5-band Broadband Hexbeam

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For long time I was considering building a light multiband shortwave antenna, collected information about different constructions, their parameters and experiences with them. Construction of widely used Spiderbeam (by DF4SA) attracted me at most, until the moment when during building our IOTA Contest 2007 QTH in Isola di Ventotene (IB0/OM0C) I have realized the proportions of full sized beam antenna, which would be too big for my home QTH. At that time I already knew about compact Hexbeam antenna construction, however it had many disadvantages - “narrowbandness”, unclear construction steps and complicated tuning together with lack of information on Internet. However its compactness - diameter of Hexbeam for 20m band is only little above 6m - convinced me to start the project of building small but efficient antenna of uncommon shape.

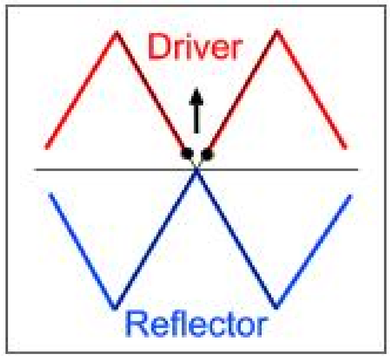

Figure 1 – Classic (original) Hexbeam; source /1/

Hexbeam is in fact modified 2-element Yagi antenna designed with goal to maximally save the space. The driver element has W shape (or M, depending on viewing perspective), the reflector is mirror image of the driver (Figure 1, original constuction of Hexbeam). It functions on principle of paracitic 2-element beam (like Moxon antenna). By modeling of different ratios between driver/reflector lengths, spacing between the center parts and spacing between their ends was achieved optimal interaction between the two elements, thus maximal directive gain of the antenna. The gain of ideal Hexbeam is stated to be in range of 6.8dBi (4.7dB more than dipole).

Surely there are other 2-element antennas with better gain, however one should not forget the main goal of this antenna design – space saving. The price for the compact size of classical Hexbeam is its “narrowbandness”. One of the Hexbeam enthusiasts Steve G3TXQ discovered that the reason for this is high Q of the reflector, i.e. steep change of it’s impedance with frequency. Steve tried out traditional methods to decrease the Q of reflector such as using wider wires but there was no dramatic change. He also tried out modified geometry of the reflector eliminating cranking in the center, which was originally proposed by legendary L.B. Cebik, however the antenna was still not “wide enough” to be usable e.g. in whole 20m band. He did not give up and finally came with neat solution to completely eliminate the cranked W shape of the reflector by stretching it over perimeter of the hexagon (Figure 2.). The reflector now extends over half of the hexagon perimeter. This modification increases the overall Hexbeam diameter by about 15% which is still acceptable. However the main advantage of this modification was really wort the effort – the antenna is now **wide enough** to cover given amateur band.

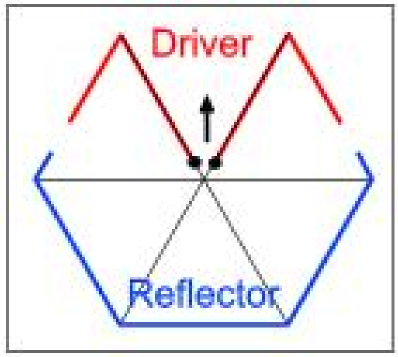

Figure 2 - Broadband Hexbeam; source /1/

This driver/reflector geometry can be effectively built on self-supporting constuction made from laminated poles organized in symmetrical star configuration. The pole ends are pulled together and raised up which creates a kind of inverted umbrella construction (Figure 3). The reflector wires can be now stretched over the perimeter of the hexagon, the driver extends from the centre to the perimeter where it bends and continues with the perimeter. The spacing between driver and reflector wire ends is made by insulated lines; the whole system of wires is freely tightened. The complete construction is self supporting, it is extraordinary light, symmetrical and thus windproof.

