X10 Passive Couplers and Repeaters

Only half my house works! X10 is Junk!

Jeff Volp (Links updated 04/22/2015)

How many times have you seen that subtitle posted in a forum? Perhaps you even experienced that problem yourself, and have already installed a phase coupler. This tutorial will explain why a phase coupler is necessary for many installations. It will describe the difference between passive couplers and repeaters. And it will offer some of the factors to consider when dealing with phase coupling problems.

Background

Many of you probably know that the X10 protocol was developed back in the 70's by a Scottish firm called Pico Electronics. Back then we had incandescent lamps and fluorescent lamps with magnetic ballasts. Computers were barely on the horizon. Almost all home entertainment equipment used large transformer-based power supplies. None of those devices exhibited any significant load to X10 signals. As time has progressed, our homes are becoming filled with more and more electronic devices. Many of them present heavy loads to X10 signals, and are what we call "signal suckers".

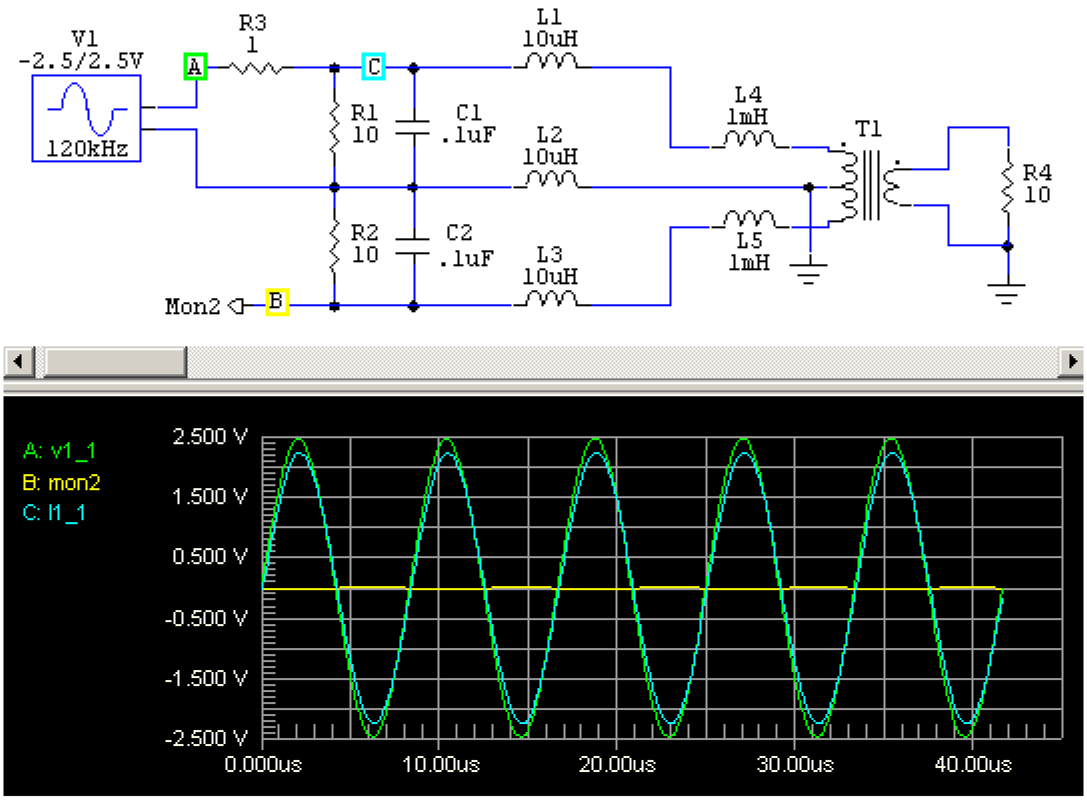
All electrical wire has inductance. The longer the run, the more inductance it has. Inductance acts like resistance to impede the flow of signals, but its effect is determined by the frequency of the signal passing through it. Inductance doesn't matter at all for DC power, and has very little effect at the 60Hz powerline frequency. But inductance does have an effect at the 120KHz X10 carrier frequency, especially on a long wire run. Combining that inductance with even moderate signal suckers, and the X10 signal quickly decreases as it propagates away from the transmitter.

The power supplied by the utility company to most homes in North America is a split-phase 240V service. The convenience receptacles scattered throughout our homes are for 120V lamps and appliances. The utility company main feed coming into a neighborhood is usually between 2.4KV and 33KV, depending on the size of the area served. The high voltage means less current flow for the same delivered power, reducing energy loss and allowing smaller conductors to be used. A step-down transformer on a nearby utility pole or in an enclosure reduces the high voltage to the 120/240V that powers our homes. That transformer has a center-tapped secondary. The 240V used by high power loads, such as electric ranges, dryers, water heaters, and A/C compressors, is obtained across the full secondary. The 120V used by lamps and most appliances is available from the center tap to either end of the secondary. Individual circuits in our homes are normally connected to one side or the other at random.

