

EZNEC Simulation of Miracle Whip Antenna and Extensions

Requirements: EZNEC 5.0 or equivalent with transformer and L-network objects (or resistive and reactive network elements)

Introduction

The Miracle Whip is a compact, convenient, highly portable antenna for use at low power over the HF to UHF range. It incorporates a novel rotary autotransformer to provide a good match at frequencies where the whip is less than 1/4 wavelength. Many users add counter-poles or extensions to the antenna to enhance its inherently inefficient performance at HF. The author could find no published model with which to simulate and compare the basic and augmented antennas against reasonable simulations of other antennas.

An EZNEC model of the Miracle Whip antenna was developed that intuitively appears to resemble real world behaviour. The EZNEC model may be used in a standalone mode to arrive at a solution that provides an impedance match, as close to ideal as the user has time to iterate it with slight changes to parameters. Alternatively, it may be used to estimate the performance of the antenna system when the Miracle Whip autotransformer has been set to a dial position that should provide a fair match. A lookup table provides stepped parameters that indicate how finely or coarsely set the match may be.

This paper describes how the model was developed and provides guidance in using the model. Comments and constructive criticism towards improving the model would be welcomed. Email: ve3meo at gmail dot com.

Disclaimer

No claim can be made for the accuracy of the model. It has been neither sanctioned nor validated by Miracle Antennas, the manufacturer of the Miracle Whip. The model is purely the invention of the author who accepts no liability for any loss or damage that may ensue from anyone's use of the model or from the application of changes to the Miracle Whip antenna that appear to work in the model.

Modelling the Miracle Whip in EZNEC

The Miracle Whip has the following properties that help to define the model:

1. Short antenna has low radiation resistance, much lower than the 50-ohm impedance of the transmitter and any intervening coaxial cable, resulting in a high VSWR were there no matching network. Its Continuously Variable Auto-Transformer (CVAT) provides a one-knob matching network.
2. The CVAT is a step-up autotransformer that must see a load greater than 50 ohms in order to present nearly 50 ohms to the source for low VSWR.
3. The autotransformer must inductively base load the antenna in order to balance/cancel its inherent capacitive reactance for low VSWR.
4. The Miracle Whip exhibits a wide VSWR bandwidth of hundreds of kHz whereas high efficiency matching networks would exhibit tens of kHz. For radiation resistance \ll 50 ohms and the desired load on the autotransformer to be >50 ohms, a large Rloss must be included, consistent with wide VSWR bandwidth.

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Until EZNEC 5.0, there was no means to simulate the autotransformer of the Miracle Whip and so simulation would have been limited to the calculation of radiation patterns based on the geometry of the antenna, its add-ons, height above ground and type of ground. Losses within the matching network could not be modelled and almost all the simulated source power would be dissipated in the radiation resistance, regardless that the latter would be progressively tinier at lower frequencies. EZNEC would report unrealistic gains.

