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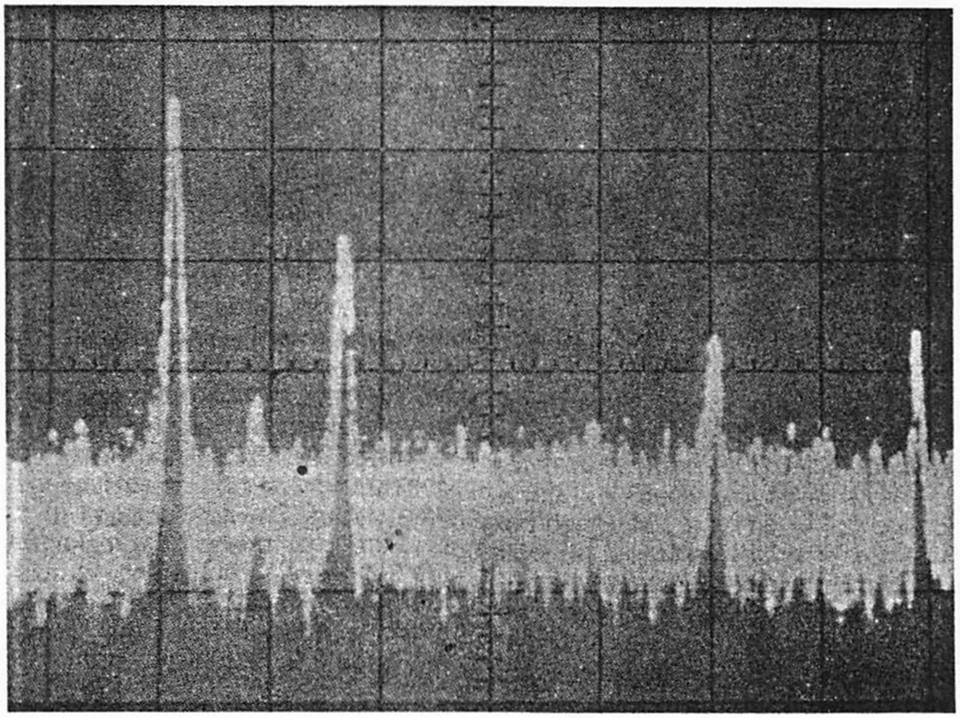
RFI, ITS DETECTION AND ELIMINATION

by Jim Harmon

One of the more difficult parameters to verify or troubleshoot in electronic instruments is RFI (radio frequency interference). The illusive nature of RFI makes it a temptation to ignore it altogether. However, as RFI intrudes more and more into an already overcrowded electromagnetic spectrum, instrument manufacturers must pay greater attention to RFI specifications and devote more design effort to containing it. Did you ever wonder why RF enclosures are castings and why their covers are secured by 16 screws when four would normally do?

Hopefully, when an instrument leaves the factory it is well sealed and has been carefully checked for RF leakage. If it has, it will normally remain that way until opened as, for example, when being serviced. After being serviced, it is generally assumed by the user that it still meets its RFI specs. But does it? Was RF leakage actually measured?

Most leakage specs are written in terms of a military standard (such as contained in MIL-I-6181D). Although these specs are quantitative and meaningful, to check them generally requires special equipment, knowledge, and lots of time. Typical of the equipment needed are calibrated antennas, calibrated receivers, and a screen room. However, some new instruments also include a more practical leakage specification which reads: "Less than 3 μV is induced in a 2-turn, 1-inch diameter loop 1 inch away from any surface and measured into a 50-ohm receiver." This spec defines a simple RFI test which can be quickly set up on a bench.



In viewing the display of a spectrum analyzer, you may discover that one or more of the spectral lines are being generated by your test instruments. This article discusses some of the causes and solutions to the problem of RFI.

Before discussing the test itself, a brief discussion of RFI—its sources and prevention—is in order. The ultimate source of RFI is usually an RF oscillator designed to perform some useful task. Not deliberately a part of the design are parasitic antennas in the RF path which radiate the RF into the surroundings. One way to stop the radiation is to contain the radiation source in a metal box. The box probably has a cover secured by screws. If the cover, however, does not mate with the box over the entire surface, RF may leak out as through a waveguide. See Figure 1. A waveguide will allow a field to propagate through it if the effective width (w) is larger than one-half wavelength and if the electric field is perpendicular to the gap. As an example, a two-inch gap will support a 3 GHz wave. The height (h) of the gap primarily affects only the dissipation through the waveguide and not the cutoff frequency.

