

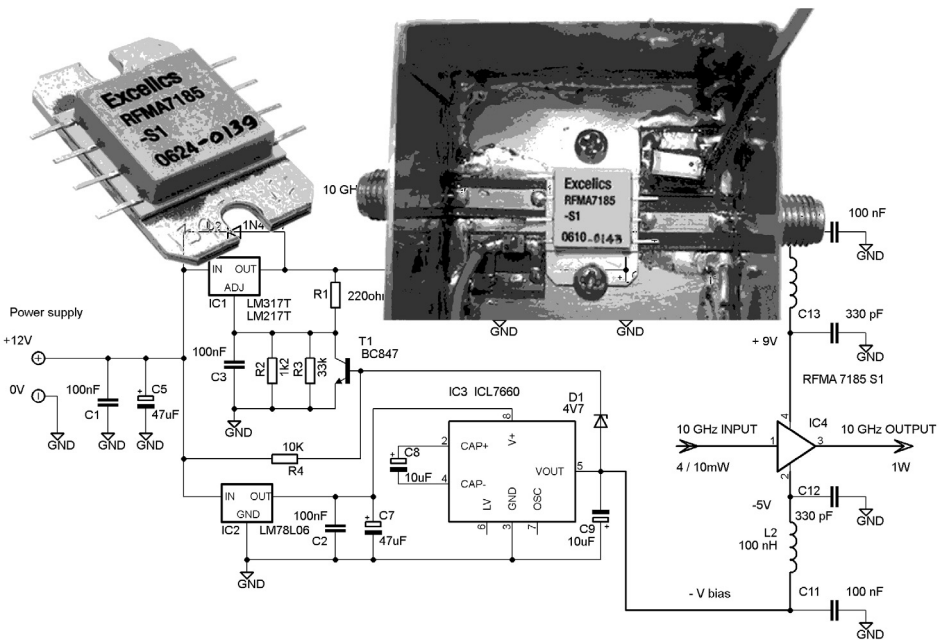


*A Publication for the
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VHF COMMUNICATIONS

Volume No.42 . Autumn . 2010-Q3 . £5.35



A simple 10GHz power amplifier for beginners

Franco Rota, I2FHW

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Contents

Franco Rota I2FHW	A simple 10GHz power amplifier for beginners	130 - 135
André Jamet F9HX	Bandpass Filters: Top or Bottom Coupling?	136 - 140
Gunthard Kraus DG8GB	Radio engineering - basic knowledge Investigating Signals	141 - 154
Konrad Hupfer DJ1EE	Power amplifier for the 2m band Inspired by Doherty	155 - 165
Juan Pablo Garcia EA4CIV	4NEC2 antenna modelling program	166 - 182
John Fielding ZS5JF	John's Mechanical Gem No 11 Know your metals	183 - 186
Gunthard Kraus DG8GB	Internet Treasure Trove	188 - 189

Some excellent articles again in this issue that will appeal to the keen constructors and those more interested in the RF theory.

There are three articles from subscribers to the English magazine. It is good to receive these articles because they keep the content fresh. I will need more articles to keep things going in 2011 so if you have a project that you think would be of interest to the readers then please contact me and I will help to prepare it for publishing. I do make a small payment for articles that are published but don't give up your day job to write articles.

73s - Andy



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Franco Rota, I2FHW

A simple 10GHz power amplifier for beginners

1.0

Introduction

The purpose of this article is to demonstrate how extremely ease it is for beginners in the microwave field to build a 10GHz power amplifier.

Can you understand a guy who usually makes things “dead-bug” style (ugly construction) who proposes this for a 10GHz project?

There is no problem building this 10GHz power amplifier in a similar way to “dead-bug” style because the component that I will explain always works without problems, I even made a sample of this device that will shock hard core microwave fans but it shows the reliability of this component.

I also think that thanks to this article there will be an incentive to use the 10GHz band because many hams have a transverter with 10mW output that can be raised to 1W with this device. The amplifier can be used with SSB modulation, ATV or any other kind of modulation including pulse modulation.

To be sure of the really good application of this device I made eight prototypes with different mounting styles, different serial numbers and different data codes.

They all worked well, so I can surely say that the device has no problems.

2.0

Microwave power devices

In the microwave field there are two different ways to build a power amplifier:

- the most popular components are broadband power GaAs-FETs, they have an average price and they are well known and readily available. Because they are broadband (they can be used at 1GHz as well as at 10GHz) they need matching for all frequencies, this may cause some complications. The advantage is that these components have a wider application area and they are a little less expensive than an MMIC. They have a small package because they have no internal matching network.
- another solution is to use internally matched GaAs-FETs (also known as MMIC), they are very simple to use because the internal networks match the impedance near 50Ω but these matching networks limit the bandwidth.

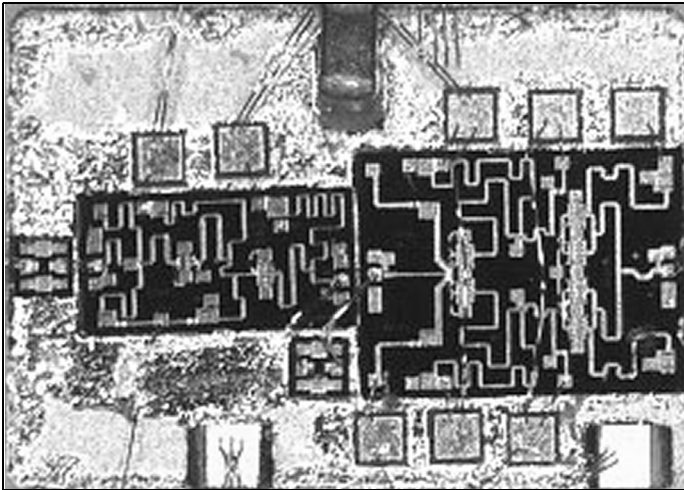


Fig 1: Microscope photograph of the RFMA7185-S1.

If we use a high power device, internally matched, the power combiners and the matching networks in the device reduce the bandwidth. The devices for high power have more complicated internal matching networks that reduce the bandwidth quite a lot.

If instead we use a medium power device, the power combiners and the matching networks in the device will have a relatively wider bandwidth that will allow it to be used for a wider frequency range than it was designed for. The devices tested are made by Excelsis with the part number RFMA7185-S1. It was matched for 7.1 – 8.5GHz but being

a device with only 1W output it is suitable for frequencies from 6 to over 10GHz.

I took a photograph using a microscope to see the internal parts of the device and I could see the internal matching network with the power combiners as shown in Fig 1.

The power combiners have a bandwidth of more or less one octave, with the matching network the overall bandwidth is reduced.

The RFMA7185-S1 has four internal amplifier stages, a block diagram is shown in Fig 2. The first and the second

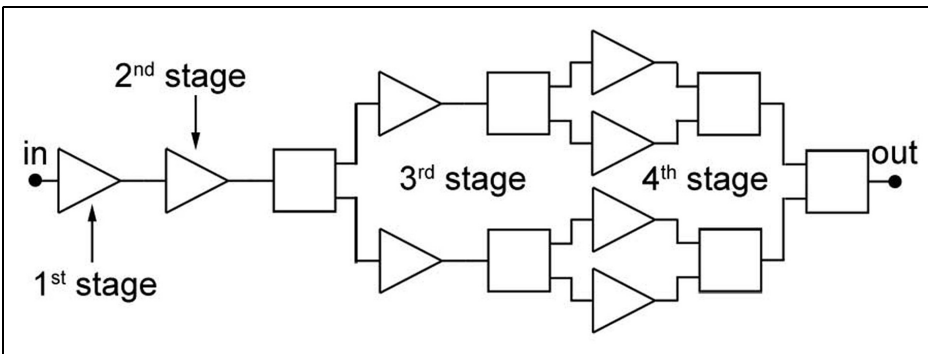


Fig 2: Block diagram of the RFMA7185-S1.

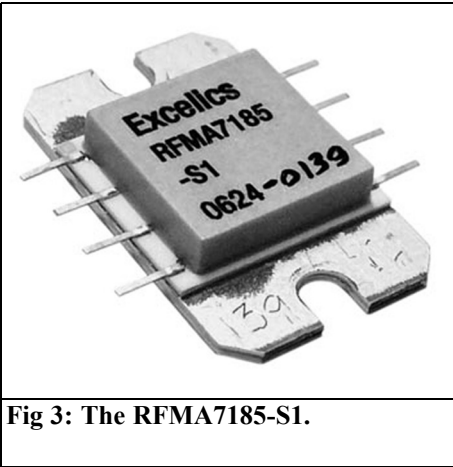


Fig 3: The RFMA7185-S1.

It has a professional gold plated case that is easy to mount. In fact the case is not SMD or ultra-miniature BGA. It has two little lugs to ease mounting and heat dissipation. (See Fig 3)

3.0

RFMA7185-S1 performance

This device is optimised for 7.1 – 8.5GHz the results obtained with my eight prototypes are shown in Table 1 with two examples of the prototypes shown in Figs 4 and 5.

are made from a single GaAs-FET, the third from two GaAs-FETs while the fourth is made of four GaAs-FETs. There are wide band matching circuits and the power combiners for the third and fourth stages.

It can be seen from the Table 1 that the device is optimised from 7 to 9GHz and in this frequency range the gain is about 30dB with an output power at least +30dBm (1W).

Out of the optimised frequency band the

Table 1: RFMA7185-S1 prototype test. Test conditions: VDD +9V power supply, VGG -5V negative bias, Pout = P1dB.

	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8
freq GHz	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm	Pout Pin dBm
10.4	+30.5 +8	+29.5 +9	+30.5 +5	+29.7 +10	+29.8 +10	+30 +8	+30.8 +6	+30.8 +8
10	+31.7 +4	+29.5 +5	+30.5 0	+30 +8	+30.2 +7	+30.7 +5	+31.4 +3	+31.2 +5
9	+31.8 +2	+29.7 -1	+30.7 -1	+30.7 0	+30.6 -1	+31.3 +2	+31.1 -1	+31 +2
8	+31.5 0	+30.2 -1	+30 -1	+29.8 0	+30.9 -1	+30.7 0	+30.5 -1	+31.1 +1
7	+31.7 -1	+30.1 0	+29.7 -2	+30 0	+30.6 -1	+31.3 0	+31.2 -1	+31.1 +1
6	+31.8 +2	+29.6 +5	+29.5 -1	+29.5 +3	+30.2 -1	+30.1 +2	+30 0	+30.5 +2
5.7	+30.5 +8	+27.5 +10	+29 +9	+28 +9	+29.3 +7	+29 +8	+28 +6	+28.3 +9

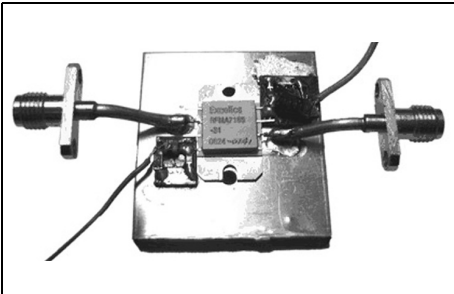


Fig 4: Prototype #2: even though it works we don't suggest mounting like this. This only demonstrates that the device works even in critical conditions.

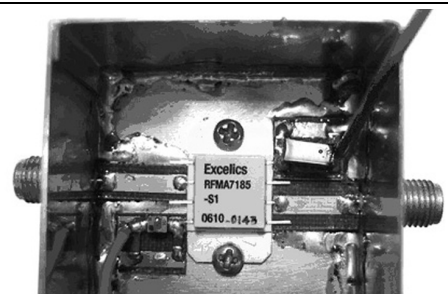


Fig 5: Prototype #6.

device is still able to provide +30dBm up to 10.4GHz even if the gain is reduced to 20/25dB.

20/25dB gain corresponds to a driver of about +7/+10dBm (5/10mW) that is ideal to be driven by a traditional low power MGF1302 GaAs-FET normally used in 10GHz transverters.

During the tests I didn't detect any self-oscillations or any other strange behaviour. I also maltreated some prototypes with mismatched input and output and

nothing happened.

The manufacturer suggests using a +6.5V power supply but the device also behaves well at +9V and it even worked at +11V but I suggest not exceeding +9V.

The -5V negative bias of about 15mA must be provided on the VGG pin by a traditional ICL7660. Under these conditions of power supply and bias the drain current is about 1A that means the device works perfectly in a linear class, in fact the manufacturer designed them for a class A radio link using digital modulation.

Fig 6 shows the circuit diagram and

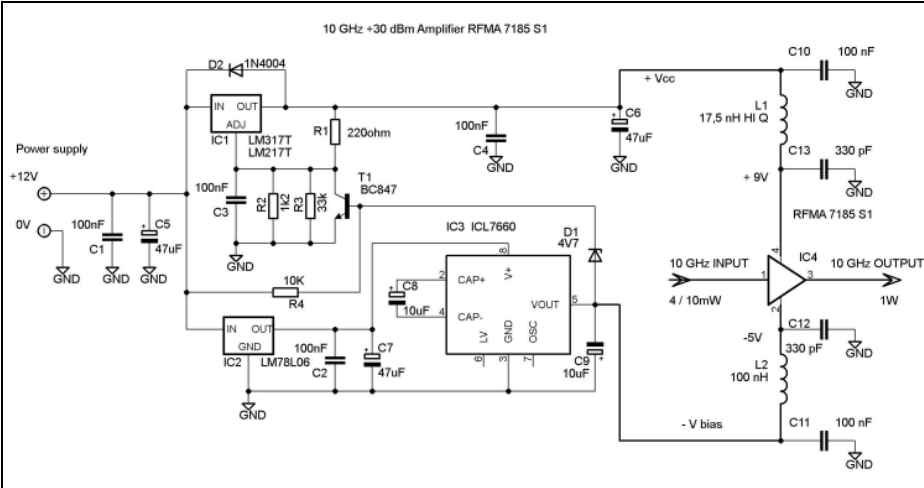


Fig 6: Circuit diagram of the amplifier and power supply.

**Table 2: Parts list.**

C1, C2, C3, C4, C10, C11	100nF
C5, C6, C7	47 μ F 16V electrolytic
C8, C9	10 μ F 10V electrolytic
C12, C13	330pF
D1	4V7 0,4W Zener diode
D2	1N4004
IC1	LM217T or LM317T
IC2	LM78L06 or any 6V 100mA regulator
IC3	ICL7660 DIL or SMD
IC4	RFMA7185-S1(2)
L1	17.5nH HQ SMD inductor
L2	100nH HQ SMD inductor
T1	BC847 or any NPN general purpose transistor
R1	220
R2	1.2K
R3	33K
R4	10K
RF PCB	see description or see SU-02 [1]
Absorber	see notes

Table 2 shows the parts list. It contains the 9V positive regulator (IC1), I used the LM217T that is the high performance version of the LM317T, the rating must be at least 1.5A.

IC2 is an LM78L06 positive regulator that drives the ICL7660 negative regulator (IC3), because the RFMA7185-S1 needs about 15mA of negative bias and the voltage drop of the ICL7660 is about 1V with that current, we will have exactly -5V as negative bias.

In order to avoid damage to the GaAs-FET it is necessary to sequence the power supply, first the negative bias and then the power supply. To do this we need the BC847 transistor (T1) and 4V7 Zener diode (D1) that enable IC1, if the negative bias is missing it will block the power supply.

The components around the GaAs-FET are not particularly critical, I only remind you that for 1A or more current it is necessary to use a choke that has this current rating, the 17.5nH Coilcraft type B06T choke (L1) can carry 4A.

4.0

Assembly

As described the assembly of the power GaAs-FET is not critical. It means that for a good result it is not necessary to use Teflon printed circuit board, if you keep the tracks short between connectors and pins you can use the normal FR4 epoxy fibre-glass laminate.

In this case I suggest using the 30 or 31 mils thickness (0.8 mm) laminate, not the 1.6mm thickness laminate.

The 50 Ω input and output tracks can be even saved from any kind of surplus PC board, for example from my SU-02 [1] (see Fig 7). In this case you can cut a piece of the track from the PC board, obviously the PC board must be double sided copper.

Other components can be SMD, or not and it is possible to mount them "dead-bug". Fig 5 shows an example of very simple mounting of the RF parts.

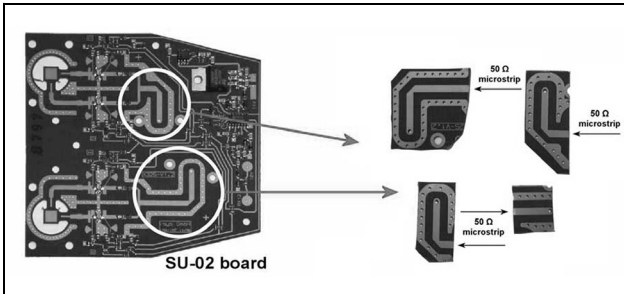


Fig 7: Using the surplus PCB type SU-02 [1].

PC board because every mounting was different but since many readers will surely want a PC board I designed one just for the power supply and bias circuits. Fig 8 shows the top of the PC board (components side). It is double sided with plated through holes for the ground connection while the bottom side is only the ground plane, Fig 9 shows

As for all microwave components it is suggested that a microwave absorber is mounted on the inner side of the top of the box in order to avoid any self-oscillations and unwanted resonances of the box. See “Franco’s Finest Microwave Absorbers” in issue 4/2004 of VHF Communications Magazine, that article explained how microwave absorbers work and the efficiency of these absorbers.

the top side, component side.

Please read my earlier comments for the RF PC board section.

Special thanks to:

F1CHF Jouan Francois and F6BVA Michel Antonioli for their work, encouragement and technical support.

5.0

Conclusions

As explained I assembled eight different prototypes with the purpose to test different solutions and different mountings, therefore it was not possible to build the

6.0

References

[1] For RF PC board see also www.rfmicrowave.it surplus page code SU-02.

[2] RFMA7185-S1 is available at www.rfmicrowave.it

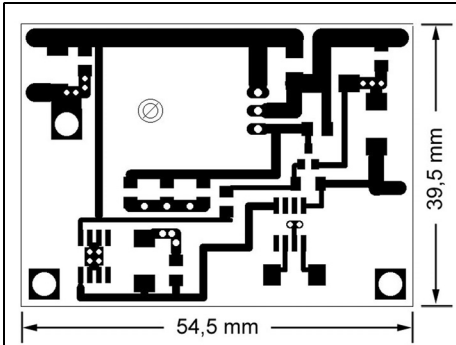


Fig 8: Double sided FR4 PCB for the power supply.

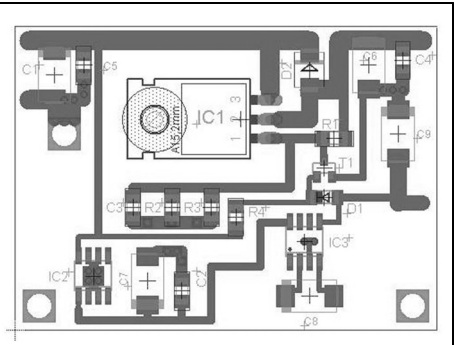


Fig 9: Component layout for the power supply PCB.



André Jamet, F9HX - agit@wanadoo.fr

Bandpass Filters: Top or Bottom coupling?

1.0

Introduction

A very interesting article, published in the VHF Communications Magazine issue 2/2009, attracted my attention [1]. It was an article from DG8GB about a bandpass filter using a very small coupling capacitor.

What do I know about coupling methods in bandpass filters? I can find many complicated calculations in modern books. Although it is very old, my Radiotron Engineer's Handbook [2] gave me an interesting page about coupling modes. Fig 1 shows a copy of this page.

2.0

Tuned circuits coupling methods

As shown in Fig 1, the coupling capacitor can be at the top or at the bottom. At VHF, the first method needs a very small capacitor and DG8GB made an interdigital arrangement on a PCB. I would like to obtain the same result with an SMD capacitor at the bottom.

3.0

Filter specifications

- $L = 67\text{-}76\text{nH}$
- $C = 13.8\text{pF}$
- Centre frequency: 145MHz
- Bandwidth: 2MHz
- $Z_{in, out} = 50\Omega$

The practical values were for a top coupling capacitor: $C_{\text{coupling}} = 0.3\text{pF}$

4.0

Calculations

Let us examine bottom coupling. From the Radiotron's formula and DG8GB values, we get:

$$k = C_m / C_{1,2} = 0.3 / 13.8$$

$$0.0217 \text{ for the top coupling.}$$

Therefore, for the same k:

$$C_m = 13.8 / 0.0217 = 635\text{pF} \text{ for the bottom coupling.}$$

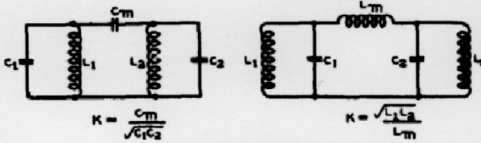


Figure 12 (left), Figure 13 (right).

When mutual inductive coupling is increased above the critical value and the two peaks appear in place of one, they are placed symmetrically on either side of the centre frequency. Further increase of coupling causes both peaks to move equal intervals further away from the centre frequency. No other types of coupling, such as those shown in Figs. 12, 13, 14, 15 and 16, possess this useful characteristic.

When the highest possible selectivity without too much loss of gain is desired from a pair of tuned coupled circuits, a practical compromise is to reduce coupling to 0.5 of critical.

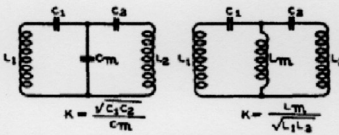


Figure 14 (left), Figure 15 (right).

when the gain is 0.3 times the maximum possible. The selectivity then approaches that which would be obtained by separating the two circuits with a valve (assuming this be done without altering Q' and Q_2). For other relationships between gain and selectivity, refer to Reed, Wireless Engineer, July 1931, or to Alken, Proc. I.R.E., Feb. 1937.

There are other types of coupling which may be used between tuned circuits as alternatives to mutual inductance. Four such circuits are shown in Figs. 12, 13, 14, and 15. A fifth type is "link" coupling shown in Fig. 16, in which a relatively small coupling inductance L'_1 is coupled to L_1 and similarly L'_2 to L_2 , and L'_1 is connected directly in series with L'_2 . The behaviour of this circuit is the same as that to be described for Fig. 15.

