A New Spring Hat – Full Documentation

By Scott Schillereff, VA7SNJ, Victoria, BC, Canada (Scott dot Schillereff at gmail dot com)

Introduction

Much has been written about the benefits of top loading ("capacitive") hats for monopole antenna elements <1/4 w.l. (see writings of R.L. Cebik W4RNL and excellent experimental results by Ignacio Cascante EA2BD https://reflector.sota.org.uk/t/cap-hats-for-whips-short-verticals-get-more-with-low-effort/40281).

I have experimented with a variety of top hats using stainless steel spring wire, with the overall objectives of developing a hat for portable HF use that is lightweight, collapsible, fully self-contained (no bits to lose), and with low profile (to reduce wind loading). I present here my results and interpretation with a wish to generate discussion and further interest in developing and building hats.

SS Spring Wire

I used 304 stainless steel (SS) spring wire (iron alloy with 18% Cr, 8% Ni; "18/8" stainless) which has excellent corrosion resistance, and high tensile and yield strength. 304 SS is not the same as music (piano) wire which is a very high-carbon steel (with no Cr or Ni), also has high tensile strength, but easily rusts. Also, make sure to use 304 SS spring wire, not ductile (annealed) wire. Spring 304 is cold-worked through dies, compressing the internal grains and giving this alloy very high tensile and yield strength. This is why the wire "springs back" to shape after deformation.

For experimentation, I bought a variety pack of 304 SS spring wire online, with a range of diameters (0.3 mm – 3 mm) all precut to 400 mm (an arbitrary length, but actually a good length for hat building). For me, the "sweet spot" diameter for hat-building was 0.8 mm. This size is both lightweight yet stiff enough to be self-supporting. Spokes of this wire can stand out straight from a hub, or be bowed (flexed) to make 3D shapes that stay together when shaken by wind.

A bundle of these wires is not expensive:
https://www.amazon.ca/Stainless-Straight-Fishing-Accessories-Diameter/dp/B0G58819ZB/ref=mp_s_a_1_3?crid=GGWSP0WTPVPJ&dib=eyJ2IjoiMSJ9.YQNTrRP2vRv8xMKUd7DW7VJrOOmJRrFM49PkpueaNpK1rkU6LyvGRL_exQcCT6XztaDCzYZfdOduAPjxZzSxoIk-l0Iy-4kZ99qC5cBM-1snFPkz3oUqbmsjWB4e8ngbrYjrg5-E7SpNoUBYhzaRX0

30f4UvXMZQuLhm_nvG3fLrrsR_s-3boqP5CWUKumqhwS7cTulcnNTVSYOZOAyxug.SAKFAHhjdsixViOo0gOrprBV1cfvV0mrRx-Gva5YqAg&dib_tag=se&keywords=304+spring+steel+wire+0.8+mm&qid=1782585574&sprefix=304+spring+steel+wire+0+8+mm%2Caps%2C197&sr=8-3
Note, these wires come slightly oily and should be cleaned with alcohol before using.

Whip, Tip Preparation, and Hat Hubs

In my experiments, I used an inexpensive 2.5 m telescoping SS whip with 10 mm male brass bolt at the base (bought online). With such whips, I found it awkward to connect to the tip metal button so I replaced it with a threaded spacer to allow screw-on fittings (see Attachment 1 for details). Where hat hubs were needed, I made them from double-sided, FP4 fibreglas PCB stock (very light, easy to machine, solderable, and durable).

Hat Configurations

I built and tested a variety of hats:

- **No hat** - baseline configuration with 2.5 m whip;

  Photo 1 – Downward view of my 2.5 m whip with female spacer mounted on tip

- **Solid disc** - thin aluminum sheet cut from disposable oven liner; 26 cm (10.2”) diameter with 2.5 cm (1”) holes near outer edge to reduce sail effect in wind; total weight 18 g (0.64 oz);

Photo 2 – Solid aluminum disc mounted on top of whip

- **“Pumpkin” hat** - Six spring wires flexed into circles and distributed evenly around a hub to resemble a torus shape; 25 cm (9.8”) total width; 12.1 cm (4.8”) height, with perimeter wire 72 cm (28.3”) long; total weight 15 g (0.54 oz). When collapsed this hat is 40 cm (15.75”) long. My XYL said it looked like a pumpkin, hence the name.

Photo 3 – “Pumpkin” hat with six SS ribs manually inserted into female end of spacer (above yellow shrink tubing). Friction on internal screw threads seize the rib wire mechanically (remarkably well!) and make electrical contact.

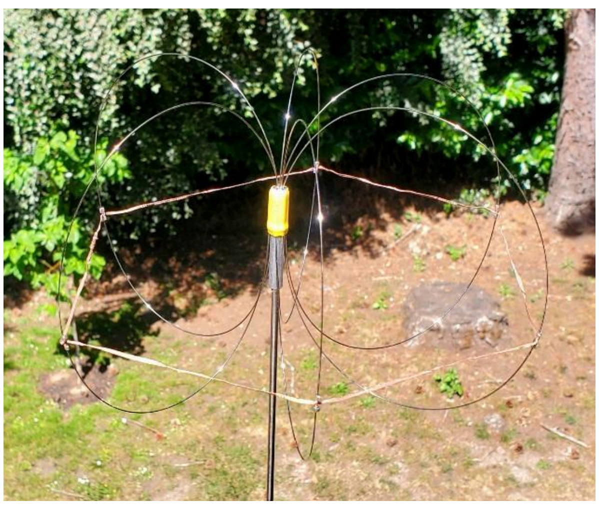
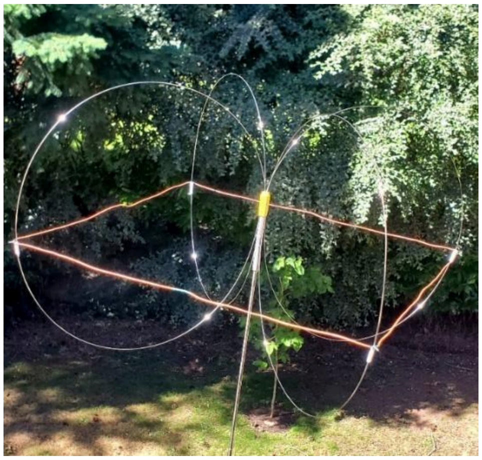


Photo 4 – Details of SS wire ribs seized by friction in open female top of spacer. This assembly is self-supporting and would in turn be screwed onto the spacer at the tip of the whip for use.

- **"Butterfly" hat** – four double-length SS rib wires flexed into circles; 46 cm (18") total width; 23 cm (9.1") height, with perimeter wire length 132 cm (52"). When fully collapsed, the Butterfly hat is 40.6 cm (16") long. Each rib is double-length, with two 40 cm SS spokes telescoping past each other and constrained within 1 cm long tight-fitting plastic sleeves (the white pieces just below perimeter wire on Photo 5). These sleeves maintain tight physical and electrical contact. My XYL thought this one resembled a butterfly.

