

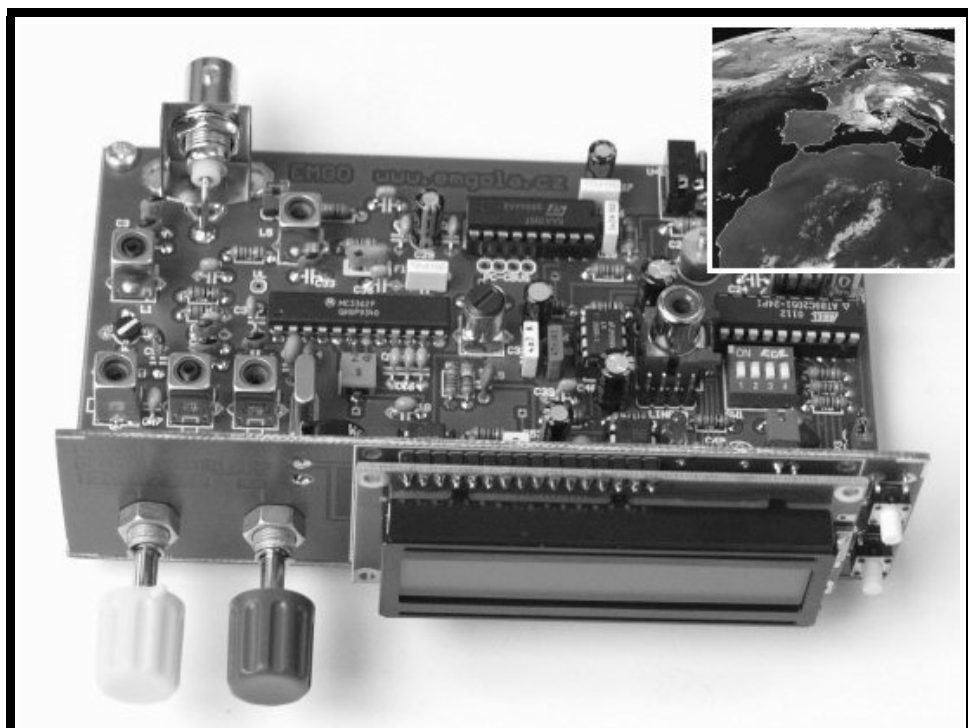


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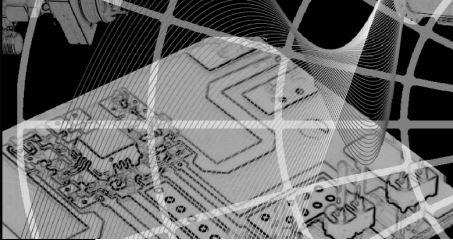
## **FM Receiver For 137 - 141MHz**

*Miroslav Gola, OK2UGS*

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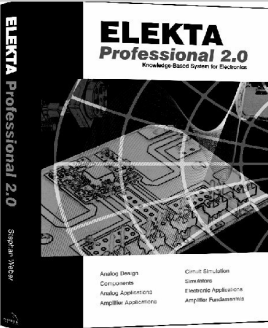
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*This issue has lots of constructional articles, I hope that this will please those of you who have contacted me to ask for more such articles.*

*Miroslav Gola is another new author to VHF Communications, the 137 - 141MHz receiver project is ideal for the new constructor.*

*If you have an interesting article that is suitable for VHF Communications, please contact me.*

*73s - Andy*



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Miroslav Gola, OK2UGS

# FM Receiver For 137 - 141MHz (A double conversion superhetrodyne with pll)

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## 1.

### Introduction

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Receiving information from FM meteorological satellites has become an interesting hobby for thousands of radio enthusiasts all over the world. Those of you who have already tried internet searches using such keywords as NOAA, METEOSAT, 137.5MHz, WEFAX, Meteor etc. , will undoubtedly confirm that they have found hundreds of links to pages of receiver manufacturers, re-sellers, professional users and particularly ham enthusiasts.

You will find among others, a link to the homepage of Radek Václavík OK2XDX, which is devoted to these issues [1]. His article on a downconverter for Meteosat reception was published also in the VHF Communications issue 4/1999 [28,29].

It is worth noting that on 1st April 2000 we commemorated the 40th anniversary of the first transmission of images from the satellite TIROS 1. The pictures were of rather low quality, nevertheless, they started an era of space research of the Earth's surface. The resolving power of today's images is currently of the order 1 pixel = 1 m. You can find more detailed information on the internet pages of the NOAA agency <http://www.earth.nasa.gov/history/tiros/tiros.html>.

Quite a few hams tried successfully in the seventies to construct receivers. These obviously did not have the technical specification that can be achieved with modern components. Images were not generated using high quality decoding programs for personal computers, simply because they did not exist at that time. The images were "decoded" using technology of the seventies; plotting on oscilloscope with medium afterglow and then photographing using an instant Polaroid camera [9].

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## 2.