It's easy to extend this construction for more bands by positioning the higher band elements above lower parts of the inverted umbrella construction. The construction remains light and symmetrical with elements for different bands stacked over each other (Figure 3). Feeding of such system can be realized by means of single coaxial line feeding the drivers from lowest (20m) to highest (10m) bands. Thus it's possible to realize even 5-band antenna system (20m, 17m, 15m, 12m, 10m) with only sligtly increased additional effort. Design of such system is of course much more complicated than monoband antenna – one has to take into account interaction between the elements for different bands, properties of the feeding line for distribution of the signal to drivers, etc. Fortunately, Steve G3TXQ made here really outstanding job by doing measurements and determining the optimal dimensions of 5-band hexbeam parts, refer to his page which describes this antenna in details /1/. He describes here also impact of different antenna properties (driver/reflector lengths, spacing of their ends, wire diameter) on antenna performance.

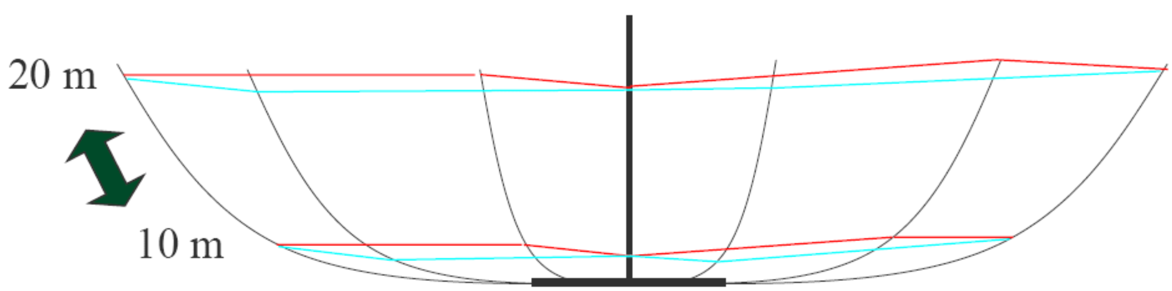

Figure 3 – Side view of supporting construction and alignment of wires for multiband hexbeam; source /3/.

Before discussing practical issues with the construction here is a short summary of 5-band hexbeam properties:

Advantages:
+ compact dimensions
+ affordable gain and F/B ratio
+ light and symmetrical construction (a lightweight mast with small rotator can be used)
+ windproof
+ 5-band antenna fed with single coax line
+ no additional matching element is needed since the properly designed antenna has impedance close to 50Ohm in all bands
+ the antenna is broadband (covers both CW and SSB parts of the bands)
+ low radiation angle, making it ideal for DX-ing (confirmed by my practical experience)

Disadvantages:
- more complicated construction
- complicated final finetuning of the antenna; use of a VNA (Vector Network Analyzer) is a necessity

Detailed description of 5-band Hexbeamu construction by OM2JU
(20m, 17m, 15m, 12m, 10m)

There are number of good pages covering the Hexbeam antennas on Internet, the information is however subject of permanent change, innovation and lately also commercialization. For the concept which I had in mind and for my conditions I have combined the information from the following three Internet sources:

- **G3TXQ** /1/ - father of the broadband Hexbeam. He describes here basic principles behind the antenna, influence of different antenna properties on antenna performance and gives detailed dimensions of the antenna.

- **K4KIO** /2/ - gives detailed cookbook for construction of 5-band Hexbeam (broadband). To great extent I have used information from this site.

- **DL7IO** /3/ - gives detailed view on construction of original ("narrowband") hexbeam. The feeding of the drivers is realized here by means of symmetrical line which seemed to me more agreeable and reliable than connecting the center drivers by means of coax cable pieces.

1. ***Base plate and center post***

For construction of the base plate I have used thicker (~8mm) pre-impregnated composite fiber plate such as used for PCB's; the used material should be tough enough and non-breakable. I cut the plate into 40cm diameter hexagonal shape; circular shape could be used here as well. With U-shaped bolt bars I have attached supporting metal (ALU) pipes on top of the base plate – these are used to hold ends of the fishing poles. The Figure 4. shows this construction planned for original “narrowband” Hexbeam. In final version I have supplemented the ALU pipes with thick plastic pipes of about 70 cm in length each to achieve 15% increase of antenna radius.

