AM LOOP ANTENNAS

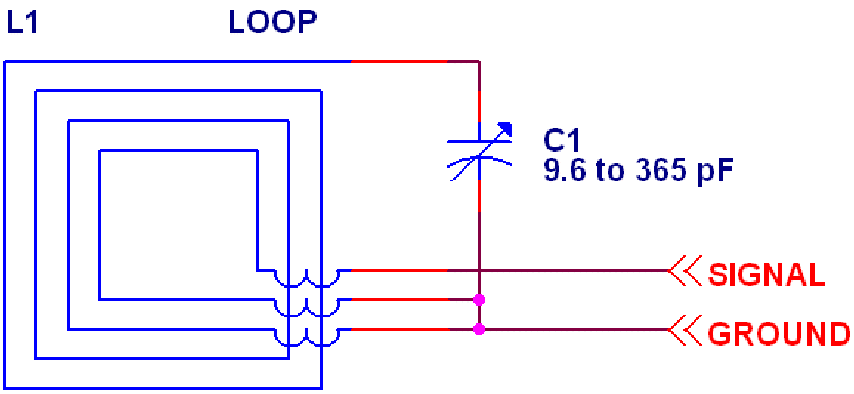
Now QUINN approved!

Erin Sanders, who plays the part of teenage inventor Quinn on Nickelodeon's "Zoey 101" show, with the author. She and her mother recently visited, and were impressed when this loop's little brother (also described below) was able to vastly improve very weak reception on KLBJ Austin (230 miles away) on an average radio. Used with a good radio, this loop is able to receive WWL 870 New Orleans, at almost 700 miles away (thanks to KJIM 870 Ft. Worth powering down).

Introduction

An AM loop antenna is one of the true marvels of electronics. Requiring no power, it takes advantage of the resonant properties of an inductor and a capacitor connected in parallel to receive weak AM stations. The "loop" part of the antenna is the inductor, and the tuning capacitor makes it resonate at a desired frequency. As a boy in Abilene in 1967, I discovered the basic principle of the loop antenna. By removing a relatively small spiral loop in my five tube table radio, and substituting a much larger loop salvaged from an older radio, I could receive my favorite station - KLIF from Dallas better. I hid the loop in a cardboard holder featuring the logo of a favorite rock band, and enjoyed many hours of good listening. Lacking the mathematical background to understand antenna theory - I could not take the concept to the next phase: designing my own loop. Nevertheless, the spiral loop - combined with the antenna section of the radio's tuning capacitor - formed a very good loop antenna. I understood quite well that the bigger the loop, the more stations I could receive.

The schematic diagram of an AM loop antenna is shown below. It consists of an inductive winding, which is supported on a frame, and a variable tuning capacitor that can be salvaged from a junk radio. The inductive winding consists of a primary, which forms a resonant network with the tuning capacitor, and a secondary "sense" winding that can be connected to a radio. In practice, however, the sense winding is not needed if the loop antenna can be placed near the radio - mutual coupling will take place with the antenna in the radio.



As nice as loop antennas are, there are some limitations you might want to consider before considering one:

- Large loops may be quite large and cumbersome. Even 8 inch loop antennas, however, may have high gain. Radio Shack and Terk manufacture very similar products - an 8 inch circular loop with a tuning capacitor embedded in the base. These small loop antennas can turn radios with poor sensitivities into modest DX rigs. Just don't expect a 6 transistor pocket radio to provide excellent reception if the distant station is near strong local stations - the selectivity and automatic volume control of the inexpensive receiver may not be up to the task.
- Loop antennas can be a bit difficult to use. If the target station is audible at all on the radio - it is a simple matter to put an external loop antenna nearby, and tune it until the weak station becomes strong. If the distant station is not audible at all, it may take several tries to "get it right". I discuss my remote reception site at length in the four foot loop article - so I won't go into detail here. I will mention briefly, however, that the radio in my daughter's room at "grandad's" is a 25 year old Radio Shack table model. There is no signal audible at all on my daughter's favorite station, which meant I had to tune the radio to a station nearby

- then tune the loop, then edge up the frequency on the radio, then the loop - etc. until the station comes in. The 8 inch Radio Shack loop brings it in almost without static! Once the radio was set, all I have to do is leave it from one visit to another. When I arrive, I put the loop near the radio, turn the radio on, tune the loop - done. Not too bad. Now if somebody ever touches the tuning on that radio between visits - it will be a bit of a hassle!

