




TRIPLETT
Loop Coil
Instruction Manual



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Triplett Loop Coil Instruction Manual

NOTE:

This manual covers both the 60Hz and 50Hz versions of the Mitigator. The parameters shown in [] are for the UK where the standard power line is 50Hz/240 Volts. Depending upon your situation, line voltage may vary from 100 - 250 Volts. Please consider this while reading the following text.

SECTION 1: INTRODUCTION

The Triplett 3232 Loop Coil is a rugged, weather resistant coil designed to aid in the search for and location of magnetic fields radiating from power lines.

As an accessory item for the Triplett MITIGATOR, it is intended to be electrically compatible with existing Loop Coils, such as the CCS105. Unlike the '105, however, the 3232 is constructed from a semi-rigid polyurethane that is highly resistant to fracturing and impact damage.

SECTION 2: MITIGATOR APPLICATIONS MANUAL

The Triplett MITIGATOR Applications Manual provides background information that can be helpful in understanding magnetic fields, harmonics, Ground Return Current, etc. It is, therefore, recommended that the Loop Coil user read the appropriate sections of the MITIGATOR Applications Manual in order to better understand the causes and solutions for induced harmonic noise problems.

References will be made throughout this test to additional information that may be found in the MITIGATOR Applications Manual.

SECTION 3:

CONNECTING THE LOOP COIL TO THE MITIGATOR OR A SIMILAR TEST SET

An interconnecting cable is supplied with the Loop Coil for the purpose of connecting the Loop Coil to a test set that utilizes standard female banana jacks spaced on 3/4" centers. The end of the cable connecting to the MITIGATOR must be plugged into the TIP and RING input jacks. The polarity of this connection is not critical.

In some cases, the user may wish to extend the length of the interconnecting cable. Although the supplied cable is shielded, a shielded cable is not really required, nor is the gauge of the wire critical. Twisted pair is probably the best because it doesn't pick up as much noise as wires that are not twisted. The lower noise pickup of twisted pair is usually not very important in this application, however, and if more available than twisted pair, common lamp cord ("zip" cord) can be used. The connectors on both the Loop Coil and the MITIGATOR are standard "5 way binding posts" and will accept bare wire connections.

SECTION 4: MITIGATOR OR TEST SET INPUT IMPEDANCE

To use the Loop Coil with the MITIGATOR, set the INPUT (F1) on the MITIGATOR's MAIN MENU to LOOP COIL. For use with an alternate test set, set the test set to "bridging" input.

SECTION 5: BASIC LOOP COIL TEST

The Backlight circuit in the MITIGATOR generates some residual noise. It can usually be measured by placing the Loop Coil next to the left side of the MITIGATOR's case. The signal is usually somewhere between 400 and 600Hz. In order for this signal to be present, the Backlight must be turned ON. This source of magnetic field can be used as a Loop Coil check if the user suspects that the Loop Coil is not functioning.

SECTION 6: POSITIONING THE LOOP COIL

The purpose of the Loop Coil is to measure the strength of magnetic fields emanating from power lines in the vicinity of the Loop Coil. Single phase, two phase, or three phase lines may be measured. The power configuration may be delta or wye.

The coil must be “pointed” at the power line that is to be measured. Figure 1 illustrates the proper method of pointing the coil. With the coil oriented as shown, maximum signal pickup should occur. This is the typical orientation used when the coil is being hand held for a close up survey of a power line. Be aware, however, that metal objects near the Loop Coil will affect the strength and orientation of the measured magnetic field.

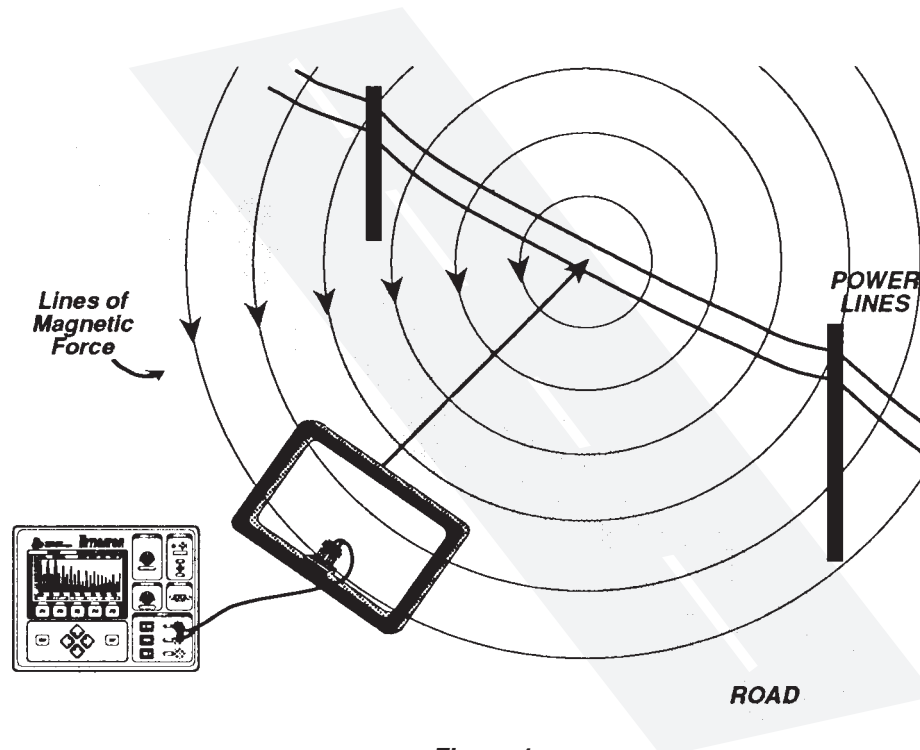


Figure 1
Pointing the Loop Coil at Power Lines

What we are attempting to do by proper positioning of the coil is achieve the best (strongest) signal pickup. This is done for two reasons. First, it is necessary that the MITIGATOR has a strong enough signal to display on its screen. And second, a more accurate measurement of magnetic field strength is achieved when the Loop Coil is oriented for the strongest pickup.

Some experimentation and experience will allow the user to judge the positioning of the coil in order to get the strongest signal.

Since it is common for the user to temporarily mount his Loop Coil to the metal body of a vehicle, in order to perform a moving survey, it is likely that the vehicle's body will distort the magnetic field around the vehicle and may necessitate a re-orientation of the coil in order to achieve the best signal strength.

What does this mean? It means that although the best signal pickup should occur when the coil is positioned as in Figure 1, the user should experiment with the orientation of the coil for the best pickup, particularly when attaching it to a vehicle. If the signal strength is fairly high, it may not be necessary to orient the coil for the strongest signal, and a fixed position mounting may be used. It is common for the coil to be mounted vertically on the top of the vehicle cab (see Figure 2). If the coil is mounted on the hood, it may pick up some engine noise. Some users have fabricated mounting brackets using magnetic mounts or suction cups. A few suggestions are shown in Figure 3 and Figure 4. In some instances, several Loop Coils are mounted to the vehicle and then individually selected via a switch.

Perhaps the easiest mounting is simply to fabricate a few "S" hooks from coat hanger wire and to hang the coil on one of the car windows. The coil can be hung on the inside of the car window. The choice made for the Loop Coil mounting may have an effect on the measurements taken with the coil. This will be explored later.

