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**The RTL-SDR Working with a USB stick**

*Dirk Müller, DB6FM*

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*There is one more article for the competition in this issue but I need more articles for issues 3 and 4 (See advert on page 124). It is disappointing that more articles have not been entered therefore I have resorted to reprinting an old article in this issue.*

*Subscriptions are well down on last year making it unlikely that I will want to produce the magazine again next year. If there is anyone who can revive the magazine and is interested in taking over the publication, please contact me.*

73s - Andy



**K M Publications**, 503 Northdown Road, Margate, Kent, CT9 3HD, UK

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web : <http://www.vhfcomm.co.uk>



Wolfgang Schneider, DJ8ES

# Modern beacon design

The modern operating modes used in amateur radio e.g. WSPR, JT65, JT4, Opera, require thoughts of a new modern design for beacons. Discussions among radio amateurs produced the first beacons e.g. the English beacon GB3VHF on 144MHz. In Scandinavia there is a new universal system, under the leadership of OZ7M, using a DDS chip as the centrepiece. All frequencies are stabilised via GPS.

## 1.

### Introduction

In recent years modern software generated modes are used for amateur radio. A PC or laptop computer with sound card and the necessary software can generate

the signals that can be detected far below the noise level. Examples of these new modes are: WSPR, JT65, JT4, and Opera. Also very slow CW e.g. QRSS3 falls into this category. The software reduces the bandwidth down to a few Hertz and displays signals on the screen that are inaudible to the human ear. These modes can be generated by a beacon without using a PC or laptop. A modern microcontroller combined with a DDS oscillator can undertake this task with minimal effort.

## 2.

### A modern beacon design

An amateur radio beacon consists of three main components, Fig 1. These are

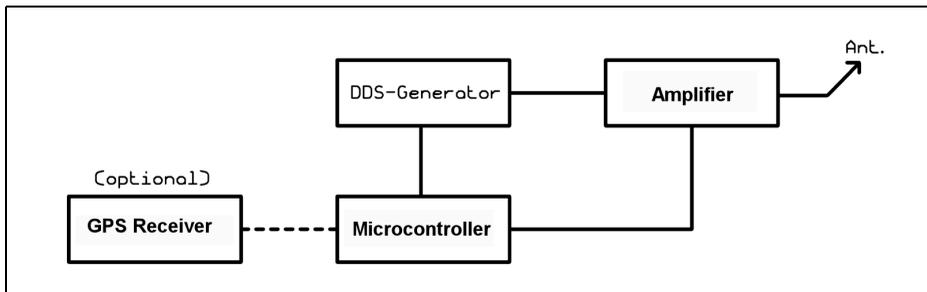
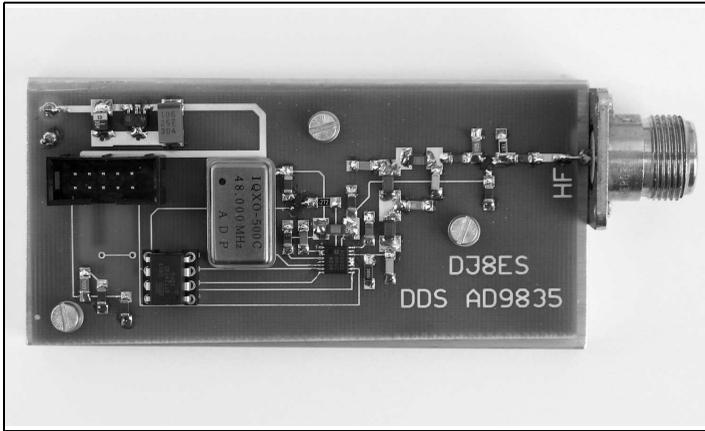
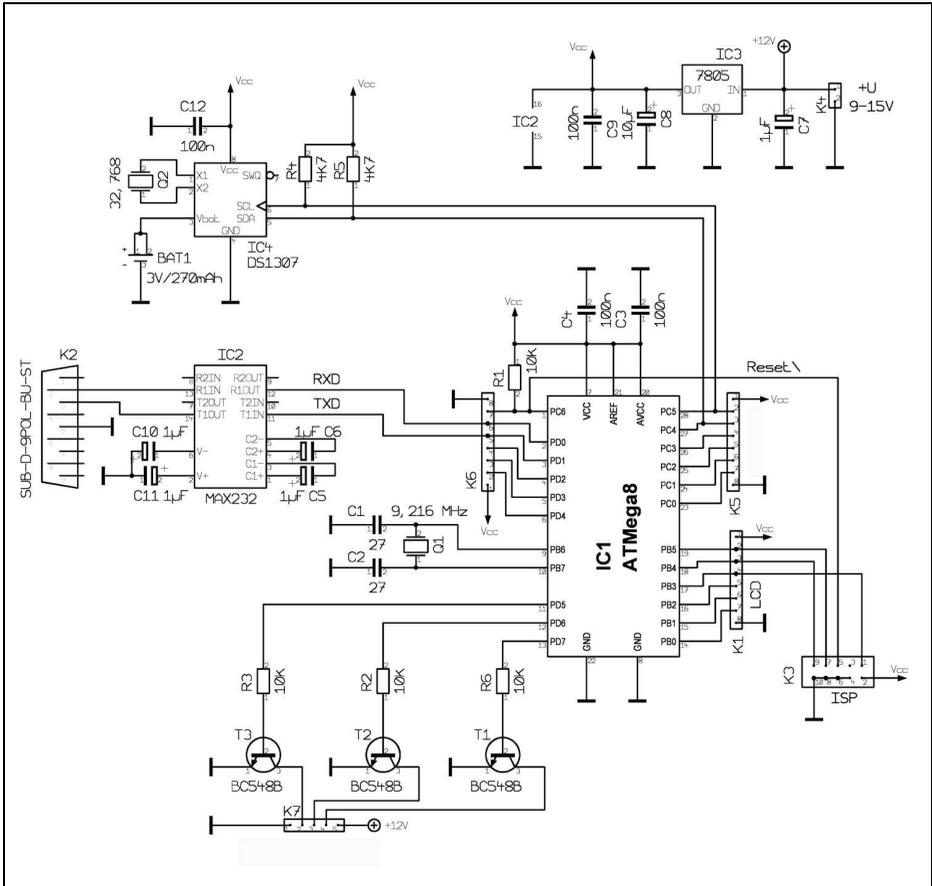


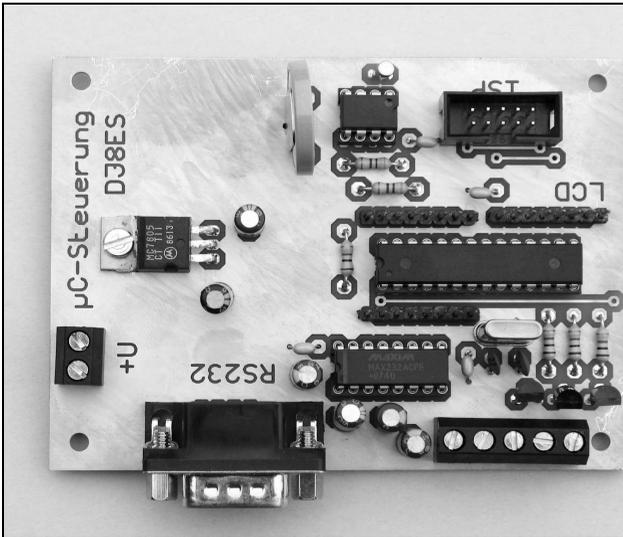
Fig 1: Block diagram of a modern beacon.



**Fig 2: A modern DDS oscillator with an AD9835.**



**Fig 3: Circuit diagram of the ATmega8 microcontroller module.**



**Fig 4: The microcontroller module with all the functions for a beacon controller.**

the frequency generator, a downstream amplifier and the control circuit. Today, the latter is realised by a microcontroller.

Frequency and time control can be added via GPS or DCF77. These can be used to stabilise the internal oscillators used which guarantees an extremely stable output frequency.

### 3.

#### Existing modules

The central element of a modern beacon is undoubtedly the DDS module. For frequencies up to about 20MHz a DDS oscillator [1] with an AD9835 (DJ8ES-079) was published by the author. An example of connection to a GPS frequency standard with a 10MHz OCXO using a TTL clock multiplier was published [2] as DJ8ES-085.

The DDS module (Fig 2) provides a sinusoidal output signal with an output level of about 1mW (0dBm).

The ATTiny45 microcontroller used accepts the frequency setting and can modulate the output signal in the desired mode.

Sample software has already been created and is available on request via VHF Communications Magazine.

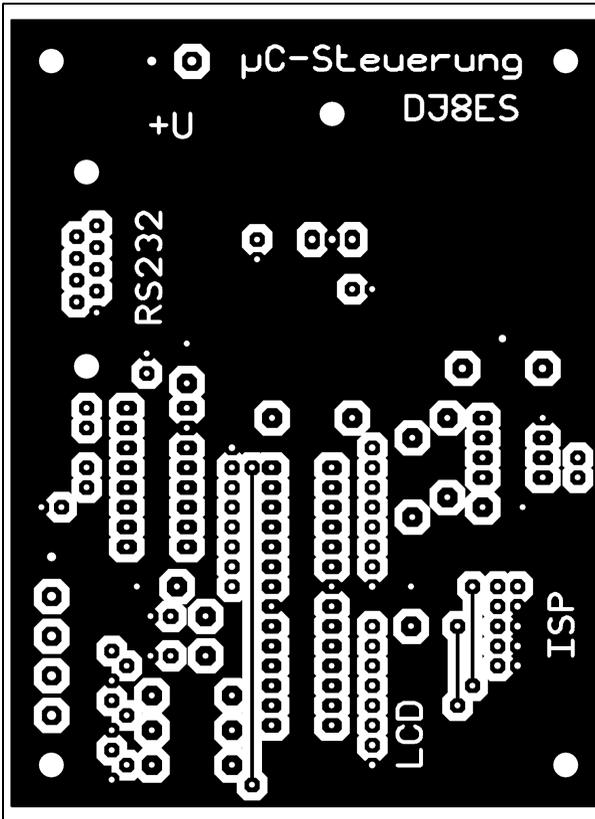
In the shortwave range one of the two amplifier modules published DJ8ES-080 or DJ8ES-081 [1] can be used as a downstream amplifier, depending on the desired power output.

### 4.

#### The control circuit using a microcontroller

At the heart of the microcontroller control circuit in Fig 3 is the ATmega 8 (IC1) from Atmel Microcontrollers. This IC is in a 28 pin DIL package and offers sufficient input / output ports for connection to the peripherals for the controls required. It has an internal memory (8k ROM) giving enough space for extensive operating software. This is not fully used for the beacon control, at least not in the present state of development.

The microcontroller is programmed via K3, the ISP port (ISP = In System



**Fig 5: Ground side PCB layout for the microcontroller.**

Programming). The easy-to-use programming language, BASCOM is used. The development environment offered by the manufacturer as freeware is more than adequate for this application despite the limited scope of 4k.

At first glance the frequency of 9,216-MHz used for the microcontroller is unusual. It was chosen to produce standard bit rates rather than use the more standard frequencies of 8, 12, or 16MHz. The final consideration for the clock frequency is the processing speed but for this application that is of less importance.

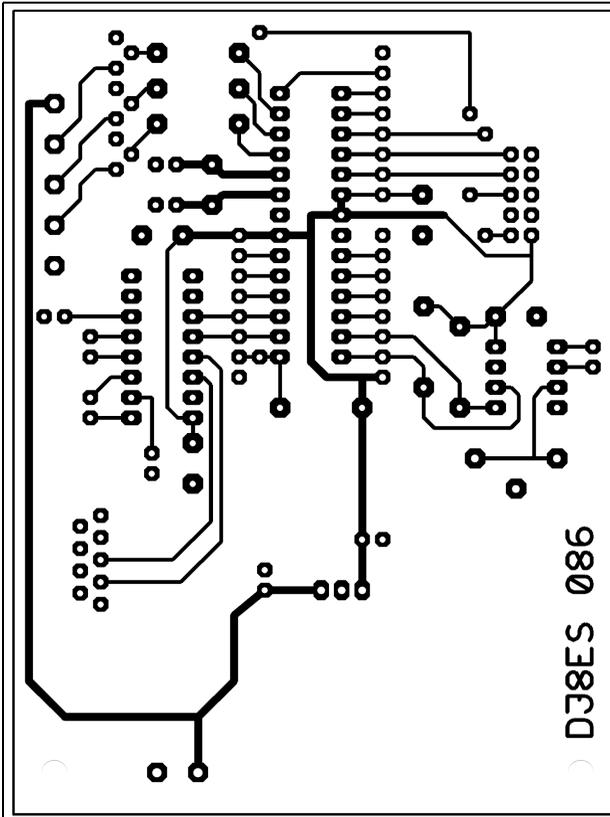
The microcontroller ports PD5, PD6 and PD7 are switching outputs feeding driver transistors T1, T2 and T3. These can be used for switching individual modules such as the DDS oscillator, amplifier, etc.

Commands for the microcontroller can be entered via four digital inputs, ports PC0 to PC3.

A LCD display with 4 lines of 20 characters is intended to display current values, or the current status of the beacon to be controlled. This display unit uses the K1 connector (8-pin) directly connected to the microcontroller to port B (PB0 - PB3 data and PB4 and PB5 commands).

A MAX232 level converter is connected between K6 and the RS232 serial port. The 9 pin output connector K2 is the serial interface for the optional GPS receiver used for time and frequency synchronisation.

An important additional component of the microcontroller control module is the DS1307 real time clock (IC4). The

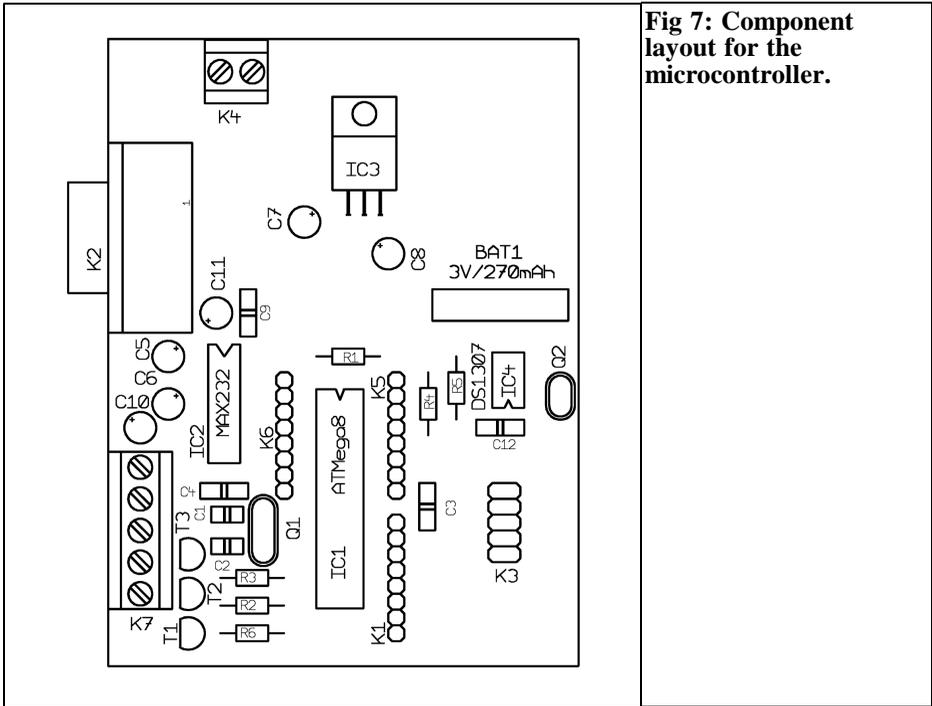


**Fig 6: Track side PCB layout for the microcontroller.**

DS1307 in an 8 pin package and has all the functionality required. It has a built in clock, calendar, and 64 bytes of static RAM with 56 bytes free for the user (the clock needs 8 bytes) and all at a very reasonable price. With an external battery (BAT 1, CR2032) the clock should run for at least 30 years. This 3 volt lithium battery is connected to pin 3 and supplies operating power if the controller is switched off. In standby the power consumption is 500nA maximum. The DS1307 uses the so-called I2C bus to communicate with the microcontroller via pin 5 (SDA = Serial Data) and PIN 6 (SCL = Serial Clock). It requires a 32.768kHz miniature watch crystal connected to pins 1 and 2 that ensures the required accuracy of the clock.

#### 4.1. List of components

IC1	ATMega8 Atmel microcontrollers
IC2	MAX232A, level converter
IC3	voltage regulator 7805
IC4	real time clock DS1307, Dallas
T1, T2, T3	BC548B, transistor
Q1	9,216MHz crystal
Q2	32.768 kHz, mini watch crystal
BAT1	3V/240mAh lithium backup battery
K3	2 x 5 pole connector, RM 2.54mm
K4	2 pole connector, RM 5mm
K7	5 pole connector, RM 5mm
	1 x 1 x 20 characters, LCD display
	Single row, pin strips RM 2.54mm K1, K5, K6, 8 pole



**Fig 7: Component layout for the microcontroller.**

**Electrolytic capacitors 25V, RM 2.5 mm**

- 5 x 1µF
- 1 x 10µF

**Ceramic capacitors, RM 2.5mm**

- 2 x 27pF
- 4 x 100nF

**Resistors 1/4W, RM 10mm**

- 4 x 10kΩ
- 2 x 4.7kΩ

**4.2. Design notes**

The microcontroller control circuit (DJ8ES-086) (Fig 4) is built on an 80 mm x 100mm double sided epoxy printed circuit board. The board is plated through in several places.

The PCB layouts (Figs 5 and 6) were deliberately made straightforward and comparatively spacious so they should be easy to copy.

Construction of the module takes place in an informal order as shown in Fig 7. Only the Atmega8 (IC1) microcontroller, two additional integrated circuits (IC2, IC4) and the LCD should be inserted after checking the supply voltage of +5V at the output of the voltage regulator 7805 (IC3). Precision sockets should be used for the ICs.

**5.**

**Outlook**

The concept described here is suitable for the Long wave, Medium wave and Short-wave ranges up to 20MHz. By multiplication or mixing the output higher frequency bands can be opened up.

To make the DDS oscillator as the centre piece of the system DDS modules up to a maximum of 65MHz are in development.



Using existing mixer modules, either commercial or do-it-yourself projects can be used to cover all VHF, UHF and SHF frequencies

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## 6.

### References

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[1] Low power experiments on short wave, Wolfgang Schneider, DJ8ES, published as an appendix to: High stability oscillator with PLL multiplier for use

with DDS components, VHF Communications Magazine, 4/2912 pp 194 – 203. Note the two amplifiers (DJ8ES-080 or DJ8ES-081) referred to in this article were not included in this appendix.

[2] High stability oscillator with PLL multiplier for use with DDS components, Wolfgang Schneider, DJ8ES, VHF Communications Magazine, 4/2912 pp 194 - 203

[3] Beacon controller using an ATmega32 and BASCOM, Wolfgang Schneider, DJ8ES, VHF Communications Magazine 3/2008, pp 178 - 185

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Massimo Donelli

# A vector measurement system for the X band (8-12GHz) based on an automatic slotted waveguide.

Entrant in the 2013 article writing contest: Article Number 3

**This work proposes an automatic waveguide prototype able to perform magnitude and phase measurements in the X band (8-12GHz). The probe of the slotted line is automatically moved by means of a servo motor, the servo motor is controlled with a microcontroller that also carries out the post processing to display the measurement on an LCD display or sends the data to a remote computer. The experimental prototype has been compared with commercial measurement system and the experimental results obtained confirm the efficacy of the proposed prototype.**

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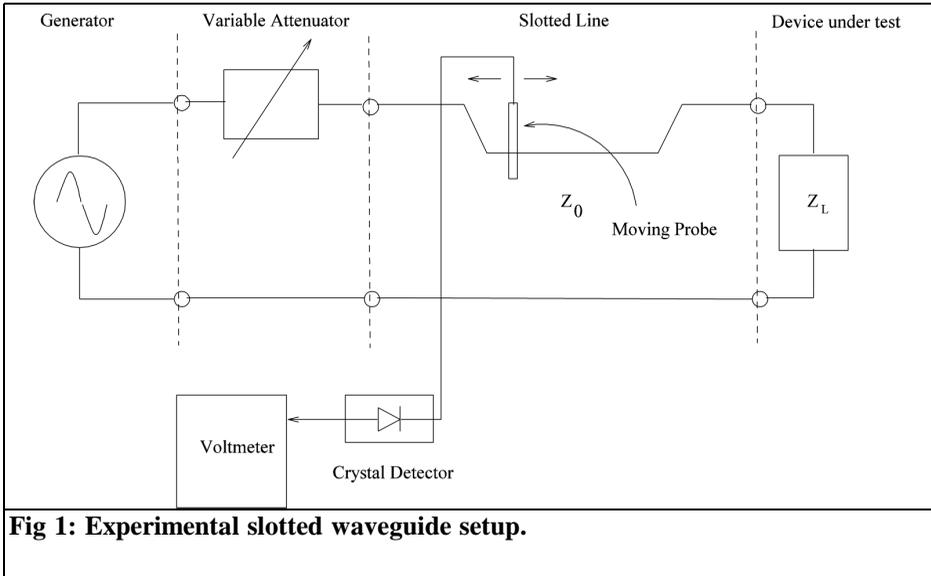
## 1.

