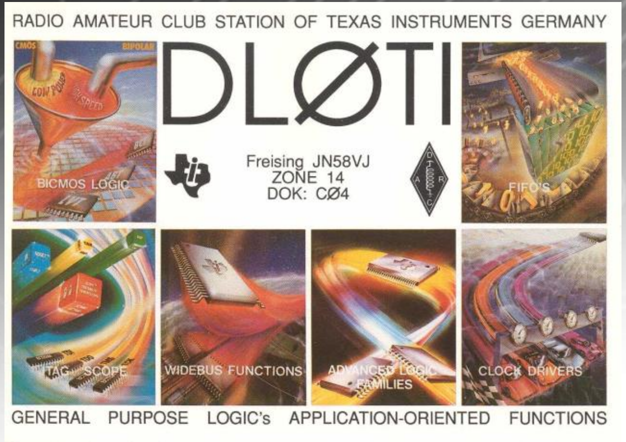
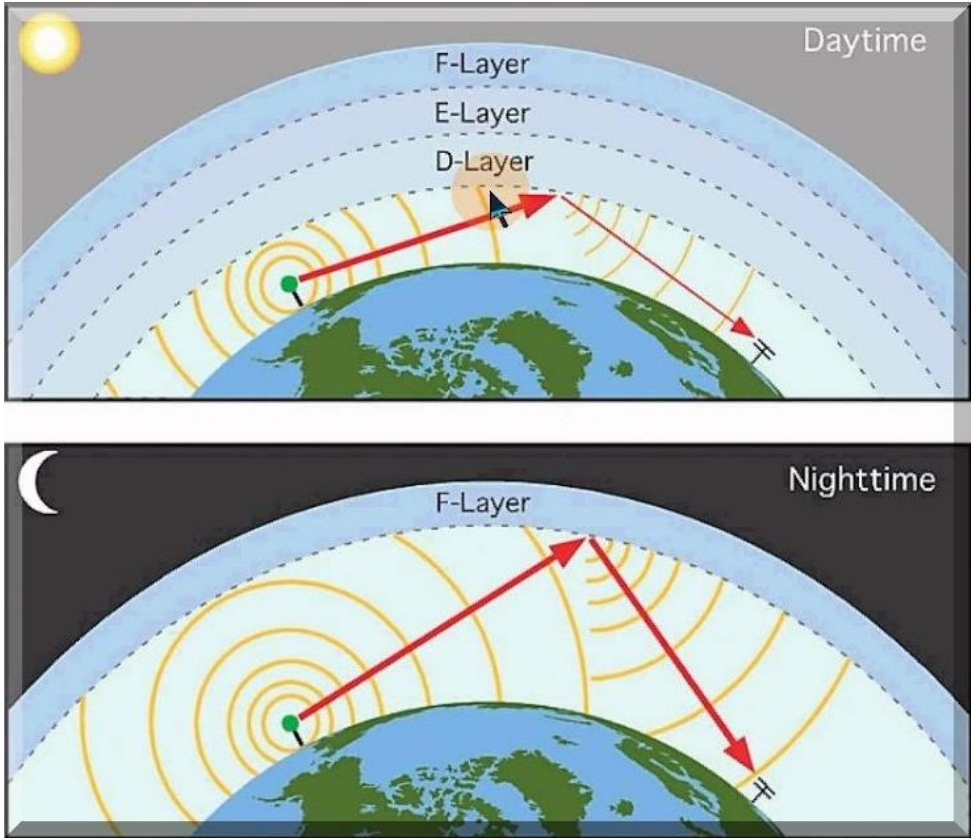


Designing an OCFD Antenna

RF Transformers home-brewed – et alias... @ DARC OV P14 Ulm, 4/1/2022

Bernd Geck, DB3GF & 9A8ABG,
operating DL0TI, club radio station of Texas Instruments Germany

Short Wave Propagation



ionosphere reflects shortwave

(sun spot activity “helps” a lot)

+ NO network, point-to-point
+ worldwide connections
+ backup for emergency usage

- dead zones in between skips
- needs knowledge & experience
- large antennas for low bands

Short Introduction to RF

- For wireless communications transmitter output impedance, wiring impedance and antenna impedance need to match – otherwise RF power gets reflected and might destroy the RF power stage (= poor standing wave ratio SWR).

