VHF-AIS masthead antenna and coax installation, selection, and test
Stan Honey
29 March 2022

Observations Regarding Selection and Installation of Masthead VHF whip antennas:

- Whip Antennas
  - Most marine VHF masthead antennas are mechanically mounted using the coaxial connector. Common VHF whips use a female SO239 socket that mates with a PL259 plug on the coax cable. PL259/SO239 coax connectors (aka "UHF") are common, mechanically rugged, and installable without tools, but they are not weather resistant. If you use an antenna with a SO239 mount and so use a PL259 connector on the coax, be sure to follow the notes below in this article to add water resistance.
  - Half-wave end fed antennas are about 36 inches (1 meter) long with a matching transformer at the base. These are the best choice overall for use on sailboats. These antennas provide reasonable gain with reasonable weight and windage. They are not so directional as to be ineffective when heeled. They do not require a ground at their base.
    - Half-wave antennas which mount with a PL259/SO239 include the common Shakespeare 5215, METZ, and the GAM SS-2 among many other options. Again, if you use an antenna such as these with a PL259/SO239 connection used as a mount, waterproof the connection carefully as described below because the PL259 is not weatherproof.
    - The V-Tronix MD20N is a half wave antenna made by Shakespeare which uses an N-type connector at its base. This antenna is the best choice for a half-wave antenna because the N-type connector is both mechanically rugged and inherently weatherproof, and so is ideally suited to the challenging environment at the masthead of a sailboat. N-type connectors for installation on the coax are available rated to ip67 level of water resistance. Versions meeting ip67 are available that can be either crimped or clamped. The crimp connectors can be crimped onto the coax with a widely available tool that costs about $30 or with a crimp die that costs $15 and fits into a standard ratcheting crimp tool. Any electronics technician will have the proper tool, but it is a tool worth owning for a boat owner.
  - Quarter wave whip antennas, of 15 to 18 inches in length, are widely used on racing boats, and meet the OSR requirements. Farallon makes an Ultrawhip which mounts using a weatherproof/rugged TNC connector as its base. Shakespeare makes a 15 inch tall, 5216 antenna which uses a PL259/SO239 at its base which therefore needs to be carefully weatherproofed. All quarter-wave antennas require that the base of the antenna, i.e. the shield of the coax, be grounded to the mast at the base of the antenna to serve as a RF counterpoise. Aluminum or carbon masts work fine as a counterpoise.
  - Antenna manufacturers often make a claim about the gain of their antenna in their promotional literature. Commercial manufacturers of professional antennas specify gain in either dBi, i.e. relative to an "isotropic" radiator, or specify gain in dBd, i.e.relative to a half-wave dipole. Note that gain must be specified relative to something, because "dB" of gain is just a ratio and is meaningless if it isn't in reference to something. A conventional 1 meter long, half-wave antenna, has a gain of 2.15 dBi (i.e. relative to an isotropic radiator). The same conventional 1

meter, half-wave antenna has a gain of 0 dBd. The 0 dBd gain is set by definition, because "dBd" is relative to a half-wave dipole, which is exactly what the 1 meter antenna is. Most marine antenna manufacturers specify their 1 meter whips as being "3 dB" or sometimes "3 Marine dB." Some marketing departments are even more aggressive with undefined numbers and specify their 1 meter antennas as being 6 dB. The physics, however, limits a perfect, lossless, 1m half-wave antenna at marine vhf frequencies to having a gain of 0 dBd, or 2.15 dBi. Because the marine antenna marketing "dB" numbers are undefined and meaningless, the OSR requirements specify a minimum length of antenna. Gain increases with length for single element vertical antennas, so the length measurement provides OSR inspectors with something that they can easily measure to require a minimum gain for an OSR compliant antenna.

