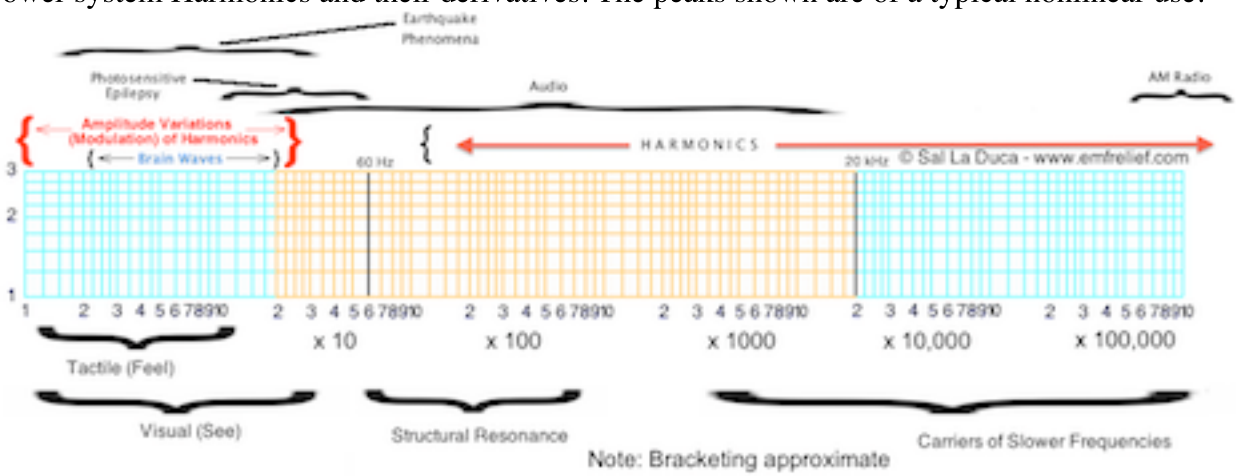

*The above shows the frequencies observed to cause photosensitive epilepsy / seizures due to flicker (*in Avionics parlance “Flicker Vertigo”*). The authors could not have perceived in their wildest dreams the fulfillment of their research, when on December 16, 1997 the Pokemon episode on television in Japan sent 685 children simultaneously into seizures, and afterwards to hospitals*. Search “Pokemon Shock” on the internet.

I have been alerted to occurrences of seizures among some clients that were not mine to advise. Again I do not know the mechanism whereby **em** entities of the appropriate frequencies entering the body are converted to audio or visual stimuli, but the phenomenon appears to be valid enough to warrant exposure reduction measures when possible.

There are several frequency ranges ways that can impact human physiology. Through Tactile sense (*zero to about 15 Hz*), Visually (*from zero to about 30 Hz*), and Aurally, from about 20 to 20,000 Hz. These elicit various physiological responses, and all of these are available as power system Harmonics and their derivatives. All of those frequencies are available through Electric field exposure due to installed wiring or plugged-in power cords, or through Magnetic fields due to Point sources, Wiring Errors, and Power lines. If you could somehow eliminate / greatly reduce electric and magnetic fields, harmonics would be a nonissue.