- Nowadays solid state power stages for radio amateurs typically provide an output impedance of 50 Ohms, standard coaxial cable provides 50 Ohms, but:
  - tube amplifiers provide high impedance output
  - symmetrical parallel two-wire line provides usually 200, 300 or 450 Ohms
  - not all antennas provide a feeder resistance of 50 Ohms:
    i.e. dipole and ground plane antenna are around 50 Ohms, very close
    i.e. an end fed long wire could be more than 1000 Ohms, **very far-off (!)**

- Certain networks are needed to match these different impedances to each other

Short Introduction to RF

- To match a high resistive tube amplifier output to a 50 Ohms system the output PI filter of the amplifier does the needed transformation beside providing the attenuation of unwanted harmonics.

- To match a 50 Ohms solid state amplifier to a two wire line, or a high resistive antenna impedance to a 50 Ohms coaxial cable RF transformers are used.

- Furthermore the right transformer wiring adapts balanced and unbalanced systems to each other:
  - i.e. BALANCED = any two wire line, dipole antenna
  - i.e. UNBALANCED = any coaxial cable, end-fed long wire antenna

Short Introduction to RF

Some RF transformer examples:

- a 50 Ohms unsymmetrical RF PA output to a 200 Ohms symmetrical two wire needs a 4:1 Balun in between PA output and two wire line (Balun stands for **bal**anced – **un**balanced)
- a 50 Ohms unsymmetrical coaxial cable to a 50 Ohms symmetrical dipole needs a 1:1 Balun
- a 50 Ohms unsymmetrical coaxial cable to a 450 Ohms end-fed long wire needs a 9:1 Unun (Unun stands for **Un**balanced – **Un**balanced)

Mismatch of impedances results in poor SWR, non-balancing of the feeding results in unwanted radiation of the feeding line due to common mode currents !

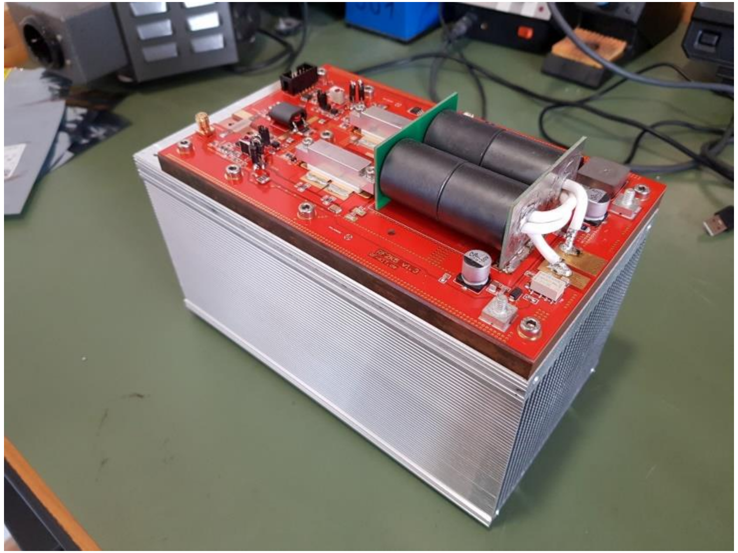
Baluns homebrewing – WHY ? Part 1

- Legal output power for shortwave radios at Germany is 750W,
  legal limit for the United States is 1500W – so the market for high power transformers around 3kW and beyond is low
  = limited availability
- The quality of commercial transformers could be fairly bad, later measurements will show a poor example and an outstanding reference (btw. from Denton, TX)
  = poor quality (bandwidth, transformation, CM suppression)
- High power results in high voltage and high currents, needs best core material, kV insulation and big copper diameters; most commercial designs are molded, small signal analysis by NWA in frequency domain might look promising,
  but large signal analysis in time domain by kW could result in a disaster
  = less power capability, high losses at winding and core

Baluns homebrewing – WHY ? Part 2

TEXAS INSTRUMENTS stands for quality, performance and power;
club radio station DL0TI will do so as well:

DL0TI on air today – tube amplifier



RF PA using 2x LDMOS is waiting

Baluns homebrewing – Starting Point

Up to know built and worked with tube amplifiers using metal ceramic tetrode GU-74B; very rugged, designed by SVETLANA (St. Petersburg) for military shortwave transmitters, but a new generation of LDMOS is available:

BLF189XRB; BLF189XRBS

Power LDMOS transistor AMPLEON

Rev. 1 — 3 October 2017 **Product data sheet**

General description

A 1900 W extremely rugged LDMOS power transistor for industrial pulsed applications in the HF to 150 MHz band.

