Notes on:

Calculating the Inductance of a Ferrite Rod-Cored Coil
and
Selecting a Wire Size

By: Dan McGillis,12/06

Various posters to the Rap ’n Tap group have talked about the benefits of using ferrite rods to make inexpensive, compact, moderately high Q coils for crystal sets. After reading Ben Tongue’s Article 29 [**http://www.bentongue.com**] “About Maximizing the Q of Solenoid Inductors that use Ferrite Rod Cores” - which is an eye-opening piece of work - I bought some Amidon 0.5” x 4” ferrite 61 rods to play with. I’d like to post a summary of what I think I’ve learned so far to see if I’m on the right track. If I’m not, maybe someone will set me straight. If this is useful, maybe someone will benefit. (By-the-way,all dimensions in the equations are in cm unless otherwise noted).

A. The inductance factor, AL

The inductance of a ferrite rod-cored coil is often described by:

EQN.1 $$L(nH) = AL*N^2,$$

where L is the inductance in nanohenries, N is the number of turns of wire in the coil wound around the ferrite rod (centered on the rod), and AL is the “inductance factor” which describes the rods’ ability to provide inductance. The AL values are in units of (nH/turn squared) which are the same as AL values in units of (mh/1000 turns). The inductance factor (AL) is not a constant; it depends on the length of the coil. As the coil length decreases, the value of AL increases.

The inductance factor can be approximately found by at least three methods (I like the third one):

a.) One method is to use the “ferrite rod antenna equation”. I’ve seen this equation written in several forms, a common one being

EQN.2 $$L(nH) \sim \{[\ \mu o * \mu rod * area\ ] / lm\} * N^2$$

where:

** the coil length (lc) “approximately” covers the entire length of the rod (lr),
L(nH) = inductance in nanohenries,
μo = permeability of vacuum = 4 * π nanohenries/cm,
μrod = relative permeability of the ferrite rod (a number >1), **†††**
area = cross-sectional area of the ferrite rod (cm^2),
N^2 = number of turns in the coil (N), squared,
lm = magnetic path length (cm),
---- it’s usually assumed that lm ~ lr,the rod length.

The inductance factor, for lc = lr, is then approximately:

EQN.3 AL(lc ~ lr) ~ [μo * μrod * area]/ lr.

[††† The relative - to vacuum - rod permeability, μrod, is determined from the ferrite rod Manufacturer's plots of (μrod) versus the (rod length/ rod diameter) ratio for various values of the ferrite material relative permeability (μi). See for example: [http://www.amidoncorp.com/aai_ferriterods.htm] From Amidon's plots, μrod for Amidon's Ferrite 61 material (μi = 125) is about 35 for a 0.5" x 4" rod, and about 65 for a 0.5" x 7.5" rod.]

So, using EQN 3 with this data gives:

AL(lc ~ lr) ~ 55 for a 0.5"x4" ferrite 61 rod, and
AL(lc ~ lr) ~ 54 for a 0.5"x7.5" ferrite 61 rod.

b.) A second method is to use the rod manufacturer's data - if it's available. The Amidon literature warns that many factors can affect AL but says that for a coil covering "nearly" all of the rod (lc ~ lr), the value of the inductance factor is:

AL(lc ~ lr) ~ 43 for a 0.5"x4" ferrite 61 rod, and
AL(lc ~ lr) ~ 49 for a 0.5"x7.5" ferrite 61 rod.

The problem with using either method (a) or method (b) is that you have to figure out what the inductance factor (AL) will be when the length of the coil (lc) is not equal to the length of the rod (lr). The most commom approach seems to be to assume that:

EQN.4 AL(lc) = AL(lc ~ lr) * [lr/ lc]^(1/3).

I don't know the origin of this approximation, it obviously has a problem at lc = 0, but I've seen it used in Amidon literature, on the web, and in a 1950's electrical engineer's handbook (with no reference).

Equation 4 is plotted in Figure 1 for a 0.5"x4" ferrite 61 rod, with AL(lc ~ lr) = 55, ie., method (a), and AL(lc ~ lr) = 43, ie., method (b). Also plotted are my measured values of AL(lc), calculated using Equation 1, for 10 recently purchased Amidon 0.5"x4" ferrite 61 rods. (The data will be described in more detail later.)