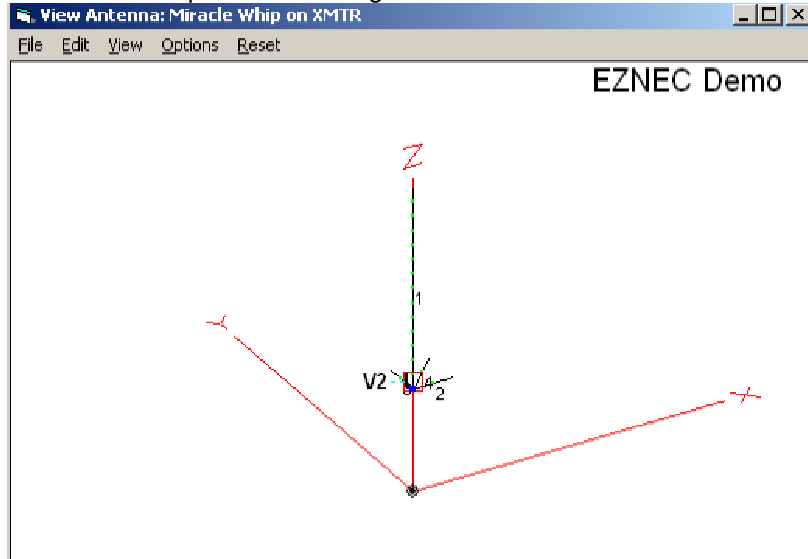


Figure 1: EZNEC View Antenna window showing the model of the unaugmented Miracle Whip mounted on the transmitter where the only counter-poise is the case of the transmitter represented by the three short radials. The EZNEC file from which all the screen displays have been taken is “MiracleWhip on transmitter.ez”.

The author started to learn antenna simulation software with EZNEC 5 and immediately applied its new transformer object to his models. However it is an ideal transformer with zero inductance and cannot be connected up as an autotransformer. It can nonetheless provide the impedance transformation function between the 50-ohm source and the rest of the antenna system.

Transformers									
No.	Port 1 Specified		Port 1 Act		Port 2 Specified		Port 2 Act		Rev/Norm
	Wire #	% From E1	Wire #	% From E1	Wire #	% From E1	Rel Z	Rel Z	
1	V1				V2		50	98	N
*									

Figure 2: EZNEC transformer object, connecting the Source from Virtual Wire 1 (V1) to the L-Network object on V2 with a 50:98 impedance ratio.

Enter the new L-network object of EZNEC 5. This was inserted between transformer and antenna to simulate the autotransformer's Rloss and inductive loading. In its R+jX mode, it is very easy to add reactance until the Source Data report indicates that the added base loading has balanced the antenna reactance. Despite the limitations of the EZNEC transformer object, we can still accomplish the second objective of the autotransformer, that is to base load the antenna with inductance to cancel the short antenna's inherent capacitive reactance.

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L Networks							
No.	Specified Pos.		Actual Pos.		R (ohms)	X (ohms)	
	Port 1 Wire #	Port 1 % From E1	% From E1	Seg	Series Branch	Series Branch	
	Port 2 Wire #	Port 2 % From E1	% From E1	Seg	Shunt Branch	Shunt Branch	
1	V2				96	1437	
	1	0	3.57143	1	1E+20	0	

Figure 3: EZNEC L-Network object, connecting the Transformer secondary on virtual wire V2 to Wire 1 of the antenna via 96 + j1437 ohms.

In this model, the EZNEC L-network object is not functioning as an L-network, rather simply a series network in series between the transformer and the antenna. The object's shunt path is open-circuited.

It should be immaterial that we had to use two EZNEC objects, the ideal transformer and the L-network, to mimic the autotransformer. We don't need an accurate model of the autotransformer to incorporate its effects into the antenna model. We don't care what proportions of its losses are due to eddy current, hysteresis, saturation, skin effect, leakage inductance, mutual coupling factor, stray capacitance, etc. Rather, we just need to mimic its gross behaviours: impedance transformation, inductive loading and loss at the frequency of interest. The ideal transformer in series with an equivalent resistive loss and an inductor is a sufficient model of that gross behaviour and one that EZNEC 5 supports, provided we can plug in reasonable values.

With the transformer turns ratio at 1:1 (impedance ratio of 50:50), the Source Data report shows the real resistance of the antenna system and the VSWR, in addition to the net reactance seen by the 50-ohm source. We know that the real autotransformer is a step-up transformer, except at the VHF and the two disconnected positions, i.e. at 47 other steps. What we don't know, unless we are modelling a working system, is what turns ratio the autotransformer should be set to and, therefore, the impedance ratio to be entered into the EZNEC transformer object and the R-value for the L-network object.