Table 1. Application information

Test signal	f (MHz)	V_{DS} (V)	P_L (W)	G_p (dB)	η_D (%)
pulsed RF	108	50	1900	26	72.5

Ruggedness in class-AB operation

The BLF189XRB and BLF189XRBS are capable of withstanding a load mismatch corresponding to VSWR > 65 : 1 through all phases under the following conditions: V_{DS} = 50 V; I_{Dq} = 200 mA; P_L = 1900 W pulsed; f = 108 MHz.

Solid State Amp.	Tube Amplifier
LDMOS Vds 50V	plate voltage 2.5kV
immediate Operation	pre-heating 90s+
50 Ohms output	PI filter, to be tuned
unbreakable	no shock & vibration
no aging	aging, vacuum lacks
high gain, <1W SDR drive	50W to 100W exciter
extremely sensitive: a bunch of ultrafast protection circuits needed	extremely rugged: w/stands several 100W of reflected power

Short Introduction to Off Center Fed Dipole OCFD

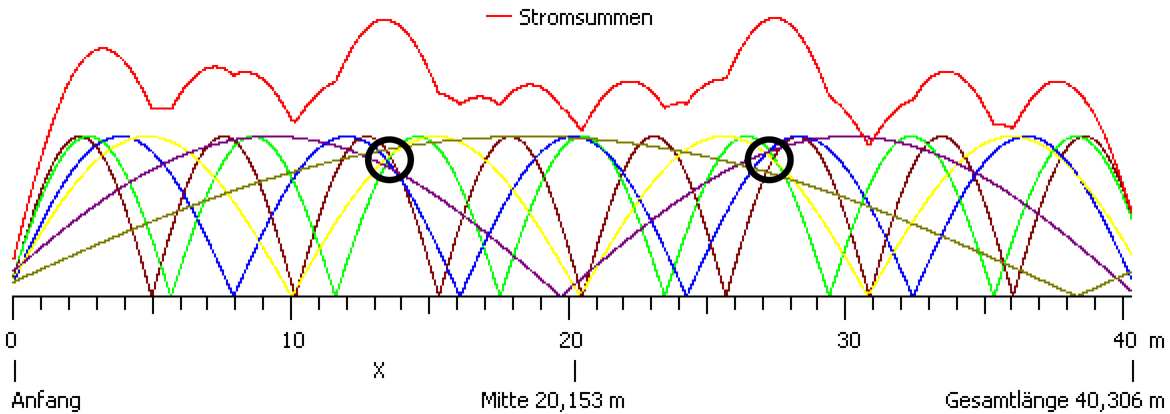
The common center fed dipole got feeder resistance around 50 Ohms, could be used only at half wave resonance, TWO QUESTIONS:

1) The common amateur bands are **160m**, **80m**, 30m, **40m**, **15m**, **20m**, **10m**;
   some frequencies are multiples 1.8MHz – 3.5MHz – 7MHz – 14MHz - 28MHz;
   is there a way to work multiple bands with a single half wave dipole ?

2) Is there a way to add the strong **15m (21MHz)** band to such an antenna ?
   (15m does **not** match the upper frequencies in a row !)

Short Introduction to Off Center Fed Dipole OCFD

Analysis of currents at a 40m long wire at various frequencies:



grey = 80m / 3.5MHz
purple = 40m / 7.0MHz
yellow = 20m / 14MHz
blue = 17m / 18MHz
green = 12m / 24MHz
brown = 10m / 28MHz
----
red = sum of currents

- the analysis shows at feed point 13.22m (27.09m) the largest sum of all currents;
- furthermore ALL the individual currents are close to each other;
- the current itself represents a feeder impedance - that is close for all bands, too.

Computer Aided Design of OCFD Antenna

```
Antenne berechnet auf Basis  14,25 MHz für  4  Halbwellen
Berechnung für SSB-Band:  28, 24, 18, 14, 7, 3,5 MHz
Geometrische Antennenlänge: 40,306 m
Verkürzungsfaktor des Drahtes: 0,93
(Zusatzverkürzung durch Drahtisolierung: 2,3   Polyethylen PE)
```

Stromsummen:

m	ØSumme	28 MHz	24,9 MHz	18 MHz	14 MHz	7 MHz	3,5 MHz
13,22	0,86	0,85	0,84	0,89	0,86	0,86	0,84

exakte Werte:

Meter	Ø-Summe	28 MHz	24 MHz	18 MHz	14 MHz	7,0 MHz	3,5 MHz
13,22	0,85799	0,84781	0,84288	0,88930	0,86148	0,86376	0,84271

Impedanzen [Ohm] *(annähernd exakt nur im Resonanzfall!)*

m	ØSumme	28 MHz	24,9 MHz	18 MHz	14 MHz	7 MHz	3,5 MHz
13,22	227	234	237max	204min	224	223	237max