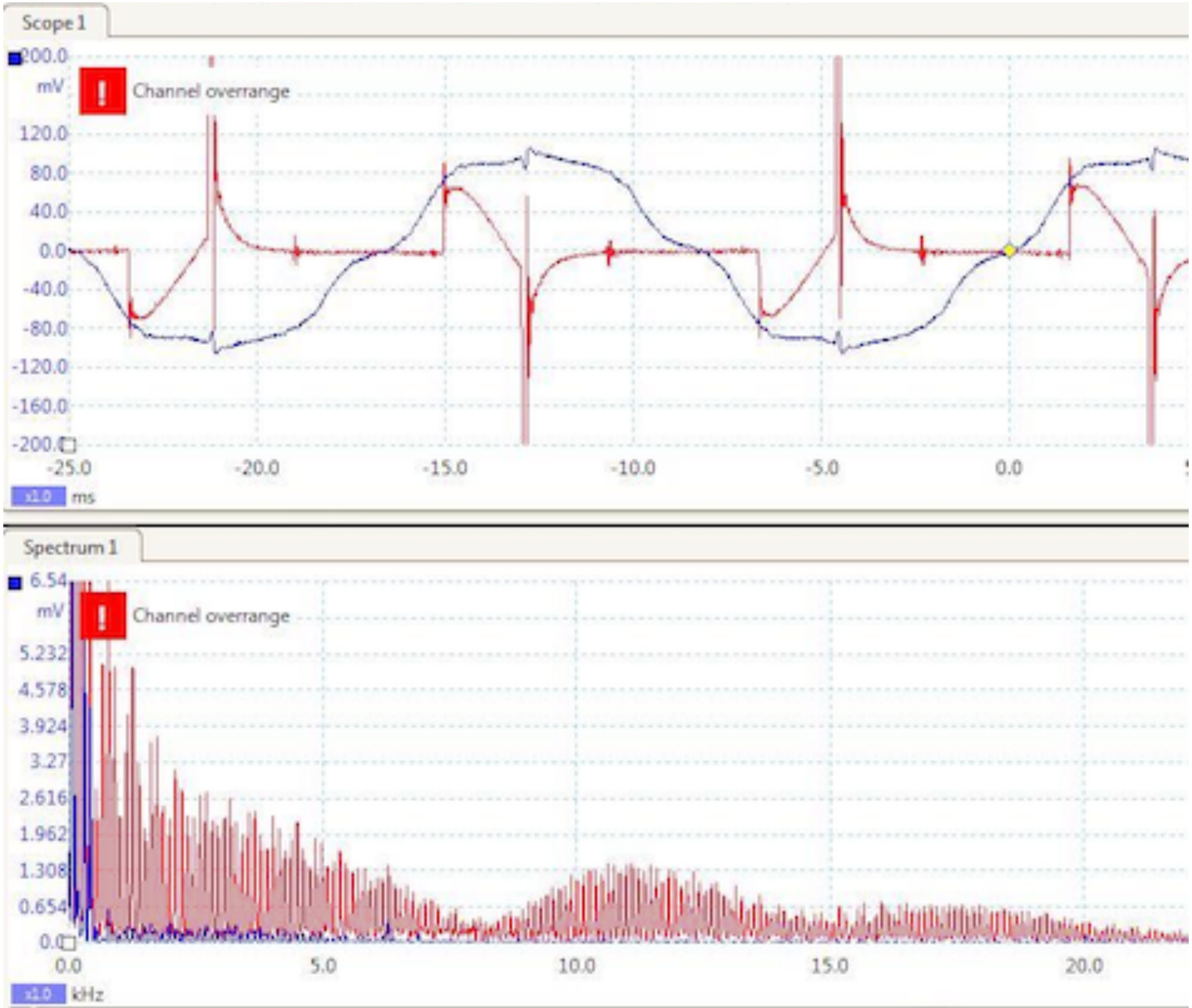


Shown above is the frequency spectrum from zero to 22 kHz. The first small block at left is that of the power frequency. The second larger block to its right is that normally used in human speech. The largest block is the remainder of the Audio spectrum. All of these are available as power system Harmonics and their derivatives. The peaks shown are of a typical nonlinear use.



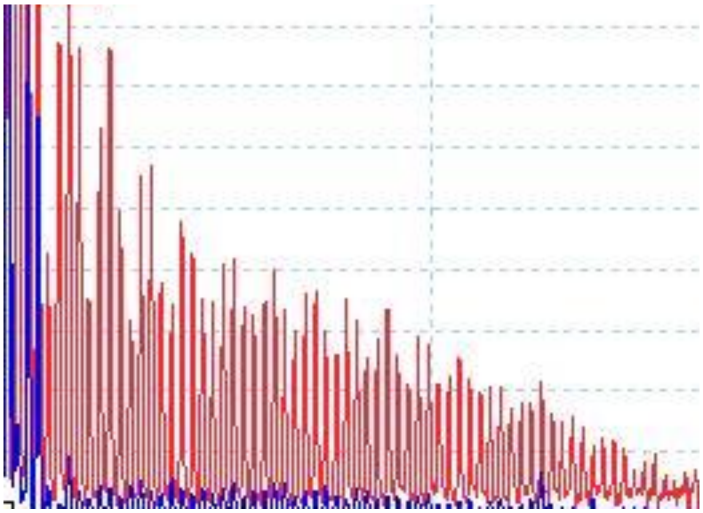

Shown above is the same frequency spectrum with various regions named as to human physiological response.

