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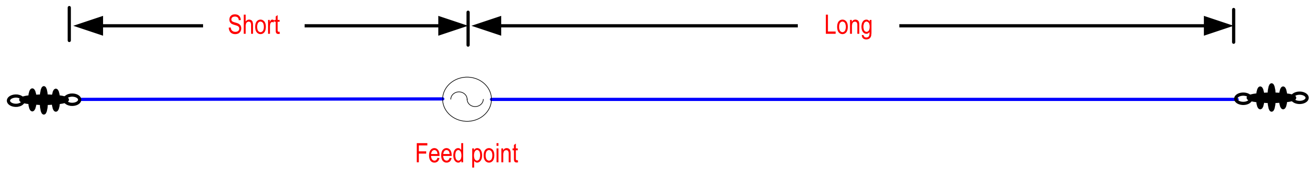

The Off Centre Fed Half-wave Dipole

The Off-Centre Fed Half-Wave Dipole, more commonly referred to as the OCFD, is very popular because it offers good performance as a multi-band antenna using an antenna matching unit in conjunction with a 4:1 or 6:1 current balun.

Background.

Loren Windom's W8GZ, original article was published in the September, 1929 issue of QST Pages 19 through 22 (re-printed Dec., 1966) and is entitled "Notes on Ethereal Adornments," and sub-titled " Practical Design Data for Single-Wire-Fed Hertz Antenna." The article begins by giving credit to the experiments of John Byrne, W8DKZ, Edward Brooke, W2QZ, Jack Ryder, W8DKJ, and Prof W.L. Everitt of the Ohio State University Dept of Electrical Engineering then goes on to discuss the attributes of an *off-centre fed dipole with an unbalanced coax feed line.* This 500 ohm antenna worked very well with valve transmitters using pi-tank matching.

By *1937 the Windom was described "as multi-band antenna that can be employed on harmonically related 160, 80, 40, 20 and 10m bands with acceptable levels of VSWR".*

Perhaps the most popular multi-band "Windom" or more accurately, OCFD was the German-made *Fritzel FD4 antenna, described by the late Dr. Fritz Spillner, DJ2KY, in 1971. The dimensions were the same as the multi-band Windom antenna, but fitted with a 200Ω (4:1) balun at its feed point and fed with 50 ohm coax at lower heights above the ground. The half-size version is known as the FD3 40-20-10m antenna. Both of these proved to be more suitable for modern day transmitters with a 50 ohm output than the original Windom antenna design.*

Today there are several multi-band OCFD antennas that also accommodate the new WARC bands, that have been designed using modern computer simulations.

Their popularity is simply explained because a center-fed dipole operates on its fundamental frequency (f0) and at 3f0, 5f0, 7f0 etc , whereas an OFCD operates on its fundamental (f0) and at 2f0, 4f0, 8f0.. This means that a centre fed dipole cut for 3.5MHz, would also operate 10.5 MHz , 17.5 MHz and 24.5 Mhz , while an OCFD cut for 3.5 MHz would operate on the harmonic frequencies of , 7.0 MHz , 14.0 MHz and 28 MHz or so it seems.

This set of studies takes a closer look at the Off Centre Fed Dipole to try and better understand its characteristics.

I would also like to add my special thanks to Steve G3TXQ for his suggestions and Barry G3YEU for his time proofreading my work.

Mario G8ODE

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1. EXCEL "Sine Wave Plots" STUDY OF THE FD3 40-20-10m OCFD – FEEDPOINT IMPEDANCE