A typical X10 transmitter drives only one side, or phase. The signal on the opposite phase must rely on coupling through the utility company's step-down transformer after perhaps hundreds of feet of cable. Back in the incandescent light era with no signal suckers, there was often enough X10 signal leaking through the utility transformer for X10 devices on the opposite phase to receive an adequate signal level. But with even a few moderate signal suckers, and the signal drops significantly. The remainder of this document goes into detail on the performance of different types of couplers used to solve this problem.

X10 Signal Transfer with No Coupling Device

When an X10 transmitter is plugged into a convenience receptacle, it is directly connected to all other circuits on its phase through the distribution panel. So, its 120KHz bursts only have to deal with the various obstacles encountered on that phase. Unless there is a direct connection across the 240V, such as through an electric range or dryer being turned on, the X10 signal can only reach the other phase through the utility company's step-down transformer. That is usually a significant distance from the home, and the combined inductance of the wire runs and of the transformer itself will usually reduce the amplitude of the X10 signal bursts to a very low level. As a result, X10 devices on the second phase often do not receive a strong enough signal to operate correctly. The diagram below is from a simulation that shows what can happen without a coupler.

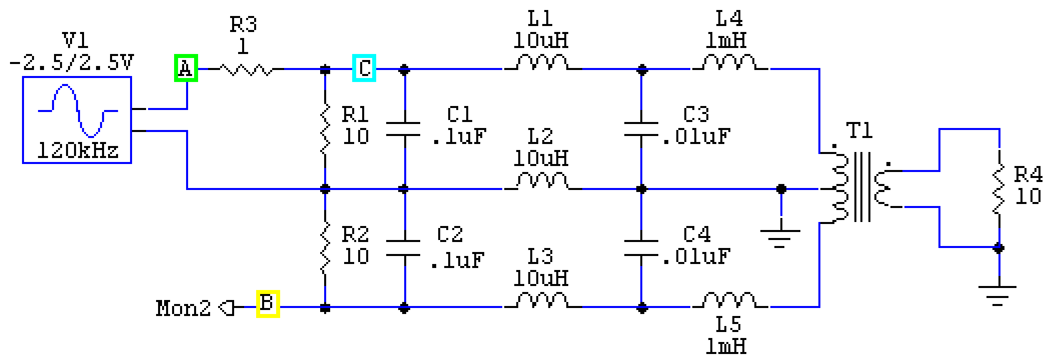


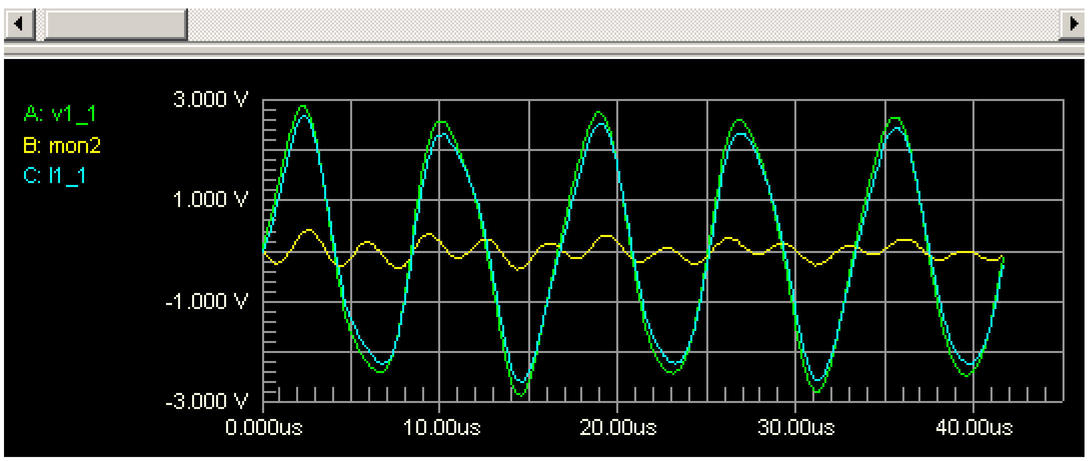
X10 Phase-to-Phase Transfer Signal with NO Coupling Device

The 10uH inductors in the schematic simulate the line inductance from the house to the step-down transformer, and the discrete 1mH inductors simulate the inductance of the utility step-down transformer itself. The 10-ohm resistors and .1uF capacitors simulate the combined effect of distributed loads on each leg. Without a coupler, the X10 signal that propagates to the second phase is very low (yellow trace).

X10 Signal Transfer in Utility Transformer

Since there will be some distributed capacitance in the utility transformer windings, I re-ran the prior simulation taking that into account. The diagram below shows the results.



