PRACTICAL ADVICE FOR THE ELECTRICALLY SENSITIVE

ARTICLE #1: WHEN OPTING OUT IS NO LONGER ENOUGH: MITIGATION OF HIGH FREQUENCY EMI FROM A NON-TRANSMITTING DIGITAL METER

By Eileen Chandler and Weber Hertz

In the fall of 2017, the Arizona Corporation Commission (ACC) ruled that Arizona Public Service (APS) would be allowed to designate smart meters as their "standard meter", with non-transmitting digital meters (not the analog meters customers already had) becoming the new "non-standard meter" for those who opt out of the smart meter program. This small change in wording allows APS to remove the existing analog meter of opt-out customers and replace it with a non-transmitting digital meter at any time. APS, the largest electricity utility in Arizona, serves 1.2 million customers in 11 counties across the state, mainly in Northern and Central AZ, out of an estimated population of 7.12 million in 2018. But APS is not the only power company making this change: Electric utilities in many other parts of the U.S. are asking for and receiving the same redefinitions of customer agreement terms from their state regulatory agencies.

Because I (Eileen) am electrically sensitive, I have been in the APS smart meter opt-out program since its creation at the ACC Opt-Out-Policy Hearing of December, 2014. So I had retained my analog meter even after most people in this area were switched over to smart meters. But, recently (late-summer 2018), I received a letter from APS stating that my analog meter would be replaced within the next few weeks with a non-transmitting digital meter. When I talked to the supervisor of the AMI* opt-out department about the letter, he said my analog meter was scheduled to be replaced shortly, by either a smart meter or a non-transmitting digital meter. Those were my only two choices. The reason he gave for the replacement was that I was using too much electricity to remain on any of the standard rate, non-time-of-use plans. (Maximum allowed usage is 1000 kwh/month, averaged over a year's time, and I was using an average of about 1100 per month.) In order to be correctly billed on a time-of-use (TOU) plan, I had to have a digital meter that could measure how much electricity I was using at various times of the day*. So that's what would be installed. He also said that, although I was being forced to change over now, all of the opt-out program participants would eventually have their existing analog meters replaced by digital meters. It was just a matter of time. That is the reason for this article.

****AMI* (*Advanced metering infrastructure*)** *is defined as "an architecture for automated, two-way communication between a smart utility meter with an IP address and a utility company. The goal of an AMI is to provide utility companies with real-time data about power consumption and allow customers to make informed choices about energy usage based on the price at the time of use."* In other words, **an AMI meter is a "smart meter" as opposed to the Itron**

__non-transmitting digital meter__ **provided to customers who opt-out of the AMI program**. (See the **Resources** section below for a link to an article explaining the dangerous health effects of both "smart meters" and "non-transmitting digital meters".)

Ten days after I received the letter, an APS technician showed up to install the new digital meter. Within a few minutes of his turning it on, I began to experience debilitating symptoms. I had hoped that perhaps I could adapt to the high frequency interference the digital meter was putting on my home power wires. But, instead of adapting, I became more sensitized and my symptoms worsened to the point where, at the end of a week, I could no longer function. I finally thought to experiment with turning off the main breaker to the porcelain trailer where I sleep. That helped tremendously, allowing me to at least sleep normally at night. Since I have no appliances, and use no electricity except for overhead lights, in the trailer, I was able to shut off all circuits and navigate by flashlight at night. But that was not an option for the other buildings where I cook, work during the day, and have my appliances, freezers, refrigerator, hot water tank, and hot water boiler for heat. Those could not be without electricity.

__Definition of Some of the Technical Terms used in this article__:

--EMI is **Electromagnetic Interference**.

--RFI is **Radio Frequency Interference**.

--SMPS stands for **Switch Mode Power Supply**. Any device which contains an SMPS will, unless filtered, put **EMI** on your household lines.

--**PLEASE NOTE**: The high frequency emissions created by a digital meter and other devices which have a switch mode power supply are sometimes referred to as **"dirty electricity"** or **DE,** but the correct terminology is **conducted Electromagnetic Interference,** i.e. EMI that is moving along a wire. This conducted EMI also radiates from the household wiring as **radiated EMI**, which can then be roughly measured using an AM radio held near the wires. We use the term EMI rather than dirty electricity in this article. (See below for how to use an AM radio to measure EMI.)

-- "**Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI**) are natural byproducts of SMPS design. Much of this noise is generated as a direct result of a switching process that produces large voltage swings caused by short-duration charging and discharging in the power supply circuitry…. efficient and cost-effective filtering technology placed between the electrical equipment and the power line is essential to reducing noise… One of the more effective ways to reduce common mode noise is to place a **Common Mode**

Choke (CMC) after the AC line full-wave diode rectifier." (Quote from article: http://premiermag.com/pdf/PremierMagnetics_WP_v2.pdf) See the detailed definitions and explanations of how common mode chokes work below and also in the **Resource** section.

(NOTE: There are currently better methods of achieving a reduction of SMPS noise during the design phase of an electronic device than when this Premier Magnetics White Paper was written: Slowing switching times is one method that is now supported by new SMPS controller Integrated Circuit (IC) chips.)

--EMC is **Electromagnetic compatibility**, i.e. "the branch of electrical engineering concerned with the unintentional generation, propagation and reception of electromagnetic energy which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage in operational equipment. The goal of EMC is the correct operation of different equipment in a common electromagnetic environment." (Quote from Wikipedia: https://en.wikipedia.org/wiki/Electromagnetic_compatibility)

While **EMC** does not address humans as the "target" of EMI (it is, rather, concerned with damage to or from, and interference with, other electronic devices) and many engineers scoff at the possibility of harm to humans, it is a mature field of engineering that does completely define the physics and engineering of how to use shielding and filtration to reduce harmful emissions. EMI reduction is most effectively done during the design process of an electronic device or system, but it can be implemented after the fact, as described below. (See the **RESOURCES** section for more information on EMI and EMC.)

I asked for help from an EI friend (Weber) who is an electrically-sensitive electrical engineer and very knowledgeable about how to deal with EMI and other EMF problems. He researched the particular digital meter that APS is using for their opt-out customers (an Itron WattHour CL200 non-transmitting digital meter) and possible options for filtering out the EMI it was putting onto my household lines. He found that, unfortunately, the Itron meter has a poorly designed and constructed switch mode power supply with no built-in filtration. A filter could have easily and cheaply been included as part of the design. It would have taken care of the problem at the source, but the designers didn't bother and saved a few dollars. So, filtration for the EMI the Itron meter creates would have to be placed between the meter and my household circuitry.

Even worse news, since I needed immediate relief, was that there is nothing available commercially that would serve as a **whole house filter** (to use a water filtration system analogy) to take out the EMI at the point of origin, i.e. right after the digital meter and before the two small buildings where I work and sleep, each with 100 amp service. A **3- or 4-signal Common Mode Choke of 100 Amp**

capacity could be made, but it would be a custom order. So both the time delay of 2-3 months and set up cost for just two small buildings would be prohibitive.