A Multi-band OCFD cut for 40m has two possible feed-points

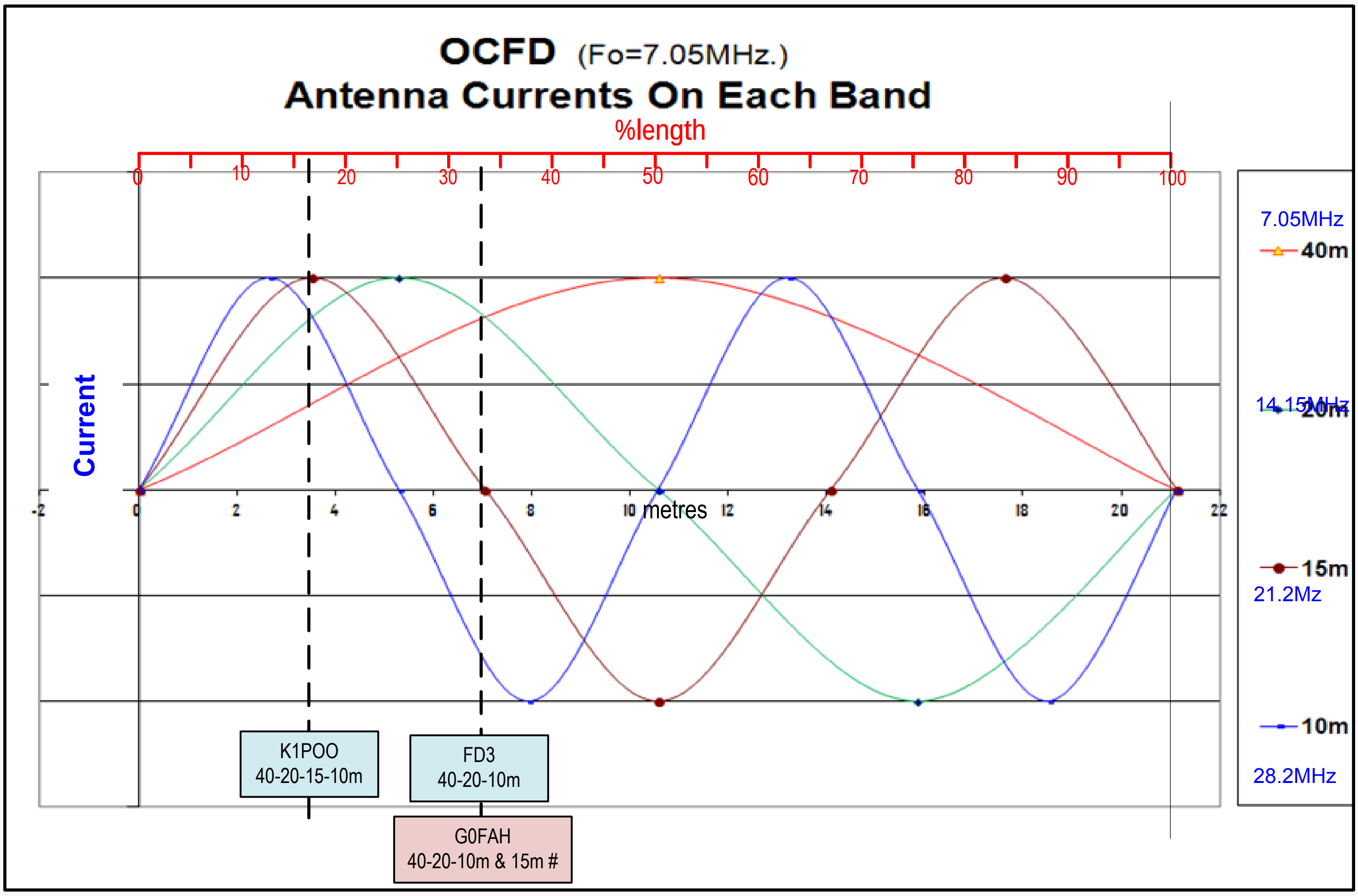
1. The graphical study of the 40m half wave dipole antenna currents assumes them to be sinusoidal in nature, The four traces are for the fundamental and three harmonic frequencies. The plotted results suggest that there are two positions where it can be fed so that it operates as an off-centre multi-band antenna.

2. The simplest being as an FD3 OCFD split in the ratio 1/3 & 2/3 (approx 33% & 66%). Designs on the web suggest that the feed point is between 200-300Ω the antenna therefore requires either a 4:1 or 6:1 current balun to feed a 50Ω coax to the shack. The variation in antenna feed point impedance being attributed primarily to the antenna's height about real ground in wavelengths (see later graph).

3. However with a 1/3+2/3 split the feed point impedance on the 15m band is very high i.e. the current is zero at this position, but it is possible to add the 15m band to the FD3 by using a 1/ 4λ transmission line transformer section made from either 300Ω or 450Ω feeder connected to a dual 4:1 & 1:1 current balun. For 15m operation the 1:1 ratio is used and for the other three bands the 4:1 ratio is used. This design was first proposed by G0FAH. The SWR on all the bands is <2:1.

4. K1POO suggested a feed point further away from the centre in QST, May & Oct 1996. His OCFD is cut to 3.65m + 17.38m where the split corresponds to approx. 1/6 & 5/6 (17% & 83%) split. This enables the 40m OCFD to operate on 40m, 20m,15m and 10m bands with the addition of a tuner. The SWR on the 40m band is <3.6:1 and <1.4:1. on the 20m,15m and 10m bands.