The data tends to match method (a) in the mid-coil-length range and method (b) in the small coil length range. The data at larger coil lengths is tending toward method (b) also.

One conclusion I draw from Figure 1 is that the inductance factor (AL) dependance on the coil length lc) is probably not proportional to [lr/ lc]^(1/3).

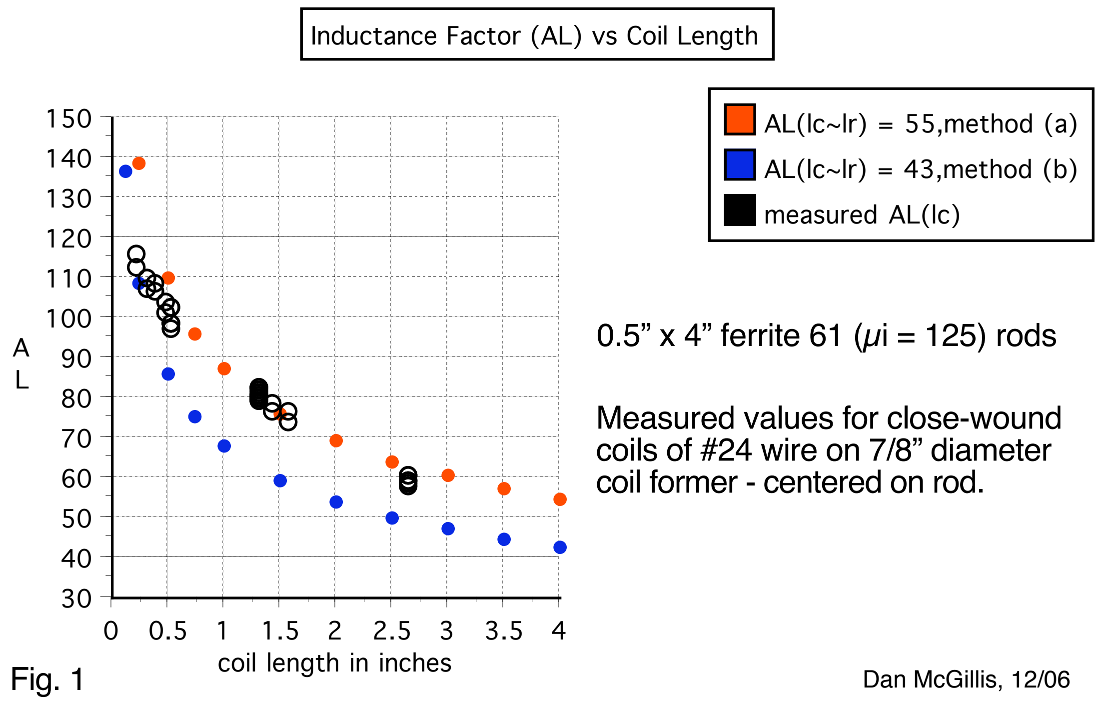

Fig. 1

c.) The third method of determining the inductance factor (AL) - the method I favor - is to measure it for each ferrite rod.

Ben Tongue’s Article 29, Table 1, shows the important result that the inductance of a rod-cored coil seems to be nearly independent of the coils’ diameter. Therefore,the inductance factor (AL) can be determined by inserting, and centering, a rod in a test coil of length lc, with N turns, and measuring the rod-cored coils’ inductance. The inductance factor AL(lc) is then calculated from Equation 1. I used 3 test coils with N = 25, 55 and 120 turns of #24 magnet wire close-wound on 7/8”OD x 5/8”ID PEX tubing. (PEX is a polyethylene potable water line tubing sold in some home centers.)

The measured values of AL(lc), as a function of coil length (lc), are shown in Figure 2 for rod # 9. The x-axis is in terms of [lc]^(1/3) because it gave the best fit.