### Looking at earth from space

---

Satellites NOAA (USA - National Oceanographic and Atmospheric Administration) and METEOR, OKEAN, RESURS (Russia) are the focus in this article. They are flying on polar orbits around the Earth at the distance of approximately 800 - 1200 kilometres passing over the same place at approximately same time every day [23]. Satellites pass the North or South pole on each orbit, that is why their orbits are called polar. It is possible to determine their trajectory precisely using "Keplerian elements", which describe the current orbit of the given satellite. Calculation of the exact time of a satellite's orbit, from the mo-



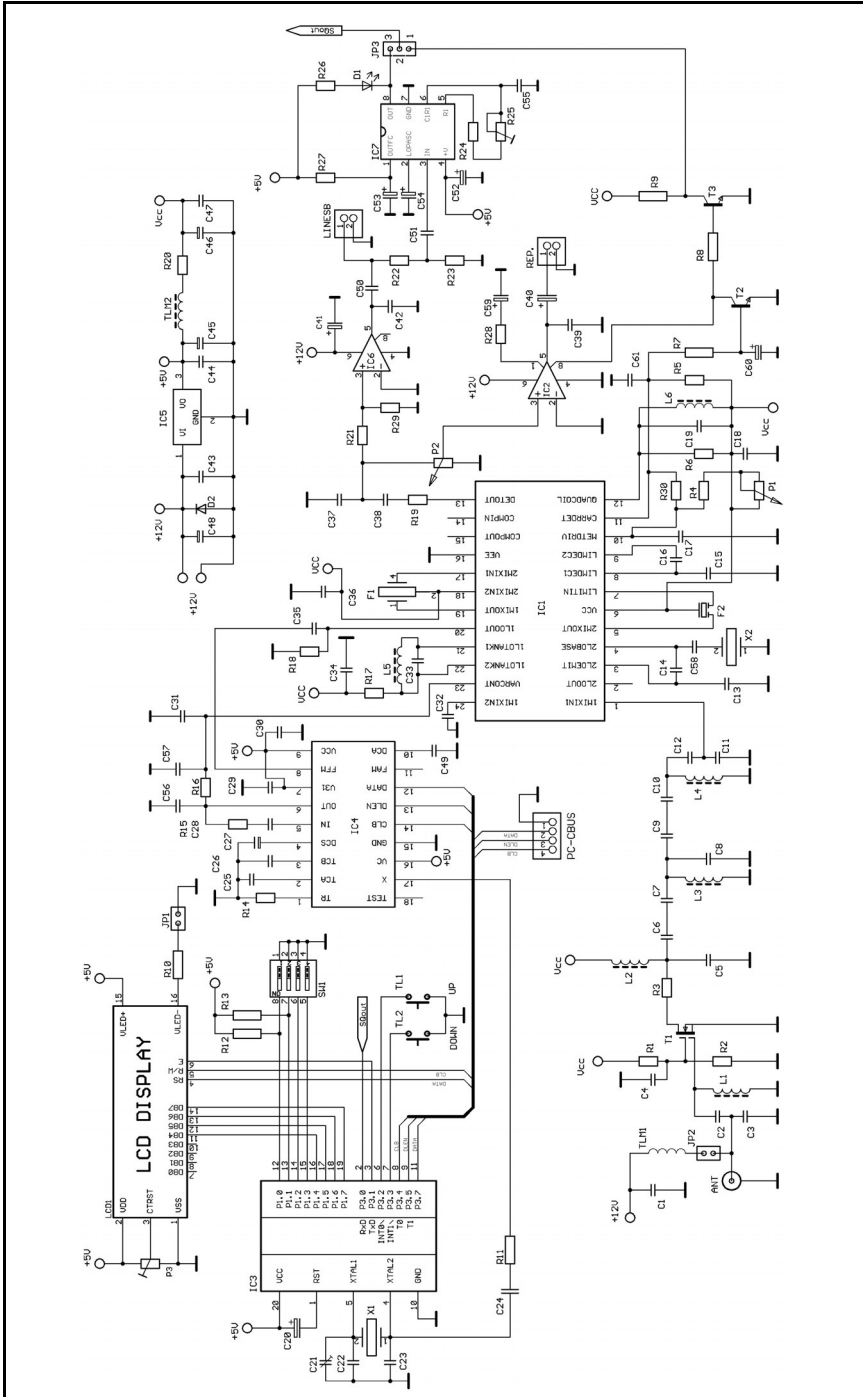


Fig 1 : Circuit diagram of receiver.



ment when it appears at the horizon till the moment when it disappears behind the horizon, can be made nowadays using many programs for personal computers. I most frequently use a simple Windows program called SatWin [10, 24]. A version of SatWin was also written for MS-DOS and can be run on older personal computers of the DX486 type. Both these programs can be downloaded free of charge together with up-to-date Keplerian elements at the following address: <http://www.emgola.cz/>. You will also find other information about the activities of satellites plus the signals that you can receive and decode using the receiver described in the following article. Pictures are transmitted continuously from polar satellites without beginning or ending. When the satellite appears over the horizon, the edge of the pictures is slightly cramped, gradually resolution of details in the picture improves. At the end of orbit the signal gets weaker and the picture begins to disappear in noise as the satellite slips behind the skyline.

