Can Home Solar Power and Ham Radio Coexist?

It's possible, with minimal interference from the solar power system, provided you make some modifications.

Tony Brock-Fisher, K1KP

When retirement came around, we decided to make significant renovations to our home, including adding a whole-house solar electric power system. Solar power systems use photovoltaic (PV) solar cells to generate dc power from sunlight, then convert the power to ac. Because solar systems generate power only while the Sun shines, during peak production the excess generated power can be sold back to the electric company. When the system is not developing enough power, the electric company sells it back to the homeowner. (And yes, the electric meter does actually run backwards.)

The author's antennas, with his home's solar panels visible below.

A typical home consuming 720 kW per month would need an average of about 1 kW continuously delivered to the home. In order to fulfill 100% of a home's annual energy needs, the solar system's peak output must be several times the average power needed by the home. A properly sized solar system would need a peak capacity of about 8 kW, supplying 1 kW to the home and "banking" 7 kW to the grid. I chose a 10 kW capacity system.

As an avid Amateur Radio operator, I considered the RFI implications of a 10 kW inverter located near my HF antennas. My supplier, Direct Energy (**www.directenergy.com**), earned my business by making every reasonable effort to respond to my RFI concerns.

How Modern Solar Power Systems Work

Solar panels deliver maximum power when properly matched to the electrical load. The optimum load depends on factors such as the amount of sunlight, temperature, and the age and type of the panel. With multiple panels, panels may be shaded by trees or snow or leaves. If connected in series, the performance of the entire array could be degraded by one shaded panel. Solar engineers have devised a way to present each panel with its optimum load using maximum power point tracking (MPPT). Each panel connects to a device that adjusts the load impedance to extract the maximum electrical power from the panel.

There are two types of systems — the *microinverter*, and the *central inverter*. In a microinverter system, the dc from each panel is converted to 240 V 60 Hz ac for direct connection to the ac mains through an appropriate circuit breaker. The outputs of all the microinverters are connected in parallel.

In a central inverter system, the dc from the solar panel is converted to a variable dc voltage, and each power optimizer performs the MPPT function. The outputs from all the power optimizers in a string of panels are connected in series. Two wires carry the output power at a high dc voltage — around 350 – 400 V — from the string to a central inverter. The central inverter accommodates varying power from the solar array, and converts it to 240 V ac with phase-synchronization to the ac mains. This hardware must handle up to 10 kW, and must meet all applicable UL, CSA, NEC, and NFPA codes.

Both types of system use switching power supplies with potentially devastating RFI on the HF bands. I wanted this major source of potential RFI placed in an accessible location, so I chose the power optimizer system with its centralized inverter.

Measuring RFI from a Solar Power System

Direct Energy kindly arranged a visit to a similar working solar installation in my neighborhood before the sale. To assess the severity of the RFI, I brought an HF radio and a 20 meter sloping dipole — mounted on my RV — to the existing customer's 8 kW home solar system. I also brought a small multi-turn pickup loop so I could localize RFI sources. I was very lucky that Direct Energy and their customer were willing to accommodate my measurements.

Using a four-turn, 4-inch diameter loop coupled to an Icom IC 756 Pro II receiver, I measured RF radiation from the central inverter on the 160, 80, 40, 20, 15, and 10 meter bands. The pickup coil detected noise with the coil flat against the front or side faces of the inverter. Noise dropped off rapidly as I moved the pickup coil a foot or so away from the inverter. The noise was broadband, with discrete spurs occurring approximately every 94 kHz. The spur levels were highest on bands above 7 MHz. The noise disappeared when the inverter was turned off.

Next, I connected a 20 meter sloping dipole suspended from a fiberglass pole on the back of my RV in the driveway, about 30 feet from the roof-mounted solar panels. My IC 756 Pro II receiver detected noise on 40 meters, which decreased at higher frequencies. Noise levels in the 7 and 14 MHz bands were the same with the inverter on or off, indicating that the inverter was not the source of this noise. The noise in the 21 and 28 MHz bands disappeared, indicating that the inverter was the likely source. A repeat measurement indoors revealed similar noise behavior.

With the inverter turned off, the power optimizers at the panels may still be in operation and may have been the source of this noise. Power optimizers draw power from the solar panels, so whenever there is light on the panel, the optimizer powers up its internal switcher and microprocessor. It is important to realize that there are parts of the system that you may not be able to turn off!