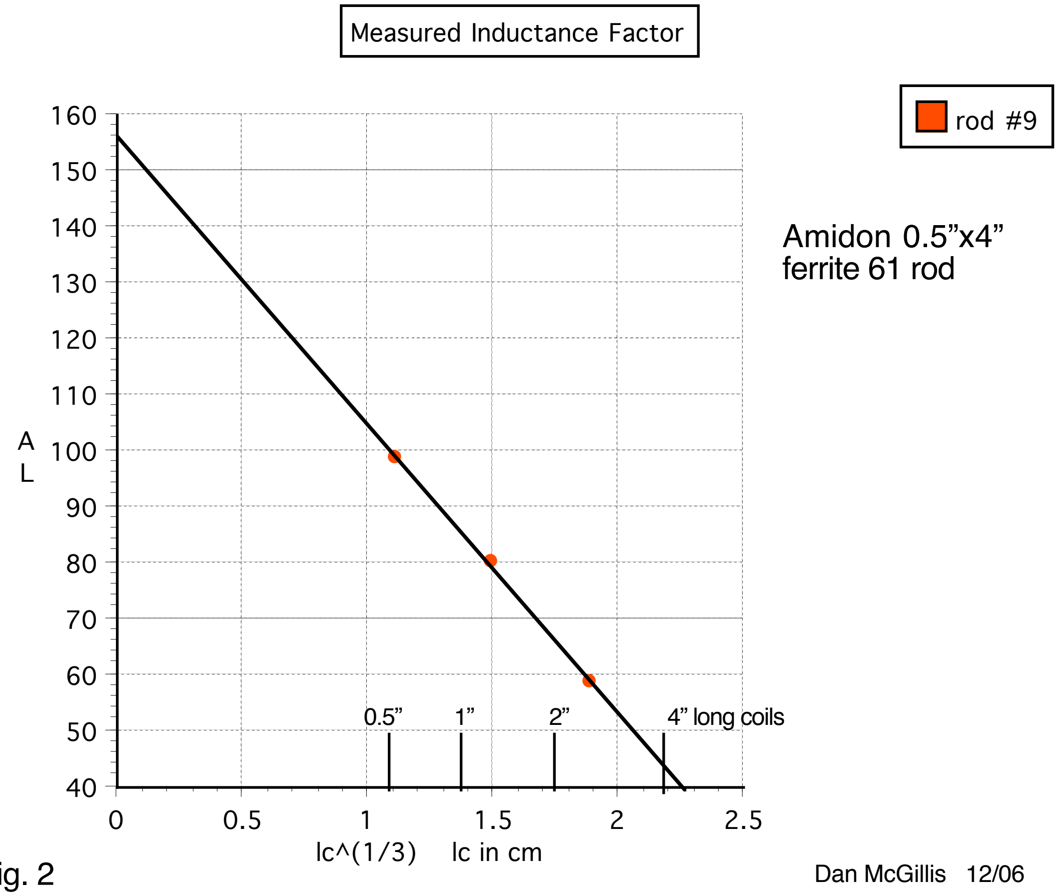

Fig. 2

The data for rod #9 fits on a straight line (y = mx +b). The measured inductance factor data for all of the other rods fit to straight lines equally as well. That means the inductance factor AL(lc) can be described by the equation:

EQN.5 $$AL(lc) = -m * lc^{(1/3)} + AL(lc=0).$$

Each rod's straight line “characteristic curve” had a slightly different slope (m) and lc =0 intercept, ALo. The average values for the group of rods were:

m = - 51.8 (+/ - 1.4, 1-sigma),

ALo = 157.5 (+/ - 3.6, 1-sigma).

The average value of AL(lc = lr) is 45.3, very close to Amidon's suggested value of 43.

Equation 5 is plotted in Figure 3 - using the average values for slope (m) and intercept (ALo) - along with the measured AL data that was previously plotted in Figure 1.