### Introduction

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The vector network analyser, VNA is a device widely used for RF and microwave design applications. A vector network analyser is a test system that is able to analyse and characterise radio frequency (RF) and microwave devices in terms of their network scattering matrix, or S parameters. The information provided by a vector network analyser are fundamental for the development of any kind of RF or Microwave systems and it is an essential device that RF and microwave design

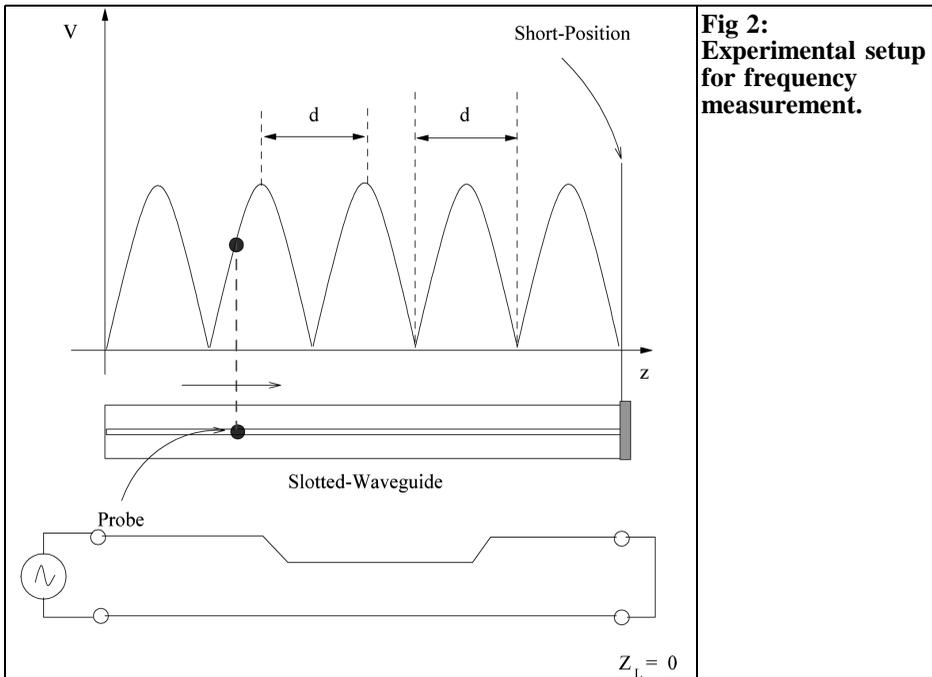
engineers would like to use in their laboratory. The key feature of a vector network analyser is that it can measure both amplitude and phase. Usually an amplitude only measurement is quite simple to make and can be made by means of less complicated instruments. The amplitude only measurement could be sufficient for many practical applications such as the evaluation of the gain of an amplifier, the amplitude response of a filter, or the estimation of the VSWR of a given load or antenna. The complete characterisation of devices and networks requires the measurement of phase as well as magnitude and a measurement that includes phase as well as amplitude is a critical measure. The knowledge of both phase and amplitude information makes it possible to easily design matching circuits, to characterise devices and systems in the time domain (by using the inverse Fourier transform), moreover it is possible to assess the performances of a system by using system decomposition. A good phase and amplitude measurement can only be done with a vector network analyser or something similar. Unfortunately vector network analysers are quite expensive especially at microwave frequency and they are not available for hobbyists, radio amateurs or small companies. It is worth mentioning that before the introduction of vector analysers, designers, engineers and microwave



**Fig 1: Experimental slotted waveguide setup.**

pioneers used a very simple device called a slotted line to measure the standing wave ratio, the frequency, and to evaluate the impedance of a given load. A slotted line is a transmission line, usually a coax line with a longitudinal slot on one side where a probe can be inserted and moved longitudinally to measure the variations of the electric field strength related to the standing wave pattern. The probe is equipped with a crystal detector that converts RF energy to DC voltage, so you can measure peaks and troughs using simple instruments such as voltmeters, or oscilloscopes. By moving the probe along the length of the line it is possible to detect the peaks and the troughs of the standing wave and immediately estimate the mismatch of a given load. Moreover by measuring the distance between two peaks or troughs it is possible to obtain information related to the frequency of the signal that flows inside the line and it is also possible to measure the impedance of a given load comparing the standing wave obtained with a reference load usually a short. Usually for microwave frequency bands a slotted waveguide is used instead to coaxial line. It is still possible to find

commercial slotted waveguides for a few hundred of dollars. A slotted line/waveguide provides quite accurate measurements, its accuracy is greater than a low/medium cost vector network analyser, and it is quite inexpensive. The only disadvantages are that it requires an expert operator and the measurement is quite long and boring especially if the frequency range requires a finer analysis with small frequency steps. In this work an automatic slotted waveguide able to perform amplitude as well as phase measurements in the X band (8GHz-12GHz), is presented. In particular, the movement of the probe of the slotted waveguide is carried out by means of a servo motor controlled with a low cost microcontroller that also takes the measurement and calculates the data. The data can be visualised by means of a display or sent to a remote computer, by means of a serial interface, to visualise the data and the standing wave pattern better. With this prototype it is possible to perform VSWR, frequency, and impedance measurements with a good degree of accuracy. The developed prototype has been assessed considering different operating conditions, and considering different reference loads. Compar-



**Fig 2:**  
Experimental setup  
for frequency  
measurement.

ing the results with those obtained using a commercial VNA confirm the effectiveness of the proposed device as valid alternative to more expensive vector network analysers.

## 2.

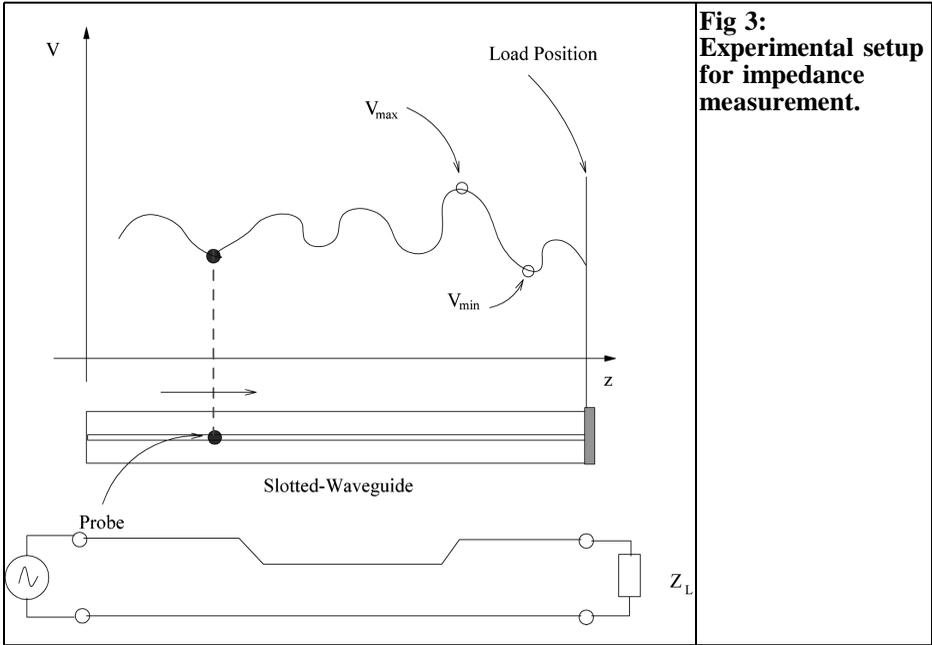
### Mathematical Formulae

The prototype is fabricated with a slotted segment of WR90 waveguide, able to work from 8GHz up to 12GHz. However it is worth mentioning that the measurement system can be adapted to different frequency bands using waveguide of a different size. The experimental setup necessary to perform different measurements, such as frequency, standing wave ratio VSWR, and impedance is shown in Fig 1. It consists of a microwave generator, a variable attenuator, a slotted line, a crystal detector and some reference

loads, in particular a short circuit is mandatory to perform frequency and impedance measurements.  $Z_L$  is the device under test (DUT), it can be any kind of microwave devices such as an antenna, stubs or others. The crystal detector is usually a low barrier Schottky diode. The variable attenuator is not mandatory its presence depends on the power of the microwave generator; it is usually inserted to protect the crystal detector. The different measurement methodologies will be explained in details in the following paragraphs.

#### 2.1 Frequency measurement

To measure the frequency with a slotted line it is necessary to close the open end of the line with a short circuit to obtain a perfect stationary wave pattern with evident peaks and troughs. Then the probe has to be moved along the length of the line and the results of the value detected by the voltmeter connected to the crystal detector at each position recorded (the slotted line has a ruler). It is possible to



**Fig 3:**  
**Experimental setup**  
**for impedance**  
**measurement.**

find a voltage minimum at half a wavelength away from the short. Fig 2 shows the setup and the corresponding standing wave obtained measuring the signal along the length of the slotted line closed with a short circuit. It can be seen from Fig 2 that the standing wave with a short as load is quite evident, troughs and peaks are present and found at the same distance  $d$ . The frequency of the electromagnetic wave that travels along the line can be found by measuring the distance between two peaks or troughs. The following formula provides the wavelength inside a waveguide filled with a dielectric material of given permittivity  $\epsilon_r$ :

$$\lambda = \frac{2d}{\sqrt{1 - \frac{d^2}{a^2}}} \quad (1)$$

Where  $d$  and  $a$  are the distance between two peaks or troughs and the width of the waveguide ( $a=2.1\text{cm}$  for WR90 rectangular waveguide) respectively. The frequency can be directly calculated using the

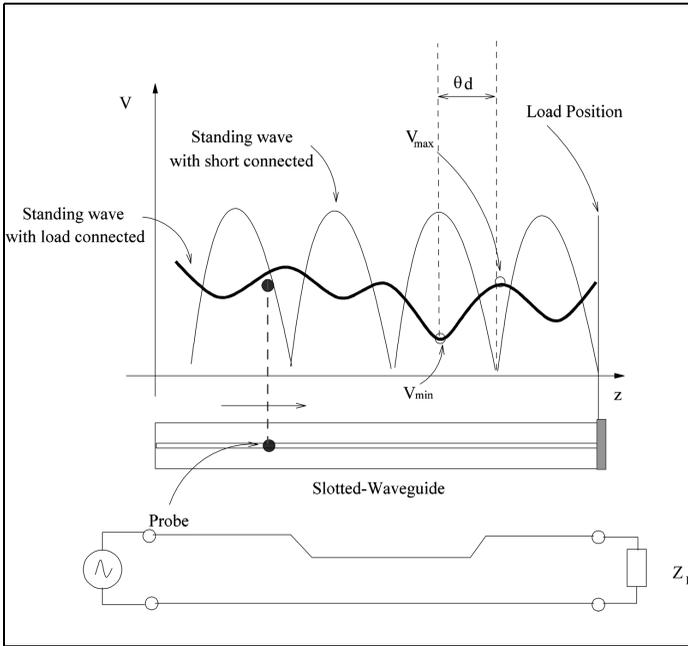
following formula:

$$f = \frac{2d}{\sqrt{\epsilon_r} \lambda} \quad (2)$$

where  $c=3 \times 10^8$  is the velocity of light and  $\epsilon_r$  is the relative permittivity of the propagation medium that fills the waveguide,  $\epsilon_r = 1$  if the waveguide is filled with air. The measurement of frequency is quite simple and accurate, the only problem is that the measurement takes a long time and the operator must be quite accurate to obtain good results

### 2.2 Standing wave ratio (VSWR) measurement

The measurement of the standing wave ratio is quite important in many practical applications since it gives indications concerning the matching condition. This parameter is particularly useful for the design of antennas. Despite the importance of such parameter directly related to the load reflection coefficient, the measu-



**Fig 4:**  
Experimental setup  
for impedance  
measurement.

rement of the VSWR with the slotted line is quite simple. The VSWR parameter can be easily obtained from the ratio between maximum and the minimum values of the standing wave. Considering the following relationship that gives the value of the VSWR expressed in linear and decibel scales respectively:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{V_{max}}{V_{min}} \quad (3)$$

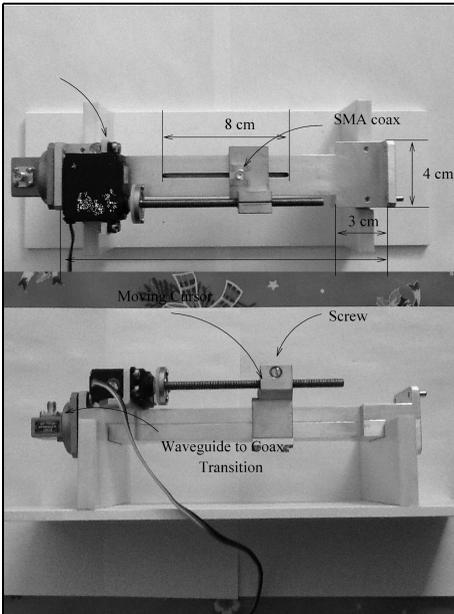
$$VSWR_{dB} = 20 \log_{10} \frac{V_{max}}{V_{min}}$$

where  $\Gamma$  is the reflection coefficient of the load. Fig 3 shows the experimental setup for the VSWR measurement with the slotted line and how the standing wave of a generic load  $Z_L$  appears. The VSWR measurement results are slightly more complicated than the frequency measurement from the previous subsection.

### 2.3 Impedance measurement

The impedance value of a generic load can be estimated starting from the knowledge of the standing wave and the VSWR. The measurement procedure is slightly more complicated than the previous measurements. First of all it is necessary to record the standing wave given by a short circuit, to calculate the wavelength of the electromagnetic wave provided by the generator. Then the short circuit must be removed and the open end of the waveguide is closed with the device under test represented by a generic load  $Z_L$ . The standing wave pattern for the load  $Z_L$  is recorded, the distance  $d$  between the first maximum of the standing wave pattern and the first minimum is measured as shown in Fig 4. Then the following relationship can be used to calculate the complex impedance of the load:

$$Z_L = Z_0 \frac{1 - j(VSWR \cdot \tan(\theta))}{VSWR - j \cdot \tan(\theta)} \quad (4)$$



**Fig 5: Photo of the developed experimental automatic slotted waveguide measurement system.**

where:  $\theta = 360d\pi/d\sqrt{\epsilon_r}$

is the wavelength inside the waveguide

$d$  is the distance between the two minima measured as shown in Fig 4

$Z_0$  is the characteristic impedance of the waveguide, for a rectangular waveguide that is  $Z_0 = Z_{TE_{10}}(f)$ .

The same calculation can be performed graphically with a Smith Chart. The measurement of impedance requires a long time and an expert operator, however all the calculations and recording of the standing wave pattern will be performed automatically by the prototype developed.

### 3.

## Prototype Description

In this section the automatic slotted waveguide prototype is described in details. The rectangular waveguide with dimensions,  $a = 2.1\text{cm}$  and  $b = 1.0\text{cm}$  was fabricated with two blocks of aluminium with a slot of thickness  $s = 2\text{mm}$  and length  $l = 8\text{cm}$  in the upper section of the structure. The length of the waveguide segment is  $L = 20\text{cm}$ . The field probe is a monopole fitted with an SMA connector and placed exactly in the middle of the waveguide to maximise the coupling between the probe and the electromagnetic wave inside the waveguide. The probe and the SMA coaxial connector are mounted on a moving carriage connected to a long screw. The screw is coupled to a servo motor and this moves the carriage and the probe along the line with a high degree of accuracy. The servo motor is an HITEC HSR-1422CR able to continuously rotate over 360 degrees. The detector is fabricated with an HMSM2850 Schottky diode inserted into a segment of aluminium pipe and fitted with two SMA coaxial connectors. The photo of the slotted waveguide prototype is shown in Fig 5. A PIC16F876A microcontroller is used to control the movement of the probe and acquire and the data related to the standing wave pattern. It provides the results of the measurements on an LCD display or sends them to a remote display unit by means of a serial interface. The PIC16F876A has two PWM control lines, four A/D conversion channels, a serial channel, and three 8 bit I/O digital ports. For this project a PWM line is used to control the servo motor and one of the A/D channels is used to acquire the value of the standing wave for each probe position. The digital port D is used to control a standard two rows 16 characters Hitachi LCD display and the serial line is used to send the data to the remote display unit that is a laptop computer.



**Table 1: Measurements of the microwave Gunn generator with the slotted waveguide compared with the data obtained from a spectrum analyser.**

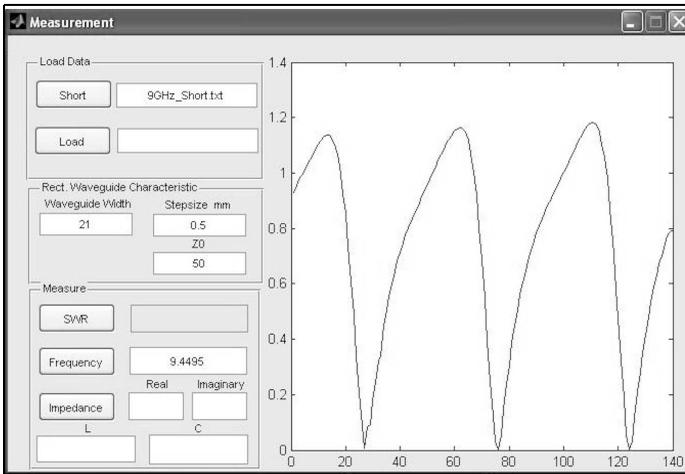
Frequency (GHz)	8.000	8.5000	9.000	9.500	10.000	10.500	11.000	11.500	12.000
Spectrum analyser	8.321	8.715	9.432	9.811	10.331	10.821	11.332	11.851	12.411
Slotted waveguide	8.301	8.705	9.373	9.821	10.212	10.810	11.309	11.844	12.491

The use of the measurement system is quite simple and suitable for inexperienced operators. It is only required to record the standing wave given by the reference short circuit load then after connecting the load under test the operator has only to push a button and the system will display a measurement of the frequency, VSWR, and complex impedance. To make the system more effective a graphical user interface has been developed in MATLAB, with the graphical user interface (GUI) it is also possible to visualise the standing wave on a graph. A PCB coaxial connector is used to connect the A/D channel to the output of the detector by means of a coaxial cable.

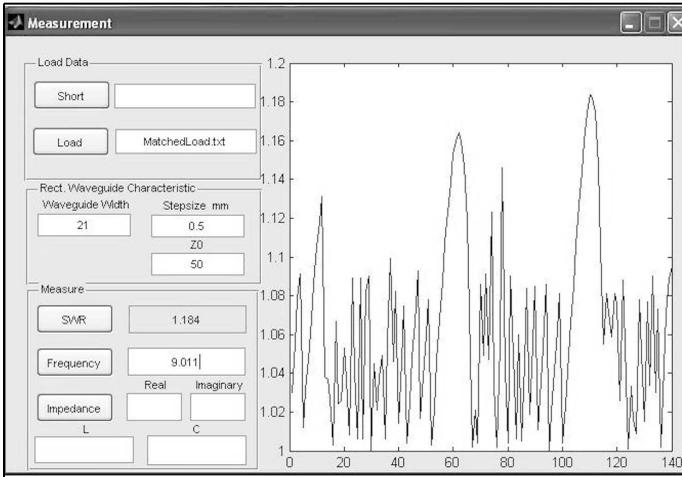
different reference loads, and the measurements made will be compared with those obtained using commercial devices such as a spectrum analyser and a VNA to correctly characterise the experimental prototype. The first test concerned the frequency measurement of an old microwave X band Gunn generator. One side of the slotted line was connected with a coax to waveguide transition and a semi rigid coaxial cable to output of the generator. The other end of the slotted waveguide was closed with the reference short load. Fig 6 shows a screen shot of the GUI for a frequency of  $f = 9\text{GHz}$ . As can be seen the standing wave pattern shown is quite clear, the peaks and troughs are evident. The frequency is shown as  $f = 9.41\text{GHz}$ , a value confirmed by a spectrum analyser that indicated a frequency of  $f = 9.401\text{GHz}$ . Measurements using the generator have been performed for the whole frequency range between 8 and 12GHz and the data compared with those obtained from a spectrum analyser. The results are summarised in Table 1. From the data in Table 1 it can

#### 4. Experimental Results

In this section the experimental measurement system will be assessed considering



**Fig 6: Measurement of a microwave generator. Snap shot of the MATLAB GUI for the frequency measurement at  $f = 9.4495\text{GHz}$ .**



**Fig 7:**  
**Measurement of a rectangular waveguide matched load. Snap shot of the MATLAB GUI at  $f = 9.011\text{GHz}$ .**

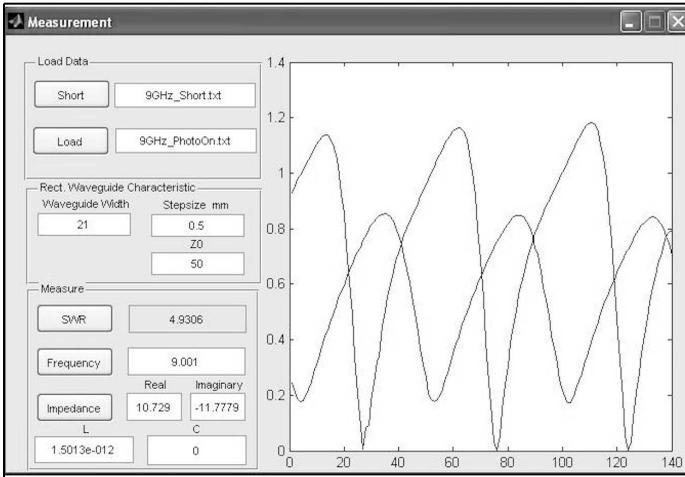
be seen that the generator requires an alignment of its frequency scale since a shift of about 0.3GHz has been observed.

The second experiment consider the measurement of a commercial X band dummy load for rectangular waveguides. The slotted line was connected to a microwave generator and the other side with the matched load. The VSWR was measured over the whole frequency band with a frequency step of 0.1GHz. Fig 7 shows the standing wave pattern measured at 9.0GHz, at this frequency the measured VSWR = 1.184. As it can be seen the variations of the standing pattern are quite limited. The data sheet for the load guarantees a VSWR < 1.2 over the whole X band. The measurements obtained with the automatic slotted waveguide have been compared with the data obtained using a commercial VNA and confirm the data shown in the data sheet.