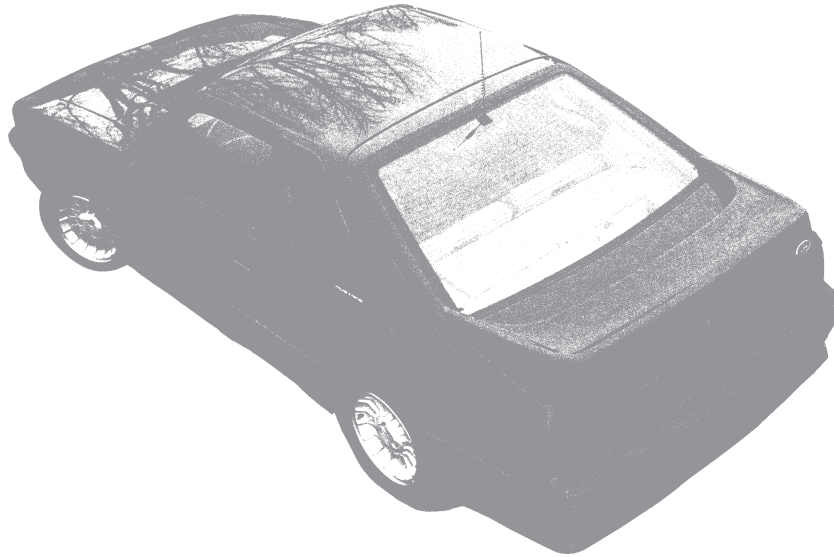


Figure 2
Loop Coil mounted on top of Vehicle

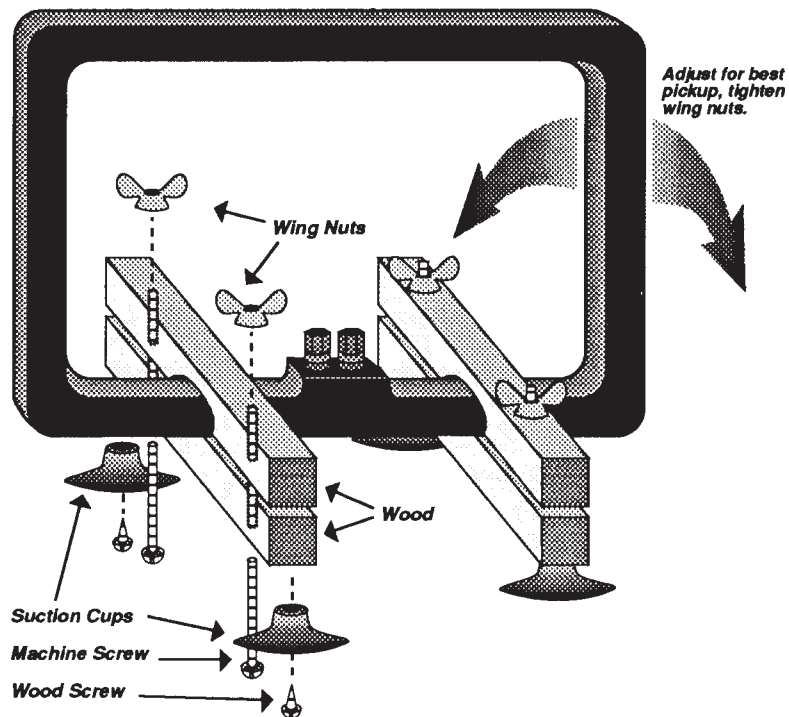


Figure 3
Example of a "Homemade" Mounting Bracket

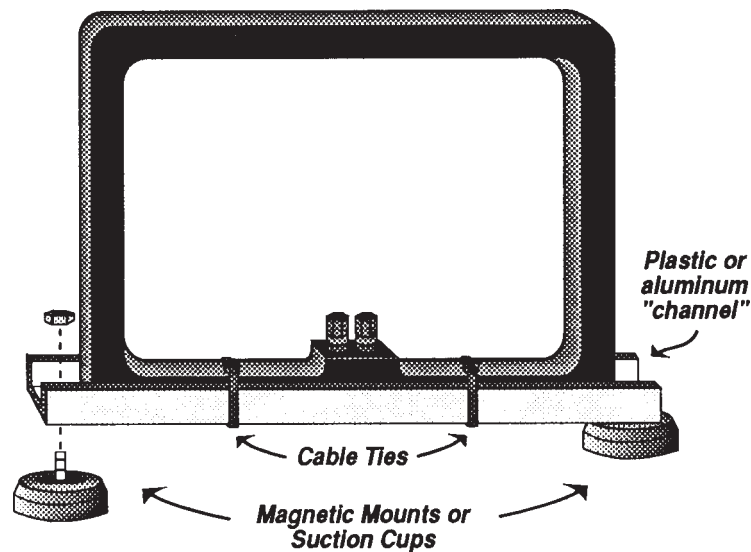


Figure 4
Another example of a "Homemade" Mounting Bracket

6.1: DON'T BE FOOLED!

The Loop Coil only responds to magnetic fields whose lines of force pass through the opening in the Loop Coil. This is shown in Figure 5. If the coil is oriented so that the lines of force do not pass through the Loop Coil opening (Figure 6), the coil will not produce an output signal.

The Loop Coil only measures the magnetic field that actually passes through the coil opening. "Pointing" the coil only serves to position the coil so that it picks up the most signal. For example, if a Loop Coil survey is made down a road that has power lines on both sides of the road, do not be fooled into thinking that you are measuring the magnetic field of only one of the power lines because you have the coil "pointed" at a particular line. **THE COIL MEASURES THE MAGNETIC FIELD AT THE LOCATION OF THE COIL, NOT WHERE THE COIL IS POINTED.** Pointing the coil only serves to maximize signal strength.

In such a situation, the user can determine which power line contains the harmonics of interest by going to a location where the lines separate from each other and measuring each line individually or by making measurements as close to each line as possible, causing the stronger magnetic field of the closer line to "override" the weaker field from the farther line.

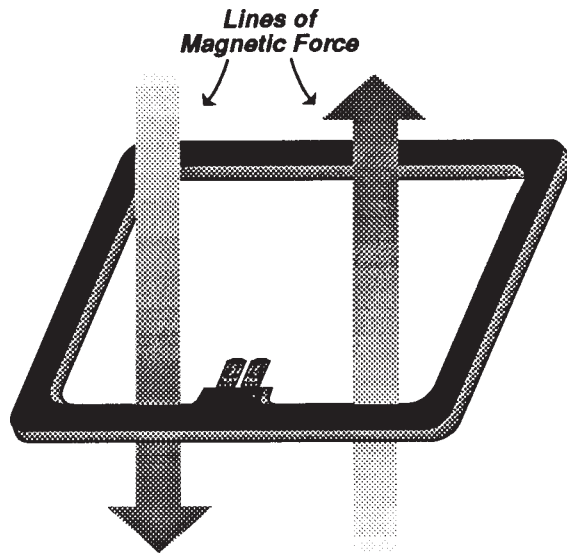


Figure 5
When the Lines of Magnetic Force pass through the opening in the Loop Coil, the Loop Coil produces an output signal.

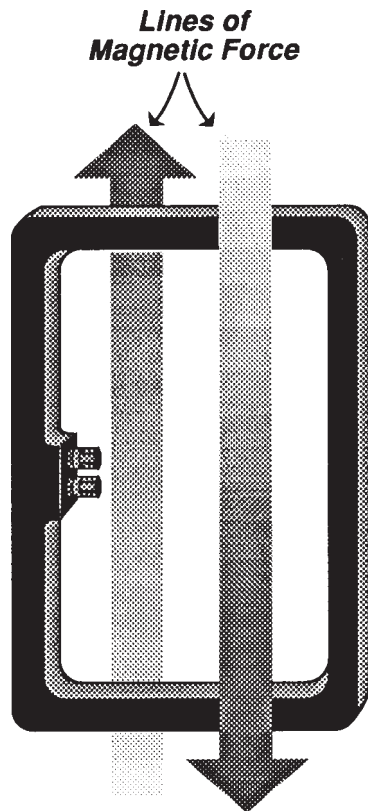


Figure 6
When the Lines of Magnetic Force do not pass through the opening in the Loop Coil, no output signal is produced.

SECTION 7: CHOOSING THE RIGHT FILTER

The signal output (voltage) of the Loop Coil increases in strength as the frequency of the magnetic field increases. This is a “direct” effect which means that, for instance, if the frequency of the magnetic field increases by 10 times, the output voltage of the coil will increase by 10 times.

With this in mind, the user can see that a magnetic field of a particular strength at 600Hz will produce an output voltage from the Loop Coil that is 10 times stronger than the same magnetic field strength at 60Hz. This effect is inherent in all Loop Coils and does not represent a deficiency in the 3232 Loop Coil. Because of this effect, the Loop Coil is more sensitive to higher frequencies.

To compensate for this effect, the MITIGATOR has a 20/F filter (pronounced “20 over F”), [1/F, one over F]. The sensitivity of the 20/F [1/F] filter is just the opposite of the Loop Coil’s sensitivity. Consequently, if the 20/F [1/F] filter is selected when the Loop Coil is being used, the “frequency response” of the measurement will be “flat” meaning that all frequencies will be displayed with the same sensitivity.

Although this may seem to be the obvious and appropriate way to filter and display the various signals coming from the Loop Coil, the 20/F [1/F] filter is usually not used by the typical craftsperson. The reason for this lies in the characteristics of the magnetic field that we are attempting to measure. As explained in the MITIGATOR Applications Manual, the magnetic field is composed of the fundamental frequency, 60Hz [50Hz], and its harmonics. It is the general nature of these harmonics to gradually decrease in level as their frequency becomes higher and higher. That is, it is likely that a higher frequency harmonic, like 1620Hz [1350Hz] will be lower in level than a lower frequency harmonic like 540Hz [450Hz].

Remember that the 20/F [1/F] filter has a sensitivity which is opposite to the Loop Coil sensitivity. The 20/F [1/F] filter is LESS SENSITIVE at higher frequencies. Consequently, because the higher frequency harmonics are naturally lower in level, and because the 20/F [1/F] filter makes the MITIGATOR less sensitive at these same frequencies, if the 20/F [1/F] filter is used, these frequencies may become so low in level that they will not be displayed on the screen of the MITIGATOR.

Is this important? Well.....Yes!

Why?

Because the user typically discovers that the magnetic field that is picked up by the Loop Coil might only measure about 30 or 40dBrn. Why is it so weak? Because it really is of relatively low intensity!

Then how does this low intensity magnetic field cause noise on a telephone line? Because in the usual situation, the length of exposure between the telephone cable and the power line is relatively long (sometimes 5 to 10 miles or more). Over these long distances, the relatively weak magnetic field of the power line will induce noise into the telephone cable. However, back to the Loop Coil output signal level. Since the Loop Coil output level is typically low to begin with, selecting in the 20/F [1/F] filter may further reduce the level of the higher harmonics and make them unmeasurable on the MITIGATOR. We are interested in these harmonics because they are often indicative of problems on the power line. Consequently, we don’t want to eliminate them from our measurements.

So, even though a 20/F [1/F] filter is the “proper” filter to use in order to examine the strengths of the harmonics, it is often not used because the signal levels involved in the measurement are too low. In such cases, the FLAT [NONE] filter or C-MESSAGE [PMSG] filter is used. The validity of the FLAT [NONE] filter was just discussed. The absence of a 20/F [1/F] filter is, essentially, a FLAT [NONE] filter. In general, the FLAT [NONE] filter does not affect the signals expected to come from the Loop Coil.