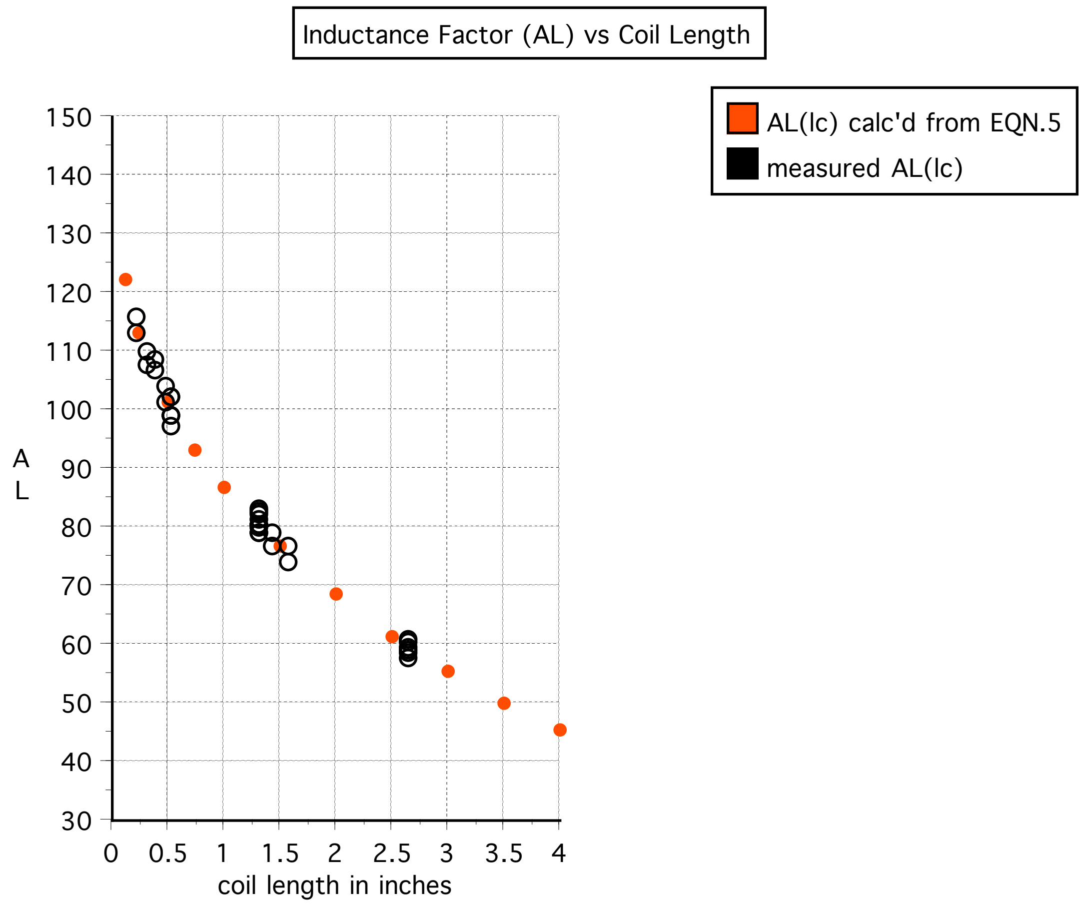

Fig. 3

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Equation 5 fits the data very well. That's why I prefer method (c).

Furthermore, Ben Tongue and others have pointed out that ferrite rods can be different , magnetically, within a production run,from manufacturer to manufacturer, and over time as the manufacturing process changes. So where it's feasible, it's probably wise to measure the inductance factor of each rod - at different test coil lengths - to avoid surprises and excessive "pruning".

B. Calculating the number of turns needed to produce a desired inductance.

By combining Equations 1 and 5, an equation can be written that gives the inductance of a ferrite rod-cored coil (with the coil centered on the rod):

EQN.6 $L(nH) = (N^2) * \{ m * lc^{(1/3)} + ALo\}$,

where:

- $L(nH)$ = the inductance in nanohenries,
- N is the number of turns of wire in the coil
- lc is the length of the coil (in cm)
- the constants (m) and ALo are determined from measurement of the rods' inductance factor using test coils.

The coil length (lc) is determined by the diameter of the wire (dw) used to wind the coil, the number of turns (N) in the coil, and by how tightly the coil is wound. My coil winding technique is not very good. There are always variable width spaces between turns. So, I define a "packing factor", (T), to describe and quantify the coil "tightness". It's defined by:

EQN.7 T = [actual coil length, (lc)]/ [the minimum coil length,(~ N*dw)].

The packing factor (T) for my coils is around 1.1 but can go as high as 1.2 -1.5 for small wires which are hard to see. If a one diameter space is between each wire, then T ~ 2.

Combining Equations 6 and 7, gives an equation that can be used to calculated the inductance of a ferrite rod-cored coil:

EQN.8 $L(nH) = (N^2) * \{ m * (N * dw * T)^{(1/3)} + ALo\}$.