In the third experiment an X band pyramidal horn antenna with a gain of about 17dBi was measured. The antenna data sheet gives a VSWR < 1.3 for the whole working frequency. For the sake of the correctness the measurement should be done inside a shielded semi anechoic chamber, to assure free space conditions. To simulate the free space conditions as closely as possible the antenna was connected to the slotted waveguide and then

aligned along the vertical direction pointing toward the sky. The VSWR measured with the proposed measurement system confirmed the data given in the data sheet, the worst VSWR = 1.3 measured at 11GHz.

In the last experiment a vector measurement was performed. In particular a microstrip stub was measured at a frequency  $f = 9.0\text{GHz}$ . The measurement first recorded the standing wave pattern obtained with the short. This step is mandatory to obtain the wavelength  $\lambda$  and then the reference necessary to measure the distance  $d$  from the first minima of the standing wave pattern produced by the load. The short was removed for the second step and the load mounted on the open end of the slotted waveguide. The microstrip stub is fitted with an SMA connector and then connected to the open end of the waveguide using a coax to waveguide transition. The standing wave pattern of the load was recorded and the impedance measurement performed. The measured impedance at  $f = 9\text{GHz}$  was  $Z_L = 10.729 - j11.7779$  as shown in Fig 8 that displays the two measured standing waves. The load shows an inductive behaviour. For the sake of comparison the same measurement was performed with a VNA, the difference obtained between the automatic slotted waveguide



**Fig 8: Impedance measurement of a microstrip open stub at 9.001GHz. Snap shot of the MATLAB GUI.**

was less than 8%.

## 5.

### Conclusion

In this work a measurement system based on an automatic slotted waveguide able to perform measurement of amplitude and phase over the whole X band (8-12GHz) has been designed fabricated and experimentally assessed. The reported experimental results, performed on reference loads, demonstrated the capabilities and the efficacy of the proposed system, confirming that such a kind of device could be considered as a good alternative to more expensive measurements systems.

## 6.

### References

- [1] D. Pozar, Microwave Engineering, John Wiley and Sons, New York, 1998.
- [2] N. Marcuwitz, Waveguide Handbook, McGraw Hill, New York, 1951.
- [3] Agilent Application Note 12871, Understanding the fundamental principles of vector network analysis, USA, 1997.
- [4] R. Sorrentino, G. Bianchi, Ingegneria delle microonde e radiofrequenze, McGraw Hill, 2006.
- [5] Massimo Donelli email: [massimodnll@gmail.com](mailto:massimodnll@gmail.com)



## The UK Six Metre Group [www.uksmg.com](http://www.uksmg.com)

With over 700 members world-wide, the **UK Six Metre Group** is the world's largest organisation devoted to 50MHz. The ambition of the group, through the medium of its 56-page quarterly newsletter 'Six News' and through its web site [www.uksmg.com](http://www.uksmg.com), is to provide the best information available on all aspects of the band: including DX news and reports, beacon news, propagation & technical articles, six-metre equipment reviews, DXpedition news and technical articles.

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Dirk Müller, DB6FM

# The RTL-SDR

## Working with a USB stick

Software defined radio is all the rage and there is now a wide variety of equipment and application software for this purpose. Commercially available DVB-T USB sticks can be used not only for their intended purpose but can be “converted to” an SDR receiver with different drivers and additional software. This is a popular area that cannot be achieved without specialist knowledge and skill. This is a practical guide to my first attempts with the RTL-SDR.

whose name derives from the chipset, comes from the simple use of the IQ stream. A lot of fun and amazement among the VHF - SHF community can be had with special open source software drivers. This offers an inexpensive entrance into the world of software defined radios and is sufficient for many users as an easy wide band receiver and analyser. Due to the performance of modern PCs and because of the enormous variety of cheap DVB-T sticks available, this offers an entirely new perspective that can complement the existing receivers and scanners. With an ELONICS E4000 tuner it is possible to reach a useful range of approximately 55 to 1700MHz. Versions that work to over 2200MHz have been found. All the versions tested have a gap of about 100MHz in the receiver coverage in the range of 1100MHz. Nevertheless, the 23cm band should be avail-

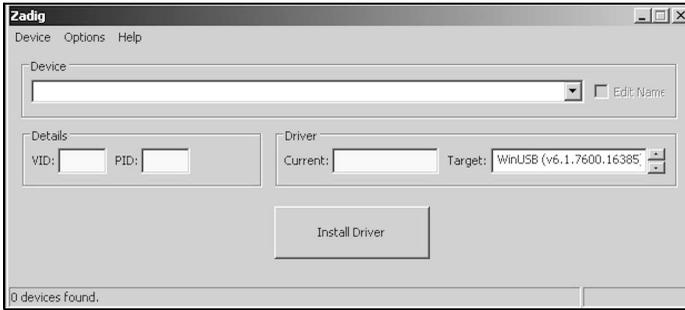
### 1.

#### The RTL-SDR

The versatility of the RTL-SDR receiver,



**Fig 1: Some variants of the DVB-T USB stick with different body shapes.**



**Fig 2: The program "Zadig" helps in the selection of the device and driver installation.**

able. The reception parameters vary from device to device and can be different in similar looking devices due to different chipsets.

## 2.

### The installation

What do you need?

- A clean installation of Windows XP, Windows Vista, or Windows 7 with the latest available Service Pack!
- Net Framework 3.5 (download from [2] or later)
- An RTL2832U stick with ELON-ICS E4000 tuner
- A high-performance computer
- Administrator rights to run the driver
- Up-to-date antivirus software

As so often with computers and freeware software solutions, there are usually some obstacles to clear out of the way before the fun can start properly. The savvy PC user is able to do this "by magic" and, if he is lucky, it works it right out of the box. But generally, it is better to follow a known method during installation that has proven to be successful several times in difficult cases. That is successful preparation.

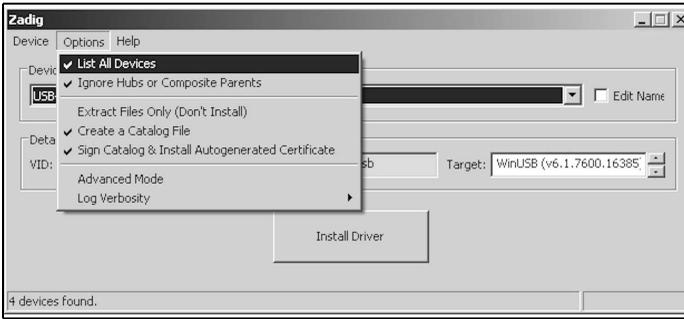
The device has almost unlimited capabilities, you can expand further in the future according to your own knowledge with ambition and existing software.

To begin with the use the basic functions that are many times better than those found even in conservative analog receivers especially comparing the purchase price of an RTL SDRs..

Like any PC hardware, you need special drivers, but the original drivers from the manufacturer offer no benefit for the alternative use as a wide band receiver. They can even be an obstacle when both drivers are installed on the same USB socket. If you want the device to operate with the functions envisaged by the manufacturer and the alternative use as a wide band receiver, two different USB ports are recommended. Only the alternative use is described below!

Use a USB port that has never been used for any device or has been completely removed so both the installation and the registry entries have been removed.

All important files for "SDR# (pronounced SDR sharp)" are located in the folder [1] and run directly (without installation). Save the compressed file in a known location on your hard drive, unzip it there and follows the instructions in this article to install. The installation refers only to the folder [1] that has been extensively tested with the versions of Windows: XP, Vista, and Windows 7. Now open the folder RTL-SDR [1] and the program "Zadig" (Fig 2).



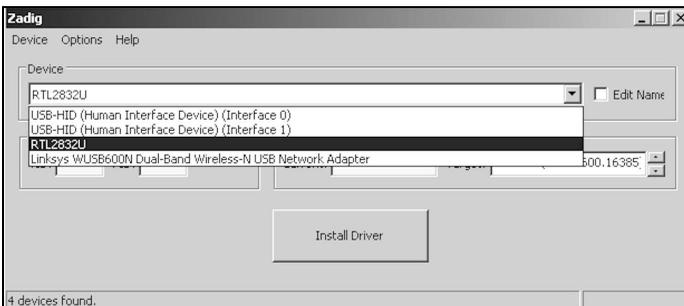
**Fig 3: Enabled options; the list shows that four devices were found.**

### 3.

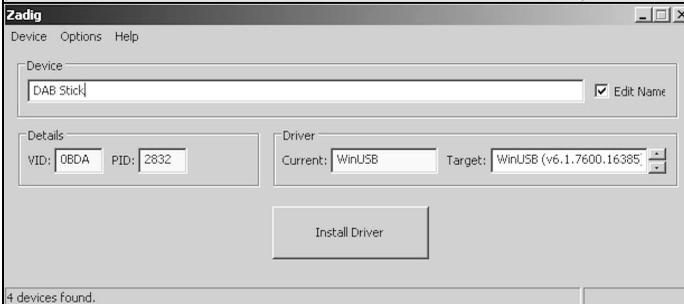
## Zadig contains the driver

When the program "Zadig" is started the devices will be found. If they are not found, select "Options" from the tab menu and select "List all devices", see Fig 3. The window should show that four devices were found. A maximum of two entries per installed RTL stick, (in most cases only one entry) are shown in the Device Manager for the hardware that you want to install, see Fig 4.

Ideally the name is already RTL2832U and this plus several programs and plug-ins are already available. Some sticks are also known as DAB stick or similar. If you cannot identify the name, briefly unplug the USB stick and observed the entry that disappears. The name varies depending on the source of the product or firmware. Alternative names, instead of RTL2832U can be used by some programs, although they may not be properly installed by "Zadig". One that I tried was identified as "HSDSR". The device can be renamed to achieve wide compatibility by using "edit name". see Fig 5.



**Fig 4: Ideally the name of the detected device is displayed; Here RTL2832U.**



**Fig 5: Using the "Edit Name" option to change the name of the hardware to RTI2832U.**



**Fig 6: "Zadig" automatically selects the correct driver to the specified hardware.**

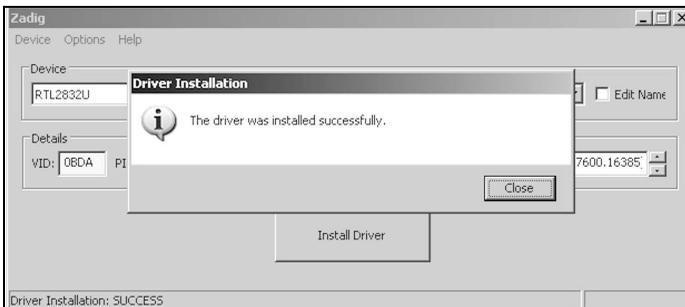
Now you can change the name of the hardware to "RTL2832U" in the white box shown in Fig 4. "Zadig" will select the correct driver in the greenish box so press the button "install driver" (Fig 6). If all program dependencies, NET Framework, and so on have been solved, a message as shown in Fig 7 should appear after a few seconds.

Normally Windows Vista and Windows 7 contain the correct NET Framework versions, or they have already been installed on the PC by some other route.

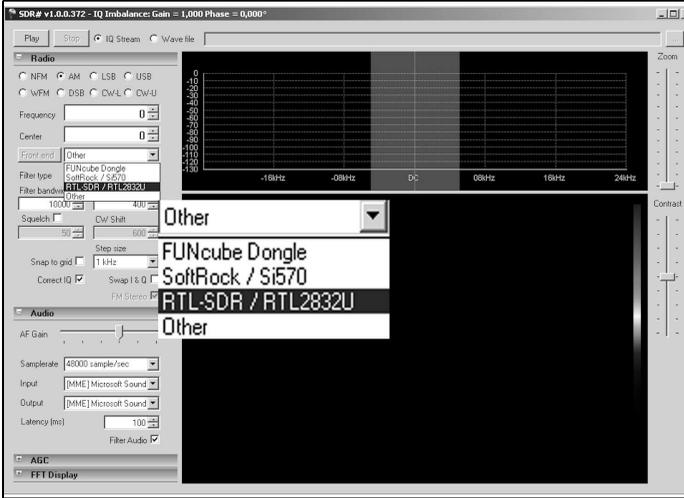
Now nothing is in the way of further use. At least the program "SDR#" should now be able to deal properly with the SDR hardware. "SDR#" is ideal for general use. Other interesting programs with more complicated adjustment procedures can be used with the stick. "SDR#" will be developed even further to provide more facilities so watch for new releases. It is open source code so the program has found many interested parties who have adapted it for their own purposes, or integrated additional functions. There are several variants on the Internet, some

older, some newer but they may have problems such as; not stable, resource hungry or fraught with bugs. A stable version should be used that can save parameters automatically while closing the program; a feature that is available in the official version. Some versions that I downloaded completely failed with the existing drivers or libraries. The folder [1] contains the all the required software (freeware) and the appropriate program components.

Computer crashes can also be caused by faulty or poorly shielded USB cables especially when they are used for transceivers. The same problem can cause interference to USB keyboards and mice. This is caused by inferior quality cables so you should not cut corners to save money but use high quality USB cables with ferrite chokes.



**Fig 7: Now nothing more is in the way of further use.**



**Fig 8: Open the program "SDR#" direct from the main folder by double clicking the SDR# icon. The program opens with this screen.**

#### 4. The program "SDR#"

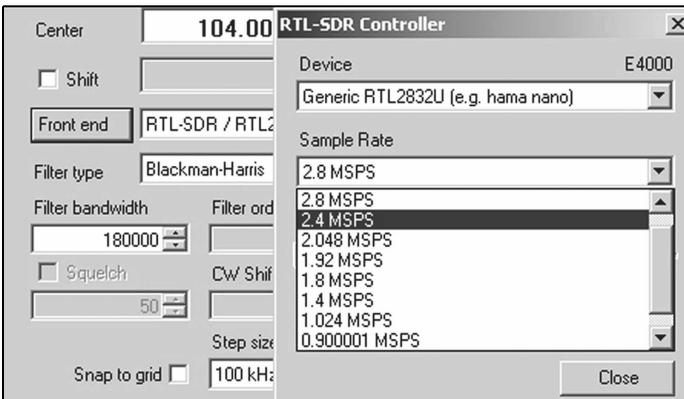
The program is loaded by double clicking the program icon "SDR#" from the main folder. When the program has loaded, select the hardware by choosing RTL2832U (Fig 8). The saved version should load defined by the existing configuration file. Now select the modulation type, the filter bandwidth and unlock the squelch.

The button "Front End" allows you to choose depending on the performance

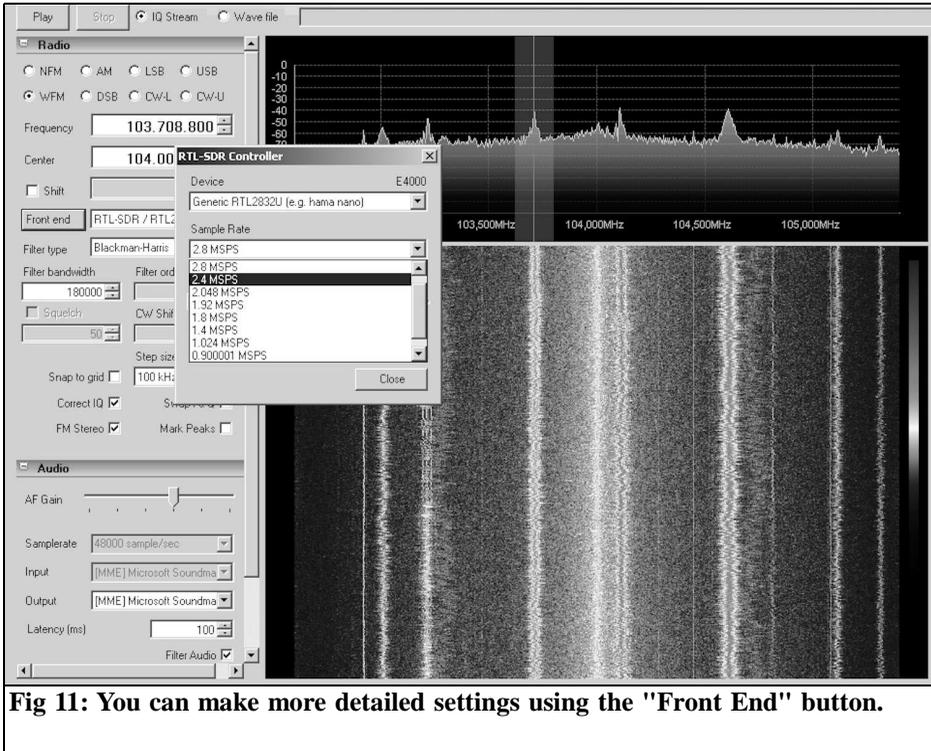
and utilisation of your PC, this should be adjusted downward if errors occur in the frequency spectrum being observed. Generally speaking, one should not exceed 2.4MSPS = 2.4MHz otherwise distortions and packet loss occur. The lowest setting is 0.9MSPS = 900kHz width (Fig 9).

First, choose the "WFM" mode and test the reception in the FM radio band. There you can immediately start your first attempt at reception even with a small antenna. The complete frequency in Hertz is always displayed, the dots are of no important; they are added automatically by the program.

The desired frequency is entered in "Cen-



**Fig 9: Setting the sampling rate.**



tre". The bandwidth can be chosen depending on the peripherals and performance of the computer up to a maximum of 2.4MHz. At 2.4MHz the quality of the signals is sufficient to apply further digital processing. An frequency offset can be compensated for by a correction factor setting called "Shift".

Choose the centre frequency; click the button "Play" to launch the spectrum display. The red line in the light grey transparent small window indicates the spectrum and the demodulated bandwidth. The window can be moved or scaled and varied so that nominal frequency and bandwidth are as required.

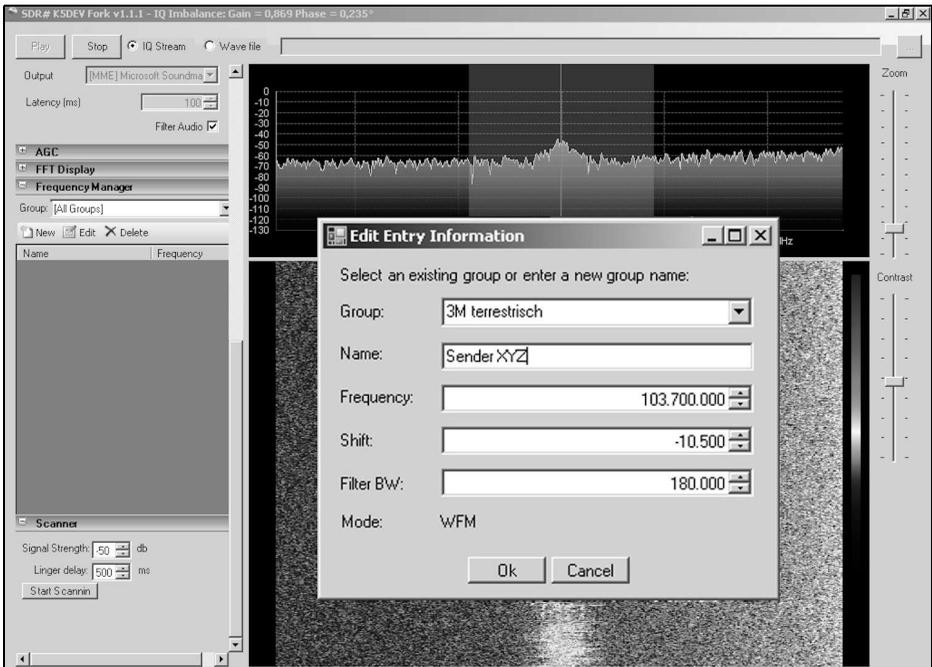
Depending on the sampling rate, the bandwidth is shown as in Fig 10. The 3m band is always a good test environment to test the function of the stick before exploring other areas.

### Note about the PC:

The power consumption of the PC and the load on the operating system increases for higher IQ stream bandwidths (0.9-2.4MHz), higher audio sampling rates and the demodulation bandwidth. The energy consumption causes the system to heat up! Some Netbooks can be overwhelmed, depending on their architecture. Smooth operation should be possible with desktop PCs made later than 2008. A 3.6GHz PC with the core 2 Intel architecture was used for these experiments and all modes and bands were correctly used.

### Caution:

Because the software is installed can interfere with existing software and the computer hardware is used excessively, failures or damage can occur – the author assumes no liability. Everyone is respon-



**Fig 11: Named groups, frequencies, and other details can be set using the "Frequency Manager".**

sible for their own setup.

---

## 5.

### Frequency Manager and scan modes

---

Frequencies can be named and organised in groups using the Frequency Manager. These groups can be scanned (Fig 11). To do this, select the "Frequency Manager" and click on "New". Additional tabs provide further facilities:

- For SSB operation, the adjustable AGC parameters prove to be useful.
- The waterfall view can be customised from the "FFT Display" option.

Depending on the antenna and site you

can receive a wide range of channels. Considering the price of the stick it is good value for money but may lack input selection. This is a do-it-yourself system so individual experiments can improve the results.

---

## 6.

### Additional Requirements

---

A good sound card is an advantage and recognised by all the programs improving overall performance but even a cheap on board device is sufficient for simple operation modes.

The installation has been tried in several different ways and has been successfully completed. Some parts of the program have been updated separately but using only programs directly from the folder



[1] is recommended. The motto: "Never touch a running system!" is very true. All programs required for the stick with the dependencies for NET Framework and service packs as well as all files matching each other are in the folder.