Some noise mitigating craftspersons may opt to use the CMSG (C-MESSAGE) [PMSG] (PSOPHOMETER) filter instead of either the 20/F [1/F] or FLAT [NONE] filters when making a Loop Coil measurement. This is understandable when one considers the effect of the CMSG [PMSG] filter. Essentially, the CMSG [PMSG] filter is more sensitive to frequencies that can be easily heard by the customer (subscriber). Consequently, when measurements are made with a CMSG [PMSG] filter, the measurement favors the frequency components that are most audible to the customer. Since the customer complaint usually is about noise on the line, this approach makes some sense.

However, because the CMSG [PMSG] filter sensitivity is dissimilar to the 20/F [1/F] filter sensitivity, the test results may be difficult to interpret. What is meant by this statement? Well, it means that the true strength of the magnetic field is not accurately measured when using the FLAT [NONE] or CMSG [PMSG] filters. Only the 20/F [1/F] filter produces a true representation of the magnetic field strength. When the FLAT [NONE] or CMSG [PMSG] filters are used, the user must understand that the measurements will be “skewed” by the effects of the filters. Even so, viewing the Loop Coil’s output signal with various filters engaged is meaningful to the experienced craftsperson.

SECTION 8: LOOP COIL TEST METHODS

A Loop Coil test is usually performed when harmonic noise has been found in the Circuit Noise and Power Influence on a pair or group of pairs (cable). Since this type of noise is usually caused by a power exposure, it is necessary to identify the location of this power exposure. The offending exposure may parallel the entire length of the telephone cable or it may only parallel it for a few spans.

As explained in the MITIGATOR Application Notes, high Circuit Noise and Power Influence that contains harmonic noise is most often the result of magnetic fields radiating from power lines that parallel phone lines. Since a Loop Coil measures magnetic fields, it is appropriate to use such a coil to search for the source of the noise.

The process typically starts at the customer site where spectral Circuit Noise and Power Influence tests are performed on a pair. The measurements are typically CMSG (C-Message) [PMSG] (Psophometer) weighted (filtered) so the harmonics most annoying to the customer are viewed on the MITIGATOR screen. The ANALYSIS mode of the MITIGATOR can be used to make suggestions to the user as to the possible causes of the harmonics. If the customer is experiencing problems related to excessive levels of 60Hz [50Hz], a FLAT [NONE] spectral test will reveal the amount of 60Hz [50Hz] present. A HARMONIC TABLE test will display the 60Hz [50Hz] level in volts.

After identifying the offending harmonics, the Loop Coil can be used to track down the exposure where the harmonics are being induced onto the telephone cable, and further, to help identify the actual cause of the fields radiating from the power line.

A common misconception by first time users of Loop Coils is that the coil will lead the user to the source of the harmonics by simply finding the strongest magnetic field with the coil. Although this is a possibility, it is very unlikely that a harmonic source will actually be found by this method. To understand the proper method of tracking a harmonic with a Loop Coil, it is first necessary to understand how harmonics are created and propagated (sent) through the power system.

SECTION 9: HARMONIC SOURCES AND LOADS

There are numerous scenarios that will result in harmonic currents flowing in a power lead. Of these, there are several which occur more frequently than others.

9.1: CUSTOMER LOADS AND MAGNETIC FIELDS

The MITIGATOR Applications Manual points out that harmonic currents in a power line can be the result of various customer loads that pull current in surges, and that this type of equipment usually contains

rectifiers. In general, in order for enough current to flow to create a detrimental magnetic field, the customer is usually a relatively large power user, like a commercial or industrial enterprise. Common forms of rectifier-type equipment (including SCR's) are large motor speed controllers, electronically controlled heaters, electronic lighting, power supplies for electroplating, etc. Loads like department store lighting and irrigation pumps have been known to produce harmonic currents. These loads produce a distorted current waveform (as compared to a sine wave) which is comprised of numerous harmonics.

In order for current to flow in a circuit, there must be a source of current and a load for that current to flow to. In our case, the source for the current may be a power substation and the load may be the customer rectifier loads.

The current flow from the substation to the customer causes a magnetic field to be generated along the entire length of the power lead from the substation to the customer. In the absence of transformers, capacitor banks, regulators, side legs, etc., the current flow will be uniform along the entire length of power line, and hence, the magnetic field created will also be of uniform strength along the entire length of the power line. This is illustrated in Figure 7.

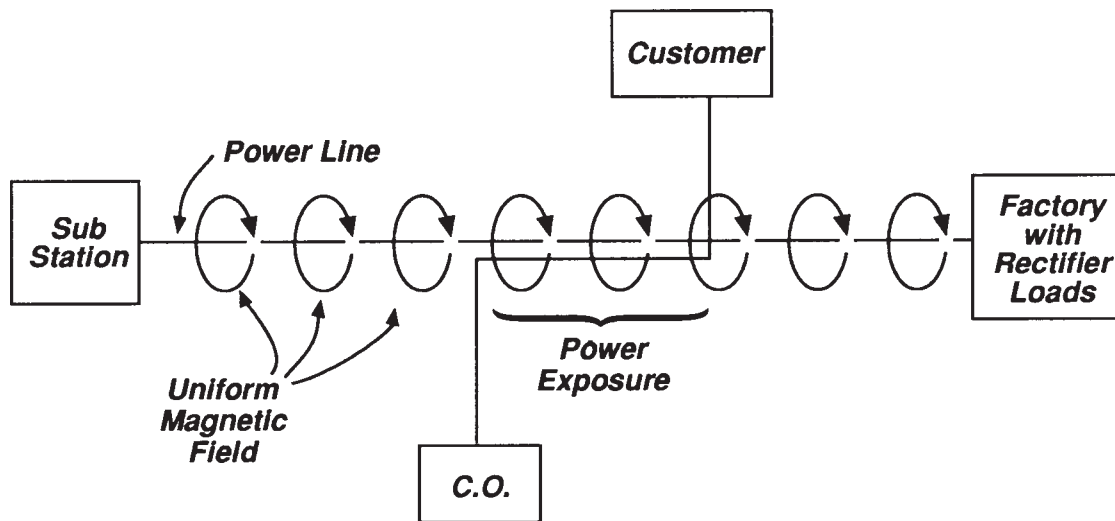


Figure 7
Uniform distribution of Magnetic Field
around a power line.

Figure 7 also shows a telephone line that is exposed to the power line for several spans. A customer on the telephone cable is experiencing harmonic noise problems and a Loop Coil survey of the cable's run identifies the spans where the power line and the telephone cable are exposed to each other.

Remember, however, that the magnetic field surrounding the power line is relatively uniform. Consider what this means. Exploring the length of the power line WILL NOT result in finding something on the line or at either end of the line which radiates a higher level of harmonics than found at the offending power exposure. That is, the output from the Loop Coil WILL NOT get stronger at either the substation or the customer. The strength of the Loop Coil's signal WILL NOT lead the craftsperson to the equipment creating the harmonic currents. (If direct access to the customer's load(s) is obtainable, it may be possible to measure increased harmonic output in the vicinity of the equipment.)

In our example, the rectifiers at the customer load are creating the harmonic currents. But, if we did not know this, using the Loop Coil as our only source of information, we would not be able to easily determine if the harmonic currents are being produced at the customer site, or if they are being produced at the

substation and sent to the customer site. In either case, the harmonic current flow along the power line looks the same (as far as the Loop Coil is concerned). All we know for sure, at the moment, is that a particular power line is radiating a lot of magnetic fields along its length.

How can we determine what is really happening? Unfortunately, there is no easy way to tell where the harmonic currents are originating from. The best method to use, with the resources available to the craftsperson, is to examine the installations at either end of the power line for signs of possible harmonic current generation (such as customer loads known to produce harmonic currents).

In the example of Figure 7, the spectral signature of the harmonic currents in the power lines provides an additional clue. The rectifier loads at the customer site (factory) will produce a signature indicative of rectifier loads. This type of signature is unlike most signatures produced by any common substation problems. Hence, the craftsperson can surmise that rectifier loads at the customer site are the most likely source of the harmonic currents.

9.2: LOAD BALANCING

When dealing with 3 phase lines, the most direct method of controlling the radiated magnetic fields is to make sure the loads on the lines are balanced. (This is not the same balance as telephone line balance.)

It may be found that the magnetic fields responsible for noise on a telephone line are coming from an exposure where 3 phase power lines are poorly balanced. It is quite possible for the same power lines to be well balanced in the rest of the exposure. Balance depends upon the customer loads on the power line.

Balance simply means there is about the same amount of current flowing in each phase wire. When this is the case, magnetic field cancellation will take place. The MITIGATOR Applications Manual gives more detail on this topic.

Load balancing is generally most helpful for suppressing 60Hz [50Hz] and the “odd non-triple harmonics”. Some cancellation of odd triple harmonics may occur, depending upon the amount of Ground Return Current flowing in the earth.

If a Loop Coil measurement of a 3 phase exposure shows a large amount of 60Hz [50Hz] and odd non-triple harmonics, and a Probe wire test confirms that Ground Return I*T is high, it would be advisable to have the power company measure the load balance in the suspected section of the power line. They can do this with a clamp-on ammeter at the site. Measuring load balance of the power line at the substation WILL NOT necessarily indicate the load balance at the Exposure site.

If they (the power company) decide to correct a poor load balance problem at the exposure site, be aware that they may end up making the load balance worse at the different location. They will, of course, try to avoid doing this, but sometimes they may just “cut and try.” The results may be somewhat random. Translation: When the power company re-balances the power line at the exposure site, you may end up with more noise on previously quiet phone lines. It may then be necessary to find the “new” poorly balanced power line section and have it re-balanced, etc. If the unbalance can be forced into an area where there is no telephone exposure, the problem may be solved.