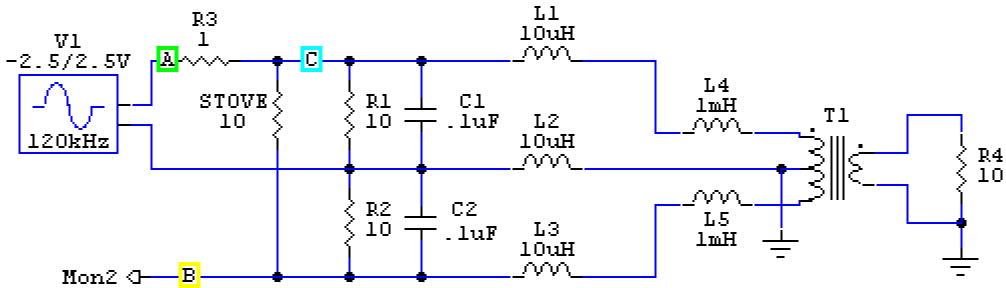


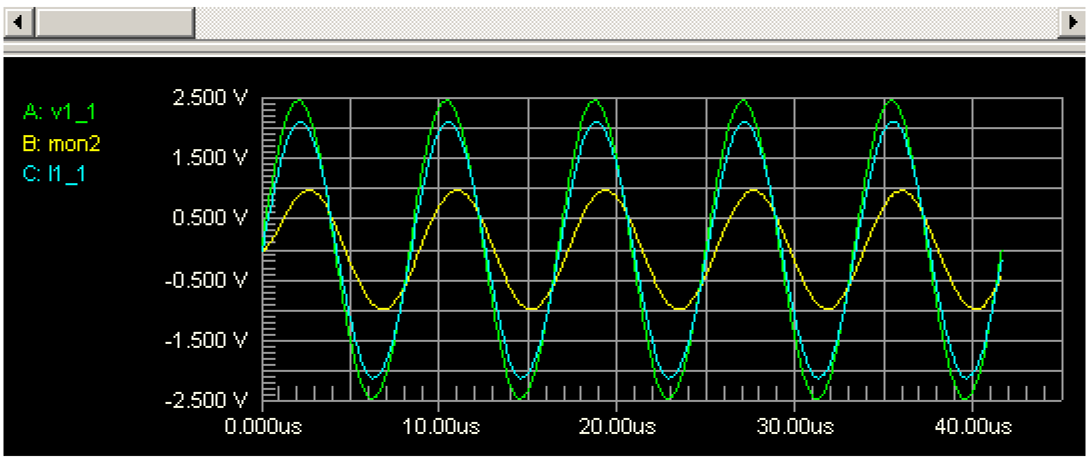
X10 Phase-to-Phase Transfer Signal with Stray Capacitance

There is still no significant energy transfer at the X10 frequency. Adding the distributed capacitance as bulk devices is a simplistic approach, but an exact model of a typical utility transformer is beyond the scope of this document. Regardless of the exact values of inductance and distributed capacitance, the utility transformer is not an efficient means to transfer X10 signals across the phases.

Passive Signal Couplers or Bridges

The purpose of a Signal Coupler or Signal Bridge is to provide a low impedance path for the X10 signal to propagate between the two phases. The diagram below shows what happens when a high current 240V appliance, such as a range or dryer, is switched on.