Using Windows 7 helped to resolve problems with starting "SDR#" from the folder [1] in the event of a fault "ext IO installation". This was probably caused by some system dependencies that were not present on other PCs. The "ext-IO installation" online update found a better SDR program "HDSDR" but this requires many times the performance of "SDR#". There are also additional settings for slow PCs.

are externally completely identical, even though they are different.

## To be continued with the topics:

- Extension of the reception range for the missing band from 0 to 55MHz using a shortwave converter
- Specifications of different SDR sticks
- The use of alternative programs.

## 7.

### Source of hardware

The stick is distributed with the following names: Noxon, Ezcab or Hama nano. A search on the Internet should give suitable suppliers of these specific models otherwise you will end up with older versions of sticks or unusable chipsets. Some sticks are visually similar, or

## 8.

### References

[1] Folder containing SDR stick software; download from [www.vhfcomm.co.uk/downloads/SDR-2-2013](http://www.vhfcomm.co.uk/downloads/SDR-2-2013)

[2] NET Framework 3.5; download from <http://www.microsoft.com/en-gb/download/details.aspx?id=21>

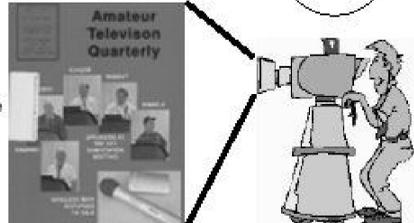
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Gunthard Kraus, DG8GB

# Development of a preamplifier for 1 to 1.7GHz with a noise figure of 0.4dB

**This article is a revised and expanded version of a lecture given at the 2012 VHF meeting in Bensheim. It shows the current state of development of low noise MMIC amplifiers and a sample demonstrating the procedure for a successful design. Measurements of the prototype should confirm the design and simulations.**

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## 1.

### Overview

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The development of high quality integrated microwave amplifier modules (MMICs) is constantly in flux, leading to better performance. Therefore it is interesting to build such an LNA because of the following benefits:

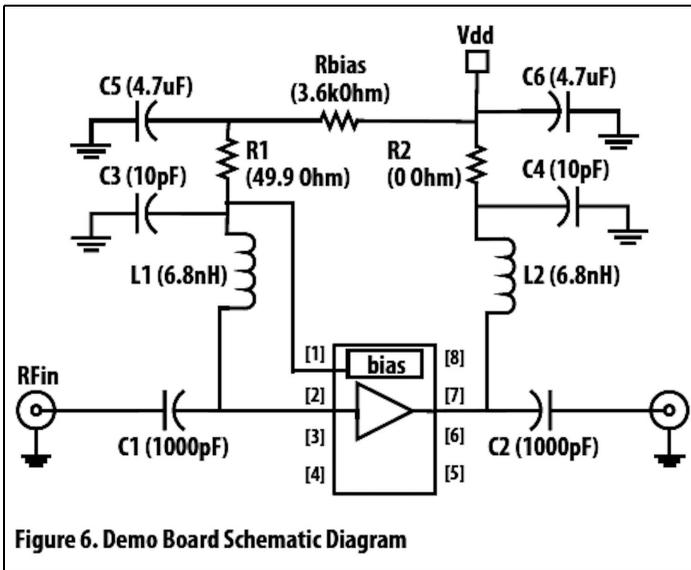
- Input and output are optimised for a 50 $\Omega$  system
- The noise figures have fallen to under 0.5dB in a 50 $\Omega$  system at higher frequencies (e.g. above 500MHz)
- A single device achieves approximately 20dB gain up to 2GHz.
- Little external circuitry necessary.

The sentence "No roses without thorns" applies here. You should know the problems because you can only achieve these

values when you solve a whole range of tasks:

- These MMICs are tiny SMD components without connecting feet. A die is used with the dimensions of 2mm x 2mm and with 4 connections on two opposite edges (Pads) plus ground.
- The common ground of the chip is often not fed to the edge of the package but in the middle of the underside
- The layout design requires very high accuracy (tracks and connection pads on the IC are typically 0.2mm with a maximum width of 0.5mm)
- The additional SMD components for the external circuit should be 0603 size (1.25 x 0.75mm) as far as possible

The cutoff frequencies of the components are so high that the stability below 1GHz and unconditionally up to 10GHz must be controlled. The operating point must be very carefully stabilised due to the high currents (often over 50mA per IC) and the supply voltages decoupled even more careful and for extremely broadband. The thickness of the board was reduced, for all applications due to this extended frequency range, to 0.25mm to prevent undesirable signal modes on the strip lines. This means that many vias are



**Fig 1:** This circuit is used as a pattern in the data sheet and two application notes; It is the starting point for my own development.

**Figure 6. Demo Board Schematic Diagram**

necessary so it cannot be made manually with silver plated tubular rivets.

This project is for use in the 23 cm band (approximately 1300MHz) and intended to receive METEOSAT at 1691MHz. The following data was used to trawl the Internet for an MMIC suitable for development:

- Noise figure: maximum 0.4dB
- Amplification (S21) approximately 20dB
- Absolute stability (k greater than 1 up to 10GHz)

The choice was Agilent Avago, whose sourcing proved absolutely no problem (die components took one week to arrive after ordering online at Mouser.com) and the price (€80 for 25 pieces) for the "MGA 635P8" was acceptable.

## 2.

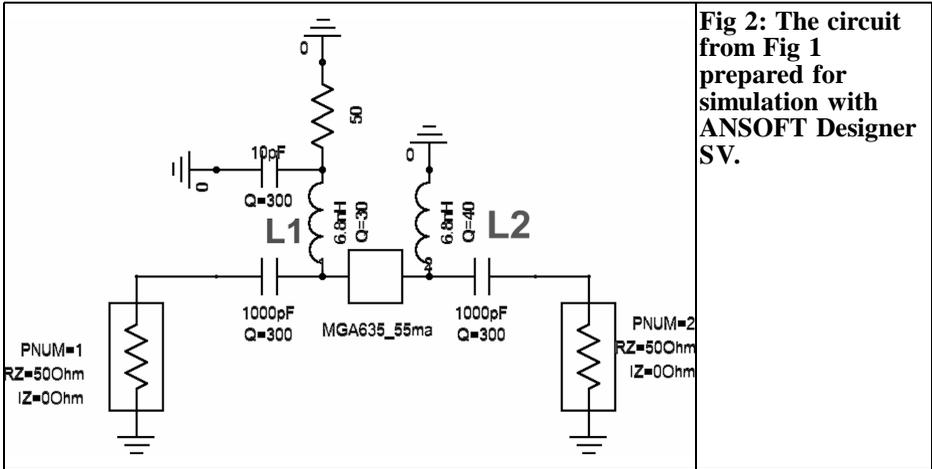
### The development of the circuit

The starting point was the data sheet for the MMIC together with the downloaded

S parameters and two application notes provided by the manufacturer for 2500MHz and 3500MHz [1] [2] [3]. The same basic amplifier circuit and the same PCB layout are used in all cases. Only the component values are adjusted to the different frequency ranges. Fig 1 shows this circuit and it is not hard to understand:

- It uses a supply voltage of VDD = +5V
- Inside the MMIC package is a GaAs pHEMT Cascode amplifier, as well as a bias circuit.
- The operating point is set to the desired 55mA using pin 1 to connect a resistor ( $3.6k\Omega = R_{bias}$ ) to the bias circuit and the generated bias is connected to the gate of the first pHEMT on pin 2 through  $L1 = 6.8nH$ .
- The other inductor ( $L2 = 6.8nH$ ) provides the load resistance of the second stage.

A major problem of the HEMT components is stability at low frequencies, they tend to oscillate. A simple trick helps to deal with this: with decreasing frequency



**Fig 2: The circuit from Fig 1 prepared for simulation with ANSOFT Designer SV.**

the additional resistor R1 of about 50Ω is introduced at the input pin 2 that effectively prevents such an oscillation.

**Explanation:**

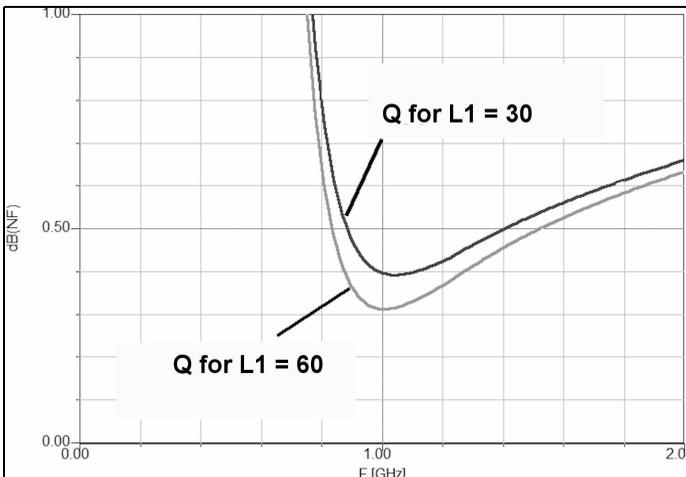
The reactance of L1 (6.8nH) decreases with decreasing frequency but the reactance of C3 (10pF) increases. So at some frequency only R1 is active on the input pin.

In addition the very small inductance L2 6.8nH as a load resistance for the second stage reduces amplification at lower frequencies down to zero. The resistor R2 also shown in the circuit with a value of

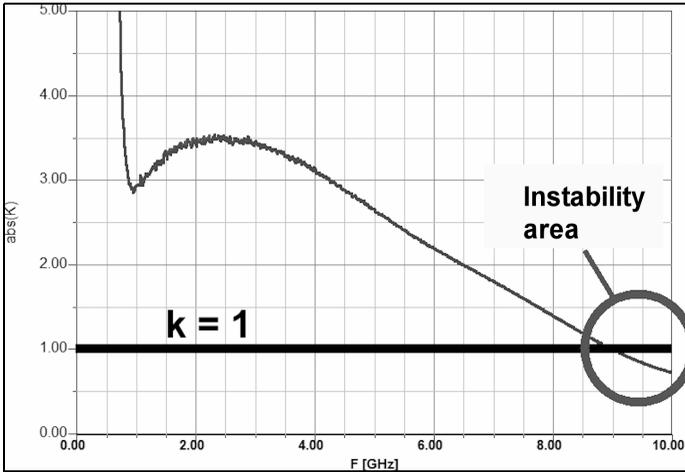
zero ohm was ignored.

Before the development began this circuit was investigated with ANSOFT Designer SV, Fig 2 shows the created simulation diagram.

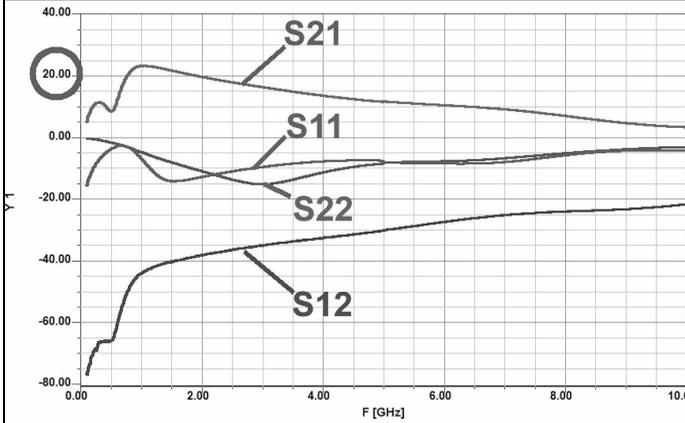
First, the noise figure in dB was simulated and at the same time the influence of the quality of L1 = 6.8nH was determined (see Fig 3). In both cases studied the NF remains below 0.6dB. However, the noise figure still needs to be reduced for our purposes in the desired frequency range from 1.3 to 1.7GHz to meet the requirements.



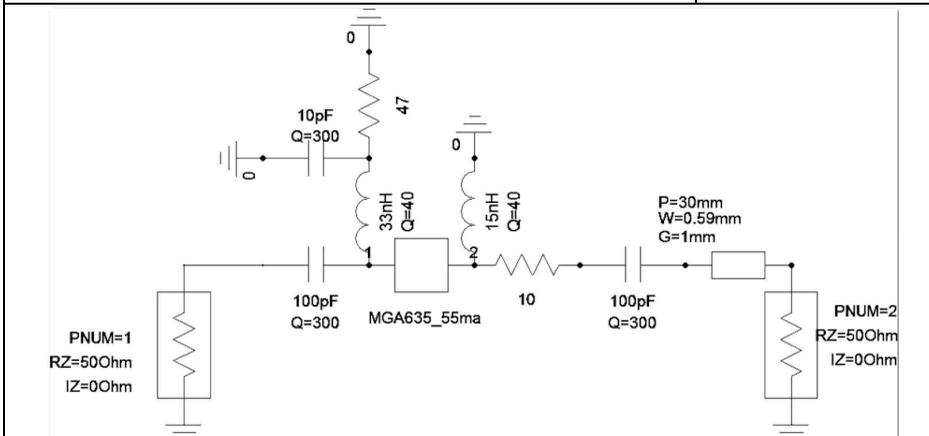
**Fig 3: The noise figure achieved from the circuit in Fig 2 is unsatisfactory and depends heavily on the quality factor Q of the choke L1 = 6.8nH.**



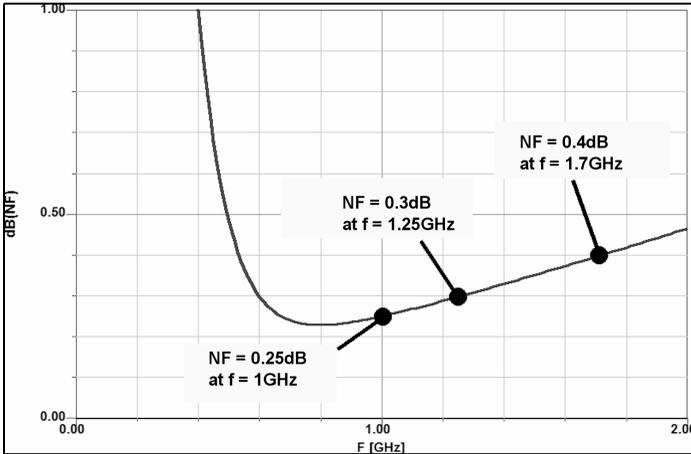
**Fig 4:** Because the developer was not carefully enough, this circuit will oscillate.



**Fig 5:** The S parameters look very promising so there is hope.



**Fig 6:** This is the simulation circuit after some work (see text).



**Fig 7: The result of the simulation to control the noise figure is almost a dream.**

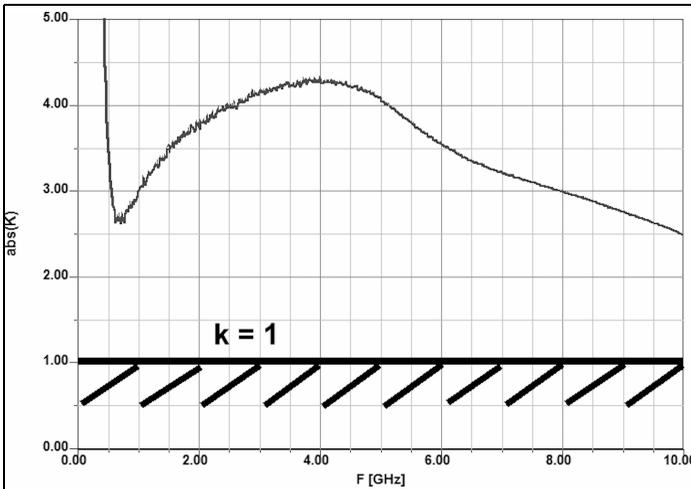
The stability was investigated up to 10GHz and it is evident that this must be improved (Fig 4). This is only under control up to 8GHz from the simulation.

The S parameters look good - S21 is shown in Fig 5 and it is greater than 20dB between 1GHz and nearly 2GHz.

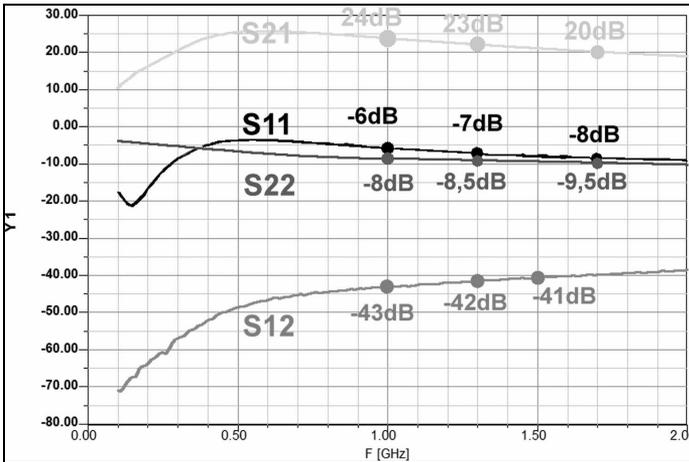
The circuit was adapted to the frequency range from 1 to 1.7GHz (Fig 6). This was carried out by gradually increasing of the values for L1 and L2 in accordance with the simulation results for the noise figure and permanent control of stability.

The desired value of 0.4dB was achieved with L1 = 33nH / L2 = 15nH and a small

additional resistance of 10Ω in the output revealed sufficient stability at 9 to 10GHz (fitted close to the output pin of the MMIC). The amplification, S21, dropped a bit as a result but not below the requirement of 20dB at 1.7GHz. The two coupling capacitors C1 and C2 on the input and output were reduced to raise the lower frequency limit. The output microstrip line (more correct: "Grounded Coplanar Waveguide" with a track width of 0.59mm, a gap distance of 1mm on each side and a length of 30mm) could not be missed in the simulation and that resulted in the final simulation diagram. The noise data achieved is shown in Fig



**Fig 8: And it looks like the stability factor "k" gives a really stable circuit: significantly greater than 1 up to 10GHz.**



**Fig 9: The S parameters have not suffered much due to the changes.**

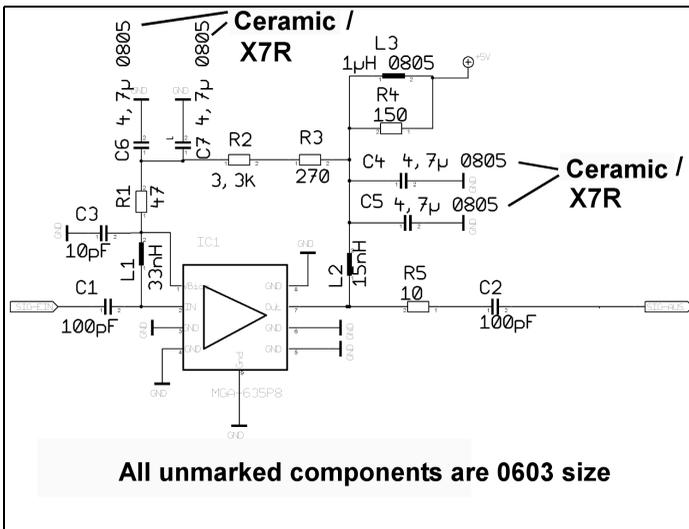
7 as a result of the simulation.

The required stability ( $k$  greater than 1 to 10GHz) is now no longer an issue, as shown in Fig 8. The simulated S parameters also give no cause for concern (Fig 9).

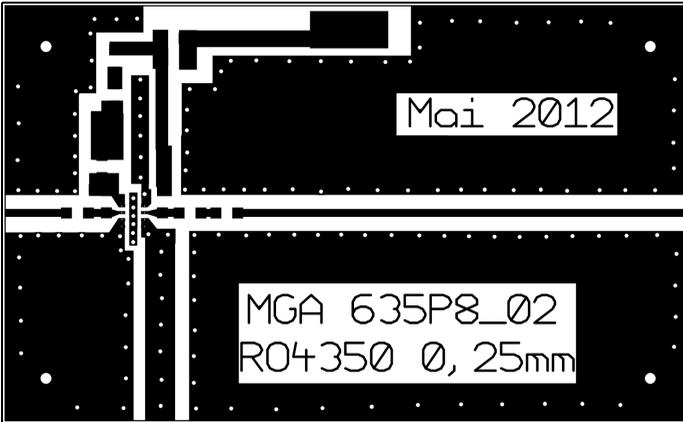
The practical circuit has been modified slightly compared to that proposed by Agilent. Fig 10 shows the final version.

The circuit board design could now be done (material: Rogers RO4350B, 35 $\mu$ m copper coated on both sides, board thick-

ness = 10mil = 0.254mm). Overall dimensions are 30mm x 50mm as shown in Fig 11. There is a short microstrip on the left up to the DC isolating capacitor before connecting to the input of the MMIC. The output stripline is 30mm long and both lines are designed as "Grounded Coplanar Waveguides" with a track width of 0.59mm and a gap of 1mm. The line calculator integrated free of charge in the ANSOFT Designer SV software provided these values for  $Z=50\Omega$ .



**Fig 10: This circuit diagram was developed for the practical circuit.**



**Fig 11: The double sided PCB, size 30mm x 50mm. See text for details.**

The central ground connection on the bottom of the MMIC required its own 0.6mm wide ground island with 6 vias that can be seen in Fig 11. All other ground islands on the circuit board have enough carefully separated vias. For those who do not heed these rules with the separate islands including many vias, the circuit will very quickly oscillate. Note: all vias have a diameter of only 0.3mm

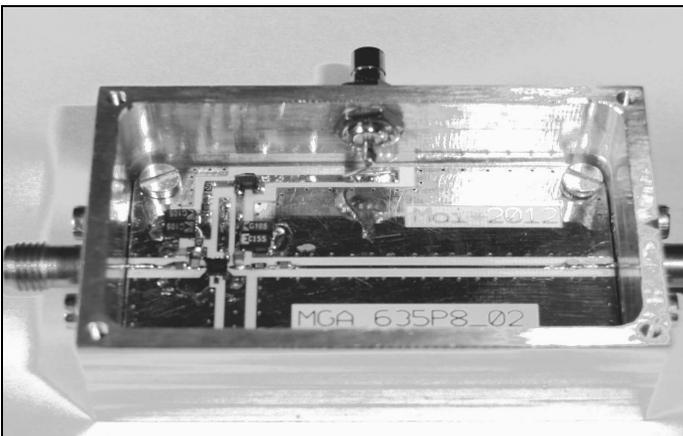
### 3.