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EZNEC Demo ver. 5.0
Miracle Whip on XMTR          04/02/2009    5:20:01 PM
----- SOURCE DATA -----
Frequency = 14 MHz
Source 1      Voltage = 597.1 V at 0.0 deg.
              Current = 0.4563 A at 89.79 deg.
              Impedance = 4.802 - J 1309 ohms
              Power = 1 watt
              SWR (50 ohm system) > 100 (75 ohm system) > 100
    
```

Figure 4: EZNEC Source Data screen results with transformer at 50:50 and L-network at 0 + j0.

Let's assume that we do know what step the CVAT dial would be set to and, thus, the turns ratio N_t/N_p , where N_p = no. of turns on primary, N_t = total no. of turns. For the source to see a 50 ohm load, the load on the secondary must be $50 \cdot (N_t/N_p)^2$.

Let's say that works out to 98 ohms and that the Source Data showed the real part of the load impedance to be 4.8 ohms with the transformer impedance ratio at 50/50. We add $98 - 5 = 93$ ohms to the series R in the L-network object and change the transformer secondary impedance to 98. Now, the Source Data report shows a low VSWR, assuming we have balanced out the reactive

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component and we may reiterate for even lower SWR. In Figure 3, reiteration led to R=96 for a VSWR of 1.004 (Figure 5)

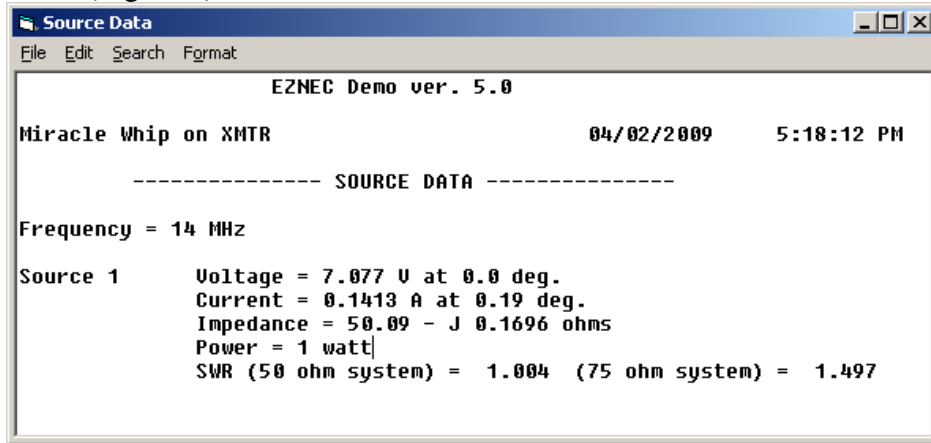


Figure 5: Source Data window after adjusting the L-network and transformer objects for a nearly perfect match.

With the added series R representing losses in the autotransformer, the antenna system now shows a significant reduction of gain, because the radiation resistance is a small fraction of the total load. Is this unrealistic? The answer must be "no" because it reflects operational experience - it has been rare to impossible to make contacts with the unaugmented Miracle Whip on 40m and below as loss increases with lower frequency (**Error! Reference source not found.**).

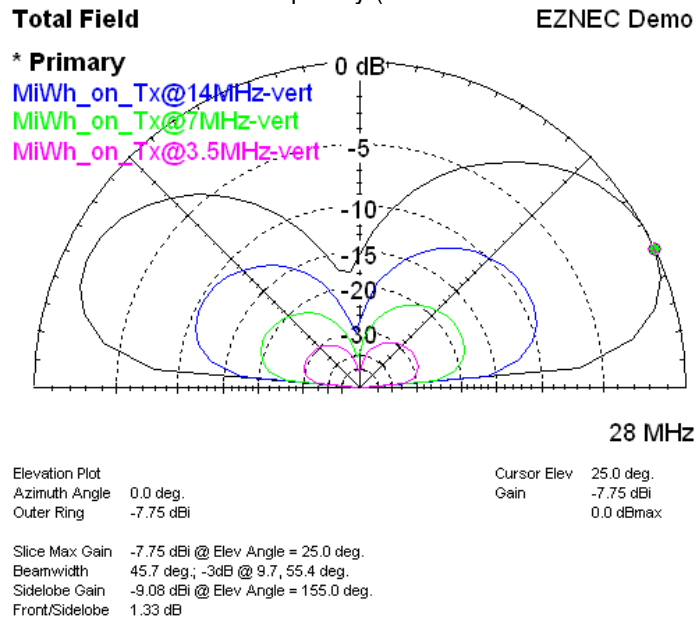


Figure 6: Simulated far-field elevation patterns for Miracle Whip on transmitter for matched condition at 3.5, 7, 14, 28 MHz, illustrating the increase in loss with lower frequency.

The key question is what is a realistic value for Rloss? It affects gain so we would like Rloss to be as low as possible. What values might it have?

In a well-matched condition of the model, the source sees negligible reactance and a 50-ohm resistive load. Rloss would have been set to one value to attain this. Let's call the antenna system

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gain for this value of Rloss the "well-matched gain" and the value of Rloss the "well-matched Rloss".