I had checked the levels of EMI in my buildings with a transistor AM radio, both when I still had the analog meter (the lines were “clean”) and after it was replaced by the digital meter. After the installation there was a new “noise” on the higher frequency end of the radio in my buildings (which are about 200 feet from the meter) and much worse noise near the meter itself. It measured higher on the hot wire, but was also present on the neutral to some extent, indicating that there was both “common mode” and “differential” EMI being produced, so not all types of power line filters would work.

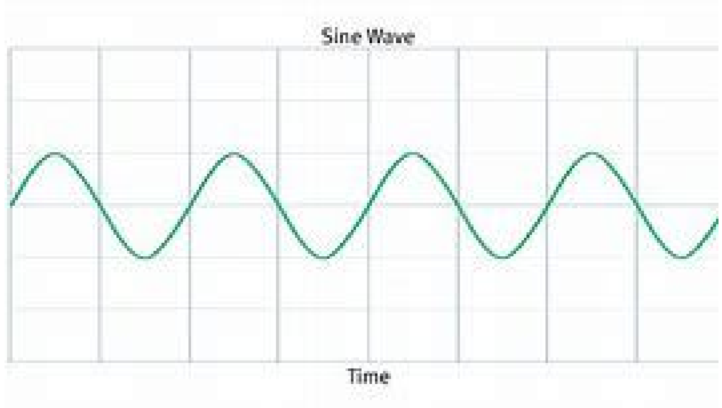
Some **Technical Information to Consider**: Inductors (common mode and single conductor) are an essential part of AC power filters. For stronger conducted (carried on the wires) high frequency emissions, multiple inductors and very small value capacitors (less than 0.1 uF) are used, both differentially and to the earth grounding system. Capacitance to ground is perilous as these capacitors pass AC and will put EMI on the grounding system unless it was specially designed for high frequencies. Connection to ground (earth) via capacitors without using a balanced transformer isolation will cause elevated magnetic fields. (The use, by U.S. power companies, of grounding practices which do not maintain transformer isolation, resulting in the creation of extremely low frequency (ELF) magnetic fields over wide areas, will be addressed in the second article in this series.)

Metal film (aka "motor run") capacitors alone, in relatively high values (20uF) between hot and neutral wires, such as those Stetzer and Greenwave are selling, are ineffective for the type of EMI, known as "common mode EMI", generated by switching mode power supplies. The companion meters they use to demonstrate the effectiveness of their products only show differential noise, and the differential capacitors in their filters are effective for converting differential noise to common mode. So while their meter shows a big improvement, your AM radio (and your body) won’t. Common mode EMI will conduct on home wiring and also radiate just as effectively as differential EMI. These large value capacitor-only devices simply cause more problems and are not effective filters.

More Technical Information to Consider: In my case, there wasn’t any measurable EMI on my household lines (as measured with a portable AM radio) until the digital meter was installed. In contrast, most modern homes have multiple sources of EMI that greatly exceed that of the Itron non-transmitting digital meter. Compared to many modern appliances, the small switching supply of the meter is only a minor source of EMI.

To put this in perspective, the EMI on my lines from the digital meter could just barely be heard at the high end of the AM radio band, when the radio was held close to the lines. In contrast, many appliances and consumer electronics devices use poorly-designed switching power supplies which are so bad that large sections of the AM band will be affected at a distance of several feet from any wires. What this means in real-life terms is that, depending on the amount of EMI already in your home, you may not even notice the amount that is added by the replacement of your analog meter with a digital meter and/or you may need to first address the other, already-present, sources of EMI in order to solve the problem.

How to Measure EMI on your Household Lines and Determine its Source.



High frequency disturbances (EMI) in the smooth 60 Hz sine waveform of your household electricity are most commonly coming from SMPS in the home: LED or CFL lamps, fluorescent lamps, electronics and variable speed motor controls, and some GFCI breakers. Other sources of EMI include arcing within thermal cutout devices and power-line-induced arcing from loose or corroded hardware near the power lines. All of these sources can be reliably detected by using an AM radio, preferably the old Radio Shack 12-467 (ebay) or Sony ICF-S10MK2 (Amazon.). Any AM radio with loud static between the stations in the daytime can be used, but these two models have tuners which are more susceptible to EMI and can be trusted not to “miss” most sources.

Switching power supplies make a wide range of squealing or harsh-edged warbling sounds. The AM radio uses a ferrite rod with coil as an antenna, so it is sensing 700KHz to 1.8MHz magnetic fields with some audio frequency modulation or variation.

An EMC “rule of thumb” of SMPS emissions is that there will be strong emissions to 10x the switching frequency, and notable emissions to 100x the switching frequency.

Since SMPS commonly have a switching frequency from 30K Hz to 100KHz (rarely to 1MHz), they have strong emissions up to 1MHz, and notable emissions up to 10Mhz. Thus the AM radio band (700KHz to 1.8MHz) is reasonably well situated to pick up at least some of their emissions. Likewise, diodes create a small burst of high frequency emissions when starting and stopping conduction, and this also has a characteristic 120Hz sound on the AM radio. The AM radio can be used as crude detector of strong EMI sources of virtually any type, despite the narrow frequency band of reception.

A strong EMI source will be so rich in harmonics that it will wipe out the entire AM band, not just a few spots on the dial. So when measuring EMI, you will need to factor in not just the distance at which it can be picked up, but also the range of the AM band which is affected. If the AM band is completely wiped out, at a range of 3 feet or more, this is a seriously bad situation. A source which is barely detectable in just one small area of the AM band, a few inches from the wire, is a minimal source. The “reading” of EMI “badness” for an AM radio must consist of both the distance to the wire where the EMI sound can be detected, and the range of the frequencies affected. For example: “4 inches away and at only one spot on the dial” is a very weak source. “4 inches away and several sections of the band affected” is several times worse but still a weak source. “36 inches away and almost the entire band affected” is a nasty source.

Unfortunately, many with ES develop sensitization to specific frequencies of EMI. When those particular frequencies are present in EMI emissions in the home, the health effects, which are sometimes immediate and sometimes delayed, will be more devastating. When you detect a source that is affecting a wide range of the AM radio frequency band, this is evidence of a wide range of strong harmonics, indicating that the likelihood of a devastating frequency-specific response is greater. Since you spend much of your time in your home, particularly at night, you are very likely to sensitize to the EMI emissions sources present in your own home/neighborhood. Eliminating these sources and effectively filtering the ones you cannot remove is your best defence. Those few of us who have created extremely low EMF environments have found we now have improved tolerance and more rapid recovery from exposures such as driving or shopping in a store with WIFI and fluorescent lights. So, educating yourself and improving your environment beyond what you “notice” via acute symptoms can be extremely beneficial to your overall state of health.

