Ferrite rods and capacitive antennas explained

The following is largely drawn from the NS audio handbook and sets out to explain the theory and practical considerations associated with ferrite rod and capacitive (car radio) types of antenna - used for receiving purposes

1 Conversion of field strength to circuit input voltage

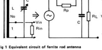


Fig 1 Equivalent circuit of ferrite rod antenna

Definition of terms

L	=	Antenna inductance
C	=	Tuning capacitor + strays
No	=	Primary/secondary turns ratio
Rin	=	Circuit input impedance
Rp	=	equivalent parallel loss resistance
R_L	=	equivalent loading resistance
Vin	=	voltage applied to circuit
Vid	=	voltage induced in antenna
V_T	=	voltage transferred across tank
Qu	=	unloaded antenna coil Q
Q_L	=	loaded antenna coil Q
Heff	=	effective height of antenna (m)
E	=	field strength in volts/metre

Formulae:

$$Qu = \frac{Rp}{X_L} \quad \text{(a)}$$

$$Q_L = \frac{Rp \| R_L}{X_L} = \frac{R_T}{X_L} \quad \text{(b)}$$

$$R_L = No^2 Rin \quad \text{(c)}$$

$$V_T = Q_L Vid \quad \text{(d)}$$

$$Vid = Heff.E \quad \text{(e)}$$

$$Vin = \frac{V_T}{No} \quad \text{(f)}$$

Heff approximates to
$$\frac{2\pi \mu_r N_1 A}{\lambda} \quad \text{(g)}$$

where

N1	=	Total number of turns
μ_r	=	relative permeability of antenna rod (function of length)
A	=	cross sectional area of antenna rod
λ	=	wavelength of received signal (3×10^8/ freq in Hz)

Noise voltage, calculated from the total Thevenin equivalent loading resistance, $R_T = Rp \| R_L$

$$en = \sqrt{4KT\Delta f\, R_T} \quad \text{(h)}$$

where

Δf	=	3dB bandwidth of the IF
T	=	temperature in °K
K	=	Boltzmanns constant = 1.38×10^{-23} joules /°K

Thus the signal to noise ratio at the antenna may be expressed as:

$$S/N = \frac{V_T m}{en} = \frac{Q_L Heff E m}{\sqrt{4KT\Delta f R_T}} \quad \text{(i)}$$

where

m = modulation index (usually 30% for AM broadcasts)

WORKED EXAMPLE

Specify the turns ratio No, total turns N1, effective height Heff, and inductance required for an antenna wound onto a rod with the characteristics specified below, designed to match an input impedance of 1k . Calculate the circuit input voltage resulting from a field strength of 100uV/m with 20dB S/N in the antenna circuit. Assume a 15-365pF tuning capacitor set at 100pF for an input of 1MHz.

Rin	=	1k	fo =	1MHz
E	=	100uV/m	rod dia =	1.5cm
S/N	=	20dB	μ_r =	65 (rod length 19cm)
C	=	100pF	m =	0.3
Qu	=	200	Δf =	10kHz

Calculate L, No, Heff, N_1, Vin

At resonance, a tuned circuit $X_L = X_C$ or

$$L = \frac{1}{C(2\pi f_0)^2} = \frac{1}{100pF\,(2\pi.1.10^6)^2}$$

$$= 2.53.10^{-4}\ H \qquad \text{L is approx. 250uH}$$

$$Rp = QuX_L = 200.\pi,1MHz.250uH \qquad \text{from a}$$

approx 314k

Under matched conditions

$$Rp = R_L = N_0^2.Rin$$

$$N_0 = \sqrt{\frac{Rp}{Rin}} = \sqrt{\frac{314k}{1k}} = 17.7$$

No is approx 18:1

$$Q_L = \frac{Rp \| R_L}{X_L} = \frac{Rp}{2X_L} \quad \frac{Qu}{2} \text{ since } Rp = R_L \qquad \text{from a \& b}$$

$$Q_L = 100$$

$$Heff = \frac{S/N\sqrt{4KT\,\Delta f\, R_T}}{Q_L.E.m}$$

$$= \frac{10\sqrt{(4)\,(1.38\times10^{-23})\,(300)\,(10kHz)\,(157k)}}{(100)\,(100uV/m)\,(0.3)} \qquad \text{rearranging (i)}$$

$$= 1.7cm$$

$$N1 = \frac{Heff\lambda}{2\pi.\mu r.A} \qquad \text{from (g)}$$

$$= \frac{(0.017m)\,(3.10^8 m/sec)}{(2\pi)(65)\,(1.10^6 Hz)\,(\pi)\,(7.5\times10^{-3}m)^2} = 70.7$$

N1 = 71 turns approx

$$Vid = Heff.E \qquad \text{from (e)}$$
$$= 0.017m\ .\ 100uV/m$$
$$= 1.7uV$$

$$V_T = Q_L.Vid$$
$$= 100.\ 1.7uV$$
$$= 170uV \qquad \text{from (d)}$$

$$Vin = \frac{V_T}{N_0} = \frac{170uV}{18} \qquad \text{from (f)}$$
$$= 9.4uV$$

Thus the ferrite rod antenna can be tailored to suit an exact set of field strength conditions - with predictable performance. The rod is assumed to be orientated in the best direction for maximum pickup.