### The prototype

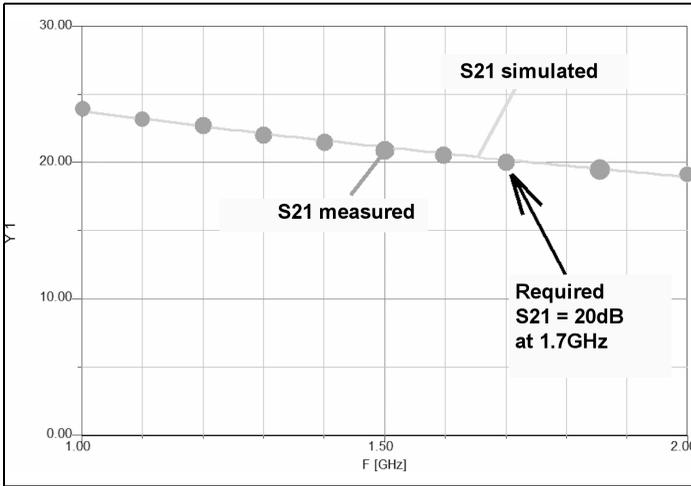
The worry with homemade PCBs is that

the silver plated tubular rivets fall out with a low board thickness of 0.25mm. So a professionally manufactured and through hole plated printed circuit board was chosen but that is not exactly cheap.

This only needs a Gerber plot to be created (1 mouse click in the "Target" software) and mailed to the PCB manufacturers then everything else runs by itself. Unfortunately there is the so-called "setup costs" and a minimum order quantity of 4 PCs due to the minimum size of board for the production base load. The people at "Aetzwerk München" [5] were very cooperative; there was even the correct PCB material (RO4350B 0.25-4mm thickness) in stock. But even the "minimum order" costs (including PCB material) was €235 for 4 PCBs



**Fig 12: Looking into the finished housing everything is small.**



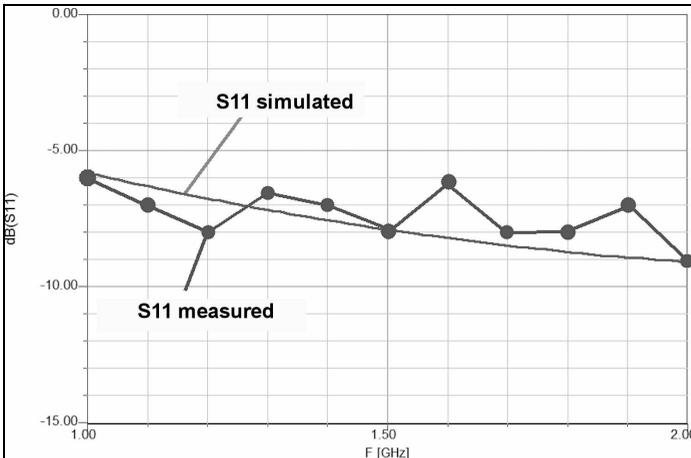
**Fig 13: When the S21 theory and practice are the same the story is complete.**

A comment on the PCB material: usually for this purpose Rogers "RO4003" is the lowest priced and low loss standard material. But it is not "flame retardant", if there is a fire, what is the advice? It has been given the appropriate additives and is now called "RO4350B". This has changed the electrical data slightly (εr rises slightly, but the losses are higher, at 10GHz: loss tangent It = 0.0027 for RO4003 and 0.0037 for RO4350. At 2.5GHz however: It = 0.0021 or 0.0031).

The assembly process is quite slow because of the 0603 size components it needs a steady hand under a stereo microscope

or an appropriate microscope (see [4]). Without SMD solder paste in a hypodermic syringe it also takes longer. It has to be attached to the solder in tiny amounts with a sharp scalpel. In addition, a narrow temperature controlled soldering tip 0.8 mm wide is required. The MMIC is only 2mm square with 4 connections on each side with a pin spacing of 0.25mm so the track and pad dimensions are tiny as well.

Fig 12 shows a picture of the unit after successful assembly and fitting into a machined aluminium housing (size = 35 x 55mm). The SMB female connector for



**Fig 14: S11 is almost the same as predicted by ANSOFT Designer SV.**

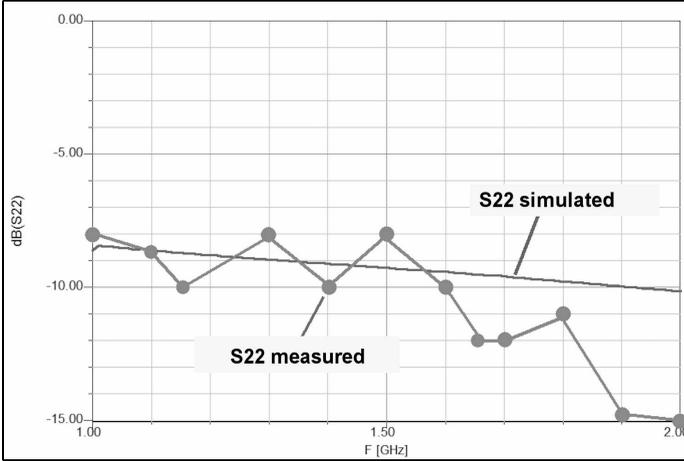


Fig 15: S22 was better than expected from 1.5GHz.

the + 5V supply can be seen at the top of the picture. The input and output signals are special SMA connectors with the centre conductor already flattened (gives the required low reflection transition from the round inner conductor within the socket to the flat microstrip line on the PCB)

An aluminium plate was placed underneath the PCB to lift the now much thinner board, with its microstrip lines, up to the flattened centre conductor of the connectors to give a good and stress free solder joint (Tip: this is absolutely necessary because it is not possible to bend the pin of the socket; this thin pin and the flat flag will break suddenly and quickly).

#### 4.

### S parameter measurements to the prototype

The S21 measurement was made with the well known vector analyser (hp8410), the associated S parameter test set (hp87-45A) and a 20dB attenuator connected in front of the input of the test piece to avoid clipping.

The S21 curve can be seen in Fig 13 and it matches the simulation exactly. The S11 measurements meander around the simulation values as shown in Fig 14.

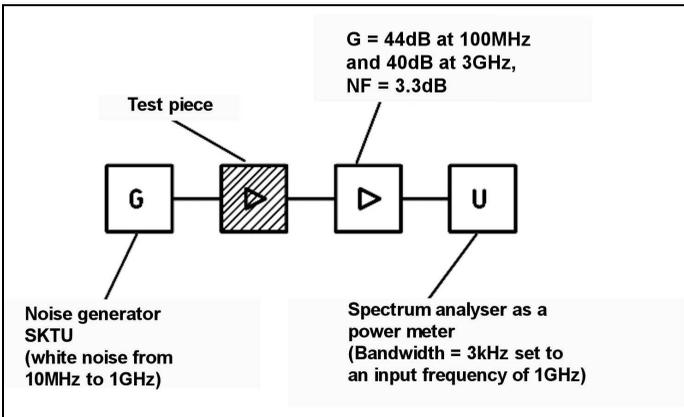
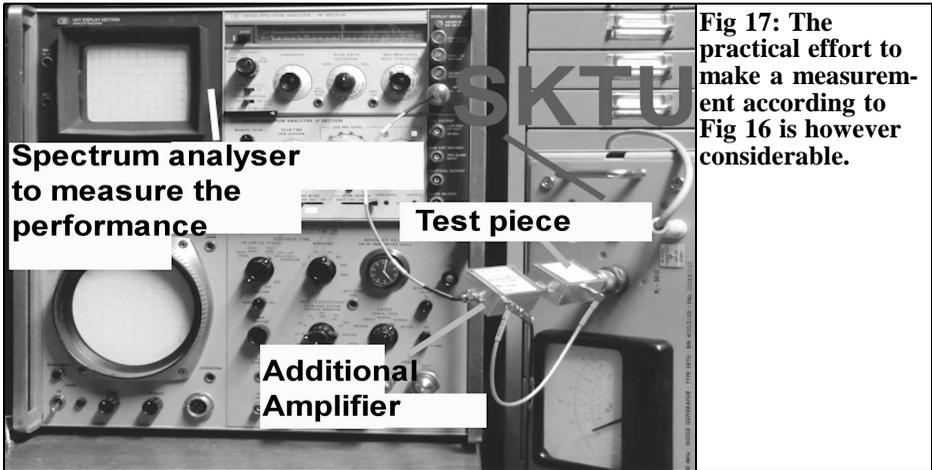


Fig 16: Measuring noise figure using the well known principle of doubling the noise power output.



**Spectrum analyser to measure the performance**

**Test piece**

**Additional Amplifier**

**Fig 17: The practical effort to make a measurement according to Fig 16 is however considerable.**

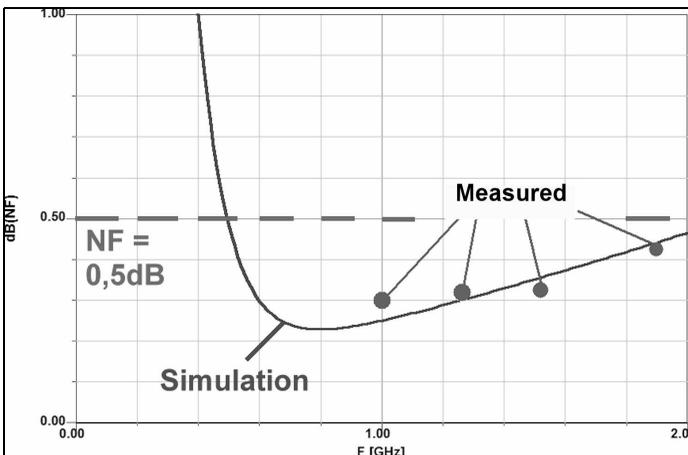
S22 matches the simulation up to 1.5GHz but is better than expected (Fig 15). The S12 measurement was more difficult due to the low amplitude. But a value of about -44dB was determined in the range from 1 to 2GHz that is still smaller than the simulation result (between -43dB to -40dB).

maximum expected, it was a very difficult to measure anything at all with the existing local laboratory equipment. Nevertheless, an attempt was made and a suitable setup for the frequency  $f = 1\text{GHz}$  was put together (Fig 16).

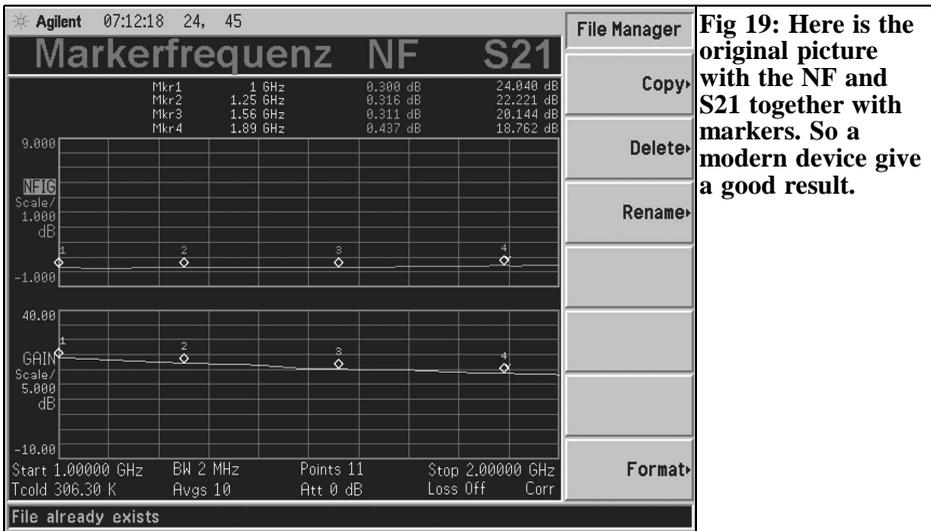
In Fig 17 you can admire what looks like something in practice. The "swept" spectrum analyser is not swept but is set as pure measuring receiver with a bandwidth of 3kHz on the frequency  $f = 1\text{GHz}$ . Then, output level of the noise generator SKTU was slowly increased until the noise power at the output of the auxiliary amplifier doubled. This corresponds to an increase of the noise displayed on the

## 5. The noise

With the very small noise figure of 0.4dB



**Fig 18: This curve can only be classified as a precious Christmas gift.**



**Fig 19: Here is the original picture with the NF and S21 together with markers. So a modern device give a good result.**

spectrum analyser of 3dB (or the displayed noise voltage by a factor of 1.41).

Now the residual noise of the amplifier is as big as the performance delivered by the noise channel and the noise figure NF in dB (or the noise factor as a linear ratio) can be read on the display of the noise generator SKTU.

Several measurements showed values of the noise factor somewhere between 1.1 and 1.2. That would be a "noise figure" (NF) for the amplifier between 0.4 and 0.8dB but because of the very low pointer deflection of the SKTU this result can only be considered as indicative. But it is at least the right size (certainly less than  $1\text{dB} = \text{NF}$ ).

The influence of the additional downstream amplifier can be neglected due to the high gain of the device being measured (24dB at 1GHz). The cascaded Noise Figure therefore only shows an increase of 0.02dB.

For more accurate measurements it relies, as always, on help from friends with a modern noise measuring instrument with high resolution and accuracy. One of these friends (Ulli Kafka with his company "Eisch Electronic" in Ulm) gave the author great pleasure with an email con-

taining pictures as well as the classification as "excellent amplifier". This will be immediately understandable if you look at Fig 18: indeed the noise figure up to 1.7GHz remained below 0.4dB and close to the simulation. It only remains to say "Thank God" and thank all contributors.

The original measurement of noise and S21 that provided the good impression was good, especially when you consider the "cold temperature specified" (Tcold) of 306.3K with about +33° Celsius during the measurement as shown in Fig 19.

For the specialist there is an addendum from the data sheet for the MGA635P8 for  $I = 55\text{mA}$  at 2.5GHz:

- Output IP3 = +35.9dBm
- P1dB\_out = +22dBm

If you then start to think about the possibilities of a two stage version for weak Meteosat signals and reception with a patch antenna ... there would be enough space on the board...



## 6.

**Addendum**

A listener of my presentation in Bensheim recently emailed me with an interesting proposal in order to determine these small noise figures with the noise generator SKTU:

"Why don't you use an attenuator with a precisely known value of 10dB between the generator output and input of the measuring device? Then you will probably need a noise level of 10.5dB delivered by the noise generator to double the output noise power indicated on the screen of the analyser. If you then subtract the 10dB of attenuation from the delivered power level you get the solution = the unknown noise figure (In this case:  $NF = 10.5\text{dB} - 10\text{dB} = 0.5\text{dB}$ ). I have done this several times in the past with success".

He is right, and this method must be tried. You are always learning.

## 7.

**Literature**

[1] Data sheet and S parameters files for the MGA635P8 from the homepage of Avago Technologies

[2] Application note from Avago: "MG-A635P8 GaAs MMIC ePHEMT 2.5GHz low noise amplifier with superior noise and linearity performance"

[3] Application note from Avago: "MG-A635P8 GaAs MMIC ePHEMT 3.5GHz low noise amplifier with superior noise and linearity performance"

[4] Soldering advice for 0.5mm pitch SMD ICs, Bernd Kaa, DG4RBF, VHF Communications Magazine, 4/2011 pp 232 - 236

[5] Etching factory Munich, Germany; PCB manufacturer website: [www.aetzwerk.de](http://www.aetzwerk.de)

**Convention for Amateur Television 2013**

- Technical talks program, with a special emphasis on "getting started in DATV"
- Demonstration area ranging from historic studio equipment to the latest DATV equipment
- Test and fix area
- Selected RF and video suppliers
- SMD soldering class
- Members bring and buy area

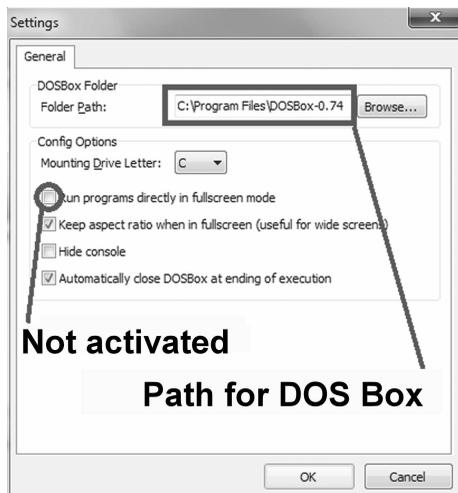
October 26<sup>th</sup> & 27<sup>th</sup> - Finningley Amateur Radio Club, Robin Hood International airport, Yorkshire.

See <http://www.batc.org.uk/cat13> for more details

Gunthard Kraus, DG8GB

# An interesting program: DOS programs (e.g. PUFF) on Windows 7

Since the transition to Windows 7 as an operating system (e.g. after buying a new notebook or PC), most existing DOS programs no longer run. This is annoying because there are one or two small tools only available in a DOS version. The solution to this problem is relatively easy if you ask someone who knows. And you should redistribute the findings... So what is it?

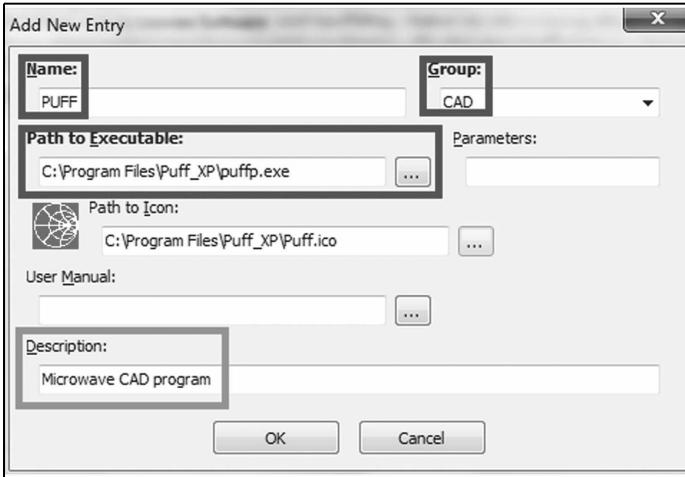


**Fig 1:** This basic setting of the path to the DOS box must be set. The full screen setting is rather annoying and should be deactivated.

## 1.

### Introduction

It was an afternoon in the laboratory of the telecommunications company, Duale Hochschule Baden Württemberg, Friedrichshafen. The task was to design a 10MHz Tschebyschef lowpass filter and (thanks to Windows XP that was still active) the necessary component values could be determined pretty quickly with the proven DOS filter calculator "fds.exe". Because you must move with the times the filter design was practiced with a modern online calculator from the Internet. When walking out through the ranks of students at their workplaces, a notebook with Windows 7 obviously had an "action game" on the screen. Of course, it disappeared from the screen within milliseconds and the game was replaced by the familiar form of "fds" on Windows 7! So, how is that possible? You can safely skip the next 10 minutes. All the details on the subject of "DOS programs under Windows 7" were coaxed from the student and the game was immediately forgotten. It is amazing how easily this can be done on your own computer by following the instructions here.



**Fig 2: A DOS program is added as shown. The top three entries must be made. The remaining entries are optional.**

**2.**

**Step by step instructions**

**First step:**

You search the Internet for the program "dosbox", download it and install it on the local computer.

**Second step:**

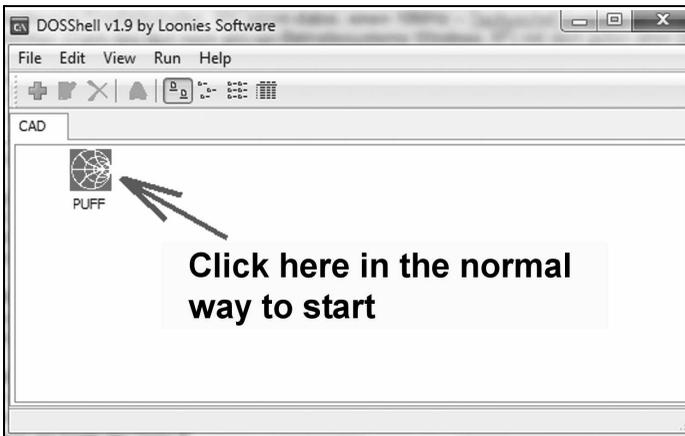
Then repeat the procedure with the program "dosshell" (from the Russian server of "Loonie's software"). Tip: the option to download can only be found at the bottom of the page.

**Third step:**

"Dosshell" is started and connected to the DOS box. It goes like this: "Edit settings" is used to open the window shown in Fig 1. First set the path to the DOS box (using the "Browse" button). Also it is advisable to switch off the full screen mode, because the graphics of most DOS programs looks so shockingly poor.