Inclination is the angle made by the plane of satellites orbit and equatorial plane. A satellite that passes over both poles (on so called polar orbit) has the inclination of  $90^\circ$ . The inclination of American satellites NOAA 10-16 is  $98^\circ$ , their period is approximately 102 minutes and height of satellite is approximately 820 - 850 kilometres.

Signals from the satellites are in WEFAX format (Weather Faximile). This is an old, but still useful, system for transmission of black and white visual information using a standard audio channel where a change of amplitude of the 2400Hz sub carrier represents the level of the video signal brightness. Maximum modulation (black) is not zero, but approximately 5%, white is then approximately 87%. This audio signal is frequency modulated on the main carrier, e.g. 137.50MHz for the satellite NOAA 15. After demodulation by the FM receiver we therefore obtain an amplitude modulated tone of 2400Hz. This signal is

sent to the input of standard sound card in a PC and processed by a software decoder such as JVComm32 which can be downloaded from <http://www.jvcomm.de/>. JVComm32 even handles bad quality demodulated signals due to the efficient digital filters. The result of this processing is shown in Fig 12 as picture displayed on a computer monitor.

Transmission of images from NOAA satellites are composed of lines lasting 0.5 second, which correspond with data from sensors. They provide one picture of the Earth surface containing data from two channels. Channel A transmits picture in the visible spectrum (VIS) and channel B transmits picture in the infrared spectrum (IR). Each line contains time multiplexed data from both channels and is composed of separation tones interlaced with picture modulation. Data from channel A is preceded by and short impulse of 1040Hz and similarly data from channel B are preceded by and short impulse of 832Hz. Each line also contains a calibration sequence. Thanks to this the decoding program can display only the chosen type of picture. You will find more detailed information at <http://www.noaa.gov/>. You will find up-to-date information about Russian satellites METEOR, OKEAN, RESURS at <http://sputnik.infospace.ru/>. These satellites have higher orbit than that of NOAA satellites (1200 km). For example inclination of satellites METEOR is  $82^\circ$  and their period is 115 min. The system of picture transmission from METEOR satellites is compatible, however slightly different, from that of NOAA satellites. Modulation is similar, but pictures contain only one photo with higher resolution. Edges of lines contain sets of phasing lines (alternately black and white), the lines mark end of picture and greyscale. Pictures in the infrared spectrum do not contain the greyscale. The pictures are also inverted as in comparison with NOAA pictures. Photos from NOAA satellites show warmer places by darker shade and colder places are brighter. The



NOAA 11	137.62MHz	Not operating
NOAA 12	137.50MHz	
NOAA 13	137.62MHz	Not operating
NOAA 14	137.62MHz	
NOAA 15	137.50MHz	
NOAA 16	137.62MHz	Not operating
NOAA 17	137.62MHz	
NOAA beacons	136.77 and 137.77MHz	
METEOR 2-21	137.40MHz	
METEOR 3-5	137.30MHz	
OKEAN-O	137.40MHz	
RESURS O 1.1	137.85MHz	

**Table 1 : Not all the satellites given are always active. Some of them are still flying on polar orbits, but their transmitters have been switched off. Some others do not transmit due to a failure, e.g. the modern satellite NOAA 16 only transmits in the mode HRPT at the frequency 1.698 GHz due to a defect. This is the fate of all artificial satellites, when they fail they can only be repaired using very costly methods. Not all the satellites are as important as the Hubble space telescope, which was repaired by the space shuttle that we watched with excitement and admiration.**

See <http://noaasis.noaa.gov/NOAASIS/ml/status.html>

pictures from METEOR use inverse scale warm seas are white and cold cloud formations are black.

It is also possible to decode visual information from the receiver any time. To do this it is necessary to save the received modulated signal as a WAV sound file on a high quality recorder (we had the best results with SONY Minidisk). If you take holidays in distant countries, it is recommended that you use a portable and easily mounted Quadrifillar Helix antenna, see [19], take the receiver described below and a Minidisk. During your trip you can record exotic pictures from any of the meteorological satellites. When you return you can decode the saved WAV sound files in the same manner as during direct reception.

### 3.

#### Description of the receiver RX-137-141MHz

The receiver RX-137-141MHz has been designed for high quality reception of signals from polar meteo-satellites NOAA, METEOR, OKEAN and others. It is compatible with the converter from 1691MHz to 137.50MHz which is suitable for reception from geo-stationary satellite METEOSAT 7 [14, 23].

Looking at the Table 1, you will find that satellites in polar orbits transmit signals in the range of 137.30-137.85MHz, therefore a very narrow frequency range is sufficient. We have chosen, for practical reasons, a lower frequency of 137.00MHz and an upper frequency of 141MHz. No meteorological satellites transmit at frequencies above 137.85MHz but the frequency of



Frequency range:	137 - 141MHz, smoothly in steps of 10kHz
Function SCAN:	137.00 137.30 137.40-137.50 137.62 137.85-141.00MHz,
Intermediate frequencies:	10.7MHz and 455 kHz
Input sensitivity:	0.4 $\mu$ V (rms-typ.) for 12dB SINAD
Output signal:	2400Hz amplitude modulated (black 5% and white 87%)
Display:	LCD single line, 16 displayed characters
Current consumption:	70mA, (with converter LNC1700 250-500mA)

**Table 2 : Specification of the receiver.**

141MHz will make it possible to use the converter for the METEOSAT 7 satellite. This makes it possible to process information from both channels, the first channel (1691MHz) converts to 137.50MHz and the second channel (1694.50MHz) converts to 141.00 MHz.