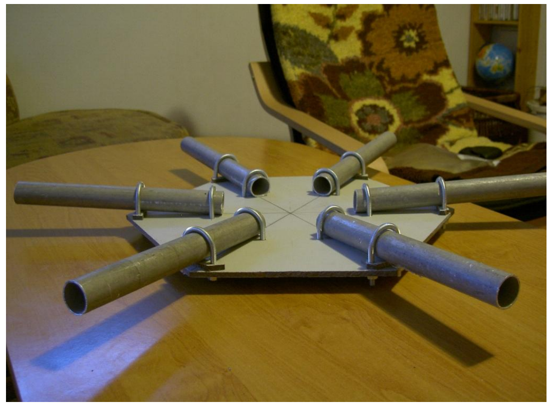

Figure 4. – Base plate of Hexbeam with original ALU pipes which I later replaced by longer plastic pipes

In the middle of the base plate, I drilled a hole with a diameter of approximately 5 cm for insertion of the supporting vertical metal pipe. It has 4 angle brackets (strong and long enough) welded to it; the base plate is fixed on top of the angle brackets using screws. The vertical pipe should stretch approximately 30-40cm over the base plate as supporting vertical stick will be later inserted into it. The supporting stick must be made of insulating material since it will support feeding line. It must be also strong enough as it supports the whole Hexbeam construction – I have used plastic water-pipe with inserted wood stick (broom stick) into it. The supporting stick has 120 cm, with about 30-40 cm of it inserted into supporting metal pipe which is from the bottom side attached to the mast or rotator.

2. *Supporting Hexbeam construction*

Figure 5. – Fixing elements

As already mentioned, the supporting construction uses fishing poles – I have used six cheap 4-meter poles of which I have removed the thinnest end parts. One should avoid carbon poles as they are conductive; they are more expensive anyhow. According /2/, the **arm length should be minimally/approxmately 360 cm**, therefore I have attached additional thick-walled plastic tubes of length about 70 cm to the thick ends of fishing poles. Each pole is plugged about 20 cm into plastic tube and fixed to tube with UV-resistant insulating tape. BTW, it's good practice to paint all plastic parts used in Hexbeam construction with UV-resistant paint.

Into the thin ends of the poles I have inserted fasteners with screws and specially prepared S-shape hooks made of thick Copper wire which can be seen on Figure 5. The **6 pieces S-shape hooks** which will be inserted into pole ends should be additionally strengthened by soldering the loose ends to the rest of the hook body with tin. For robustness I have finally strengthened the thin pole ends with inserted fasteners and hooks by wraping them several times around with firm insulating and vulcanization tape. **Additional 24 pieces of hooks** are needed for construction of fixation wire strands defining the shape of the hexbeam – 6 wire strands from the center to each of 6 pole ends, next 6 wire strands for fixation of distance between each pole end to the other end on external radius. The overall wire strand length together with S-shaped hooks is **around 327 cm**. I have used rather thin Kevlar/Dacron strand which I have found in fishing shop under name Dyneema Raptor. It is only 0.6mm in diameter; however has 90kg load capacity and very small expansivity which is very important in order to keep the supporting construction dimensions constant. For sake of durability I have used always two wire strands in parallel.

Inspired by recommendation of my friend Adi S55M I have additionally strengthened interior hollow cavity of the poles with PU foam (used in building industry). This way the poles will be much stronger to withstand harsh weather conditions, while keeping their flexibility. If you do not have experience with PU foam then better leave this job to someone more experienced. Just shortly: extend the PU-foam vent pipe so that you can deliver the foam almost to the other end of fishing pole cavity; fold the poles inside each other; start with the thinnest pole; when filled fix it to the other one and start filling next one; do not use too much of the foam as it expands later; do not touch the remains of the PU-foam; work quickly and wear protection glasses and plastic gloves.

So far, we have the baseplate with center post inserted vertically and 6 pieces of 360 cm poles extending horizontally from baseplate in regular hexagonal spacing. The next step is to use 6 of wire strands with hooks on each side to pull the end of poles up and fix them to the center post. I'm using similar hooks as counterparts also on center post. Similarly, use 6 pieces of wire strands to fix neghbouring pole ends to each other on diameter. Later, one of such strands in antenna direction will be moved down to roughly the half of the poles since later that part will be strained by Cu-wires. Do not forget to lock the S-shaped hooks using pliers so that the strands do not get out. If you worked correctly then nice inverted umbrella shape is ready for hanging the clothes if you would like to to stop here, or for attaching wires if you want to use it for hamradio purposes.