The source of **EMI on your household lines** can be readily located by using an AM radio at the power panel, and first turning off the main breaker. Any source still present with the main breaker OFF is coming **from your neighboring power lines and neighbor's equipment**. These sources can be located, i.e. traced to the offending pole(s) or home, by using the AM radio and the Air Band (100MHz AM) radio. If the EMI found between AM radio stations has a strong 60/120Hz buzz, this is characteristic of the induced arcing on power line hardware near the lines. Power companies are often not monitoring their lines, particularly in rural areas, but in others as well. If you locate a source, you can often mark it and report it to the power companies for them to repair.

Sources in the home are much more common and can be quickly and easily located. Turn individual breakers on/off, checking them one at a time with the AM radio, to identify which circuits have the problem. Once the source is identified, it can be disconnected or filtered (typically with a dual common mode choke power filter) to eliminate the problem. If the device is only used occasionally, it may be adequate to just keep it turned off when not in use. A common example of this is the often horribly-poor-quality switching power supply in electric ranges used for clock and oven controls/timing. Adding a switch to keep the clock/timer off allows use of the burners without any EMI, and only when the oven is used and the clock/timer switched on again will the house wiring be filled with EMI from the oven electronics power supply.

The AM radio is very cheap, but it is a very powerful EMI measurement tool for those who can learn its use and understand it's abilities. As Marv Loftness noted in his *AC Power Interference Handbook* (the original "Bible" of power line EMI), extremely low frequency pulsed sources are NOT well measured by typical swept tuner spectrum analyzers. Only the newest real time spectrum analysis tools (real time analog recording with FFT analysis of signal) can, at great expense, accomplish this. The AM radio is not nearly as capable, but for practical home EMI troubleshooting, it is astonishingly effective. (Click here https://www.amazon.com/Power-Interference-Handbook-Marv-Loftness/dp/0965376036 for a link to the book.
(NOTE: The American Radio Relay League has a good article on how to use an AM radio for home EMI diagnosis: http://www.arrl.org/power-line-noise)

Now back to how we did the installation of CMCs on my Electrical System:

Since commercially available filters would not work on the EMI from the digital meter, we decided to experiment with smaller "point-of-use" filters (to again use a water filtration analogy) that could be installed on each breaker in the box (or a bundle of several low-load breakers) to filter the electricity going to each of the household circuits individually. The type of filter we used is called a **"common mode choke" (CMC).** It has several advantages over larger inline filters for this type of application: It is readily available commercially in a number of different sizes and capacities, is relatively inexpensive, can be installed by an electrician with a basic understanding of electrical wiring, and works well for the type of EMI produced by the Itron digital meter and/or other electronic devices with a switching-mode power supply.

For me, it was an experiment that worked: The installation of the chokes made a "night and day" difference, successfully removing the digital meter EMI from my household lines so that I was no longer having the symptoms which had begun when the meter was installed. With the chokes in place, I felt even better than I had with the breakers off because the slight amount of EMI that had remained on the lines (due to the fact that the neutral wires were still connected and conducting EMI) was removed once all wires, not just the hot, were being filtered. We, of course, checked the lines after installation of the chokes with the AM radio to verify that EMI "noise" could no longer be measured on the household lines.
It is worth noting here that **Common Mode Chokes installed in the breaker box will reduce the EMI coming from neighboring power lines as well as that from the digital meter.** This may be another reason why I felt better after the chokes were installed than when I was simply turning off the breakers.

NOTE: If you find yourself needing to deal with a similar problem and want to try using common mode chokes for filtration, there are several factors to consider:

(1) Use a portable AM radio or other EMF measuring device to verify that you do have EMI on your lines and to discover the exact sources for it before you install any filtration devices. (See instructions above on how to use an AM radio.) Many homes already have a terrible problem with EMI from household appliances that use switching-mode devices (battery chargers, computers, modems, laptop chargers, digital clocks and timers on stoves, washing machines, dryers, even refrigerators, in some cases.) These all cause EMI that is much higher than what you will likely get from a non-transmitting digital electric meter. The small switching supply of the digital meter is a comparatively minor source of EMI, which we could just barely hear at the high end of the AM radio band. Many appliances and consumer electronics devices use poorly-designed switching power supplies which are so bad that large sections of the AM band will be affected at a distance of several feet from any wires. So there may be no point in going to great effort to filter out the small component coming from the digital meter unless you have first taken care of the other sources.

NOTE: Filtration of EMI coming from **appliances and/or devices in the home which have switch mode power supplies** should be done between each offending appliance and the outlet in order to prevent radiation of EMI from the home wiring. A single common mode choke can be very effective if the source is not too strong, and commercial dual stage common mode choke filters are also readily available and inexpensive. When more filtration is needed, multistage passive filters are effective, but they will be much more costly. In addition, they require an isolation transformer to create a balanced line, and a high frequency earth ground installed at the filter location. The use of a balanced line prevents 60Hz current from flowing on the grounding system from filter capacitors, and so prevents creation of an ELF magnetic field problem. (Multistage filter design is complex and not within the scope of this article. We may address it in a future article.)

(2) Turn off the breaker feeding the sub-panel, and check that the panel is no longer "live" via voltmeter. Next install one choke on a test circuit line and then turn the power back on and check that circuit with an AM radio (with all other circuits still off) to be certain that you have successfully removed the EMI from this line before putting in any more of the chokes. If the EMI is still there, unchanged in strength, it means either you have installed the chokes incorrectly, or there was a pre-existing wiring error for that circuit (read below). If the EMI is reduced but still clearly present, you may have to resort to a much more complex and more costly passive filtering solution such as a facility filter, with the main meter panel moved away from the house. A facility filter is a multistage passive filter with fairly significant capacitance to ground, and requires a high frequency grounding system. (We do not deal with facility filters in this article).

***NOTE**: Any circuit with **pre-existing wiring errors**, such as a neutral-to-another- circuit's-neutral short or neutral-to-ground short will cause the CM choke to be ineffective. This is due to the fact that, if the CM choke doesn't have exactly matching 60Hz (power) currents on the hot and neutral, the ferrite core will saturate and inductance (and EMI filtering) will drop dramatically. These errors also cause grossly elevated magnetic fields over a large area. The average home has 2-3 of these errors; they need to be located and fixed before the CM chokes are installed or the chokes will not work properly.

Many people with Electrical Sensitivity (ES) are living in homes with both bad home power EMI problems, affecting most of the AM band at more than a foot from wires, and ELF magnetic fields levels at least 10 times higher than the average home (0.1-0.2 milligaus). Unfortunately, once ES is acquired, the normally tolerated levels of EMI and ELF magnetic fields drop by 10 to 100 times, which often renders the average home intolerable for the electrically sensitive.