Two phase power lines cannot be balanced to completely cancel the radiated magnetic fields. Even so, SOME magnetic field cancellation will take place. So, it is beneficial to balance the line as well as possible, even though the results will not be as good as those obtainable with 3 phase lines.

Single phase lines cannot be balanced. A phase reversal transformer, however, may prove effective in reducing noise in the paralleling phone line. If the exposure is fairly long, at the approximate midpoint of the exposure, the polarity of the power line can be reversed with a 1:1 (one-to-one) transformer. This will

reverse the polarity of the magnetic field radiating from the line following the transformer. This does not cause any cancellation of magnetic fields, but an interesting phenomenon takes place in the phone line. On one side of the transformer, the noise induced into the phone line is of a particular polarity (or phase). On the other side of the transformer, the induced phone line noise polarity is not opposite to the original polarity. If the overall strength of the noise signals on either side of the phase reversal transformer is the same, the noise itself will cancel out.

Although it is best to “solve” the problem of excessive influence (i.e. power line magnetic fields) at its source, this is not always possible or reasonable. In these cases, devices can be added to the telephone line to mitigate the effects of the excessive influence. These effects may be excessive 60Hz [50Hz], excessive harmonics, or both.

Some of the available devices treat individual pairs, some treat groups of pairs, and some treat entire cables.

These devices are often called “noise chokes”, “drainage coils”, “choke and drains”, Harmonic Drainage Reactors (HDR’s), Induction Neutralizing Transformers (INT’s), etc. Each of these devices has a particular function, and, consequently, their use is dependent upon the specific situation.

9.3: SUBSTATION HARMONIC GENERATION

In general, the most common malfunctions at a power substation that could lead to the generation of excessive harmonic currents are over-excited or defective power transformers. Over-excited transformers are transformers that have too much primary voltage applied to them. Independent tests have shown that as little as 1 or 2% of primary “overvoltage” can cause a significant increase in the harmonic currents produced by the transformer. At specific harmonic frequencies, current can rise by 10dB (approximately 3 times as much, or 200% more) due to a 3% increase in primary voltage. Although the overall THD (Total Harmonic Distortion) may increase only slightly in this situation, the harmonic currents rise dramatically. This increase in harmonic current can translate into a rise in induced noise on the telephone line.

Why would the primary voltage on the substation transformer be too high? Often, the power company does this on purpose! They are required to deliver at least 120 volts [240 volts] (usually) to any customer on the line. Sometimes, in order to satisfy the end-of-line customer, they simply crank up the voltage at the substation. This is similar to the telephone company practice of cranking up the C.O. battery in order to get more loop current on long lines.

When the primary voltage is raised, however, a significant rise in harmonic currents in the power line can occur, which in turn causes noise on exposed telephone lines. Since the power company seldom checks for harmonic current every time they adjust a voltage, they don’t know that they’ve just created the potential for some very noisy phone lines in the surrounding area.

To make matters worse, the power company sometimes installs “voltage regulators” (also called “automatic tap changers”) at the substation (and in the power lines). A voltage regulator automatically adjusts the voltage applied to a transformer or power line. Regulators are usually installed on power lines that experience large changes in load during the day. When the line is heavily loaded (by customers using a lot of power), the line voltage has a tendency to sag. A voltage regulator automatically cranks up the voltage to make up for the sag. Alternately, when the line is lightly loaded, the regulator turns down the voltage. This could lead to a situation in which, under heavily loaded conditions, the regulator cranks up and causes harmonic current generation in a transformer, which then sends the harmonic current down the power line past telephone cable exposures. This means that the telephone line only “noises up” when the loads on the power line are heavy. If the craftsperson is unaware of this “connection” between the power line load and telephone noise, it may appear to the craftsperson that the noise comes and goes randomly. More often than not, however, the noise will be discovered to be cyclic in nature, varying with the time of day, as the power line loads vary with the time of day.

Harmonic currents can also come from a lightly loaded transformer. Transformers “reflect” their secondary load current into their primary winding. This means that if a heavy load is placed on the secondary of a transformer, the load will reflect into the primary of the transformer, causing it to be heavily loaded. This heavy primary load will cause the primary voltage to sag (be lower than normal) due to resistance in the power lines feeding the primary winding. If, under this loaded condition, the primary voltage is at its nominal rating (100% rating), and if the secondary load decreases, the primary voltage will rise above its nominal current generation. As previously mentioned, a small amount of overvoltage can cause a significant rise in harmonic current generation. Consequently, lightly loaded transformers can be just as guilty as heavily loaded transformers when it comes to harmonic current generation. It is actually more appropriate to consider the effect of the primary voltage (or overvoltage), but this depends to some degree on the loads on the transformer.

It is also necessary to consider the possibility of a bad substation transformer. Some transformers contain “tertiary” (third) windings. These windings are incorporated into the transformer specifically for the purpose of suppressing harmonic current generation. They typically consist of a set of delta connected windings in the transformer. These windings sometimes supply power to loads in the substation. Other times, they are only connected to each other inside of the transformer and are not connected to any external loads. Consequently, if one or more of the tertiary windings fail, it may not be immediately obvious to power company personnel. No customers call up to complain about their power going off. Instead, if other conditions warrant it, harmonics suddenly appear on the power line.

Not all transformers contain tertiary windings. They are typically only necessary in wye-wye connected transformers.

As in the telephone company, some power line installations function for many years requiring a minimum of maintenance. In these installations, transformers that are 20 or 30 years old are not uncommon.

The craftsman should also be aware that the power company reuses a lot of their old gear. In general, transformers have a long life if properly cared for. Consequently, as power lines are rerouted, the used equipment is often sent to a refurbishing / warehousing depot where old transformers are refurbished and, after some time in the warehouse, are eventually reinstalled to repair a blown transformer, or installed in a new power line run. The depot seldom checks the transformers for their susceptibility to produce harmonic currents.

As the country has gone through some periods of prosperity and decline, the transformers made in those eras show signs of the national financial health. A typical method of reducing the generation of harmonic currents in a transformer is simply by using a large magnetic core. This core is made out of silicon steel, typically called “transformer steel”. It is possible to get the transformer to work reasonably well, within limits, with less steel. When this is done, however, the transformer has very little “headroom” and often becomes a significant producer of harmonics when the primary voltage is increased by just a few percentage points. Be particularly wary of transformers made during World War II. A lot of products skimmed on basic materials in order to satisfy the appetite of the war effort. Transformers are usually marked with their date of manufacture.

The situation just presented (over-excited transformer) is only the simplest of the possible scenarios. The example was purposely simplified to illustrate the basic causes of the problem. In the real world, there are usually several in-line distribution transformers as well as capacitor banks between the customer and the substation. We will examine how these elements affect the generation and propagation of harmonic currents.

9.4: TRANSFORMERS

There are several types of transformers that are often seen on the power lines that parallel telephone lines. The transformers at the customer locations that step down the power line voltage to the voltages used by the customer (often 120/240 volts) are called distribution transformers. In rural areas, there is often one transformer per customer, and in urban and suburban areas, several customers are often connected to the same transformer. Customers that use large amounts of power may have several transformers or a small substation dedicated exclusively for their usage.

An observer will also note that some transformers are inserted in-line in the power line. These are generally found in rural areas where it is necessary to boost the line voltage slightly to make up for losses in the power line. Sometimes these are fixed “boosters”, and sometimes they are voltage regulators (as previously described).

All of these transformers found on the power line have the potential to generate harmonic currents. These currents may travel down the power lines in either direction, or both directions, from a power transformer. Just as previously described, the generation of harmonic currents is usually due to elevated line voltage or defective transformers.

A common test procedure used by noise mitigators who suspect that elevated power line voltages are causing harmonic currents is simply to measure the voltage coming out of the typical AC wall outlet. Measurements of the wall outlet voltage along a suspected power line can indicate if the harmonic currents may be due to elevated line voltage. The nominal outlet voltage is 120 [240] volts, and it has been stated that small increase in the percentage of excess voltage can cause dramatic increases in harmonic current. Therefore, if the voltage is 3 [6] or more volts above 120 [240], an excess voltage condition may be present. Low wall outlet voltage is usually not indicative of a problem (as far as noise on the telephone line is concerned).

It must be remembered that in order for the harmonic currents to flow in the power line, there must be a load on the line. If harmonic currents are generated but there is NO LOAD for them to flow to, THEY WILL NOT FLOW down the power line. If there is no current flow, there are no magnetic fields produced, and no noise induced into nearby ‘phone lines. While this is a well-understood basic principle, it gets more complicated where harmonics are concerned.

This is because all of the loads on the power line are designed to be loads at 60Hz [50Hz], the fundamental current that the power line was designed to transmit. Since the loads were only intended to be loads at 60Hz [50Hz], their load characteristics at harmonics of 60Hz [50Hz] are uncertain. Engineers often talk about the way loads behave at different frequencies (such as the fundamental and the harmonic frequencies) by noting how much “reactance” the loads have at different frequencies. If a load has less reactance, it means that more current will flow through it, and conversely, if a load has more reactance, less current will flow through it. It gets complicated though, because different types of loads have different reactances at different frequencies. Fortunately, there is a general trend to the way reactance varies in different loads, so we can make some reasonably valid assumptions that suit our situation.