**Fourth step:**

Now for the applications that is demonstrated using the microwave CAD program "PUFF". First start the dosshell program and click on "Edit". You need to "Add new entry" to open the window shown in



**Fig 3: All DOS programs included can be run from here in future.**

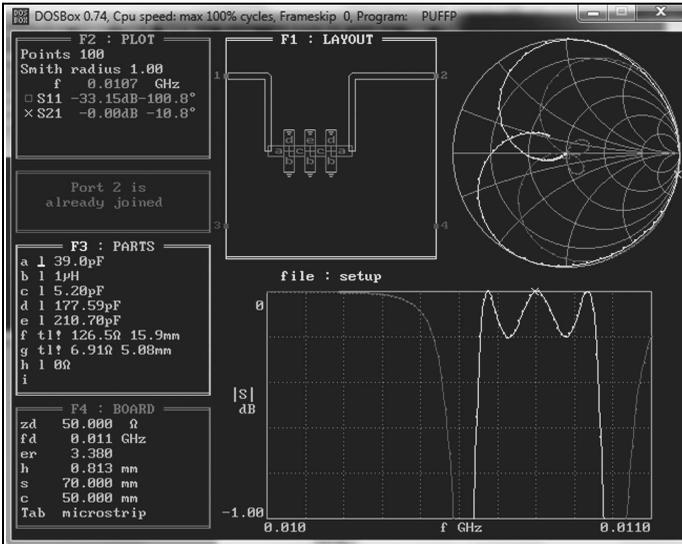


Fig 4: PUFF lives again!

Fig 2. The entries marked in red (the top 3 for those viewing in black and white) must be correct otherwise things will not run at all (name / group / path to the exe file). The other entries are optional (e.g. a small Smith Chart as an icon for "PUFF" is available) and the green marked field is more for your own information (the bottom one for those viewing in black and white).

**Fifth step:**

So far, so good! Now click on the

highlighted icon (Fig 3) to see exactly what you wanted to see again (Fig 4), the familiar screen of a DOS program.

**Sixth step:**

Now you can repeat this with all your old "DOS Favorites" to your heart's content – the filter program "fds" (Fig 5), the antennas calculator "PCAAD21" (Fig 6) or the Patch antenna design program "patch16" (Fig 7).

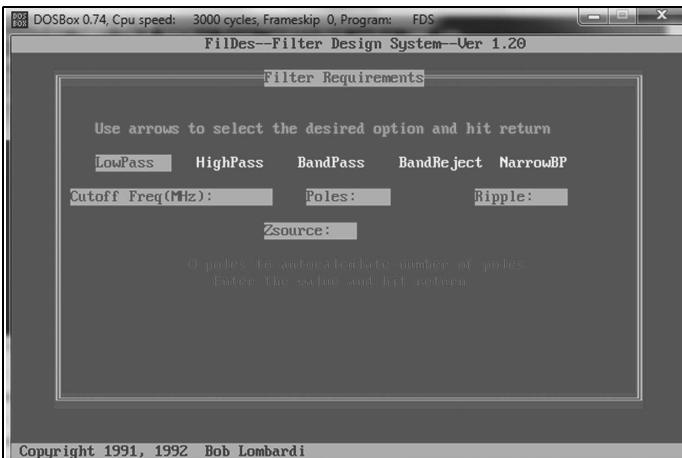
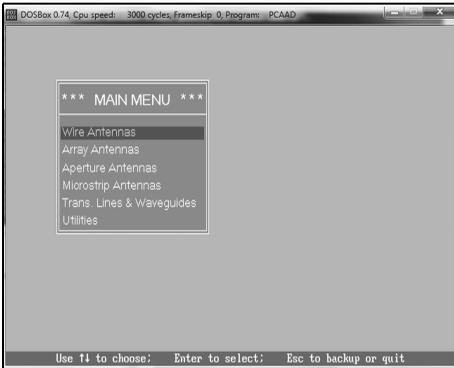


Fig 5: Also, the very best filter design program "fds" is just a click away.



**Fig 6: "PCAAD" makes calculating different antennas (including lines and waveguides) easy.**

3.

**Closing remarks**

**By the way:**

- Anyone who wants any of the DOS programs that are no longer available on the Internet, please email me and the problem can be solved.
- Since March 2013 there are full

instructions for the above in English on the web site:

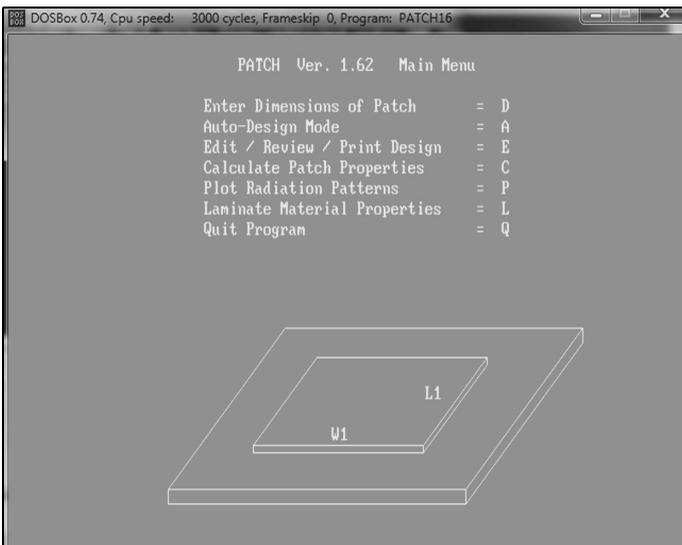
<http://www.gunthard-kraus.de/>

plus a tutorial on using PUFF and a package of useful files.

- Direct printing of the results or charts is not possible but easier than it was under the original DOS program. Simply take a screen shot ("Print Screen") and then open the stored screen in a photo editing program (e.g. Irfan view). There you can cut out the interesting portion and save on a blank page under "WORD" and finally print out.

By the way: the return and toggle between Windows mode and full screen mode when in a DOS program is quite simple: ALT + Enter.

This now means that you can have fun with all your old "DOS Favourites". The student was right: the game "Indiana Jones Atlanta" can be more fascinating than many modern programs. Already tried...



**Fig 7: The proven program "Patch 16" for calculating Patch antennas is useful.**



*Matjaz Vidmar, S53MV*

# Updating the AX.25 network in Slovenia. Radio transceivers for the new Non-Flawless Protocol (NBP) Network

The AX.25 protocol was defined around 1980, shortly after the successful Vancouver experiments. From the protocol point-of-view, AX.25 used amateur radio callsigns as addresses in an otherwise very similar protocol to other professional protocols.

From the amateur radio point of view, AX.25 was the first widespread protocol to allow automatic networking in place of simple point-to-point contacts. The AX.25 built-in but inefficient "digipeater" was soon replaced by many different AX.25 network nodes developed all around the world.

AX.25 arrived in Slovenia around 1985. Initially all contacts were made on a single frequency 144.675MHz using narrow band, voice grade NBFM (15kHz) radios with Bell-202 AFSK modems. A single 1200bps channel only allowed hand typed chatting. Increasing the number of channels and installing 70cm band interlinks among nodes only brought minor improvements.

The first decision was simple. In 1988 simple WBFM radios operating in the 23cm amateur band were developed, where "wide band" means 230kHz filters as used in broadcast FM receivers. These radios allowed a 38400bps network backbone with simple Manchester modems.

This article was taken from part of Matjaz Vidmar's web site [1] and describes the new transceivers designed for a major upgrade to the Slovenian AX.25 network using a new version of the AX.25 protocol. The new protocol is described in detail on the web site.

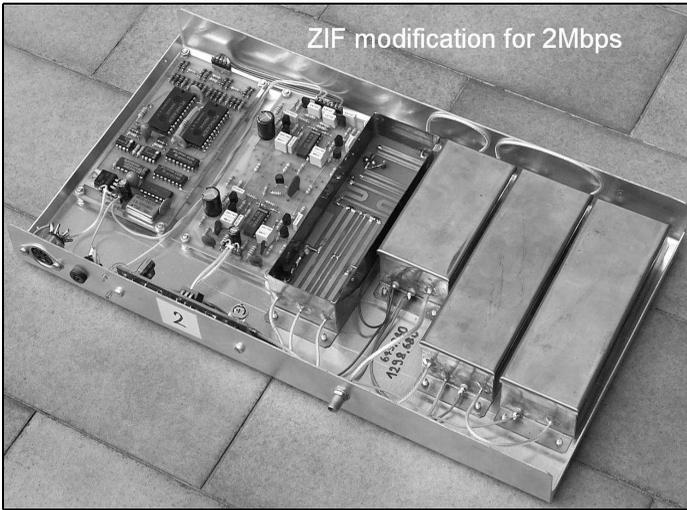
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## 1. BPSK RTX update

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Several decades of AX.25 packet radio networking left a comprehensive hardware heritage in Slovenia including mountain top sites, antennas, cable installations, cabinets, power supplies and radio transceivers of all kinds. Most of this hardware is still useful today while deploying the new NBP (Non-Flawless Protocol) network. Of course, new, even more efficient radio transceivers are also planned for NBP while old hardware requires maintenance or updates.

All megabit BPSK transceivers developed for the AX.25 SuperVozelj project are still useful today with NBP. Besides replacing electrolytic capacitors after many years of continuous operation the complete list of maintenance, modifications and updates will be briefly summarised.

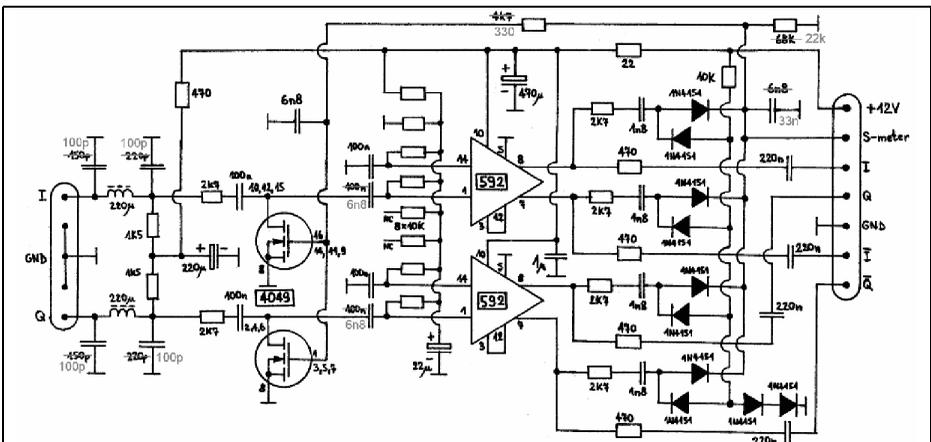


**Fig 1: The old dual-channel ZIF restored and ready for the 2Mbps service.**

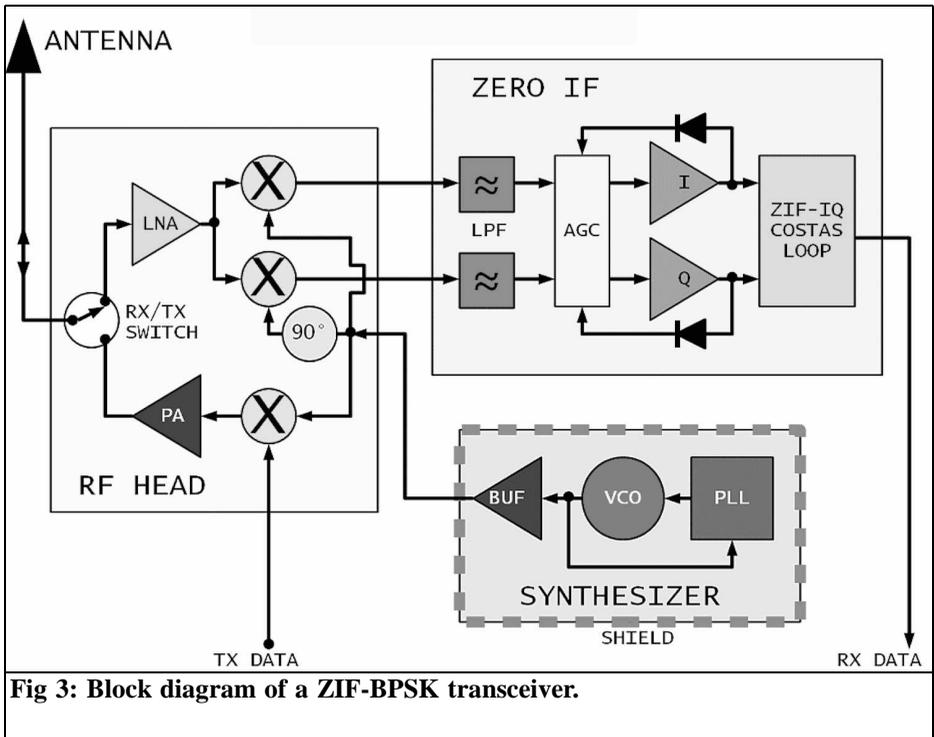
- Old BPSK transceivers (1995) for 2360MHz with double conversion receivers (75MHz/10MHz) can only be used at 1.2288Mbps with some limitations. All ZIF-BPSK transceivers can be modified for operation at 2Mbps or more.
- In all ZIF receivers it makes sense to check the quadrature (symmetry and phase shift) of the ZIF chain. A CW signal generator has to be connected to the receiver input. A frequency offset of about 100kHz is recommen-

ded so that the I and Q signals can be compared with an oscilloscope at different locations in the ZIF chain.

- Small differences (1 - 2dB) between the I and Q outputs of the receiving mixer can be corrected by soldering small pieces of copper foil on the quadrature hybrid. The 1.27GHz ZIF-BPSK RTX usually requires such trimming on the transverse arms of the quadrature hybrid.
- On the other hand, the 2.36GHz ZIF-



**Fig 2: Modifications to the old NE59-2-ZIF chain.**



**Fig 3: Block diagram of a ZIF-BPSK transceiver.**

BPSK RTX may require such trimming on the longitudinal arms of the quadrature hybrid.

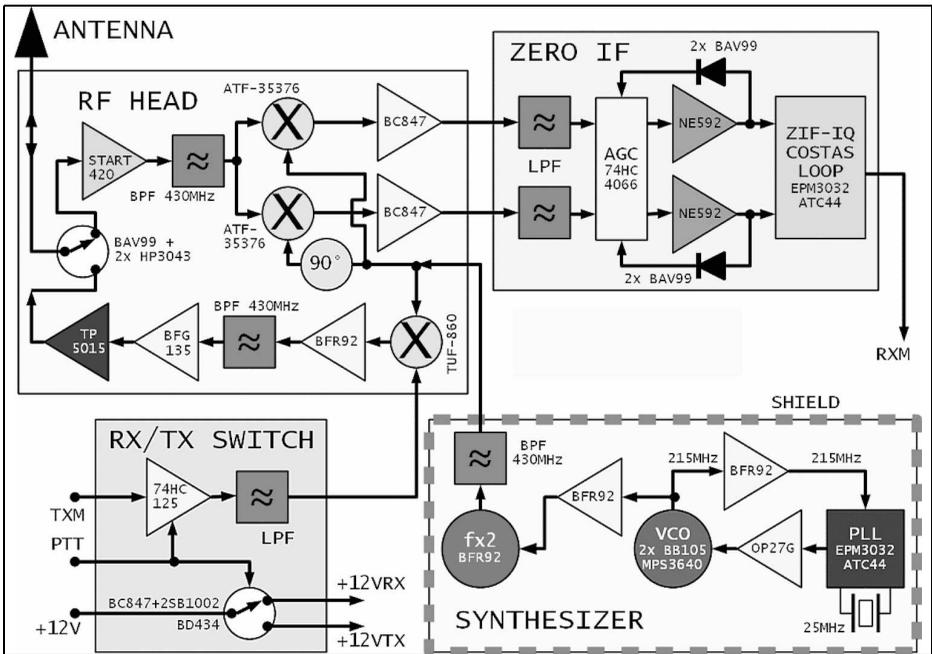
- The schottky quads BAT14-099R are no longer available, but may be replaced by the HSMS-8209 schottky quads. For best performance, the original choke (differing values in different versions) and the original 4.7 $\mu$ F tantalum electrolytic capacitor have to be replaced with a 33 $\mu$ H choke followed by a 1 $\mu$ F capacitor.
- The old dual-channel ZIF (1996) with many BF199 transistors and corresponding demodulator with two 74HC4067 analog switches require several modifications for operation at 2Mbps, including the removal of one complete ZIF stage. Fig 1 shows a refurbished unit.

Even with all of the modifications in place, the BF199 ZIF loses some 2 - 3dB

S/N ratio when compared to new NE592-ZIF chains. A much better solution is to remove the two old BF199-ZIF and 74HC4067 demodulator modules and replace them with the latest SMD ZIF chain (2011) described later as part of the "Low power ZIF-BPSK".

The improved BPSK demodulator (2001) with 8 comparators LM311, 74HCxxx logic and NE592 ZIF already works as it is at 2Mbps. For best performance at 2Mbps, a few modifications to the NE592-ZIF chain shown in Fig 2 are recommended.

The same circuit diagram of the improved BPSK demodulator is also used in the latest SMD version (2011), except that the 74HCxxx logic in the Costas loop is programmed into a CPLD (Altera EPM3032ATC44).



**Fig 5: Block diagram of the 430MHz BPSK transceiver.**

**2.**

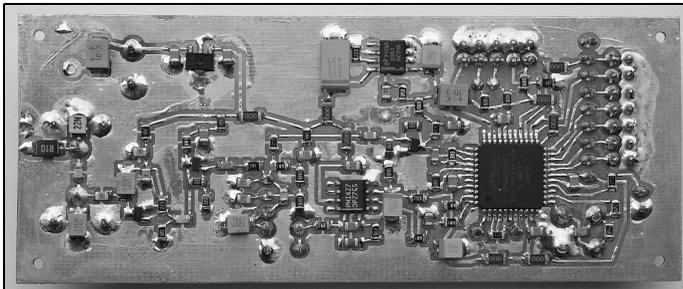
**ZIF-BPSK RTX for 430MHz**

The block diagram of a ZIF-BPSK transceiver shown in Fig 3 may look quite simple. In the real world there is a hidden problem. Some radio frequency may leak from the antenna back into the frequency synthesiser. Such a leak causes unwanted frequency modulation of the VCO. The

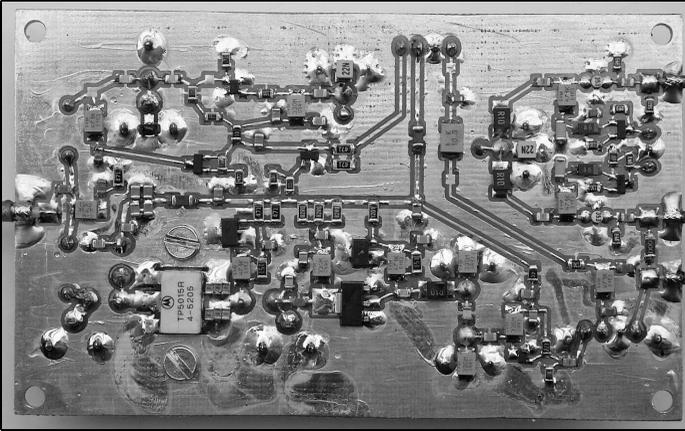
resulting carrier instability may corrupt so much the BPSK signal to make it useless.

In the BPSK transceivers developed for the SuperVozelj network, the above problem was avoided by not using frequency synthesisers at all. All of the required frequencies were obtained by crystal oscillators followed by complex multiplier chains.

In the meantime, professionals found a workaround called fractional PLL. A fractional PLL does not produce such a



**Fig 6: 70cm PLL synthesiser.**



**Fig 7: 70cm RF front end**

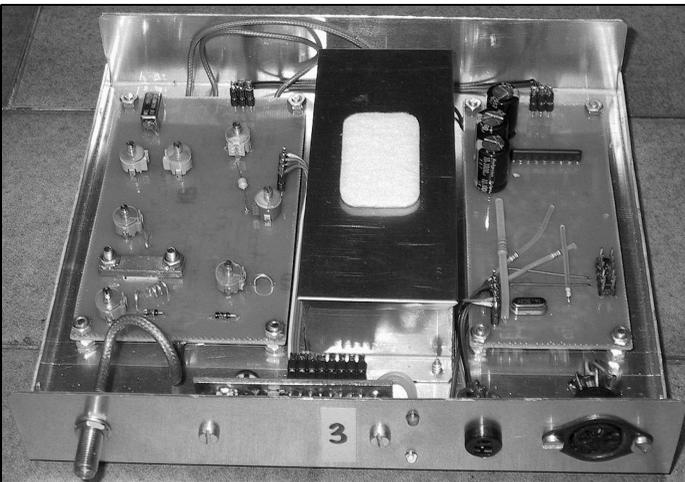
clean spectrum as a conventional, integer PLL. On the other hand, the comparison frequency of a fractional PLL can be made several orders of magnitude faster to actively suppress any external unwanted modulation of the VCO. Fractional PLLs are widely used in WLAN (WiFi) equipment, since they allow the integration of a complete radio transceiver on a single chip.

If reasonably good shielding is available, a conventional, integer PLL could also be used in a BPSK transceiver. The first attempt was to build a prototype BPSK transceiver for 430MHz, since less absolute frequency instability is expected at

lower frequencies. The whole frequency synthesiser was installed in a brass box while recycled ZIF modules used form 1.27GHz or 2.36GHz transceivers.