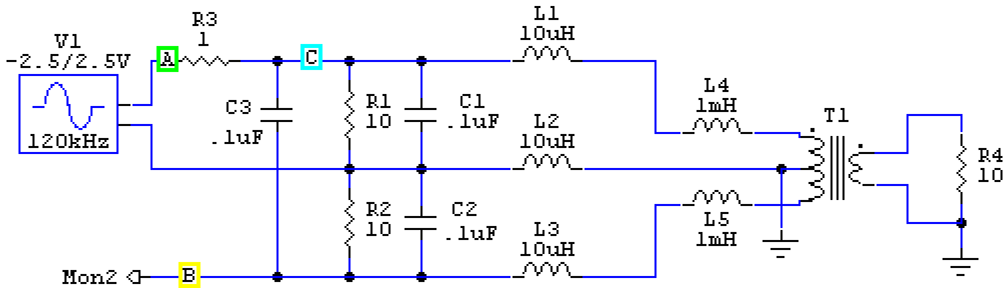


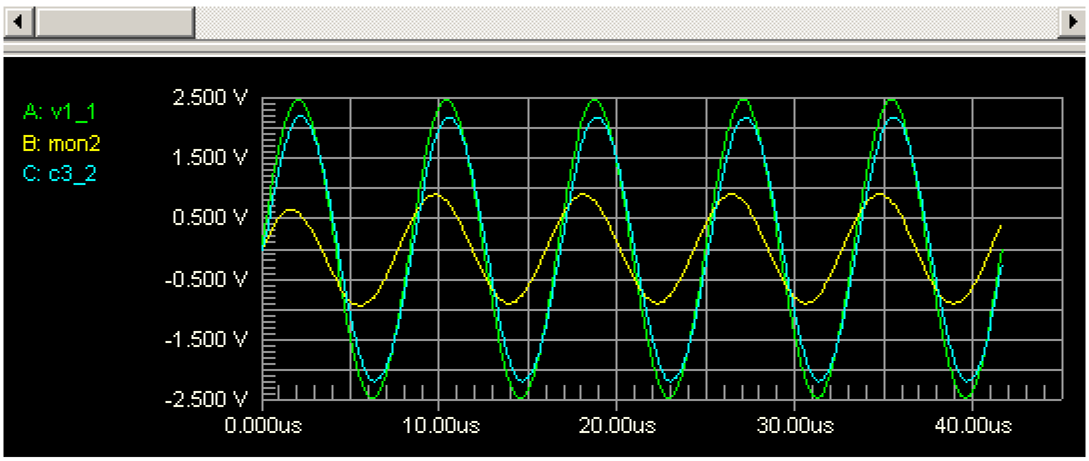
X10 Phase-to-Phase Signal Transfer Through a 240V Appliance

The signal on the second phase has increased significantly. While the range or dryer does provide a low impedance path for X10 signal propagation, it is impractical (and expensive) to leave such a load on continuously. However, there are other solutions that work even better, and consume virtually no electricity.

Using a Simple Capacitor Coupler

Many people use an inexpensive 0.1uF capacitor to provide this path. This can be adequate for smaller homes with a relatively small number of X10 devices. The diagram below uses a 0.1uF capacitor for a signal bridge. A reactive load such as this consumes no real power, and costs virtually nothing to operate.



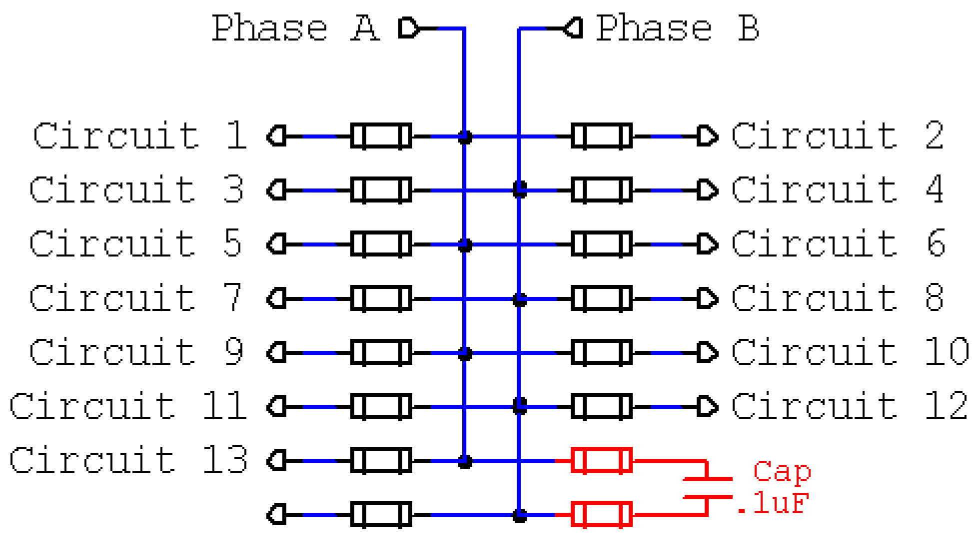


X10 Phase-to-Phase Signal Transfer with .1uF Coupling Capacitor

Again, the signal on the second phase has increased significantly. While this inexpensive fix can work well, there are a couple of negative factors with this approach. First, the capacitor has a reactance of 13 ohms at the X10 carrier frequency, and any "Signal Suckers" on the second phase will still have a significant impact on all signals levels on that phase. Also, a simple capacitor coupler cannot discriminate between the X10 120KHz carrier frequency and any noise on the powerline. So, noise can be coupled across the phases just as well as the X10 signal itself.

Note: A simple capacitor coupler is not "Tuned to the X10 Frequency" as one eBay seller states, and it does NOT provide "Optimum Signal Coupling".

The diagram below shows how an inexpensive coupling capacitor would be connected to the electrical distribution panel through a dual-gang 15A 240V circuit breaker.