As stated earlier, Dirty Electricity meters begin sensing around 4 to 5 kHz, bypassing the entire speech and subsonic frequency range. With a spectrum analyzer, power system Harmonic detection is reliable, unambiguous, and visual. Frequencies slower than the fundamental (*60 or 50 Hz*) can be visualized by the wobbling up and down of the various harmonic peaks, although their subsonic frequencies cannot be easily identified without additional instruments. A common and simple spectrum analyzer application is available for most laptops with freely available software, using the onboard microphone, or externally using the mike-input jack and a few inexpensive attachments to extract Electric and Magnetic field entities and their Harmonics. Yet even engineers have bought into “dirty electricity” meters either because they are stupid, or because they think their client is stupid. Your guess is as good as mine.



*Shown above are the Voltage and Current waveforms at top, Blue for Voltage and Red for Current respectively, for a treadmill operating at 2 MPH, acquired using a Picoscope (*an external USB-driven instrument*). At bottom are the Frequency spectra to near 20 kHz, again for Voltage in Blue, and Current in Red.*

In lieu of separate detached instruments possible ranging to tens of $1000, or USB-driven instruments, decent oscilloscope and spectrum analyzer applications are available freely for most laptops by free software, and a few inexpensive attachments to the 3.5mm plug, without the need to use a separate USB device, simplifying testing.



*Shown above is an enlargement of the previous graph, focusing in on the human speech region, showing that most of the activity resides in the Current (*RED*), a possible source of Magnetic fields, if a wiring error is associated with the circuit feeding they appliance, or if an interconnection with a metallic neighborhood piping system is in place.*

When the question is raised as to whether the electric utility is providing the Harmonic content to the customer (*the floor and the furniture are "shaking"*), one needs to measure the Harmonic distortion at the breaker panel with all power on, and then with all power off. A "dirty electricity" meter will just not do (*as it needs 120V to operate*). This is as close as one can possibly get to the **PCC** (*point of common coupling*) referred to in the **IEEE Std 519**, without electric utility involvement, with the exception of any smart meter contribution, which is immediately near the breaker panel. Measuring at this point, one can then determine whose the major contribution happens to be, and whether independent measures can be employed without consulting the electric utility.

Standard tolerance criteria exists for Harmonics on the power system. **IEEE Std 519** stipulates that any one harmonic should be less than 5% of the applied voltage. So if the voltage is 120, any one harmonic cannot be higher than 6 V. Anything larger is out of tolerance and needs to be remedied. The same standard stipulates that the aggregate of harmonics should be less than 8% or 10 V equivalent in a 120 V system. If system voltages tolerances are exceeded, the electric utility is quick to advise the producing user to adjust their power usage to reduce harmonic content. In a commercial case this is a strict guideline. Considering the increasing proliferation of Solar installations and their "dirty electricity" inverters, not to mention the plethora of nonlinear consumer devices, whether those same utilities are willing to clamp down on residential users with the same criteria is an open question. Unfortunately, the residential environment is where the greatest majority of such exposure and negative biological impact occurs.

One consideration to note is that the electric system is as close as possible to an unlimited supply of Current. That is, Current demand should Not impact the supplied Voltage. So with appropriate tools you can visualize that while the Current waveform is greatly distorted and its frequency spectrum rich in Harmonic content, the Voltage waveform is only marginally distorted and its frequency spectrum is nowhere near as rich in Harmonics as the Current. **Accordingly, an**