Resonanzfrequenzen [MHz] bei einer Antennenlänge von 40,306 m:

28 MHz-Band:	28,731	28.300 bis 29.000 OK
24 MHz-Band:	25,063	24.940 bis 24.990
18 MHz-Band:	17,92	18.120 bis 18.168
14 MHz-Band:	14,25	**Vorzugsband, Ausgangswert**
7 MHz-Band:	6,881	zu tief, Antenne zu lang
3,5 MHz-Band:	3,419	zu tief, Antenne zu lang

- the software is equation based, similar to Power Stage Designer, needs tuning

- Velocity factor at low height will vary across the different frequencies, will NOT match 100% !
  a multiband antenna is a TRADE OFF

- the calculation is optimized for mid band 20m band / 14MHz:
  for lower bands wire is too long
  for upper bands wire is too short

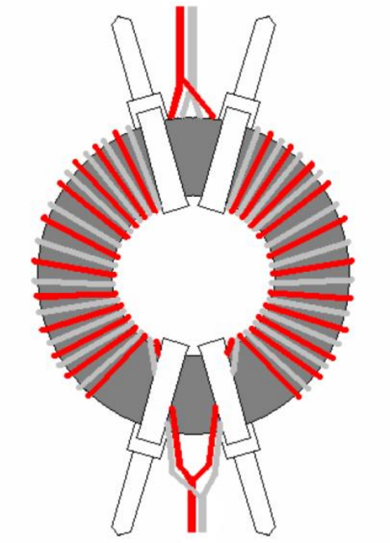
THE FINAL RESULT:
the feeder resistance at feed point 13.22m is 204 Ohms to 237 Ohms;
a transformer 4:1 needs to be built
a common mode choke to be added

RF Transformer Specification

- Power rating 2kW+ continuous at 60c ambient temperature
  > core size & core losses; wire diameter & windings losses
- Low winding losses (DC/AC) and low core losses needed for best efficiency
  > magnetics inside waterproof sealed box at antenna mast - in the hot sun
- 50 Ohms output impedance of PA, use of high power 50 Ohms coaxial cable
  > unbalanced PA output to balanced 200 Ohms off center fed dipole = Balun 1:4
- Frequency coverage 80m band to 10m band (3.5MHz to 29.7MHz)
  > well suited core material for almost a decade
- Low windings capacitance to achieve high self resonating frequency SRF
  > short winding length and proper windings layout to enable 30MHz operations
- Mismatch at low frequencies 80m, 40m will need a common mode choke
  > core material for low frequencies; 2kW+ rating, too

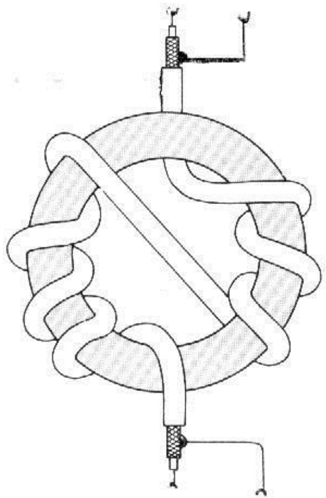
1) CMC to prevent from Sheath Waves at 80m/40m

For power designers Common Mode Chokes are well known; similar to kHz designs those filters prevent from common mode currents in the MHz range as well; at RF this CM current causes the shield of a coaxial cable to radiate !



cheapest solution:
two wire approach;
(close to SMPS)

BUT: wires to be
tuned to 100 Ohms
(we deal w/ RF…)



Joe Reisert, W1JR:
coaxial approach;
no need for tuning,

BUT: hard to build,
and kW application
needs expensive kW
Teflon coaxial cable

1) CMC, invented by Joe Reisert, W1JR

- ferrite core material AMIDON #77
  (best suited for 160m to 40m)