The circuit diagram of the receiver is shown in Fig 1. It was originally developed for the nearby ham frequency range of 144-146MHz [3]. The circuit of the receiver is designed for wideband FM (bandwidth 30kHz). The low-frequency WEEFAX signal is sent from the output to the PC sound card. The frequency synthesiser PLL and LCD display are controlled by an ATMEL micro-computer.

The receiver is a double conversion superhetrodyne. Design of the receiver has been significantly simplified by using an MC 3362P (IC1) integrated circuit made by Motorola [5], which comprises all main elements of modern FM receiver. All that is required to connect to the MC3362P is an input band-pass filter, a resonant circuit for the first mixer oscillator, 2 ceramic filters for 10.7MHz and 455kHz, a quartz crystal oscillator for the second mixer, a resonant circuit for the demodulator and few other passive components. We will thus obtain an excellent receiver with a rather simple circuit and with supply voltage of 2-5V [12].

### 3.1 Input circuits of the receiver

The signal from the antenna (or from the

converter) go to a capacitance divider C2-C3 (input impedance adjustment). The divider together with L1 forms the first tuned circuit, the "hot end" of which is connected to T1 a dual gate MOS-FET, preferably "low-noise" type BF982. T1 ensures sufficient amplification of the input signal. Resistor R3 suppresses the tendency of input amplifier to oscillate, but it does reduce overall amplification. The signal from resistor R3 is further filtered by a band-pass filter L2-C5, L3-C8, L4-C11+C12 with the bandwidth of approximately 4MHz. Critical coupling between the band-pass filter circuits is determined by serial connection of SMD capacitors C6 + C7 and C9 + C10. The signal passes through the capacitance divider C11+ C12 to the input of the first mixer in IC1 with mixing signal from oscillator (L5, C33).

### 3.2 PLL Oscillator

The stability of the oscillator for the first mixer is achieved using a PLL with reference frequency of 4MHz. IC4 is a Philips SAA1057 single chip synthesiser designed for tuning of VHF FM radio receivers with medium frequency bandwidths [4, 6]. It was produced in 1983, but surprisingly enough it is still available on the market and at very good price. In the circuit shown in Fig 1 the synthesiser can be tuned from 110MHz to 150MHz with steps of 10kHz using a maximum tuning voltage of 4.5V. The tuning voltage (max. 5.5V) is taken from the power supply to the pin 7 of IC4. R14, C25 and C26 are the passive com-



ponents of the phase detector, C27 filters the internal stabilised voltage. The stability of the PLL is determined by the filter connected to pins 5 and 6 of IC4, R15, R16, C28, C31, C56, C57 determine the time constant of active low-pass filter. It is important here to pay special attention to recommended values of components. The tuning voltage from the PLL is connected to the pin 23 of IC1 to an internal varicap diode. The output from the first oscillator of the circuit in IC1 (oscillator buffer) is connected through the coupling capacitor C35 to pin 8 (FFM), the input pre-divider of the synthesiser IC4. In the majority of applications of the SAA1057 the reference frequency is determined by a 4MHz internal oscillator controlled by external quartz crystal connected to pin 17 (X). In our circuit we have chosen an economic option and used a common quartz crystal for the reference frequency of both PLL and ATMEL micro-computer [7]. The quartz crystal X1 is part of the oscillator in IC3 and the reference frequency for IC4 is connected through the capacitor C24 and resistor R11.

For the first mixer we have chosen frequency one intermediate frequency (10.7MHz) lower than the signal frequency. The synthesiser therefore generates frequencies from 126.3MHz to 130.3MHz for a reception frequency range from 137.0MHz to 141MHz. The synthesiser frequency can be finely tuned with use of trimming capacitor C21. The control word for setting the dividing ratio of the divider is accepted by the synthesiser IC4 through the inputs CLB, DLEN, DATA from the micro-processor IC3 via a three wire data bus, C-BUS, which is also connected to the connector PC-BUS for other uses.

### 3.3 Intermediate frequency

The first mixer oscillator is 10.7MHz lower than the input signal. The difference component ( $f_{IN} - f_{OSC}$ ) is the intermediate frequency signal of 10.7MHz being amplified by the amplifier in IC1

and fed to the ceramic filter F1, this is a common type muRata 10.7MHz/180 kHz. The filtered signal is fed to the second mixer where it is mixed with the signal of a quartz crystal oscillator with the frequency of 10.245MHz (X2). The resulting difference component is filtered by ceramic filter 455kHz (F2) with a bandwidth is 30kHz. Due to frequency swing of the WEFAX signal's modulation of +/-17kHz the width of F2 should be approximately 40-50kHz. Unfortunately, the only ceramic filter available is the muRata/455/B. We have found that the narrower width of the filter has an unrecognisable impact on quality of the final image. Modulation of the first oscillator can have a substantial influence on the quality of decoded image. That is why increased attention must be paid, in this project, to the feedback loop of the PLL.