Why Another Loop Antenna Page?

Many articles have been written describing the construction of loop antennas, but they have been deficient in many respects. Some areas that are never adequately explained are:

- The differences between spiral winding and edge winding – which is better and why. I have elected to construct edge wound loops – it makes calculations easier.
- Whether the winding is spiral or edge, what is the spacing between the turns of the winding?
- Does the winding really relate to a standard tuning capacitor with a value of 9.6 to 365 pF, or does it use another value? My construction articles will specify the value of capacitance.
- Does the loop handle frequencies in the expanded band from 1610 to 1700 kHz?
- How is the loop interfaced to a receiver – where and how do you place the secondary? How many turns should the secondary be?

This introductory article will describe the mathematics of AM Loop Antennas and serve as the link point for construction articles. I have actually constructed several loop projects, and conducted controlled test of them from a remote test site. Construction projects are linked below.

Mathematics of Rectangular Loop Antennas

A loop antenna resonates according to the formula:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where:

- $\mathbf{f_O}$ is the resonant frequency in Hz
- **L** is the inductance of the loop in Henries
- **C** is the capacitance of the loop in Farads

The problem for loop designers comes in designing a loop with the desired value of inductance for their tuning capacitor. Ideally, the fully meshed position of the tuning capacitor should tune the loop antenna just below the lowest frequency in the desired band, and the fully open position of the tuning capacitor should tune the loop antenna just above the highest frequency in the desired band. In practice, this is sometimes a challenge because the AM band tunes over a frequency range that is 3:1 (1700 / 540 = 3.15). Surprisingly, I get the best results by adding more turns to the loop so I can use the newer 9.6 to 250 pf tuning capacitors. But then - there was a reason why transistor radio manufacturers did this in the first place - could it possibly be that it was easier to design antenna sections that tracked the entire band?

There are two formulas for loop inductance that I have found on the web - the Joe Carr formula and the UMR-EMC lab (University of Missouri-Rolla Electromagnetic Compatibility Laboratory) formula. I have used both in building loop antennas, and find the UMR-EMC lab formula works a little better. Both formulas are large, both are ugly. But this is the nature of loop antennas.

Incidentally, the "holy grail" of loop antenna design would be a formula that gives the dimensions of the frame based on the frequency, number of turns, and spacing of turns. I spent many hours working to derive such a formula from both the Joe Carr and UNC-EMC lab formulas. My attempts at derivation failed. The best thing for you to do is to tweak the dimensions of your loop to get the inductance - and therefore the frequency range - where you want it.

The Joe Carr Formula

The Joe Carr's Tech Note formula has worked for large square box loop antennas with wide spacing between the windings. It does not work for ribbon cable loops. It approximates rectangular loops provided that the aspect ratio is not too large. The formula is:

$$L(\mu H) = 0.008 \times N^2 \times A \times \left[\ln\left(\frac{1.4142 \times A \times N}{(N+1) \times B} \right) + 0.37942 + \left(\frac{0.333 \times (N+1) \times B}{A \times N} \right) \right]$$

Where:

- **L** is the loop inductance in mH
- **A** is the length of one side of the loop in cm
- **B** is the loop depth (thickness) in cm
- **N** is the number of turns

I have taken the Joe Carr formula and created a Javascript calculator for square loop antennas.

The UMR-EMC Lab Formula

The UMR EMC Lab formula appears to be a more general form of the Joe Carr formula. If I get some spare time, I may try to put h = w in the UMR EMC lab formula and see if it reduces to the Joe Carr formula. Anybody who wants to do this - write me and tell me if you succeed. The UMC EMC lab formula is:

$$L = N^2 \frac{\mu_0 \mu_r}{\pi}\left[-2(w+h)+2\sqrt{h^2+w^2}-h\times\ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right)-w\times\ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right)+h\times\ln\left(\frac{2h}{a}\right)+w\times\ln\left(\frac{2w}{a}\right)\right]$$

Where:

- **L** is the loop inductance in H
- **N** is the number of turns
- **w** is the loop length in cm
- **h** is the loop height in cm
- **a** is the radius of the spacing between wires (equal to the wire radius for adjacent winding, equal to 0.0635 for 0.127 (.050 inch) spaced ribbon cable, etc.
- $\mathbf{m_r}$ is the relative permeability of the medium - just use 1
- $\mathbf{m_o}$ is a physical constant - the permability of a vaccuum: m_o = 4p*10^{-7} T^2m^3/J = 12.566370614*10^{-7}

I also created a Javascript Calculator for the UMR EMC lab formula.