(3) The **CM chokes should be rated higher than the breaker size** by a wide margin so that they don't get too warm, since they may be close to surrounding wires. The common mode chokes we used were about 330 microhenries.* The two-signal ones used on my 20 amp breakers were rated for 35 amps and the three-signal one used on my dryer circuit (which has a 30 amp breaker) was rated for 50 amps.

(**Microhenry** (plural microhenrys or microhenries): A unit of electrical inductance, one millionth of a henry. ***Henry**: The practical meter-kilogram-second unit of inductance equal to the self-inductance (SI) of a circuit or the mutual inductance of two circuits in which the variation of one ampere per second results in an induced electromotive force of one volt.)*

If Common Mode Chokes are to be used in an NEC code-compliant power panel, with its connection to the power company neutral/ground (rather than in smaller sub panel with an isolated ground, as in my case) it would require a **3-signal (6 wires total) choke**, not the smaller 2-signal (4 wires total) chokes we mostly used, because all three wires -- ground, hot, and neutral -- must be filtered through the common mode choke. This is because the SMPS of the digital meter puts common mode noise on the ground as well as the hot and neutral wires.

To put the same information slightly differently: If **2-signal common mode chokes** are to be used in a sub panel, that panel MUST NOT have code-compliant grounding via a separate ground wire from the main panel, but must instead use an isolated ground (earth) connection and **Transient Voltage Suppressor(s) (TVS)*** between it and the green safety ground from the main panel. If the sub panel was not up to code and has no ground to the main panel and uses the neutral wire instead, the TVS goes between the neutral and now-separated ground bus.

***NOTE**: **TVS, aka Transient Voltage Surge Suppressor (TVSS), devices** are normally used to protect equipment and circuits from brief spikes or surges in voltage. The bidirectional (for AC power) diode-based devices are being used here to allow a separate grounding system to “float”, i.e. be unconnected to the power company ground/neutral, **unless** there is a catastrophic hot wire short to ground of such high current that the separate ground voltage rises above 20 volts. Multiple TVS devices are used in parallel to increase the current capacity. (As mentioned above, we plan to write a companion article on grounding that will explain the use of TVS devices in the sub panel to create an isolated grounding system that allows the use of the 2-signal CM chokes.)

In Summary: The two-signal (4 wires total) common mode chokes can be used in any panel that has an isolated grounding system. (**See Below for Instructions and Diagram of how to Install a 2-signal CMC.)** Panels that do not have an isolated grounding system must use 3-signal (6 wire) chokes, as noted above. **(See Below for Instructions and Diagram of how to install a 3-signal CMC.)**

If, instead of filtering individual circuits, you wanted to make, or have made commercially, a **large Common Mode Choke filter -- for a 100 amp service to a sub panel**, for example -- it would normally have to be a 4-signal type, (8 wires total). The signals are: 2 hots, a neutral, and the safety ground. This type of large CMC can be made with a large ferrite or laminated toroidal transformer-type core. Several toroidal transformer and choke manufacturing companies in the US could make it, but it is not a standard commercial product so the cost will be substantial.

(4) You will probably not be able to filter out the EMI produced by a digital meter if that meter is located on the side of your house, because the radiated EMI from the meter itself will be strong enough to be picked up by nearby wires, putting conducted EMI back on your household wiring. First you need to “remote” the meter to a pedestal in the yard (8-10 ft from the house minimum.) This will require a permit from the power company, trenching for wires to reconnect the meter to the household breaker box, the rewiring of the entry from the pedestal to the house by a qualified electrician, and then the installation of the CMC filters.

How Common Mode Chokes Work: A choke is a type of inductor which chokes or restricts the passage of high frequencies while allowing AC or DC power to pass unrestricted. Since impedance or resistance increases with frequency (a characteristic of all inductors), the choke will allow passage of the lower frequency 60 Hz current, but block or “resist” passage of high frequency EMI.

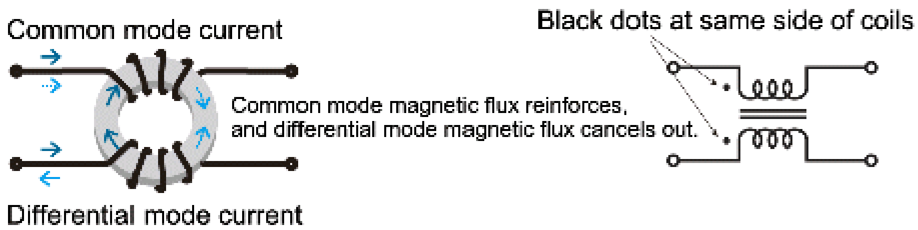
“A common mode choke is used to filter out noise that is common to, or coupled to, the power and network lines. A CMC features two identical windings with the current in each winding flowing in the opposite direction of the other. The live and return currents are of the same magnitude since they are from the same power source. But the direction of the magnetic flux lines created by the current flowing into the first winding is opposite the flux lines created by the return current in the second winding. These two magnetic pulses cancel each other out, creating a theoretical net flux of zero.

As a result the choke presents little inductance or impedance to the differential-mode currents. This means the CMC’s core will not saturate due to the amplitude of the main currents. High frequency noise currents, however, which are of much lower amplitude, will see a high impedance due to the common inductance of the windings and will be severely attenuated or filtered out.” (Quoted from Premier Mechanics White Paper “Using Common Mode Chokes to Reduce EMI/RFI in Off Line Switching Power Supplies”. Click here http://www.premiermag.com/pdf/PremierMagnetics_WP_v2.pdf for article.)

Because, as explained above, the core of the choke doesn’t “see” the 60Hz power at all, ferrite-type core material with very high magnetic permeability can be used, and huge currents can be passed through this choke, which is relatively small and inexpensive but has a large common mode inductance value. Greater inductance (measured in microhenries) means better “choking” of high frequencies. Power chokes that are not common mode type must typically use larger, powdered iron or gapped laminated electrical steel cores, and more turns of larger copper windings to achieve the same effect. Large inductance values of non-common mode chokes can’t be used for AC power as they will distort the sine waveform. (See page 5 above.) So common mode chokes are an especially useful element in AC power filtering.

Below is a **schematic** showing how a common mode choke is connected in the breaker box, between the source of EMI (in this case, the switch mode power supply of a digital meter) and your household lines, and how it works to filter out EMI noise before the noise reaches those household lines. It is from an article on common mode chokes by Murata Manufacturing. Click here to see the article https://www.murata.com/products/emiconfun/emc/2014/07/24/en-20140724-p1

(NOTE: Ignore the information on the diagram about the “black dots”. It is not relevant.)