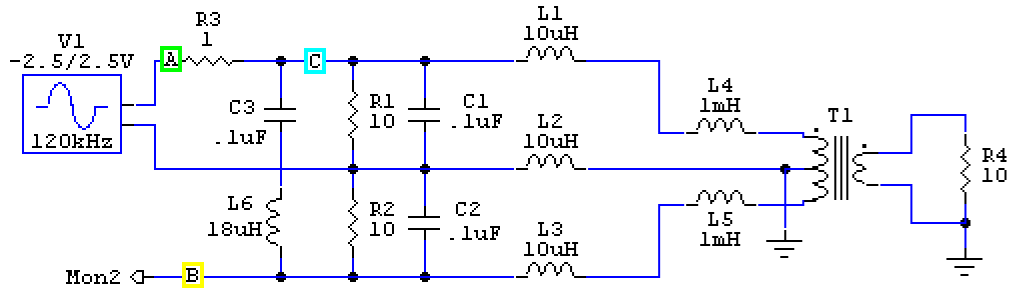


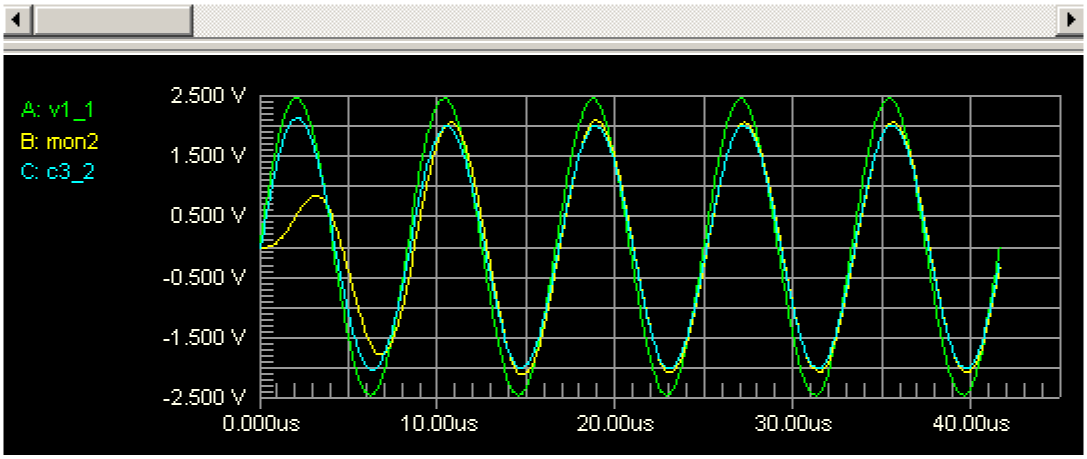
Installing a 250VAC Coupling Capacitor in a Typical Electrical Panel

If you choose this option, the capacitor must be rated for use directly across a 250VAC powerline. Not all capacitors are designed to withstand sustained high-voltage AC operation. Recommended capacitors will have a UL rating of 250VAC or more for across powerline operation. Others that have a dual rating, such as 630VDC / 250VAC, are also fine. Just because a capacitor is rated for 600VDC does not mean it is suitable for use directly across the powerline. Some of the reports we see regarding an "exploded capacitor" may be due to using the wrong capacitor for this application.

Using a Tuned-Circuit Coupler

The best passive couplers use a tuned-circuit to transfer the maximum amount of energy between the phases. The following simulation adds an inductor in series with the 0.1uF capacitor to cancel out the reactance at 120KHz. The SmartHome SignaLinc (R) uses this approach.





X10 Phase-to-Phase Signal Transfer with Tuned-Circuit Coupling

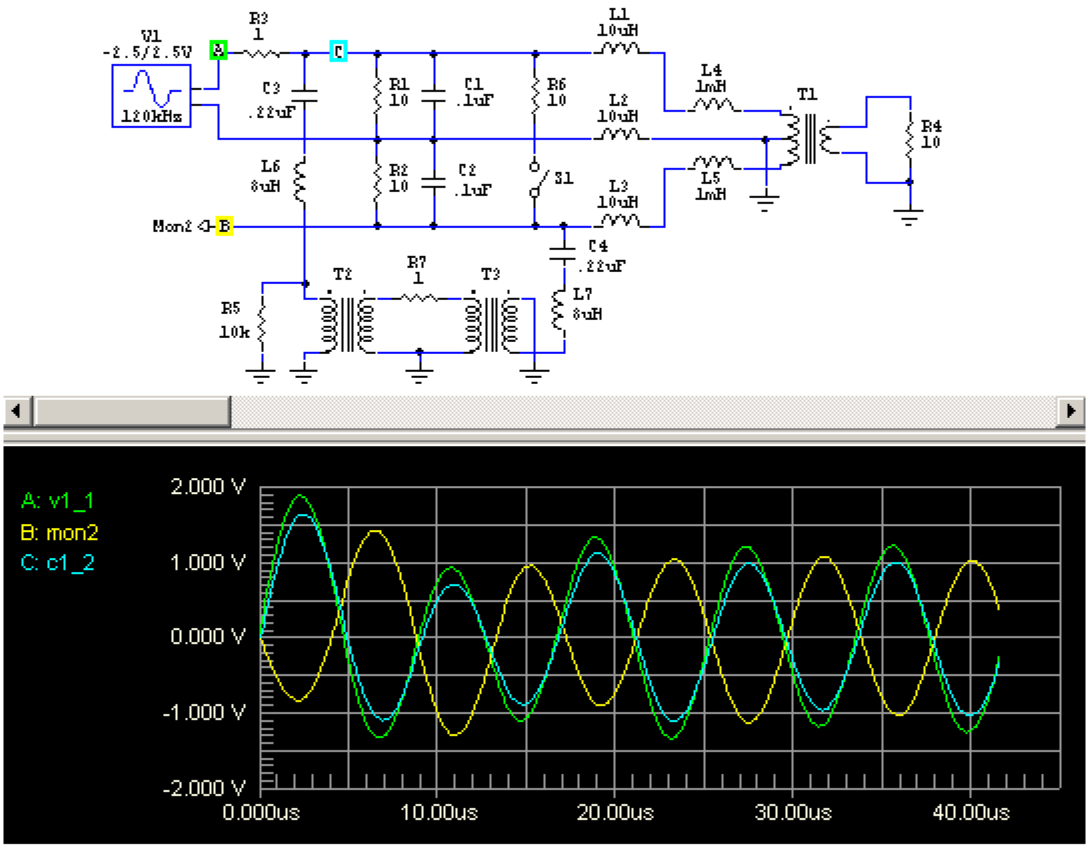
Here you can see that both phases have virtually the same signal level. That is why I recommend a good tuned-circuit passive coupler be installed for maximum energy transfer when using the plug-in XTBR. There are several good tuned-circuit couplers available, such as the X10 XPCP. Best results are obtained with a coupler installed adjacent to the main distribution panel, and connected directly across a 240V breaker.