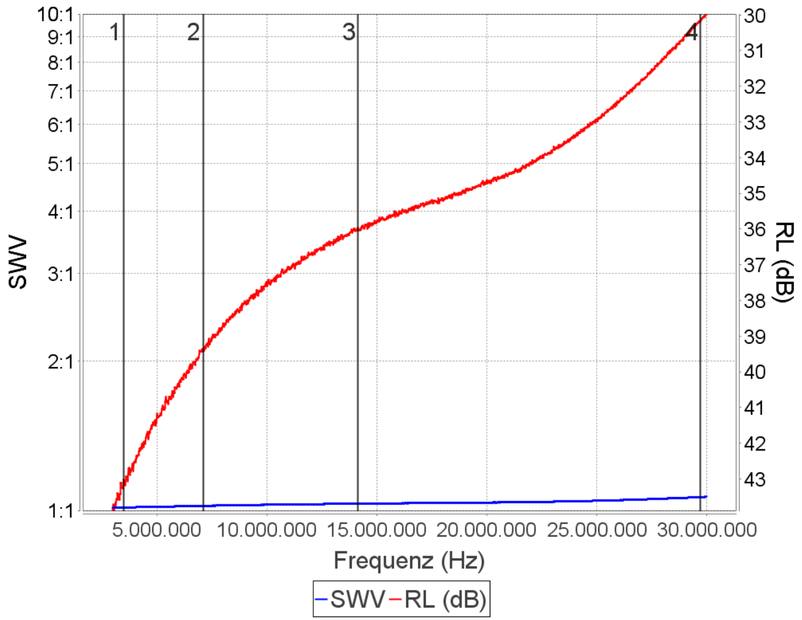
- core size 0.24", stacked two pieces
  (results in AL 3.13uH/N^2 x 2pcs)

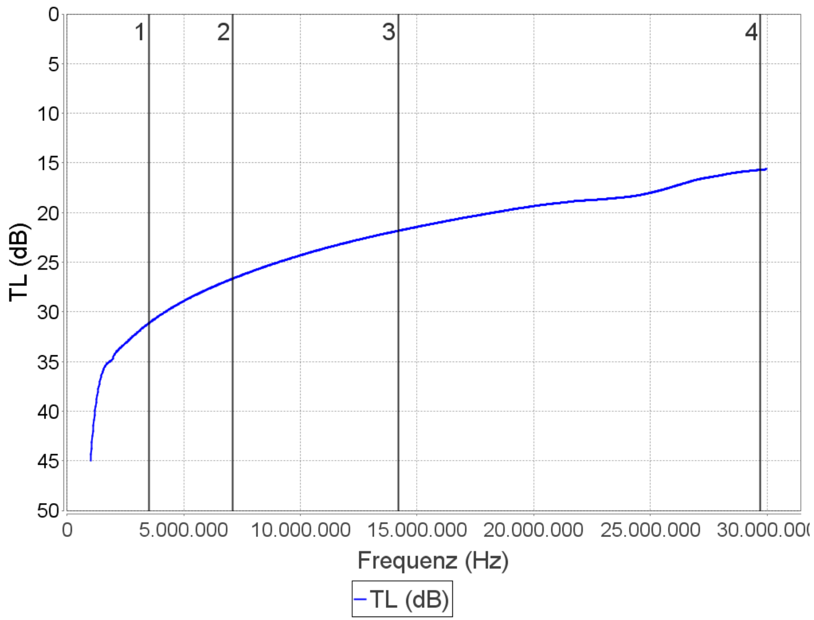
- RG-142 Teflon coax, 1.5m needed
  (w/stands 3.2kW @ 30MHz, 8$/m)

- 5mm diameter allows 2x 7 wdgs.
  (results in 2x 307uH)

- Teflon tape to protect the core

1) CMC, The Results



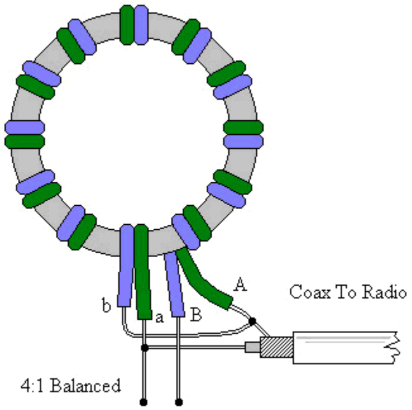


Return Loss better than 30dB
SWR better than 1.06:1

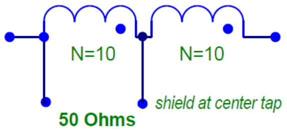
Insertion loss 0.14dB, CM attenuation:
160m/-33dB, 80m/-29dB, 40m/-25dB

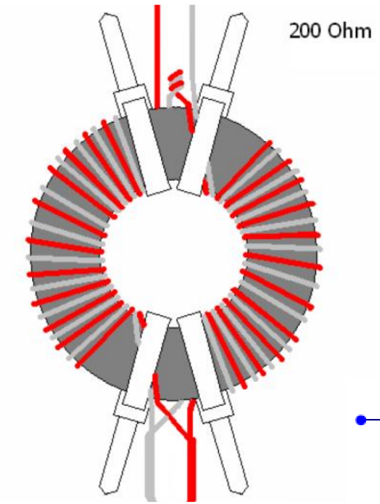
2) Balun 1:4, 50 Ohms transformed to 200 Ohms