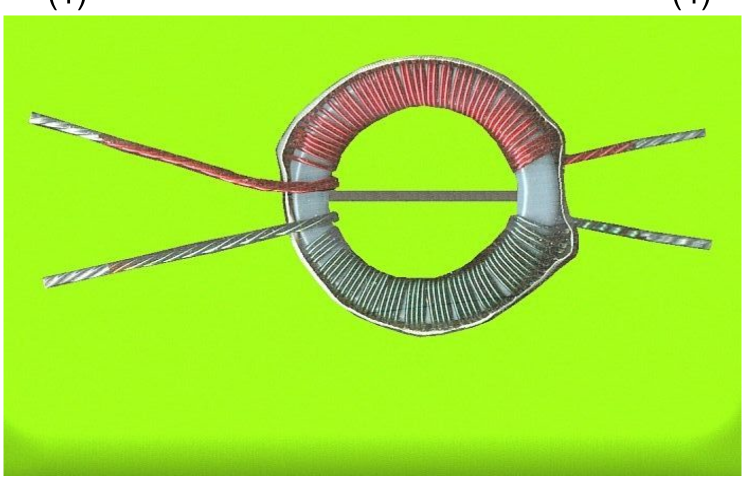


Common mode choke coil magnetic coupling and equivalent circuit

(See the **RESOURCES** section at the end of this article for links to additional descriptions and diagrams of how common mode chokes work.)

Picture of Torotel 2-signal Common Mode Choke 31902-A2714 (This is the 2-signal CMC we used on my 20 amp breakers. The numbers along the top and bottom edges of the picture correspond to the wires and steps in the instructions (below) of how to hook up a 2-signal choke.)

(1) (4)



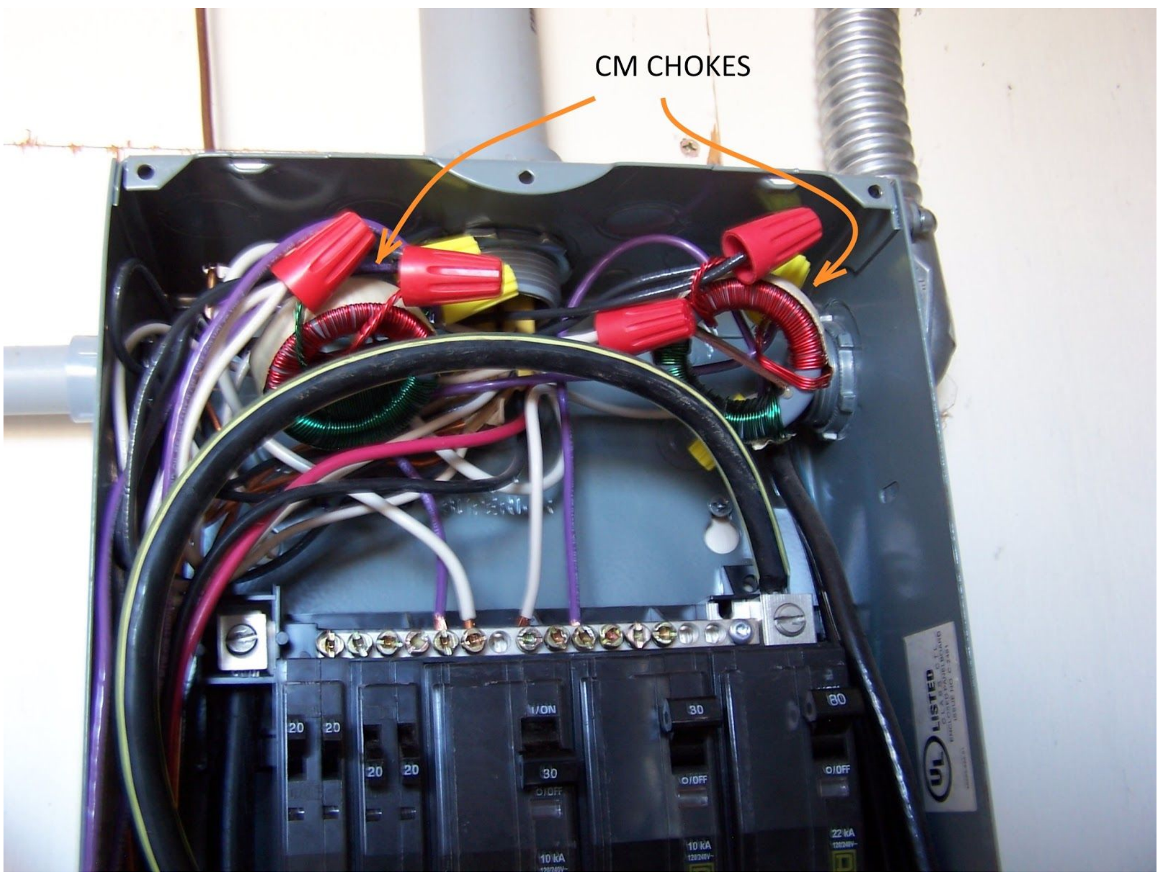
(2) (3)

Click here
https://www.ebay.com/itm/lot-8-50-mm-35-amp-common-mode-choke-Torotel-31

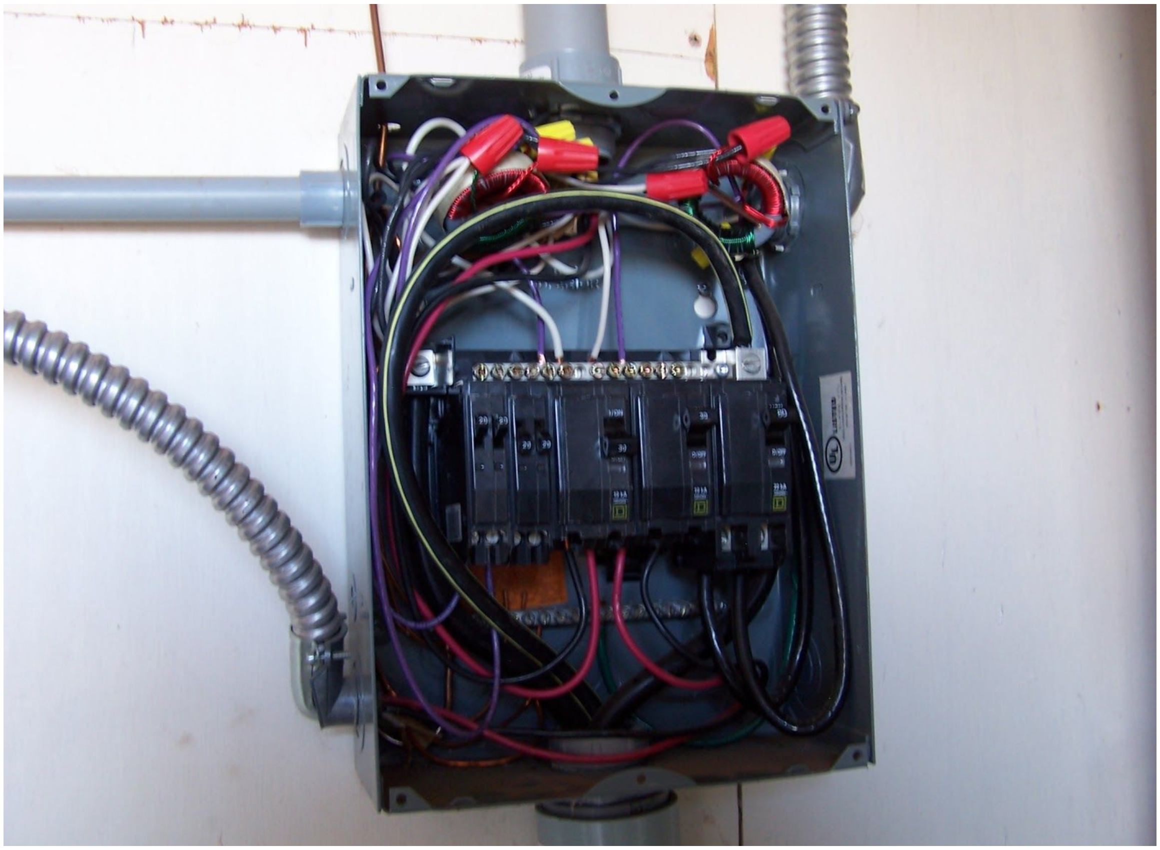
902-A2714-line-RFI-filters-/370641963364?hash=item564bfb8964 for link to an Ebay site selling the Torotel brand 31902 A9714, 2-signal common mode choke. These chokes are made with two different-colored wires wrapped in opposite directions around a ferrite core. They are rated for 35 amps. The colored wires make it easier to keep track of which wire goes where during installation. These chokes are flat circles, approximately 2 inches in diameter. They are surplus products being sold for a bargain price.