3. *Feeding line*

Authors in original sources cut the coaxial cable RG213 at given lengths and connect (solder) them again in order to make feedpoints of the director wires at specific location. This solution is not bad, however more attractive and more weatherproof seemed to me to feed the directors with symmetrical twin feedline. Chalenge here is however to make it really low impedance – for this we will need rather thick Cu wires, with diameter of even 1 cm, which are not so common to get. For characteristic impedance of such twinline holds:

$$Zo = 120*ArcCosh(b/a)$$

where b = distance of wire centers

a = diameter of wire
and *arccosh* is an exotic function found in each better calculator

In technical literature one can find also a formula with logarithm, this one with *arcosh* is however more precise.

Thus, in order to keep the impedance of feedline low one has to keep the ratio b/a low, in other words the wires should be rather thick and the distance between them should be minimal. I got such Cu stranded wire from my friend, unfortunately it had rather thick insulation which I had to remove and replace with thin thermo-shrinking insulation. The thin insulation is partly removed at the points where feedline connects to radiator wires so that with help of Cu-strip one can solder the soldering eyelets to the feedline (refer to Figure 6.). The radiator wires have on one end soldering eylets which connects to these points. The feedline wires are at these points moved slightly apart from each other in order to avoid shorts and fixed with plastic glue (using Hot Melt Glue Gun). On other places they are led close to each other and fixed with plastic strip to vertical pipe. Note that the feeding of the antenna starts from the top, it is essential for proper function of the feedline. Also note that this way, we will need about 80cm of Cu wire (strands) for the feedlines.

For connection of the RG213 coax to feedline I did not use any balun, as to my opinion the radiating angle of the antenna is rather broad so unbalanced-to-balanced error will be negligible, and additional nonlinear elements (ferrites) inserted into the path woud only cause additional problems with higher power. However, in order to eliminate propagation of HF currents on coax shielding it is important to put several toroids and fix them on coax near the point where coax connects with the feeding line (top of the Hexbeam).

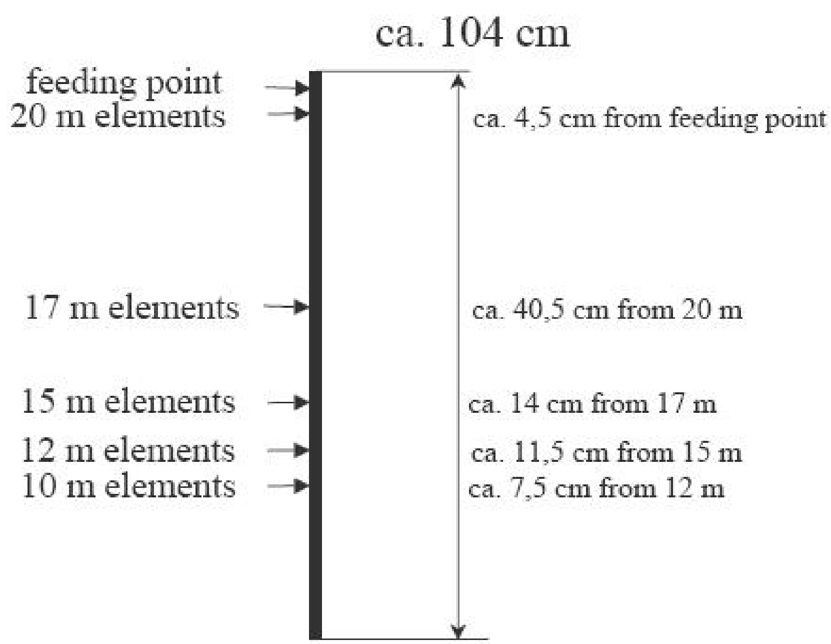

Figure 6. – view of the feedline with feeding points for different bands

4. Wires, dimensions, distances, fixation

I took the wire dimensions from G3TXQ /1/ which I converted from inches to centimeters. His dimensions apply to bare Cu wire. From my friend working as serviceman for medical equipments I got plenty of 1.25mm2 Cu (about #16 AWG) insulated wire strands. Insulation serves as additional weather and mechanical protective layer so it seemed to me reasonable to use these instead of bare Cu strands. With VNA I made quick experiment to determine “shortening-factor” of insulated wire – the result is k = 0.985.