A practical and simple way to use Equation 8 is to calculate the inductance L(nH) for various values of N and plot the results. This was done and is shown in Figure 4 for the following conditions:

- a 0.5"x4" ferrite 61 rod with measured parameters: m = -51.4, and, ALo = 156.3;
- a 165/46 litz coil with wire diameter: dw = 0.027" (remember to convert to cm);
- the coil was wound directly on the ferrite rod (on a piece of carpet tape);
- the coil packing factor was about: T = 1.13.

Measured inductance values, measured as the coil was being "pruned", are also shown in Figure 4. The agreement between the measured and calculated inductance is good. The results suggest that Equation 8 is accurate enough to give you a starting point that is close to the correct number of turns to get a desired inductance.

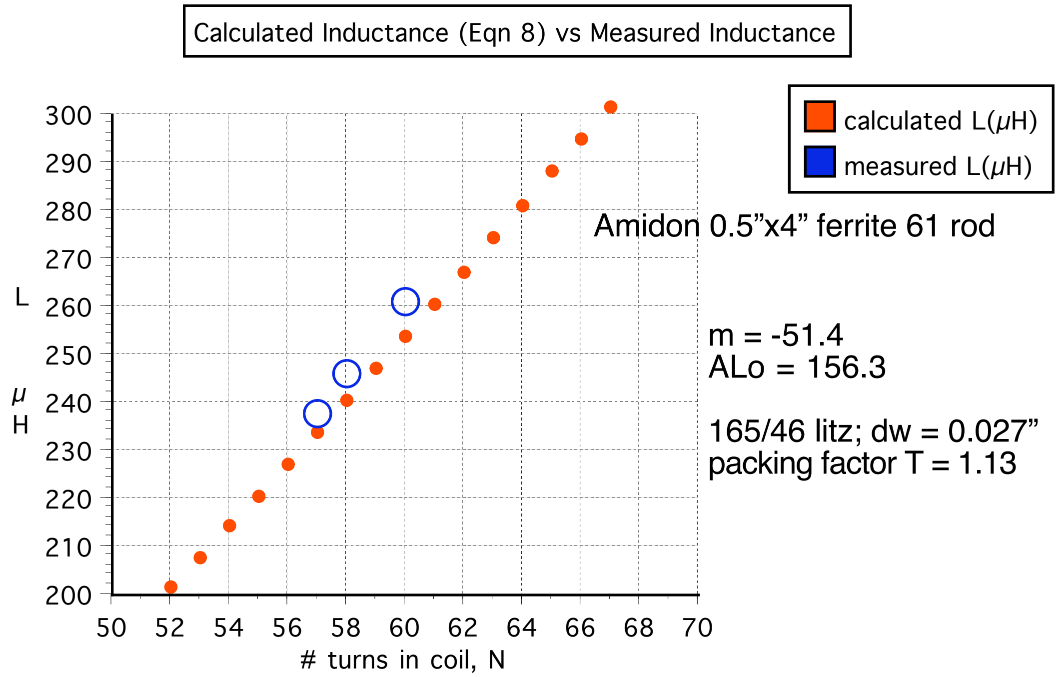

Fig. 4 Dan McGillis, 12/06

C. Selecting a wire size

In Ben Tongue’s Article 29, Section 4, Table 6, -- Ben points out that his simulation results show something never seen before. He shows that to get about 95% of the ferrite rod’s maximum Q capability, the ratio(lc/lr) must be less than or about equal to 0.25; [plot Table 6’s data as Q/Qmax vs lc/lr to see this]. I think this means, using EQN.7, that to minimize rod caused losses:

EQN.9 $lc/lr = T*N*dw/lr \sim 0.25$, or $N \sim (0..25*lr)/(T*dw)$.

Combining Equations 8 and 9 gives, at the condition of maximum rod Q capability:

EQN.10 $L(nH) = [(0.25*lr/T*dw)^{2}] * \{ m*(0.25*lr)^{(1/3)} + ALo\}$.

After some rearranging, the wire diameter dwmaxq that gives a coil length corresponding to the maximum rod Q capability, is:

EQN.11 $$dwmaxq = \left\{ \frac{[(0.25*lr/T)^{2}] * \{ m*(0.25*lr)^{(1/3)} + ALo\} }{L(nH)} \right\}^{(1/2)}.$$

Equation 11 is plotted in Figure 5 for the average 0.5"x4" Amidon rod parameters previously given (m = -51.8 and ALo = 157.5) with a wire packing factor T = 1.13.