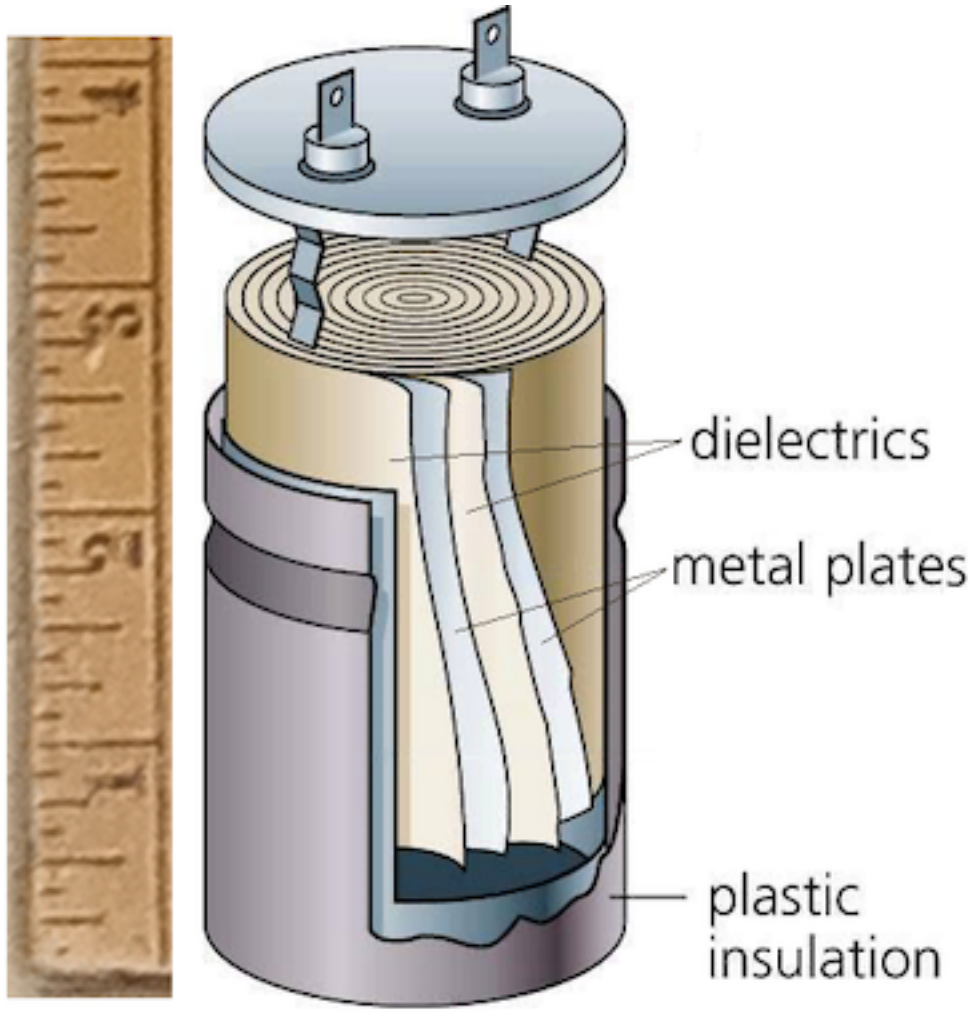
**objectionable Magnetic field due to Current flow (*the exception rather than the rule*) will be much richer in Harmonics than the pervasive Electric field due to Voltage (*the rule rather than the exception*).**

Interestingly, Dirty Electricity meters can only detect the Voltage content (*the source of Electric fields, where the least interaction occurs*), while also disregarding the content slower than 4 to 5 kHz where the most energetic content is located. In that respect, Dirty Electricity meters measure electrical "dust" with the promise of "filters" to correct same. It also neglects to consider the free-space interaction between polarities from the two opposite-polarity buses.