see http://www.amateurradio.com/200-ohm-feed-point-off-centre-fed-dipole/



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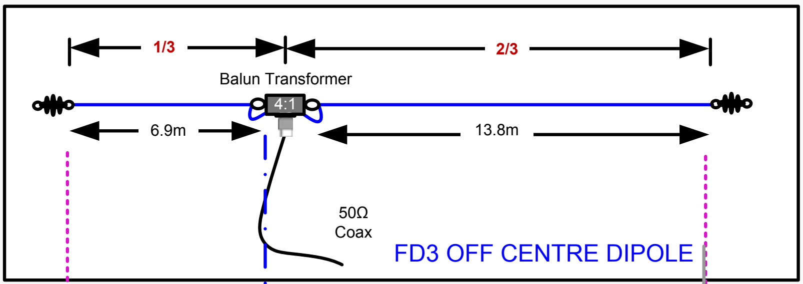
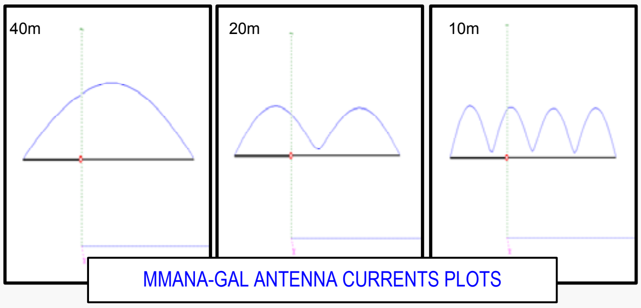
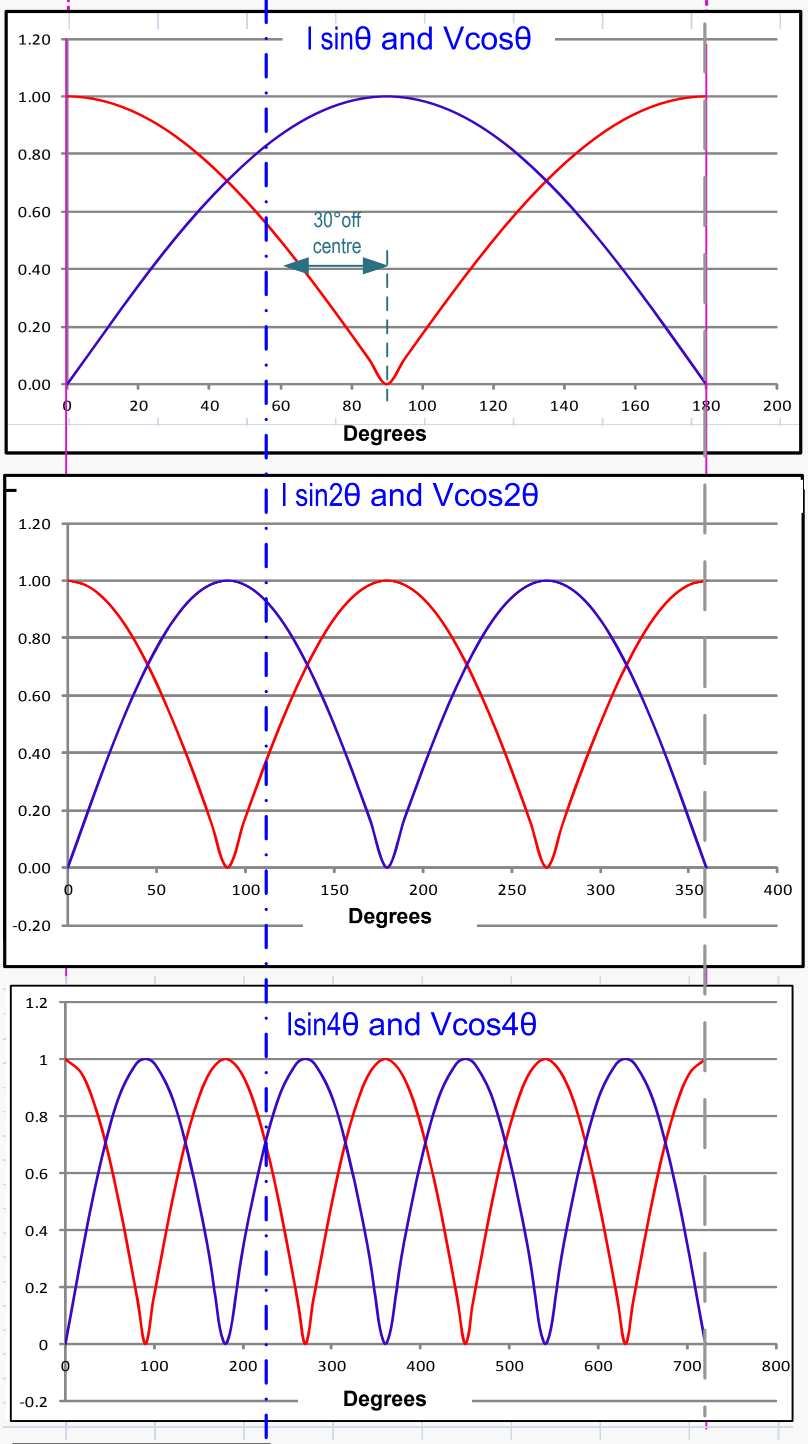
2. GRAPHICAL STUDY OF THE FD3 40-20-10m OCFD – FEEDPOINT POSITION







Current and voltage magnitudes plots for the FD3

This study focuses on the simple FD3 OCFD for 3-bands because fewer results are required to plot just three graphs of voltage and current magnitudes as shown on the left. These plots correspond to the antenna operating on its fundamental frequency and its two harmonics. In each case the X-axis scale is in degrees related to the antenna wire's electrical length at that frequency.

To simplify matters, It is assumed that the antenna wire is very thin relative to the wavelength consequently the current distribution is roughly sinusoidal and the voltage roughly follows co-sinusoidal distribution.

The aim of the study was to try and determine the nature of the feed-point impedance of the FD3 OCFD when it operates on the three harmonically related frequencies. .

To do this the three graphs have been carefully aligned to a scaled diagram of an FD3 antenna and a line drawn through the antenna feed-point.

This line intersects the voltage and current waves at the 60°,120°and 240°points on the three graphs, and it can be seen that in each case the voltages have a value of about 0.5 and the currents about 0.85 units.

Thus these graphs demonstrate that the impedance (Zin =V/I) appears to be constant when the FD3 operates on its fundamental frequency and even harmonics .

However, these graphs do not determine the feed-point impedance, only that it appears to be constant and the study disregards near field effects and the height of the antenna above real ground conditions.

Another study and approach to is required to determine this intermediate value.