9.5: INDUCTIVE REACTANCE

Most devices that have coils of wire in them have inductive reactance. Actually, even a straight piece of wire has a small amount of inductive reactance. These devices are often called “inductors”, “chokes”, transformers, coils, etc. A common industrial source of inductive reactance is induction motors. Most AC motors that don’t have brushes are induction motors. In these inductive devices, the reactance is lowest at low frequencies, and it increases at high frequencies. This means that at higher frequencies, like at the frequency of harmonic currents, current will not flow through these devices very well. As with every rule or principle, there are exceptions. But the general behavior of current through an inductor is that it diminishes as the frequency of the current increases.

What does this mean to us? It means that loads like industrial motors often don't represent a very good path for harmonic currents to flow through, i.e. they are a much better load to the 60Hz [50Hz] current than they are to the harmonic currents.

9.6: CAPACITIVE REACTANCE: RESONANCE AND SINKS

Capacitors, on the other hand, are very good harmonic current loads. This is because capacitive reactance goes down as frequency increases. Remember, current flows better in lower reactances.

Now is the ideal time to start talking about capacitors on the power line. Capacitors are employed by the power company to improve the power factor of a power line. This is discussed in the MITIGATOR Applications Manual. In that text, we talk about a condition called "resonance", which can develop on the power line. If a resonant condition exists on a power line, the reactance of the capacitor involved in the resonant circuit, in combination with the inductance involved in the resonant circuit, is very low. Consequently, a resonant condition may allow harmonic current to flow. Since resonance is a "tuned" condition, it will be necessary for the resonant circuit to be tuned to a harmonic frequency for any substantial current to flow. On the other hand, some harmonic current will flow even if the circuit is not at resonance. In these cases, the capacitor may act as a "sink".

Because capacitive reactance goes down as frequency increases, a capacitor acts as more of a load as the harmonic frequencies increase. Consequently, a capacitor that is not in a resonant condition causes current flow at all harmonic frequencies, not just a single predominant frequency, which occurs at resonance. However, the amount of current flow at that single resonant frequency is usually much greater than the total current flow of the harmonic currents flowing through a non-resonant circuit. This is because the reactance of the resonant circuit is considerably lower than that of a non-resonant capacitor circuit.

When a capacitor is allowing harmonic current to flow through it, and the circuit is not in resonance, the capacitor is said to be acting as a "sink". Figure 8 shows a simplified version of a common harmonic current problem.

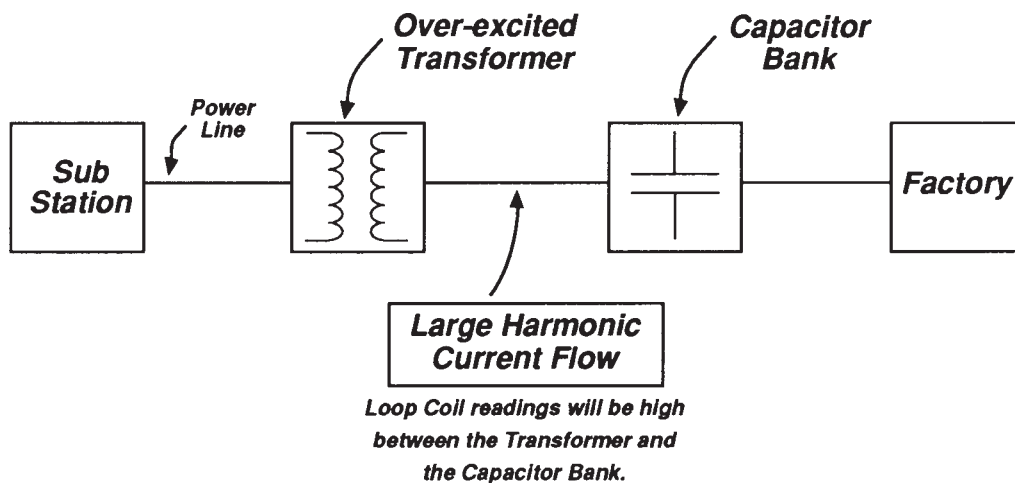


Figure 8
Elevated Harmonic Currents "Circulating" between a Transformer and a Capacitor Bank.

A transformer is supplying power to a factory that uses a large number of induction motors. These inductive loads cause the power line to have a very poor Power Factor (see MITIGATOR Applications Manual). To compensate for this effect, the power company has added a capacitor bank to the line. The capacitor bank, while correcting the 60Hz [50Hz] Power Factor, could cause a resonant circuit if conditions are just right, but it will certainly act like a sink. Remember, none of this is of any consequence

unless there is some source of harmonic current. For our example, we'll accept that the transformer is "over-excited" (has too much voltage applied to it) and is generating harmonic currents.

Because the capacitor bank is acting as a load for these harmonics, these currents will flow from the transformer to the capacitor bank. A small portion of the harmonic currents will flow through the induction motors, but due to their inductive reactance, the currents will be small compared to those flowing through the capacitor. Consequently, in the section of power line between the transformer and the capacitor bank, harmonic currents will be flowing, which means that harmonic magnetic fields will be created, and the potential to induce noise into an exposed telephone cable is very real.

To complicate matters even more, the over-excited transformer could cause harmonic currents to flow on the power line that goes back to the substation. It all depends on whether there is a load for the harmonic currents to flow to. This load doesn't even have to be in-line with the power line. It could be at a customer site being fed from the power line.

Industrial customers often have their own power factor correction capacitors on their premises. Since the power company charges a premium for supplying power to customers with poor power factor, it is often to the customer's advantage to correct his power factor himself, with his own capacitor bank, so that his facility approaches unity power factor.

Consequently, a customer could have a capacitor bank acting as a resonant circuit or a sink on his premises. This means that a Loop Coil survey of a power line going to a customer could indicate that the customer is either generating harmonics or is acting as a load for harmonics. As stated before, it is not possible to tell which is occurring with just the Loop Coil readings.

This is the problem with Loop Coil readings. Although they indicate that magnetic fields are present, they are unable to indicate which way the current is flowing in the power lines. In fact, this is difficult to do with the large majority of test equipment, even equipment attached directly to the power lines.

I hope the reader has recognized by now that the harmonic currents do not flow in the same way as do the 60Hz [50Hz] fundamental currents. While the 60Hz [50Hz] currents will always flow from the power line to the customer, harmonic currents can flow from the customer back into the power lines. In fact, harmonic currents can flow between several customers without flowing back to the substation. Consider a situation in which a customer has an on-site power distribution transformer which is over-excited, and an adjacent customer has his own power factor correction capacitor bank. Harmonic current could flow between the transformer and the capacitor, "noising up" any exposed telephone lines in between.

Because of the variety of loads that customers put on a power line and the transformers and capacitors placed on the line by the power company, the combinations that could result in harmonic current flow are numerous. In most cases, the possibility of causing harmonics in a new installation is not easily predictable. It is not even easy to predict how changing an existing installation may affect harmonics. So many variables are involved that a "cut and try" approach is often used. Unfortunately, this approach seldom solves the problem unless those involved have a clear understanding of the nature and causes of harmonic propagation on the power lines. A lot of this "understanding" is just plain old common sense and some experience. And if it isn't already obvious, the craftsperson is going to have to learn more about how power lines work. He (or she) is also going to need to have a knowledge of power line paths as well as phone cable paths in the area in which he works.

SECTION 10: POTENTIAL VERSUS ACTUAL

Up to this time, we have been talking about the potential noise that could be induced onto a telephone line by a magnetic field. The word "potential" is very important. The presence of a magnetic field does not guarantee that noise will be induced onto a phone line immersed in the field.

In the MITIGATOR Applications Manual, we noted that in order for noise to appear on a phone line, there had to be Influence, Exposure, and Susceptibility. The magnetic field is the Influence. The Exposure refers to how much of the telephone line runs parallel to a power line. And Susceptibility describes the ability of the cable sheath and pair balance to suppress or reject noise. The magnetic field measured by the Loop Coil only provides the Influence. Exposure and Susceptibility must also be present for noise to occur on a phone line.

Consequently, the craftsperson should not assume that a strong magnetic field is the cause of noise on a pair. While this usually is the case, don't overlook the possibility that noise may be induced onto a pair in a location where the magnetic field is much less intense, but the Exposure or Susceptibility is much greater.

SECTION 11: INTERPRETING LOOP COIL MEASUREMENTS

A strict interpretation of specific frequency harmonics at particular levels is not possible when using a Loop Coil as the measuring device. This is because the absolute level of the measured frequencies are greatly affected by the positioning of the Loop Coil in relationship to the power lines. Not only is the distance between the two a factor, but the angular position of the coil affects the level. Also, magnetic field distortions caused by metallic objects in the vicinity distorts the strength of the field.

Fortunately, none of these things affect the accuracy of the frequencies. Consequently, we can note the presence of the frequencies themselves, without giving undue significance to the levels of the frequencies. After the craftsperson has some experience using the Loop Coil, he will be able to determine some general guidelines for the expected levels based upon his test technique and the prevailing method of power line construction in his area.

For the purpose of our discussion, we will divide the levels into three ranges: Low, Medium, and High.

THESE LEVELS AND THE FOLLOWING DISCUSSION ARE BASED ON READINGS TAKEN WITH A C-MESSAGE [PMSG] FILTER.