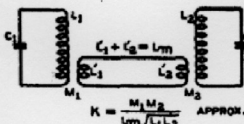


Figure 16.

In Figs. 12 and 13 high impedance or "top" coupling is used, while in Figs. 14 and 15 low impedance or "bottom" coupling is shown. Howe (editorial, Wireless Engineer, Sept. 1932) defines coupling between two circuits from a general point of view as the relation between the possible rate of transfer of energy and the stored energy of the circuits. Application of this principle leads to the result that for high impedance coupling,

$$K = \sqrt{X_1 X_2} / X_m,$$

while for low impedance coupling,

$$K = X_m / \sqrt{X_1 X_2}$$

where X_m is the reactance of the coupling, and X_1 and X_2 are the reactances of either the coils or the condensers with which the circuits are tuned.

For high impedance coupling X_m must be taken in parallel with the tuning reactance to obtain X_1 or X_2 , and for low impedance coupling it must be taken in series with X_1 or X_2 . The tuning reactance is of the same nature as X_m .

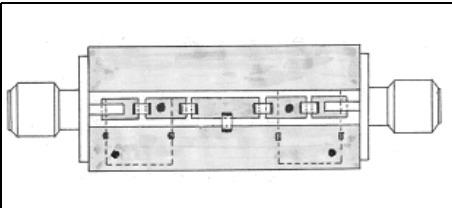


Fig 2: Filter arrangement from the SMD component side, not showing vias.

5.0

Construction

I used a very small PCB: 15 x 31 x 1.6mm, double side FR4, hand made with a cutter, and:

- two NEOSID 514630 coils with ferrite cores 63 - 76nH
- 0805 SMD COG capacitors
- two square SMA sockets
- several vias to connect both sides of the PCB, made of 0.8mm holes and pieces of 0.6mm copper wire soldered on each side.

The two coil cans are put on the opposed side to the SMD capacitor. They are carefully soldered to the ground plane.

The arrangement is very compact to reduce any parasitic inductance, because they are very influential for bottom coupling like parasitic capacitance is for top coupling.

6.0

Experimentation

Fig 2 shows the component layout and Fig 3 the circuit diagram. The auxiliary capacitor C_m does the coupling.

From the above calculations and by cut

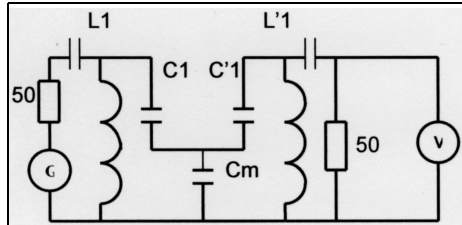


Fig 3: Bottom coupling filter circuit diagram.

and try, the following values were used:

- $C1 = C'1 = 2.2\text{pF}$
- $C2 = C'2 = 15\text{pF}$
- $C_m = 470\text{pF}$
- $L1 = L'1 = 70\text{nH}$

C_m values govern the bandwidth as:

- C_m low, under-coupling, increased selectivity, increased transmission loss
- C_m adjusted, critical coupling, medium selectivity, minimal loss
- C_m high, over-coupling, decreased selectivity, increased transmission loss, “camel” response

Fig 4 shows a simulation done by my friend F5CAU and Figs 5 and 6 give the results obtained by another friend F1EER using a Rohde and Swartz Vector Analyser ZVA 40. The actual loss shown by this method is higher than the simulation loss that does not include pad losses.

7.0

Conclusion

Simulation and measurements have confirmed the equivalence between top and bottom coupling. We have to choose the most suitable for a specific case.

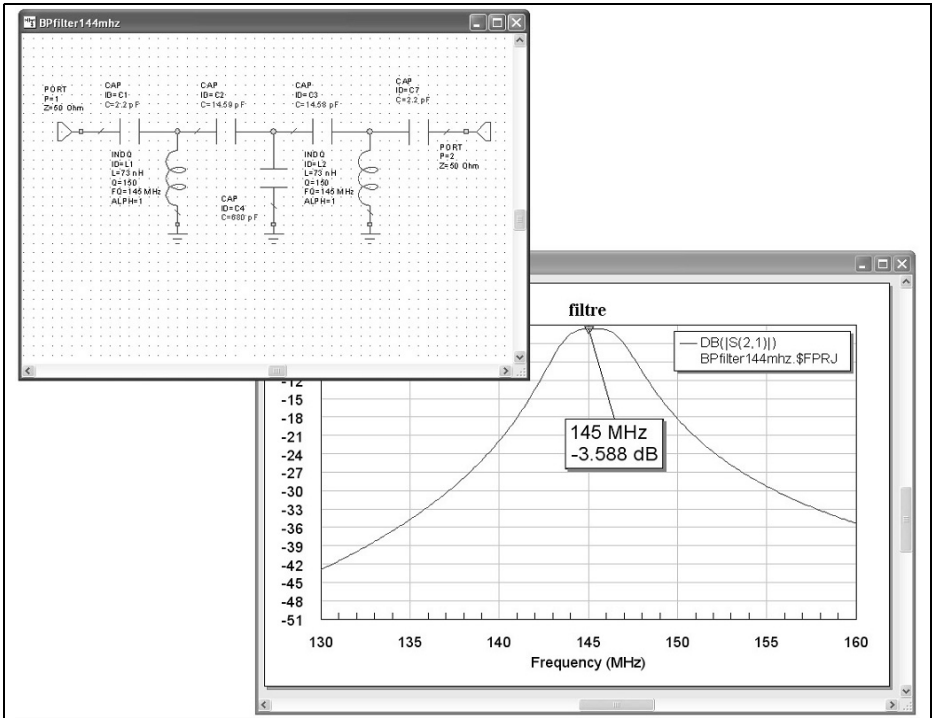


Fig 4: A simulation done by my friend F5CAU.

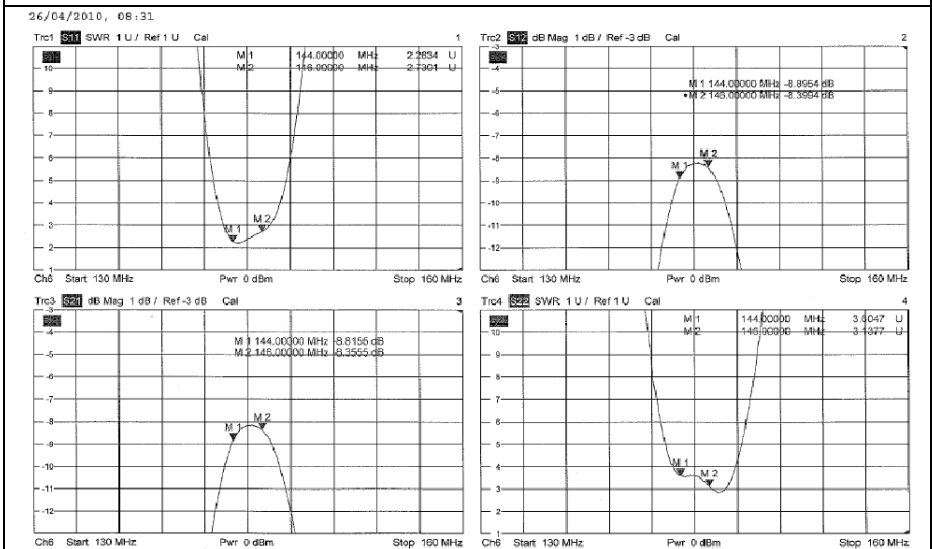


Fig 5: Filter S parameters scale 1dB/division.

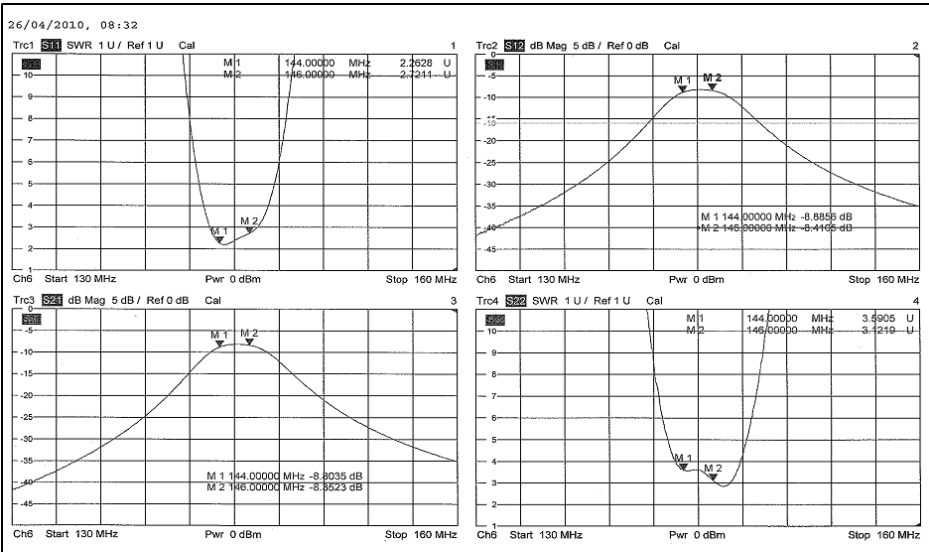


Fig 6: Filter S parameters scale 10dB/division.

8.0

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[1] Ansoft Designer SV project: Using microstrip interdigital capacitors,

Gunthard Kraus, DG8GB, VHF Communications Magazine 2/2009 pp 78 - 95

[2] RADIOTRON Designer's Handbook, Radio Corporation, of America, Third Edition, May 1948

[3] On the correct use of attenuators, F9HX, RadCom 6/2007

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Gunthard Kraus, DG8GB

Radio engineering - basic knowledge

Investigating Signals

1.0

Introduction

Even many laymen immediately know the answer to the question: “What voltage is supplied to each socket in a house”? It is obviously a sine wave of 230V (RMS) and a frequency of 50Hz.

But the next question is:

“Does the signal at the socket actually contain different frequencies”? Often even specialists give the wrong answer. That is because one must first of all consider exactly the measuring and observation conditions, because this directly influences the solution. Secondly one must take, as it were, a large magnifying glass and search into each little change or irregularity to study the signal properly. The correct answer should read:

“Only a pure sinusoidal voltage that has been switched on for a very long time and does not stop for a foreseeable time consists of only one frequency” (See Fig 1: $f = 1\text{kHz}$).

Since this definition does not fit many signals in daily life the solution of the mystery is as follows: One must differentiate very carefully between “decaying processes” and “distortion of the waveform of periodic signals”.

1.1. Decaying processes

Each unique change (switching on, switching off, making smaller, briefly interrupting...) produces a unique “spurious signal” or “interference spectrum” that moves away from the source. It is known that “cracks” on the radio are produced if a light is switched on in the area. It is not often consciously considered in such a way.

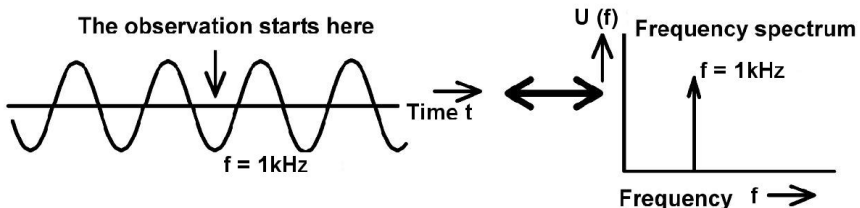


Fig 1: An individual spectral line only belongs to a signal where neither beginning nor end are recognised

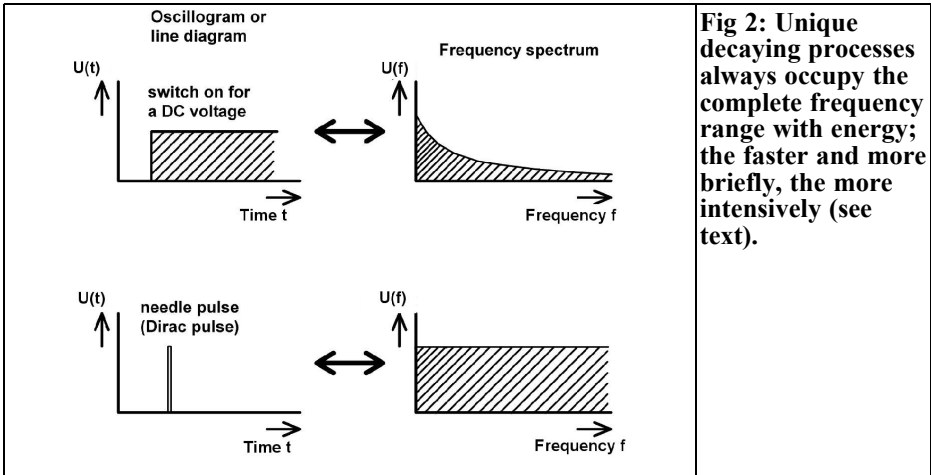


Fig 2: Unique decaying processes always occupy the complete frequency range with energy; the faster and more briefly, the more intensively (see text).

In fact the spurious signal crucial contains the complete frequency range, including very high frequencies, for a short time it is completely filled with signals. The low frequency portions naturally spread through the wiring. The high frequency portions are radiated as electromagnetic waves from the wiring working like antennas. These caused the “cracks” on the radio that can be heard even on a battery operated portable receiver at some distance. Fortunately the amplitude of the high frequency portions fall very quickly with the usual decay processes otherwise it would not be possible to have wireless communication.

The speed of the change of the decay process substantially determines this amplitude distribution and confirms the most important basic principle of a calm professional approach to a solution.

If the change is very slow or has passed since a time it is not easy to prove these effects. But there is a signal that contains all frequencies: it is “the Dirac pulse” (unit pulse function) an infinitely short pulse time and infinitely large amplitude. Fig 2 shows two examples:

- The left side shows an oscillogram style line diagram of switching on a DC voltage and a needle pulse that approximates to the Dirac pulse.

- The right side shows the two frequency spectra, and only the spectrum of the needle pulse is constant over the complete frequency range. No gaps exist in both spectra.

1.2. Distortion of periodic signals

Regularly repeating deviation from the ideal sine wave form leads new signals in the frequency spectrum. This information should be noted.

These new frequencies carry the technical term “harmonics” and are always an integral multiple of the basic frequency. In plain language, frequencies that are double, three times, four times, five times, etc the basic frequency are found in the spectrum.

This leads to another important rule shown in Fig. 3:

- If one half of the wave is affected by the distortion or the positive and the negative half waves are deformed differently this is called asymmetrical distortion. In this case all harmonics are present in the spectrum.

If the originally ideal sine signal is symmetrically distorted (positive and negative half waves are changed in the same way) there will only be odd harmonics (the basic frequency plus three times, five times, seven times, nine times

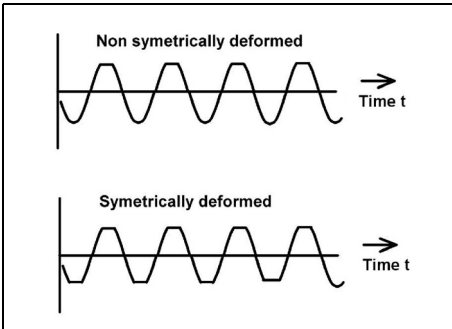


Fig 3: Showing asymmetrical and symmetrical distortion. The even numbered harmonics are missing for strictly symmetry signals.

etc the basic frequency).

This leads to the playing field of the Fourier transform and Fast Fourier transformation (FFT). Using this the spectrum can be computed. On the Internet there are a great many introduction articles, Tutorials, Text Books, programs, animations etc on the topic of harmonic wave distribution as a function signal form, Simple enter “Fourier”, “Fourier transform” or “Fourier tutorial” into a search engine and see what comes up.

For reference:

So as soon as something of the ideal sine wave (amplitude, phase or frequency) is changed in the rhythm of another signal, also new signals must exist. But this is the field of modulation and the sidebands.

2.0

Simulation of a unique procedure with SPICE

The statements above are to be tested with the free and completely unlimited simulator “LTSpice” by Linear Technologies. It can be loaded from [1] without registration and has already been used

extensively in [2].

This article makes intensive use of this software and the individual examples have been selected so that the readers can reconstruct them using their own PC.

2.1. The Dirac pulse and the equivalent

This plays a very large role in the analysis of automatic control loops and transmission systems and is a fantastic tool. But the Dirac pulse seems to be a crazy idea: an infinite amplitude combined with a pulse time approaching zero but the constant pulse area of $1V \times 1s$. Fortunately there are some possibilities to simulate such a signal. It can be replaced by a pulse whose pulse length is only hundredths or thousandths of the time constant of the system being examined. This is sufficient in order to receive the same results as with a perfect Dirac pulse. If it is used on a linear system the amplitude can be made smaller so that it is harmless to the system. The reaction of the system to this impulse is not changed but the amplitude effects are changed accordingly

Example: $1V \cdot 1s$

An ideal case would result in a 1 Megavolt pulse $1\mu s$ long. That would be quite uncomfortable for semiconductor circuits. A pulse of 10V for $1\mu s$ can be used but this gives a reduced effect. The pulse response is multiplied by a factor 100,000 so that it agrees with the theory.

This is a highly interesting area with possibilities that are undreamt of. Therefore the following task is a worked example:

- A linear system is to be examined with a Dirac pulse; it has a time constant of approximately 10ms. A pulse length of $10ms/1000 = 10\mu s$ will be used with an amplitude of 1V. A rise and fall time of 1% of the pulse time is used, thus $0.01 \times 10\mu s = 100ns$. The pulse is to begin 2ms after the start. The time scale and

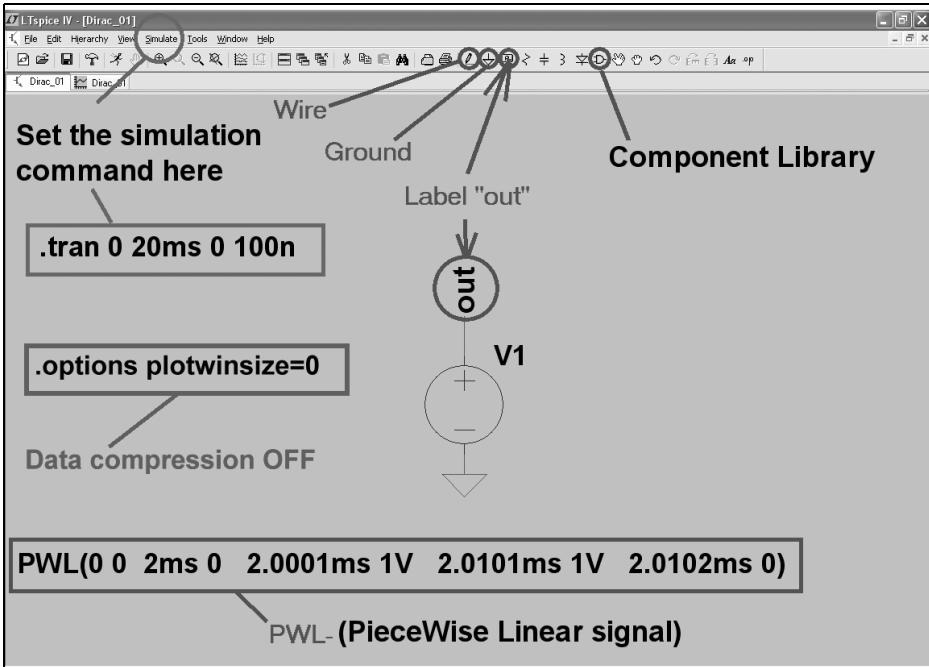


Fig 4: Starting is heavy going but if all these defaults are set correctly (see text), it soon becomes interesting.

spectrum of this signal are to be simulated from 0 to 20ms.

The simulation diagram shown in Fig 4 is used for LTspice. The circuit symbol for the voltage source can be found in the approaching list after pressing the Component Library Button. The ground symbol and the “Out” label are to be found left of the Component Library Button on the main task bar. Once everything is positioned it can be connected with “Wire” (Button with the pencil symbol).

By the way:

- To delete something from the circuit, press F5 and the cursor will change to scissors. Then click on the item concerned and it disappears. Use ESC to exit from the delete function.
- To move something, press F7, pick the item with the cursor and pull it to a new place. Again use ESC to exit from this function.

The voltage source is programmed to produce a PWL signal (PieceWise Linear signal). Pairs of parameters are entered (each pair consists of a time and a voltage level) the program then connects these points with a continuous line to produce the unique signal required. To enter this programming, right click on the voltage source symbol select “PWL” from the “Advanced” option and enter the following:

Time zero	zero V
Time 2ms	zero V
Time 2.0001ms	1V
Time 2.0101ms	1 V
Time 2.0102ms	zero V

The command for the simulation time scale is entered using the “Edit Simulation Command” found in the “Simulate” menu on the task bar. The stop time (simulation duration) is 20ms and the largest time step that the program will use when simulating (maximum time

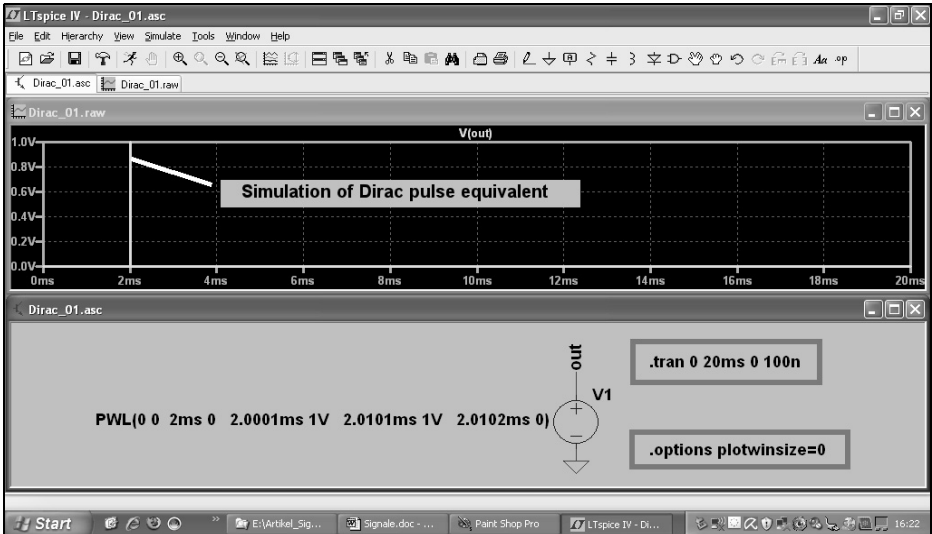


Fig 5: Some mouse clicks are required to get to this screen with the circuit included (see text).

step) is 100ns. The command produced is:

```
.tran 0 20ms 0 100n
```

The additional SPICE directive is very important to define the spectrum:

```
.options plotwinsize = 0
```

This prevents the compression of the result data that the program would otherwise make automatically. This would cause problems with the FFT production of the spectrum. It is very simple to add this: select "Edit" then "Spice Directive" and enter the required line.