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3. MATHEMATICAL STUDY OF THE OFCD FEEDPOINT IMPEDANCE

This study mathematically evaluates the radiation resistance of any off-centre feed-point based on the knowledge that a centre- fed dipole in free space has a theoretical radiation resistance of 73.2 ohms

However, practical measurements have shown that this value is not a constant. The graph on the right from Antenna Theory & Design Vol 2 by HP Williams published by Pitman shows this variation for both vertical and horizontal dipole radiators.

This shows that for heights between 0.15λ- 0.25λ the radiation resistance varies from 45Ω-75Ω. For the FD3 operating on the 40m band these heights correspond to 6m - 10m above real ground

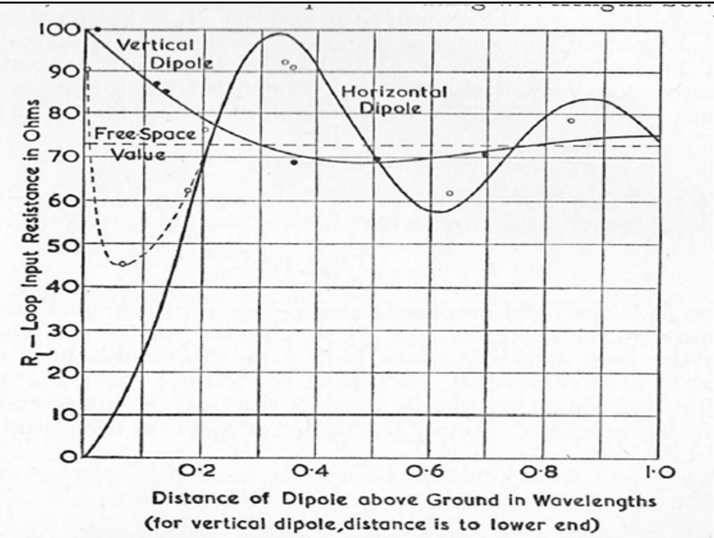
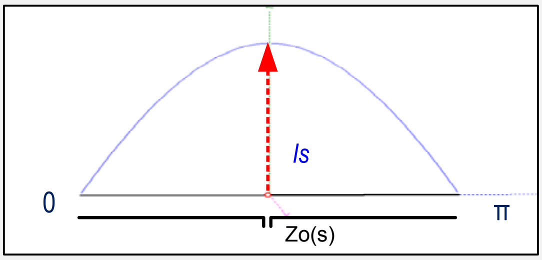
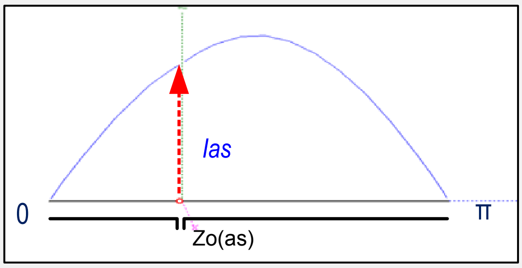


FIG. 3.14. VARIATION OF THE INPUT RESISTANCE OF A HALF-WAVE DIPOLE WITH HEIGHT ABOVE THE EARTH
(Friis, Feldman and Sharpless, *Proc. I.R.E.*, Jan., 1934)

Simple Mathematical Analysis

Consider a centre fed symmetrical half-wave dipole and an asymmetric dipole cut to the same frequency and radiating the same power with currents as shown below at the feed points assuming a sine wave current distribution





then; *Power radiated by both = Is²Rs = Ias²Ras .... equation 1* where Rs and Ras are the feed point radiation resistances

The asymmetric smaller current is thus Ias = Is sin(x°) where x is measured from one end in electrical degrees. Equation 1 becomes;

$$Ras = \frac{Rs\ (Is^2)}{(\ Is\ \sin^2(\ x°))}$$

and if we let Is=1 the equation becomes;

$$Ras = \frac{Rs\ (1)}{(1\ \sin^2(\ x°))} \quad .... \quad equation\ 2$$

Since a half-wave dipole is electrically 180° (π radians) long, then an FD3 or FD4 OCFD each split 1/3 +2/3, then on the fundamental frequency the shorter element is electrically 1/3x180°= 60° long and the longer 2 /3 element is therefore 120° long. From equation 2 above using sin(60°) =0.866, the impedance of the OFCD is therefore 1/0.866² or a factor of 1.333 times larger than the centre fed dipole impedance. N.B For the harmonic frequencies the sin(60°) is the same as sin(120°) and sin(240°)

So, referring to Fig 3.14, if the radiation resistance at the centre is 50 Ohms the impedance of the OCFD is calculated to be 66.7 Ohms, and if the impedance at the centre is 75 Ohms, the calculated value is 100 Ohms!. It's another of those "ham myths" which simply won't die that the impedance one third the way along a half-wave is 200 Ohms.

Another study is required!