For frequencies below the cutoff frequency, the signal may still pass

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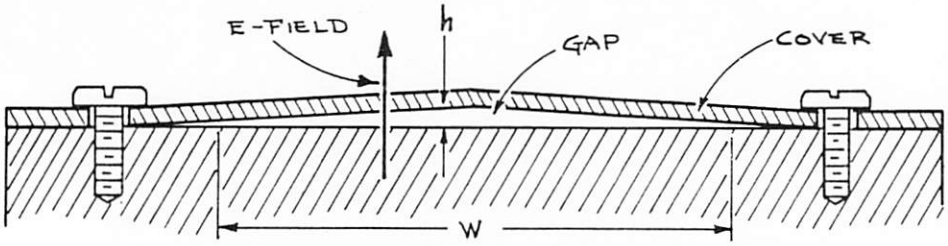

Figure 1. A Box Sealed With a Bowed Cover.

through the gap but it is attenuated as it does so. The amount of attenuation depends on the depth of the gap and is given in dB by 27.3 × *d*/*w* where *d* is the gap depth.[1] In our example, if the cover contacts ¼ inch of surface, the attenuation is only about 3 dB for frequencies below 3 GHz.

To increase the effectiveness of the cover one can: (1) add more screws to reduce *w*, (2) increase the depth of the mating surface to increase *d*, (3) machine, lap, or cast the cover and box to better mate the surfaces, (4) mate the two surfaces in a groove, and (5) add a gasket or silver paint which essentially breaks *w* into a series of smaller lengths. Needless to say, a thin sheet metal cover offers limited immunity against RFI.

Another way in which electromagnetic fields can propagate from an enclosure is if RF currents are allowed to flow on an outside surface. The currents cause a voltage drop due to the finite conductance of the surface material which is further reduced by the skin effect. This voltage drop then sets up the RF fields. In the example of Figure 1, the gap may force RF currents to concentrate near the edge of the enclosure and thereby cause radiation. The phenomenon is more prevalent at lower frequencies. Also, the currents themselves can set up magnetic fields if they flow along a path that forms a loop. Sealing the enclosure by the methods mentioned above will aid in reducing external current flow.

Once outside the enclosure, the RF wave may either radiate or it may propagate along a nearby transmission line as in Figure 2. In this example the outer conductor of a cable and the chassis form a transmission line. The source of RF is a leaky connector and the opposite end of the line terminates the wave in a short. As with any transmission line not terminated in its characteristic impedance, standing waves are set up. At certain frequencies the structure will form a resonator, and the fields may become very strong. The best solution to this problem is to prevent the leakage in the first place by tightening or replacing the connector. The use of polyiron or a resistive material to dissipate the fields may also help.

Figure 3 shows a setup which can be used to check RFI. The spectrum analyzer is used as a sensitive receiver in which the different RFI signals can be observed and sorted out from external interfering signals. The RF amplifier is needed if levels of 3 μV are to be easily observed with a reasonably wide bandwidth; the gain of the amplifier should be at least 20 dB with a good noise figure (6 dB or less) and cover the frequency range of interest. Double-shielded cable is also recommended. An antenna which meets the criteria of the simplified RFI specification is HP Part Number 08640-60501. It is shown in Figure 4. A one-inch loop is embedded in a hollowed out rexolite tip one inch away from the end. The loop is placed on the end of a long handle to keep fingers from disturbing the RF fields near the loop and giving unrepeatable or erroneous measurements.