  Photo 5 – Butterfly hat with four SS ribs inserted into the female space (as with the Pumpkin hat).

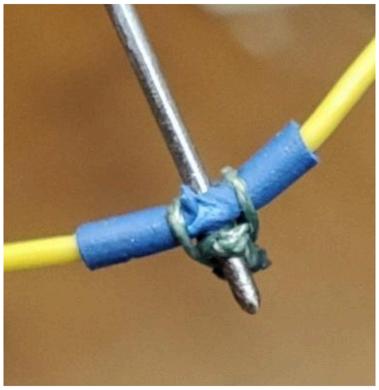


- **Hex hat** - Six SS radial spokes arrayed equally around hub and bowed slightly (15 cm amplitude) by slightly-too-small perimeter wire. This hat is similar to the conventional flat spoke and wire hats reported in many other articles, except slightly bowed to create some rigidity. Total width 70 cm (27.6”); total weight 14 g (0.5 oz); length when collapsed 40 cm (15.75”).

  Photo 6 – Hex Hat with six SS spokes bowed by perimeter wire (red and green). This was an early version of my Spring Hat (same electrical properties).

The perimeter wire for the Butterfly and Hex hats was made from 28-gauge, PVC insulated, 7-strand copper wire, scavenged from a multi-conductor computer cable. My focus was to use very light wire with low-profile (to reduce wind loading and packing weight). This perimeter wire was attached to the SS spokes (Hex Hat) or ribs (Butterfly hat) <u>without bulky or heavy connectors</u> by *impaling* the wire onto the SS wires. This mechanical connection was then tied to the tip of the SS wire with fly-fishing line (see Attachment 2 for details).

Photo 7 – Details of a finished impaling connection highlighting low profile and negligible connection weight



In addition, for the Pumpkin hat, I experimented with 1 mm-wide, braided copper solder wick as the perimeter wire, tying it to the torus rib with Clove Hitch knots. This worked OK, but I prefer the lower-profile and more electrically-secure impaling method.

Test Set Ups

I did three types of tests with a bare whip (no hat base case) and all four hats:

- Test (a) - changes in resonant frequency and bandwidth;
- Test (b) - changes in RF current profile along whip element; and
- Test (c) – far-field propagation signal strength A/A' tests (no hat/hat) using data from the Reverse Beacon Network (RBN).

For Tests (a) and (b), I set up my 2.5 m (8.2') whip on top of a 1.5 m (5') photo tripod on grass just off my 4 m (13.1') wooden balcony (on wood-frame house). All test instruments were at a table on the balcony. The whip tip was even with my balcony railing for easy access. I attached a 5 m (16.4') radial extending horizontally from the 1.5 m high feed point (tied to bushes). I ran 5 m (16.4') of RG-174 coax up to the balcony test area. For test (c), I set up my whip atop a 1.4 m (4.6') hiking pole at a cobble beach adjacent to the ocean at Victoria, BC. I attached two 5 m and one 2.6 m raised radials from the elevated feed point. The same 5 m RG-174 coax was used to an L-match ATU attached to an ICOM IC-705 transceiver. Photos below show the test set up.

Photo 8 – Balcony test set up. Tip of whip can just be seen against dark shadow. The coiled wire and clamp are the lead from the RF sensor to the orange DVM. IC-705 transceiver at bottom right; H4 nanoVNA to left of blue clipboard.

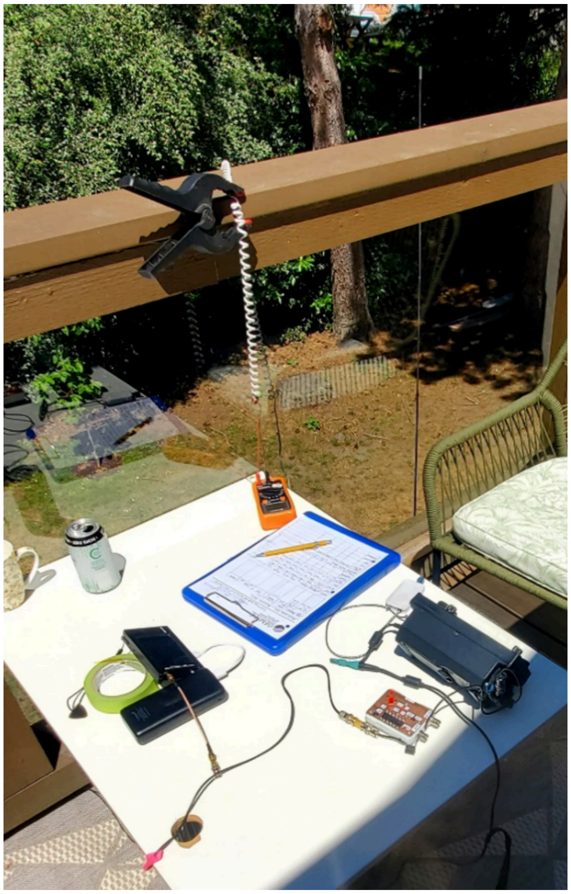


Photo 9 – Detail of toroid and RF rectifier assembly on whip. Bamboo skewer and DC leads go to lower left. White line to bottom of photo is thin cord used to raise and lower the assembly from the balcony rail.

Photo 10 – The hats laid out before testing. L to R: solid disc, Pumpkin, Hex, and Butterfly.

Test (a) was done using a H4 nanoVNA connected directly by coax to the whip system (no antenna tuning unit, ATU). Resonant frequency was noted where SWR (null) was lowest. For convenience, "bandwidth" was recorded as the frequency interval between points where SWR = 2 on either side of the SWR null.

Test (b) was done using a homebrew, moveable toroid and diode RF sensor, with rectified DC voltage measured with a DVM through a 3.7 m (12') piece of two-conductor household telephone cable (draped over balcony to measurement point along whip). The sensor assembly was mounted on a 30 cm (12") bamboo skewer to route the telephone cable at a high angle away from the whip.   For all tests, I keyed 5 W on 14045 KHz, tuned through my L-match tuner, with SWR tweaked to 1:1 in all cases. RF current was sampled at the base of whip and every 0.5 m upwards, so 0 m (base of whip), 0.5, 1.0, 1.5, 2.0, 2.5 m (tip of whip) (total six test positions).

Based on results of tests (a) and (b) (see below), I chose the Hex Hat for Test (c). For test (c), I sent multiple batches of CQs at 1 or 2 minute intervals on 17 m and 20 m, with and without the Hex Hat. Test (c) was conducted about 21:00-23:00 UTC, June 23, 2026; solar propagation conditions were reported as “Good”. Later, I retrieved RBN data, referenced it to my transmit batch times and frequencies, and analyzed signal strength results (S/N dB) for spotter stations reporting spots both with and without the Hex Hat.