The Bob's Tesla Web Lab Formula

Many web articles utilize the Bob's Tesla Web Lab formula for loop antenna design. This formula is for a round loop, not rectangular, so I really won't go into detail here. It seems to work properly - when I reverse engineered the Terk AM Advantage - which is a circular loop:

- Radius = 4.234 inches
- Coil length B = 1.26 inches
- L = 318 mH

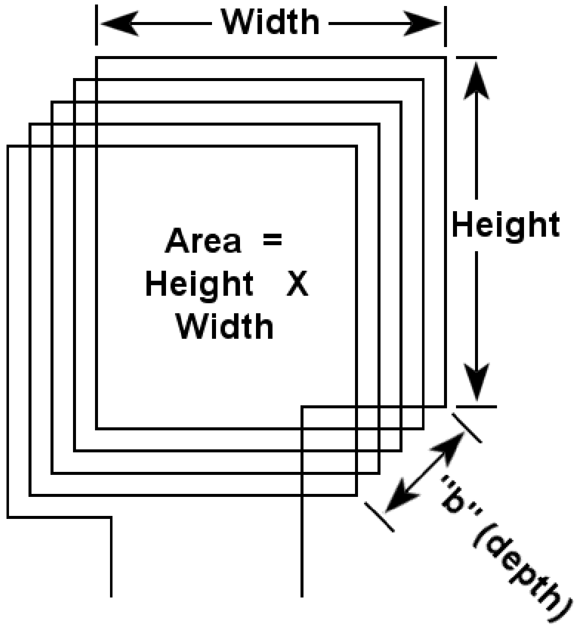
L calculates to 318 mH, which makes about 474 kHz with a 250 pF capacitor. A little low, but we know the Terk works, so probably adding in interwinding capacitance makes it correct. When I try to use the equivalent area for a rectangular loop, it doesn't work. I used the 3 foot loop as an example, the equivalent area circle has a 20.3 inch radius and coil length of 0.4. L calculates to 141 mH, which gives 700 kHz with a 365 pF capacitor, not even close! The 3 foot loops tunes to 540 with no problem.

Loop Antenna Mechanical Construction

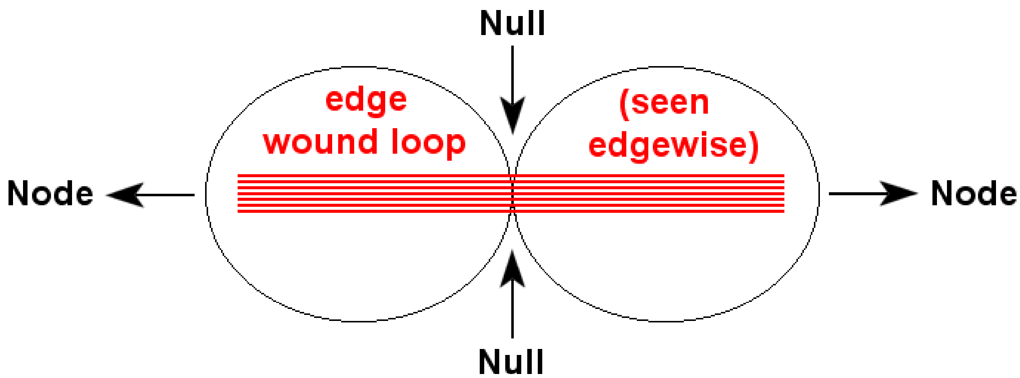
There are two choices for loop mechanical construction - edge wound and spiral wound. My construction articles are all for edge wound antennas, but many articles linked below describe spiral wound loops.