- In summary, any ~1 meter, 36 inch, half-wave antenna will have 0 dBd gain, no matter what the marketing paperwork says, and will be a good choice for mounting at the masthead of a sailboat. Racing boats might decide to use 15-18 inch (quarter wave) antennas which have less gain but are still OSR compliant. The OSR requirement is that a VHF/AIS antenna be at least 15 inches long.
- DC ground warning: It is desirable to only have one DC connection between the DC electrical system ground and the ocean, to reduce the likelihood for galvanic or electrolytic corrosion. Generally this ground connection is via the engine negative terminal or its bus, and then to ocean via the propeller shaft and propeller. If the shield of the VHF coax is connected to the aluminum or carbon mast at the masthead (which is essential for a quarter wave antenna) you will create a second and undesirable DC connection between the electrical system and the ocean, via the keel. This is because the mast is generally connected to the keel for a lightning ground. To avoid the undesirable additional DC ground connection put an inner-outer DC block in the antenna coax. For background and more detail on this see the article on grounding in the marine electrical category on the following website:
  http://honeynav.com/

- Antenna location for VHF and AIS
  - The OSR's require that the VHF whip be mounted at the masthead. This makes sense because daytime VHF range, when there is unlikely to be ducting, is limited to line of sight. For you to have a reasonable range (e.g. 7-8 miles) to receive a call for help from somebody using a handheld VHF at deck level, sailboats should take advantage of the height of their mast.
  - The OSR's permit the AIS to either share the primary antenna via an AIS antenna splitter, or to use a dedicated antenna that is mounted 3m or higher above the waterline. Given that one of the most important uses of AIS is to find the location of a person overboard who is equipped with an AIS MOB beacon, and the beacon will be right on the surface of the ocean, the masthead location is highly preferable to be also used for AIS, in order to have a reasonable (3-4 mile) receive range from an AIS MOB beacon. Thus it makes sense to use an AIS antenna splitter and share the masthead VHF antenna for both VHF and AIS. The AIS will not receive while the VHF is transmitting voice, but AIS MOB beacons repeat their transmissions frequently, and MOB's don't move very fast, so the shared antenna at the masthead makes the most sense. It is worth noting that even if you have separate antennas for the VHF and AIS, the AIS will likely not be able to receive when the VHF is transmitting voice due to having its

receiver blocked by the relatively high-power transmission in the marine VHF band from an antenna on the same boat.
    - VHF antennas should never be mounted closer to one-another than one wavelength, which in the case of marine VHF is 2 meters. Thus it isn't possible to mount two VHF antennas on the same masthead.

- Coax Selection
    - The OSR's require that the coax from the VHF radio and AIS have a maximum loss of 2.2 dB. Add up the loss per meter of the coax and make sure that the total loss of your coax is less than 2.2 dB. Include all segments of coax from the AIS antenna splitter to the masthead antenna. There is a link to a handy calculator in the references.
    - Losses for some common types of coax (at 156.8 MHz), in dB per meter, are:
        - LMR600 0.032 dB/m
        - LMR400 0.052 dB/m
        - RG8 or RG213 0.082 dB/m
        - LMR240 0.101 dB/m
        - RG8X 0.153 dB/m
        - RG58 0.189 dB/m
    - Coax connectors have essentially zero loss at marine VHF frequencies, and modern AIS antenna splitters have essentially zero loss on receive. If your coax has less than 2.2 dB loss and your VHF whip is at least 15 inches long, your installation will meet the OSR's and will work well. The most common performance problem is water intrusion into the coax at the masthead or at the base of the mast which can also be a wet environment.

Recommended Installation Practice for RF cables in a wet environment:

- If practical, use water-resistant coax connectors such as Type N or TNC. PL259-SO239 and BNC connectors are not weatherproof and so are less dependable in a marine environment, particularly at the masthead.
- Be cautious of "quick-connect" connectors such as BNC where the bayonet shell is held by springs. These connectors are made for rapid connection and disconnection. They do not provide strong and vibration-resistant mechanical support for the contacts.
- If you do use a PL259 connector, unless you are an experienced professional, it is preferred to use a connector with a crimp for the shield rather than the kind that requires that the shield be soldered. A crimp tool only costs about $30, or $15 for a die for a standard ratchet tool and can also be used on N-Type connectors as well. The PL259 connectors that require that the shield be soldered require significant skill and practice to attach properly and are nearly impossible to install correctly when sitting in a bosun's chair at the masthead on a windy day. There is a "how-to" reference at the end of this article on crimping coax connectors.
- Don't skimp on the connectors themselves. Amphenol is a good source of quality connectors. Avoid quick-connect piercing or screw-on connectors for permanent installations. They are great for jury rigging.
- If you use LMR-LW coax (e.g. lightweight) you must use a connector with a crimp for the shield because the shield braid is aluminum and can't be soldered with conventional solders and fluxes.