Just to give the craftsperson some idea of the expected levels, although these may not correlate with the levels in his area, the following general guideline is given:

<i>Low:</i>	<i>less than 30dBrnC [P]</i>
<i>Medium:</i>	<i>30 to 40dBrnC [P]</i>
<i>High:</i>	<i>greater than 40dBrnC [P]</i>

"Low" signals generally do not induce any audible noises onto a telephone line. If noise is heard on the telephone line when the Loop Coil signal level is Low, there may be a problem with bonding and grounding of the cable sheath.

"Medium" signals may produce noise on a telephone line if long Exposures (several miles or more) exist.

"High" signal levels will produce noise on a telephone line, even when the exposure is short and the telephone cable shield is in good condition.

11.1: SPECTRAL SIGNATURES

In general, the spectral signatures of the Loop Coil signal are similar to those identified in the Contel Chart (see MITIGATOR Applications Manual). Since the Contel Chart was developed for use with metallic measurements on a "pair", and not a Loop Coil, we must ignore the graph part of the Chart and look only at the Matrix. A few typical signatures will be examined.

11.1.1: Over-Excited Transformer

When a transformer is over-excited by excessive primary voltage, it can create a harmonic current flow if there is sufficient capacitance on the line to act as a sink. A typical signature of this condition usually consists of the odd harmonics up to about the 13th harmonic (780Hz)[650Hz]. Specifically: 180Hz, 300Hz, 420Hz, 540Hz, 660Hz, and 780Hz. [150Hz, 250Hz, 350Hz, 450Hz, 550Hz, 650Hz]

11.1.2: Bad Capacitors

Actually, this signature really indicates that there is a reactive unbalance on 3 phase power lines. The unbalance may be either capacitive or inductive. An inductive unbalance could be due to an inordinate number of customer inductive loads improperly distributed across the phases. A capacitive unbalance could be the result of a bad capacitor in a bank of capacitors, or a wrong size capacitor in a bank. Usually, this problem causes a harmonic current at 300Hz [250Hz], but sometimes it is also seen at 420Hz or 660Hz [350Hz or 550Hz]. These are the 5th, 7th, and 11th harmonics and, notably, they are not odd triple harmonics but are centered around 540Hz [450Hz], which is an odd triple harmonic.

11.1.3: Resonance

This condition will go unnoticed unless the resonance occurs at a frequency where there is sufficient current flow to “excite” the condition. It usually occurs at a harmonic frequency (of 60Hz [50Hz]) because these are the most likely currents to be available in the power line. The actual source of the harmonic currents may be an over-excited transformer or industrial machinery. The signature will tend to follow the signatures of these phenomenon, but there will be a distinct peak in level at a “resonant” frequency. The power line is considered to be in resonance if there is a predominant frequency that is at least 6dB greater in level than the adjacent harmonics.

Conditions in the power system make resonance likely to occur at odd harmonics below 1000Hz. 540Hz [450Hz] is a common resonant frequency. Do not forget, however, that resonance can occur at any frequency if there is sufficient energy to excite it.

11.1.4: Rectifiers: DC Harmonics

Rectifiers are often used in industrial electronics. They might be found in commercial electroplating facilities, any industry that uses large electronically controlled motors, commercial lighting systems, etc. The harmonics produced on the DC side of the rectifiers is immediately obvious because they are at “even” frequencies. If the rectifier assembly is not well balanced or has a defective rectifier, large even harmonics will appear on the power line. In general, the more rectifiers involved in the assembly, the fewer low frequency harmonics are produced.

6 Pulse Rectifier: 360Hz, 720Hz, 1080Hz, 1440Hz, 1800Hz, 2160Hz, 2520Hz
[300Hz, 600Hz, 900Hz, 1200Hz, 1500Hz, 1800Hz, 2100Hz]

12 Pulse Rectifier: 720Hz, 1440Hz, 2160Hz
[600Hz, 1200Hz, 1800Hz]

11.1.5: Rectifiers: AC Harmonics

Rectifiers, in addition to producing “even” harmonics, also produce odd harmonic currents on the AC side (power line side) of the rectifier assembly. The odd triple harmonics, however, “cancel out” in 6 pulse rectifiers, and additional odd harmonics cancel out in 12 pulse rectifiers.

6 Pulse: 300Hz, 420Hz, 660Hz, 780Hz, 1020Hz, 1140Hz, 1380Hz, 1500Hz
1740Hz, 1860Hz, 2100Hz, 2220Hz, 2460Hz, 2580Hz, 2820Hz
[250Hz, 350Hz, 550Hz, 650Hz, 850Hz, 950Hz, 1150Hz, 1250Hz
1450Hz, 1550Hz, 1750Hz, 1850Hz, 2050Hz, 2150Hz, 2350Hz]

12 Pulse: 660Hz, 780Hz, 1380Hz, 1500Hz, 2100Hz, 2220Hz, 2820Hz
[550Hz, 650Hz, 1150Hz, 1250Hz, 1750Hz, 1850Hz, 2350Hz]

11.1.6: “Off Frequency” Harmonics: Electronic Convertors

Various types of electronic power conversion devices are becoming more common. These devices often convert the 60Hz [50Hz] power line current into some other frequency, often for the purpose of controlling motor speed. Sometimes, heating equipment or lighting electronics is involved. Since the converted frequencies are not multiples of 60Hz [50Hz], they stand out as “converted” frequencies.

11.1.7: “Off Frequency” Harmonics: Motors and Generators

Motors and generators can create off frequency harmonics that are close to 60Hz [50Hz] but off by several Hertz (high or low). Facilities that have their own power plant can produce off frequency currents from their generators. These plants often incorporate diesel engines whose speed (RPM) is not controlled precisely enough to produce exactly 60Hz [50Hz]. Induction motors run slower than “synchronous speed” motors. This is due to an inherent “slip” effect between the rotor and the magnetic field of the stator. The result can be “slot” harmonics that are off frequency by the amount of slip in the motor.

SECTION 12: COORDINATION

Obviously, there is little that a telephone craftsman can do to solve these power problems himself. If it is known that the telephone wire plant is bonded, grounded, and balanced, as well as can be expected, then the only solution may be coordination.

Coordination simply refers to the power company and the telephone company working together in a COORDINATED effort to solve the problem.

Why should the power company want to help? Often times they are REQUIRED to help solve telephone noise problems that result from harmonic currents in the power line. Some states have enacted regulations that set the maximum limits on radiated harmonic noise. Local Public Utilities Commissions usually stipulate that the different utilities work together to solve problems.

In addition, it is to the advantage of the power company to solve harmonic current problems. In severe cases, the harmonic currents can damage power company equipment. Harmonic currents often cause equipment, including the power lines themselves, to run hotter than usual. A 10 degree C temperature increase (above normal operating temperatures) can cut motor life in half! Harmonic currents can also cause metering errors, which affect the power company’s revenues. In general, harmonic currents have no beneficial effects and are often detrimental to efficient operation of the power line.

From the power customer’s point of view, harmonic currents can cause excessive heating or failure of various loads connected to the power line. If the power company is generating large harmonic currents that end up being dissipated as excess heat in customer loads, that customer could legitimately litigate against the power company for damage caused to their (the customer’s) equipment.

Obviously, the power company would want to curtail such occurrences by keeping their harmonics at acceptably low levels. To this end, most power companies and telephone companies have worked out informal or official channels whereby they can communicate and work together to solve their “joint” problems.

If this is a power company problem, why does the telephone craftsman have to identify the problem and explain it to the power company? For several reasons. First, the power company is often unaware of the problem. Noise Mitigators have joked for years about how they (the Noise Mitigators) act as watchdogs for the power company’s harmonic problems. Telephone lines are great “detectors” of harmonic problems in power lines. Second, the power company sometimes does not have any equipment to measure the extent of the problem. The MITIGATOR and a Loop Coil, in the hands of a telephone craftsman, may be the only way that the power company can “see” the problem. This isn’t to

suggest that there aren't pieces of test equipment that the power company can use to measure harmonic currents. There are. Two of the more common brand names are Dranetz and BMI. However, the local power company may not have one of these available. Even if they do, their equipment is designed to measure harmonic current flow in the power lines, not the magnetic fields produced by these currents. The actual magnetic fields, while closely related to the current flowing in the power lines, is affected by various other factors, like power line geometry (spacing, height, etc.), magnetic field cancellation, magnetic field distortion caused by metallic objects in the vicinity, Ground Return Current, etc. Since the telephone lines respond to the induction produced by the magnetic fields, it is more appropriate to examine the fields rather than the current flowing in the power lines.

SECTION 13: "FIRST TIMERS"

Solving a harmonic noise problem will require a coordinated effort. And since the power company may be unfamiliar with causes and fixes for harmonic problems, they may end up relying upon the telephone craftsman to tell them what to do.

For those just embarking upon this adventure with no prior experience and no power company contacts, it would be wise to "study up" on the things that we've just briefly mentioned. Various training sessions and seminars are put on by consultants who are intimately familiar with the problems and are well versed in the solutions. These "experts" could do a lot to improve your understanding of noise mitigation and give you the confidence to tackle a noise problem that requires coordination.

Many states have started associations where power and telephone people get together and informally discuss their problems and try to decide on a plan of action for solving them. Their names often end in the letters . . . PCA, which means Power and Communications Association. For example, Missouri has the MPCA and Oklahoma has the OPCA.

SECTION 14: SOLVING THE PROBLEM

14.1: OVER-EXCITED TRANSFORMERS

The obvious thing to do when transformers are over-excited is simply to turn down the voltage. The power company can do this, and by making some other changes, still supply their customers with the necessary 120 volts of power. Since the propensity for a transformer to produce harmonic currents is determined by its construction, a different transformer may produce less harmonic currents. The problem transformer could be "changed out" with a lower distortion transformer. Beware, however, that if the power company "turns down" the voltage where you are having problems, that they may have to boost the voltage somewhere else, which means that instead of solving the noise problem, you might be transferring your noise problem down the road.