My system from Direct Energy would use components manufactured by SolarEdge, Inc. I obtained technical information from **www.solaredge.us**, including installation and operating manuals. I learned how a system is typically installed and wired. This gave me the starting point for finding ways to stop RFI before it started. The central inverter and the power optimizers are FCC part 15 class B devices, so the burden of RFI remediation reverts to the "operator" of the device. With the various forms of ownership of home solar power systems, the responsibility for curing RFI issues is unclear.

As a member of the Yankee Clipper Contest Club, I was very fortunate to get help from Chuck Counselman, W1HIS. Chuck, a retired MIT professor, has extensive experience in RFI reduction techniques. We examined the panels and optimizers on the roof, the cables bringing power from the roof to the central inverter, the central inverter, and the connection to the ac mains from the inverter.

Roof Panels and Optimizers

Connections on the roof use specialized PV wire and MC4 connectors. PV wire is #10 or #11 AWG copper-stranded single-conductor cable with heavy-duty high-density cross-linked polyethylene insulation. MC4 connectors are locking, water-proof, single

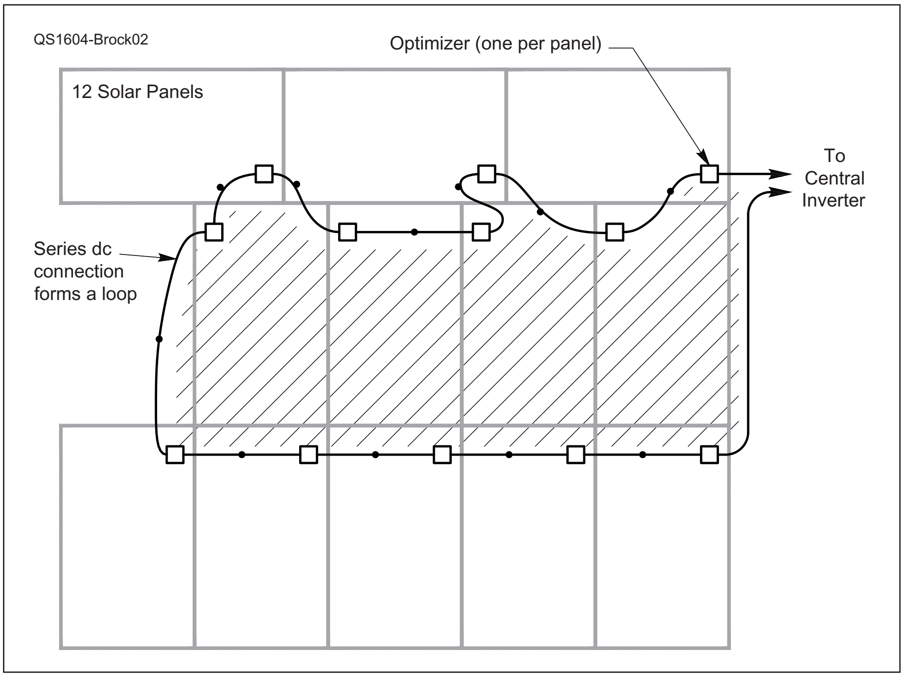

Figure 1 — The standard installation resembles a large current-carrying loop for emitting RFI.