The signal after the filter F2 is amplified in the internal limiter with the output to the quadrature demodulator, which uses the resonance circuit L6-C19. In order to ensure only minor signal distortion after demodulation the linear characteristic of the demodulator must have width of at least 40kHz. For this reason we have chosen the value of the damping resistor of 39k. For use with the METEOSAT satellite a bandwidth of approximately 20kHz is sufficient.

### 3.4 Low-Frequency output

The demodulated low-frequency signal is a tone of 2.4kHz that passes through a simple filter, formed by R19, C37, C38, which suppresses undesirable products. After the filter the signal is divided into two parts, one to the potentiometer P2 which feeds the low-frequency amplifier IC2 with output to the loudspeaker, the other to the pre-amplifier IC6 for the 2.4kHz tone decoder circuit IC7, and also to the output for the PC sound card.

### 3.5 2400Hz tone decoder

A tone decoder [13] was included in the receiver after considering possible modi-



fications to the software for the original receiver from [2, 3, 8]. From the table of orbit times for individual satellites and frequencies at which they transmit, it is apparent that the receiver must scan the band from 137 - 141MHz and stop only at signals with modulation by a tone of 2400Hz and not at incidental interference. We have chosen a simple algorithm; the receiver performs a test after switching on and stops at the first channel having a signal modulated by tone of 2400Hz. When the satellite disappears behind the horizon the signal modulated by a tone gets lost in the noise and the receiver begins scanning again. It stops at the next signal with 2400Hz tone modulation. The tone decoding is reliably accomplished by the integrated circuit NE(SE)567 (IC7). As soon as a signal appears on the input of the tone decoder, it is compared with the frequency of the internal oscillator. When a tone is detected the output, pin 8, of IC7 is set to the a low level and diode D1 is lit. The frequency of internal oscillator is set roughly by the capacitor C55 and accurately to the value of 2400Hz by the trimming resistor R25. The logic signal on pin 8 of IC7 is connected via the jumper JP3 to the input of the microprocessor SQ OUT which controls mode of automatic searching for signals in the received bandwidth (SCAN). The jumper JP3 can be used to select control of automatic scanning for signals either on the basis of presence of 2400Hz tone, or by active squelch.

### 3.6 Squelch

A side effect of receiving weak FM signals or operation of the receiver beyond the tuned station is an unpleasant noise in loudspeaker. That is why squelch (SQL) forms an integral part of any FM receiver. It interrupts the low-frequency signal to the amplifier at absence of sufficient level of input signal.

The DC component of LF signal from the pin 10 (MetDriv) of IC1 is fed through R4 to the potentiometer P1, which is

used to set the sensitivity threshold of the squelch. When the slider of potentiometer P1 is in the extreme left position the squelch is disabled. Turning the potentiometer clockwise increases the level at which the squelch switches off. Pin 11 of IC1 is carrier detect which is used to control the squelch switch having a voltage of approximately 0V for a signal without noise or a voltage of approximately 2.8V for no signal, or a signal with increased noise level. This is inverted by transistor T2 and fed to pin 8 of the loudspeaker amplifier IC2 that mutes the signal path when the squelch is active

When the squelch is switched off the collector of the transistor T2 and pin 8 of IC2 have voltage of 1.25V, and the low-frequency is not muted. When at constant signal is received at the antenna and the potentiometer P1 is turned clockwise, we will reach a state where the squelch activated i.e. a voltage 0V appears at the collector T2 and the low-frequency path is muted. When signal voltage on the receivers input increases slightly the squelch deactivates and opens the low-frequency path.

The squelch signal has been used also for automatic scanning of signals. We have added transistor T3, which inverts the squelch signal which can be connected to the input P3.0 (SQ OUT) of the microprocessor IC3. The processor program then takes care of the rest (see the chapter Setting-Up Of The Receiver for more details).

Note: If you do not like the small hysteresis of squelch, connect pins 10 and 11 of IC1 using a resistor of 2 - 5M (R30) and connect a ceramic 100nF capacitor (C61, preferably SMD) between pin 11 and GND. Another option to soften the squelch rise time is to use an electrolytic capacitor C60.





**Fig 2 : General view of a Turnstile antenna.**

4.

### Experiment with an AFC circuit

During the design of this receiver described in [2, 3, 8] experiments were made for AFC. This tuned the frequency of the reference oscillator using the DC component of the voltage from the quadrature demodulator at pin 13 of the IC1. This was connected to the inverting input of an operational amplifier TL071 with its output connected to a pair of varactor diodes, KB105G, which replaced the trimming capacitor C21 in the circuit of reference oscillator. Thanks to the very good stability of PLL we did not notice any change in quality of the final image when AFC was used, that is why we decided to exclude the AFC circuit in order to make the design as simple as possible. For people interested in AFC, the circuit diagram is available at the authors homepage.