14.2: VOLTAGE REGULATORS

Voltage regulators have a range of approximately $\pm 10\%$. This amount of adjustment can obviously over-excite down-line transformers. The power company can adjust the regulator so that when it is turned up all the way, its output voltage is low enough that it won't over-excite down-line transformers. It may also be possible to re-distribute some of the loads so that a much smaller adjustment range is required.

14.3: RELOCATING TRANSFORMERS AND CAPACITOR BANKS

Because harmonic currents often develop between transformers and capacitors, it makes sense that relocating the transformer, capacitor, or both, could alter the flow of harmonic currents so as to reduce the severity of the noise induced into the telephone lines. Sometimes, it is not possible to reduce the harmonic currents themselves, but it may be possible to re-route the currents in such a way so as to reduce the exposure to the telephone cable.

If capacitor banks are creating a resonant condition at a harmonic frequency, it may be possible to move the capacitor bank to a different location, thereby altering the power line inductance and changing the resonant frequency. If the new resonant frequency is not at a 60Hz [50Hz] harmonic, then there will be little current flow.

Sometimes capacitor banks can be changed in value or removed from circuit. These possibilities should be discussed with the power engineer. Occasionally, the capacitor banks will be found to be an unnecessary leftover from a since modified power distribution scheme. Removing capacitors from circuit for the purpose of testing or permanent noise reduction may be as simple as pulling their fuses.

14.4: "FLOATING" CAPACITOR BANKS

When all of the capacitor banks are removed from circuit for the purpose of testing, the craftsperson usually finds that a significant reduction in Power Influence will occur on the affected telephone cable. Reductions of 15 to 20dBrnC [P] are typical. If this were to translate into improvement in Circuit Noise, as it often does, then Circuit Noise would also drop by 15 to 20dBrnC [P].

Unfortunately, the power lines cannot be operated efficiently without the capacitors connected. As each capacitor is put back "on-line", the exposed telephone cable's Power Influence will rise back up to the original level. It may be discovered, though, that 1 or 2 capacitor banks affect the Power Influence significantly, and the rest have only a minor effect. Wouldn't it be nice if there was some way to satisfy the power company's need to have these capacitors on-line but be able to prevent them from increasing the phone cable's Power Influence?

It just so happens that such a solution exists. And the best part is that, sometimes, no additional devices need to be added to the power line or the telephone line. This magic technique is called "floating the capacitor bank".

Unfortunately, this technique ONLY works on 3 phase lines, and some power companies will not allow their capacitors to be floated. Even so, this is a viable technique for the situations in which it can be used.

So how does it work? Figure 9 shows an electrical diagram of a 3 phase capacitor bank connected to a 3 phase power line. Notice that one side of all 3 capacitors connect together to the "wye point", and that this is connected to the power line neutral. The neutral is also connected to earth ground. The wye point is obviously held at earth ground potential.

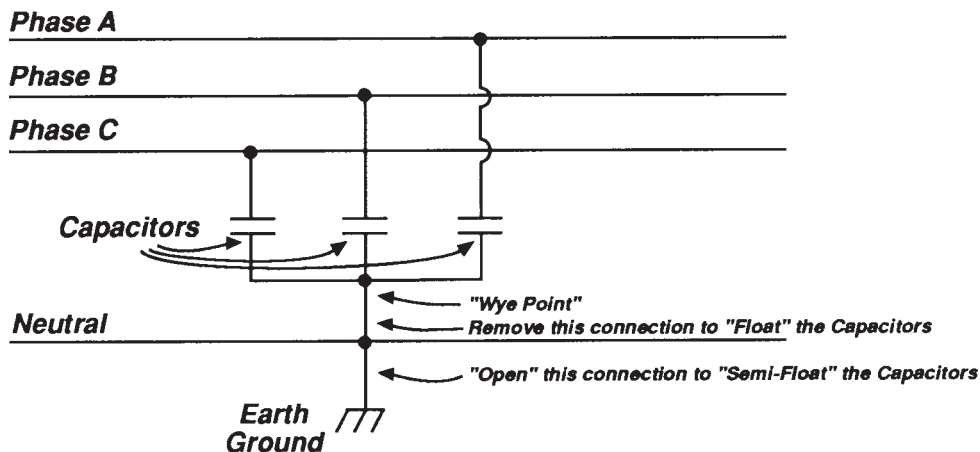


Figure 9

The capacitors' connection to the neutral and the earth ground are the culprits in this game. As already explained, capacitors act as very good harmonic current loads. If we assume that there is a source of harmonic current on the power line, this current will flow to the capacitor load and complete its circuit by flowing into the neutral wire and earth ground. Since a portion of the current flows in the earth ground, the neutral wire will not produce sufficient magnetic fields to cancel the fields of the phase wires. The result is the radiation of excessive magnetic fields from the power lines. This is explained in better detail in the MITIGATOR Applications Manual.

How can we prevent the flow of these harmonic currents to neutral and the earth ground? What if we just disconnected the wye point from the neutral and earth ground? What would the consequences be?

Surprisingly, with the wye point disconnected from the neutral and earth ground, THE CAPACITORS STILL PROVIDE POWER FACTOR CORRECTION OF THE 60HZ [50HZ] CURRENTS ON THE POWER LINE.

Consequently, the path for the harmonic currents can be effectively interrupted, and the power company is able to maintain its 60Hz [50Hz] power factor correction.

In the ideal situation, the wire that connects the wye point to the neutral could be removed, and the wye point would still remain at ground potential. However, in the real world, conditions are far from ideal, and the voltage on the wye point would float around, possibly reaching several thousand volts under certain conditions.

This is why the power company doesn't like floating capacitors. A point which is usually thought to be at ground potential could have hazardous voltages on it. But, as said, in some situations, this technique results in a significant reduction in Power Influence without adding any extra devices.

Floating a capacitor bank can be effective in reducing influence problems resulting from both resonant conditions and sink effects.

A cautionary note. This technique should only be attempted by knowledgeable craftspersons and power engineers. The capacitors must be of the "double bushing" type. For the purpose of testing the performance of the floated capacitor, single bushing units may be used with the proper safety precautions. Beware, though, that the cases of single bushing capacitors will be "live" during the test. Any permanent floating capacitor installation must be of the double bushing type to reduce the safety hazards.

14.4.1 "SEMI-FLOATED" CAPACITORS

A less effective method for reducing Power Influence that results from harmonic currents flowing through capacitor banks is the "semi-floated" technique.

As detailed in the MITIGATOR Applications Manual, Ground Return Current can be a major component in noise problems on a telephone line. This current essentially returns to the substation through the earth ground instead of the power line neutral wire. By doing so, the Ground Return Current "steals" neutral current and reduces the strength of the canceling magnetic field that the neutral produces. This reduction in magnetic field cancellation translates into an increase in induction and more noise on the telephone line.

The Ground Return Current is a side effect of the safety grounding scheme that the power company uses. Essentially, all transformers, capacitors, etc. are earth grounded, and on long spans, the neutral may also be grounded at intervals. These earth grounds prevent excessive voltage rise on the neutral in the event of lightning strike or "power cross" faults.

Unfortunately, the earth ground also creates a path for the Ground Return Currents to flow through.

What if current flow could be confined to the neutral wire? If this were possible, a canceling magnetic field would be generated by the neutral and the induced noise in the telephone line should drop.

How can this be accomplished? Well, the obvious way is to remove ALL of the earth grounds from the neutral wire. This would force the current to flow in the neutral wire. It would also present a serious safety hazard.

However, the hazard could be minimized by removing just SOME of the earth grounds. By choosing the grounds where most of the harmonic currents are flowing into the earth and modifying the path of these currents so that they flow in the neutral wire, a magnetic canceling effect can be achieved that will result in reduction of the Power Influence.

Since this technique compromises the safety of the power lines, the fewest number of disconnected earth grounds is desirable. This means that the semi-floating method is really only usable in situations where the Power Exposure is relatively short. Figure 10 shows an example where semi-floating may be of some help.

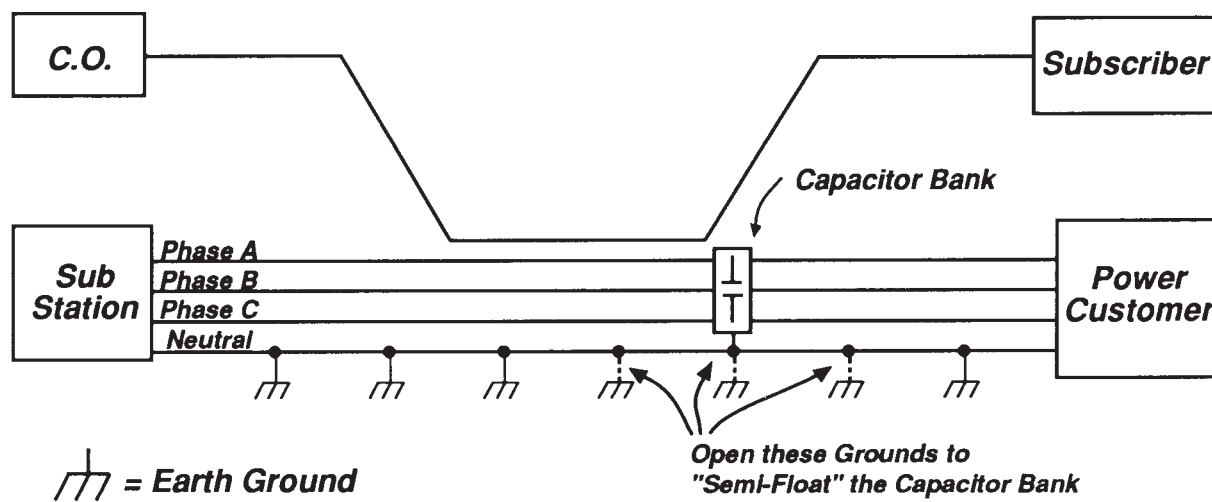


Figure 10

Removing the earth ground at the capacitor has been found to be effective in providing the desired noise reduction in some cases. But, often, the harmonic current simply flows to the next ground rod and completes its circuit to ground. In such a situation, several grounds may need to be removed. It must be understood that current flow in the neutral and earth ground, together, make up the total unbalanced load current and harmonic current that must flow back to the substation. This total amount of current divides between the neutral and the earth, the ratio depending upon a variety of conditions (mostly, neutral resistance versus earth resistance).