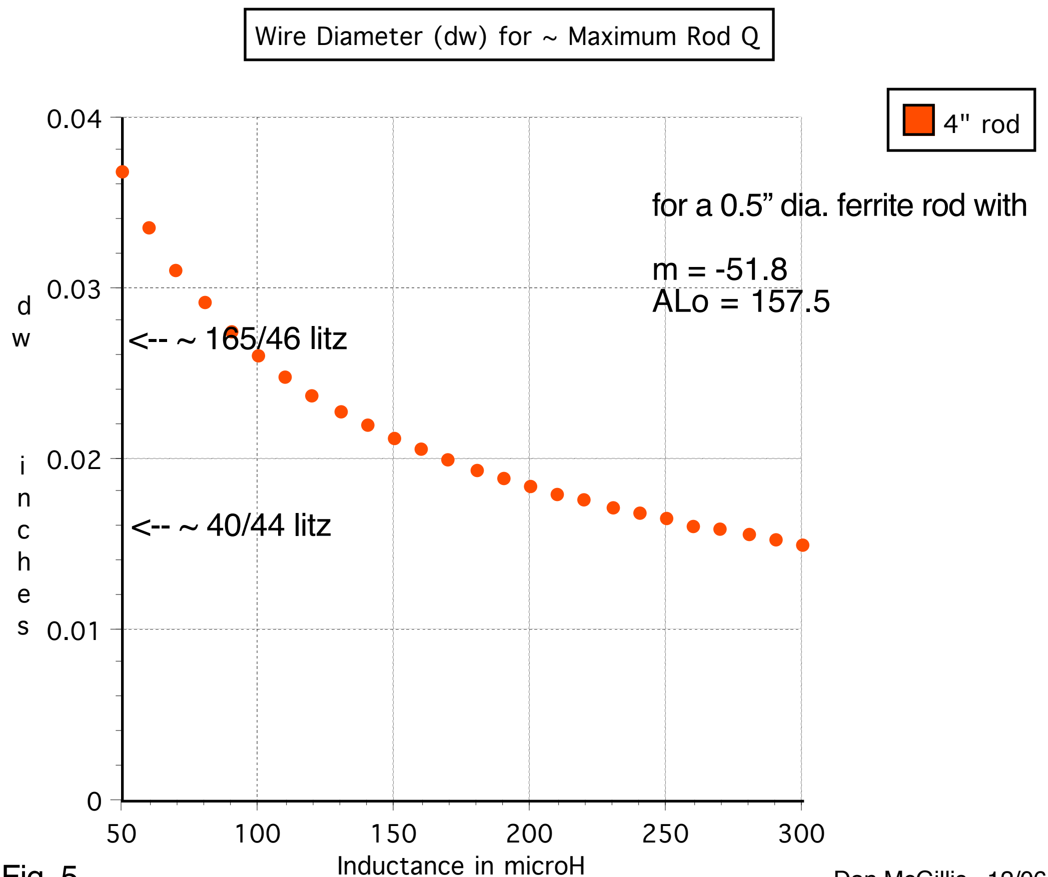

Fig. 5

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Figure 5 indicates that for an inductance of ~240 μH, the diameter of 40/44 litz wire will produce a coil length that will cause the ferrite rod's losses to be lower than if it had been wound with165/46 wire. Ignoring wire effects, the ferrite rod-cored coil with 40/44 litz should have the highest Q.

Before plotting Figure 5, I had wound a 237μH coil with 40/44 litz, and a 238 μH coil with 165/46 litz, on Amidon 0.5"x4" ferrite 61 rods. I used both coils as detector coils in my double tuned, hobbydyne coupled, FO-215 diode, crystal set. Subjectively, from listening comparisons, the apparent selectivity with the 40/44 coil was definitely better than with the 165/46 coil. And, the 165/46 coil selectivity was definitely better than my 4.5" diameter, #16 ga. space-wound coil selectivity. The observations agree with Figure 5.

Based on the performance of the ferrite rod-cored coils and Ben Tongues' Article 29, I'm switching over to ferrites. Thanks Ben !

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