Several winding topologies are possible – and have been measured;
for this special case buildings are w/in the near field of the antenna,
causing imbalance on the windings:
the GUANELLA winding on a single core tolerates this best

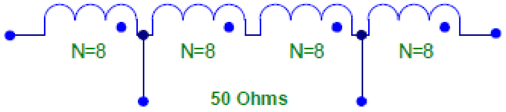


common approach:
by RUTHROFF,
a voltage Balun 1:4
(shielding to long
wire results in Unun)





went for GUANELLA
current Balun 1:4
(single core solution)



2) Balun 1:4, invented by Gustav Guanella

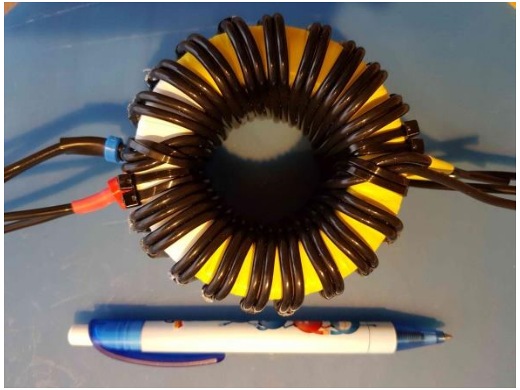
- ferrite core material AMIDON #43
  (best suited for low bands)

- core size 0.29”, stacked two pieces
  (results in 1.375uH/N^2 x 2pcs)

- Teflon litz wire, 2x 2x 1.1m

- inner diameter of core allows
  up to 2x 2x 8 windings of AWG12

- Teflon tape to protect and isolate
  from core



2) Balun 1:4, Quick Design Guide part 1

- Select the right core material, for 3MHz to 30MHz well suited is:

AMIDON,	Ferrite #43,	beneficial at low bands
AMIDON,	Ferrite #61,	beneficial at high bands
FairRite,	Ferrite #52,	* not tested *
Ferroxcube,	Ferrite 4C65,	* not tested *

  > went for Ferrite #43 to minimize losses at low band;
  prior antenna analysis predicts mismatch at low bands

- Select the right core volume, needs 6ccm per 100W continuous power:

  > went for 290" core, stacked two of them, core volume 34.8ccm each,
  good for 1.2kW <u>continuous</u> power, <u>non-intermittent</u> - and 2kW+ PEP

2) Balun 1:4, Quick Design Guide part 2

- Check magnetic flux at desired number of turns and lowest frequency:

Bmax = (Vmax x 100) / (4.44 x Ae x N x Fmin)

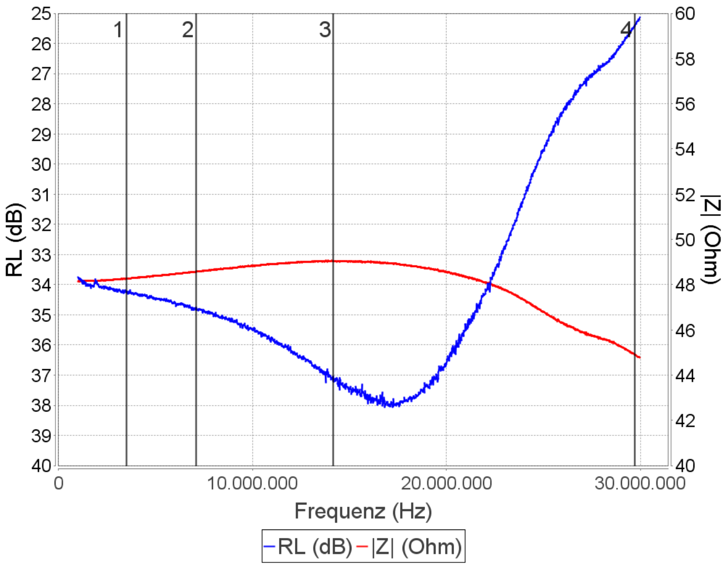
- maximum voltage: 2kW to 50 Ohms results in 316Vrms / 447Vpk
  (mismatch causes bigger voltage by reflexion, for r=0.5 used 671Vmax **= HV**)
- cross section Ae is 2.15cm^2 each core
- maximum number of turns using AWG12 is 2x 2x 8, so 16 primary windings
- minimum Frequency is worst case, so 3.5MHz

- Maximum allowed flux at 80m band is 80gs – check:

Bmax = (671Vmax x 100) / 4.44 x 4.3cm^2 x 16 x 3.5MHz) = 67.76gs, O.K.