Test Results and Interpretation

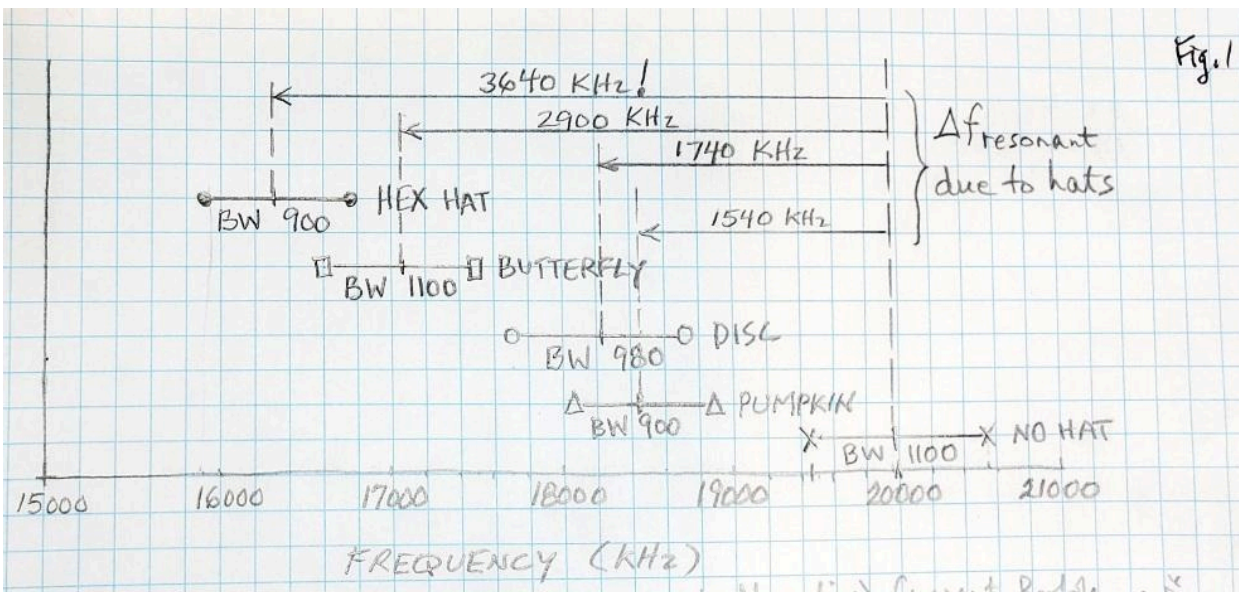
Test (a) - Changes in Resonant Frequency and Bandwidth

Table 1 shows the data for Test (a). Figure 1 depicts changes in resonant frequency, f(res), and bandwidth, BW, for all four hats and no hat.

Table 1 – Summary of resonant frequency and bandwidth results for Test (a)

Hat	f(res) MHz	f(res) cf no hat MHz	SWR null	f(-2 SWR) MHz	f(+2 SWR) MHz	BW KHz
No hat	19.960	x	1.16	19.460	20.560	1100
Pumpkin	18.420	-1.54	1.45	17.980	18.880	900
Disc	18.220	-1.74	1.45	17.740	18.720	980
Butterfly	17.060	-2.90	1.53	16.600	17.500	1100
Hex	16.320	-3.64	1.52	15.880	16.780	900

Figure 1 – Summary of f(res) and BW results for Test (a)



As expected, the bare whip (no hat) had the highest f(res). The disc and Pumpkin hats showed a similar decreases in f(res), 1.74 and 1.54 MHz, respectively. The Hex Hat showed the greatest drop in f(res), 3.64 MHz.

I estimated the effective electrical elongation of the whip due to the Hex hat frequency drop by solving this expression, where f = resonant frequency, and L = total antenna length:

f (no hat) x L(no hat) = f (hat) x L (hat)

Rearranging:

L(hat) = L(no hat) x f(no hat)/f(hat).

L(no hat) = 2.5 m(whip) + 5 m (tuned radial) = 7.5 m

So, L(hat) = 7.5 m x 19.96 MHz/16.32 MHz = 9.17 m.

Since the radial length was unchanged, the effective elongation of the whip due to the Hex hat was:

L(hat) – L(no hat) = 9.17 – 7.5 m = 1.67 m (5.5')

There are likely multiple factors affecting changes in f(res) (e.g., materials, 2D or 3D shapes, number of spokes or ribs, perimeter wire and type). However, it strikes me that the dominant factor controlling hat effectiveness was simply the diameter (width) of the hat or, more specifically, the *distance from the hub to the midpoint of the perimeter wire between spokes (or ribs)*. This is where RF current finally reaches zero; truly the "end of the line" for the electrical length of the vertical monopole element.

There seems to be no magic juju in the hats formed into 3D shapes. The Pumpkin hat diameter (viewed from above) was just less than the disc diameter, and both hats behaved in similar manner.

From previous reading, I had expected that BW would increase when using hats. However, the BWs for all test hats were *equal to or less than* that of the bare whip (no hat). I attribute this to the effects of using thin hat wires (0.8 mm spokes and 0.32 mm perimeter wire) compared with the much fatter uppermost section of the telescoping whip (3.5 mm diameter). Regardless, BW in the 900+ KHz range seems perfectly acceptable for ham CW or SSB band segments.

Test (b) – Changes in RF Current along the Whip due to Hats

Table 2 shows the data for Test (b).