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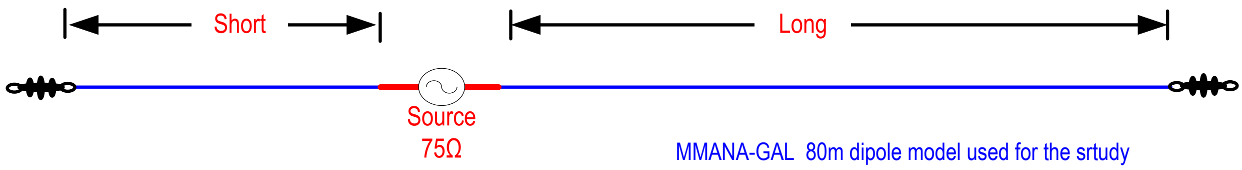
4. STUDY TO DETERMINE THE POSITION OF THE 300 OHMS FEED-POINT OF THE FD4 ANTENNA



Note source wire is 0.2m long

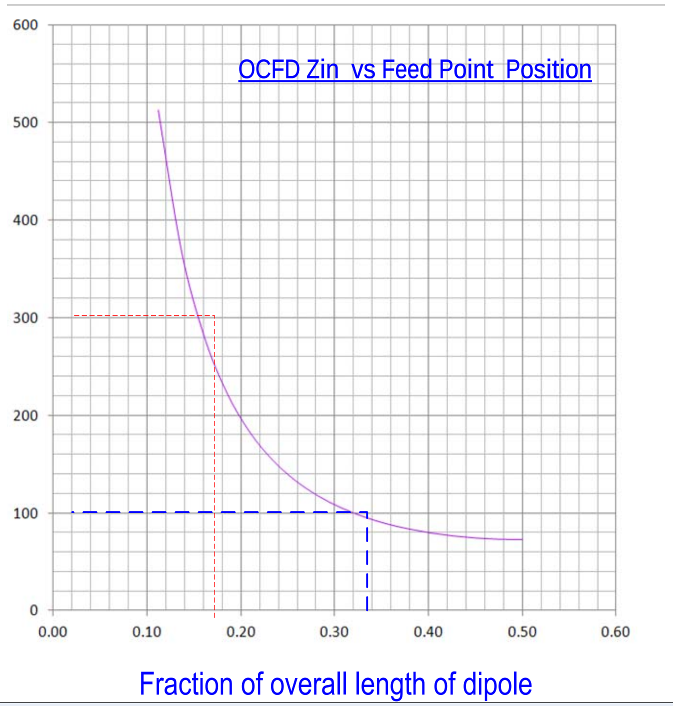
MMANA-GAL 80m dipole model used for the srtudy
(overall length 41.2m)

The FD4 (80m-10M) antenna is modelled using MMANA-GAL as shown above. The study documents the behaviour of moving the feed point away from the centre of the half-wave 80m dipole in free space in order to simulate off-centre feeding. The FD4 was used because the short 0.2m wire with the source is very small in comparison with the overall length of the antenna so would not introduce any large errors in the study,

Initially the "short" and "long " wires start off as equal lengths, thus simulating a normal half-wave dipole. The "short" element is reduced in size by one metre and the "long "element is increased in size by a metre , effectively shifting the 75Ω source away from the central position, and a new calculation made. This process continues in one metre steps until the feed point is close the insulator at one end

MMANA-GAL OCFD Zin analysis

wire 0.8mm rad Freq 3.55Hz	No loss wire SWR ref 75Ω			Free Space emulation		
long side	**short side**	**SWR**	**R**		**L+S**	**S/ (L+S)**
20.6	20.6	1.04	72.22		41.2	0.50
21.6	19.6	103	72.62		41.2	0.48
22.6	18.6	1.03	73.84		41.2	0.45
23.6	17.6	1.01	75.93		41.2	0.43
24.6	16.6	1.05	78.99		41.2	0.40
25.6	15.6	1.11	83.19		41.2	0.38
26.6	14.6	1.18	88.7		41.2	0.35
27.6	13.6	1.28	95.9		41.2	0.33
28.6	12.6	1.4	105.2		41.2	0.31
29.6	11.6	1.57	117.3		41.2	0.28
30.6	10.6	1.78	133.2		41.2	0.26
31.6	9.6	2.07	154.3		41.2	0.23
32.6	8.6	2.46	183		41.2	0.21
33.6	7.6	3.01	223.3		41.2	0.18
34.6	6.6	3.83	281.6	300Ω	41.2	0.16
35.6	5.6	5.11	370		41.2	0.14
36.6	4.6	7.26	512.5		41.2	0.11
37.6	3.6	11.3	757.9		41.2	0.09
38.6	2.6	20.6	1212		41.2	0.06
39.6	1.6	50.8	2046		41.2	0.04
40.6	0.6	312	2888		41.2	0.01



The table's results are plotted on the right using MS Excel and show the variation of the resistive value of the feed point impedance (R+ jX) calculated by MMANA-GAL as the feed point moves away from the centre of the dipole when S/(L+S) = 0.5 and the calculated R = 72.22 Ω.

By interpolation of S/(L+S) = 0.15 the R is approximately 300 Ω and corresponds to the antenna split as 1/6 + 5/6 as per a K1POO OCFD . The model also shows that at point 0.33 corresponding to a 1/3 + 2/3 split, the feed point impedance is close to 100 Ω as per the **"3. Mathematical study of the OCFD"** on the previous page. However this study still disregards near field effects and the height of the antenna above real ground conditions.

Another study is required

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5. MMANA-GAL STUDY FD3 MODEL THE EFFECT OF THE GROUND ON IMPEDANCE.