The type of material used in the construction of the ferrite rod, and the nature of the wire used in the winding are crucial factors in determining the Q at a given frequency, hence the circuit impedance. Various types of ferrite exist for different basic applications, usually referred to with a number derived from Neosid's classification:

F5	Initial permeability	1600	AF/VLF
F6		1200	..
F7		1800	..
F8		1200	..
F9		3500	..
F11		500	LF (LW/Marine beacons)
F13		650	..
F14		220	LW/MW
F16		125	SW to 10MHz
F25		50	SW to 20MHz
F22		19	SW to 30MHz
F29		12	VHF to 200MHz

F14 Material is the most widely used type for ferrite rod LW/MW antennas - and it is important to note the frequency limitations of the various types of ferrite. F14 material at 5MHz is more lossy than F16 - though still just useable. F16 is a better choice, though with a lower permeability - more turns will be required to result in the same inductance.

The core loss factor, $\tan\delta/\mu i$ relates to specific materials and is the factor determining the frequency range of a given material. It is beyond the scope of this brief explanation - but further reference may be found in many ferrite manufacturers data books and application notes.

Ferrite rod antennas are never suited to transmission applications when wound in the manner described here - although certain techniques for winding rods to suit both receiver and transmitter applications are appearing now in the technical press. At the moment, though, it would appear that these techniques are the subject of trial and error experimentation, without a substantial grounding in theory.

Further experimental evidence shows that windings spaced some 20% of the rod diameter from the core show appreciable increases in the resonant Q of a given inductor.

Ferrite temperature coefficients are not linear - and probably represent the single biggest headache to the coil designer working with wide spans of temperature. Over the more restricted "domestic" range of 23-70°C, a factor can be approximated for general purposes. Again, this factor is dependent on the grade of ferrite being used and varies from 2 to 40 ppm /°C

The use of ferrite rods at VHF is another subject which appears from time to time, only to disappear just as quickly. The main motivating force stems from a desire to conceal the antenna of VHF portables and various pagers. In some pager applications, it is virtually obligatory from the point of view of both practicality and appearance - but it is invariably a compromise over a rod antenna. Ferrite antennas of this type are usually described in connection with tuned preamps, and a little experimentation shows that a very short piece of wire with the same preamp offers rather similar performance - albeit more subject to the capacitive effects of the body that prompt the use of the ferrite alternative in pager-type applications.

F29 material is not cost effective in all but commercial/industrial applications where there is little alternative. For radio reception the rod antenna is always a better solution if available.

At lower frequencies, the electrostatic field effects, versus the electro-magnetic field effects make the use of ferrite a very much more desireable feature - especially where the antenna is subject to normal enviromental noise that besets domestic reception.

Capacitive antennas

The capacitive antenna as described here, is a very high impedance type of receiver antenna - as implied by its position at the top of the tuned circuit. It is the type of antenna almost exclusively used in connection with car radio design - and should not be confused a loaded whip or similar electrically short type of antenna, which is basically matched to a low impedance load at the receiver input.
The circuit described here is not particularly practical as a car radio antenna - since the not inconsiderable capacity of the feeder is rather underestimated. A typical input circuit adopts the pi configuration to provide matching.
With this in mind, the analysis of the capacitive rod antenna is very similar to the ferrite rod, with many of the terms being the same.

Analysis

C1 is the capacitance of the vertical rod to the horizontal ground plane, while C2 is the capacitance of the feeder cable. The capacitance C2 is tuned out with an inductor L (part of the usual permeability tuning arrangement). The losses of the inductor and input resistance form the load R_L.
The signal then appearing at the input of the radio is related to field strength according to:

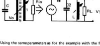
$$V_T = V_{id}.Q_L.\frac{C1}{C_T} \quad (j)$$

where Vid is derived from (e)
and Q_L from (b)

$$C_T = C1 + C2$$

$$S/N = \frac{H_{eff}.E.m.Q_L.(C1/C2)}{\sqrt{4KT\Delta f.Q_L.X_{CT}}} \quad (k)$$

It can be shown that the effect height of such a whip antenna approximates to (height in metres)/2 (m)



Using the same parameters as for the example with the ferrite rod,

R_{in} = 1kΩ	Δf = 10kHz	h = 1m
E = 100uV/m	C1 = 10pF	
Q_L = 80	C_T = 90pF	
f_o = 1MHz	m = 0.3	

Calculate S/N, N_o, Vin

H_{eff} = 0.5m
solving for X_{CT}

$$= \frac{1}{2\pi.f.C_T} = \frac{1}{2\pi.1MHz.90pF}$$

$$X_{CT} = 1768\Omega$$

from (k)

$$S/N = \frac{H_{eff}.E.m.\frac{C1}{C2}.Q_L}{4.K.T.\Delta f.X_{CT}}$$

$$= \frac{(0.5)(100uV/m)(0.3)(10pF/90pF)\sqrt{80}}{\sqrt{(4)(1.38\times10^{-23})(300)((10k)(1768)}}$$