Clicking the Simulation Button (the running male symbol) gives the display shown in Fig 5 that shows the simulation diagram and all instructions and commands. But after the simulation you must click on the simulation diagram and then place the cursor on the "Out" label. At once the cursor will change its form to a test probe and a further click displays the simulated potential gradient.

For a spectrograph analysis, right click on the result diagram and select "View" to see the FFT. Start with 65,536 sam-

ples, click on OK and Fig 6 is displayed. Three things should be noted:

- The simulation time of 20ms in the time Domain gives a starting frequency of $1/20\text{ms} = 50\text{Hz}$ for the FFT. That is also the best resolution of frequency and therefore the smallest possible line width in the spectrum.
- The highest frequency that can be shown in the spectrum increases with the sampling rate (set by the maximum time step of 100ns) and by the number of the samples used for the FFT computation (65,536). A further good side effect of the large FFT sample number is an increased dynamic range. In order to be able to select more samples for the computation, sufficient data must be stored. For this example a maximum time step of 100ns and a simulation time of 20ms gives:
 $20\text{ms}/100\text{ns} = 200,000$ measuring points
 This would be enough for 131,072 genuine samples with the FFT.
- The minimum sampling rate speci-

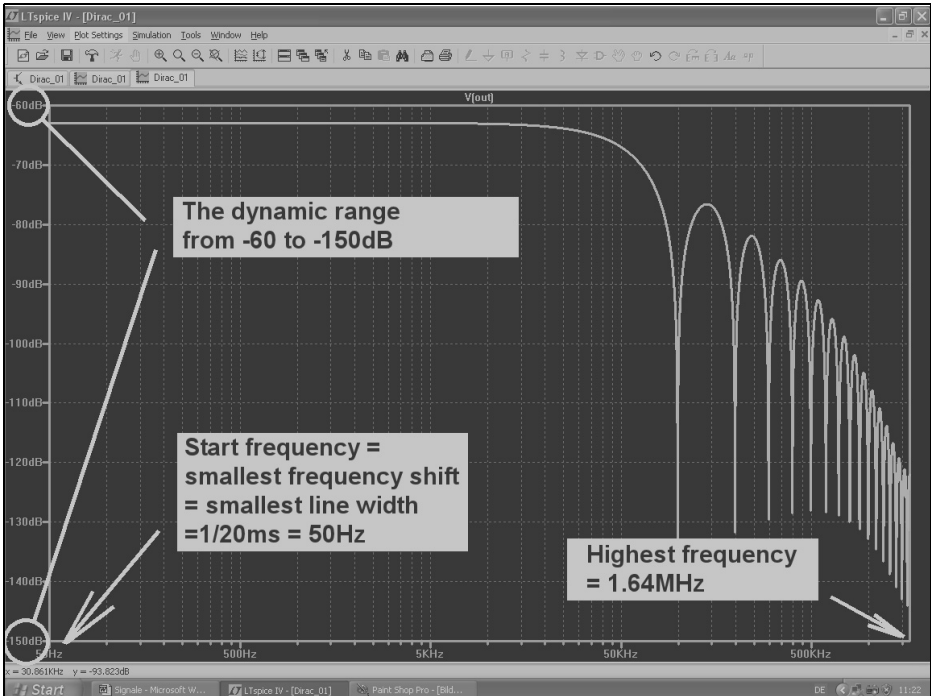


Fig 6: The dual logarithmic representation of the simulated spectrum has its attraction: the information is shown for large ranges (90dB dynamic range and from 50Hz to 1.6MHz).

fied by the maximum time step of 100ns amounts to $1/100\text{ns} = 10\text{MHz}$. This sampling rate must always be at least a factor 2 higher than the highest frequency contained in the measured signal (Shannon Nyquist condition). Otherwise there are aliasing effects that disturb and falsify result and cannot be eliminated.

More samples for the FFT increase the upper cutoff frequency and the dynamic range but unfortunately also the computing time and the resulting data set are increased.

That is examined by repeating the simulation with $2 \times 65,536 = 131,072$ samples. The computation lasts twice as long but the result shown in Fig 7 is interesting:

- The highest indicated frequency in-

creases from 1.6MHz to $2 \times 1.6\text{MHz} = \text{approximately } 3.2\text{MHz}$ with a dynamic range of -60dB to -160dB .

To save computing time the number of samples for the FFT can be reduced so that the upper frequency and the dynamic range are sufficient for a correct representation. If it is reduced too much errors appear such as background noise e.g. unexplainable new lines or more importantly the absence of lines that should exist.

There is another linear representation that can be displayed for the frequency range from 0 to 1MHz with 100kHz steps. Renaming of the axes is very simple: move the mouse over the number division on the axis until a small ruler appears. Left click to register the new scale. This produces Fig 8:

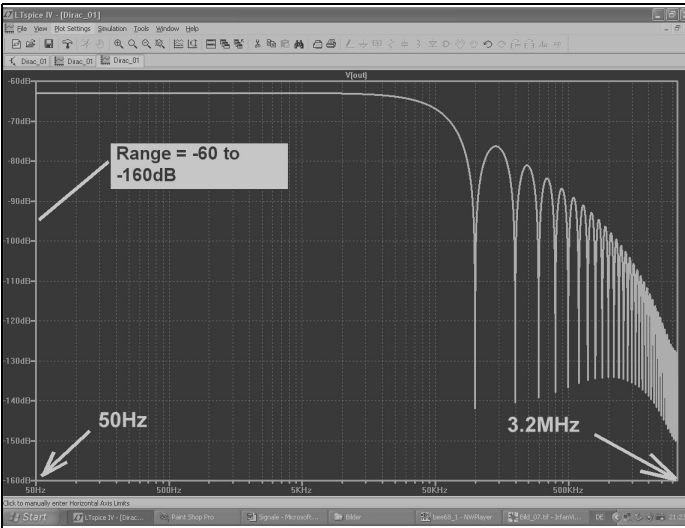


Fig 7: The increase of the sampling number by a factor of 2 extends the range of the display considerably.

- Now the complete frequency range is loaded with energy and no spectral lines can be found. So we get only a

diagram with the "Spectral Density" (energy per Hz of bandwidth). A voltage can now be measured if the

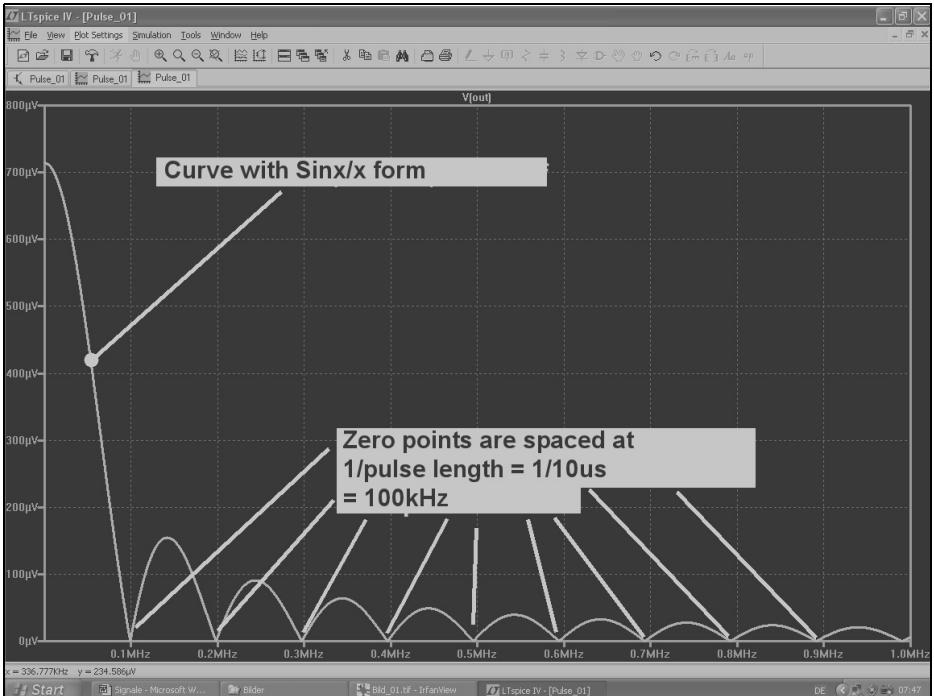


Fig 8: However only the linear representation reveals the interesting and fine details (envelope and zeros).



energy is "collected in a definite bandwidth" and this energy applied as power to a load resistance.

- The envelope of this spectral power density is of the form:

$$\frac{\text{Sinx}}{x}$$

- The power density is zero every 100kHz. These zeros are specified by the pulse length = 1/pulse length = 1/10μs = 100kHz.

Another conclusion is that there is a relationship between the system time constant and the pulse length (recommended as 100 to 1000, see above). If the system with a time constant of 10ms is considered as a simple RC low pass filter then the following applies:

$$\text{cutoff - frequency} = \frac{1}{2\pi \cdot RC} = \frac{1}{2\pi \cdot \text{time constant}}$$

For the current example a time constant of 10ms was selected giving a cut off frequency of:

$$f_g = \frac{1}{2\pi \cdot 10\text{ms}} = 15.9\text{Hz}$$

If the logarithmic representation of the Dirac pulse spectrum shown in Fig 6 or Fig 7 is reviewed the demands posed on the pulse length suddenly become meaningful:

The system is fed with a signal where the spectral power density is constant in the frequency range of interest. Additionally an AC Sweep simulation or a test with a signal generator can be used to determine the frequency response.

Note for specialists:

- The difference between the AC Sweep or Wobulator and the test with the Dirac pulse lies in the fact that with the Wobulator and the AC Sweep the information for the individual frequencies is presented sequentially but with the Dirac pulse it is presented in one blow as a poten-

tial gradient in the time domain. So the famous "Convolution" process must now be applied to get the desired frequency response. But do not forget: for a start frequency and a resolution of 1Hz you need a simulation time of 1/1Hz = 1 second and for a maximum time step of 100ns the PC has to compute and transform 1/100ns = 10,000,000 samples. That will cost in computing time and storage.

3.0

Investigation of periodic signals

This is safe: periodic signals must always have a spectrum consisting of discrete individual spectral lines. For the simulation the same restrictions apply, e.g. the relationship between simulation duration, starting frequency, line width or the increase of the highest indicated frequency and the improvement of the dynamic range by increasing the sample number for the FFT computation.

3.1. Playing with sine signals

3.1.1. A constant sine wave

This article began with the statement: "Only a pure sinusoidal voltage that has been switched on for a very long time and does not stop for a foreseeable time consists of only one frequency", this will be tested by simulation.

The circuit from the preceding chapter can be used, the only change is to make the voltage source a "Sine" with a peak value from 1V and f = 1kHz.

To do this, right click on the circuit symbol of the source and select "Advanced". Then select "Sine" and set the required values. The spectrum is to be represented with a resolution of 50Hz and in a simulation time of 1/50Hz = 20ms.

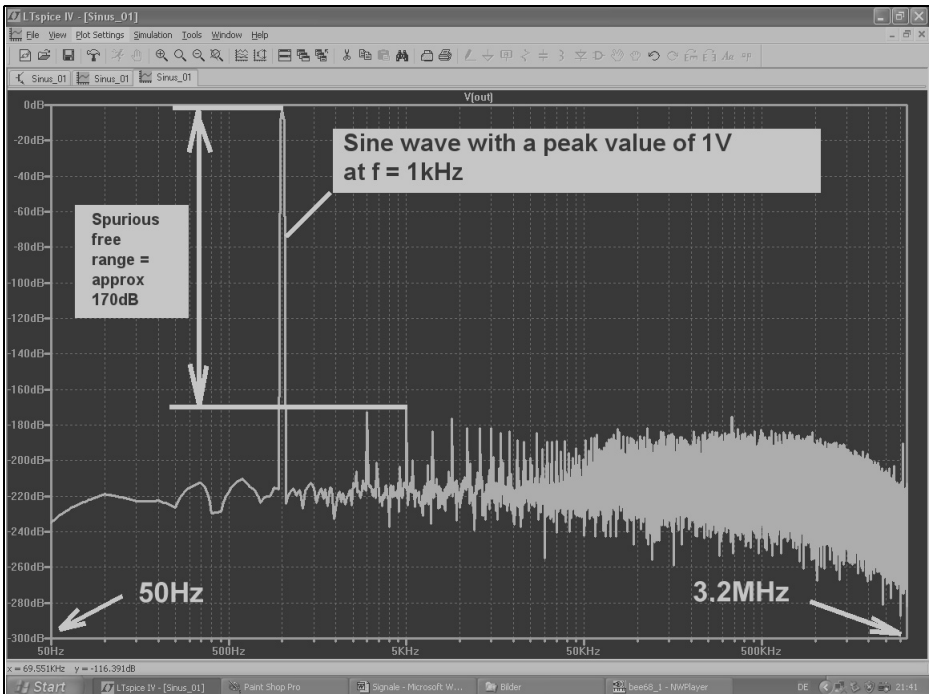


Fig 9: The nearly ideal sine gives a spurious free range of over 170dB without other unwanted signals. (There is speculation among specialists about the 170 dB without spuri).

This should give 200,000 samples available with a maximum time step of 20ms/200,000 = 100ns. 131,072 samples can easily be used without fear of errors. The data compression is switched off.

The calculated spectrum in logarithmic form is shown in Fig 9. This is produced following the FFT simulation with 131,072 samples. The range of the frequency axis is enough from 50Hz to 3.2MHz and the dynamic range is 170dB.

Changing the axis to “linear” shows another thing, a peak value for the sine signal of 1V was set but the spectrum will always indicate RMS. This can be seen in Fig 10; please examine.

3.1.2. An extremely asymmetrically distorted sine wave

For this example a sine signal with a half

wave completely missing is used. This could be simulated by a Schottky diode in parallel with the load resistance and selecting a very large amplitude so that the threshold voltage of the diode is no longer noticeable.

A more elegantly solution is to use the “bv” (behavioural voltage) source voltage component whose signal process can be specified by equations or functions. A practical component.

To cut a half wave off of the sine wave:

- Use the previous source of sine and produce a sine wave with $f = 1\text{kHz}$ and a peak value of 1V. This signal has the label Sine.
- Get another voltage source on the screen programmed as “pulse” to produce a symmetrical 1kHz square wave signal with a maximum value

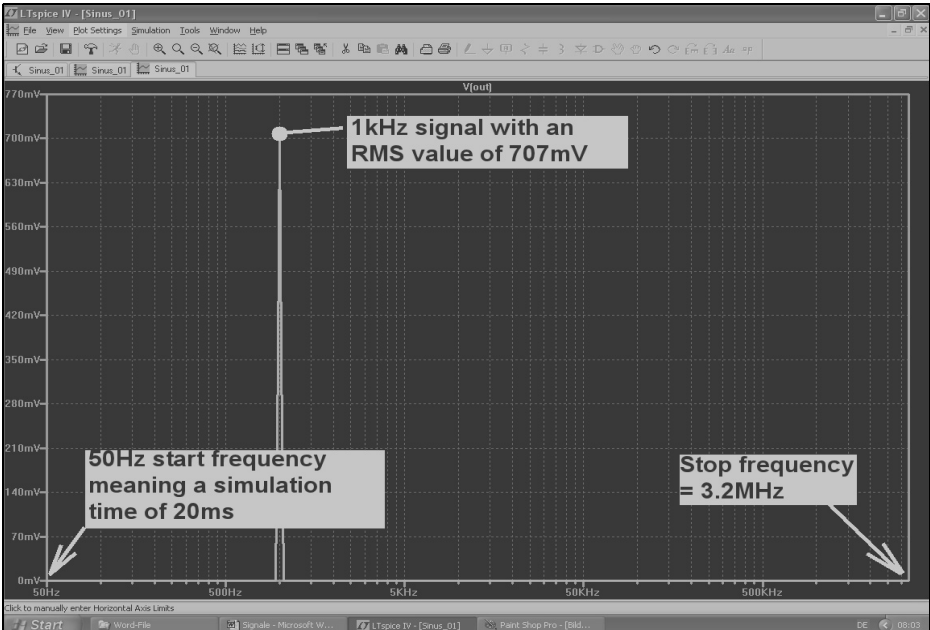


Fig 10: Exact amplitude measurements are made better when linear axes are used.

of +1V and a minimum value of 0V with rise and fall times of 100ns. Label this “switch”, it has the square waves in phase with the “Sine”.

- Now the “bv” source is used with the signal process: $V = V(\text{switch}) * V(\text{sine})$. This multiplies the two signals with one another. If the switch signal is “1”, “bv” is the required half sine wave. The other half wave will be missing because during this time the switch voltage is zero. This source should be labelled “Out”.

Fig 11 shows the circuit and the simulation result with a stop time = 20ms and maximum time step = 100ns. The data compression is switched off. The FFT simulation with 131,072 samples produces the result shown in Fig 12.

The dynamic range is 140dB. Because the frequency axis is linear it is easy to see that the unbalanced signal produces only even numbered harmonics.

3.1.3. Sine wave with one distorted side

Making life easy a diode can be used to limit one half of the sine wave. Using a 15V Zener diode the voltage must be increased in order to achieve a one sided distortion. Therefore a peak value of 50V with a frequency of 1kHz is used. The data compression is switched off.

Fig 13 shows all the information including the simulation with 131,072 samples with the spectrum amplitude range of 110dB (+30 to -80dB). The harmonics at the output can be seen.

The 15V Zener diode can be added very easily; click on the Component Library Button and select Zener in the list. Right click on the placed symbol to display the menu to Pick new diode. Choose BZX84C15L.

3.1.4. Symmetrically limited sine wave

Adding more diodes into the circuit

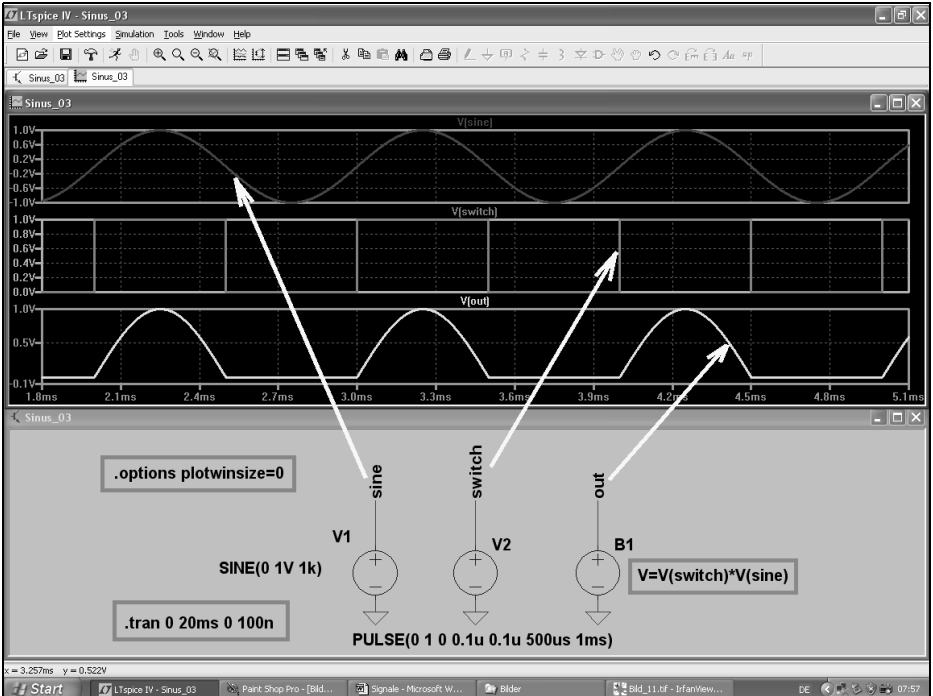


Fig 11: The perfect electric rectifier. This time produced by a programmable voltage source.

shown in Fig 13 gives the diagram shown in Fig 14 giving a symmetrical limiting. All other settings remain unchanged.

As expected there are no surprises and only the forecast odd numbered harmonics are present.

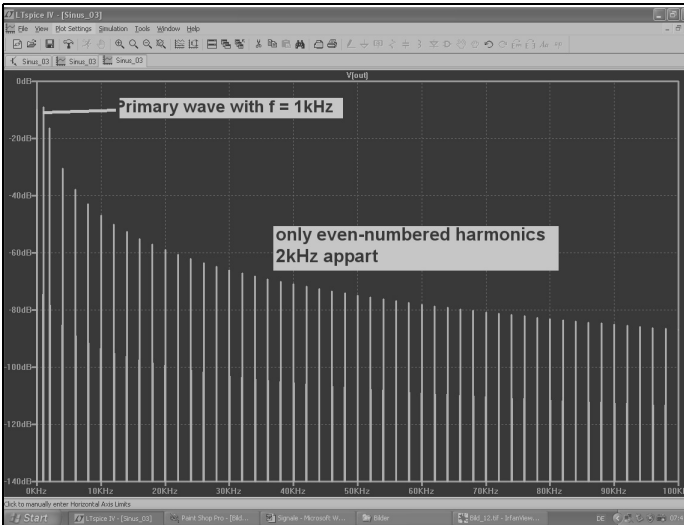


Fig 12: The extremely unbalanced signal produces a spectrum that contains only even numbered harmonics. This output voltage belongs to a perfect electric rectifier.