In relation to the use of AFC, it is appropriate to mention Doppler shifting of frequency. This phenomenon is observed if a signal source, in our case a meteorological satellite, is approaching,

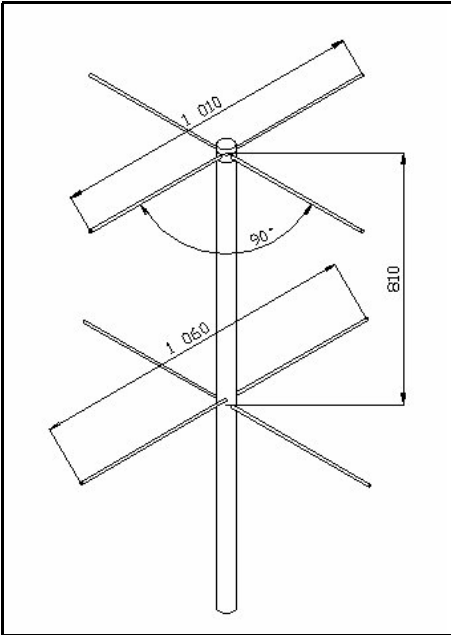
you perceive its frequency as higher, and when it moves away, you perceive its frequency as lower than it in fact is. The magnitude of the Doppler shift for orbital satellites is a maximum of 5kHz which is still in the pass-band of the filters and does not cause visible distortion of final image.

5.

### Antenna

A requirement for assuring high quality reception of signals from meteorological satellites is the use of a high quality antenna. Polar meteorological satellites are rotation stabilised and transmit circular polarisation. It is therefore impossible to use ordinary Yagi or ground plane antenna. When you listen to the signal from the loudspeaker it seems to be noise free, however when you observe the picture after it is decoded you will see that it is unusable. Anyone can build high quality antenna. Two basic types are used: Turnstile and Quadrifillar Helix.

The turnstile consists of two crossed dipoles (Fig. 2) phased for circular polarisation. This antenna should be situ-



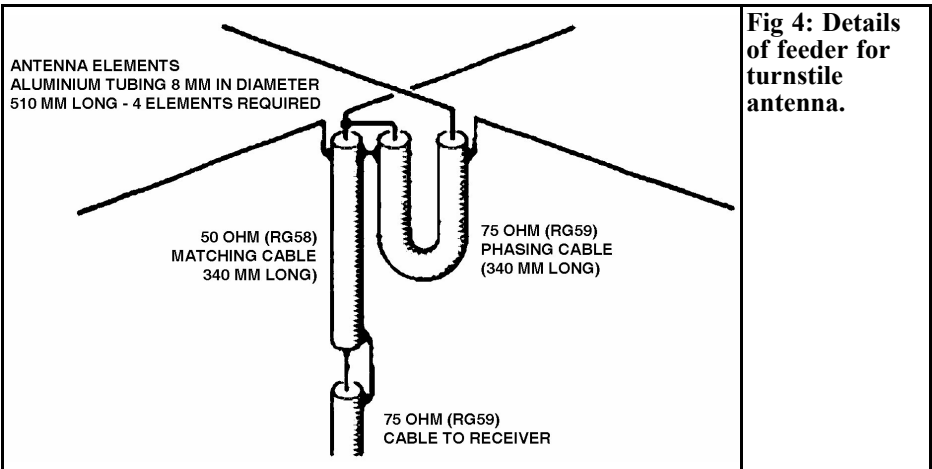
**Fig 3: Practical design of a turnstile antenna.**

ated as high as possible above the horizon, preferably above the house roof or in an open air space. Experiments made with a turnstile antenna located on the balcony of a blockhouse, satellites flying over at a low elevation angle were shielded by building or balcony. In short,

it is only possible to receive signals that are “seen” by the antenna. Instructions for building several types of turnstile antennas are on the authors homepage. Drawings describing the construction of a simple antenna made from plastic tube and 8 - 12 mm aluminium tube are given in the literature [18].

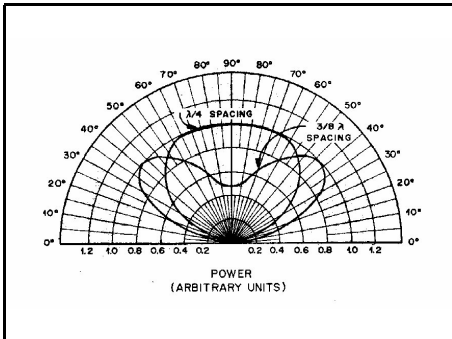
We have tested the antenna shown in Fig 3 with the receiver. The antenna was installed on a roof at 40m above the ground and gives high quality signal reception. The feeder connection for circular polarisation is shown in Fig 4. Fig 5 shows the polar diagram for this antenna, particular attention should be paid to the dipole to reflector spacing because it changes the polar diagram, the author chose  $3/8\lambda$ .

The manufacture of the Quadrifillar Helix antenna, which is shown in Fig. 6 can be done only in a well equipped machine shop. This antenna has slightly better reception of signals and moreover it can be used also in moving objects, such as yachts cruising in Mediterranean Sea. The article [20, 21] contain many descriptions of simpler mechanical constructions suitable, however, only for a short-term seasonal use, or for antennas made of copper heating tubes. If the distance of your receiver from the antenna will exceed 10m, I would recom-



**Fig 4: Details of feeder for turnstile antenna.**





**Fig 5: Polar diagram for turnstile antenna.**

mend use of selective pre-amplifier for frequency range of 137MHz, preferably using bipolar transistor. Experience has shown that summer storms have a rather bad impact on MOS-FET transistors. In an environment with industrial interference it is often desirable to use a band pass filter in front of the pre-amplifier.