> worst case analysis, core is well below 80gs, even at mismatch

2) Balun 1:4, The Results



Return loss better 25dB

Transformation 45 Ohms to 49 Ohms

(used a simple 200 Ohms resistor)

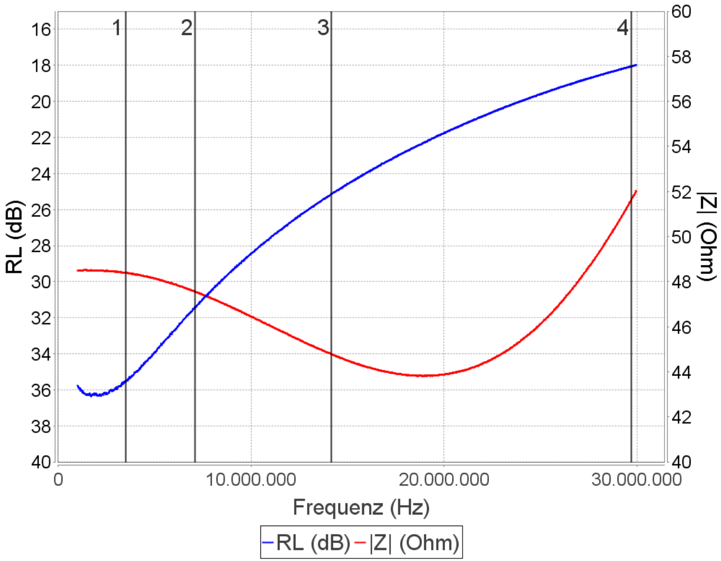
LESSON LEARNED:

to reduce flux just increasing number of turns does NOT work – RL & SWR gets worse by windings length !

Frequenz	SWV	RL	TL	Phase	|Z|	Rs	Xs
1) 3.518.770	1,04:1	34,25	0,00	155,69	48,3	48,3	0,8
2) 7.107.460	1,04:1	34,76	0,00	142,56	48,6	48,6	1,1
3) 14.173.390	1,03:1	37,05	0,00	134,19	49,0	49,0	1,0
4) 29.709.520	1,11:1	25,42	0,00	178,93	44,9	44,9	0,1

3) Balun 1:4 plus CMC - the Feeder System

built in, UV resistant case



Frequenz	SWV	RL	Phase	|Z|	Rs	Xs
0) 1.802.440	1,03:1	36,59	-175,87	48,5	48,5	0,1
1) 3.496.480	1,03:1	35,55	-168,39	48,4	48,4	-0,3
2) 7.107.460	1,06:1	31,41	-159,22	47,5	47,5	-0,9
3) 14.173.39	1,12:1	25,15	174,98	44,8	44,8	0,4
4) 29.709.52	1,29:1	18,06	82,54	51,6	50,1	12,6

The Antenna – adding the 15m Band

- **The strong 15m band could not be matched with a single antenna wire**

- adding a second OCFD for 30m/15m band, connected in parallel to the main OCFD:
  *> **FAILED**, both antennas influencing each other*

- adding a second OCFD for 30m/15m band, just radiation driven by main OCFD:
  *> **FAILED**, grounded mast influences secondary OCFD at feeding point*

- just miss the 30m band (of low interest) and add a radiation driven CFD;
  the center of a pure dipole is “cold”, maximum current – but NO VOLTAGE:
  > stay tuned; resonance is defined by length - impedance by distance…