Changing only Rloss, there are two values that will result in a 2:1 VSWR - one that results in a 25-ohm load and one that results in a 100-ohm load. Clearly Rloss will be lower than the well-matched Rloss for the former and will result in lower loss, higher gain and narrower VSWR bandwidth; let's call them the "optimistic" Rloss and gain. Then the 100-ohm load will be associated with the "pessimistic" Rloss and gain. Let's take an example at 14MHz from the model for a bare Miracle Whip on a transmitter:

	VSWR	Rloss	Gain (dBi)
Optimistic	1.99	47	-14
Well-matched	1.01	95	-17
Pessimistic	2	194	-20.1

See Figure 7 for the corresponding VSWR curves

And at 7 MHz:

	VSWR	Rloss	Gain (dBi)
Optimistic	2	94	-22.6
Well-matched	1.02	186	-25.5
Pessimistic	2.03	384	-28.7

It is clear from these results that the actual value of Rloss could be at variance from that assumed for a well-matched simulation and thus cause a discrepancy of some +/-3dB. That is probably no worse than the influence of environmental variables, which we cannot model. For the purpose of comparative simulations, it is probably best to aim consistently for a well-matched condition.

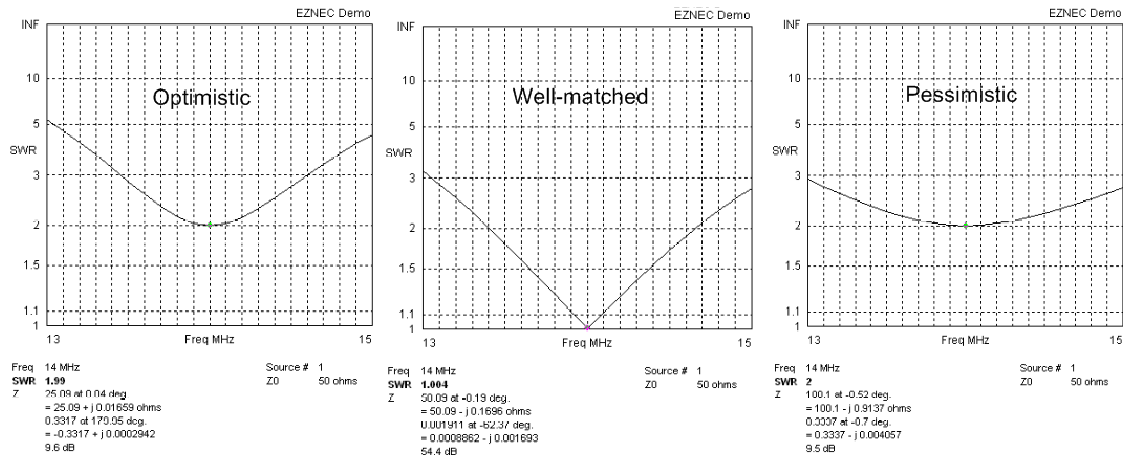


Figure 7: Simulated VSWR curves at 14MHz for three values of Rloss.

Parameters for the EZNEC Model

Given that an antenna configuration requires a certain amount of base loading to be resonated (balance the antenna's inherent reactance), we need to know what position of the autotransformer and its corresponding impedance ratio will provide the needed inductive reactance. That is the purpose of the attached table, for which some explanation is warranted.

Here is a description of each column:

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Freq Mark: the labels from the front face of the Miracle Whip showing nominal positions for the autotransformer for three frequencies and the VHF position (no transformer, just parallel inductor). These were probably chosen to correspond roughly with matching the unaugmented Miracle Whip mounted on a FT-817 transceiver.

Nominal Freq from Graphical Interpolation: fills in the gaps between the marked frequencies. Note that different antenna configurations will require variance from these nominal frequencies.

Pos'n: the rotary CVAT position. #1 is the lowest frequency, first step after the two dead spots. #48 is the VHF position.

Pri Turns: the number of turns on the primary side of the transformer (N_p) out of 80 total (N_t).

Sec/Pri Turns Ratio: N_t/N_p