This study focused on the FD3 three band antenna as it requires fewer calculations compared to larger OCFD's. The results are for the antenna optimised at a specific frequency in two situations; (1). Over perfect ground and (2). Over real ground – 5mS/m and a dielectric of 13 and modelled at 6 different heights.

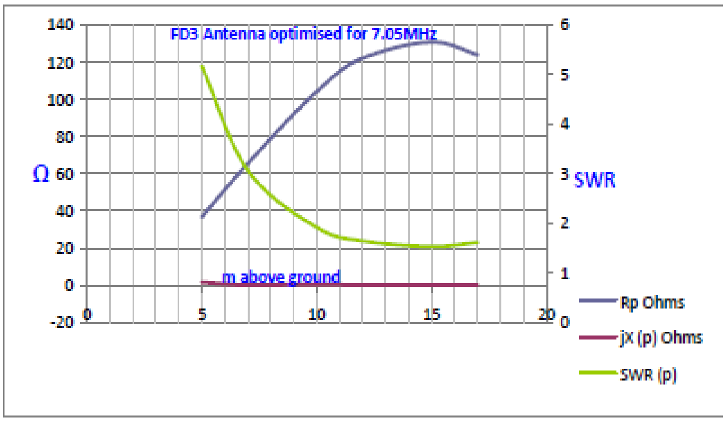
The graphs show that the impedance for perfect and real ground are very close and that the impedance of the FD3 is not 300 ohms as is often suggested in the articles for the OCFD. What in fact changes in these two situations is the antenna gain and the elevation of the radiation, but this was not the point of interest of this study so these details have been omitted.

The graphs clearly show that the height above ground does affect the impedance of the antenna, the lowest value is on the 40m band at a height of 5m (<< 0.25λ) and only rises to 130Ω at 15m. Generalising for all three situations, once the antenna height is at least a 0.25λ above the ground the radiation R > 100Ω. On 20m this averages 125Ω and 140Ω for the 10m band. At 10m above the ground the SWR ranges from 1.92:1 (40m), 2.2:1(20m) and 3.3:1(10) most antenna matching units can cope with these values.

N.B. SWR reference 200Ω in all three situations

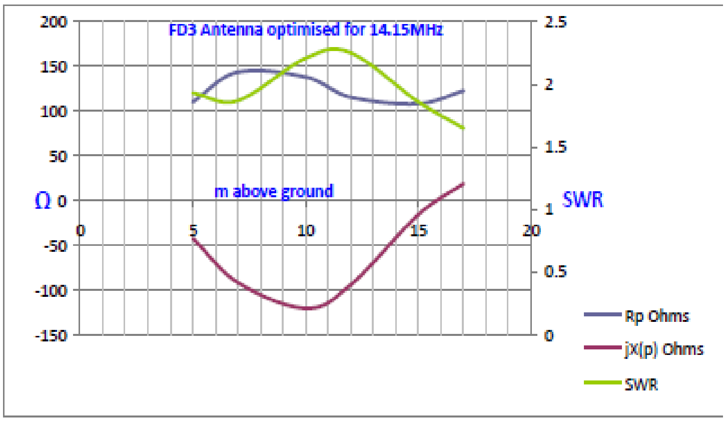
RESULTS FD3 Optimised for 7.05 MHz

Height above ground (m)	Over Perfect Ground			Over Real Ground 5mS/m dielectric 13		
	R Ω	jXΩ	SWR	R Ω	jXΩ	SWR
5	36.68	1.543	5.17	38.56	0.001	5.19
7	65.45	-0.0343	3.06	65.45	-0.034	3.06
10	104.1	0.54	1.92	104	-0.0026	1.92
12	122.1	-0.037	1.64	122.1	-0.0372	1.64
15	130.7	-0.034	1.53	130.7	-0.0343	1.53
17	124	0.013	1.61	124	0.0131	1.61



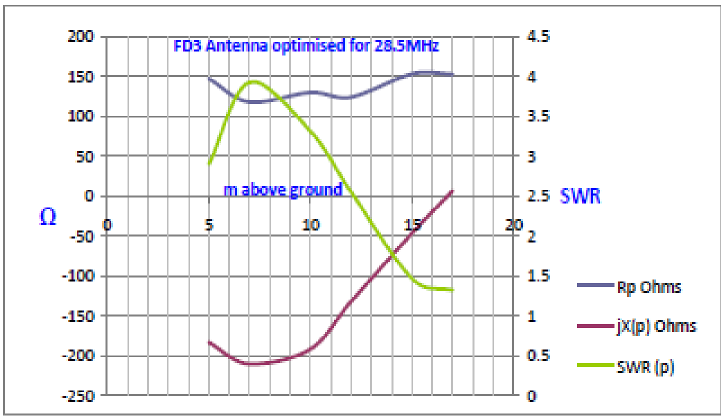
RESULTS FD3 Optimised for 14.15 MHz

Height above ground (m)	Over Perfect Ground			Over Real Ground 5mS/m dielectric 13		
	R Ω	jXΩ	SWR	R Ω	jXΩ	SWR
5	110.2	-41.9	1.93	110	-44.74	1.94
7	143.4	-91.4	1.87	143.4	-91.4	1.87
10	138.1	-120.1	2.21	138.1	-121.1	2.22
12	115.5	-94.05	2.25	115.5	-94.05	2.25
15	108.2	-15.57	1.86	108.2	-15.57	1.86
17	122.8	19.06	1.65	122.8	19.08	1.65