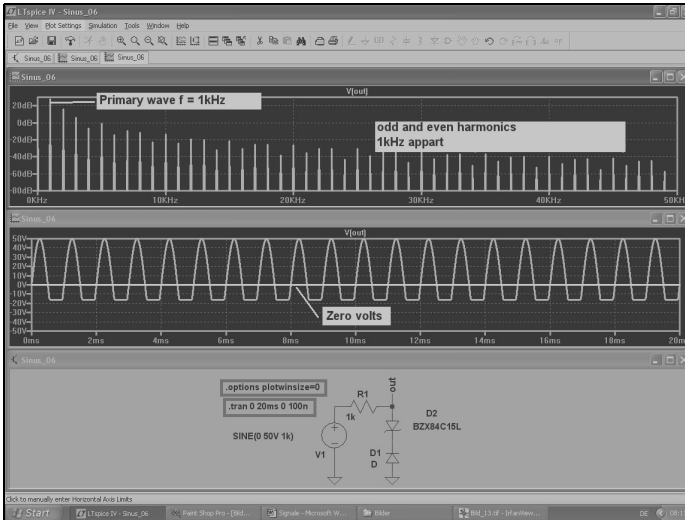


Fig 13: Unsymmetrical limiting is simply done by a Zener diode.

3.2. Playing with square wave signals

3.2.1. Symmetrical square wave

This signal type can be found in the “voltage” option and it should be set for a 1kHz signal with the following data:

- Signal form: “pulse”
- Minimum value: Zero V
- Maximum value: 1V
- Rise and fall time: 1µs
- Pulse length: 500µs

Period duration: 1ms

The circuit and the simulated potential gradient for 0 to 20ms plus the FFT for 131,072 samples is shown in Fig 15. The theory is beautifully confirmed because:

- A symmetrical rectangle contains only odd number harmonics with decreasing amplitudes. Practically this means that the line three times the basic frequency is 1/3 of the primary wave amplitude. The line

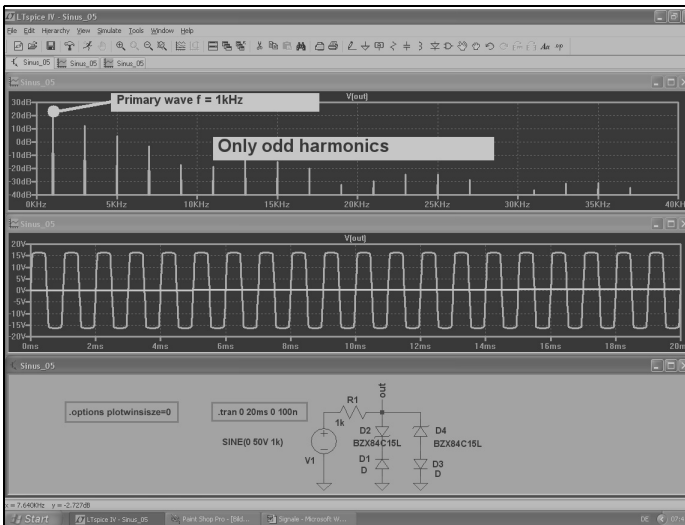
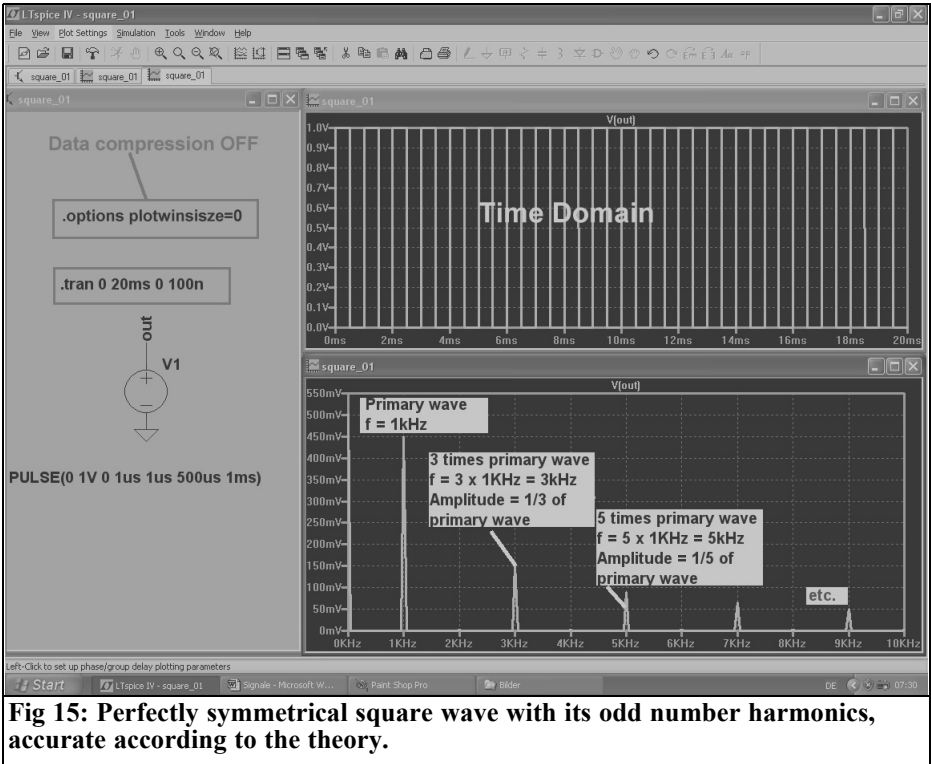


Fig 14: Symmetrical cutting of the sine wave signal leaves only the odd harmonics.



five times the basic frequency is 1/5 of the primary wave amplitude... etc.

3.2.2. Asymmetrical square wave

Simply reduce the pulse length of the signal from the previous example to 100µs and leave everything else unaffected. Fig 16 confirms the theory that states:

- Even numbered harmonics are present.
- The envelope of the spectrum has a form Sinx/x.
- The zeros of the envelope are always at a multiple of 1/pulse length.

3.2.3. A triangle wave under the magnifying glass

This does not seem to belong here, but it never the less it fits. Take a symmetrical pulse signal and make the rise and trailing edge very long and the pulse time

very short and the triangle is finished.

The data for programming the pulse source:

Signal form:	“pulse”
Minimum value	0V
Maximum value	1V
Rise time	500µs
Fall time	499.9µs
Pulse time	100ns
Period duration	1ms

All remaining details can be inferred from Fig 17. Again for 20ms with a maximum time step of 100ns simulated with 131,072 samples used for the FFT. The result shows only odd number harmonics from an almost perfectly symmetrical signal.

To be continued in part of 2

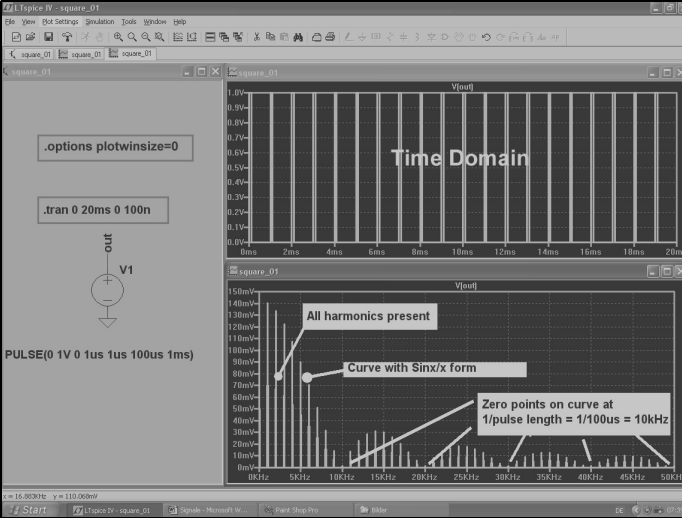


Fig 16: This should not occur: a periodic asymmetrical pulse signal with a line spectrum and all harmonics. But its origin of the single pulse proves the Sinx/x envelope.

X.

Literature

[1] To download “LTSpice” go to the homepage of Linear Technology - www.linear.com

[2] An Interesting Program: Simulation of RF circuits with LTSpice IV. Part 1, Gunthard Kraus, DG8GB, VHF Communications Magazine 2/2010 pp 75 - 89

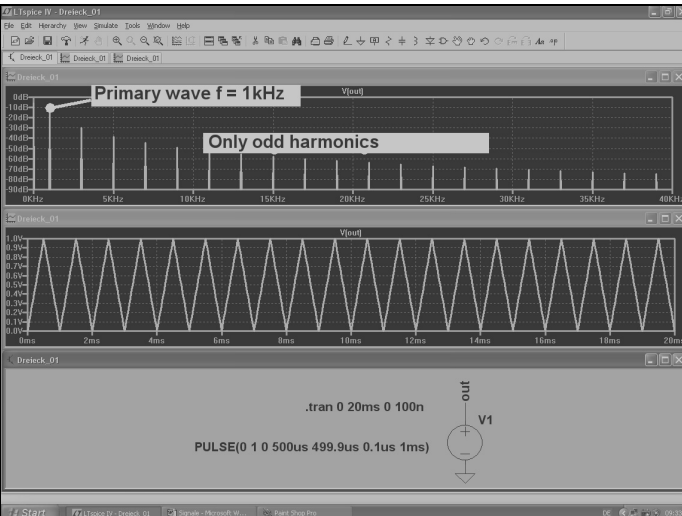


Fig 17: This triangle signal is strictly symmetrical and therefore there are only odd number harmonics.



Konrad Hupfer, DJ1EE

Power amplifier for the 2m band inspired by Doherty

1.0

Introduction

High frequency power amplifiers work with the highest efficiency (theoretically 78%) at full power, close to the compression point. This is usually the case for pure FM mode or CW operation. With modern types of modulation e.g. QPSK, QAM and SSB, signals with different amplitudes must be amplified linearly (during modulation the drain voltage remains constant). Therefore the amplifier will operate far below the compression on average (backing off). The efficiency falls substantially. This is described in

[2] in various examples.

The relatively high current consumption and the power dissipation (heat) lead the large broadcasting stations in the 1930s to look for power saving ways to modulate the first stages of an amplifier.

One of these measures to increase the efficiency came from William Doherty in 1936 at Bell Telephone Laboratories for valve transmitters. Efficiency increases of up to 30% could be achieved.

Over the past 20 years satellites have needed highly efficient power amplifiers with cooling requirements as low as possible. In recent years portable radios and mobile phones have had to re-design the old driver stages to give longer working times for a given battery size.

This has also been good for portable and mobile 2m amateur radio equipment. A block diagram of a proposed single stage 100W PEP SSB amplifier for amateur use is described in [3]. This is an in line amplifier or “after burner” for small portable 2m transceivers with 1 to 2W PEP power output.

The amplifier fits in a small aluminum housing with an aluminum heatsink (170mm x 110mm x 55mm). It weighs 850g, the familiar IC202 1600g without batteries.

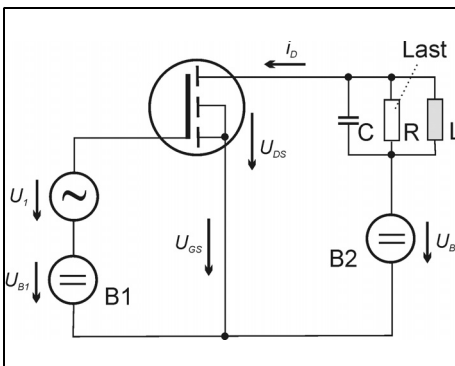


Fig 1: Single stage MOSFET amplifier.

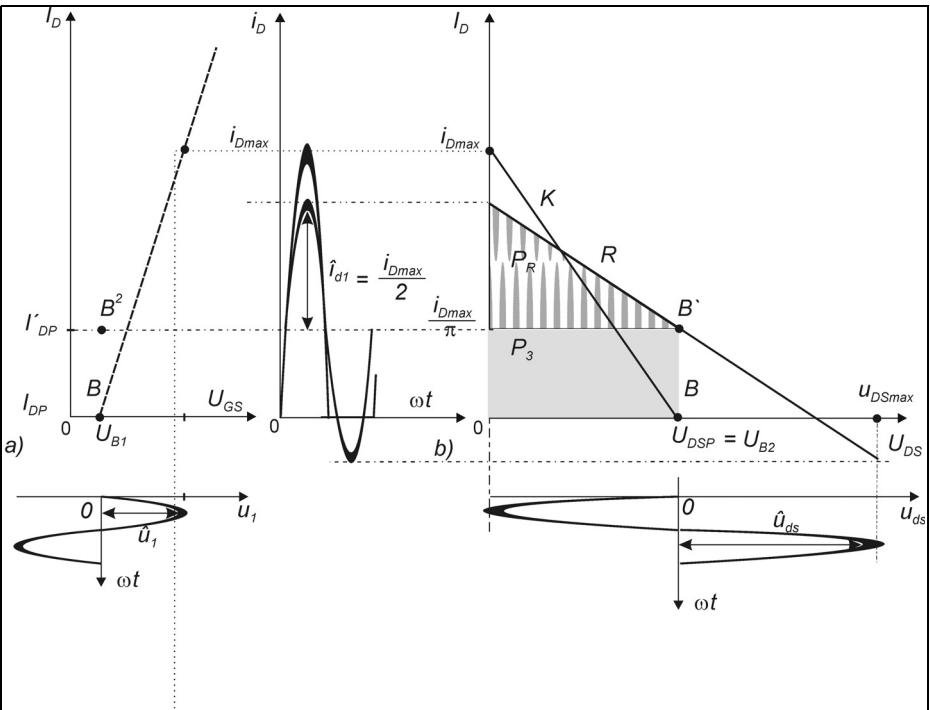


Fig 2: Control conditions of a class B amplifier with a resonant circuit load showing the resonance transfer characteristic. (a) Output characteristics. (b) Dynamic characteristics, K and R.

2.0

Driving a linear amplifier stage

The following examples show how to drive a linear amplifier. Figs 1 and 2 show the the circuit diagram and efficiency of a single stage FET.

For class B operation the angle of current flow is defined as 180°. From Fig 3 the area for a symmetrical alternating current as a function of the angle of current flow can be inferred.

The periodic component from the peak current i_{Dmax} :

$$I'_{DP} = \frac{i_{Dmax}}{\pi}$$

The peak value of the drain current

$$\hat{i}_{d1} = \frac{i_{Dmax}}{2} \quad (\text{The so called "primary wave"})$$

The maximum drain to source voltage:

$$U_{DSmax} = U_{B2} + \hat{u}_{ds} = 2U_{B2}$$

Load resistance: $R = \frac{U_{ds}}{i_{D1}}$

Direct current input power:

$$P_q = I'_{DP} \cdot U_{B2}$$

RF power output:

$$P_R = \frac{\hat{i}_{d1} \cdot \hat{U}_{DS}}{2} = \frac{i_{Dmax} \cdot \hat{U}_{ds}}{4}$$

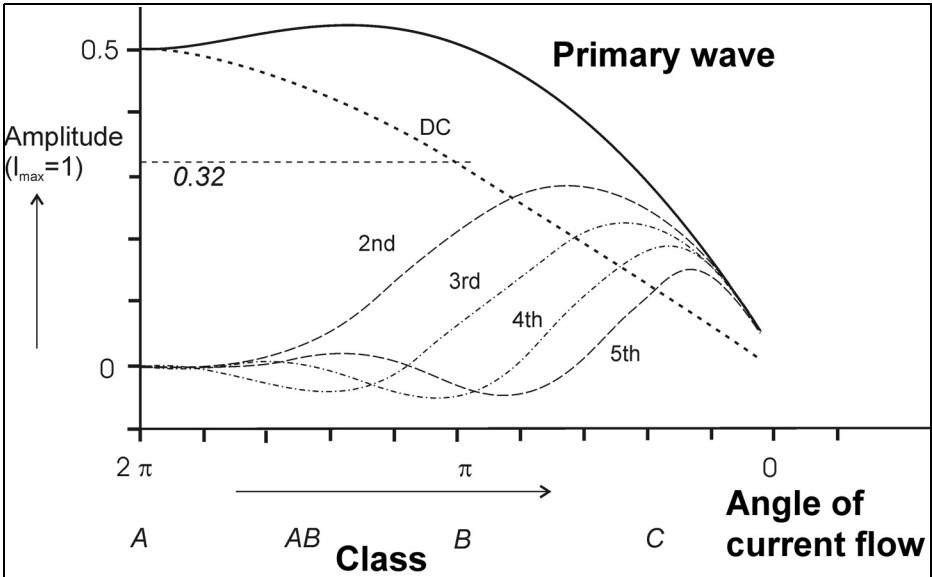


Fig 3: The proportion of the pulse current i_{Dmax} in I_{DP} for the harmonics f_1, f_2 etc.

or

$$P_R = \frac{U_{B2}^2}{2 \cdot R}$$

$$\eta = \frac{P_R}{P_q} = \frac{i_{Dmax} \cdot U_{DS}}{4 \cdot I_{DP} \cdot U_{B2}} = \frac{\pi}{4} = 78.5\%$$

Characteristic K: From i_{Dmax} point in class B, and the U_{DSmax} point. This shows the non-linearity for a pulse drive.

Based on a 50W output stage the efficiency for:

- a Full drive with supply voltage 30V and $R_L = 8.60\Omega$
- b Half drive with supply voltage 30V and $R_L = 8.60\Omega$
- c Half drive with supply voltage 15V and $R_L = 8.60\Omega$
- d Half drive with supply voltage 30V and $R_L = 17.20\Omega$

are shown in Fig 4 and described as follows:

- a Full drive: $\hat{u}_d = 4V, I_{Dmax} = 7.0A$

Primary wave current (from Fig 3):

$$\hat{i}_{D1} = \frac{I_{Dmax}}{2} = 3.50A$$

Direct current (from fig. 3):

$$I_{DM} = \frac{I_{Dmax}}{\pi} = 2.23A$$

Full swing at drain: $\hat{u}_d = 30V$:

$$R_L = \frac{\hat{U}_D}{\hat{i}_{D1}} = \frac{30V}{3.5V} = 8.57\Omega$$

Direct current power:

$$P_B = U_B \cdot I_{DM} = 30 \cdot 2.23A = 66.9W$$

RF power:

$$P_{HF} = \frac{\hat{U}_D}{\sqrt{2}} \cdot \frac{\hat{i}_D}{\sqrt{2}} = 52.50W$$

Efficiency:

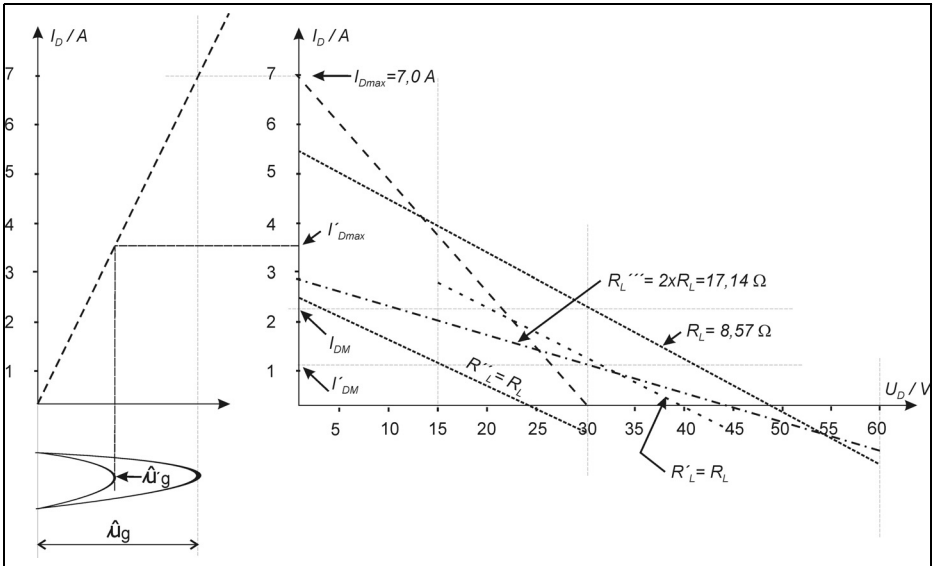


Fig 4: Control for a. b. c. and d.

$$\eta = \frac{P_{HF}}{P_B} = \frac{52.50}{66.90} = 78\%$$

b Half drive:

$$\hat{u}'_g = 2V \quad I'_{Dmax} = 3.5A; \quad I'_{DM} = 1.11A$$

$$i'_{D1} = 1.75A \quad R'_L = 8.57\Omega$$

$$\hat{u}'_D = 1.75A \cdot 8.57\Omega = 15V$$

$$P'_{HF} = \left(\frac{i'_{D1}}{\sqrt{2}}\right)^2 \cdot R'_L = \frac{1.75^2}{2} \cdot 8.57 = 13.12W$$

$$I'_{DM} = \frac{3.5A}{\pi} = 1.11A$$

$$P'_B = U_B \cdot I'_{DM} = 30 \cdot 1.11A = 33.3W$$

$$\eta' = \frac{P'_{HF}}{P'_B} = \frac{13.12}{33.3} = 39\%$$

c Half drive: Supply voltage $U_{BS} = 15V$

$I_{Dmax} = 3.5A$. The currents I'_{DM} and \hat{i}_{D1} do not change. The RF voltage swings symmetrically around the 15V supply and therefore $\hat{u}_D = 15V$; from it load resistance:

$$R_L'' = \frac{15V}{1.75A} = 8.6\Omega$$

The RF power is:

$$\frac{15V}{\sqrt{2}} \cdot \frac{1.75A}{\sqrt{2}} = 13.3W$$

The input power is 16.6W giving an efficiency of 78%. From this it can be seen that the efficiency can be improved by modulating the supply voltage. A controllable switch mode power supply could achieve this but the effort required is not inconsiderable.

d Half drive: Supply voltage 30V

Load resistance = $2 \times R_L = 2 \times 8.6\Omega = 17.2\Omega$ (R_L''' in the Fig 4)

I'_{DM} and \hat{i}_{D1} remain the same at 1.1A and 1.75A respectively. The voltage drop with the higher load resistance $R_L''' = 17.2\Omega$ (see Fig 4) and the current $\hat{i}_{D1} = 1.75A$ is 30V, thus it is a full swing of the supply voltage.