An equivalent choke is available at Digikey: https://www.digikey.com/product-detail/en/kemet/SCR38-350-1R8B008JH/399-10783-ND/4290849

Close-up view of Torotel 2-signal chokes installed in breaker box. The chokes are tucked into the top left and right hand corners of the breaker box, connected by short lengths of wire to the bus bar and circuit breakers.



Torotel 2-signal chokes installed in breaker box



<u>**How to Hook up a 2-signal (4 wire) Common Mode Choke**</u>**:**

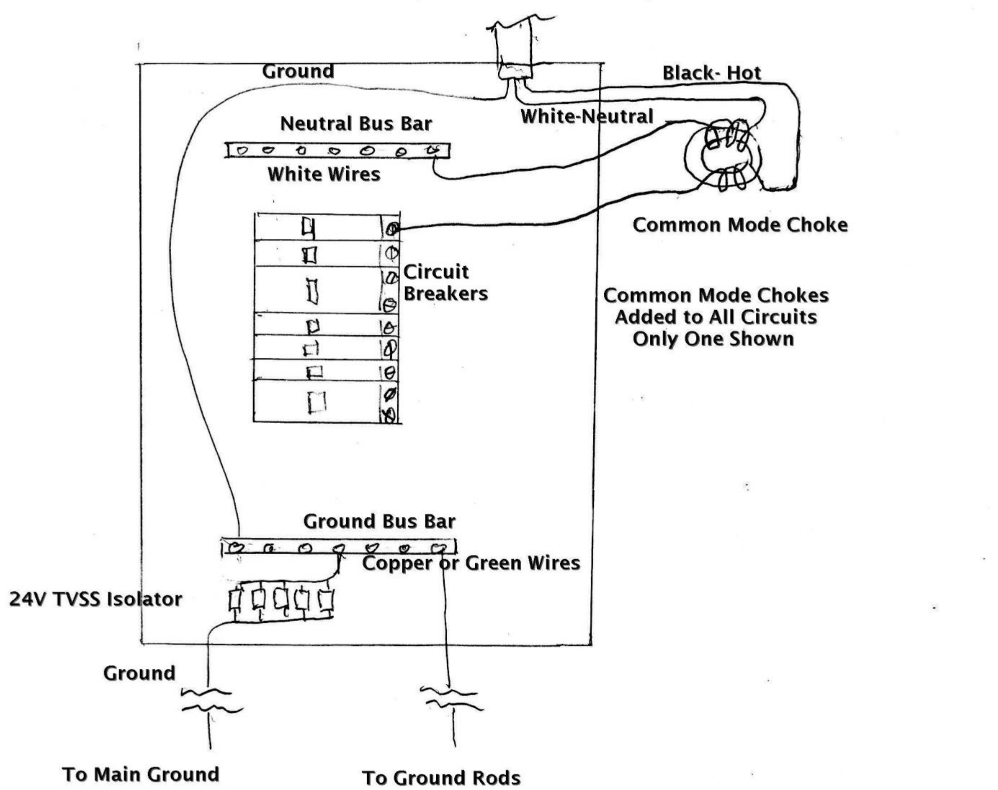
Please **refer to the picture of the Torotel 2-signal choke (above, page 12) and the sketch of the Sub Panel (directly below) as you read through the directions**. The numbers along the top and bottom of the picture of the Torotel choke (on page 12) correspond to the steps in the directions for installing the choke as well as to the wires which are to be connected together.

First designate one end of the choke as “input” and the other as “output”. In this example, we have decided to call the left end of the choke “input” and the right end “output”. One of the wires (red or green in our example) wrapped around the choke will carry the current coming into the sub panel from the meter and the other will carry the return current back. The two wires are wrapped in opposite directions so that the 60Hz current passing through the wires cancels out and passes unaffected through the choke, but the higher frequency EMI is reflected. This is what allows the choke to work, so you must be certain to connect the wires correctly. The colored wires on the 2-signal chokes we used made it easier to keep track of what we were doing, but not all CMCs will have this feature. You can use any orientation of the choke that you prefer, but you must keep the correct correlations between the wires, the breaker, the bus bar and the choke.

With the main breaker turned OFF, locate the pair of hot and neutral wires for the circuit you want to filter. You must maintain the original pairings of hot and neutral wires for each circuit or the choke will not work correctly. Follow the wires back to the Romex plastic jacket to insure you have the right set of wires.

(1) Remove the white (neutral) wire from the neutral bus bar and connect one of the colored wires (red, in our example) on the “input” end of the choke to the neutral bus bar. (2) Remove the black “hot” wire from the breaker for the circuit you want to filter, then connect the other wire (green, in our example) on the “input” side of the choke to that breaker. (3) Connect the black (hot) wire to the green wire on the “output” side of the choke. (4) Connect the paired white (neutral) wire to the remaining (red) wire on the “output” side of the choke. (You will likely need to cut one or several short connecting wires in order to bridge the distance between the choke and the breaker and/or bus bar.) Check for wiring errors using an inexpensive Continuity Tester, available online or at Home Depot or Lowe’s.

Sub Panel with TVSS Isolated Ground and 2-Signal Common Mode Choke



Technical Notes: GFI and/or AFCI breakers can be used with CM chokes; just connect the neutral to the GFI breaker neutral connection, not to the neutral bus bar. Their fault detection will not be impeded by the CM choke. Warning -- GFI and AFCI breakers should be checked via AM radio for EMI.