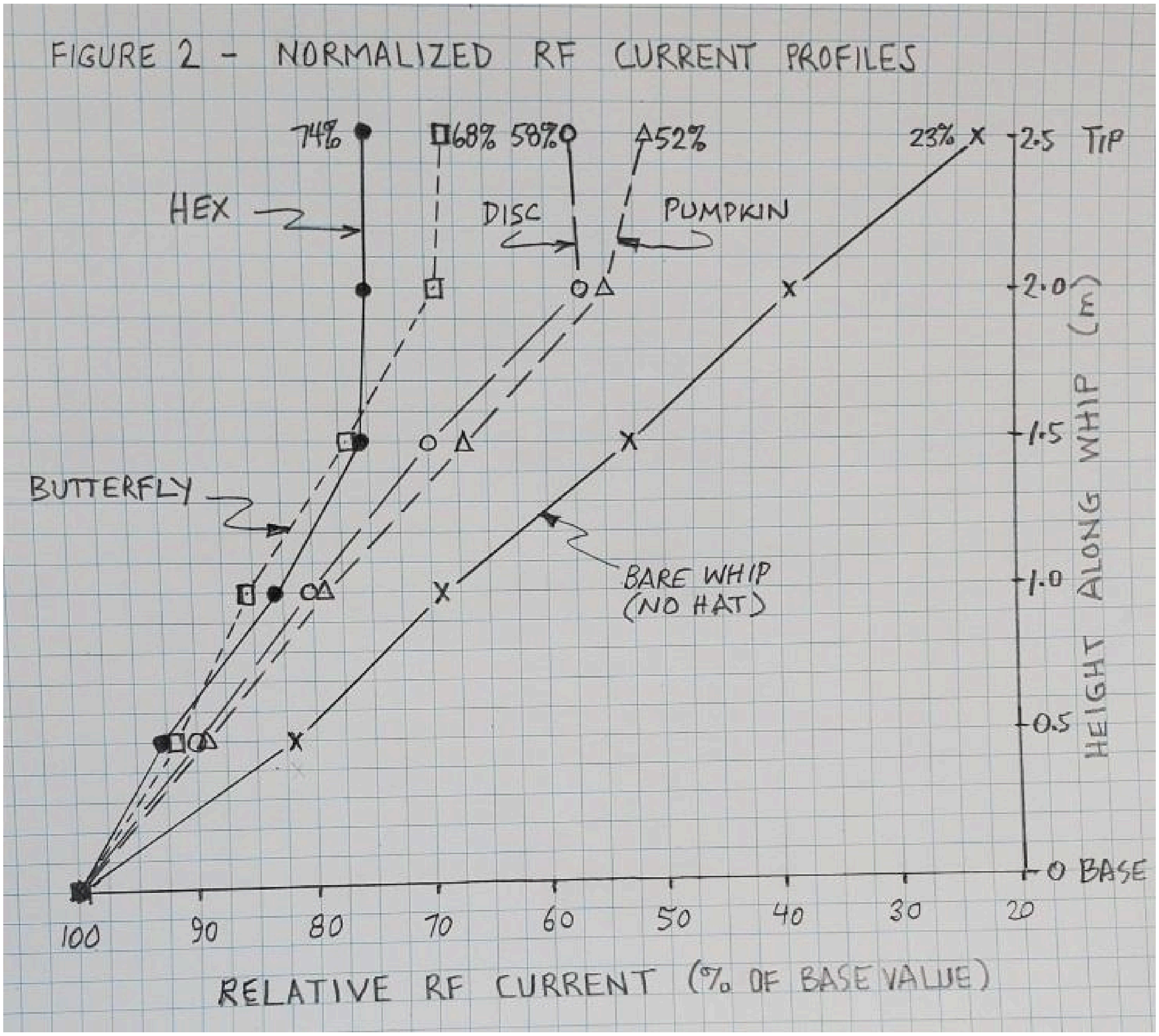
Table 2 – Summary of DC voltages from RF sensor along whip for hats and no hat

Hat	0 m (base)	0.5 m	1.0 m	1.5 m	2.0 m	2.5 m (tip)
No hat	932 [100%]	761 [82%]	643 [69%]	498 [53%]	361 [39%]	218 [23%]
Pumpkin	1165 [100%]	1040 [89%]	911[78%]	786 [67%]	638 [55%]	606 [52%]
Disc	1205 [100%]	1087 [90%]	976 [81%]	843 [70%]	692 [57%]	696 [58%]
Butterfly	1456 [100%]	1345 [92%]	1247 [86%]	1127 [77%]	1003 [69%]	996 [68%]
Hex	1692 [100%]	1570 [93%]	1400 [83%]	1292 [76%]	1270 [75%]	1248 [74%]

Note: all values in DC millivolts. Values in [ ] are % of base value for that hat configuration.

Table 2 shows that the rectified DC voltages (proportional to RF current) for all hats were greater than that for no hat, and progressively increased as the hats got larger. I attribute this to progressive electrical lengthening of the vertical monopole due to progressively larger hats diameters. As the electrical length of the vertical element gets closer to the electrical length of the horizontal element (i.e., my tuned radial, length 5 m (16.4')), the antenna more closely resembles an *L-shaped dipole*. As with all dipoles, the maximum RF current occurs at the center feed point. So, as the legs get closer to being electrically equal, it makes sense that the RF current should rise in the shorter leg.

Figure 2 shows normalized RF current profiles for all the test cases (expressed as % of base current for that hat). As expected, relative RF current in all cases was highest at the base and lower at the tip. The bare whip (no hat) shows the largest current decrease (only 23% of base current at the tip), while the Hex Hat shows the highest relative RF current at the tip (74%; 3.2 times more relative tip current than for no hat). From this result, and the fact that the Hex hat induced the greatest drop in resonant frequency, I conclude that the Hex hat is the most potent of the hats tested.



The *shapes* of the profiles are interesting (and mystifying). I had expected from past reading that the RF profiles should have a *convex* shape (bulge to the left) heading up toward the tip. This was not seen in any of my test profiles. The no hat profile shows a very linear profile from base to tip. The profiles for all hat cases were approximately linear from the base up to 60% of whip height (1.5 m), then inflected to steeper slopes higher up the whip. The profile for the solid disc even showed a slight *increase* in relative RF current from 2.0 m (56%) to 2.5 m at the tip (58%). I am not sure why all this occurs but, if real, it is a bonus; it shows RF current rises more steeply in the upper 30-40% of a whip.

In general, all of the hats showed a marked increase in relative RF current at the tip, exceeding the no hat tip value by factors of 2.3 to 3.2. To me, this represents one of the most valuable benefits of using a hat: raising the RF current profile, which in turn increases antenna radiation efficiency. Basically, for electrically-short monopoles, **any hat is better than no hat.**

Test (c)- Changes in Propagated Signal Strength

I recovered data for a total of 62 RBN spots from stations throughout western North America. I used data from spotter stations that reported S/N dB signal strength values for CQs both with and without the Hex hat. For multiple spots from the same spotter station, I calculated arithmetic means.

Comparing signal strength values (or averages) for hat and no hat, there *appeared* to be an increase in strength when using the hat. For example, spotter station AC0C-1 reported S/N values of 26, 20, and 19 dB (for one CQ batch with hat on; average 21.7 dB), and 15, 16, 16, and 12 dB (hat off; average 14.8 dB). Comparing these averages *appears* to show a 6.9 dB signal strength increase due to the hat. Fantastic! All peachy..right? Hmmm…not really.

I also found spotter reports showing mild to moderate *decreases* in signal strength (1.0 to 2.5 dB) with the hat on. I attribute this to *natural propagation variability* affecting RBN results to a degree greater than the influence of the hat. As evidence of this, one spotter station (W6YX; 20 m; hat on) initially reported 37 dB but then, just 10 minutes later, only 9 dB (with no changes in antenna or transmitter power!). This 28 dB change occurred naturally, *within* my CQ batch time frame. Propagation fading can occur in a matter of seconds. Thinking about this, even the duration of a CQ (say, 15-20 seconds) may be longer than the time required for substantial changes in natural propagation conditions.

In my view, Test (c) was a bust. In general, I conclude that unless one can rapidly switch a hat in or out of an antenna system and obtain A/A' propagation results *within seconds*, approaches using far-field signal strength data (like from the RBN system) are not well-suited to quantify the effects of a hat.