To make an RFI check, first calibrate the system so that 3 μV (−107 dBm) is at a convenient reference line on the spectrum analyzer display. If a signal generator is being tested, use its output to set up the reference; otherwise, use the analyzer's calibration taking into account the amplifier gain. Now

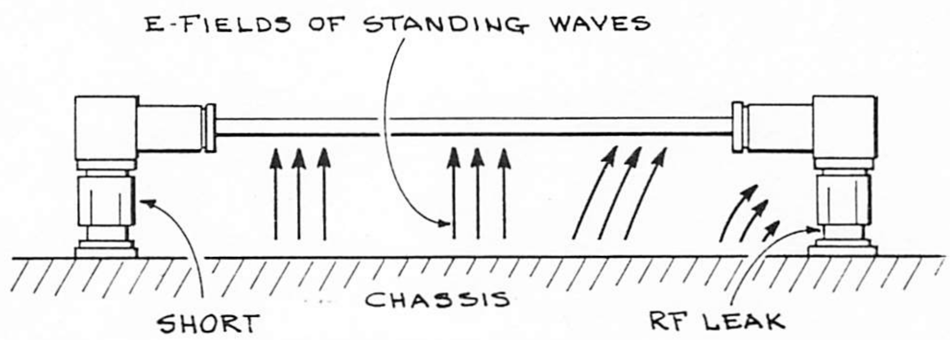

Figure 2. Leakage Along the Outside of a Cable.

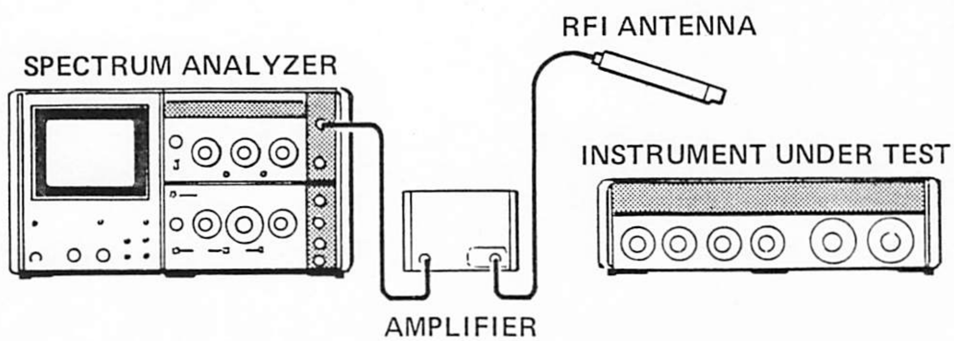

Figure 3. RFI Test Setup.

1. This is derived from the equation for attentuation through a waveguide when the frequency is well below cutoff:

$$\text{attenuation ratio} = \epsilon^{-\alpha z}$$

where α is the attenuation constant of the particular waveguide and z is the distance down the waveguide.

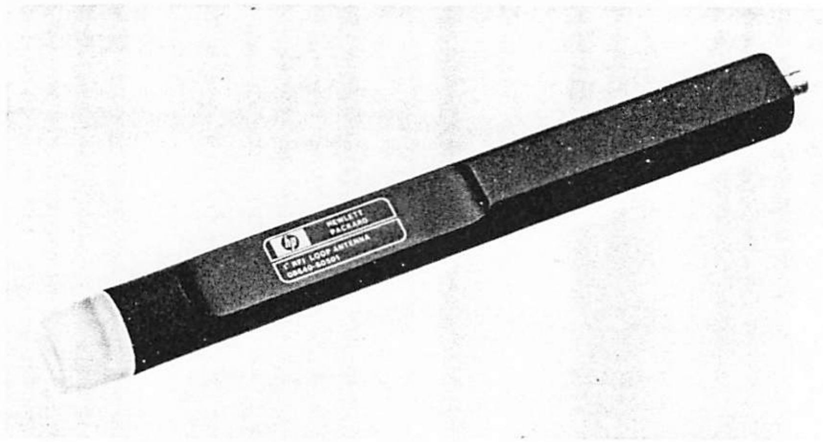

Figure 4. HP 08640-60501 One-Inch RFI Loop Antenna.

connect the antenna. If the frequencies generated inside the test instrument are not known, the frequency spectrum will have to be carefully surveyed. This is made more difficult by the fact that interfering signals from other sources may be present (such as a nearby radio station) in which case a screen room will make the measurement easier. If the frequencies are known, however, the analyzer can be tuned to the frequency in question and the amplitude observed with a narrow scan width and bandwidth.

Hold the tip of the antenna against the instrument and check the signal amplitude as the antenna is moved along the surface. Usually, the specification states that all ports be terminated with a good (low leak) load; this may apply even though a jack is normally capped. In the case of a signal generator, it is usually assumed that the output level control is in its minimum output position. If RFI is out of spec, the antenna is used to snoop inside the instrument.