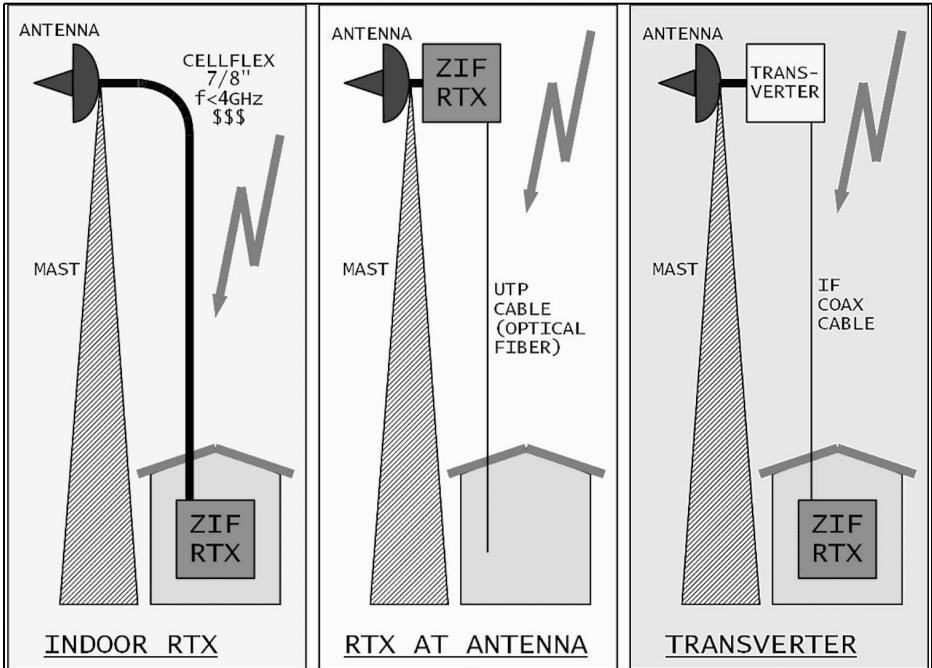
Since the prototype results were encouraging, a new ZIF built with SMD components and CPLD logic was developed. The whole 70cm BPSK transceiver only includes three RF printed circuit boards and is not much more complicated nor much larger than the simple 70cm WBFM RTX developed two decades ago.

The synthesiser VCO operates at half of the final frequency to further reduce shielding requirements, see Fig 4. The PLL logic is programmed into an Altera



**Fig 8: The complete ZIF-BPSK transceiver showing the additional shielding required.**





**Fig 11: Three different ways to solve the problem of where to place the equipment.**

The antenna switch uses two PIN diodes HP3043 and the receiver input is further protected by a BAV99 limiter.

The ZIF chain (Fig 7) includes an AGC stage (74HC4066), two NE592 amplifiers (SOIC-8 version) and a Costas loop demodulator programmed into an Altera EPM3032ATC44 CPLD. The inputs of the latter are biased into linear operation to accept analog signals directly without additional comparators. The Costas loop uses a DPLL/1024 in the version for 1.2288Mbps, 430MHz

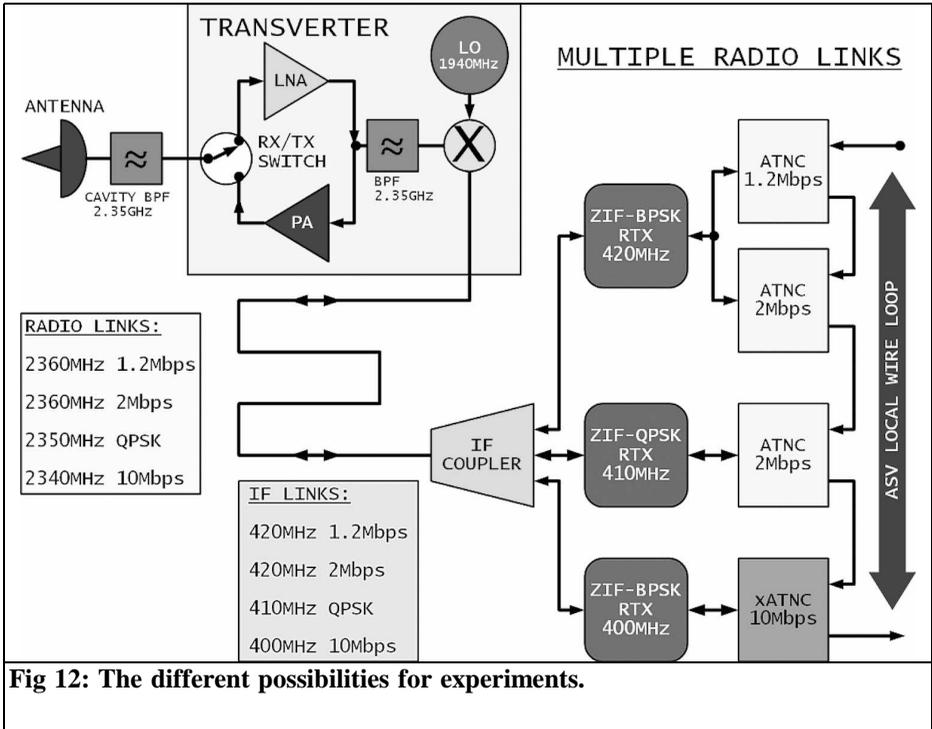
The whole ZIF-BPSK transceiver for 430MHz is 170mm wide, 150mm deep and 30mm high. Only the frequency synthesiser requires additional shielding, see Fig 8.

A much more detailed description of the ZIF-BPSK RTX for 430MHz including all circuit diagrams is available in the ZIP archive [2]

Using 1.2288Mbps BPSK in the 430MHz band might cause interference to other users. Some simple calculations (Fig 9) show that the likelihood of interference to narrow band users is very small provided that the operating frequency and antenna polarisation of the BPSK link is chosen carefully

In practice, no complaints about interference from 1.2288Mbps BPSK transmissions were ever received although some BPSK links in the 430MHz band were intensively used every day for a period of two years. On the other hand, the BPSK links occasionally suffer interference from narrow band users. The ZIF-BPSK transceiver for 430MHz excels in non-line-of-sight links, see Fig 10.

In the above example, a pair of ZIF-BPSK transceivers for 430MHz transfers as much as 80kbytes/s using TCP/IP over NBP with a 10dB power margin. No known professional equipment (2012)



can match this result in such unfavourable conditions and no commercial WLAN (WiFi) equipment can ever come close!

### 3.

#### Low power ZIF-BPSK

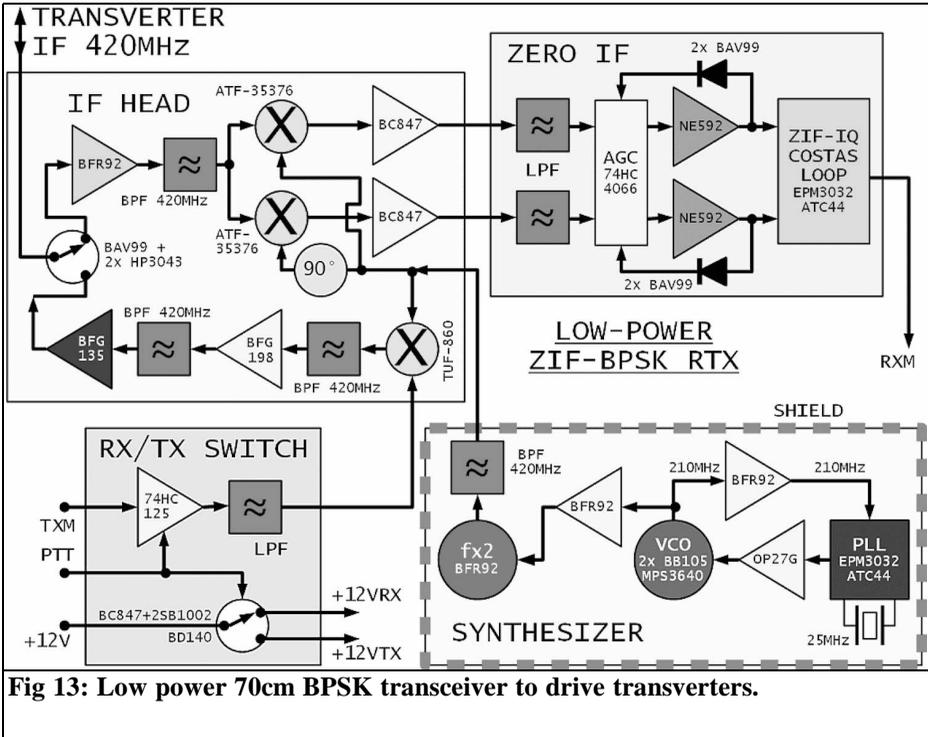
A packet radio network also requires mountain top network nodes. Frequently, radio amateur equipment is only a guest in some larger telecommunication or broadcast installation. In these conditions, amateur equipment has to accept long antenna cables, interference from high power professional transmitters, severe size limitations of both amateur antennas and equipment cabinets and last but not least restricted access to the site, especially to the antenna tower. The problem of

a long antenna cable can be handled in different ways as shown in Fig 11.

The traditional solution is to have all electronics indoor and use expensive antenna cables like Cellflex 7/8". This solution is not scalable, since the larger the coax cable, the lower its cut off frequency caused by higher order waveguide modes.

The inexpensive commercial WLAN (WiFi) solution is to put all electronics close to the antenna. Inexpensive data cables, UTP or optical fibre, are used to connect to the indoor equipment. Copper data cables like UTP or STP are not really designed to operate in a difficult electromagnetic environment, like high power broadcast transmitters or nearby lightning strikes. Electronic equipment maintenance on the antenna mast is difficult if possible at all.

An intermediate solution is to put part of



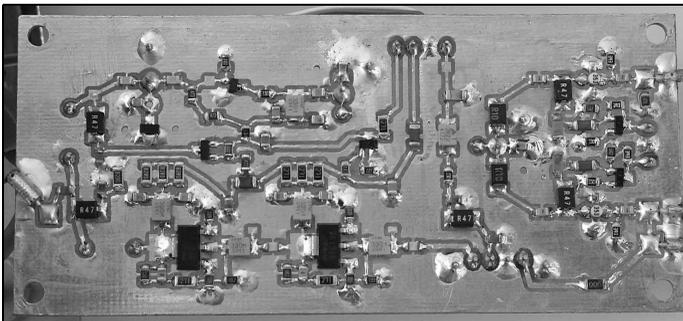
**Fig 13: Low power 70cm BPSK transceiver to drive transverters.**

the electronics, the microwave head, close to the antenna and the remaining electronics, IF modulators and demodulators, indoor. Losses in the IF coax cable can be overcome easily and the same cable can be used for power supply to the antenna unit. Although this solution is the most complex, professional microwave links use it regularly.

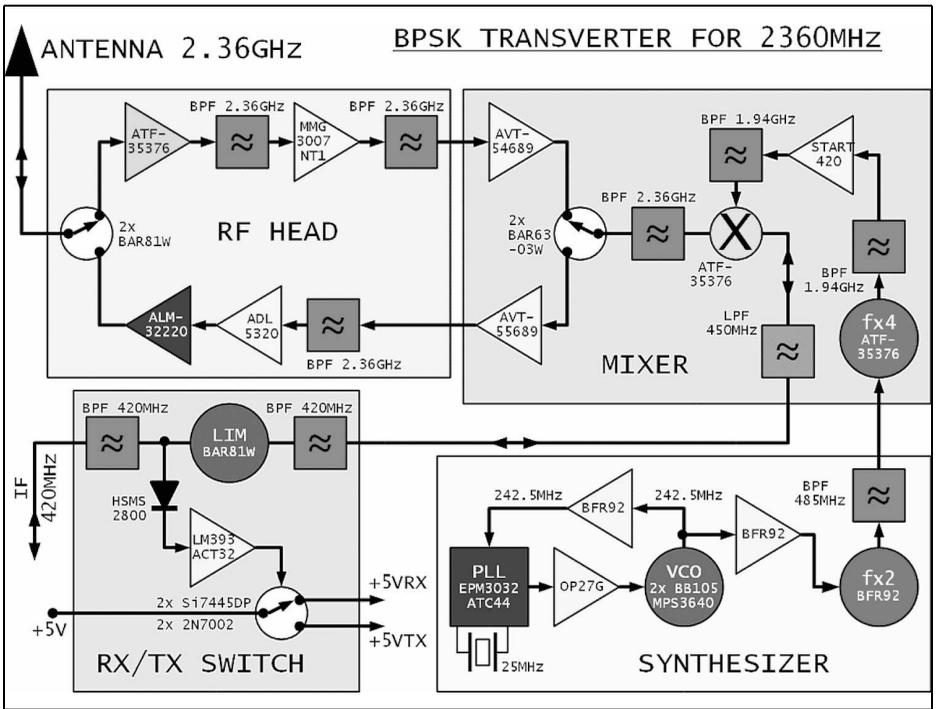
Considering amateur packet radio links of a few megabits in the 2.3GHz and

3.4GHz frequency ranges, an intermediate frequency around 400MHz is a reasonable choice. Such a "transverter" microwave link offers yet another possibility for amateur radio experiments, see Fig 12. Besides connecting two or more (x)ATNCs to a single IF unit, two or more IF units can be connected to the same outdoor RF head using a simple, passive IF coupler.

Of course only a single IF unit is allowed



**Fig 14: The RF head.**



**Fig 15: Block diagram of the transverter for 2360MHz.**

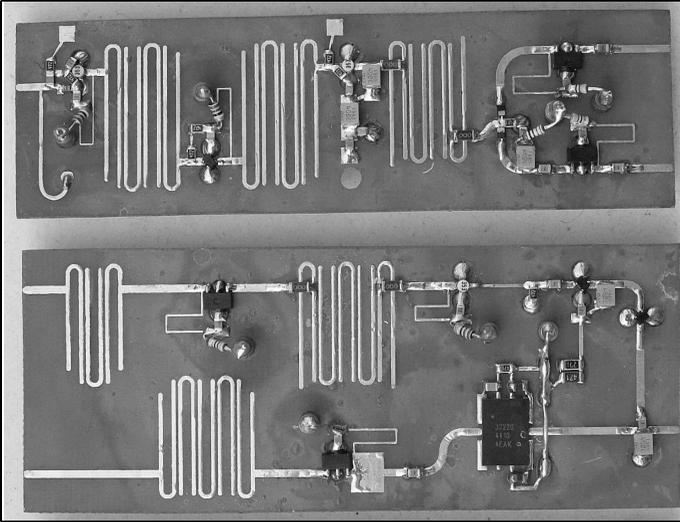
to transmit at the same time. A cavity filter is required at the antenna to limit interference in the unfortunate case of two or more simultaneous transmissions. Additional IF units allow experimenting with different modulation formats and very different data rates. A common antenna and a common RF head allow a fair comparison among different modulation techniques in our experiments. Most important of all, adding new experimental equipment does not require any work on the antenna tower!

The ZIF-BPSK RTX for 430MHz could be tuned to be used as an IF in the 400MHz band. A better solution is to redesign this transceiver for a lower transmit power, a lower receiver gain, faster RX/TX switching, higher data rates and tolerating wider carrier frequency errors as expected when using microwave transverters, see Fig 13.

The RF head (Fig 14) is redesigned and now becomes an IF head. The main differences are in the transmitter power amplifier. The output power of the new design is reduced to 200mW and both amplifier stages operate in class "A" with a strong feedback for stability.

The modifications to the other modules only include a few component values for higher data rates and different firmware to be programmed in the two CPLDs. The PLL CPLD is programmed for a lower frequency range. The Costas loop CPLD is programmed for a DPLL/256 to tolerate wider carrier frequency errors as expected in the microwave frequency bands.

The low power ZIF-BPSK RTX is 150mm wide, 150mm deep and 30mm high, therefore slightly narrower than the full power version for 430MHz.



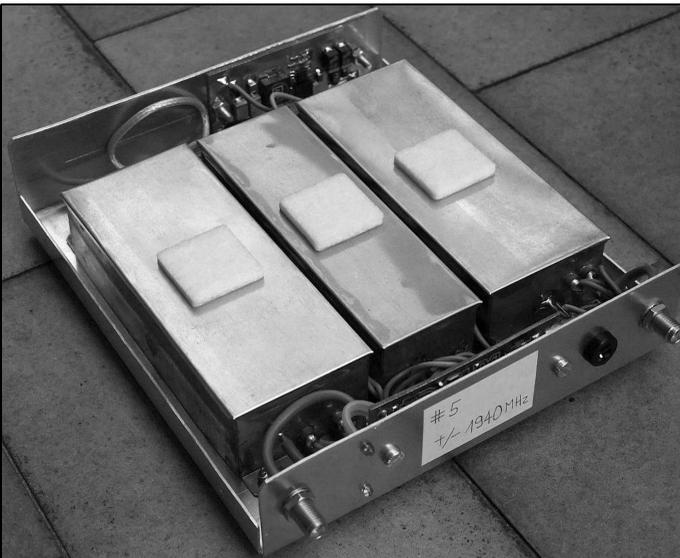
**Fig 16: The RF head and mixer built on two microstrip printed circuit boards.**

Another successful experiment was to replace the unreliable and expensive capacitive trimmers in the RF/IF tuned circuits with fixed SMD capacitors. The corresponding SMD coils had to be replaced with air wound, silver plated copper wire coils. Circuit tuning was accomplished by coil stretching

A much more detailed description of the low power ZIF-BPSK RTX including all

circuit diagrams is available in the ZIP archive [3]

The PLL and ZIF printed circuit boards include a few minor corrections and may also be used in the full power ZIF-BPSK RTX for 430MHz with some advantages. The same PLL printed circuit board is also used in the following BPSK transverter for 2360MHz.



**Fig 17: The complete 2360MHz transverter.**




---

#### 4.

### BPSK transverter for 2360MHz

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A BPSK transverter for 2360MHz (Fig 15) had to be developed first to replace old BPSK transceivers (1995) for 2360-MHz with double conversion receivers (75MHz/10MHz). The latter could only be used at 1.2288Mbps with some limitations, like rather slow RX/TX switching. Of course, the new transverter should include a wide bandwidth and fast RX/TX switching to allow present and future packet-radio network extensions.

The transverter uses a single, passive HEMT mixer for both transmission and reception. The receive and transmit amplifier chains at 2.36GHz are switched by PIN diodes. MMIC amplifiers allow a simple design of low power stages at the expense of higher power drain. The transmitter uses an ALM-32220 hybrid amplifier to achieve 2W of RF power at the antenna connector, including losses in the antenna switch.

The RF head and mixer (Fig 16) are built on two microstrip printed circuit boards etched on 0.6mm thick FR4 laminate. The latter introduces losses especially in the bandpass filters that have to be compensated by the MMIC amplifiers. On the other hand, a lossy laminate helps to avoid unwanted millimetre wave oscillations of HEMTs. Microstrip bandpass filters with unsymmetrical frequency response are used as appropriate.

The IF limiter (AGC) allows IF drive power levels between 20mW (+13dBm) and 200mW (+23dBm). The same IF drive signal also controls the RX/TX switching of the transverter. Fast and reliable, IF driven RX/TX switching requires quite some electronic components.

Both microstrip modules and the frequency synthesiser are installed in three brass frames for shielding.

The whole transverter (Fig 17) is 135mm

wide, 150mm deep and 30mm wide including a switching power regulator for +5V.

The shape of the printed circuit boards is selected to avoid unwanted resonances in the frequency range below 4GHz. The brass frames therefore only require covers from thin copper sheet while microwave absorber foam is not required.

A much more detailed description of the BPSK transverter for 2360MHz including all circuit diagrams is available in the ZIP archive [4]

Practical experiments show that the receiving section of the described BPSK transverter offers similar sensitivity and interference rejection as the old BPSK and ZIF-BPSK receiver designs. The transmitting section of the described BPSK transverter provides some 6 - 7dB improvement in the link margin thanks to the higher output power (around 2W) when compared to the old BPSK transmitters with the CLY2 output stage generating 400 - 500mW. The transverter spurious emissions are 40 - 50dB below the desired signal at 2360MHz and can be totally eliminated with an external cavity filter.

---

#### 5.

### References

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[1] <http://lea.hamradio.si/~s53mv/nbp/rtx.html>

[2] <http://lea.hamradio.si/~s53mv/nbp/rtx/OpisPSK70.zip>

[3] <http://lea.hamradio.si/~s53mv/nbp/rtx/MalaPSK70.zip>

[4] <http://lea.hamradio.si/~s53mv/nbp/rtx/OpisTrv13.zip>

[5] 13cm PSK Transceiver for 1.2Mbit/s Packet Radio. Matjaz Vidmar, VHF Communication Magazine, 3/1996 and 4/1996



Carsten Vieland, DJ4GC

# A Sensitive Thermal Power Meter

Reprint from issue 4/1983

A measuring instrument is to be described that has seven measuring ranges from  $100\mu\text{W}$  to  $300\text{mW}$ , and whose upper frequency limit is way up in the X band. Construction should not be difficult for those readers having adequate mechanical skill and a magnifying glass. Only a few special parts are required which are easily available.

## 1.

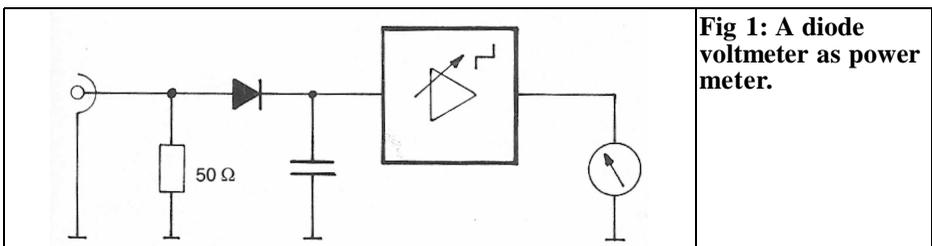
### Power Measurement Problems

For radio amateurs, power measurement is probably one of the most difficult areas in radio frequency measuring technology. The various types of diode voltmeters, see Fig 1, have three distinct disadvantages:

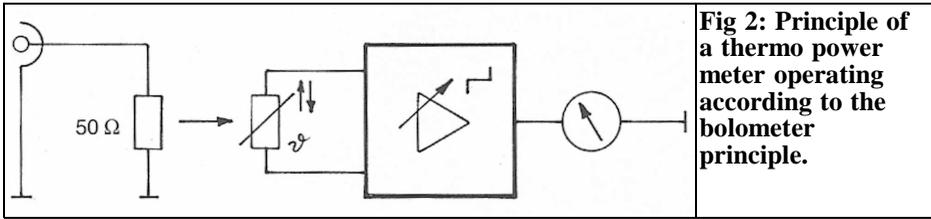
- 1 The junction capacitance of the test diode (1-4 pF) represents a parallel capacitance to the load resistance. For instance, the amount of the capa-

citive reactive impedance will be less than the  $50\Omega$  load resistor when using a Schottky diode HP 2800 even at 1.6GHz. In conjunction with the unavoidable circuit inductivity, this will lead to noticeable resonance effects, which limit this type of power measurement to frequencies up to approximately 1GHz, if a special scale calibration is not used.