The RF power is:

$$P_{HF} = \frac{\hat{U}_D}{\sqrt{2}} \cdot \frac{\hat{i}_D}{\sqrt{2}} = \frac{30V \cdot 1.75A}{2} = 26.25W$$

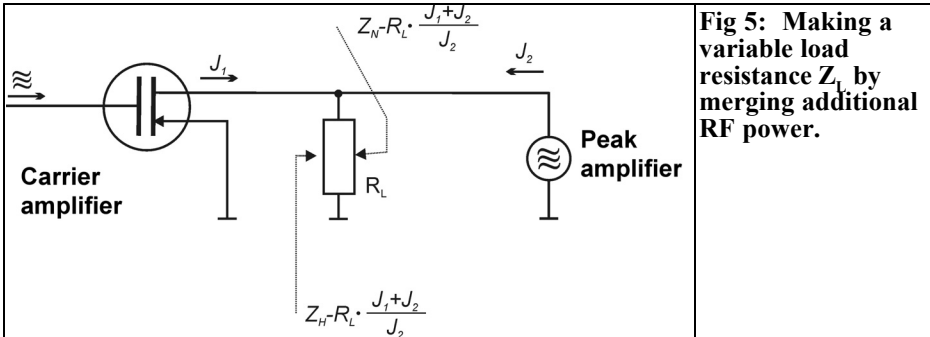


Fig 5: Making a variable load resistance Z_L by merging additional RF power.

The input power is $P_B = 30V \cdot 1.11A = 33.3W$ giving an efficiency of:

$$\eta = \frac{26.25W}{33.3W} = 78\%$$

From this example (d) it can be clearly seen the modulation of the transistor load resistance leads to a remarkable improvement of the efficiency. This was also the basic idea of the Doherty amplifier.

frequency and suitable phase is necessary. This additional power amplifier (peak amplifier) feeds the adjustable load together with the main amplifier (carrier amplifier) see Fig 5.

A Doherty amplifier consists of two components; two similar RF amplifier stages, the carrier amplifier (working in class B) that works together with the peak amplifier (working in class C). Both amplifiers must deliver their individual performance into the common load resistance R_L . During full drive each amplifier supplies half of the total output.

3.0

The Doherty principle

It is necessary to have an electrically controllable load resistance. An additional RF power generator with the same

The principle of the Doherty amplifier is that the carrier amplifier and the peak amplifier share the task of supplying the load resistance in a controlled way see Figs 6 and 8. The block diagram of such an amplifier is shown in Fig 7.

For full drive both amplifiers supply the same power. In this case both amplifiers can be regarded as single amplifiers that need a load of 25Ω at the combining point K. The $\lambda/4$ line $Z_3 = 35\Omega$ transforms the standard 50Ω load to this value. The amplifier works with the highest efficiency.

The entire operating range can be roughly divided into three parts that merge, more or less, smoothly into one another. The carrier amplifier gate voltage is set to give class B operation The peak amplifier gate voltage is set to give class C operation.

For the first part of the dynamic range,

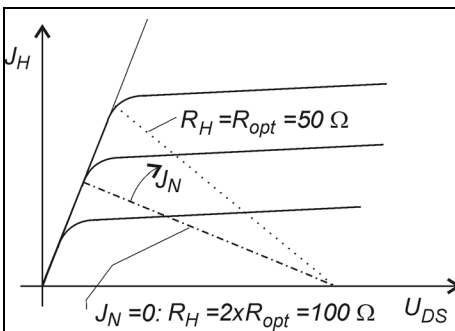


Fig 6: Modulation of the load line of the main amplifier by the current I_N of the peak amplifier.

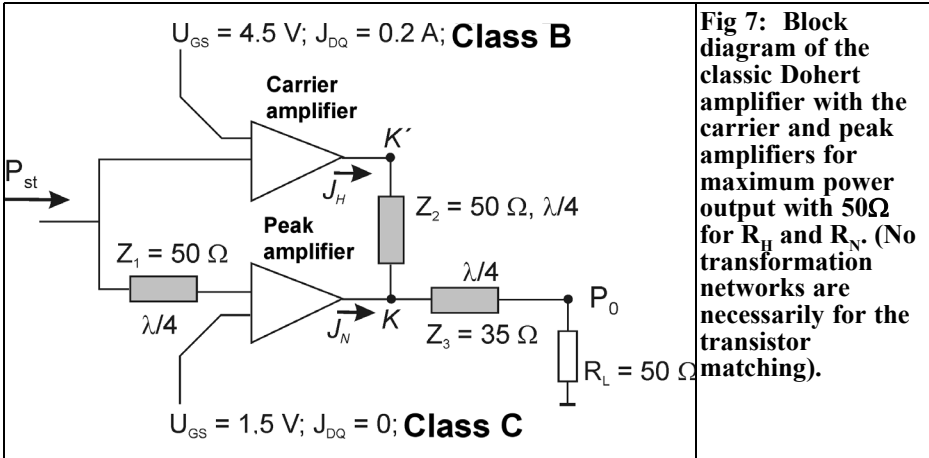


Fig 7: Block diagram of the classic Doherty amplifier with the carrier and peak amplifiers for maximum power output with 50Ω for R_H and R_N . (No transformation networks are necessarily for the transistor matching).

up to approximately 1/4 of maximum power output (-6dB point), only the carrier amplifier is active because the input is still too small to activate the peak amplifier so it draws no current. The load resistance of 25Ω, offered at the point K, is transformed by $Z_2 = 50\Omega$ to a working resistance of $R_H = 100\Omega$ for the carrier amplifier. Therefore a high voltage is used and that results in a higher efficiency see Fig 4 and 6.

With a larger input (exceeding the -6dB point) the second part of operation begins and the peak amplifier starts to draw current.

As shown in Fig 6 the load resistance for the carrier amplifier, R_H , must be increased so that the power is produced with good efficiency when high drive approaches compression. This is achieved with a $\lambda/4$ impedance transformer $Z_2 = 50\Omega$. The unwanted phase shift produced in outputs of the two amplifiers is compensated by an additional phase shift at the input with a $\lambda/4$ line $Z_1 = 50\Omega$ or a 90° -3dB coupler (see realisation). The output current of the peak amplifier increases with increase input and the load of the peak amplifier

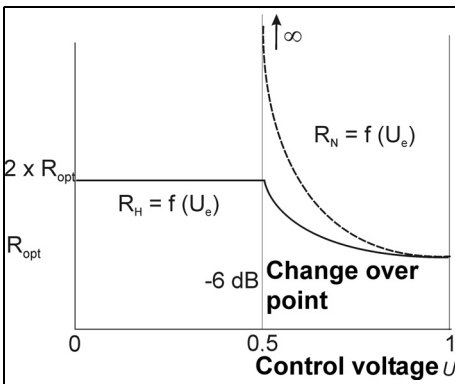


Fig 8: Dependence of the load resistances R_H and R_N on the drive level.

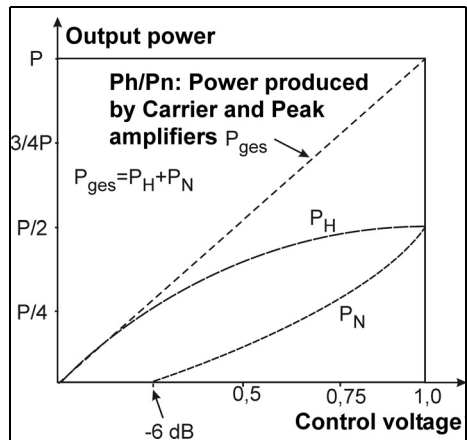


Fig 9: Power addition of carrier and peak amplifiers.

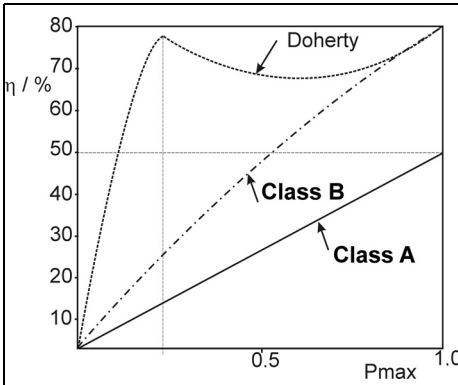


Fig 10: Efficiencies of different modes (theoretical).

increases. The load resistance falls from to $R_N = 50\Omega$. This is the transition to the third part of operation, $R_H = R_N = R_{opt} = 50\Omega$, this is at the point of the 1dB compression point.

The amplifier operates with the same characteristics as two single stage amplifiers connected together with a 3dB 90° coupler (same efficiency). The individual performances are represented in Fig 9. The theoretically attainable efficiency is shown in Fig 10.

4.0

Realisation of a 100W PEP linear amplifier using the Doherty principle

A push-pull DMOS FET type D1012 UK is available manufactured by Semelab U.K.

Brief data:

- $P_0 = 50W$ CW at 500MHz each transistor
- UDS = 28V
- Maximum power dissipation 290W
- Minimum amplification at 500MHz 10dB
- Maximum permissible load VSWR 20: 1
- Quiescent current for linear operation 0.6A per transistor
- Output capacitance with 28V 70pF per transistor
- Output inductance (approximate) 0.6nH per transistor

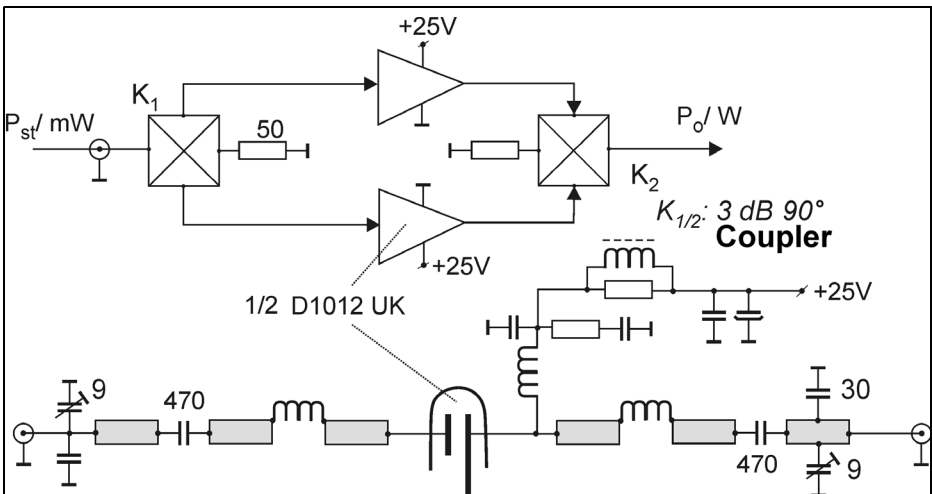


Fig 11: Circuit diagram of the single amplifiers.

**Table 1: Measurements for the hybrid amplifier.**

P_o/W	10	20	30	40	50	60	70	80	90
P_{st}/mW	76	123	170	220	278	330	390	450	530
I_{ges}/A	1.87	2.47	2.94	3.39	3.80	4.16	4.51	4.80	5.09
$\eta/\%$	21	32	41	47	53	58	62	67	71

4.1. Single amplifier using a hybrid integrated circuit

Since the two individual transistors can be regarded as completely electrically separate, two complete single amplifiers can be constructed, optimised and then connected with 3dB 90° couplers at input and output Fig 11.

The output networks require some computation to design, this is not going to be done here but has already been calculated. The output network designed for optimum efficiency with a supply voltage of 25V. This gives a bit of protection against unfavourable loads (high VSWR). In addition the amplifier could be operated mobile or portable (e.g. 2 x 12V).

Table 1 shows the measured values for a single amplifier for $U_{DS} = 25V$; $I_{DQ1} = I_{DQ2} = 0.3A$.

The gain was approximately 22dB, the amplifier can be easily driven with an IC202. For SSB operation the quiescent current of approximately 0.7A per transistor can be adjusted but the efficiency falls by approximately 1 to 2%. Table 2 shows the measured third order intermodulation distortion.

The amplifier takes some time to settle down when it is switched on so it was decided to measure the absolute drain voltage at start-up using a diode rectifier (e.g. 2 x HP2800 in series). Depending

the matching circuit efficiency can be >70% with oscillation swing at the drain caused by unfavourably harmonics (F amplifier) that become very large so that the absolutely maximum drain voltage is exceeded. The values measured for this hybrid amplifier were approximately 65 - 68V.

4.2. Interconnection of the single amplifiers in Doherty style

The block diagram shown in Fig 7 is expanded in Fig 12. The phase shifting of Z1 is replaced with a hybrid integrated circuit 3dB 90° coupler. This also has the advantage of decoupling the two amplifier inputs.

NW1, NW2 and NW1', NW2' are LC networks used to transform the gate input impedance to 50Ω and the output resistances of the transistors (R_H , R_N) to 50Ω

$$R_{Lopt} = \frac{U_D - 2V}{2 \cdot P_o} = \frac{23^2}{100} = 5.3\Omega$$

The Doherty output network using a $\lambda/4$ 50Ω line as a phase shift is still used in each case at the points K and K'. This line is necessary so that the load resistance appears e.g. $R_H = 100\Omega$ for the carrier amplifier (for low drive), with 2 x 5.2Ω on the drain. For simplicity the transformation line Z3 = 35Ω was replaced with a transforming low pass filter that is part of the output filter that is required.

Three disadvantages of the Doherty circuit cannot be overlooked:

- Worse linearity: This is approximately 3 – 5dB worse than the hybrid integrated circuit amplifier.
- Narrow band coverage: Approxi-

Table 2: Measured third order intermodulation distortion.

PEP/W	40	60	70	80	90
IM/dB	-33	-33	-30	-28	-24

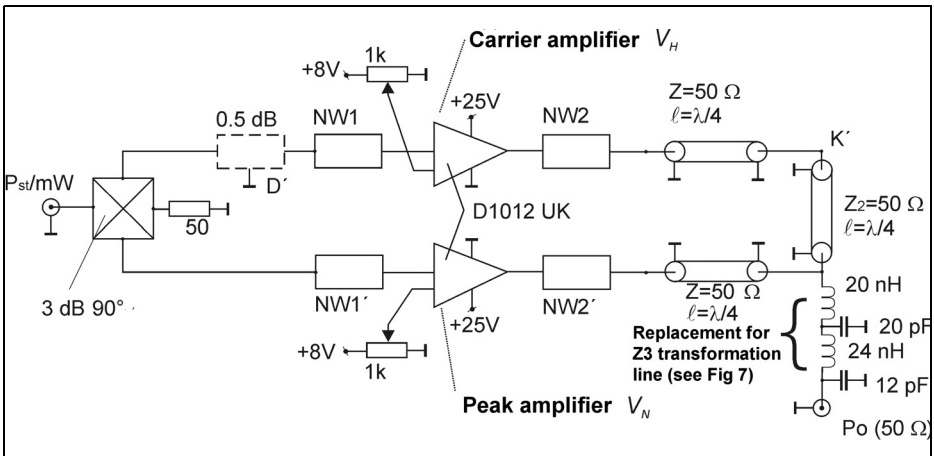


Fig 12: Block diagram for a 100W PEP Doherty amplifier.

mately 5MHz range at 2m, this is not important for amateur radio use.

- Load VSWR affects the intermodulation distortion: The load VSWR should not be more than 1.3: 1 because the intermodulation distortion (depending on the phase of the load) will suffer by approximately 2dB.

4.3. Improving the poor linearity of the Doherty amplifier

By correctly choosing of the operating

points of the carrier and peak amplifiers the efficiency and the linearity can be substantially improved. Simply balancing the voltages V_N and V_H (see Fig 12) can improve the linearity by approximately ± 0.5 to 1.0dB without reducing the efficiency substantially.

In the circuit shown an improvement of approximately 2dB was made by inserting a 0.5dB attenuator at the input of the carrier amplifier. The efficiency dropped by approximately 1%.

The efficiency increases of >25% ob-

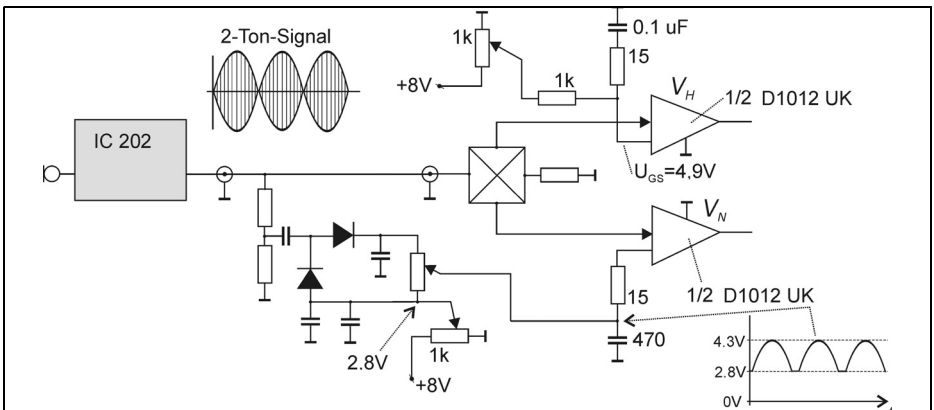


Fig 13: Circuit diagram of the linearisation for the Doherty amplifier.



Table 3: Measurements for the linearised Doherty amplifier.

P_o/W	10	30	50	70	90	100
P_{st}/W	0.09	0.28	0.47	0.64	0.78	0.90
I_{DH}/A	1.2	1.67	2.06	2.42	2.73	2.89
I_{DN}/A	0.02	0.50	1.34	2.07	2.60	2.80
G/dB	20.5	20.2	20.3	20.4	20.6	20.5
I_{Dges}/A	1.22	2.17	3.40	4.49	5.33	5.69
$\eta/\%$	34	58	61	65	70	72

P_o : Output power, P_{st}/W : Drive power from IC202, I_{DH}/A : Carrier amplifier current, I_{DN}/A : Peak amplifier current, I_{Dges}/A : Absolute current, $\eta/\%$: Efficiency.

tained by Doherty in the 1930s cannot be achieved yet with transistor amplifiers. The semiconductor manufacturers are about to bring out “Doherty suitable semiconductors” with special control characteristics and increased drain breakdown voltage.

Additional control systems can improve the linearity of a Doherty amplifier substantially. Because the peak amplifier supplies the largest contribution at high drive levels the control of the class C mode can be adjusted using feed-forward modulation of the gate supply. This is shown in Fig 13, the SSB signal is rectified and used to adjust the gate voltage V_N to give approximately 4.5V.

This simple linearisation technique is not only applicable to Doherty amplifiers. Most linear amplifiers can use this technique to straighten their characteristics providing that the non-linearities are not due to phase distortions.

RF feedback was also tested: An approximately 3dB improvement of the intermodulation distortion could be achieved but the overall gain was lower.

With the correct combination of the gate voltage and feed-forward adjustment the following stable results were obtained with the parameters shown in Table 3.

- PEP: 5W to 100W
- IM distortion: -28dB to -30dB

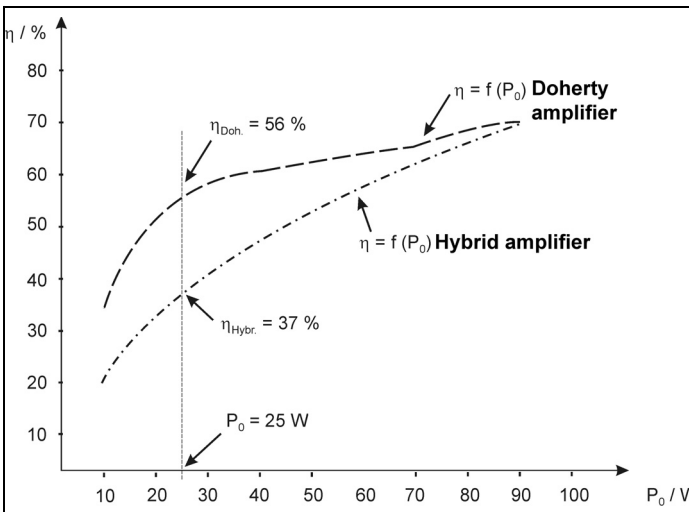


Fig 14: Trade off of the efficiency over the distortion for a hybrid and an Doherty amplifier with feed-forward adjustment.

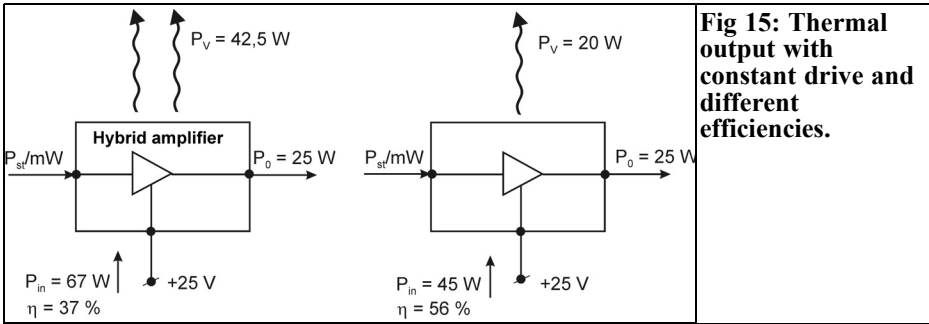


Fig 15: Thermal output with constant drive and different efficiencies.

Drive: IC202 approximately 1W PEP

Finally the improvement of efficiency compared to the hybrid amplifier is shown in Fig 14 and the thermal effects are shown in Fig 15.

Have fun experimenting.

5.0

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 [6] Konrad Huofer DAS 129 7703; 19.06.69, Switching Configuration for Linearising the Amplification of an RF Amplifier for SSB signals



Juan Pablo García, EA4CIV

4NEC2 Antenna Modelling Program

Many antenna projects are focused to get a good SWR matching with the aim that the directivity and gain obtained will meet with theoretical studies and text published in books and high reputation publications. Is that all there is to do? Nowadays most of us have a PC at home and Internet access. During recent years a community of clever and laborious people put their efforts into the www to allow any body to download and play with a large variety of useful programs that become a valuable set of tools to complete our workshop. This is the case for 4NEC2 [1], an Antenna Modelling Program, which allows detailed study of antenna behaviour before starting construction.

1.0

Introduction

In the help menu the author, Arie Voors, says that 4NEC2 is the answer to solve the problem of modelling antennae and for ITSHF propagation prediction. Because of the interest created and help of many people, the program has become a powerful tool; easy to use limited only by computer power and the public NEC2 engine, also it is free. More than ama-

teurs can dream of.