- All coax connectors (including N-type or TNC connectors that are ip67 rated) should be carefully sealed as described below. Careful sealing is particularly important for PL259 /SO239 connectors which have no water resistance by themselves.
- The Amphenol 82-6513 is the most waterproof N-type coax connector that I've found. That particular model is for LMR-400 coax but various versions are available for different coax. The connector is IP-67 rated by itself. It has an internal rubber gasket to seal the connector and a long overlap area for the adhesive-lined-heat-shrink with a ridge for the heat shrink to shrink around, to seal the connection to the coax.
- If a coax connector is used in a wet environment (e.g. the masthead or mast base), fill the interior of the coax connector with silicone dielectric grease (e.g. Dow Corning 4 but there are many equivalents). With no air cavities in the coax connector, there is no place for water to go. The silicone grease adds zero RF loss at any frequency below 1 GHz but adds enormous immunity to water intrusion and corrosion.
- Note that silicone dielectric grease is itself an insulator. The benefit of using it is not to add conductivity. The silicone grease is displaced by the contact force of the metal contacts but its presence prevents water and air from corroding the metal contacts.
- Seal the back of the connector to the coax with adhesive-lined-heat-shrink.
- Wrap the completed connector tightly with self-amalgamating tape (e.g. Scotch 2228) for water protection, and then wrap again with vinyl electrical tape (e.g. Scotch 33+) for mechanical and UV protection.
- Test the coax loss periodically to detect water intrusion.

Interference from LED lights at the masthead:

A few older design masthead LED lights (e.g. tricolor or anchor lights) emit noise in the marine VHF band from their switching circuitry. A quick way to test for this is to tune your VHF radio to an unused channel, turn the squelch all the way down so that you can hear the receiver noise, and then turn the masthead lights on and off to see if you can hear them.

Another test that works in a coastal area with lots of AIS contacts is to run your AIS transponder for 10 minutes and develop an impression of how many AIS contacts there are, and how far away the most distant ones are. Then turn on the masthead LED lights, restart the AIS transponder and run it for the same period, and compare the results.

Most currently available masthead LED lights are sufficiently well-designed to emit no interference, or just barely noticeable interference in the marine VHF band. It is worth testing however. Some early and poorly designed masthead LED lights would nearly deafen a VHF or AIS due to emitting strong RF interference.

Testing of Coaxial Cables installed on boats:

The loss in RF coaxial cable increases substantially, and quickly, when there is water intrusion. Coax that uses foam dielectric, like RG8X and LMR type coax, is particularly prone to this problem because the water can quickly propagate along the foam dielectric used in these type coaxes. The lightweight versions of LMR coax (LMR-LW) have yet another problem when wet, which is an aluminum shield which corrodes very quickly when wet. Simply measuring SWR from the base of the mast is not able to detect lossy coax because the increased attenuation due to lossy coax is indistinguishable from a well-matched antenna.

A relatively convenient solution is to disconnect the antenna at the masthead and then measure the “return loss” which is the amount of RF power reflecting back down the coax from the open end. Because the top of the coax is disconnected there will be 100 percent reflection, so the coax loss is half the measured return loss. This test requires the use of a SWR meter.

Test procedure with an SWR meter with coax in place in the mast: This is the most common test because SWR meters are widely available, inexpensive, and easy to use. Install the SWR meter between the radio and the antenna lead.

1. If the SWR is >4.0 with the antenna disconnected, then coax loss is acceptable (i.e. less than 2.2 dB loss).
2. If he SWR is < 1.5 with the antenna re-connected then the antenna and coax are ok.

Alternate procedures for RF engineers/technicians:

Test procedure with a directional power meter such as a Bird 43, with coax in place in the mast

1. Disconnect the antenna at the masthead
2. Connect the VHF radio to the directional power meter, and the other port of the directional power meter to the end of the coax that connects from the mast to the AIS splitter.
3. Measure the forward power (from the radio to the coax)
4. Measure the reflected power (from the coax back to the radio)
5. The reflected power should be greater than 36% of the forward power.
    a. For example, if the forward power is 25 watts, the reflected power should be greater than 9 watts, which is 0.36*25
    b. Explanation: the OSR’s require a maximum power loss 2.2 dB, which is a maximum power loss of 40%. That corresponds to a minimum power transmission of 60%. The reflected power is passing though the coax twice, up and down, so that would be a minimum power transmission of 60% up and 60% return, which is 36% power transmission for the round trip.
6. Finally, to test the antenna, reconnect the antenna at the mast head. Again, measure the reflected power at the boat end of the coax. The reflected power should now be less than 1 watt (which is a SWR of 1.5 or less) if the antenna is good. If the reflected power is still 9 watts or greater, then the antenna or coax is open or shorted.