My New Spring Hat

Based on the above results, I concluded that the Hex hat was the winner and I set about developing a version of this hat that would be:

- Ultra light-weight
- Fully integrated (no bits and pieces to lose)
- Collapsible
- Easily transportable (stored connected to the collapsed whip itself)

- Relatively easy to make with hand tools and a drill, and
- Cheap.

The photos below show the progressive development and construction of my Spring Hat. In a nutshell, the hat is based on a reversible hub, with radial SS spokes that rotate on a circular axle of wire, soldered to the hub. For transport, it is screwed into the tip of the whip. To deploy, simply unscrew the hat from the whip tip, flip it over so that the spokes and perimeter wire flop outward, screw it all back onto the tip, and flex the spokes downward until the bowed structure "snaps" into place. That's it – the hat is always fully assembled and deploying/stowing takes less than a minute.

Photo 11 – Hex hat hub drafted onto FP4 PCB stock. Distance between flat sides is 23 mm.

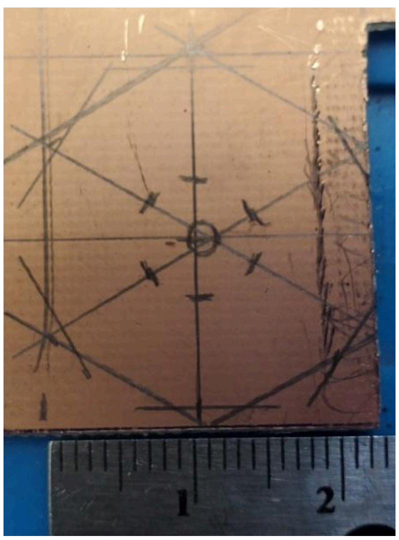


Photo 12 – Hub blank with hole drilled and cut out of PCB stock (tip: drill hole before cutting PCB). Black lines are 8 mm long and mark hack saw cut locations.

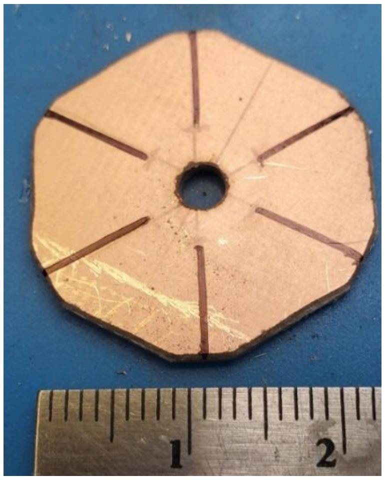


Photo 13 – Hub in vise for hack saw cuts. Cut slowly and support hub with fingertips.

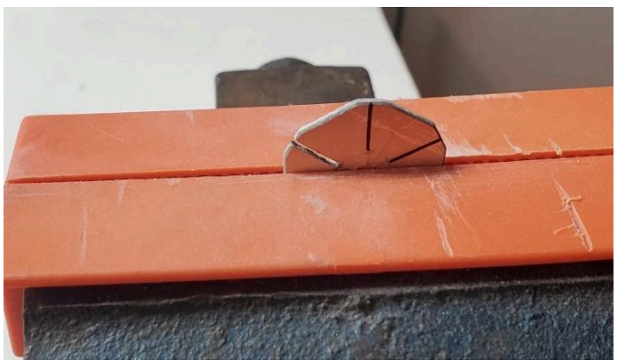


Photo 14 – Hub slots completed and widened with X-Acto blade so that the SS wires will just swing freely. Clean up all edges with X-Acto blade and jewelers file.

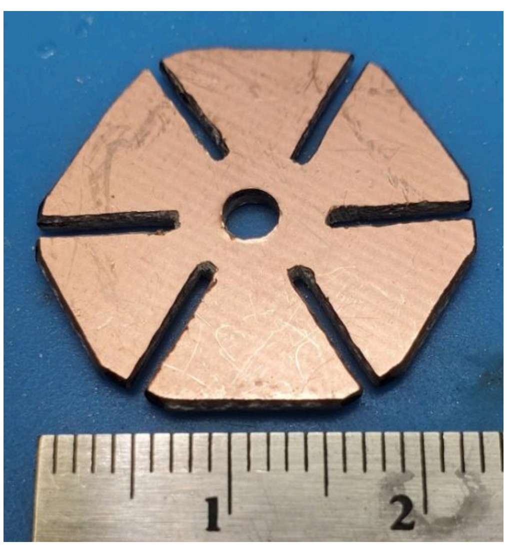


Photo 15 – Install spoke stop wires. Cut six 5 mm pieces of 20 gauge copper wire, bend to match hub, clamp temporarily with alligator clip, solder to PCB parallel to edge

Photo 16 – Form eyes in end of six SS spokes with tip of needle nose pliers. Start 7 mm back from end, bend back a bit, then roll eye in other direction. Center of eye should be in line with spoke. Can pinch eye closed a bit. Can practice on a test piece of SS spoke wire.

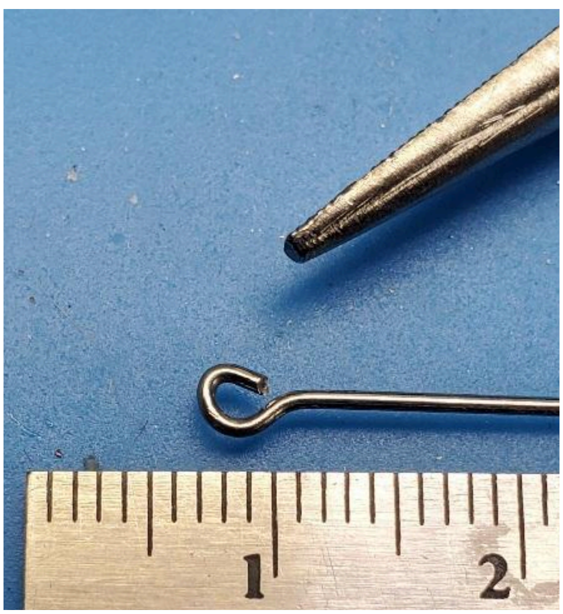


Photo 17 – Six spoke eyes positioned in slots (note stop wires (see Photo 15) are on *underside)*. Form circle of 20 gauge copper wire; thread through eyes. This wire forms a circular axle on which the spokes rotate. Hold all in place with alligator clips.