I have applied the shortening factor to all the wire ans spacing dimensions, refer to Table 1. To my surprise, the antenna resonated on all bands too low so I have shortened all the wires in three successive iterations, the results are also in Table 1. Note that I did not change the reflector – director spacing dimensions; the reflector dimensions were changed only slightly. Interesting observation here is that dimensions of outer band wires (20m and 10m) were changed only slightly, while by inner antennas the corrections were more significant, perhaps due to more interaction between each other. My final wire dimensions are given at the bottom of Table 1.

For connection of each radiator wire to feedline on center post I have soldered eyelets for M4 bolts to one end, the other eyelet resides on feedline itself. One could also solder them directly to feedline, however this connection will be quite stressed so it is better to have it strong. The eyelets on feedline are soldered either directly inside the thick feedline wire-strands or by using additional copper strips.

For leading of the wires in desired geometry one has to use strong rings through which the wires MUST LOOSELY MOVE ! Moving of the wires thorough rings is essential for durability of the complete Hexbeam construction. Im my first attempt I have uses hose-clamps fastened to fishing poles (with plastic insulation underneath to better distribute the tension), to which I have attached plastic rings standing upwards through which the wires are led. Unfortunately, the plastic rings were broken after 2 years and I had to find more durable solution. I have ended up simply with strong 2.5 mm2 insulated Cu wire which I have twisted several times in order to get quite solid ring; additionally I have removed the hose clamps and attached the new ring with extending branches directly to poles with thick layer of plastic tape and strips.

We should start to „attach“ the wires to the construction from upper part (20m) downto lower one (10m). First attaching radiators to center post feedline using bolts, then reflector through the perimeter and finally insulating spacer strands connecting radiator ends with reflector ends. The lines have to move loosely through the rings, therefore we do not attach the plastic rings to fixed position yet - at the end the positions of rings have to be slightly tuned. Also make sure that all the wires for different bands run parallel and the overall construction remains symmetrical. Ocasionally shake the construction several times in order to achieve equal force distribution ! For fixation of radiator – reflector spacing distances I have used solution in /2/ - brass terminals into which connects from one side insulated Cu wire, from other side insulating Kevlar/Dacron strand (several in parallel if you use thin one).

In order to achieve final symmetry it is essential to move one fixation strand in antenna radiating direction from top to about 2/3 of the poles. This is needed since the wires are stretching apart the two poles bearing radiators, therefore we have to have opposite pull. It might not be cesessarily in 2/3 of the poles, one has to find the proper position – use here already described shaking method. Finally fix sturdily all the rings thorough which wires are led to poles. Also check again if all S-shape hooks are closed.

Tuning of the antenna should be definitely done with VNA in height of about 3 meters above ground. Use only short piece of coax or impedance transformation through coax length feature in VNA programm so that you get real values of impedance. Very handy utility for evaluation of measured results is ZPLOTS from AC6LA, it saved me a lot of time. One should rather start from longer wires with several shortening iterations as to later prolonging the wires if they get too short. You can however directly use final dimmensions from bottom of Table 1. as I have noticed that my antenna still resonates a bit low in some bands, this is however still OK due to it's „broandbandness".

Before putting the antenna definitely to mast make sure that all joints, bolts, hoox are fixed, the toroids are on the place. Connections exposed to weather conditions should be covered with plastic glue using Hot Melt Glue Gun. The antenna on mast will resonate a bit higher, but to my surprise the difference was not significant.

The antenna fulfilled my expectations and does great job to my satisfaction already for several years. With only 100W I'm able to work pile-up stations in reasonable time. The band signals are strong, noise level is low. The directivity is not as I have expected, which is on other side good feature since I'm lazy to turn it each time to the right direction. I hope that my information and experience with described here was helpful, especially if you decide to build this excellent and nice looking antenna. Experimenting and exploration is to my opinion essential feature of radio-amaeur hobby and building this antenna fulfilled also this attribute of my/our hobby.