= 27.55 dB

from (j) and (e)

$$V_T = H_{eff}.E.Q_L\ (C1/C_T)$$

= 0.5m.100uV/m.80.(10/90pF)

= 444uV

Under matched conditions, $R_p = R_L$, and $X_{CT}=X_L$ (at resonance) so from (b)

$$R_p/2 = Q_L X_{CT}$$

$$R_p = 2.80.\frac{1}{2\pi.(1MHz)(90pF)} = 283k = R_L$$

So from (c)

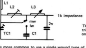
$$N_o = \sqrt{\frac{R_L}{R_{in}}} = \sqrt{283/1} = 16.8$$

use N_o = 17:1

From (a) $Q_u = \frac{R_p}{X_{CT}}$ = 283k.2π.1MHz.90pF = 160

Thus to summarize the effect of the capacitive rod antenna is to provide approx. three times as much voltage to the input of the circuit - leading to the improved signal to noise ratio of 27.55dB.

A practical input stage for car radio



TC1 is the antenna trimmer - effective on mw only.

It is more common to use a single wound type of coil in the permeability (variable inductance / variometer) tuners of car radio. So the No:N1 transformation is performed via a pi-network circuit as shown. In European radios incorporating longwave, the use of this type of circuit permits easy conversion to longwave, by simply switching in a preset tuning coil (L2) in series - and adding C1 to the input matching of the pi circuit. (about 900uH).

The trend towards varicap tuned car radio (in conjunction with digital displays, synthesis etc.) will inevitably cause a rethink, but since most such sets are aimed at markets where LW is not a problem, it is quite possible that manufacturers may avoid the question for the time being.

Modern receiver trends

A brief word on the subject of the way things are heading in the realm of 'consumer' and broadcast radio - since it is very apparent that the digital revolution is about to take over from the old established mechanical tuning means. The technology to do this has been about for some time, with hyperabrupt tuning diodes (KV1210/1211, MVAM series, BB113 etc), but the practical manufacturing problems of getting to grips with the broad end point tolerances of varicap diodes has kept varicap AM tuning out of all but the most adventurous equipment.

However, the revolution has been spurred on by the emergence of the new families of LSI for direct count and display of received frequency, such as the OKI types described elsewhere in this catalogue.

Scale alignment problems no longer exist, and so varicap tuning has come into its own. From now onwards, most new HiFi, and increasing amounts of 'ordinary' radio equipment will be sprouting digital readouts. The choice of display is still unresolved, but LED seems to be the current favourite, although LCD and Futaba type fluorescent arrays are found in many high ambient light applications. LED is certainly the simplest to drive, with best life and enviromental characteristics.

But apart from DFMs, the synthesiser is beginning to proliferate in conjunction with various forms of MPU control. Mullard have recently announced a two chip system that cost us £50 for a samplepair. It uses a double phase detector in a manner that gets around many of the objections to synthesised LOs for HiFi FM. Firstly, a digital phase detector is used for fast capture, and then an analogue system switches in once lock is achieved, resulting in a very pure output, but with fast lockup. We understand that Plessey are close on the heels of this with their own system - and by the next catalogue, we expect to be offering a building block system using one or other manufacturers' devices.

As cheap solutions to digital display of frequency have catalyzed the use of varicap tuning, so the synthesiser will encourage the use of MPU control. Various systems are going around in prototype form at the moment, but most still bear the marks of haste, and do not offer everything that is possible and desireable.

The synthesiser also makes the use of up conversion a very simple matter. Part one of this catalogue describes the basic approach using an IF of around 100MHz, but a simpler version for 100kHz to 5MHz, with a 10.7MHz IF is possible, using the TDA1062 - or even the TDA1083 for the whole lot. Work needs to be done on lowering the cost of the basic synthesiser, but it is obvious from the experience of other LSI that a dramatic price cut is imminent, and when it happens, we trust you will be prepared to throw away the cherished ideas of bandswitching, tracking, multiple tunedcircuits - and all the bother they entail.

Our own research using the TDA1062/1220/1083 type of devices shows that a very sophisticated performance can be extracted from a humble piece of silicon. A preview of a Japanese MW/FM portable with synthesiser and digital readout that was approx. 8mm thick, with an area of twice the average credit card leads us to suspect that the consumer market is about to be shaken up in a big way.

The MC3357 has also shown itself as an intriguing SSB receiver for HF, which with the addition of a cmos synthesiser and LCD display would make an ideal project for any electronics magazine. If any reader would like to pursue experimental work in this type of advanced receiver design, we are happy to consider the sponsership of such projects for publication - even with fairly humble test equipment, it is surprising how much original work is available with the latest radio ICs when using them outside their originally intended applications.

Perhaps with the sophistication of modern receiver design, broadcasters and amateurs might be persuaded to cut down pollution of the airwaves with multikilowatt transmissions. The fact that low power can span oceans is demonstrated daily - so maybe there's hope.