- 2 The non-linearity of the diode characteristic will be noticeable at low AC voltages. This leads to a non-constant mathematical scale calibration in spite of subsequent amplification and de-logging. If one is to avoid the very extensive compensation method, it will be necessary for the scales to be calibrated point by point, for instance by calibrating it against a precision meter.
- 3 The calibration of the diode voltmeter is made in RMS values; however, the measurements are made with peak voltages. In the case of subsequent measurements on amateur equip-



**Fig 1: A diode voltmeter as power meter.**



**Fig 2: Principle of a thermo power meter operating according to the bolometer principle.**

ment, the required sine wave signal will be superimposed with harmonics, sub harmonics, conversion products, and unwanted oscillations. When the maximum values of the individual voltages coincide, peak voltages are provided to the diode, which have no relationship to the RMS value. The output power of oscillating stages can be even higher than the power consumption from the power line.

The described disadvantages of diode voltmeters can be avoided or at least reduced when using the bolometer principle (see Fig 2), since the load resistance is only to be found in the RF circuit. The heating is a linear function of the RMS value of the RF power, at least at low temperatures. The temperature increase is measured with the aid of a NTC resistor, which will lead to a power linear scale calibration. Calibration and accuracy measurements on such a unit can be made with the aid of DC voltages.

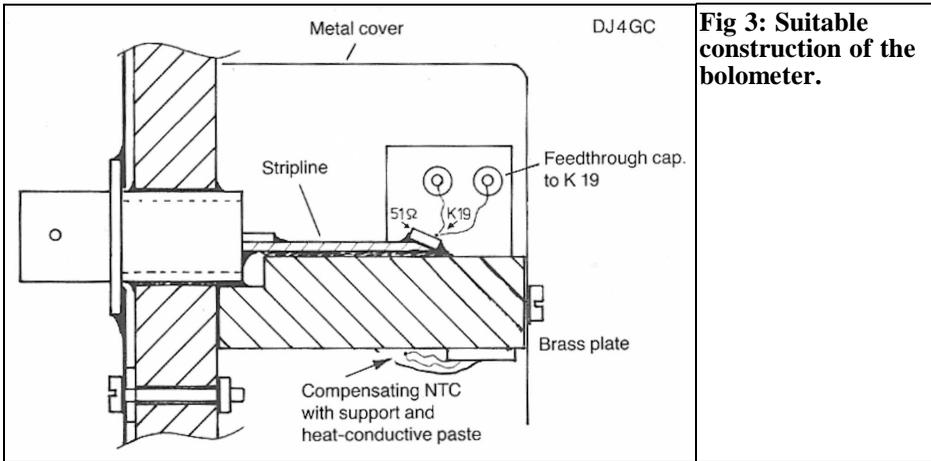
Fundamental considerations were made in [1], [2], [3] and [4]. A suitable construction was described in [1]. Higher sensitivities can be achieved with the aid of thermo-elements using thin film technology [5].

The described meter has seven measuring ranges from  $100\mu\text{W}$  to  $300\text{mW}$  (FSD). Its upper frequency limit is in the X band. One disadvantage is the somewhat long transient time of this method (50% of full scale after 1s), which means that no modulation measurements can be made

## 2. Component Selection

The  $50\Omega$  load resistor should be as small as possible. A small mass results in a short thermal transient time, as well as a high temperature coefficient (meter sensitivity), and has a positive effect on the upper limit frequency. The smallest, inexpensive, and available resistor ( $51\Omega$ ) uses a flat metal-glazed conductor and is sometimes designated as micro-miniature resistor ( $62.5\text{mW}$ ). It is in the form of a bead-type microchip resistor that has been dipped in lacquer, and they are usually used in layer circuits. After carefully removing the lacquer, one will obtain a ceramic chip whose dimensions are  $2.2\text{mm} \times 1.2\text{mm} \times 0.8\text{mm}$ . The temperature probe resistor should also have a low mass and thus a short transient time. In addition to this, high impedance resistors are preferable, since these exhibit the lowest intrinsic heating as result of the connected test voltage. The Siemens Thernewid NTC resistor type K 19 is very suitable. This component comprises a glass bead of  $0.4\text{mm}$  diameter and possesses virtually invisible connection wires. This component is so sensitive that it will react to the radiation heat of one's hand without delay, even at a spacing of 1 meter. Unfortunately, this resistor, which can also be supplied in pairs, is not inexpensive, but it is also offered by several other manufacturers.

Experiments made with the thermoprobes SAK 1000 and KTY 11 resulted in an inferior limit sensitivity, and the transient time was at least ten times longer



**Fig 3: Suitable construction of the bolometer.**

### 3. Construction of the RF Circuit

Of course, the NTC resistor must be directly glued to the load resistor (with very little two component adhesive). However, due to its high sensitivity, it should be thermally decoupled from the input connector. For this reason, it is not recommended for the load resistor to be directly soldered to the RF connector, since the mechanical tension passed via the inner conductor could destroy the chip resistor. A favourable solution was found by using a  $50\Omega$  stripline in conjunction with a heat sink (brass plate) for interconnecting the load resistor to the input connector. This type of construction is shown in Fig 3.

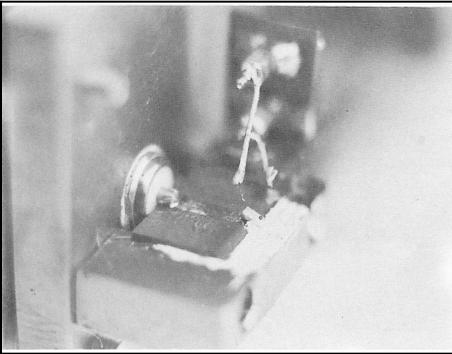
In order to ensure a high cut off frequency, the stripline should be ideally on a PTFE material (double coated). A stripline width of 2.3mm will result when using 0.8mm thick RT/duroid 5870 material. In the author's prototype, the stripline is 12mm in length. Of course, epoxy PC boards can be used up to several GHz without problems due to the non-resonant conductor lane. When using 1.5mm thick epoxy PC board material, the stripline width is 3.1mm.

Special care must be taken in the transition between the coaxial connector and the stripline. Although N connectors have more favourable RF characteristics than BNC connectors, the former will exhibit more noticeable discontinuity at the transition. Professional users specify SMA connectors up to 18GHz.

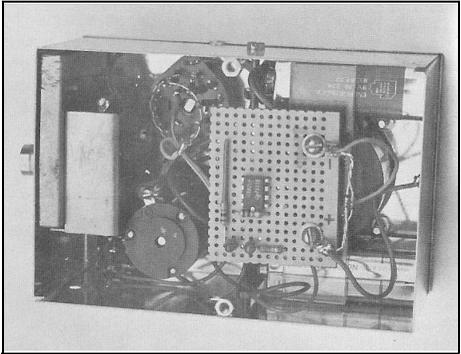
In order to achieve the shortest possible transient time of the bolometer, a good heat dissipation is obtained at the cost of maximum sensitivity. Heat conductive paste should be provided between the stripline board and the brass heatsink, which is also placed around the chip resistor. Temperature fluctuations coming from the input connector are compensated for with the aid of a second brass plate (Fig 4). Since the thermal probe still reacts to the radiation heat reaching the case, the whole bolometer is surrounded in a metal case.

Any excessive solder on the stripline should be removed with a file in order to ensure a low heat delay. The NTC resistor should be glued into position only after this has been carried out.

The fragile connection wires of the K 19 are supported on the RF side with the aid of feedthrough capacitors, and on the lower side with the aid of a small board that has been glued into place.



**Fig 4: RF circuit with bolometer and heat sink.**



**Fig 5: Photograph of the author's prototype; RF portion under the metal cover.**

#### 4.

### Measuring Amplifier

In order to maintain the zero point stability and the calibrated meter sensitivity it is recommended that a bridge circuit be used together with a second K 19 (paired to have the same temperature coefficient) in order to compensate for ambient temperature fluctuations (see Fig 6)

The first operational amplifier, maintains a constant current via the test NTC resistor, which allows a linear transfer of its resistance value to the actual test amplifier. The zero point should be adjusted before commencing the measurement with the aid of a low-impedance, shunted, ten-turn helical potentiometer. If a larger case is used, it is also possible for less expensive coarse and fine controls to be used.

The reference voltage is provided by a LED, which is connected as zener diode. Higher voltages than 1.5V will, however, improve the sensitivity of the reading. However, will lead to considerable intrinsic heating of the thermal probe.

In order to change the measuring range the feedback resistors of the second operational amplifier are switched.

The resistance values and measuring

ranges (full-scale deflection) are:

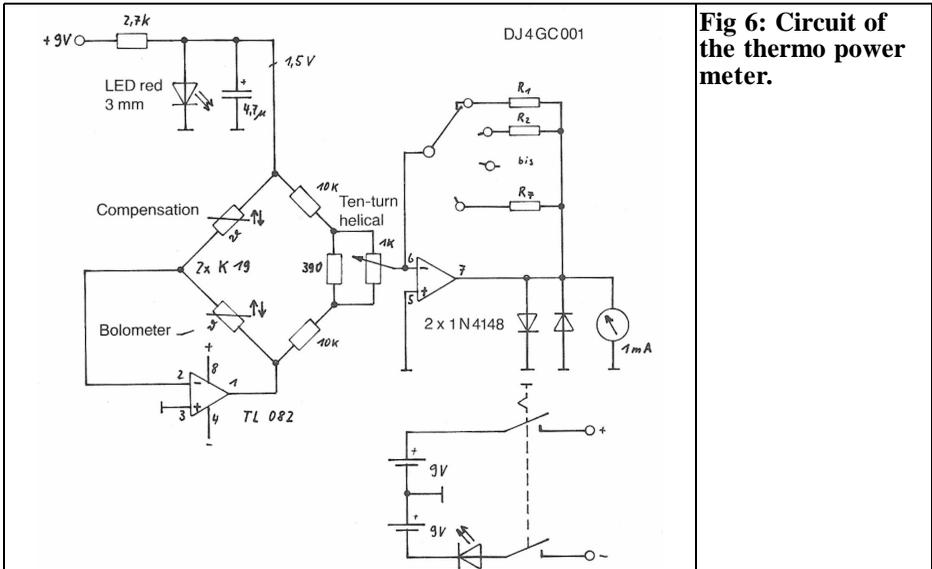
- R1 = 2.2M $\Omega$  (0.1mW)
- R2 = 680k $\Omega$  (0.3mW)
- R3 = 220k $\Omega$  (1mW)
- R4 = 68k $\Omega$  (3mW)
- R5 = 22k $\Omega$  (10mW)
- R6 = 6.8k $\Omega$  (30mW)
- R7 = 1.4k $\Omega$  (300mW)

The meter cannot be overloaded since the operational amplifier possesses an internal current limiting. Since an offset alignment is not required, it is advisable to use a low drift dual operational amplifier in an eight pin case, such as the TL 082. In the most sensitive range, the flicker noise of the operational amplifier will cause a certain fluctuation of the meter reading. The operating current is only in the order of 5mA, which means that two 9V batteries can be used as power supply. The meter will also operate perfectly at  $\pm 5V$ .

#### 5.

### Alignment

Calibration of the meter is made with direct current. It is advisable to adjust the full scale deflection current of the appropriate range with a digital multimeter.



**Fig 6: Circuit of the thermo power meter.**

The feedback resistors R1 to R6 of the test amplifier are selected to have the highest accuracy from a large selection of resistors. Since the sensitivity of the bolometer is greatly dependent on the mechanical construction, the given values are only for orientation.

Due to the non-linear relationship between the temperature and the resistance value of the NTC resistor, it is necessary for the highest range of 300mW to be calibrated independently on the scale, (see Fig 7). In the 30mW range, the deviation is still only a maximum of 4%, and should thus be acceptable.

## 6.

### Measured Values

It was possible before manufacturing the power meter to measure the input return loss of the RF circuit with the aid of a network analyser. It was found that a return loss of 20dB (corresponding to approximately 1.2 VSWR) can be achieved up to a frequency of 2.1GHz. The

return loss of 10dB (approximately 2 VSWR) is only exceeded at 11GHz.

A 3GHz oscillator having an output power of 25mW with an accuracy of  $\pm 0.1$ dB was now connected to the meter and this power was indicated with an accuracy of the meter needle.

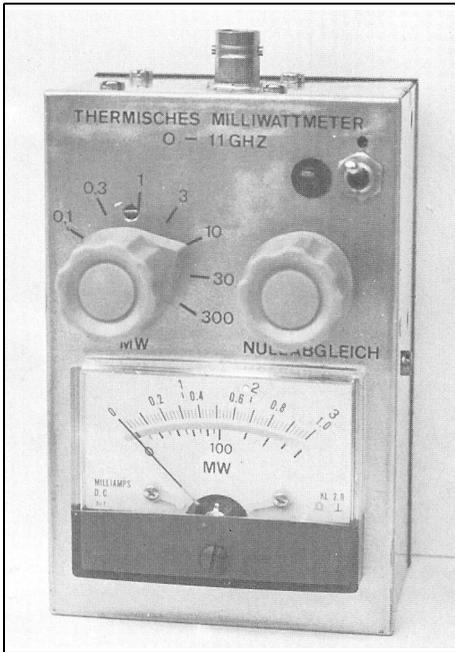
The Gunnplexer manufactured by Microwave Associates (15mW at 10.36GHz) provided 12mW of heat after being adapted from waveguide to BNC.

The meter reaches 50% of the full scale value after approximately 1 second; 90% of the final value is passed after 3.4s. The transient time  $t$  (63% of the final value) is in the order of 1.5s.

## 7.

### Practical Experience

Due to the short length of the stripline used, a certain temperature sensitivity exists via the inner conductor of the input connector, since both NTC resistors are not heated simultaneously. In the very



**Fig 7: This photograph shows the scale calibration with the 300mW scale at the bottom.**

low power range, it is advisable to work together with an intermediate cable which remains connected to the meter. Otherwise, the zero point stability is so high that it is possible to carry out measurements directly after switching on. In the case of the two most sensitive ranges, it is advisable to leave a warm up time of approximately three minutes.

The calibration was made at 20°C. A further test in a refrigerator at 5°C did not show large deviations.

The speed of the reading is approximately as high as that of a dampened laboratory meter. Taking all advantages of this measuring system into consideration, it will not be found that alignment work is made more difficult due too slow an indication.

The dynamic range of the power meter can be increased by adding wideband amplifiers (e.g. as described by DJ7VY),

attenuators, or directional couplers. However, the frequency range will be limited by this. It is possible, for instance, to use a directional coupler with an attenuation of 40dB to increase the measuring range up to 3kW. The exact value of the loss can be measured previously using this meter.

The high sensitivity of this meter (the resolution is in the order of 1pW) allows one to also measure the frequency, or attenuation characteristics of filters, band-pass filters, directional couplers, frequency multipliers, mixers, low signal amplifiers, etc., in addition to purely power measurements, and its high dynamic range can be used right up to X band.

## 8.

### References

- [1] O. Frosinn, DF7QF, A Home Made UHF/SHF Power Meter, VHF Communications Magazine 13, Edition 4/1981, Pages 221-229
- [2] A. Kraus, Einführung in die Hochfrequenz Meßtechnik, Pflaum-Verlag München 1980, Pages 21 9-227
- [3] A. Hock, u.a., Hochfrequenz-Meßtechnik Part 1 Volume 31a, Kontakt & Studium, Expert Verlag, Grafenau 1981, Pages 121-129
- [4] VHF-UHF Manual, 3rd Edition, Chapter 10
- [5] Marconi Instruments Catalogue of Microwave Instruments, Components and Waveguides 1981/82



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Gunthard Kraus, DG8GB

# Internet Treasure Trove

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## Mixer noise and design

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This document represents the absolute best, most accurate, and yet easily readable summary of the topic of the noise in mixers to be found on the Internet.

Address: [http://rfic.eecs.berkeley.edu/~niknejad/ee242/pdf/ee242\\_mixer\\_noise\\_design.pdf](http://rfic.eecs.berkeley.edu/~niknejad/ee242/pdf/ee242_mixer_noise_design.pdf)

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## 1.2 THz SIS mixer for Herschel radio observatory

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If you are interested in the forefront of receiver development and the resulting technology, it is time to take a look at this publication. A 1.2 Terahertz mixer with integrated antenna on a chip using new technologies and ideas. That is definitely not boring!

Address: <http://safir.jpl.nasa.gov/BeyondSpitzerConf/proceedings/posters4/karpov.pdf>

and for those who wants to look at a short film on "Superconductivity", go to the University of Cambridge site

Address: <http://www.msm.cam.ac.uk/ascg/lectures/electronics/stjdetector.php?video=flash>

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## NXP

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Because Philips are hiding behind this name it takes some time to recognise. There are as always interesting new RF module developments (E.g. a complete Ku - band LNB for 10.7 and 12.7GHz in a small IC). You should visit this page more often.

Address:  
<http://www.nxp.com/products/rf/>

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## Fundamentals of RF and microwave noise figure measurements

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This is the famous "HP application note 57/1" in a beautiful new edition. It has been listed in almost every publication on this topic for decades.

Address: <http://cp.literature.agilent.com/litweb/pdf/5952-8255E.pdf>

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## Ferrites

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For those who want to develop and use components with Ferrites you can find



some interesting points of contact on the Internet in the following list. These give basic information as well as component suppliers.

Address: <http://www.epcos.com/web/generator/Web/Sections/Publications/Ferrites/Page.locale=en.html>

[http://www.we-online.de/web/en/wuerth\\_elektronik/start.php](http://www.we-online.de/web/en/wuerth_elektronik/start.php)

<http://ferrite.de/en/>

<http://www.ferroxcube.com/>

<http://www.fair-rite.com/newfair/index.htm>

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## Skyworks

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You must remember this name because the RF semiconductors are always interesting. For the developer, there are LNAs from this manufacturer with noise figures that have already fallen below 0.5dB.

Address: <http://www.skyworksinc.com/categories.aspx?CategoryID=4>

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## Integrated LNA and mixer basics

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This well-known application note 884 from National Semiconductor is also used by Texas Instruments with the same content but a different cover. Still good and worth reading!

Address: <http://www.ti.com/lit/an/snoa290/snoa290.pdf>

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## Horn antenna design

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There are some very nice sites on the Internet and if you are designing a Horn antenna these may be useful.

Address: [http://www.radio.feec.vutbr.cz/kosy/soubory/bocia/High\\_performance\\_horn\\_antenna\\_design\\_II.pdf](http://www.radio.feec.vutbr.cz/kosy/soubory/bocia/High_performance_horn_antenna_design_II.pdf)

Or: [http://smartech.gatech.edu/jspui/bitstream/1853/34414/1/PG\\_TR\\_040813\\_YL.pdf](http://smartech.gatech.edu/jspui/bitstream/1853/34414/1/PG_TR_040813_YL.pdf)

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Address: <http://smartech.gatech.edu/>

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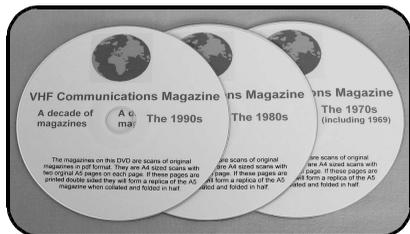
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From 2002 the magazine has been produced electronically therefore pdf files are available of the text and images. These have been used to produce the 2000s decade DVD.

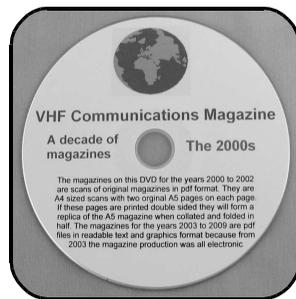


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KM PUBLICATIONS,  
503 Northdown Road, Margate,  
Kent, CT9 3HD, United Kingdom  
Tel: +44 (0) 1843 220080  
Fax: +44 (0) 1843 220080

Email:  
andy@vhfcomm.co.uk

## Editor

Andy Barter G8ATD

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AUSTRALIA - Mark Spooner c/o, W.I.A. SA/NT Division, GPO Box 1234, Adelaide, SA 5001, Australia Tel/Fax 08 8261 1998

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Tel: (33) 03 86 44 06 91, email christiane.michel.s5sm@orange.fr

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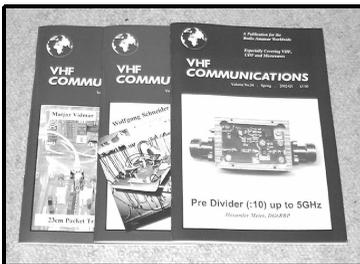
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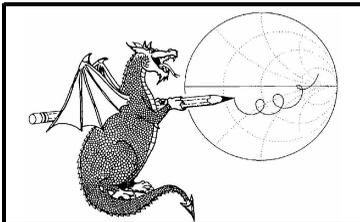
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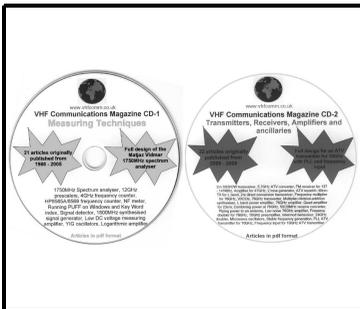
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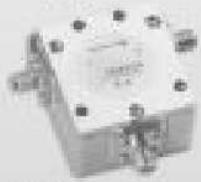
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