Let's go to see what 4NEC2 can do for us and how it does it by simple examples. First of all install the program. There are two icons called, 4NEC2 and 4NEC2X. 4NEC2 is a 16bit version for old computers that do not support 3D images and 4NEC2X is same program plus 3D capability. The modelling results are the same. There is another icon called build that is an excellent tool to simplify the heavy job of defining surfaces and other more complex elements.

NEC2 works with straight wires so an antenna is defined by a set of pieces defined by their ends and diameter. Each piece of wire is divided in segments and each segment has to comply with certain rules of size and diameter in wavelengths. You can read the NEC2 manual supplied with 4NEC2 to find out more. Using more segments increases the accuracy of modelling, but a compromise must be made when working with a wide band antennas.

4NEC2 has many tools that help to speed up antenna design and study. We can simulate environment, free space, sweep frequency, sweep parameters, loads, dimensions, etc. to get the best match, radiation pattern, better front to back ratio etc. Such studies were performed in the past using very expensive instruments and installations. Antenna laboratories

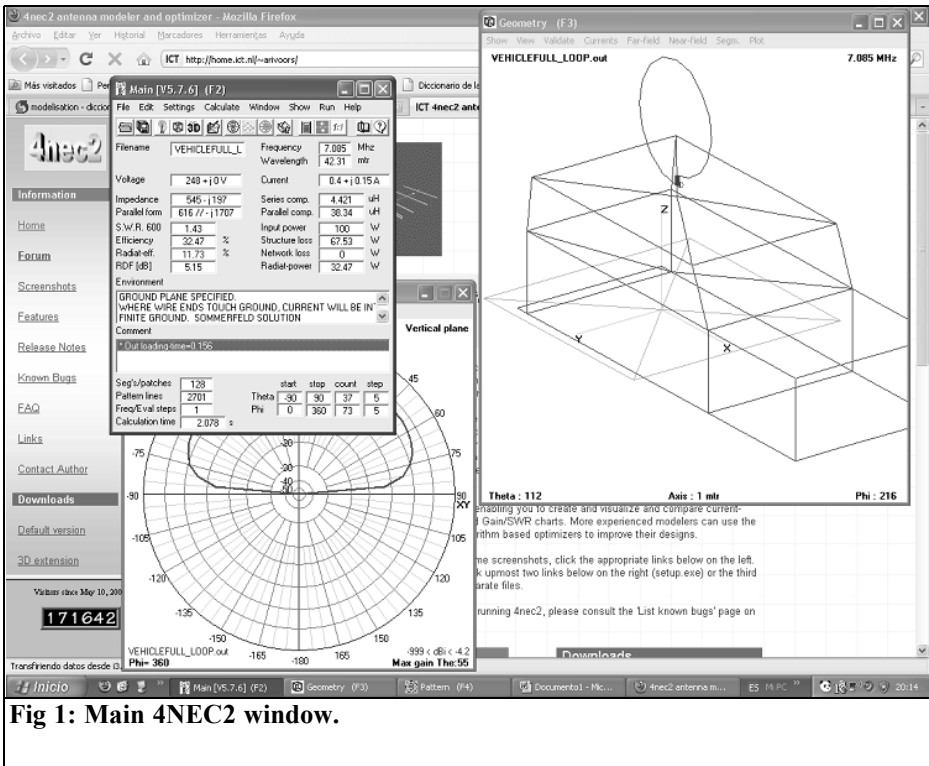


Fig 1: Main 4NEC2 window.

especially for HF and VHF bands needed large spaces to install the antennas and measure them. Such places have to be in a quiet area far away from urban areas. Definitely not for most radio amateurs.

2.0

Starting with 4NEC2

Hit the icon 4NEC2 or 4NEC2X and get the main window (Fig 1) that sets the configurations and actions. It has a set of menus, like all Windows programs, file, edit, help etc and a set of buttons that launch accessories like 3D view, smith chart, matching, sweep, etc.

The main window shows some extra information and simulations. File name, simulation frequency, impedance, power,

efficiency, comments, etc. There is much more behind this window, be patient.

2.1 Editor

The editor tool is a Man Machine Interface (MMI) to introduce or update antenna data. 4NEC2 allows use of a text editor if you know NEC2 syntax. A spreadsheet or graphic editor is much simpler to use and no extra knowledge is needed. We can jump from one to the other if we wish; start with the graphic editor and make fine changes with the spreadsheet.

We are going to create a simple antenna, a dipole, to see how it works. A dipole is a piece of wire that can be defined by two vectors, the coordinates are X1,Y1,Z1 and X2,Y2,Z2. There are two extra parameters, the wire radius and material used. Before starting we have to select which units we are going to use. I

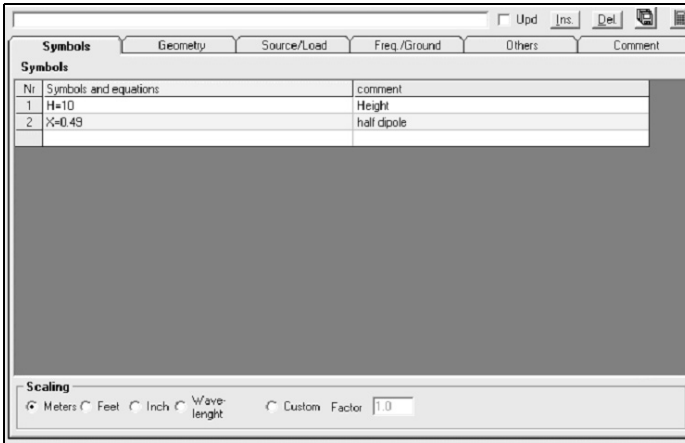


Fig 2: Symbols spreadsheet editor tab for definitions and formulae.

always use metres but you can select feet, inches, wavelength and custom too. To introduce the data we launch the editor using $\text{Ctrl} + \text{F4}$ or selecting a menu edit->input (.nec) file F6 or F6 if you have already defined the editor that will be used. Notice, the last file used is the one that 4NEC2 opens by default, modifications of that file if saved will overwrite the earlier antenna. Menu file->save as, saves the existing antenna with another name. Click on the Symbols tab and select the units, metres in this case as shown in Fig 2. The symbols and equations can be defined, very useful for further modifications if required. Define height like $H=10$, half antenna length $X=0.49$.

Now change to the Geometry tab (Fig 3) and set the wire coordinates. Enter Wire in the type column, the number of segments = 9, $X1 = -X$, $Y1 = 0$, $Z1 = H$, $X2 = X$, $Y2 = 0$, $Z2 = H$ and radius = 0.001. 9 segments have been selected that is an odd number, this is important because we will connect the generator in the middle of the wire at segment 5. If an even number is selected the generator would not be in the middle.

Now select the Source/Load (Fig 4) tab to introduce the generator and its signal; magnitude 1, tag 1 and segment 5, the type of wire, in our case copper. NEC2 works with segments; loads and generators are connected to a segment. If we

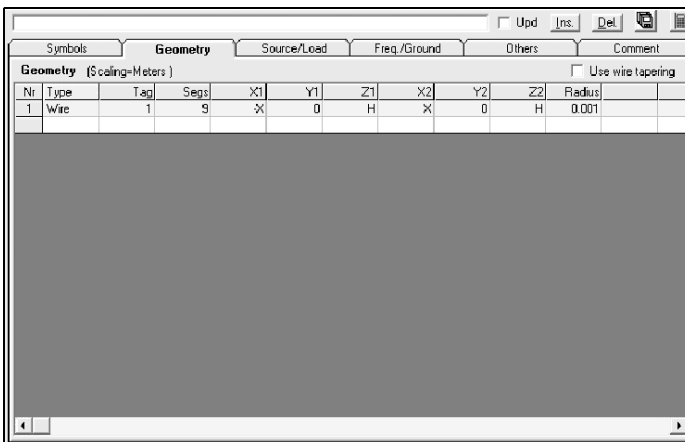


Fig 3: Geometry tab for antenna parts definition.



Fig 4: Source/Load tab for definition of source(s), load(s) and lines. Check appropriate combo box to go to sub tab.

want to displace one of these we can select which segment we want or divide the wire in several pieces then the source/load will be in one of smallest pieces made from one segment. So we can move to the best location for impedance, etc..

Now select the Freq/Ground tab and introduce the resonant frequency required, 145MHz, and the type of ground. Now save the file.

3.0 Simulation

Hit F7 and introduce the simulation parameters. Simulation may be near field, far field, frequency sweep an IT-SHF [2] output. Selecting sweep opens extra combo boxes to fill, start frequency = 140 and stop frequency = 150, step frequency = 0.1, etc. Then push the generate button.

A DOS progress window shows that the program is running making calculations, wait until it ends. After simulation an

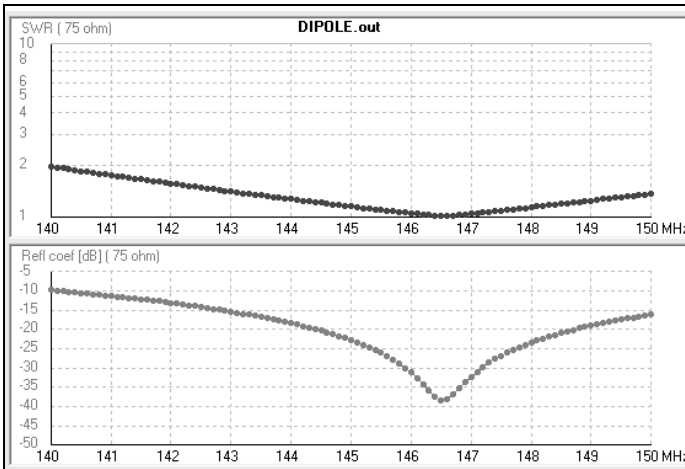


Fig 5: SWR sweep chart at selected impedance. The S or I keys change from SWR to Impedance sweeps.

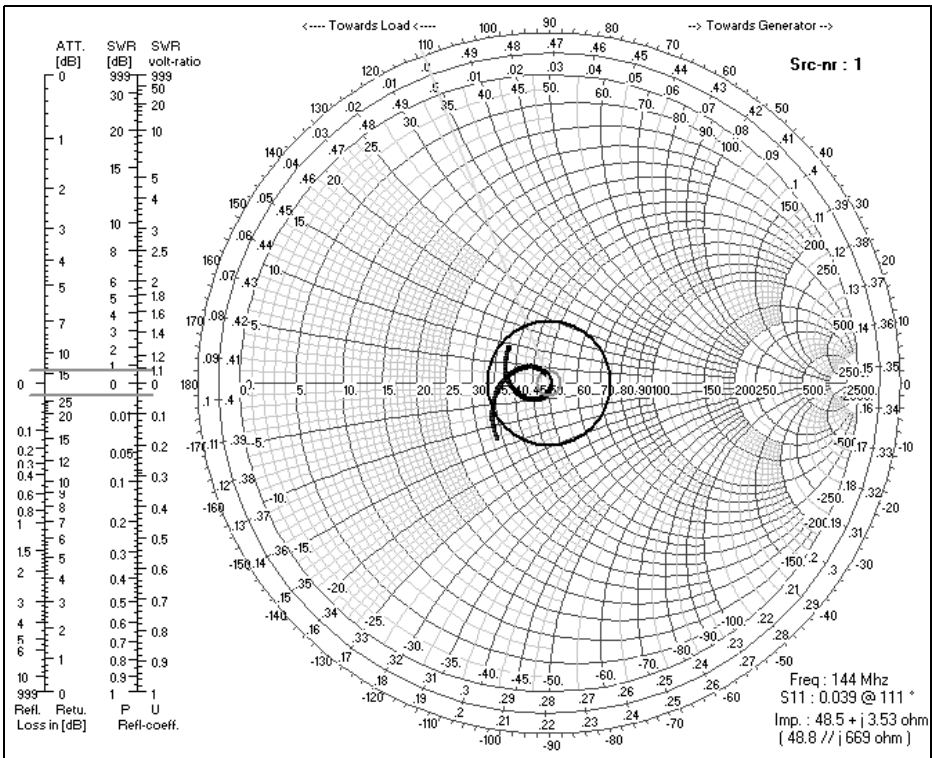


Fig 6: Smith chart impedance diagram. The arrow keys change the frequency to read off the selected impedance.

error report is produced for any errors.

In the main window we can check the SWR, impedance, etc. at 145MHz. Two windows have opened after the simulation, a radiation pattern window and an SWR window. We can change SWR and impedance by hitting “S” for SWR or “I” for impedance (Fig 5). See menu “show” in this window. The best matching is close to 145MHz, 1.45:1 SWR. Change to the main window, menu setting->Char-impedance and select 75. Now change to window SWR and check for SWR close up to 1:1 at 146.5 Mhz.

Select the main window again, hit the smith chart icon in the menu bar. This opens the smith chart (Fig 6) and using the left and right arrow keys we can change the frequency and see the impedance, normalised impedance and fre-

quency, bottom right side of this window. Hit ‘S’ and introduce the SWR circle, 1.5 for example. Now you can see the impedance line, the selected frequency, green line, 1.5:1 SWR circle, and left side the SWR, reflection coefficient and other typical smith chart values that change with the selected frequency.

4.0 Optimiser

We can change the antenna dimension in the editor window and try again. Because the antenna is short we can increase the X value a bit, 1cm for example. Another method is the optimiser. Select the main



Settings

Function: Optimize Option: Default

Variables

Variable	Selected
H=10	X
X=0.4948	

Weighting factors (FOM) in %:

SWR	Gain	F/B	F/R	R-in	X-in	Eff.
1.1	0	0	0	0	100	0

Surf-wave at distance = Km

Theta:

Phi:

Resolution: deg.

d-Theta:

d-Phi:

Tot-gain: ▼

Freq-sweep

Frequency:

Resume Update NEC-file Exit

Variable Sensivity:

Run:	X
1-1	1
2-1	1
3-1	1
4-1	-1
5-1	1
6-1	-1

Calculated results: Show Log Plot result

Run:	SWR	Gain	F/B	F/R	R-in	X-in	Eff.	Res. %	Step %
3-4	1.0392	0	0	0	73.515	2.4346	99.65	-7e-3	0.4
4-1	1.051	0	0	0	73.723	3.4682	99.65	-0.01	0.1
4-2	1.0301	0	0	0	73.306	1.3989	99.65	0.01	0.1
4-3	1.0265	0	0	0	73.097	0.3633	99.65	0.01	0.1
4-4	1.0304	0	0	0	72.89	-0.67	99.65	-3e-3	0.1
5-1	1.0265	0	0	0	73.097	0.3633	99.65	3.e-3	0.1
5-2	1.0288	0	0	0	72.942	-0.411	99.65	3.e-3	0.025
5-3	1.0276	0	0	0	72.994	-0.152	99.65	3.e-3	0.025
5-4	1.0268	0	0	0	73.045	0.1044	99.65	5.e-4	0.025
5-5	1.0265	0	0	0	73.097	0.3633	99.65	-3e-3	0.025
6-1	1.0267	0	0	0	73.056	0.1566	99.65	-5e-4	5.e-3

Variable Values:

Run:	X
3-4	0.4959
4-1	0.4964
4-2	0.4954
4-3	0.4949
4-4	0.4944
5-1	0.4949
5-2	0.4945
5-3	0.4947
5-4	0.4948
5-5	0.4949
6-1	0.4948
6-2	0.4948

Fig 7: Optimiser menu used to set the variables for sweep, target optimisation value, SWR, Gaie etc. Optimisation results can be transferred to the design.

window and push the next button beside the calculator. This opens the optimiser window, the program asks for the editor

window to be closed before proceeding. This window shows the variables that can

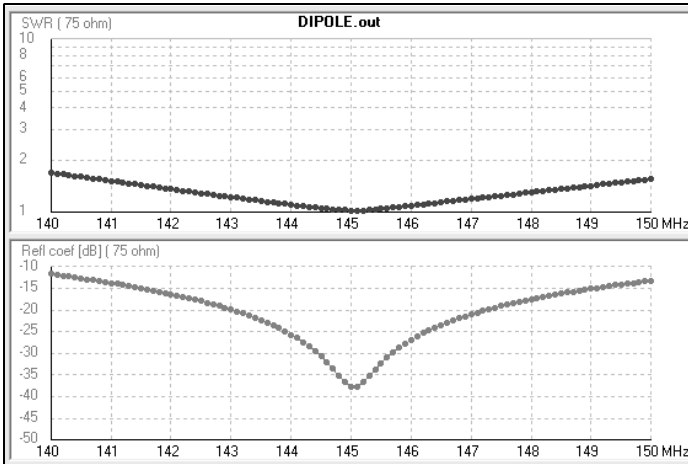


Fig 8: SWR sweep after optimistaion.

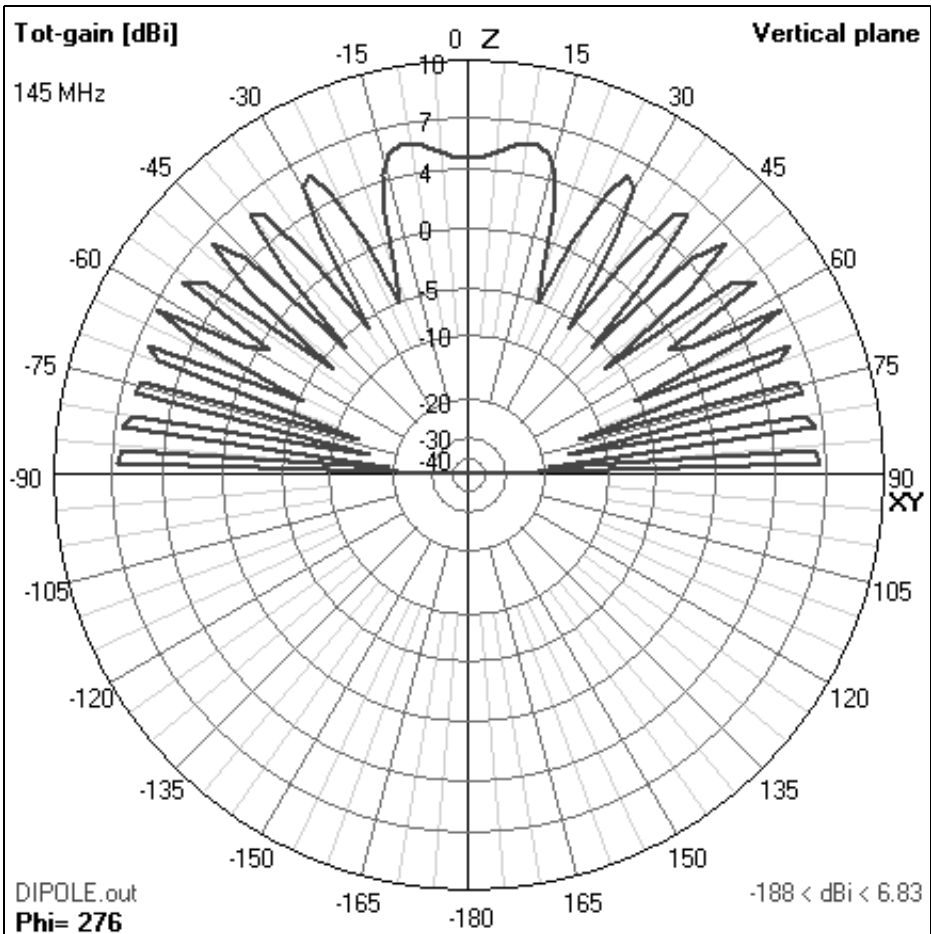


Fig 9: 2D gain plot. The space bar toggles the plane on view.

be used for optimisation (Fig 7). Select X, then select SWR and write the target value, 1.1 for example. Hit the “start” button and wait while the program runs. It shows the progress and after a while it stops and shows the results. In the SWR column we can select the lowest value.

Iteration 4-3 is the lowest and in the variable table we can see the value of X for that SWR. If we push the button Update NEC file then this value will replace the one in the NEC file. The next simulation will show better matching at

145MHz instead of 146.5MHz see Fig 8.

5.0 Gain

Select the main window and simulate the antenna again. Now select the far field option and check the Full option. After simulation the radiation pattern window is updated with the radiation pattern for

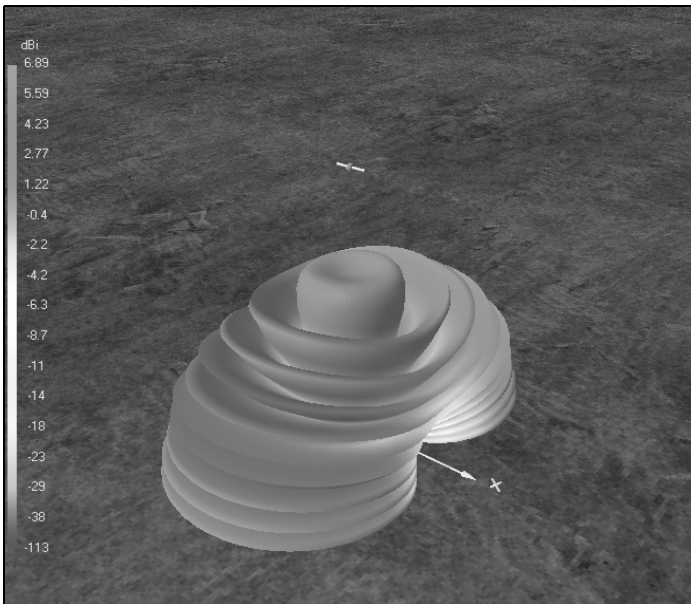


Fig 10: 3D gain plot. 4NEC2 plots this in colour but unfortunately this magazine can only show it in black and white. The gain scale on the left can be used to identify the best radiation. The plot can be moved in any direction using the mouse.

RLC Matching (F10)

Z-src (rig) Z-load (antenna) Freq Mhz

J J

Min netw-Q

Stub match

Q-coil Q-cap.