There are certainly more convenient couplers, such as the type that plugs into a dryer receptacle. That type of coupler can also work well if that receptacle connects directly to the main distribution panel through a short cable run. In our case, all 240V electrical appliances are fed from another panel located where power comes into the house. It is a long run from that panel to our main distribution panel, which is centrally located in the basement. If we used a dryer coupler, signals would have to propagate from the transmitter to the main panel, then to the entrance panel, then to the dryer coupler, back to the entrance panel, and finally back to the main panel before they could be distributed to circuits on the opposite phase. The hundreds of feet of wire would significantly reduce the effectiveness of a dryer coupler.

Passive Couplers and 240V X10 devices

There is another issue about phase coupling that isn't often discussed. That concerns the phase relationship of the 120KHz signals that are coupled to each phase of the 60Hz powerline. Inexpensive phase couplers, such as a .1uF capacitor or the SignaLinc (R), couple the 120KHz signal "in-phase". That means that the two 120KHz signals will be in perfect alignment with each other. All diagrams above show "in-phase" coupling. That works fine for 120V devices, since the signal on each phase is referenced to neutral. However, "in-phase" coupling may not work as well with 240V X10 devices because they receive the signal across the two hot leads. If both hot leads have exactly the same signal, then the 240V X10 device would see no signal at all. Not many homes include 240V X10 devices, but this is something to consider for those installations that do. In an actual installation, unbalanced loads would likely attenuate one signal more than the other, and allow a 240V X10 device to receive a sufficient signal to work.

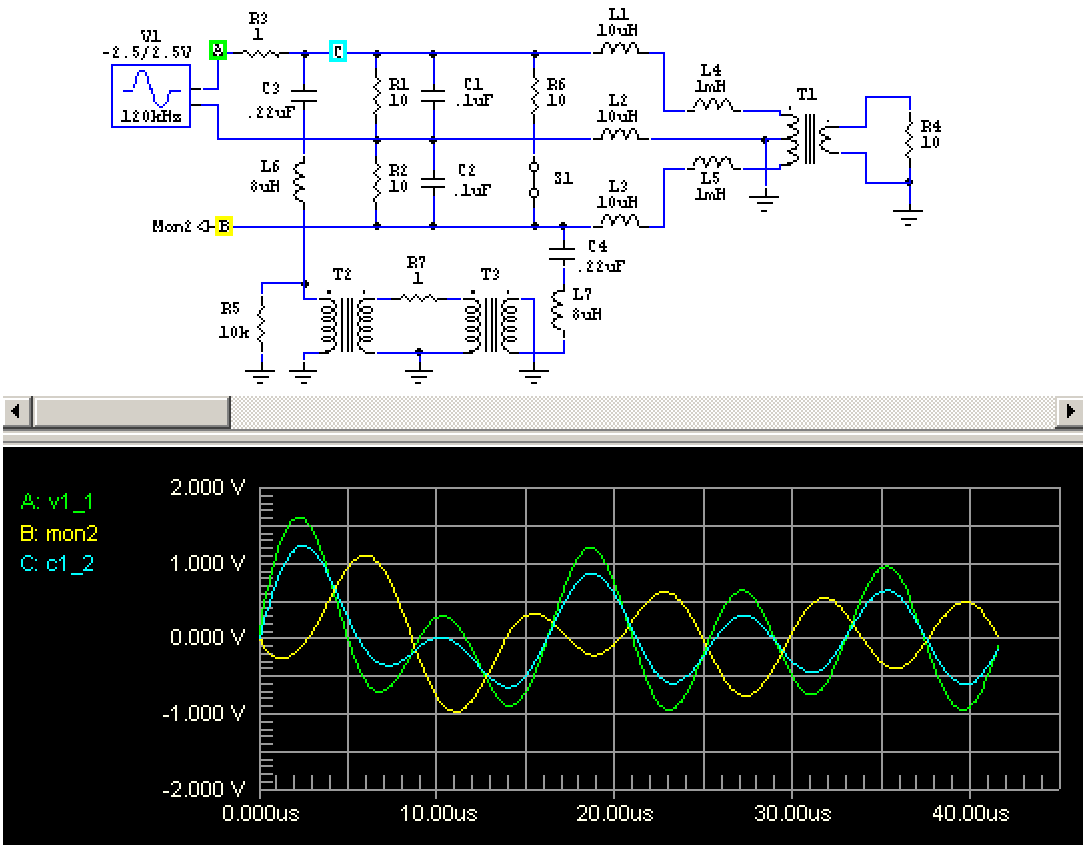
To address the issue of 240V X10 devices, some phase couplers and repeaters drive the two 120KHz signals "out-of-phase". In that case both 120KHz signals appear as mirror images to one another. 120V X10 devices still work fine because they receive their signal referenced to the mid-point neutral. But now the two signals will add together at a 240V X10 device, which will produce a much stronger signal than with in-phase coupling. The simulation below shows "out-of-phase" coupling.