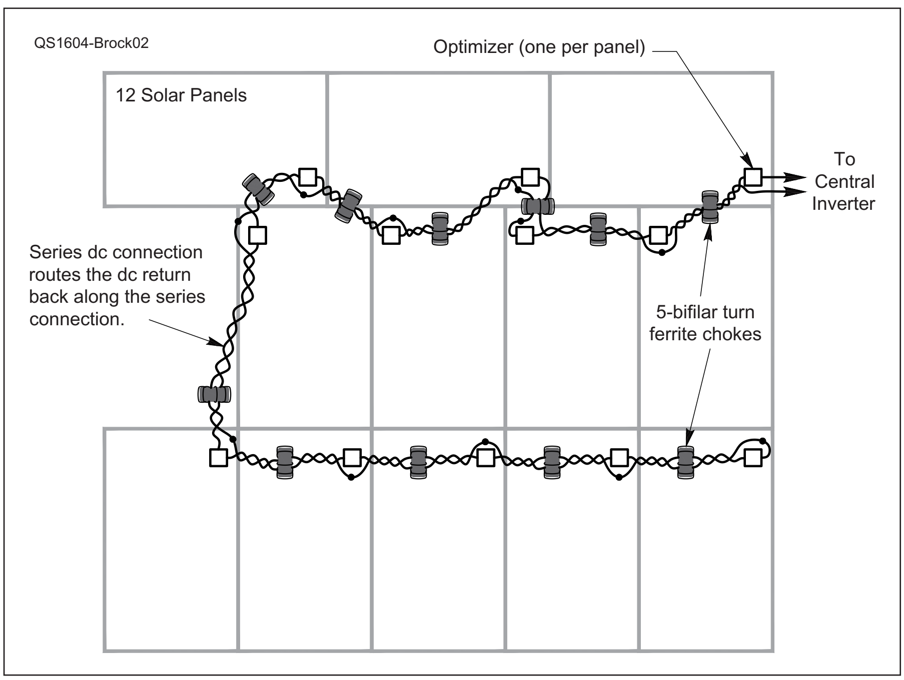

Figure 2 — New wiring configuration shows a closed loop of a twisted pair of conductors, and ferrite beads to suppress common mode currents.

conductor, polarized connectors rated to handle 20 A. Each power optimizer connects to a single solar panel with two leads terminated in MC4 connectors. All the optimizer outputs form a series-connected string of panels that terminates in two dc conductors at the central inverter. These panel connections form a large current carrying loop — see Figure 1. That makes it a very effective RFI antenna — exactly what we *don't* want.

Because solar systems generate power only while the Sun shines, during peak production the excess generated energy can be sold back to the electric company.

Loops radiate well, but transmission lines don't, so we reconfigured the dc interconnection topology to form a transmission line by routing the dc return for the string of inverters back along the original path formed by the interconnected optimizers.

I purchased premade 6-foot-long jumpers, each fitted with a male MC4 on one end and a female on the other. The wires were twisted together to keep them close to each other, as were the input leads from each panel to its optimizer. This reduces the possibility of exciting the mounting rail with RF current that might radiate.

Each optimizer is a switching power supply that converts the varying dc voltage from the each solar panel into a programmable dc voltage. The central inverter communicates with the optimizers over the dc lines using power line communications (PLC) techniques and programs each optimizer so the total voltage of the string is about 400 V.

To suppress common mode noise, I added a Fair-Rite 2631803802 ferrite bead to the transmission line between each optimizer. The bead is large enough to pass the MC4 connectors through to wind five bifilar turns. Optimizers are now connected to a long transmission line. In order to maintain balance in the dc transmission line, the optimizers are alternately connected in either side of the transmission line, as shown in Figure 2. This configuration was a compromise with the Direct Energy engineers as being both RFI-reducing and reasonably easy to construct with the existing materials.

Cables from the Roof

A long run of wires, which could potentially radiate RF, connects the dc from the roof to the central inverter. There is also a safety ground wire that provides an Earth ground from the ac panel to the mounting rails on the roof. This safety ground can also carry RF currents. The easiest way to shield these long runs was to put them into electrical metallic tubing (EMT). Direct Energy agreed to enclose the run from the roof to the central inverter in EMT, with tight metal-to-metal connections all the way.

Three conductors exit the EMT at the roof — two dc wires and the safety ground. We installed chokes, see Figure 3, of three separate ferrite beads (Fair-Rite 2631803802) at this point. Each bead has six trifilar turns of the two dc leads and the safety ground. Each choke is separated by at least a foot from the next to prevent capacitive coupling across the chokes. These three chokes were mounted to the support rails. We took care to make sure that the bare copper safety ground did not contact the rail until after the last choke on the panel/optimizer side.

The Central Inverter

The central inverter converts 400 V dc to 240 V ac power, which is then applied to the main service from the power company. The inverter synchronizes with the phase of the ac mains. The central inverter has two dc connections from the roof, and two ac leads, L1 and L2, which deliver ac

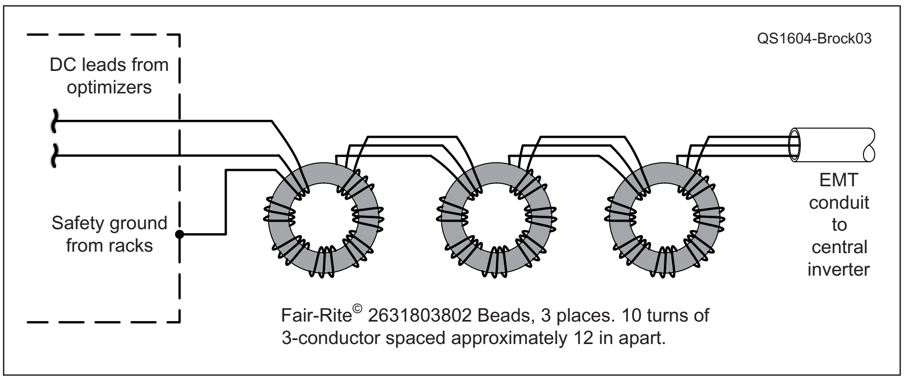

Figure 3 — Triple chokes at the conduit entry on the roof.