If the instrument contains frequency dividers (such as in a counter) or harmonic generators (such as in a phase lock loop), frequencies that are multiples or submultiples of the fundamental should also be examined. Any variable frequency RF source should be checked at several frequencies, but usually the highest frequency leaks the most. If the RF leak is illusive and varies radically with frequency, one technique that can be used to locate the problem is to substitute a tracking generator (i.e., a generator that exactly tracks the spectrum analyzer) in place of the RF source and snoop around with the antenna using the analyzer in a wide sweep mode. Here it is assumed that RF is not leaking from the RF source itself and that only fundamental frequencies are involved. This technique makes it easy to ignore any external interfering sources.

Finally, if a problem spot is found, the following suggestions may help in eliminating the RFI:

- Check flexible cables for wear near the crimp sleeve.
- Check all joints in connectors for tightness. Sometimes soldering hole plugs and end pieces will eliminate leakage.
- Check that covers are well secured. Also see that mating surfaces are clean.
- Check that flexible cables have no sharp bends.
- Check that all RFI prevention braids, shields, screens, etc. are in place.
- Replace well-used RFI gaskets.
- Silver paint along cracks. (The paint may not be effective until several hours after applying.)

Jim Harmon joined HP in 1967 at the Stanford Park Division in Palo Alto and is currently a Product Support Engineer. In this job, Jim is one of the factory technical experts available to provide back-up to the HP field service organization. Jim's latest project was the handling of the 8640A/B Signal Generator product support, including the development of troubleshooting and other service information.

After receiving a BSEE at Utah State University in Logan, Utah, Jim completed his MSEE at Stanford University in Palo Alto, California. Jim is married and has two children.

ATTN 8705A SIGNAL MULTIPLEXER OWNERS

Owners of the 8705A Signal Multiplexer with serial prefixes 985A through 1142A are urged to order Service Note 8705A-1.

There is a possibility that some units were shipped with incorrect wiring on the primary. This Service Note points out how to verify that your unit is correctly (and safely) wired.

Service Note 8705A-1 can be obtained free of charge by checking the appropriate box on the Order Form on the last page.

MORE ON HALF-SPLITTING

by the Editor

PROBLEM EXISTS IN	TEST POINTS MEASURED	TOTAL NUMBER OF MEASUREMENTS
Stage 1	B	1
Stage 2	B, C	2
Stage 3	B, C, D	3
Stage 4	B, C, D, E	4
Stage 5	B, C, D, E, F	5
Stage 6	B, C, D, E, F, G	6
Stage 7	B, C, D, E, F, G, H	7
Stage 8	B, C, D, E, F, G, H	7

Table 1. "Serial" Method (not recommended)

In the last issue of Bench Briefs we discussed a troubleshooting technique called "half-splitting." This method suggests making a test measurement midway between the point where a signal is known to exist (or is correct) and the point where the signal is known not to exist (or is incorrect).

Unfortunately many people use a less effective technique. Let's compare them. Assume that we are troubleshooting a linear path with eight stages as shown in Figure 1. Assume also that there is a signal at the input (point A) but no signal at the output (point I). Using the half-splitting technique will lead you to the problem with the least number of measurements (and presumably also the least amount of time). Therefore, you are more effective in your job. Let's compare the "half-split" technique with the "serial" method, and approach used all too often of measuring along the signal path until the signal disappears (i.e., measure point B, then point C, then D, E, F, G, and H until the signal disappears). The faulty circuit exists just before the point where the signal disappeared.

Serial Method

How many measurements will be needed, on the average, to find a problem using the serial method? This technique (which is NOT recommended) will be to measure point B. If no signal exists, we have found the problem. If point B is ok, measure point C. If no signal exists, the failure is in Stage 2. If point B is ok, measure point C, etc.

Table 1 lists the number of measurements required to find a circuit failure in the various stages. Note that very few measurements are needed if the failure happens to occur in Stage 1 or 2, but many tests are required to find a failure near the end of the chain. We assume that each stage has an equal chance of failure. Therefore, in $\frac{1}{8}$ of the failures, one measurement (point B) will be needed to isolate the faulty stage. Two measurements (B andC) will be required in another $\frac{1}{8}$, 3 measurements (B, C and D) will be needed for another $\frac{1}{8}$, etc.