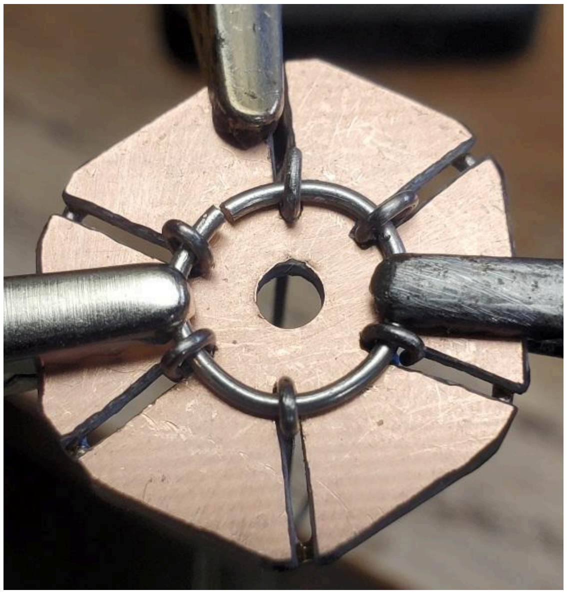


Photo 18 – Solder the axle wire to the PCB. Don’t worry about solder touching the spokes; it will not stick to the SS wire.

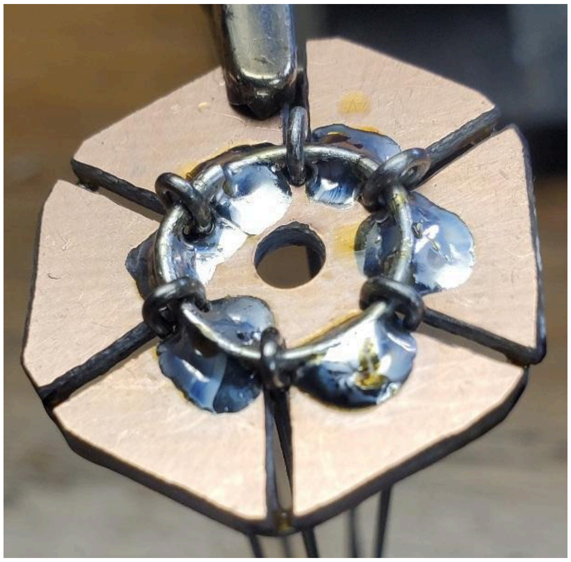


Photo 19 – Soldering complete and spoke wires freely hanging vertically at rest.

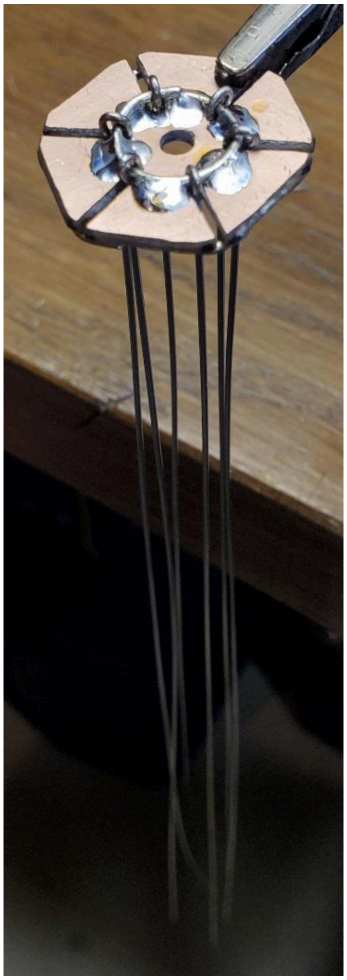


Photo 20 – Install 20 mm long stainless steel threaded rod to fit threads of female spacer at top of whip (in my case 6-32). Can make rod by cutting head off machine screw and filing cut end so rod threads easily. Place nut and locknut on one side; just nut on other. Ideally, adjust nuts so equal amount of threads are exposed on both sides (not so great here!). In this photo, threads on the right would be used to store the hat onto the whip for transport/storage; threads on the left would be used when flipped over to deploy.

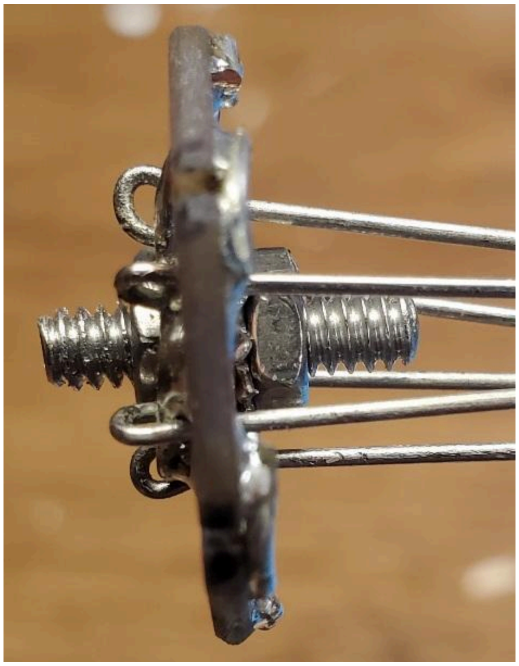


Photo 21 – Detail of hub with spokes deployed. The spokes rotate on the circular axle (here on underside) and flop outwards to rest against the stop wires at the edge of the hub.

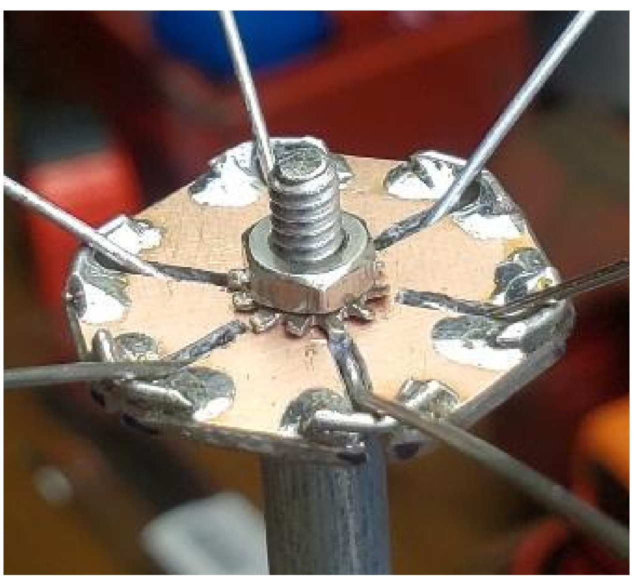


Photo 22 – Hex hat deployed on my 2.5 m whip (mostly telescoped in). After initial flopping (Photo 21), gentle downward pushing on a couple of spokes causes the hat to collectively snap downwards into this rigid umbrella shape. Release the hat by gently flexing spokes upward until the hat collapses back to relaxed shape shown in Photo 21.