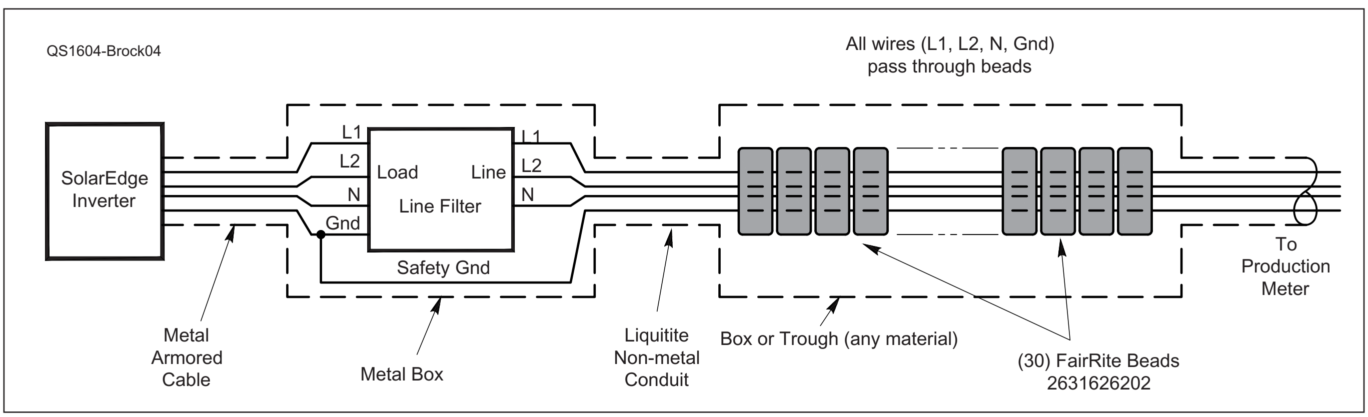

Figure 4 — Line filtering of ac between the inverter and line connection.

power to the mains, along with a neutral (N) lead. There is also a safety ground. The dc input leads with their safety ground are routed to the inverter in EMT; they are filtered at the roof. The ac output side of the inverter could have a combination of common-mode and differential mode noise. The differential mode is suppressed by a large two-section line filter (Corcom 60AYT6C). Its 60 A rating meets the 20% safety margin required by the National Electrical Code (NEC). The filter provides 75 dB of suppression from 0.5 to 10 MHz, and 60 dB at 30 MHz on the L1, L2, and N lines from the inverter. The NEC requires that the safety ground bypass the filter, so that if the filter should fail, the safety ground is not interrupted. Figure 4 illustrates the connections.

Connection to the Mains

I constructed a large common-mode choke consisting of 30 Fair-Rite 2631626202 cores, each 1.5 inches long with 1-inch inner diameter. The four leads — L1, L2, N, and ground — pass through the 30 beads. The line filter and the common-mode choke are each enclosed in metal troughs supplied by Direct Energy (see Figure 4). To be effective, *all* current in the safety ground must pass *through* the beads. This means that the outer metal enclosure for the beads must *not* be electrically connected on both ends. I made the physical connection from the line filter enclosure to the common-mode choke enclosure using plastic conduit, thereby forcing all ground currents to pass through the beads.

Sunny with a Few Clouds

My system became operational on the weekend of the WPX contest. My initial grade for noise silence from the system was a B+. I counted it as a partial success, but the RF environment was not completely quiet. I decided to further reduce the emissions from the system. I was not going to spend my retirement years listening to QRM from the solar power system!

Requests for detailed technical information from SolarEdge, the manufacturer of the optimizers and the inverter, were not very productive. However, a search revealed US Patent 8,531,055, which yielded a tremendous amount of detail about how the system and the optimizers operate.

The Next Phase

Further emission reduction required precise measurements, calculations, modeling, observations, and specific changes. I purchased an extra power optimizer for bench measurements. I also obtained a damaged solar panel — the glass was broken, but it still provided nearly full power when exposed to sunlight. I also purchased a battery-powered shortwave radio to sniff out specific sources of RFI.

Armed with information from the US patent, I characterized the RF emissions from the optimizer. On the bench, the optimizer emitted the same RF noises I heard on my antennas. I found that the device was generating common-mode noise on the input and output terminals.