X10 Signal Transfer with Out-of-Phase Coupling

X10 Signal Transfer with Out-of-Phase coupling and a resistive load

One additional factor regarding the phase of 120KHz signals concerns big 240V resistive loads, such as an electric range, dryer, or hot water heater. As seen in one of the earlier diagrams, a load like that can provide "in-phase" coupling all by itself. It can also aid an "in-phase" passive coupler. However, it will act as a "signal sucker" when the two 120KHz signals are driven "out-of-phase". The simulation below shows what happens when a large 240V resistive load is switched on. The reduction in signal level on both phases could cause devices receiving marginal signal levels to stop working when the 240V load is switched on. So there is a tradeoff even when using 240V X10 devices.



X10 Signal Transfer with Out-of-Phase Coupling & 240V Appliance Load

We know the simple capacitor, and simple series tuned circuit found in the SignaLinc (R) provide "in-phase" coupling. The X10 XPCP and similar Leviton 6299 are more complex units that can provide "out-of-phase" coupling. The Leviton 6299 I have tested provides "out-of-phase" coupling when wired per the instructions. There are apparently two different versions of the X10 XPCP. The older wire-in version was reportedly identical to the Leviton 6299, and probably also provides "out-of-phase" coupling. The newer XPCP in a plastic case with screw connections produces "in-phase" coupling when wired per the instructions. Since the input and output of that unit are electrically isolated, it is easy to reverse the coupling phase by just reversing the output connections. So, the XPCP makes it easy to flip the coupling phase when there is difficulty with a 240V X10 device.

Repeaters

Active Repeaters are an alternative to passive signal couplers. If the X10 transmitter is located a long distance from the main distribution panel, the inductance in that run will significantly attenuate the X10 signal before it even reaches the panel for distribution onto other circuits. Unless it is feasible to relocate the transmitter closer to the distribution panel, it may be necessary to consider using a repeater. They accept X10 commands at low signal levels, and re-transmit them higher levels. Some repeaters have transformerless power supplies that limit their output power, and they may not work much better than a passive coupler when the X10 transmitter is located adjacent to the distribution panel. The XTBR and XTB-IIR repeaters have powerful transformer power supplies, and will deliver much stronger signals.

X10 data is sent over the powerline as a series of 1 mS bursts of 120KHz just after each zero crossing of the 60Hz waveform. Presence or absence of a burst signifies a logic "1" or a logic "0" respectively. A standard transmission is comprised of 44 bits spread over 22 cycles of 60Hz. This is organized as a 4-bit "1110" start pattern followed by 9 data bits transmitted in complimentary pairs. That same 22-bit pattern is then transmitted again for the second half of the command. More detailed information is available in this document: X10 Communications Protocol (It is 1.3MB, and may take time to download.)

Most repeaters take advantage of the fact that the same data pattern is transmitted twice. They monitor the line and receive data during the first half of a command. Then they transmit that copy in bit sync with the source transmission during the second half of the command. This method works well for most commands where a module only needs one valid copy to take action.

There are special cases where this simplistic approach does not work well. Bright/Dim commands are one of the special cases that work different from most X10 commands. There are normal bright/dim steps, which will ramp the dimmer from full-on to full-off in about 18 steps. Then there are micro-dim steps, which take about 200 from full-on to full-off. The X10 protocol uses exactly the same command for both, and the only way the receiving module can tell them apart is how they are strung together.