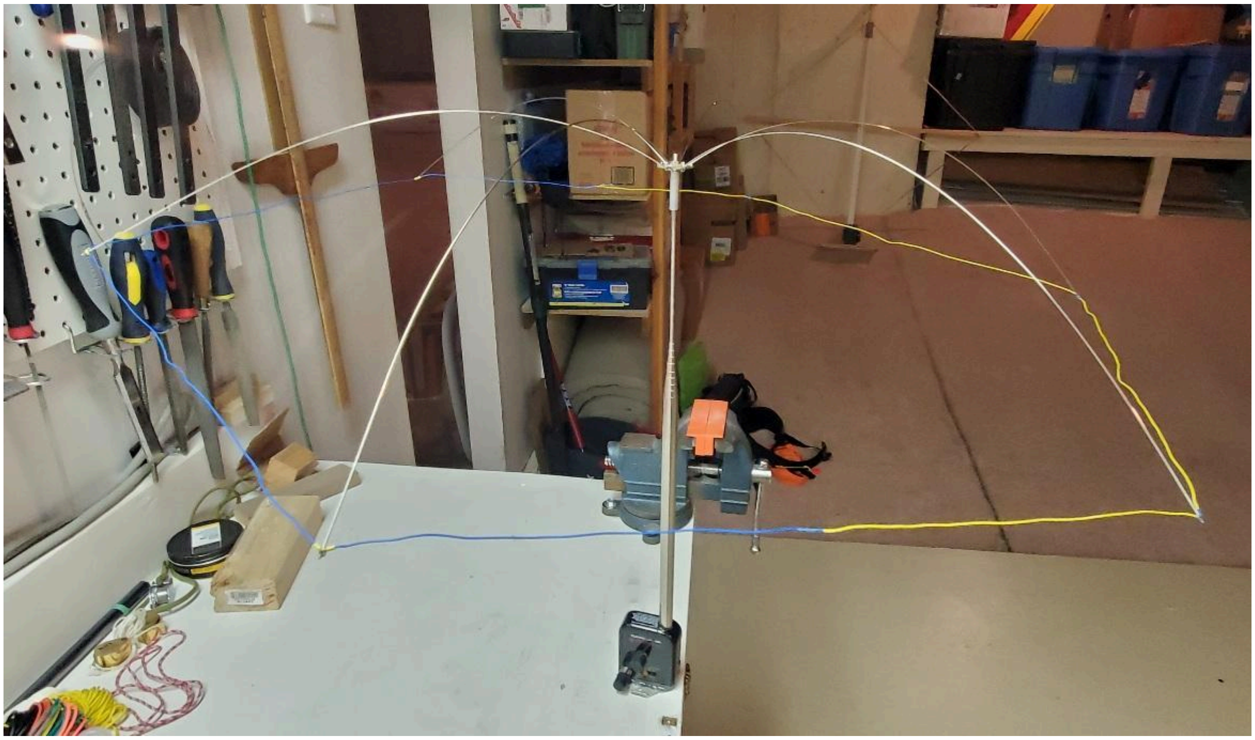


Photo 23 – Hex Hat collapsed and stowed against collapsed telescoping whip. Spokes and perimeter wire loop to be wrapped by Velcro strap at bottom of whip. This is how it stows into my antenna bag inside my pack (no heavy or bulky armouring added).

Vital stats for Spring Hat:
- Total weight: 14 g (0.5 oz)
- Width (between opposing spoke tips): 70 cm (27.6”)
- Perimeter wire length: 210 cm (82.7”, 6.9’)
- Collapsed length 40 cm (15.75”)
- Cost (materials): ~CAD$10 (6.2 Euro, US$7).

I would classify this as an intermediate-level construction project. You will need a bench, hand tools, a drill, and the ability to cut and shape FP4 PCB stock, shape the SS spoke eyes, solder, and make the impaled perimeter wire connections. This is definitely a labour of love. If you have questions on building one, please email me. If you want me to make you one, please send me US$1,000 and I will put you on the list…😉.

Conclusions

1. For electrically-short monopoles, any hat is better than no hat. Low-cost hats can be made with basic tools, readily-available materials, and intermediate-level ability at building things from scratch.
2. The hats tested here raised relative RF current at the tip of the monopole by factors of 2.3 to 3.2 and lowered the resonant frequency by up to 3.64 MHz compared with a bare whip.
3. The effectiveness of hats seems largely dependent on the length from the tip of monopole out to a point where RF current is zero (i.e., spoke radius (if no perimeter wire) or midway along a perimeter wire between spokes). 3D hat structures (like the Pumpking or Butterfly hats here) did not show special electrical behaviour.
4. Since skywave propagation can vary drastically in a matter of seconds, far-field propagation reporting systems (like the Reverse Beacon Network) which can report spotted signal strengths only at intervals of minutes or longer are inherently ill-suited to test hat effectiveness.
5. A “Spring Hat” design using 304 stainless steel spring wire is presented which is a compact, 14 g, collapsible, fully-integrated, radial hex hat with a 2.1 m long perimeter wire loop. A novel impaling method was developed to permanently attach the perimeter wire without bulky or heavy connectors. Field tests show this hat is quick to put up and take down (< 1 min.) and not strongly affected by wind load.
6. For future work, it would be interesting to experiment with “condensed” hats - that is, hats that maintain hub-to-zero-RF length but reduce hat diameter (e.g., by

folding spokes back on themselves (like a folded dipole) or using spiral or fractal spoke patterns), and by using ultra-lightweight conductors (e.g., Mylar film).

Attachments

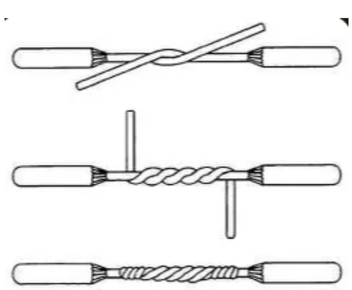
<u>Attachment 1 – Installing a threaded spacer at the tip of a telescoping whip</u>

- Cut off the tip button with a hack saw,
- Sand the upper 1 cm of hollow whip section with 150- or 220-grit sand paper; wipe clean with isopropyl alcohol,
- Carefully torque on an female-female aluminum spacer, 19 mm long. I used 6-32 threads; could use 4 mm. The spacer threads mash onto the sanded SS for a tight mechanical connection. If you use a brass spacer (slightly heavier), you could solder it to the SS whip tip (brush with rosin flux and use high heat (butane) flame).
- Paint the outside of the mechanical joint with fingernail polish or epoxy glue to protect it. (Note: DO NOT use cyano-acrylate (Krazy Glue) to attach the tip to the whip; it is not conductive and can wick into the threads and degrade electrical continuity).

The top of the spacer gives a secure screw mount for hats or whip extensions.