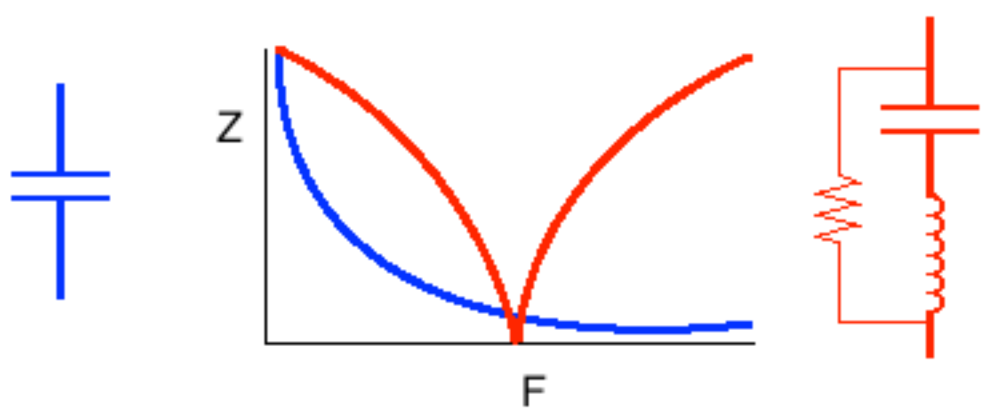
Those "filters," are composed of a few Capacitors, and a Resistor. The capacitors have an electrical response that **should** make them an electrical short circuit for faster frequencies (*the Harmonics / electrical "dirt"*). The resistor is provided to quickly deplete the charge once they're unplugged, to prevent electric shock.

However, those filter capacitors need to be identified for what they really are.

A capacitor is nothing more than two electrically conductive plates at different voltages, one from the other, separated by a nonconductive / dielectric layer. When the plates are flat, they simply have Capacitance. When the plates are curled about each other as below, they acquire Inductance, which tends to make them an electrical short circuit for slower frequencies (*the opposite of that desired*). The balancing act is to keep the Capacitance large and the Inductance small. However, to increase the amount of electrical Capacitance, the curled plates are made longer, also increasing the Inductance.