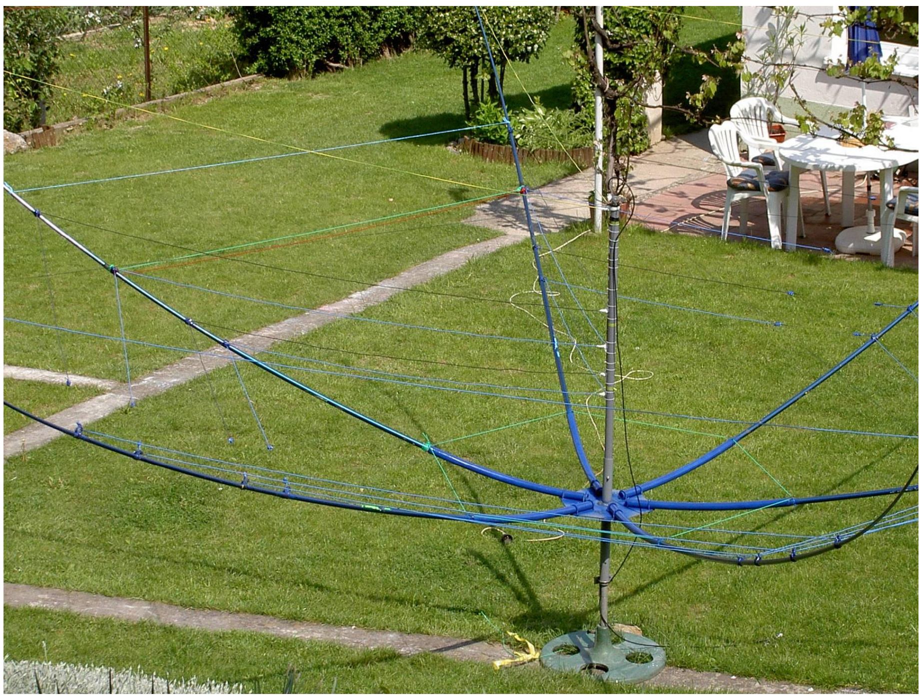

Figure 7. – Hexbem construction just before finishing. Insulated plastic ropes close to the center assure better stability, and I left them also on final construction

Hexbeam elements by G3TXQ		**20m**	**17m**	**15m**	**12m**	**10m**
Driver ld/2	**inch**	218,00	169,50	144,50	121,70	106,80
Reflector lr	**inch**	412,00	321,00	274,40	232,00	204,40
Spacing	**inch**	24,00	18,50	16,00	13,50	12,00
Vert. spacing from bottom	**inch**	38,00	15,00	9,00	5,00	0,00
Driver ld/2	**cm**	553,72	430,53	367,03	309,12	271,27
Reflector lr	**cm**	1046,48	815,34	696,98	589,28	519,18

Spacing	**cm**	60,96	46,99	40,64	34,29	30,48
Vert. spacing from bottom	**cm**	96,52	38,10	22,86	12,70	0,00
Insulated wire 1.25mm2 k=	0,985					
Driver arm ld/2		545,41	424,07	361,52	304,48	267,20
Reflector lr		1030,78	803,11	686,52	580,44	511,39

OM2JU Corrections based on VNA measurements						
1-st iteration driver ld/2	cm			-4,00		-3,00
reflector	cm					
2-nd iteration driver ld/2	cm	-2,00	-3,00	-2,00	-4,00	
reflector	cm		-3,00	-1,00		
3-rd iteration driver ld/2	cm		-6,00		-7,00	
reflector	cm		-8,00		-3,00	
Final dimension driver arm ld/2	cm	543,41	415,07	355,52	293,48	264,20
reflector lr	cm	1030,78	792,11	685,52	577,44	511,39
Correction factor for driver arm	%	-0,37%	-2,12%	-1,66%	-3,61%	-1,12%
Correction factor for reflector	%	0,00%	-1,37%	-0,15%	-0,52%	0,00%

Table 1. – Original hexbeam dimensions according G3TXQ + my iterations and final dimensions

References:

/1/ - G3TXQ Hexbeam pages - http://www.karinya.net/g3txq/hexbeam/

http://www.karinya.net/g3txq/twin_feed /

/2/ - K4KIO - Building the Broadband Hexbeam

http://www.leoshoemaker.com/hexbeambyk4kio/general.html

/3/ - DL7IO Hexbeam pages - http://www.hexbeam.de/files/reflectedW-design-en.pdf

/4/ - S55M - Technical articles - http://www.s55m.com

Appendix: Derivation of formula for calculation of distance from center

Derivation of formula for calculation of distance from center:

a + b + spacing = x

a = ld2 - x

b = (lr - 3x) / 2

ld2 - x + (lr - 3x)/2 + spacing = x

*x = (2*ld2 + lr + 2*spacing) / 7* x = distance from center