Secondary Impedance for 50 ohm primary (for EZNEC xfmr): $=50*(N_t/N_p)^2$. Value to plug into the EZNEC transformer object as the secondary impedance (primary impedance = 50). EZNEC 5 does not care whether the impedance ratio is expressed as 1:6 or 50:300. It is more convenient to use the 50 base because it facilitates estimation of R_{loss} .

Estimated Primary Inductance (uH) if $L_{tot} = 150\mu H$: Self-inductance of the autotransformer primary, $L_p = N_p/N_t * L_{tot}$. Merely an intermediate calculation leading to the base loading reactance. The value of 150 uH for the total self-inductance of the autotransformer was arrived at not by measurement but rather by simulation behaviour. Homebrew variants of the Miracle Whip have used 25 uH and 2 mH autotransformers.

Estimated Base Load Inductance (uH) if $L_{tot} = 150\mu H$: this is the inductance looking from the antenna side back toward the transmitter and is, surprisingly, not simply $L_{tot} - L_p$ because of the current common to both the primary and the secondary through the primary. Nor is it $L_p*(N_t/N_p)^2$ as would be the case for an inductor ahead of the transformer. It was through a related simulation of an autotransformer with real properties in RFSIM99 that I realised the expression for the self-inductance of the secondary is: $L_s = L_p*((N_t-N_p)/N_p)^2$

Estimated Base Loading Reactance at (freq) MHz: $+jX$ ohms for EZNEC L-net series branch: $X = 2*\pi()*f*L_s$. Given that some configuration of the Miracle Whip antenna requires an inductive reactance of a certain value, we look here under the frequency of interest for the nearest value. In the same row, we look up the expected secondary impedance to plug into the transformer object and the position number to compare against the real world experience.

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Parameters for EZNEC Simulations of Miracle Whip Antenna

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Ltot (uH) =

150

Estimated Base Loading Reactance at (freq) MHz: +jX ohms
for EZNEC L-net series branch

Freq Mark	Nominal Freq from Graphical Interpolation	Pos'n	Pri Turns	Sec/Pri Turns Ratio	Secondary Impedance for 50 ohm primary (for EZNEC xfmr)	Estimated Primary Inductance (uH) if Ltot= 150uH	Estimated Base Load Inductance (uH) if Ltot= 150uH	1.8	3.5	5	7	10	14	18	21	25	28
		1	5	16.00	12800	9.4	2.11E+03	23856									
		2	7	11.43	6531	13.1	1.43E+03	16144									
		3	9	8.89	3951	16.9	1.05E+03	11878									
		4	11	7.27	2645	20.6	8.12E+02	9178									
		5	13	6.15	1893	24.4	6.47E+02	7323									
		6	15	5.33	1422	28.1	5.28E+02	5973									
		7	17	4.71	1107	31.9	4.38E+02	4951									