Select network

(none)

NT parameters

Y11

Y12

Y22

L-network $q' = 0.68$

Low-pass	High-pass
<input type="text" value="37.3 nH"/>	<input type="text" value="32.3 pF"/>
<input type="text" value="10.2 pF"/>	<input type="text" value="118 nH"/>

Pi-network $Q = 0.69$

Low-pass	High-pass
<input type="text" value="1.75 pF"/>	<input type="text" value="689 nH"/>
<input type="text" value="41.7 nH"/>	<input type="text" value="28.9 pF"/>
<input type="text" value="10.3 pF"/>	<input type="text" value="117 nH"/>

T-network $Q = 0.69$

Low-pass	High-pass
<input type="text" value="37.6 nH"/>	<input type="text" value="32 pF"/>
<input type="text" value="11.4 pF"/>	<input type="text" value="105 nH"/>
<input type="text" value="6.28 nH"/>	<input type="text" value="186 pF"/>

The interface also includes three circuit diagrams for different matching topologies: L-network, Pi-network, and T-network, each with 'SOURCE' and 'LOAD' labels.

Fig 11: The RLC matching menu gives several matching solutions. The selected network can be used for further simulation.



Stub Matching (F10)

Z0 (rig/feed) Z-load (antenna) J Freq Mhz

Select matching network
Parallel stub

Line (antenna to stub)
Imp/Z0 V_f
(user specified)

Stub (L2)
Imp/Z0 V_f
(user specified)

Exit

Edit/Select results

	Line length L1	Stub-length L2		mtr
		Open	Short	
A	<input type="text" value="0.19135"/>	<input type="text" value="0.56961"/>	<input type="text" value="0.22846"/>	
B	<input type="text" value="0.49165"/>	<input type="text" value="0.11269"/>	<input type="text" value="0.45384"/>	

Select solution
A: open stub

Use Stub

Fig 12: Stub matching menu gives several matching solutions with commercial cable selection for open or closed stubs. The selected network can be used for further simulation.

the antenna see Fig 9. Using the right and left keys is possible to see the radiation pattern for different azimuths and bearings. The space bar toggles from side view to top view. Play with the mouse and keys to see all the possibilities for the radiation pattern.

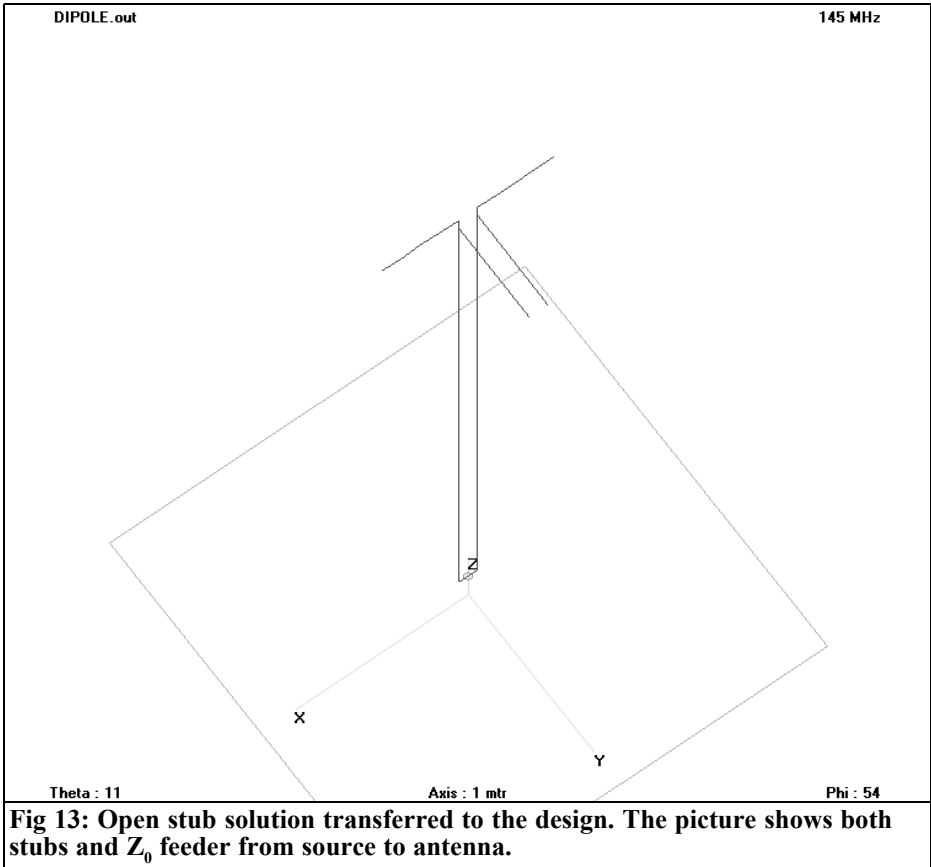
If 4NEC2X is being used, select the main window and push the 3D button on the tool bar. Wait for a while and you will be surprised with a nice 3D view of the antenna that can be rotated with the mouse with the left mouse button pressed. Select pattern and you will have a nice picture of your antenna and radi-

ation pattern in colours (see Fig 10 – sorry only in black and white in this magazine).

Use the mouse to see the radiation pattern from another position. The Page Up and Page Down keys zoom the radiation pattern.

6.0 Matching

It is not usual to get the best radiation



pattern and 1:1 SWR matching or just get a good SWR match. To solve this problem a matching device is often required as part of the antenna, a gamma match etc.

4NEC2 help to design the matching network either LC or stub. Select settings-> Char impedance 50 from the menu. Push the 1:1 button on the main menu and it opens a matching window. The antenna impedance and source impedance are shown at the top with the calculated LC values shown to the right of each matching network. The matching network can be selected as either low pass or high pass for each one solution see Fig 11.

Another matching network is the stub.

Pushing the stub button opens a new window to select which kind of stub solution is of interest. It is possible to select which kind of feeder cable is being used for the stub, there is a list or we can use a user defined cable see Fig 12.

There is an important button, use network in the RLC window or use stub in the stub window. Pushing this button transposes the network into the simulator so we can see the behaviour of our antenna once matched. In Fig 13 the stub solution has been selected. A 3D sketch window shows the stub, the source has been removed from antenna wire and moved to the end of the feeder with pieces of feeder forming the stub.

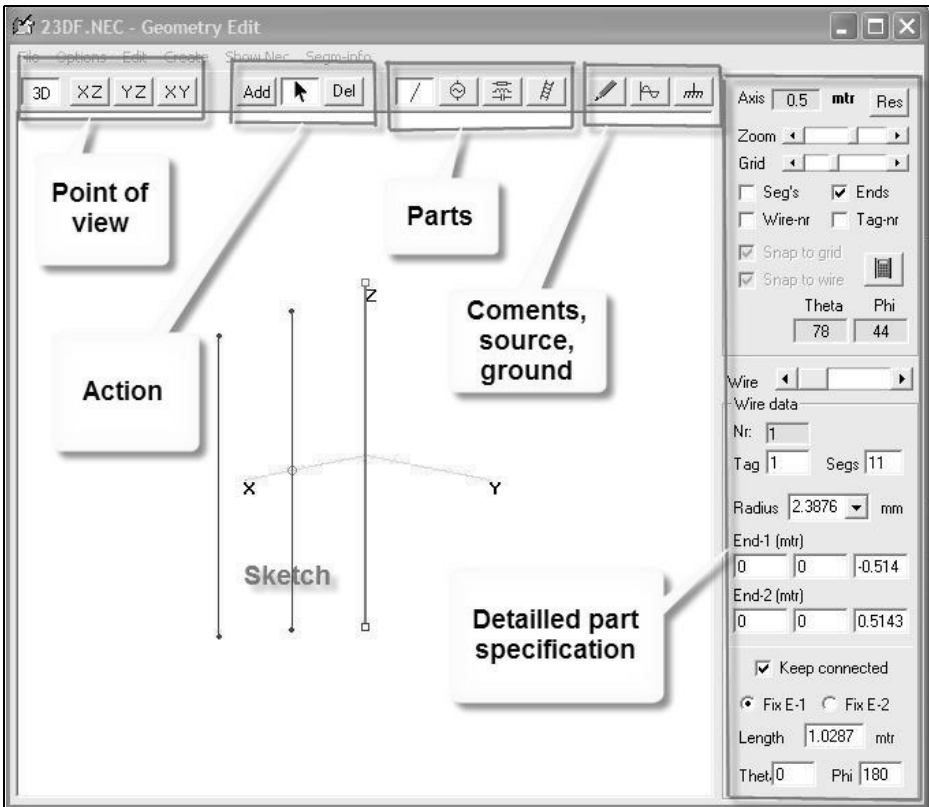


Fig 14: The graphic editor window allows antenna definition as a spreadsheet but we have a 3D image that helps a lot at this stage.

7.0

Graphic editor

The graphic editor (Fig 14) is divided into two parts. The view, 2D or one of the 3D views, is selected at the top of the window. The actions available are add, del or use the pointer to select something to investigate. The selected part properties are shown on the right. For example for a wire it shows the dimensions, wire number, segmentation, end coordinates, etc. We can modify anything here and it is translated to the graphic view. If a wire or wire end is picked up and dragged, the

new coordinates are transferred to the right side in numbers and vice versa.

Select a part, wire for example then select the add button. Now select a plane a grid scale and zoom then you can draw a wire in drawing area. It is possible to modify the coordinates using numbers in the properties section.

8.0

Build Tool

This is an extra tool to help with the definition of complex forms (Fig 15).

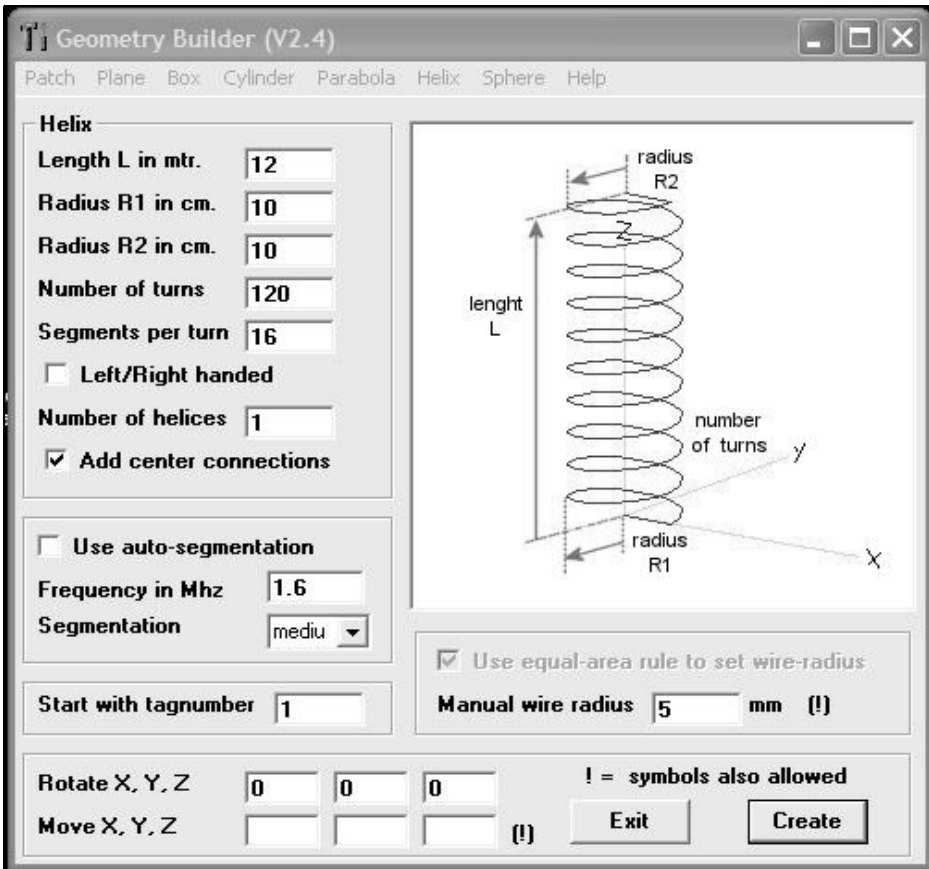


Fig 15: The built tool simplifies the definition of surfaces and complex forms.

The form that we want to work with is selected at the top of the window. The option selected is shown in sketch form on the right side. The rest of the window

shows the names, dimensions and values. The tool does not check anything and does not help definition by frequency. If we are making a helix antenna we have to know the dimensions and number of turns for the target frequency.

Table 1: Dimensions of the sample 4 element UHF antenna.

	X	Element
Reflector	0	346
Dipole	104	340
Director 1	146	321
Director 2	224	311

9.0

Yagi Antenna Simulation

There are many examples and programs that show yagi antenna designs. We are



4e1435STRUCTaluminium.nec - 4nec2 Edit (file changed)

File Cell Rows Selection Options

Upd Ins Del

Symbols	Geometry	Source/Load	Freq./Ground	Others	Comment
Symbols					
Nr	Symbols and equations				comment
1	RX=0.095				Posición del reflector
2	RZ=0.172				Tamaño del semireflector
3	D1X=0.119				Posición del director
4	D1Z=0.140				Tamaño del semidirector
5	D2X=0.365				Posición 2nd director
6	D2Z=0.118				Tamaño del 2nd director
7	D0Z=0.144				Tamaño del semidipolo excitado
8	D0Y=0.025				Apertura del trombon
9	R1=0.004				Radio tubo reflector y directores
10	R2=0.003				Radio tubo dipolo excitado
11	S0Z=0.015				Tamaño del semielemento del generador
12	R3=0.005				Radio tubo boom
13	Coax = 0.113				Longitud feeder 75 ohms
14	VF = 0.66				Factor de velocidad del cable
15	Feeder= Coax/VF				Long feeder para simulación
16	FX=D0Y+Feeder				Posición del generador

Scaling

Meters Feet Inch Wave-length Custom Factor 1.0

Fig 16: The UHF antenna symbol definition, the dimensions are not optimised yet.

going to study a sample 4 element UHF Yagi with 4NEC2 to see how to improve the design. This is a theoretical example and the focus is to show what 4NEC2 can do for us to help in the design phase to get the best results.

Dimensions for an antenna, found on the Internet, matched with a gamma match are shown in Table 1.

To get a larger bandwidth we are going to use a folded dipole instead an open

4e1435STRUCTaluminium.nec - 4nec2 Edit (file changed)

File Cell Rows Selection Options

Default straight line wire-element Upd Ins Del

Symbols	Geometry	Source/Load	Freq./Ground	Others	Comment					
Geometry (Scaling=Meters)										
Nr	Type	Tag	Segs	X1	Y1	Z1	X2	Y2	Z2	Radius
1	Wire	1	1	0	-D0Y	-D0Z	0	D0Y	-D0Z	R2
2	Wire	2	4	0	D0Y	-D0Z	0	D0Y	-S0Z	R2
3	Wire	3	1	0	D0Y	S0Z	0	D0Y	-S0Z	R2
4	Wire	4	4	0	D0Y	S0Z	0	D0Y	S0Z	R2
5	Wire	5	1	0	-D0Y	D0Z	0	D0Y	D0Z	R2
6	Wire	6	5	0	-D0Y	D0Z	0	-D0Y	0	R2
7	Wire	7	5	0	-D0Y	-D0Z	0	-D0Y	0	R2
8	Wire	8	6	-RX	0	-RZ	-RX	0	0	R1
9	Wire	9	6	-RX	0	0	-RX	0	0	R2
10	Wire	10	5	D1X	0	-D1Z	D1X	0	0	R1
11	Wire	11	5	D1X	0	0	D1X	0	D1Z	R1
12	Wire	12	5	D2X	0	-D2Z	D2X	0	0	R1
13	Wire	13	5	D2X	0	0	D2X	0	D2Z	R1
14	Wire	14	8	-2RX	0	0	-RX	0	0	R3
15	Wire	15	8	-RX	0	0	0	0	0	R3
16	Wire	16	8	0	0	0	D1X	0	0	R3
17	Wire	17	8	D1X	0	0	D2X	0	0	R3
18	Wire	18	1	0	0	0	0	-D0Y	0	R2
19	Wire	19	1	-FX	D0Y	S0Z	-FX	D0Y	-S0Z	R2

Fig 17: The geometry definition. Each part is divided into smaller parts to allow connection of the boom and antenna parts, folded dipole etc. NEC2 does not work with bent elements so the driven dipole is made as a rectangle.

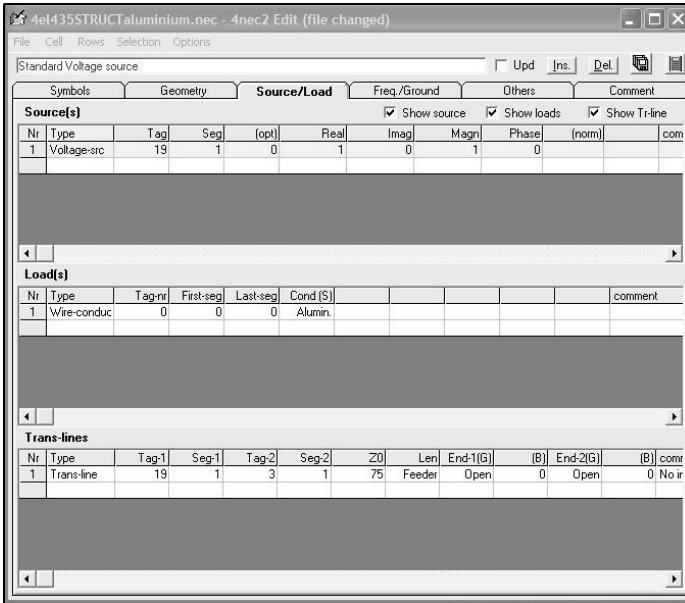


Fig 18: The source and load spreadsheet. The antenna is made of aluminium so all wires are defined as that material. Changing the material conductivity changes the simulation and matching so it is important to consider this.

dipole. That increases the impedance so the target impedance is either 112Ω where a simple quarter wave feeder of 75Ω is good for matching to 50Ω or 200Ω where a coaxial 4:1 transformer is suitable for that application. Other requirements are to maximise front to back ratio and forward gain. With 4 elements we cannot expect high directivity. To allow optimisation the antenna dimensions will be introduced using formulae (Fig 16) so any dimension to be optimised is defined by an equation. This is done using the spreadsheet editor (Ctrl + F4).

Now we introduce each antenna part,

Table 2: Optimised dimensions of the 4 element UHF antenna.

	X	Element	Diameter
Reflector	0	344	8
Dipole	95	288	6
Director 1	214	280	8
Director 2	460	236	8

reflector, directors and boom are in plane XZ. The driven dipole, feeder and source are in plane YZ (Fig 17). The graphic editor may help to do this job but it creates its own symbol definitions and some rework is needed later.

The source, antenna material and transmission line is also introduced. The transmission line is defined by a velocity factor of 1. To work with real feeder dimensions a formula makes the calculation. Feeder is a 75Ω and 0.66 VF.

The diameter of each antenna part has to be defined too, Fig 17. This is an important parameter that changes the final results. The first step is to look in a hardware store to find the available materials. I have selected aluminium tubes (Fig 18), 10 x 12mm for the boom, 8mm diameter for R, D1 and D2 and 6mm diameter for the folded dipole.

The real work is the optimisation process. After this job and several iterations fixing the SWR then the gain and finally the front to back ratio, the dimensions for best match, forward gain and front to back ratio obtained are shown in Table 2.

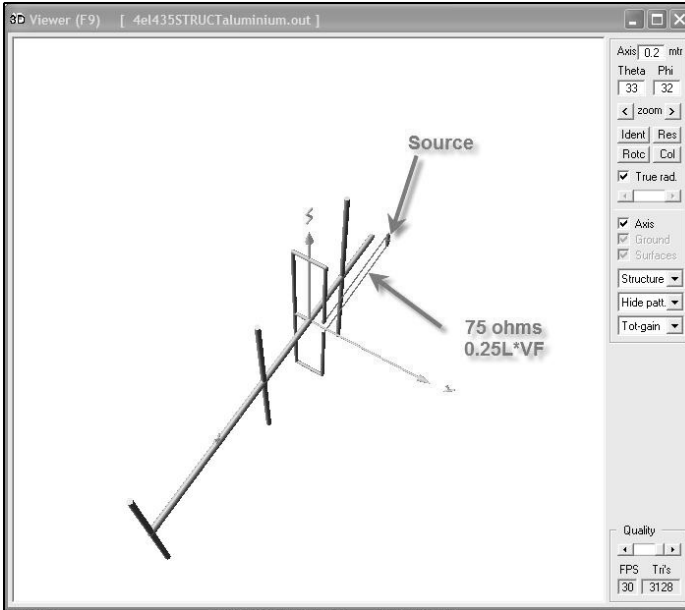


Fig 19: The finished 4 element UHF antenna.

The antenna looks like Fig 19. The feeder runs parallel to boom backwards. The feeder length is shorter than it looks on the 3D drawing because the ideal feeder with VF = 1 is shown.

Now the impedance chart for 50Ω is selected because we have the matching network included in antenna definition. Fig 20 shows an SWR sweep from 425 to

445MHz, SWR is very good and matching is wider than the amateur band.

The matching is excellent, now let us check the directivity gain, we get with this arrangement (Fig 21 and 22).

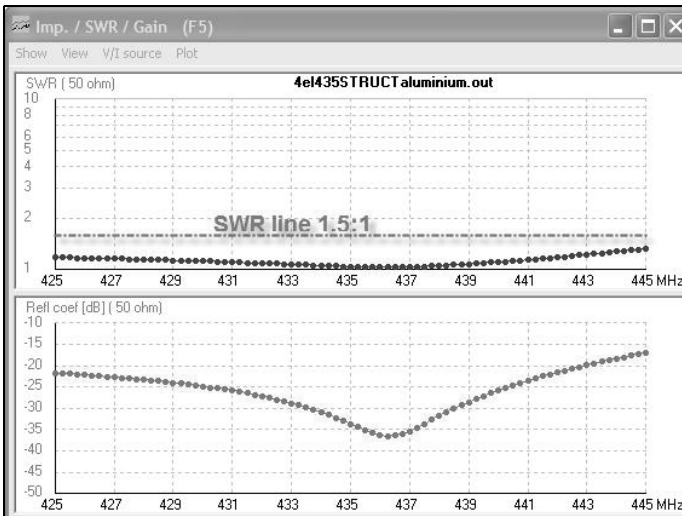


Fig 20: SWR sweep of the optimised 4 element UHF antenna.