Test procedure with a directional power meter such as a Bird43, for RF engineers and technicians unafraid of some math.

1. Disconnect the antenna at the masthead.
2. Connect the VHF radio to the directional power meter, and the other port of the directional power meter to end of the coax that connects from the mast to the AIS splitter.
3. Measure the forward power (from the radio to the coax)
4. Measure the reflected power (from the coax back to the radio)
5. Compute the coax loss in dB as 5* (log (P(fwd)/P(ref)))
7. Compare the measured coax loss to the cable specifications and to the requirements. The coax must have less than the OSR maximum 2.2 dB (i.e. 40%) power loss.
8. Finally, to test the antenna, reconnect the antenna at the mast head. Again measure the reflected power at the boat end of the coax. Compute the SWR from the nomographs that come with the directional power meter. The SWR should be 1.5 or lower. A higher SWR indicates that the antenna or coax is open or shorted.

Bench test for coax using a directional power meter.

1. The return loss approach to testing coax above works great for long lengths of coax, e.g. for coax in the mast where it would be inconvenient to operate a power meter at the masthead. For short lengths of coax, the return loss may be low enough so that the VHF radio will not transmit into such a high mismatch. To test shorter lengths of coax on a bench use the following approach which requires a 50 ohm, 25 w (or more) RF dummy load.
2. Connect the VHF radio to the directional power meter, and the other end of the directional power meter to the coax.
3. Connect the dummy load to the far end of the coax.
4. Measure the forward power from the VHF radio to the coax.
    a. Note the reflected power. If there is any measurable reflected power, it indicates a bad connection or flaw in the coax
5. Move the directional power meter to the far end of the coax, between the coax and the dummy load.
6. Measure the forward power from the coax to the dummy load.
7. Compute the coax loss in dB as 10* (log (P(radio)/P(load)))
8. Note that Losses for some common types of coax, in dB per meter, are:
    a. LMR600 0.032 dB/m
    b. LMR400 0.052 dB/m
    c. RG8 or RG213 0.082 dB/m
    d. LMR240 0.101 dB/m
    e. RG8X 0.153 dB/m
    f. RG58 0.189 dB/m
9. Comparison between the measured loss and the theoretical loss will indicate coax that has suffered from a wet dielectric. The coax losses above are for 156.8 MHz, in the marine band. Well installed coax connectors of any type (PL259, N, TNC) have essentially zero loss in the marine VHF band.

Test using a Vector Network Analyzer for RF engineers and technicians who are familiar with S Parameters, and Smith Charts and have a VNA.

The NanoVNA is a small network analyzer available from Amazon for $60 to $80. It is a full two-port, S-parameter capable network analyzer that works from 50 kHz through 300 MHz, with some functionality to 1.5 GHz. A NanoVNA can make very accurate measurements of SWR, return loss, FFT based TDR display, and Smith Chart display. For electrical engineers this is by far the most capable, accurate, and cost-effective way to measure coax loss, to test vhf antennas, and to find imperfections in coax using TDR. The functionality and price are astonishing but the NanoVNA is a general-purpose piece of test equipment which makes it tricky to use.

I might work on a detailed set of instructions on how to use a NanoVNA for marine coax and antenna test. If I do, I'll post it as an addendum to this document.

Stan Honey

References:

Coax loss calculator spreadsheet; this provides an easy way to calculate whether the loss from the coaxial feeder cable on a boat, meets the OSR requirement of 2.2 dB (40%) maximum power loss. The calculator is in the marine electrical articles category on the following website:
http://honeynav.com

RF connector specifications: note that N-type and TNC are available in IP67 rated versions.
https://www.amphenolrf.com/connectors/uhf.html
https://www.amphenolrf.com/connectors/n-type.html
https://www.amphenolrf.com/connectors/tnc.html

Practical instructions on installing coax connectors.
https://marinehowto.com/easy-vhf-terminations/

Article on Grounding in the marine electrical articles category on the following website:
http://honeynav.com

Amazon listing for the AURSINC version of the NanoVNA. There are many options on Amazon so pick one that has good reviews. Some have larger displays and rugged enclosures.