RESULTS FD3 Optimised for 28.5 MHz

Height above ground (m)	Over Perfect Ground			Over Real Ground 5mS/m dielectric 13		
	R Ω	jXΩ	SWR	R Ω	jXΩ	SWR
5	146.9	-183.6	2.9	146.9	-183.6	2.9
7	117.5	-210.7	3.92	117.5	-210.7	3.92
10	129.5	-192	3.31	129.4	-193.6	3.34
12	123.6	-132.5	2.55	131.1	-135.7	2.48
15	152.7	-46.82	1.46	152.7	-46.83	1.46
17	152.3	6.048	1.32	152.3	6.038	1.32



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6. MMANA-GAL STUDY - MODEL OF 40M FD3 OPERATING ON 2Fo AND 3Fo

"The other mistake often made by radio amateurs when trying to do a simple analysis of the OCFD is to assume that a wire which is half-wave resonant at frequency Fo will also be three-half-wave resonant at 3 x Fo - it isn't !"
Steve G3TXQ.

Wire loops tied to insulators at each end of the antenna add extra capacitance often called the "end effect". The extra end capacitance prevents the current at the wire ends reaching zero, this effectively lengthens the antenna and lowers its frequency in a manner similar to adding a capacitor to any tuned circuit.

The end effect increases with frequency and the formula for a half-wave thin-wire dipole L (feet) = 468 / Freq (MHz) takes the effect into account, for antennas up to 30MHz the overall length is reduced by about 5%, but this does not apply to antennas greater than a half-wavelength.

Another formula which can be used to predict the harmonic resonance frequencies of an antenna is Fo = 492(n-0.05) / Lt[1] ; where Lt is the overall length (feet) of the antenna, n is the number of half wavelengths at resonance and Fo the resonant frequency.

The mathematics to model and investigate this is very complicated, fortunately, there are free antenna modelling programs that can provide results to demonstrate these "end effects"; MMANA-GAL being one of them. Shown below are results for the FD3 model tuned for 7.0 MHz. at a modest height of 10m above real ground that many amateurs will operate at.

In the top table ; at 7.0 MHz the antenna is resonant with little reactance. However the same antenna operating on 14.0 MHz & 28.0 MHz shows significant amounts of reactance indicating that the antenna is no longer resonant.

The lower table ; shows that other resonant frequencies (no reactance) are not multiples of 7.0 MHz and appear at 14.50 MHz and 29.10 MHz.

The "2. Graphical Study of the FD3" concluded that the impedance remains constant, however this study demonstrates that this is not wholly correct. The antenna impedance actually increases with increasing harmonic frequency.

1. Ref The ARRL Antenna Book 14th Edition Chap 2

MMANA-GAL FD3 OCFD Antenna Model's Results

Antenna modelled as 2mm dia. Copper wire
10m height over real ground 5mS/m , dielectric 13, and optimised for 7MHz.

The FD3 operating on fundamental Fo, 2Fo & 3Fo

Freq (MHz)	R(Ω)	jX(Ω)	SWR Ref(200Ω)	Ga(dBi)	F/B(dB)
7.00 MHz.	103.28	0.03	1.94	6.02	0
14.00 MHz.	128.61	-135.1	2.37	7.19	-13.09
28.00 MHz.	138.9	-261.24	4.64	8.38	-9.8

The FD3 Harmonic Resonances When Fo = 7.00MHz.

Freq (MHz)	R(Ω)	jX(Ω)	SWR Ref(200Ω)	Ga(dBi)	F/B(dB)
7.00 MHz.	103.28	0.03	1.94	6.02	0
14.50 MHz.	142.83	-0.53	1.40	7.309	-16.06
29.10 MHz.	156.05	-0.44	1.28	9.20	-16.27

Note1.

Operated on Fo, 2Fo & 3Fo the antenna's reactance jX(Ω) increases with frequency. The variation in radiation resistance is caused by ground reflections altering the current in the antenna wire, hence the impedance. (see Study 5)

Note 2.

The antenna's resonant frequency (jX(Ω)=0) on the higher bands is no longer harmonically related to Fo and there is a further increase in radiation resistance RΩ).

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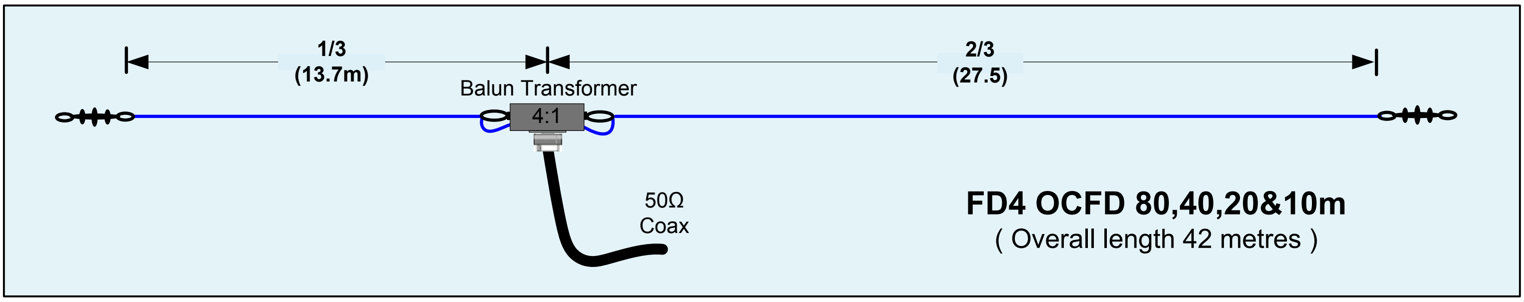
7. MMANA-GAL STUDY - FD4 IMPEDANCE VARIATION AT DIFFERENT POSITIONS