Normal bright/dim commands are sent in sequence with no gap between. A sequence of several bright/dim commands sent that way will ramp a light quickly. A typical repeater messes up this sequence by only repeating the second half of each bright/dim command. So those bright/dim commands are recognized as micro-dim steps by any module that does not receive the first half. Some repeaters like the XTB and ACT units have a fix for this.

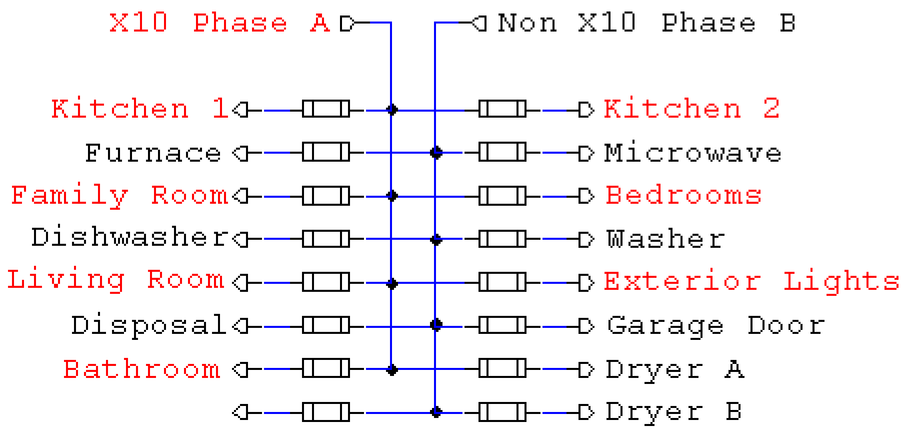
Extended commands are another special case. They include a variable length addendum tacked onto the basic 22-cycle X10 command, and may be transmitted just once. As a result, extended commands must be handled differently. Because repeating an extended command that is only transmitted once could result in a collision with another command closely following the extended command, the XTBR and XTB-IIR will only repeat extended commands that are transmitted as a doublet with two identical halves.

Another problem encountered when using repeaters is the ping-pong effect. In large installations, it may be tempting to use multiple repeaters. However, under certain circumstances it is possible that two repeaters will bounce a command back and forth between each other. That will tie up the powerline, and prevent all other X10 communication. The XTB-IIR and ACT repeaters include an option to repeat a given command only once to prevent the ping-pong effect.

Another Alternative?

There are two alternatives that are worthy of consideration. One eliminates the need for any X10 signal coupler at all. Even in our house fewer than half the circuits actually power devices controlled by X10. With some careful planning at the main distribution panel, it is likely that all X10 circuits can be moved onto the same phase. If this can be done, only that one phase must be driven by X10 transmitters, and there is no need for any X10 signal coupler at all.

Doing this may be easier than it sounds. Electrical distribution panels normally alternate phases on adjacent full-width breakers so that a double-width 240V breaker can connect to both phases. Depending on how your circuits map out, it may be possible to transfer everything to the same phase by just interchanging a few wires. Below is an example of how a small distribution panel could be partitioned so all X10 circuits are on the same phase. Note that in some panels the phases zigzag across rather than alternating above one another. **For your safety, this work should be done by a qualified electrician.**



Example of All X10 Circuits on the Same Phase

A second option is to install the XTB-IIR, which contains two output-coupling networks. It will drive both phases directly with its powerful output. When not transmitting, its twin output coupling networks will function as a passive coupler to propagate X10 signals across the phases. And, if you operate it in the TW523 emulation mode, you can even take advantage of its basic repeater capability. Since the XTB-IIR has a single driver stage, both outputs are "in-phase". That might be a factor to consider for an installation containing 240V X10 devices.

Which is Best?

Unless you can move all you X10 devices to the same phase, some sort of coupling device is usually necessary for proper operation of an X10 automation system. Choosing the best alternative is not a simple decision. The inexpensive capacitor coupler may work well for many smaller homes. My clearly biased opinion is that the XTB-IIR is probably the best choice for larger homes with many X10 devices. The plug-in XTBR teamed with a good passive coupler at the distribution panel can also work very well. Although they don't deliver as much signal power as the XTB units, the ACT repeaters also have a good reputation.

It costs very little to try the coupling capacitor as a first step. If you need to hire an electrician for the work, I would certainly start with a good tuned-circuit passive coupler, such as the X10 XPCP. In the end it comes down to a cost/benefit tradeoff that you will have to decide for yourself.

I hope sharing my experience in these tutorials will help others obtain the same level of reliability that we have here. X10 has been with us for over 3 decades. Its low cost and rich selection of devices still makes it a cost-effective solution. Installations today can certainly be more challenging than they were decades ago, but investing some time and effort up front will give a big payoff in the years to come.