3.0	3.0	8	19	4.21	886	35.6	3.67E+02	4153	8075								
	3.3	9	21	3.81	726	39.4	3.11E+02	3515	6835								
	3.7	10	23	3.48	605	43.1	2.65E+02	2996	5825								
	4.0	11	25	3.20	512	46.9	2.27E+02	2566	4989	7127							
	4.3	12	27	2.96	439	50.6	1.95E+02	2206	4290	6128							
	4.7	13	29	2.76	380	54.4	1.68E+02	1902	3698	5283							
	5.0	14	31	2.58	333	58.1	1.45E+02	1642	3194	4562							
	5.5	15	33	2.42	294	61.9	1.26E+02		2760	3943							
	6.0	16	35	2.29	261	65.6	1.08E+02		2386	3408	4771						
	6.5	17	37	2.16	234	69.4	9.37E+01		2061	2944	4121						
	7.0	18	39	2.05	210	73.1	8.08E+01		1777	2539	3555						
	7.5	19	41	1.95	190	76.9	6.96E+01		1530	2185	3059						
	8.0	20	43	1.86	173	80.6	5.97E+01			1875	2626						
	8.5	21	45	1.78	158	84.4	5.10E+01			1604	2245						
	9.0	22	47	1.70	145	88.1	4.34E+01			1365	1911	2730					
	9.5	23	49	1.63	133	91.9	3.68E+01			1155	1617	2311					

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10	10.0	24	51	1.57	123	95.6	3.09E+01			971	1360	1943						
	11.0	25	53	1.51	114	99.4	2.58E+01				1134	1620						
	12.0	26	54	1.48	110	101.3	2.35E+01				1032	1475	2065					
	13.0	27	56	1.43	102	105.0	1.93E+01				848	1212	1696					
	14.0	28	57	1.40	98	106.9	1.74E+01				765	1093	1531					
Freq Mark	Nominal Freq from Graphical Inter- polation	Pos'n	Pri Turns	Sec/Pri Turns Ratio	Secondary Impedance for 50 ohm primary (for EZNEC xfmr)	Estimated Primary Inductance (uH) if Ltot= 150uH	Estimated Base Load Inductance (uH) if Ltot= 150uH	1.8	3.5	5	7	10	14	18	21	25	28	
	15.0	29	59	1.36	92	110.6	1.40E+01					881	1233					
	16.3	30	60	1.33	89	112.5	1.25E+01					785	1100	1414				
	17.5	31	62	1.29	83	116.3	9.80E+00					616	862	1108				
	18.8	32	63	1.27	81	118.1	8.60E+00					540	757	973	1135			
	20.0	33	65	1.23	76	121.9	6.49E+00					408	571	734	856			
	21.3	34	66	1.21	73	123.8	5.57E+00						490	630	735			
	22.5	35	67	1.19	71	125.6	4.73E+00						416	535	624	743	832	
	23.8	36	68	1.18	69	127.5	3.97E+00						349	449	524	624	699	
	25.0	37	69	1.16	67	129.4	3.29E+00						289	372	434	516	578	
	26.3	38	70	1.14	65	131.3	2.68E+00						236	303	353	421	471	
	27.5	39	71	1.13	63	133.1	2.14E+00						188	242	282	336	376	
	28.8	40	72	1.11	62	135.0	1.67E+00							188	220	262	293	
30	30.0	41	73	1.10	60	136.9	1.26E+00							142	166	198	221	
		42	74	1.08	58	138.8	9.12E-01							103	120	143	160	
		43	75	1.07	57	140.6	6.25E-01								82	98	110	
		44	76	1.05	55	142.5	3.95E-01								52	62	69	
		45	77	1.04	54	144.4	2.19E-01								29	34	39	
		46	78	1.03	53	146.3	9.62E-02								13	15	17	
		47	79	1.01	51	148.1	2.37E-02								3	4	4	
VHF		48	80	1.00	50	150.0	0.00E+00								0	0	0	

Sec 80