For new construction, the use of a 3 pole RCD (residual current detection -- aka ground fault interrupting) breaker as the feed to the sub panel is preferred. This eliminates the need for the TVS isolators and is now widely used in Europe and Japan for T-T grounding. (See note below on grounding terminology.) If it is possible to retrofit your sub panel with an RCD and T-T grounding (earth only to safety ground), you might want to consider it. This system is widely used outside the US and is an excellent alternative where health needs require a cleaner ground. Specific model RCD or GFI-type breakers must be tested for possible EMI generation, because the internal power supplies on some units may generate EMI. This is also true for GFCI outlets; some are EMI disasters.

For the larger 30 amp breaker that powers my dryer, a larger 3-signal choke (total of 6 wires) was used. The CMC should have a current rating well above the breaker amp's value and 0.3 Millihenries inductance or more. Higher inductance values are preferred.

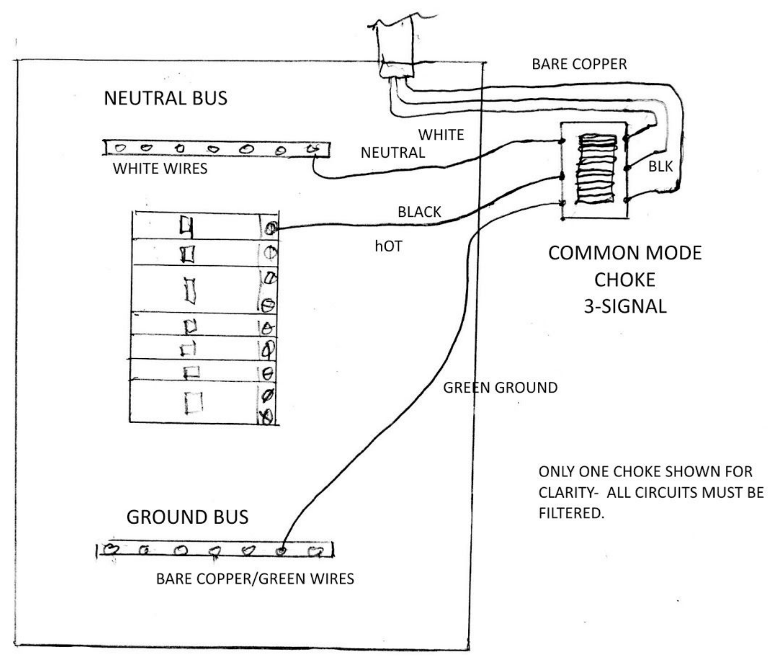
Click here https://www.digikey.com/product-detail/en/schaffner-emc-inc/RB8532-50-0M3/817-1662-ND/3125510 for link to a site (Digikey Electronics) that sells this choke and others.

This particular choke is made by Shaffner EMC Inc. It is rated for 50 amps. Because it is larger (about the size of your fist) and would not fit into the breaker box, another small metal box was attached beside the breaker box to contain the choke, which is connected back to the main breaker box with 6 wires and a ground. A photo of the auxiliary box, 3-signal, 50 amp choke, and hook-up for my dryer circuit is shown below, as is a drawing of how to install a 3-signal choke in a sub panel that does not have an isolated ground.

How to Hook up a 3-signal (6 wire) Common Mode Choke: A 3-signal (6 wire) choke for a 120V circuit is hooked up in the same fashion as a 2-signal choke, but with the addition of a connection between the choke, the ground wire and the ground bus bar. (See pictures and diagram below.) A 3-signal choke can (and must) be used if the sub panel does not have an isolated ground in order to filter out the EMI that would otherwise be carried by the ground wire.

A 3-signal choke is wound so that each wire (hot, neutral, ground) is carried automatically through the choke from the “input” to the “output” side, as long as the correct connections are made. In this diagram the connections are: White-Neutral wire connected at the top of the choke, Black-Hot wire in the middle; and Ground wire at the bottom of the choke, on both sides.

SUB-PANEL WITH 3 SIGNAL COMMON MODE CHOKE



Note: An NEC compliant sub panel has separate neutral and ground wires run from the main panel. The neutral and ground busses must not have a connection. There is no ground rod at the sub panel(s).

Conversion to T-T grounding provides a cleaner ground and is shown in the 2 signal choke diagram.

NOTE: The **National Electrical Code (NEC)**, or NFPA 70, is a regionally adoptable standard for the safe installation of electrical wiring and equipment in the United States. It is part of the National Fire Codes series published by the National Fire Protection Association (NFPA), a private trade association. Despite the use of the term "national", it is not a federal law; it is an insurance company recommendation.

NOTE ON T-T GROUNDING: T-T grounding is widely used in Europe and its use is growing internationally. It has the benefit of providing the cleanest ground with lowest magnetic fields at the homesite. It is therefore a good choice for homeowners with serious electrical sensitivity. T-T grounding is normally used with an RCD (GFI) breaker as the main power disconnect at the home. The “T” on the left of the name “T-T” indicates that one conductor of the power company distribution system is grounded, i.e. connected, to earth (terra) back at the power plant and/or substation. The right hand “T” indicates that the customer’s system is connected to earth (terra) at the home’s main power panel, with no direct connection to the power company neutral. The T-T grounding method provides a very ‘’clean” ground for the home safety ground and for metals that might be used for shielding or as a chemical barrier. (The issue of grounding systems and ELF magnetic fields will be addressed in more detail in the second article in this series.)

Digikey 3-signal (6 wires) Common Mode Choke installed in Auxiliary box and connected to sub-panel through knockouts on sides of boxes.

NOTE: My system is set up with several individual buildings, each with its own breaker box and circuitry, so we were able (except for the dryer choke) to fit the necessary chokes and connecting wires into the subpanel breaker boxes. But if you are installing the common mode chokes on the main breaker box that runs your entire house, it would probably work best to install one or two auxiliary boxes beside the original breaker box and put the chokes in those, as we did for the larger sized dryer choke. Otherwise, it will be difficult to make all the connections, fit the chokes and connecting wires (with wire nuts) into the breaker box, and close the outer cover.

NOTE: If you are electrically sensitive and are considering adding CMC filters to your household circuitry to remove EMI, it would be a good idea to also consider reducing the total number of breakers being used, by combining or consolidating circuits. Often, homes are wired with one breaker per one or two Romex circuits, with little thought given to the actual amount of current that is being used. If you don't use electric heaters or other high current devices on outlets except in the kitchen, it might work well to combine all other lighting and outlet circuits into a single 20A breaker, with a single common mode choke. If you do use electric heaters in other rooms, then each of those circuits should have its own breaker and common mode choke. Appliances such as dryers and water heaters, which draw a high current, should also have a dedicated circuit and common mode choke.