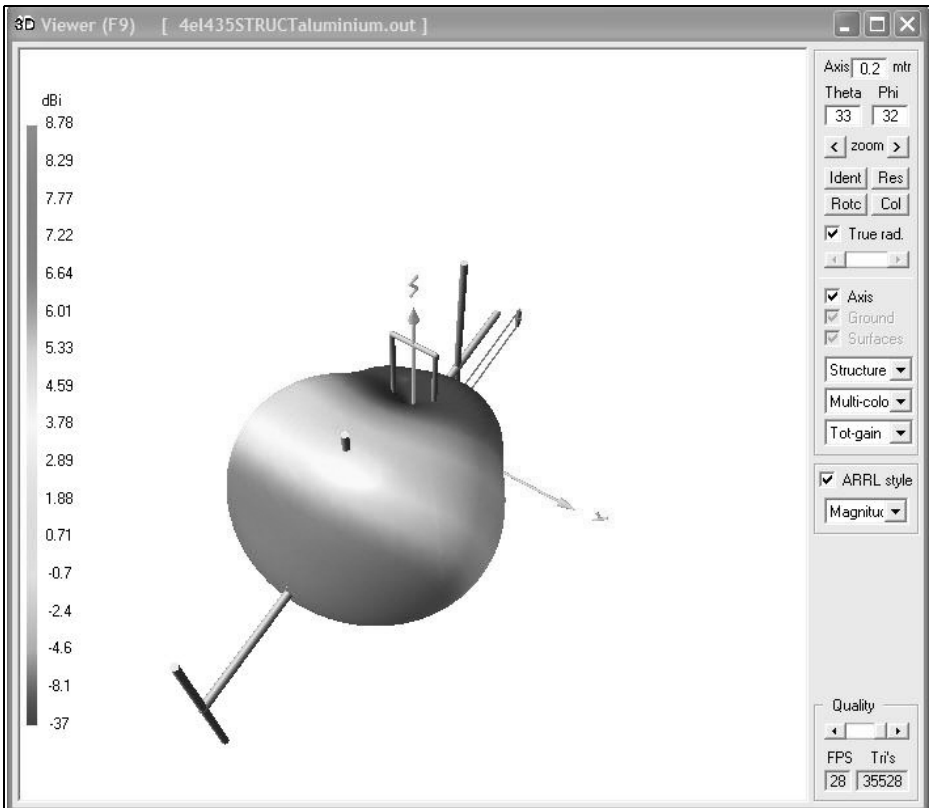


Fig 21: The 3D antenna gain diagram. The forward gain is 8.78dBi and at the back there are some 37dBi nulls.

10.0

Conclusions

The optimisation process and detailed study takes a few hours. During this time we can play with the impact of tolerances of dimensions. So before the antenna is made we have a vast knowledge about what can be expected. If we know that a dimension is critical then we will use more effort and tooling to meet the specification.

This is a theoretical study and one hopes the design, if made, will meet the theo-

retical results. This will be part of another article.

Do not forget that this is a simulation tool, it works with mathematical models that try to be as close as possible to the real world. The precision NEC4 engine cost a lot and it is not available for the amateur pocket so the available NEC2 does not guarantee that real things will be as good as it shows in the simulation tool. If the modelling performance is poor it is 100% certain that the constructed antenna will be worse than the theoretical design. If the simulation is so good it is probable the constructed antenna will be good enough.

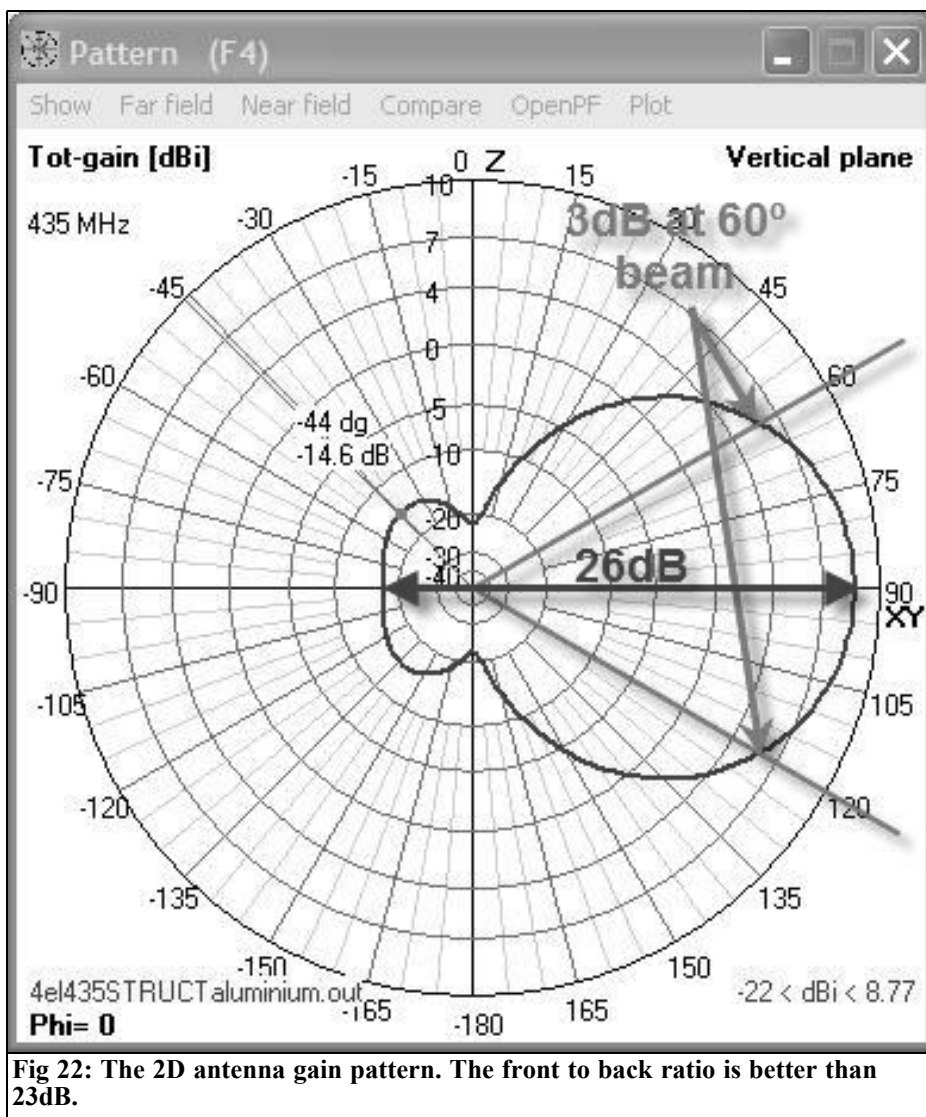


Fig 22: The 2D antenna gain pattern. The front to back ratio is better than 23dB.

11.0

References

[1] <http://home.ict.nl/~arivoors/>

[2] The software ITSHF is available free via the internet at <http://www.greg-hand.com/hf.html>



John Fielding, ZS5JF

John's Mechanical Gem No. 11, Know your metals

Amateurs use many different metals to construct items for the hobby. Often the knowledge of the various metals is lacking and the following should be of some help.

1.0

Aluminium

The name aluminium is often given to the pure metal and its alloys. Pure aluminium is a soft, ductile metal of fairly low strength. Under continuous bending it work hardens and becomes brittle. It is notable for its low weight, excellent resistance to corrosion and good electrical conductivity (second only to copper). Alloying with other materials can considerably strengthen aluminium. Alloyed aluminium can be substantially the same weight per unit volume as pure aluminium but attaining tensile strengths approaching or exceeding mild steel. Alloyed aluminium however often has a lower corrosion resistance of pure aluminium.

Pure aluminium is generally resistant to most normal environments, including salt water. The surface of aluminium develops a "skin" by oxidation that excludes corrosive materials and this can be enhanced by a process known as "anodising". A unique property of aluminium is that a highly protective surface film of oxide can readily be applied by electro-

lytic methods. This film is porous enough to accept colouring dyes to produce a coloured attractive finish, which can then be sealed to exclude any further corrosion. Aluminium oxide is extremely hard and forms the basis of many abrasive materials, such as grinding wheels. It is only slightly less hard than diamond.

2.0

Iron

Iron is a zero carbon material, produced by smelting the iron ore at high temperature to release the liquid metal, called pig iron. It has very little strength compared to alloyed modern steels. From prehistoric days its value was noted to make tools and other implements, axes, hammers, swords etc. It could also be cast into complex shapes and formed the basis of early iron fabrications used for bridges etc. The furnace used by the early craftsmen were usually charcoal or coke fired and a very small amount of carbon was inadvertently introduced in the process, but far less than modern low carbon steels. Wrought iron today is non-existent, what people call wrought iron used for decorative railings and other items, is really low carbon steel. The manufacture of wrought iron involved reheating the pig iron from the furnace and hammering it into flat sheets (wrought means to hammer).



Later as the skills grew it was found that repeatedly heating and folding the sheets and then hammering them flat made the material more suitable for cutting tools and increased the ductility so the material was not as brittle as normal iron. During the Industrial Revolution steam powered drop hammers were invented that took a lot of the manual labour from the hammer-welding workers. The Spanish craftsmen who made swords and lances perfected this folding method, in some cases the metal was folded more than twenty times and the finished product could be honed to a long lasting sharp edge. This was also the basis of making razors and surgical instruments, such as scalpels.

Iron suffers from corrosion when attacked by the air and moisture, forming rust.

3.0

Cast Iron

Although cast iron is not commonly used by amateurs it has some unique properties. Cast iron is an alloy of pure iron and carbon; the carbon gives it considerable strength both in tensile and compressive strength. The addition of carbon also causes the pores of the material to contain minute flakes or nodules of carbon, which form an excellent bearing surface. These under a microscope are seen as a “sponge” that holds lubricant well and gives an extremely low friction surface. The compressive strength of cast iron is comparable with steel and easily cast into complex shapes.

4.0

Steel

The name steel is applied widely to

various types of irons with a controlled carbon content. The percentage of carbon determines the ultimate tensile strength of the various types of steel. Straight steels are low carbon steel varying between 0.1% to 1% of carbon. Often some manganese and sulphur as well as phosphorous are added to modify the strength. Mild steel is often about 0.5% carbon content with minor additives. Some free cutting mild steels contain a small amount of lead or phosphorous. Most steels have a ductile property meaning that they can withstand considerable bending before they work harden and become brittle, mild steel is the material of choice for structural engineering as it is relatively low cost and simple to work with. It is easily formed and welded into complex shapes. It however is susceptible to corrosion and a method to exclude moisture, such as painting or galvanising, is often required to prevent serious erosion.

5.0

Stainless Steel

This is a sometimes a misnomer, as some people believe this means rustless or corrosion resistant. Stainless steel is exactly what the name describes; it does not stain under the action of mild acids or alkalis. There are three different types of stainless steel, Ferritic steels, Martensitic steels and Austenitic steels.

- Ferritic steels are magnetic, non-hardenable and easy to machine.
- Martensitic steels are magnetic, heat treatable and relatively easy to machine.
- Austenitic steels are non-magnetic, very hard and strong and difficult to machine, they tend to work harden under pressure.

Stainless steels are basically an alloy of



iron and more than 10% chromium with some other minor alloying metals to alter the characteristics. Some grades work harden and are not suitable for continuous bending, this work hardens the material and the strength rapidly decreases.

6.0

Copper and its alloys

Pure copper is a rare metal and most versions have additional metals alloyed to it to change the parameters. Pure copper is difficult to refine and expensive. Copper is however a major constituent of other alloys, notably brasses and bronzes.

6.1 Brasses

There are as many brasses as days in a month; each has a particular characteristic making it suitable for some purpose. Brass is essentially an alloy of copper and zinc, although other metals may be added to modify the parameters. Alloys containing 80 to 90% copper are known as gilding metals, because of their decorative appearance. Straight brasses contain between 63 to 75% copper and the remainder is zinc, with minor inclusions of other metals. Straight brass has a problem with corrosion called “dezincification” as the zinc leaches out under corrosive liquids, lowering the strength considerably. This is mostly found in brass exposed to salt-water and acids.

Special alloys of brass include aluminium brass, Admiralty brass and Naval brass.

6.2 Bronzes

Bronzes are in reality a variation of brasses. The major constituent is copper but instead of zinc it is tin that is the major alloying metal. Other bronzes have unique properties such as phosphor bronze, this material is similar in compo-

sition to cast iron as the material contains micro-pores which hold lubricant giving very low friction and often formed into bearing sleeves or bushes. These are sold under the trade name of “Oilite” and before use they are immersed in hot oil to fill the pores with lubricant.

Two special versions of bronze are known as “Bell Metal” and “Gun Metal”. Bell metal is used exclusively to cast church bells and other bells, it is 77% copper and 23% tin, and this combination gives a particular tonal quality. Gun Metal was the metal used to cast naval cannons during the Napoleonic era by the British Admiralty; the composition gave the required strength to withstand the pressures in naval guns. Today gun metal is a preferred bearing material for stringent applications for high load bearings in industrial applications.

Aluminium bronzes are alloys of copper and tin with a small percentage of aluminium. They are particularly resistant to salt water corrosion and used extensively for marine applications.

Manganese bronzes are a copper-zinc alloy with a very small amount of manganese, so bronze is a misnomer, it does however contain a small percentage of tin, it should really be called a brass than a bronze. It is extremely resistant to salt water and finds many uses in marine application especially as propellers.

7.0

Magnesium

Magnesium is the lightest of all the structural metals. It is usually alloyed with aluminium and a small amount of zinc to give it superior strength. Magnesium-Alloy is often a mixture of pure magnesium and aluminium and used for automotive components, especially wheels. These alloys are normally 90% magnesium and the rest is aluminium,



with small traces of other metals, and it is about half the weight of aluminium but the same tensile strength. The down side of magnesium is its flammability, if its temperature is raised to the combustion point it burns violently and is almost impossible to extinguish. Magnesium powder was used in days gone by for photographic flash purposes and in incendiary bombs. Machining magnesium alloy can be a traumatic experience as a cigarette can ignite the dust given off, once ignited it can explode into a fireball. Companies who machine magnesium alloy flood the machine with coolant to reduce the fire hazard.

8.0

Lead

Lead, (whose symbol is Pb from the Latin plumbum), is used for many purposes. Originally used for water pipes by the Romans, where the trade name of a plumber comes from. Today it is mostly out of favour due to its toxicity, but it is used in solder of the old types and as an alloying metal in many metals. Lead is an extremely dense material, weighing 11.34 times that of water. In sheet form, due to its easy forming into complex shapes, it was used for roof flashing and folded up into troughs that are resistant to most acids and alkalis. Today the greatest use of lead is in automotive batteries, which account for 95% of the world's production.

9.0

Tin

Tin is one of the oldest known metals and widely used in alloying with other metals. Pure tin in rod or strip form has an unusual property, when bent it emits a

loud screeching noise known as "The Cry of Tin". In the electronics industry it is widely used for alloying into solders. Tin is widely used for plating thin mild steel sheets as a corrosion resistant barrier and also used in molten form in baths to manufacture "float glass".

10.0

Zinc

Zinc is widely used for protecting iron and steel from corrosion. It is a sacrificial metal that forms a resistant skin when attacked by water, mild acids and alkalis, notably used in hot-dip galvanising baths where the molten metal adheres to the parent metal. Zinc oxide is a white powder formed by heating zinc into the molten state and then passing air through the molten metal. It is used in pharmaceutical products and as heat sink paste for semiconductors. Zinc is used for many intricate castings in the electronic and automotive applications, when alloyed with aluminium it is used to manufacture carburettors and door handles, under the trade name of Mazak. It is also used for cast boxes for electronics applications.

11.0

Gold & Platinum

These two are the most expensive metals commonly used. They are highly resistant to corrosion and widely used in the electronics industry for plating components to reduce contact resistance on relay contacts and switches. A common use for these two metals is in jewellery.



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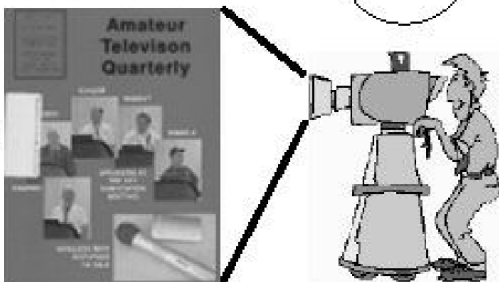
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SWR Bridge and Power Meter

This is a very nice example of a home construction project. It is a good development project that is well documented. Looking closer you will find some interesting things.

Address: http://flfrv.free.fr/main3h_SWR_Bridges.html

Designing Antenna systems for Maximum Sensitivity

Everyone wants to try a new antenna system design. It is difficult to define the scope of a design in terms of the main lobe and side lobes. This article is well structured and very useful for such a project.

Address: <http://www.aktuellum.com/circuits/receiving/>

Communications Design for communications design engineers

This is something for the dedicated

reader. This side looks harmless at first site but the deeper you look the more interesting it becomes.

Address: <http://www.commsdesign.com/dcenters/wireless/>

eHam.net

This site has something for every radio amateur but you have to spend the time to look around and find the things that interest you.

Address: <http://www.eham.net/>

Ian Purdie's Amateur Eadio Tutorial Pages

The title says everything, there is a wealth of information on this site. As an example there are tutorials on Double Balanced Mixers and Baluns.

Address: http://my.integritynet.com.au/purdic/dbl_bal_mix.htm



Tutorial on Basic Link Budget Analysis

This tutorial is for anyone who has something to do with digital communications (today nearly everything in communications is digital) or base stations. This is a good look at such applications; it is meticulous and accurate but also understandable. The chapter on Communications Basics has some good calculated examples.

Address: <http://www.sss-mag.com/pdf/an9804.pdf>

Noise and Noise Figure Measurement

This is a very descriptive Website with extensive material. It is honestly more detailed and more accurately described than most people need.

Address:
<http://www.rose-hulman.edu/~black/Noise/ppframe.htm>

Intersil

Intersil have been a well-known company in the semiconductor industry for a long time (the author has memories of the first products more than 30 years ago. They were the first with an integrated sine/rectangle/triangle generator IC). They have moved on and this site shows their best products with application notes. The Design Assistance gives much more.

Address: <http://www.intersil.com/support/techdocs.asp?x=AppNote>

Spread Spectrum Scene

This homepage and Internet group should be visited regularly because there is always something new in the documents or tutorials. The page selected is "RF Topics" because everything is fascinating and dealt with from basics. There is plenty more to find if you look further.

Address: <http://www.sss-mag.com/rftopics.html>

Noisecom

There is everything you need to know about noise here. Not only the basics but some good practical application notes and tips.

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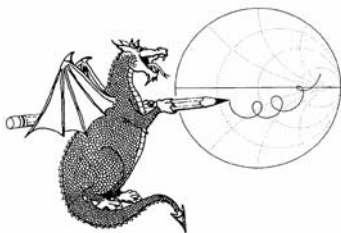
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Blue Binders



A new style for 2010. These binders hold 12 issues (3 years) and keep your library of VHF Communications neat and tidy. You will be able to find the issue that you want easily. Binders are £6.50 each + postage. (UK £0.90, Surface mail £1.90, Air mail to Europe £2.20, Air mail outside Europe £3.60)

PUFF Version 2.1 Microwave CAD Software



This software is used by many authors of articles in VHF Communications. It is supplied on 3.5 inch floppy disc or CD with a full English handbook. PUFF is £20.00 + postage. (UK £0.70, Surface mail £1.45, Air mail to Europe £1.60, Air mail outside Europe £2.60)

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VHF Communications Web Site www.vhfcomm.co.uk



Visit the web site for more information on previous articles. There is a full index from 1969 to the present issue, it can be searched on line or downloaded to your own PC to search at your leisure. If you want to purchase back issues, kits or PUFF there is a secure order form or full details of how to contact us. The web site also contains a very useful list of site links, and downloads of some previous articles and supporting information.

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VHF COMMUNICATIONS

A Publication for the Radio Amateur Worldwide

Especially Covering VHF, UHF and Microwaves

Volume No.42

Autumn

Edition 2010-Q3

Publishers

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63 Ringwood Road, Luton,
LU2 7BG, United Kingdom

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The international edition of the German publication UKW-Berichte is a quarterly amateur radio magazine, especially catering for the VHF/UHF/SHF technology. It is owned and published in the United Kingdom in Spring, Summer, Autumn and Winter by KM PUBLICATIONS.

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Translated using Translution translation software:
www.translution.com

Printed in the United Kingdom by:
Printwize, 9 Stepfield, Witham,
Essex, CM8 3BN, UK.

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ISSN 0177-7505

Back Issues on DVD

VHF Communications Magazine has been published since 1969. Up to 2002 it was produced by traditional printing methods. All these back issue have been scanned and converted to pdf files containing images of the A4 sheets that formed the A5 magazine when folded in half. These have been put together on DVD in decade sets.

From 2002 the magazine has been produced electronically therefore pdf files are available of the text and images. These have been used to produce the 2000s decade DVD.

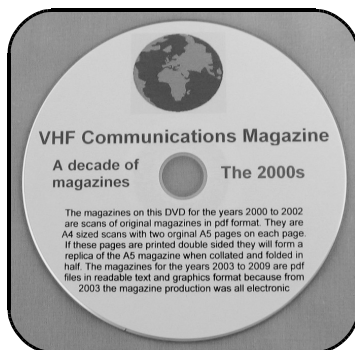


1970s - 1980s - 1990s

These three DVDs cover the first 3 decades of the magazine. The 1970s DVD contains all magazines from 1969 to 1979 (44 magazines) the 1980s and 1990s DVDs contain 40 magazines for the decade. The DVDs are £20.00 each

2000s

This DVD contains magazines from 1/2000 to 4/2001 in scanned image format and from 1/2002 to 4/2009 in text and image format. This DVD is £35.00



Bumper 4 decade DVD

This DVD contains all magazines from 1969 to 2009. That is 164 magazines. It also contains the full index for those 41 years in pdf and Excel format so that you can search for that illusive article easily. This DVD is just £85.00 - just 52 pence per magazine.

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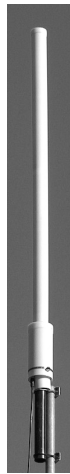


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150W AM-RTTY

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COBRA 30
93 x Ø 12,5 cm
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