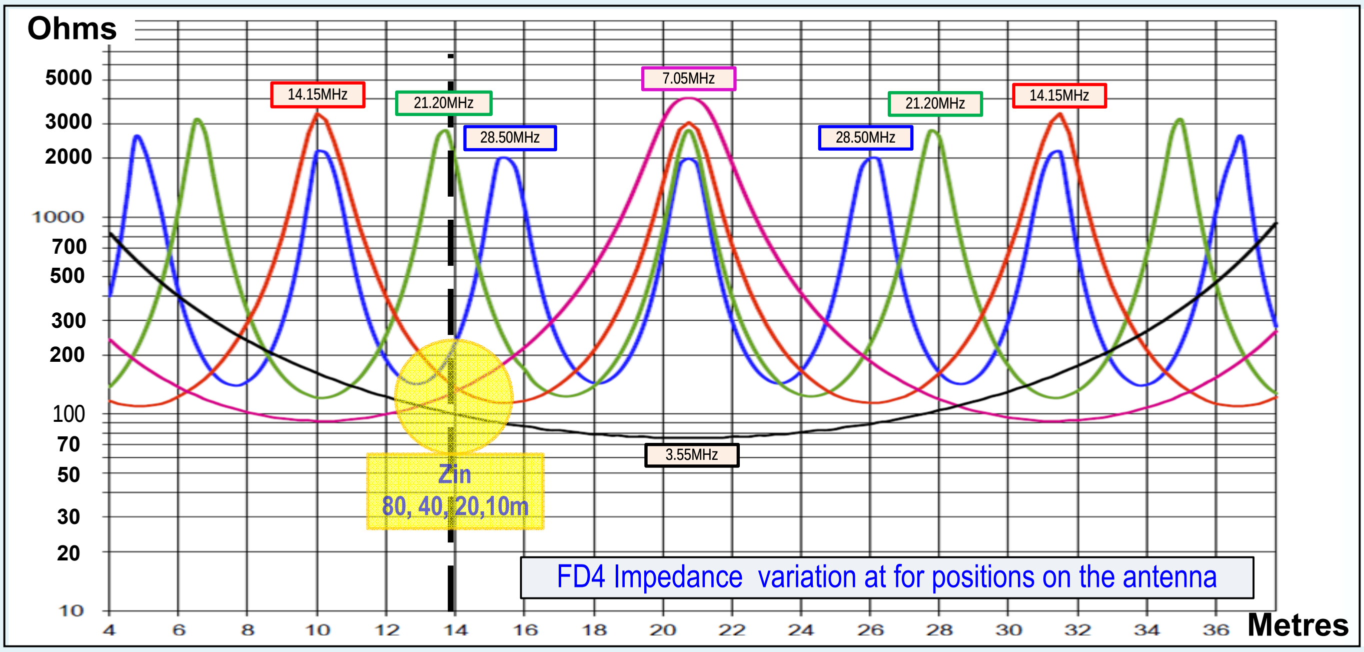
The calculation of an antenna's impedance requires knowledge of Maxwell's equations and the ability to develop equations to describe the antenna being studied. Solving these equations can be a daunting process for many radio amateurs; however there are free antenna modelling programs available on the WEB to model the antennas and solve these equations for us. One such program is the MMANA-GAL freeware program that Igor DL2KQ has helped to develop. http://hamsoft.ca/pages/mmana-gal.php.

The results from a MMANA-GAL model of the 4-band FD4 OCFD (split 1/3 +2/3) in free space have been used to produce the graph above. Placed above the graph is a scaled version of the FD4 antenna - (the larger version of the FD3).

A line has been drawn through the antenna feed point and aligned on the graph's x-axis 14m point, a 1/3 of the 42m overall length of the FD4. The graph only spans 4-36m to keep the y-axis scale reasonable because the models calculated impedances at the extreme ends are in excess of 5000 Ω.

At the 20m position (centre of the dipole) the 3.55MHz has an impedance of about 75ohms which corresponds to the theoretical value of a half-wave dipole in free space. The yellow highlighted area corresponds to the feed point where the 80,40,20,10, bands have impedance values between 100-200 ohms. The spread in impedances is due to the fact that the frequencies used in the model are not harmonically related to the fundamental frequency of 3.55MHz, on which the antenna was optimised

– see Study 6 on the previous page



Graphic results from Igor DL2KQ using MMANA-GAL Model data for a 80-10m Band OCFD
(Lossless Conductor In Free Space)

N.B. The Graph's X-axis is truncated so that the Y values are < 4100Ω to keep the detail in the central area as large as possible.

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