## 6.

### Power supply for the receiver

The receiver requires a stabilised power supply adapter with a voltage of 9 - 12V. It is highly that you pay special attention to the selection of a power supply adapter. If you have an oscilloscope, look at it's output when on load at 150mA and check that there is no ripple. The low-frequency amplifiers IC2 and IC6 are fed directly from the adapter. The other supply voltages, 5V for receivers circuits and 5V for synthesiser and microprocessor, are stabilised by IC5 (LM7805). The supply voltage for the analogue part of the receiver is also isolated by choke L6. The input of the power supply is protected against reverse polarity by diode D2. Bridging jumper JP2 enables the use the feeder cable to supply the antenna pre-amplifier or Meteosat converter. This requires a higher capacity power supply



**Fig 6 : General views of Quadrifilar Helix antennas.**

adapter, for connection of the OK2XDX Meteosat converter [16], I recommend a power supply adapter of 12V/500mA.

## 7.

### Construction of the receiver

Building the receiver is very simple, it can be done by any beginner, who has a knowledge of rf techniques, and is able to use a multimeter. If care is taken there will be no need for special rf measurement equipment. The secret of success is to put the correct value components in the right place on the printed circuit board and solder them in properly.

If you build the receiver from the EMGO kit you will have all of the components



needed. First of all visually check the components against the parts list. The values of the resistors and capacitors can be checked, the resistors can be measured and the markings checked on the capacitors. Do not forget that the marking 470 on some capacitors does not mean 470pF, but 47pF. It is important that you pay special attention to this initial measurement of components and visual inspection, including printed circuits. After first construction guide was published [3] I agreed, out of curiosity, to complete several almost finished kits. Although these receivers seemed to be assembled, they did not work. In all the cases I found that this was caused either by mistakes, negligence or bad soldering of components. After minor repairs all of the receivers worked perfectly.

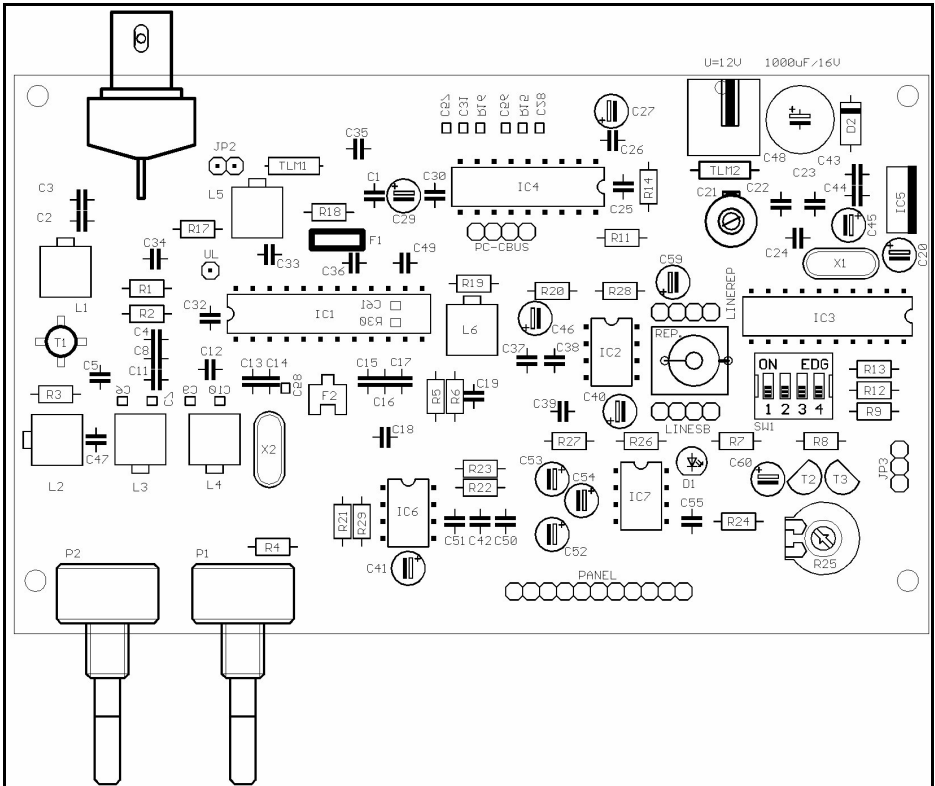
After visual inspection of the printed circuit board (PCB) fit the four pillars in the corners, they will simplify the insertion of components (Fig 7). Start by fitting the 9 SMD capacitors and one SMD resistor using a small quantity of 1mm diameter SnPbCu solder. Next insert and solder the remaining resistors, capacitors, semiconductors and the connectors for the loudspeaker and power supply starting with small components and continue with larger ones. Sockets are used for the integrated circuits IC3 and IC4. Before soldering the two quartz crystals, X1 and X2, fit a 0.5mm paper pad and removed it after soldering. Similarly the 5 TOKO coils with metal covers should be fitted into PCB with small space of about 0.5 mm., this prevents the case shorting to other tracks on the PCB. The tank circuit of the discriminator, L6, also has a metal cover and should be fitted approximately 0.5mm above the PCB. If L6 does not contain a capacitor, fit C19. Finally fit the switch SW1 and JP3 and connectors LINESB and LIN-EREP. If you use your own printed circuit board and it does not have plated through holes, do not forget to solder the top and bottom of components leads and fit fed through wires where required. Fit

the pre wound coils L1 to L5 for the input band-pass filter, these are high quality coils made by Japanese manufacturer TOKO.