The average number of measurements required to find the failure in a great number of different repairs is:

$$\tfrac{1}{8}(1) + \tfrac{1}{8}(2) + \tfrac{1}{8}(3) + \tfrac{1}{8}(4) + \tfrac{1}{8}(5) + \tfrac{1}{8}(6) + \tfrac{1}{8}(7) + \tfrac{1}{8}(8) = 35/8 = 4\tfrac{3}{8}$$

Thus, an average of $4\frac{3}{8}$ measurement will be required to find the faulty stage in a product being repaired. (Of course, you cannot make a fraction of a measurement; that is just an average. If that makes you uneasy, look at it this way: to repair 1000 instruments, you would have to make 4375 measurements.)

Half-splitting Method

Let's now use the half-splitting method to find the problem. Assume that Stage 1 has failed. We would split the chain into two sections and measure at point E. Finding no signal there, we would next measure point C and find no signal there. Next measure point B and find no signal there. Therefore, three measurements are needed to find the failure. Assume Stage 2 has failed. Measure points E and C, finding no signal at either point. Measure point B and find a signal present.

Therefore, Stage 2 has failed. Three measurements needed. Similarly, any other stage can be isolated with three measurements, a sharp contrast to the "serial" method. Table 2 lists the measurements needed in the order shown for isolation of a problem in any stage. Note that only three measurements are required to find a problem anywhere in our example of 8 stages. The "serial" method requires an average of $4\frac{3}{8}$—an increase of 45%!

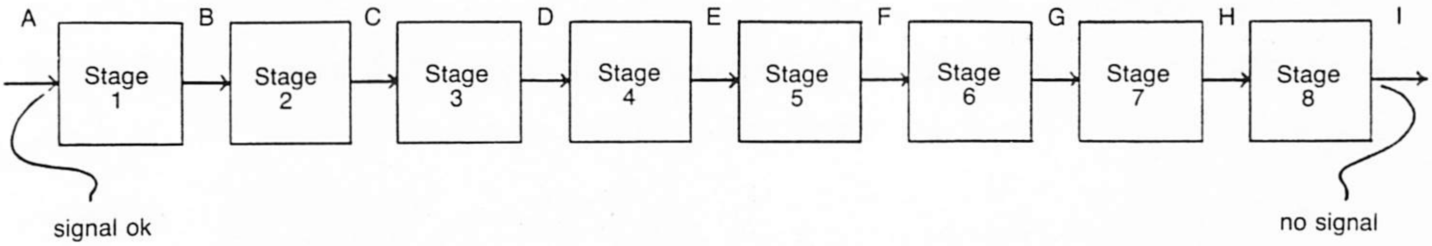

Figure 1

PROBLEM EXISTS IN	TEST POINT MEASURED	TOTAL NUMBER OF MEASUREMENTS
Stage 1	E, C, B	3
Stage 2	E, C, B	3
Stage 3	E, C, D	3
Stage 4	E, C, D	3
Stage 5	E, G, F	3
Stage 6	E, G, F	3
Stage 7	E, G, H	3
Stage 8	E, G, H	3

Table 2. "Half-split" Method

The difference in effectiveness of these two techniques becomes even more dramatic as the number of stages is increased.

High Failure History

In the calculations above, we assumed that each stage has an equal chance of failing (i.e. similar reliability). This is probably a good assumption if we don't have any prior experience or knowledge of the product being repaired.

Many times, though, we *do* have additional information that is useful. If previous experience indicates that one stage is particularly prone to failure, this should be considered in deciding where to make the measurements.

Looking back at Figure 1, let's assume that stage 8 has poor reliability (which is often the case because of higher power than the previous stages, plus possibly being subjected to excessive loads, short circuits, etc., if it feeds an output connector that is accessible by the user.) Let's assume that 65% of the failures occur in Stage 8. Let's also assume that the remaining stages are equally reliable, each incurring 5% of the failures. (These numbers were chosen to make the math easy. The exact numbers are not needed as we will see later.) How will this affect our technique?

Half-splitting as described earlier would lead us to the problem in 3 measurements (the difference would be that 65% of the time the points measured would be E, G and H instead of 12.5% of the time as above.)