Edge Wound

An edge wound loop has each turn exactly the same size and on top of the preceding turn:



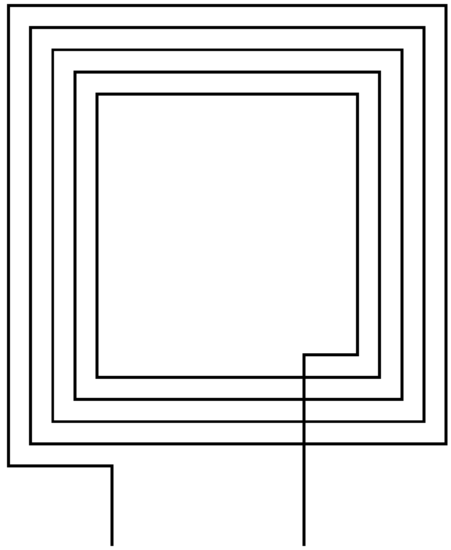
It is most sensitive to signals coming in the plane of the windings:



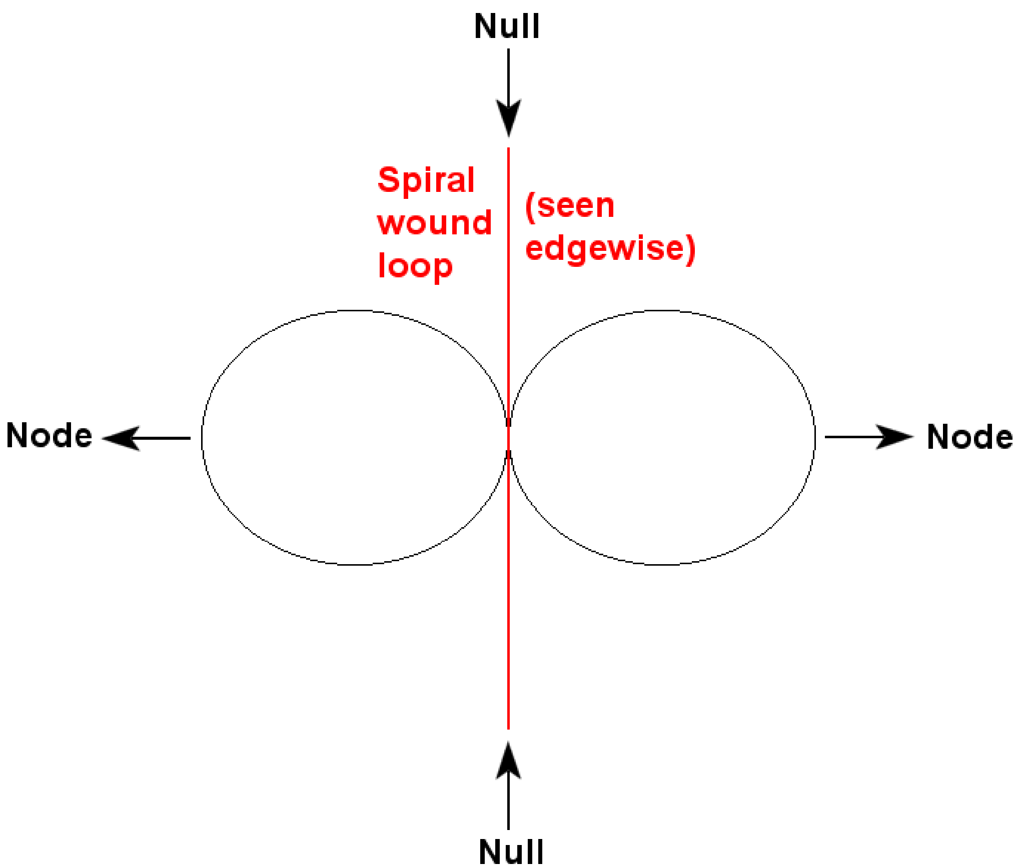
The reception pattern can be visualized as a figure 8 pattern, with the loop most sensitive to anything inside the "8", and less sensitive to anything outside the "8". The actual reception pattern is many times the physical size of the loop - the loop size was increased orders of magnitude in the figure to show the physical construction and orientation. The term "node" refers to the areas of highest sensitivity, and "null" to the areas of lowest sensitivity. While the nodes of loop antennas are quite broad, the nulls can be very sharp. A signal source perpendicular to the axis of an edge wound loop may not be received at all!