The Antenna – Set Up

feeder system and CFD spacers

main OCFD connected to feeder

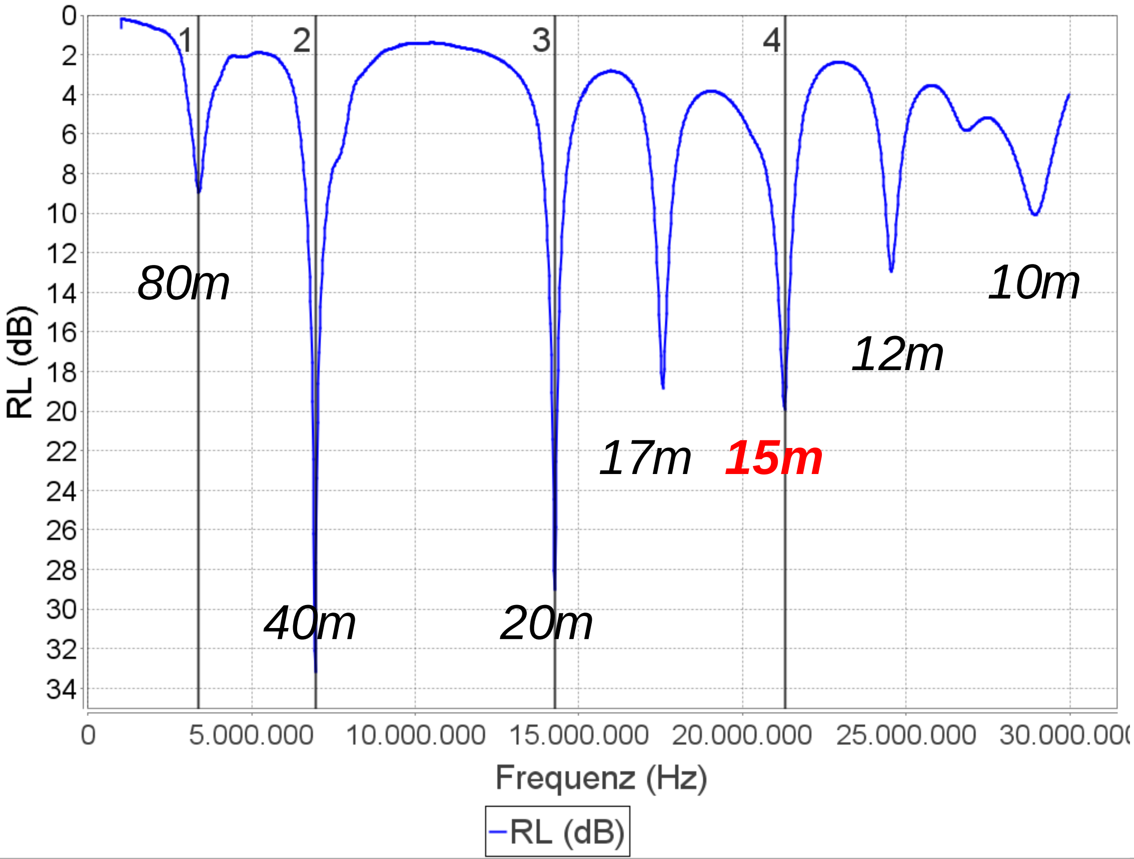
The Antenna – mounted

40m+ long wire OCFD

parallel dipole

feeder system

The Antenna – Proof of Concept



The Antenna – to be investigated

	Frequenz	SWV	RL	Phase	|Z|	Rs	Xs
1)	3.385.030	2,11:1	8,93	-38,31	86,3	76,9	-39,1
2)	6.951.430	1,04:1	33,18	33,91	51,9	51,8	1,3
3)	14.262.550	1,07:1	29,02	-67,78	51,4	51,2	-3,4
4)	21.283.900	1,23:1	19,89	-115,04	45,9	45,2	-8,4

- resonance at 80m is even lower as calculated (3.419MHz calculated)

- impedance of 15m dipole slightly too low, distance to OCFD 22cm needed

- expected much better return loss at 10m band

+ resonance at 40m is closer than expected (6.881MHz calculated)
+ principle of parallel dipole to an OCFD works fine !

Has it been that easy ? No…

This presentation just showed the final results, a summary of:

- three revisions of the antenna, climbing the roof 30+ times…

- error in antenna sim, true spacing 22cm vs. calculation 15cm…

- tried and measured several winding techniques, means “try and error” as well…

- tried and measured various core materials…
  (failed with AMIDON iron powder #2 regarding bandwidth of almost a decade)

- still not understanding why literature goes for 300 Ohm feeder system

Some Pictures

Summary

A multi band long wire antenna to work at seven amateur bands has been designed and mounted, tested at 80m / 40m / 20m / 17m / 15m / 12m / 10m

A feeder system has been calculated and built successfully, but still needs to be tested at full 2000W RF power – up to now limited to 800W by hardware;
Appendix April 2022: OCFD antenna is "QRO tested" for almost one year !

If accepted, the 2kW RF LDMOS power amplifier will be presented, too…
Appendix April 2022: QRO PA is built & tested & presented !

Interested in Wireless Communications ?

Deutscher Amateur Radio Club DARC:
https://www.darc.de/home/

Ortsverband Ulm, P14:
https://www.darc.de/der-club/distrikte/p/ortsverbaende/14/

…and how to get your license:
https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/SpezielleAnwendungen/Amateurfunk/start.html

https://www.darc.de/einsteiger/darc-online-lehrgang/