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Next, I modeled the geometry of the optimizer and the solar panel as if it were an antenna, and calculated the RF impedance of the input lines to the optimizer. I was using antenna modeling to optimize an antenna for *minimum* gain! These studies showed that I could reduce the common mode current in the leads to the solar panel by several orders of magnitude, by adding three bifilar turns on the Fair-Rite 2631626202 ferrite bead to the input leads from the panel to the optimizers.

Experimental Confirmation of Improvements

I constructed a simple mock-up of a single optimizer and panel using a 10-foot section of Rohn 25 tower to represent the roof rail support system. Illuminating the panel with a 300 W halogen work light woke up the optimizer and started its switcher. I measured the common mode current flowing in the leads from the optimizer to the panel using a current probe made from five turns of #14 AWG wire on a 2631803802 core, and routed the sensed output noise through a step attenuator to the station receiver.

I measured a reference noise level of noise in the 20, 15, and 10 meter bands. Next, I inserted prototype common mode chokes between the panel and the optimizer, and re-measured the noise, adjusting the step attenuator to give the same S-meter reading with and without the choke. My most effective choke was three bifilar turns of the PV wire on a 2631626202 core (see Figure 5).

Chuck, W1HIS, suggested that I directly measure the impedance of the connection to the panel with and without the choke. I connected one side of a mini-VNA to the optimizer leads, and the other to the panel leads through large-value dc blocking capacitors. This measurement revealed that the impedance in the panel leads was very low resistance, and that it was resonant in the 20 meter band. After inserting my choke in series with the optimizer leads, the impedance was now both high resistance and high capacitive reactance — this means that common mode currents would be suppressed by many tens of decibels.

Additional RFI Suppression

I made subassemblies of three turns of PV wire wound on the core *before* installing MC4 connectors on the wires (see Figure 5). With assistance from Direct Energy, we installed additional choke assemblies on the leads from each panel on the roof (Figure 6, before this retro-fit).

I had carefully measured and logged noise before this retro-fit. Subsequent measurements showed an improvement of about 20 dB on 20 meters for both states of the system during daylight hours — system on and producing power, and system off, but optimizers still powered up. The chokes were not as effective on 15 and 10 meters.

Figure 5 — Three bifilar turns of #10 PV wire on Fair-Rite 2631626202 core with MC4 connectors installed.

Figure 6 — The chokes from Figure 2, as well as the twisted wire transmission cables can be seen between two of the aluminum support rails before solar panels were installed.

When the system is off, the optimizers are still powered up by the panels, but they are not switching high currents onto the bus, so they are significantly less noisy. If the remaining interference was objectionable when the solar system was operating, I could further reduce noise by turning the system off to work the weak ones. My final grade for noise silence is an A.

I can tune across the HF bands and experience only minimal and occasional interference from the solar power system, while it supplies all of the power needs for the home. Some of the residual noise can be reduced further by turning the system off. The system produces no noise at night.

The essential added components for RFI reduction were the line filter and common mode chokes on the ac connections, and at the entry to the conduit on the roof, and between the panels and the optimizers, EMT conduit for the dc run from the roof to the inverter, and configuring the dc output loop on the roof into a transmission line with a minimal loop area.

Conclusions

Home solar power and ham radio can coexist, but you will have to be responsible for this effort to work. Home solar power installation companies have very little expertise in RFI issues. Find a company willing to work with you, both before and after the sale. If possible, visit a site with the same equipment and test it for potential RFI problems. Be prepared to spend as much as 10% of the system's cost to mitigate RFI. Not all systems use the same technology, and you may get significantly different RFI from your system.

This project would not have been successful without the generous consultation of Chuck Counselman, W1HIS, who spent many hours first learning about the SolarEdge system technology, then finding ways to minimize its RFI. Thanks also to Dan Goodridge of Direct Energy for his cooperation and the extra effort he and his team of installers put into my unique installation.

Photos by the author.

Tony Brock-Fisher, K1KP, was originally licensed in 1967 as WA1IKP and upgraded to Amateur Extra class license in 1976. He has a BS In Physics and an MS in Ocean Engineering. Tony retired from Philips Electronics in 2013 following a 35-year career in Medical Ultrasound design. Tony currently serves as president of Yankee Clipper Contest Club. He enjoys contesting, DXing, and station construction projects, as well as writing for *QST*. You can reach Tony at **barockteer@aol.com**.

Feedback

In "An Introduction to Coaxial Cable for RF Applications," Feb 2016 *QST*, pp 43 – 46, there is an error in the first column of page 46. In the paragraph *Power handling capability*, referring to the power indicated in Table 2, the correct description is "Average Power (W)," not W_{RMS}, as indicated.