If a large amount of the total current is flowing in the earth, and the bulk of that current flow is coming through the ground rod connection at a capacitor bank, removing the single ground rod connection at the bank may produce a significant reduction in the total Ground Return Current (which means an increase in the neutral current and magnetic canceling field) and reduce telephone noise accordingly.

The technique of lifting (removing) the ground connection is very useful, but in some areas of the country, it is not permitted, or if it is permitted, it is done reluctantly by the power company. The actual procedure itself is quite simple. Just remove the earth ground connection at the capacitor bank, i.e. disconnect the "vertical" below the neutral wire. The neutral remains connected to the capacitor bank. Although the danger of injurious shock is significantly less with a semi-floated capacitor bank, and

single bushing capacitors will not have a “live” housing (except under power fault or surge conditions), it is still recommended that the capacitor bank be of the “double bushing” type. If the existing capacitor bank is of the “single bushing” type, it is recommended that it be changed to a double bushing type.

“Semi-Floating” has no effect upon the 60Hz [50Hz] performance of the capacitor, and hence, does not affect the power factor correction abilities of the capacitor. It only prevents harmonic currents from flowing to earth ground at the capacitor.

For the purpose of determining whether floating or semi-floating a capacitor bank will produce the desired noise reduction, the capacitor can be temporarily floated, even if it is a single bushing type.

To monitor the effect that floating or semi-floating the capacitor produces, a loop coil in the immediate vicinity of the capacitor bank should register a reduction in level when the bank is floated. Additionally, a craftsperson monitoring the Power Influence on the noisy line(s) should also see a reduction in level.

Many power companies that routinely float capacitor banks “tag” the floated banks at the bottom of the poles and at the capacitors themselves.

In some situations, the capacitors are located on the ground, but the technique used to reduce harmonic current flow to the earth ground is the same.

The induction caused by both resonant and sink effects in the power line can often be suppressed by floating the appropriate capacitor banks. Note that floating a capacitor bank is usually much easier than relocating a capacitor bank. Hence, if allowed by the local power company, floating should be examined before going through a relocation.

14.5: HSR'S

Harmonic Suppression Reactors (HSRs) offer another method of noise reduction. As their name implies, they suppress harmonic currents. “Reactor” is another name for a coil or choke.

HSRs are placed on the power lines. They are only recommended for use on 3 phase lines, although they have sometimes been used on 2 phase lines.

An HSR reduces harmonic current flow in the phase wires and the neutral. It can sometimes provide a greater degree of noise reduction than obtained by floating a capacitor bank.

As previously discussed, a capacitor can create a resonant condition on the power line or act as a “sink”. Often, a capacitor will both resonant to some degree AND act as a sink.

An HSR is an effective means of reducing harmonic current flow through a capacitor while having only a minor effect upon the 60Hz [50Hz] current. This allows it to work without significantly affecting the power factor of the power line. The HSR is essentially wired in series with the capacitor bank and prevents harmonic current flow through it. Since it is wired in series, it must handle all of the residual current (60Hz [50Hz] current) as well as the harmonic current.

In order to be effective, the HSR must be “tuned” to work correctly in a specific application. Consequently, when an HSR is to be used to solve a noise problem, a “test reactor” is temporarily installed in the circuit and is tuned to suppress the problem harmonic currents (while causing the minimum of side effects). When the proper inductance value is determined by using the test reactor, the HSR is set (it is adjustable) to the proper value and installed. Complete details on the theory of operation and method of installation are available from the HSR manufacturer.

Note: SNC is a manufacturer of HSRs and is very knowledgeable about their use. They offer a “white paper” and a video tape that describes HSR applications and installation methods. For the craftsperson considering the use of HSRs, their paper and video tape is very informative and is highly recommended.

14.6: FUSES

Capacitor banks are usually fused. On a three phase capacitor bank, there are three fuses, one on each phase. For various reasons, such as a lightning strike, one or more of the fuses may open. If this occurs, a sudden increase in noise on a nearby telephone line may occur. Removing capacitor banks from a power line will not always cause a reduction in telephone noise. It may cause the noise to increase!

If one or two fuses in a three phase capacitor bank open, the capacitor bank itself will be unbalanced. Some harmonic frequencies do benefit from magnetic field cancellation (the odd “non-triple” harmonics). Since harmonic frequencies tend to flow readily through capacitors, in the process creating canceling magnetic fields, open fuses will prevent the current flow and the subsequent beneficial fields.

Solving this problem is as easy as replacing the fuses. Open fuses are easily identified from the ground because they “hang open” when they blow.

14.7: BAD CAPACITORS

Capacitors can go bad. You can’t tell by looking at the capacitor if it’s bad. In a three phase capacitor bank, the three capacitors need to be of the same value. Sometimes, a capacitor will go bad and change value. In all other aspects, it will look OK.

This problem can be identified by examining the 60Hz [50Hz] current through each capacitor. The 60Hz [50Hz] current through each capacitor should be similar. If a significant difference in current is found, the capacitors should be removed from circuit and tested. Don’t go by the markings on the capacitors. These have been known to be wrong! They sometimes get mis-marked by the manufacturer.

Another problem to be wary of. The KVAR rating on the capacitor is ONLY VALID if the power line and the capacitor are of the same voltage rating. If the ratings are different, be suspicious. The KVAR rating was probably “sized” to provide a certain degree of power factor correction. Since the KVAR rating of the capacitor depends on its voltage rating, if it is connected to a different line voltage than it is rated for, its KVAR value is different! This means that the power company may not be providing the amount of correction to the line that they thought they were. Consequently, they may opt to re-size the capacitor bank, and in the process, the telephone noise may be abated (or it may get worse).

14.8: “TRAPPING” HARMONICS

Sometimes, noise can be reduced by INCREASING the flow of harmonic currents. This technique is based upon attempting to control the telephone line exposure to the harmonic currents. Consider a situation in which an isolated (no telephone lines in the vicinity) transformer and capacitor create a resonant circuit. Even though the harmonic current flow may be very high, and the magnetic fields generated very strong, if there are no telephone lines in which to induce noise...then no noise will be forthcoming.

Now, consider a situation in which a power line runs parallel to telephone line for several spans and then diverges from the telephone cable’s path. Perhaps the power line runs from a substation to an industrial facility (factory) that has harmonic generating equipment. Let’s say that the power line diverges from the phone line before going into the factory. Because of the harmonic currents drawn by the factory, magnetic fields will be created down the entire length of the power line back to the substation. So, in the area where the power line parallels the phone lines, the exposure will allow noise to be induced onto the phone lines.

If the harmonic currents could be confined to the area where there is no exposure, then no noise would be induced into the phone line. So how do we trap the harmonic currents in the “No Exposure” zone? By using a capacitor bank...

Since harmonics like to flow through capacitors, we can take advantage of this effect and force the factory’s harmonic currents to flow in a localized loop in the No Exposure Zone. The capacitor bank is placed on the power line after it diverges from the phone line. Consequently, the harmonic currents will be “trapped” on the section of power line between the factory and the capacitor bank.

It is likely that some of the harmonic current will escape the trap and flow on the power line back to the substation. If the level of the harmonic currents are low enough, they may not cause any undue rise in noise on the exposed phone line. If, however, the induced noise is still a problem, the trap can be made more effective by placing an appropriately sized inductor at the capacitor bank location. By tuning the trapped circuit to some degree of resonance, by using the proper value inductor, more of the harmonic current can be trapped in the No Exposure Zone.

This is essentially opposite to the approach taken with the HSR. But in the case of the HSR, the power line in question was exposed to the phone line along its entire length.

Actually, an HSR could be used as the inductor used to trap the harmonic currents, as long as the current through the HSR is below its maximum current rating. Sometimes, a special inductor is used instead of an HSR.

SECTION 15: SUMMARY

The techniques and procedures outlined in this manual are not meant to be an in depth examination of Loop Coil use or harmonic current problems. This text only takes a superficial look at these issues.

There is more information available on these topics. Various telephone company (Bell, AT&T, etc.) and government (REA) Methods and Practices detail individual test techniques and solutions. On the power company side, the Westinghouse Transmission and Distribution manual is the handbook of the industry.

Using the Triplet 3232 Loop Coil, a Triplet MITIGATOR, and some knowledge and experience, a craftsman should be able to fix harmonic noise problems that have gone unsolved for years.