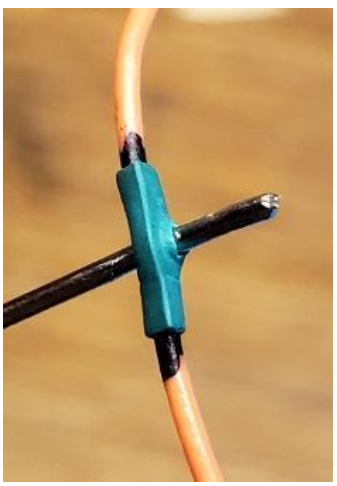
<u>Attachment 2 – Impaling Method to attach Perimeter Wire to SS Spoke</u>

- First, measure perimeter wire so that it will form loop with final size such that SS spokes are *bowed inward* (to give about 15 cm (6”) amplitude on spoke). For example, with my Hex Hat, the horizontal component of the bowed 40 cm (15.75”) spoke was 35 cm (13.8”), hence the finished perimeter wire length was 6 x 35 cm = 210 cm (82.7”). <u>Note</u>: add an extra 1 cm when cutting the wire (e.g., 21**1** cm) to allow wire length for the loop solder joint.
- Measure and mark the impaling locations on the loop wire. Position the perimeter loop joint mid-air between two impaling points.
- <u>*Before joining and soldering the loop*</u>, slide six 4 mm (3/16”)-long pieces of 1 mm shrink tubing onto the loop wire (these will form reinforcements at the impaling points), and one 1 cm (7/16”) length (to cover the solder joint of the loop joint).
- Strip 1 cm (7/16”) from each free end and join the perimeter loop ends using a Western Union Long Tie splice, as shown below:

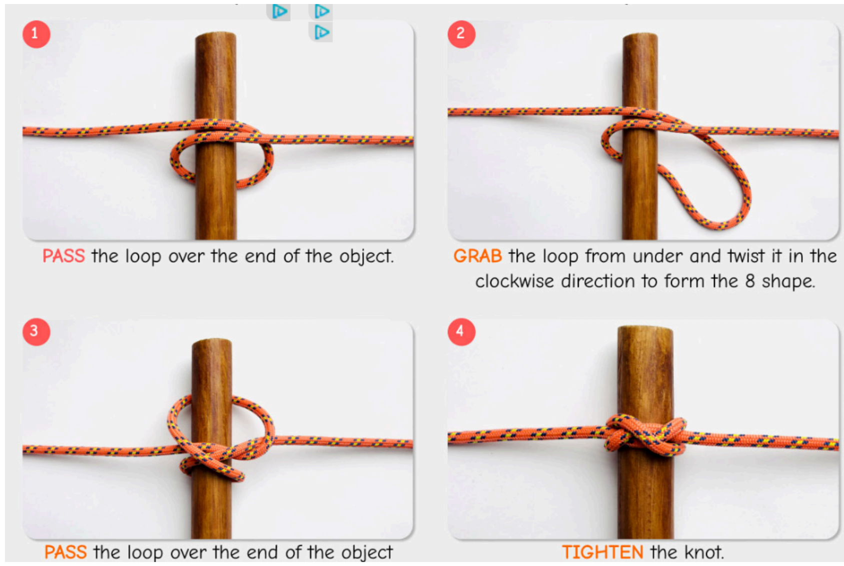


Solder the joint, then cover with the 1 cm piece of shrink tubing. This produces a physically strong but low-profile electrical connection.

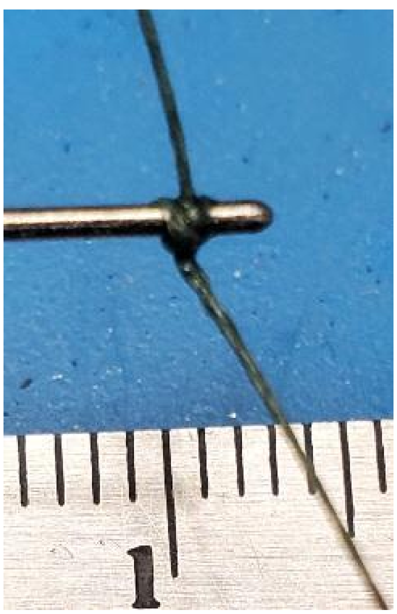
- At each impaling location, position and heat shrink one of the 4 mm long shrink tubes. Then squeeze the middle of the heat-shrink section flat with the tip of needle nose pliers (about 2 mm wide).
- Pierce the middle of this flat section by slowly pushing and wobbling a sewing needle (diameter a bit less than SS spoke). Create an open hole through the middle of the perimeter wire *without breaking any of the core strands*.
- Round the tip of each SS spoke with a jeweler's file. Sand the spoke ~1 cm (0.5") back from tip by pinching in a fold of 100-grit sandpaper and rotating in circular motions around the spoke (not along its length). This creates micro-grooves around the spoke which makes the lashing knots (see below) sieze better.
- Now (finally!) impale the perimeter wire by *gently* pushing and wiggling the rounded tip through the needle hole *without breaking any core strands*.



- Move the impaled wire down the spoke out of the way.
- Using 30 cm (12") of thin, braided Dyneema (Spectra) fly-fishing line or similar, form a *Constrictor Knot* around tip of spoke, as shown below:



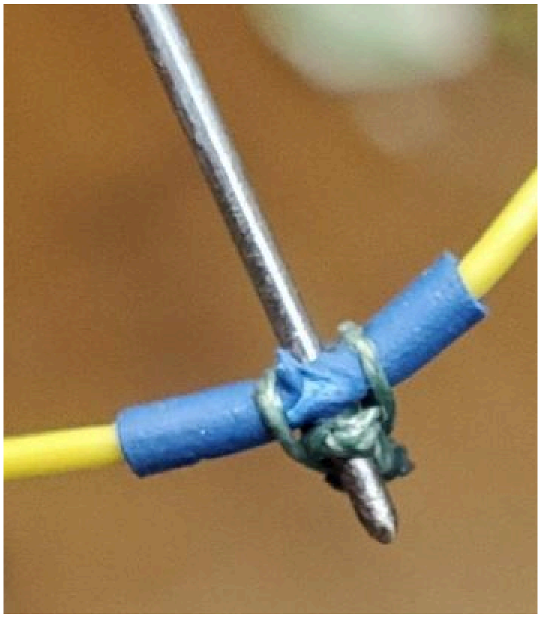
Leaving ~15 cm tails and snug up knot tightly 3 mm (1/8") from spoke tip. Place *small* drop of CA glue on *outer* (tip) side to secure knot. This knot is now **permanent;** you will have to cut it off to remove.



- Lightly scrape spoke for ~1 cm *inside* of the Constrictor Knot with X-Acto blade to remove glue/other residue from electrical contact area. Then slide impaled perimeter wire up into scraped zone, butting against hub side of Constrictor Knot.
- Wrap 15 cm tails from the Constrictor Knot in opposing directions *under* the impaled wire and back up to the exposed tip of the spoke. Lash in place with

three tight overhand knots. This lashing seizes and compresses the perimeter wire core strands against the bare SS spoke making a sound electrical contact.

- Cut excess fly line to leave 1 cm (0.5”) tails. From the side, *slowly* bring a lighter flame near these exposed tails; they will rapidly shrivel and ball up.



This finishes your impaled wire connection. These connections remain somewhat flexible and can be refreshed with a spritz of contact cleaner now and then.

Note: if something goes wrong with your Constrictor Knot or lashing, simply move the perimeter wire back down the spoke out of the way, cut off the knots with X-Acto blade, scrape off CA glue residue, and start again.