Spiral Wound

A spiral wound loop consists of a flat spiral of wire, where each turn is enough larger than the previous to fit snugly around it:



The reception pattern of a spiral loop is shown below:



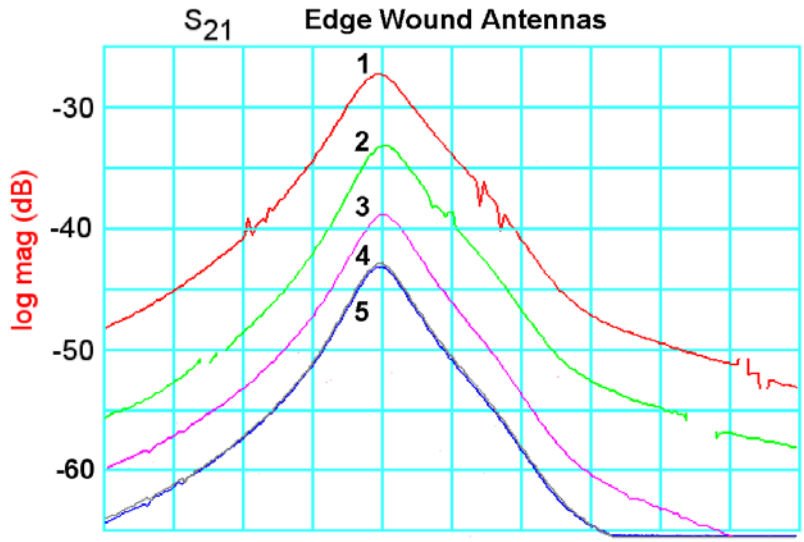
A spiral loop is least sensitive to signals received in its plane.

Loop Antenna Tru-isms Proved

I recently had occasion to do extensive loop antenna testing in a controlled, laboratory environment. I was working at a higher frequency, but the mathematics and behavior of loops is identical to the behavior of AM loops. Because I was dealing with very small loops, I could make as many loop antennas as I wanted - and they were easy to deal with.

Bigger is Better

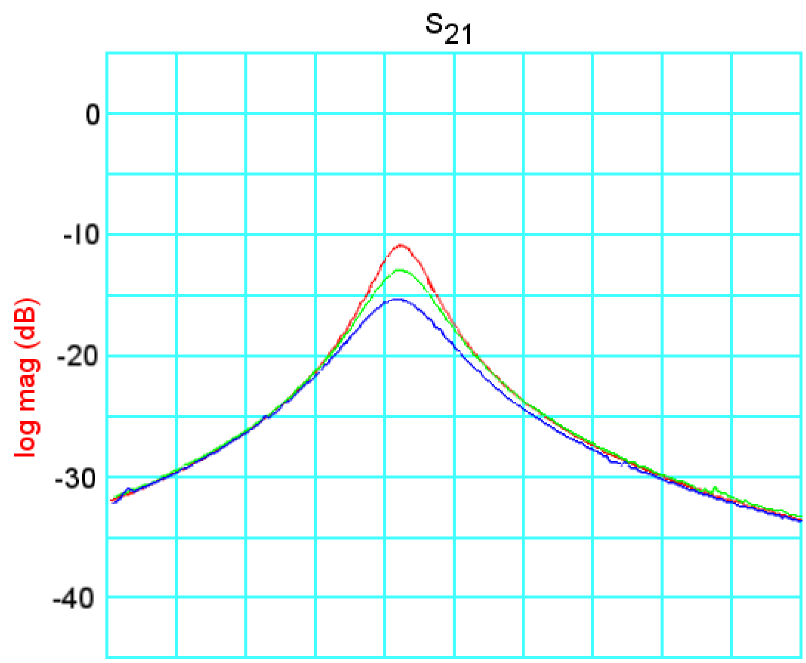
We all know that the bigger the loop, the more sensitive it is. Here is the proof:



This data, taken from a nework analyzer, shows the results for rectangular, edge wound loops varying from a single turn (3.775 inch edge) to 5 turns (0.32 inch edge), which translates to an area ranging from 14 to 0.1 in^2. All were the same inductance, and resonated with almost the same value of capacitance. It is interesting that the area varied over such a wide range. It is also very interesting that the received signal strength changed in increments of about 5 dB, except for the 4 - 5 turn increment where the mechanics of the loops were increasingly difficult to control (the bending radius of 20 AWG wire made both loops almost identical). Extrapolating this down in frequency and up in size, each time the area is increased enough to require one less turn, you can expect a power increase in the received signal of 5 dB, which is a jump of 3.16:1. To receive really weak signals - make the loop **BIG**! Incidentally, I had almost identical results for spiral wound loops.