Recognizing that the failure very likely exists towards the end of the chain would suggest that we shift our initial measurement point toward the troubleshooting area. Perhaps Point H would be the first measurement point. Table 3 lists the test points that are measured to find the failure. A failure in Stage 8 will be located with 1 measurement. Notice that there are now many instances where 4 measurements are required to locate the problem. Because of the difference in failure rate, however, the *average* number needed will be reduced because 65% of the time only one will be required.

The exact number can be calculated by observing that Stage 1 will fail 5% of the time. Therefore, 5% of the time 4 measurements will be required. Same for a failure in Stage 2, etc.

The average number required can be calculated easily.

0.05 (4) + 0.05 (4) + 0.05 (4) + 0.05 (4) + 0.05 (4) + 0.05 (4) + 0.05 (3) + 0.65 (1) = 2.0 measurements.

The average is less and therefore you will find the problem faster by shifting the initial measurement point. *You want to half-split at the point where there is approximately an equal chance of finding the failure on either side of the test point.*

In our example, specific failure rates were used in a calculation to prove the validity of this method. Exact failure rates are not needed nor should you perform any calculations. Just recognize that a high failure rate in one end of a string should cause you to shift the initial point measured toward the troublesome circuit.

A good rule of thumb is 50%. Unless a particular circuit has at least 50% of the failures, do not modify the initial method.

Other Considerations

The half-splitting technique also assumes that all test points are equally accessible. Many times shielding, gaskets, cover plates and other mechanical restrictions make test points inaccessible, especially in high frequency products. This will similarly alter how you split the abnormal path.

Taking time to decide where to make a measurement will usually save time, but only if the decision takes less time than the measurement. Pondering two minutes about a measurement that could be made in one minute is not an effective technique.

It also is worthwhile to point out that when making a measurement, you must have some way of deciding whether or not the signal is correct.

Continued on Page 8

PROBLEM EXISTS IN	PROBABILITY OF FAILURE	TEST POINTS MEASURED	TOTAL NUMBER OF MEASUREMENTS
Stage 1	5%	H, E, C, B	4
Stage 2	5%	H, E, C, B	4
Stage 3	5%	H, E, C, D	4
Stage 4	5%	H, E, C, D	4
Stage 5	5%	H, E, G, F	4
Stage 6	5%	H, E, G, F	4
Stage 7	5%	H, E, G	3
Stage 8	65%	H	1

Table 3. Modified "Half-split" Method

Continued from Page 5

The main reasons for the popularity of the highly inefficient "serial" method are lack of good documentation and lack of experience. It is sometimes difficult to determine if the measurement just observed is correct. Prior experience with the circuit can be used to good advantage in cases like this.

In conclusion, half-splitting will lead you to the problem in the least time. If you know nothing about the reliability of the circuits under test, make the test measurement midway between point of a known good signal and the point of known bad signal. If one end of the signal path has a bad failure history, shift the initial measurement closer to the troublesome area.

Using a logical troubleshooting approach will make you more effective in your job. Try it; it works!

ATTN 34740A OWNERS

Anyone using or repairing a 34740A Display Module for the 3470 Measurement System should check the serial number. If your unit has serial number 1213A02200 or below, check to see if the power supply transformer wires have two gray tie-wraps around all the wires leaving the transformer. If there are no tie-wraps around these wires, a possible hazard to the operator could exist if used with battery module (Model 34720A). Please order Service Note 34740A-2 on the Order Form.

3480A/B A2IC18

The recommended replacement for A2IC18 in the 3480A and 3480B is HP p/n 5080-9053. This part is part number 1820-0349 that has been selected for a specific manufacturer (Motorola). Replacing A2IC18 with an IC produced by another manufacturer may cause a timing problem in this circuit. The other IC's on the A2 board are not critical. Any brand IC can be used. Therefore in an emergency you might find a Motorola IC somewhere else on the board and then fill that position with any available brand.

7402A OSCILLOGRAPHIC RECORDER SPEED REDUCTION OPTION INSTALLATION

It is possible to install option 009 (60:1 Chart Speed Reduction) on the Model 7402A Oscillographic Recorders with serial prefix 1350A and above. A procedure is available that gives the detailed installation instruction plus a list of parts that are required. Installation is a lengthy procedure requiring major disassembly of the instrument. *Bench Briefs*

recommends reviewing the installation procedure before embarking on this project. The installation procedure is available by checking the box marked 07402-90004 on the Order Form.

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