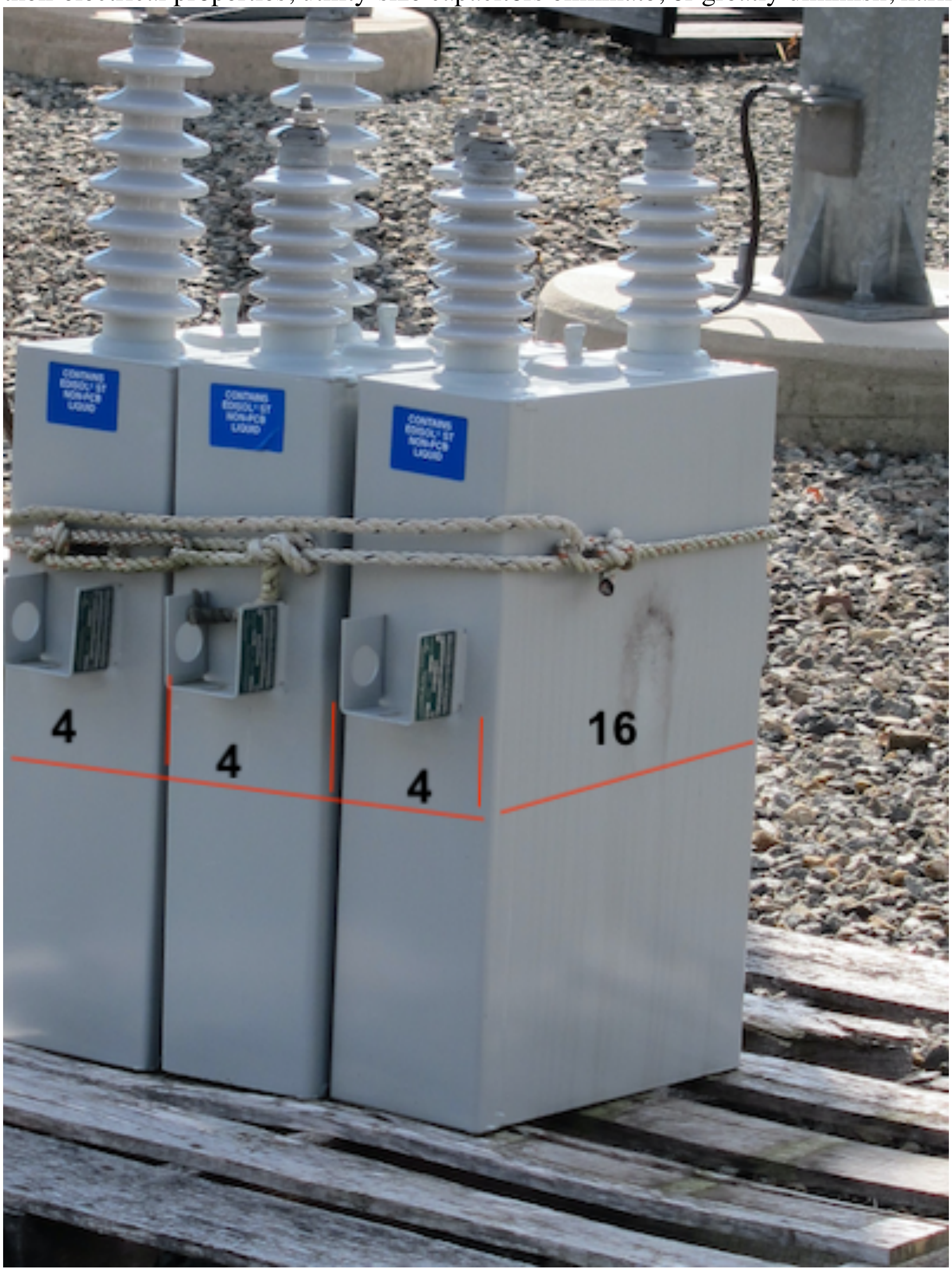



*The above shows a common (large consumer-grade) capacitor with curled plates, the terminals being at top.*




*As shown above, a flat-plate capacitor  at left is simply a capacitor, and its frequency response is that shown in Blue. A curled-plate capacitor at right, will have Capacitance, Inductance, and with the added resistor for safety, the device becomes a complex electrical circuit whose frequency response is shown in Red.*

Flat-plate capacitors are commonly used to offset the gradual voltage sag that occurs daily with increasing load current on a large-scale power system. I had daily energized capacitors across the system I was managing during the early morning hours, and de-energized them during late evening hours when the load current would taper off and the voltage would increase beyond tolerable levels. These do Not introduce Harmonics into the power system, and most utilities go out of their way to provide each customer 60 Hz (*or 50 Hz elsewhere*), and nothing but. Owing to their electrical properties, utility-size capacitors eliminate, or greatly diminish, harmonics.



*Shown above are a few utility-grade capacitors. The numbers indicate inches, by recall not spec, as I chose not to provide exact measurements. Their desired size is increased by aggravating many into a capacitor "bank," with each individually fused.*

Curled-plate capacitors, in contrast, produce low-frequency harmonics all on their own, and reduce some higher frequency harmonics. So if Harmonics are electrical "dirt," the filters marketed for residential use, remove some "dirt" and add some of their own. Being inexpensive, at $30 or so apiece, it's common practice for those that recommend them to suggest grouping several together into power strips, if not enough outlets are available. More importantly, the region they produce harmonics is in the speech range, that which we are most sensitive to.

**Complemented by a potential customer base that is ignorant of electrical concepts, marketing meters and filters for "dirty electricity" to them constitutes deception and a taking.** Coupled with whole-house units that produce the same effects, and which additionally require an electrician to install and / or remove them, the customer is provided with rose-tinted glasses and told that, if the perceptions persist after installation, the product cannot be the problem.

With inexpensive instruments, such as a laptop and a few accessories, the distortion can be visually quantified without ambiguity, whereas with a "dirty electricity" meter and filters one is supposed to believe their numbers have meaning, when justifiably they cannot have. Should someone come to your home, use a Dirty Electricity meter, and recommend filters, they may as well be selling you smoke and mirrors.

Sadly, an institution that should produce qualified investigators of electromagnetics has bought into the dirty electricity meters and filters, early on as a means of survival, and later because its course producers were incompetent. As a result it's been my repeated experience in the last 25 years to follow in the trail of some "engineered" individual or other, who acquired credentials by memorizing text, but without real-world experience, and having to perform damage-control. Unfortunately, there are many more of them, than I.