Increasing the Q Increases the Sensitivity

I have recently revised this conclusion! Science is a self-correcting discipline, and as it becomes possible to perform more carefully controlled tests, the results can often change.



As expected the Q and sensitivity increased with larger guage wire. An alternative to larger guage wire is Litz wire (available at Skycraft. The best way to get more sensitivity, however, is still to increase the loop size. Increasing the loop Q too much has a consequence. Tom Polk, a good friend of mine, and crystal / transistor radio expert clued me in to one fact: if you make the Q of a loop too high, you are going to limit your audio frequency response. This may be acceptable if you want to separate out closely packed stations, but be aware of the effect. If you are making a remote tuned loop that will be mounted outdoors, Litz wire may not be your best choice. It corrodes outside - FAST!

Construction Articles

My articles form a sort of chronological "journey" of loop construction projects and things I learned along the way - read them in the order listed below to learn along with me!

- The Four Foot Loop
- The Two Foot Loop
- The Folding Loop
- The 3 Foot Portable Ribbon Cable Loop
- The Umbrella Loop
- Styrofoam Loops

Where to from here?

- I wonder if I couldn't make a loop using a flat variation of a Hoberman Sphere. I have seen an awesome flat "Hoberman-like" structure used to support large banners at "Radio Disney" live remotes my daughter goes to. (Obviously we go to the remotes - as KMKI AM 620's fabulous signal makes it an ideal test station from Lubbock, TX). I can't find anything on the web about the display frame - since it is trade show type stuff it may be expensive. But - I have the measurements, perhaps I can find a way to make a loop frame from it.

Loop Antenna (and Related) Links

- Super Antenna plans
- Loop Aerials & ATU's
- Magnetic Loop Antenna Experiments by Jeff Imel, KB9ZUR
- AM Antennas - ABC Reception Advice Website
- LOOP
- Amidon Associates Ferrite Rods, Bars, Plates and Tubes
- Ferrite Rods, Bars, Plates and Tubes
- High-Gain Preamp
- A Magnetic Loop Antenna for Shortwave Listening (SWL) by KR1ST
- Receiving Loop Theory - N4YWK
- Magnetic Loop antenne's.
- RadioIntel.com - THE WOODEN ALTAZIMUTH HOOP LOOP
- Radio Netherlands Media Network An Introduction to Long Distance Medium Wave Listening
- Dave's Loop Antenna Page
- Air Variable Capacitors, Shafted
- RECEIVING LOOP AERIALS FOR 1.8 MHz
- LOOP DISCUSSION!
- Better AM Radio Reception
- GCC Loop Antenna Design There are now two Yahoo loop antenna groups - this one has the original content
- Yahoo! Groups loopantennas
- ARES RACES Antenna Projects
- The Ultimate AM Antenna
- Doug's R-E Loop Article Page
- Reception techniques An easy loop
- amandx-loop
- AM-FM Reception Tips
- DX News, Tips and Information page
- Joe Carr's Tech Notes
- Rectangle Loop
- Loop Page
- AM Radio Reception
- Coax-Shielded Loop Antenna for 80 - 40 meters
- a Ten Foot Receiving Loop For Low Frequency Dx Work
- Rahmenantenne
- Super Antenna plans
- Universal LF-MF Preamp
- Receiving Loop Theory - N4YWK
- Re Tuned Loop For AM Radio
- A conveniant AM loop antenna
- Loop Antenna Page
- Loop Antenna
- All About Loops - for traffic detection
- Dave's Loop Antenna Page
- Rectangle Loop
- Interference-reducing Antenna page
- 903 383-7047 STORMWISE Ferrite Rods Long Ferrite Rods VLF Antenna Element Big Ferrite Rods
- The Black Hole Antenna
- http--www.wenzel.com-pdffiles-antenna1.pdf

- AM Radio Antennas

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