There is NO danger from consolidation as long as you keep in mind the amount of current likely to be needed on a given circuit. Nuisance breaker tripping from breaker overload is the only penalty for over-consolidation. It is a good idea to label each circuit's hot (black) wire before it is removed from the labeled breaker for ease in troubleshooting or reconfiguration should you need to revise your circuit consolidation at some point in the future.

So instead of having just a single Romex circuit (black-hot; white-neutral; bare copper-ground) connected to the output of the common mode choke, as shown in the above diagrams for hook-up of the 2-signal and 3-signal common chokes, you might have 2-4 circuits connected to one choke. This is safe and code compliant, but make sure your connections are all secure.

SYNOPSIS

Installation of either an AMI "smart" meter or a non-transmitting digital meter on the home poses a danger to the health of the occupants, especially to anyone who is already electrically sensitive. Although the effects of an actual smart meter are much worse, because it radiates (transmits) bursts of high frequency electromagnetic interference (EMI), both contain a poorly-designed, unfiltered switch mode power supply (SMPS) which produces high frequency EMI and circulates it on the home wiring system. Since the conducted emissions of ‘’smart’’ meters are not filtered, both switching power supply and microwave frequencies are conducted and re-radiated from the home wiring. In the past few years, many U.S. electric utilities have switched to smart meters as their standard equipment. Although they may provide an opt-out program for customers who do not want a smart meter, they are now moving to make a non-transmitting digital meter the only other option, removing the opt-out customer’s existing analog meter and installing a digital meter in its place in order to measure time-of-use power consumption.

The type of high frequency EMI produced by an SMPS is called “common mode” EMI, because it is present on (common to) both the hot and neutral wires of the home wiring system. Common mode EMI cannot be filtered out with capacitor-only filters such as those Stetzer and Greenwave are selling. The best filter for removing common mode EMI is the common mode choke.

Unfortunately, common mode choke filters are not commercially available in a size that is large enough to use as a single “whole house” filter for a 100 -200 amp entry. But smaller-sized chokes for 15, 20 and 30 amp breakers are readily available at a relatively inexpensive price. These “point-of-use” filters can be installed on individual circuits, or a consolidation of several circuits, in the household breaker box by a competent electrician, electronics technician, electrical engineer, skilled radio hobbyist, or a homeowner with electrical wiring experience.

For an NEC code-complaint sub panel that has a safety ground from the main panel, a 3-signal common mode choke must be used, so that both the neutral and the safety ground are filtered. This is due to the fact that all connected wires, not just the hot and neutral, will carry common mode EMI.

In homes for people with serious ES, who have a medical need for a very clean ground for interior foil barrier/shielding and metal siding/roofing, Weber (co-author of this article) has been using a common European style independent earth ground, known as T-T grounding. Since a T-T grounding system has an independent earth ground, using either (1) an RCD (ground fault) breaker, or (2) 20V TVS isolators for connection to the safety ground from the main panel, or (3) a very low impedance (<0.2 ohm) earth grounding system, the independent ground wire needs no filtering and the inexpensive 2-signal common mode chokes may be used. While T-T grounding is not covered in the US NEC recommendations, it is widely used around the world and, with a main RCD breaker for all sub panels, has better safety than the U.S. T-NC (shared company and customer neutral/ground) grounding practice. It is a very good solution for those with serious ES, providing the cleanest possible grounding system and reducing net neutral-to-earth magnetic fields at the home site.

Both 2-signal and/or 3-signal common mode chokes, when correctly sized and installed, will filter out common mode EMI from the non-transmitting digital meter as well as common mode EMI coming onto the property from neighboring homes and/or power lines. They cause no increase in reactive power use and no increase in magnetic fields from home wiring and grounding.

If your non-transmitting digital meter is currently installed on the side of your house, you will need to first remote it from the house on a pedestal and rewire the main breaker box as a sub panel (or replace it). Then install the common mode chokes in the panel or in a box mounted adjacent to the sub panel. Otherwise, the radiated EMI from the poorly-designed (for EMC) processor/meter itself may be picked up (again) by the household wires after they have been filtered through the chokes, rendering them less effective for higher frequencies. This article shows how to install both 2-signal and 3-signal common mode chokes, explains how and why they work, and presents additional information you should consider in order to successfully filter out the EMI from various sources in and around your home.

RESOURCES

Below are some links to more in-depth technical information on EMI/RFI/EMC and Common Mode Choke filters.

Click here https://michiganstopsmartmeters.com/wireless-or-not-smart-meters-harm-your-health/ for an article on the health effects of both “smart meters” and non-transmitting digital meters. This is a good introduction to the subject if you are not familiar with the basics and a concise summation even if you are.

Click here https://www.bing.com/images/search?q=common+mode+chokes+images&qpvt=common+mode+chokes+images&FORM=IGRE for Images of different types of commercially-available common mode chokes.

Click here https://en.wikipedia.org/wiki/Choke_%28electronics%29 for an article on various types of chokes and their use in electronics

Click here http://premiermag.com/pdf/PremierMagnetics_WP_v2.pdf for an article titled “Using Common Mode Chokes to Reduce EMI/RFI in Off Line Switching Power Supplies”.

Clilck here https://www.murata.com/products/emiconfun/emc/2011/10/28/en-20111028-p1 and here https://www.murata.com/products/emiconfun/emc/2014/07/24/en-20140724-p1 for additional, more-detailed diagrams and explanations of how common mode chokes work.

Click here https://myantennas.com/wp/tech-info/about-cmc/ For an article on common mode chokes and their applications, written by a Ham radio operator.
and here http://www.yccc.org/Articles/W1HIS/CommonModeChokesW1HIS2006Apr06.pdf for a more in-depth exploration of the topic by the same Ham radio operator.

Click here https://en.wikipedia.org/wiki/Switched-mode_power_supply for an article from Wikipedia on Switched Mode Power Supplies (SMPS)

Click here https://en.wikipedia.org/wiki/Electromagnetic_interference for an article from Wikipedia on Electromagnetic interference.

Click here https://en.wikipedia.org/wiki/Radio_frequency for an article on Radio Frequencies (RF)

Click here http://www.arrl.org/power-line-noise for an article on power line EMI noise and also one on how to use an AM radio to locate home EMI sources. Scroll down to read the various articles posted on the site.

Click here http://www.emiguru.com/books/edn-designers-guide-paypal/ if you are interested in more in-depth information on EMI and EMC. This is the PDF version (immediate download, Price: $29.00) of a concise book on practical EMC titled *EDN Designers Guide to Electromagnetic Compatibility* by Daryl Gerke, PE, and William Kimmel, PE.

Click here https://www.amazon.com/Power-Interference-Handbook-Marv-Loftness/dp/0965376036 for link to the book *AC Power Interference Handbook* by Marv Loftness. This is an older (2001) but still relevant book on power line EMI.