If you manufacture the coils yourself, you must wind 2.75 turns of 0.215mm enamelled copper wire on 5mm formers. Solder the wire ends to the metal pins on the bottom of the former and cover the coil with a droplet of beeswax. Turns on all the coils must go in the same direction (e.g. clockwise). Insert the coils to the PCB and check orientation before soldering. Put a metal cover over the former approximately 0.5 mm above the printed circuit board. Finally fit ferrite cores made of N01 (150MHz) into the formers.

*The following components will be fitted during set-up using rf measuring equipment: capacitors C11, C12, ceramic filters F1 and F2, integrated circuits IC1 (microprocessor AT89C2051 with the program RX137DIP4X ) and IC4 (PLL SAA1057). If you do not have rf measuring equipment, insert all the components in accordance with the component layout.*

Fit the components onto the front panel (Fig 10) including the support plate for the LCD display and its fixings to the receivers main PCB. First fit the buttons TL1 and TL2 to the panel from the front and the 100k trimming resistor, for setting of display contrast, to the panel from the back. If you use a back lit LCD display, you must also fit the 120Ω limiting resistor. The panel will be fastened to the receivers PCB by soldering at the bottom corners, at places without a protecting layer of solder mask. This is strengthened by installation of two the potentiometers P1 and P2, and the angular connector. After checking that the panel is perpendicular to the receivers PCB you can solder all terminals of potentiometers and angular connector. Insert the 16 pin connector into the top part of the panel from the front and solder it from the back. Finally insert the LCD display from the front and solder its



**Fig 7 : Component layout of the main receiver PCB.**

16 pins to the front panel. Secure the potentiometers P1 and P2 by fitting the shaft nuts.

After putting the receiver RX-137-141 into operation you can fit it into a suitable plastic or metal box with apertures for the display and controls. The antenna and power supply connectors are at the rear of the box. Fig 13 shows the receiver mounted in a suitable box.

**8. Setting-up of the receiver**

Connect a stabilised power supply, of 9 - 12V, to the input connector U12. Ensure

the centre connector is positive and the outer is ground. Using a voltmeter measure +5V at the stabilised output of IC5. If there are problems with the noise properties of the receiver, check the stabilised voltage using an oscilloscope. If there is noise on the supply the stabiliser must be replaced.

The procedure for commissioning and tuning of the rf components will depend on the instruments available to the individual constructors [22]. The receiver board is already fitted with all components except the intermediate frequency filters F1 and F2. Do not fit the micro-computer IC3 and synthesiser IC4 into their sockets. Turn the potentiometer P1 (SQL) completely to the left, this will put the squelch out of operation. Do not

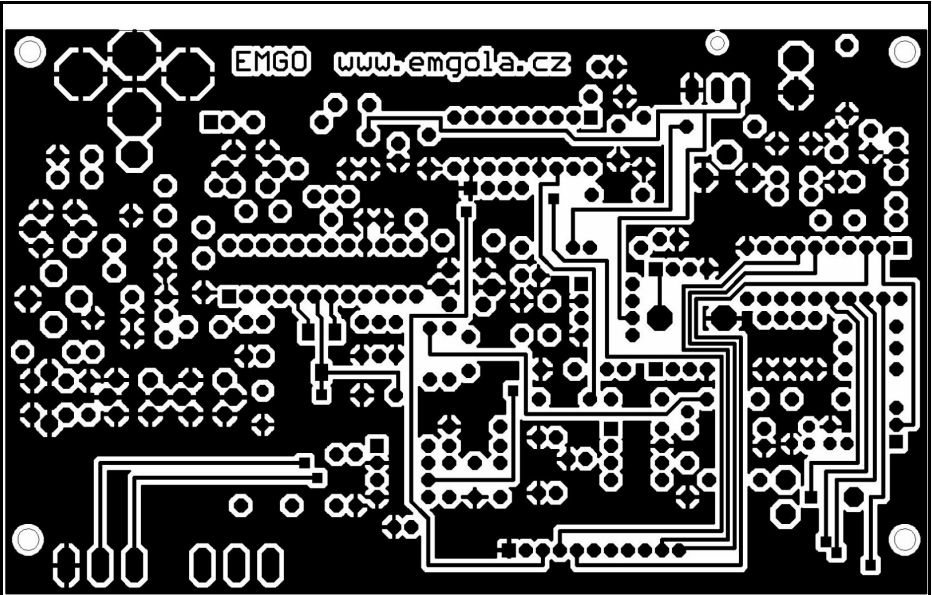


Fig 8 : Top side of the main receiver PCB.

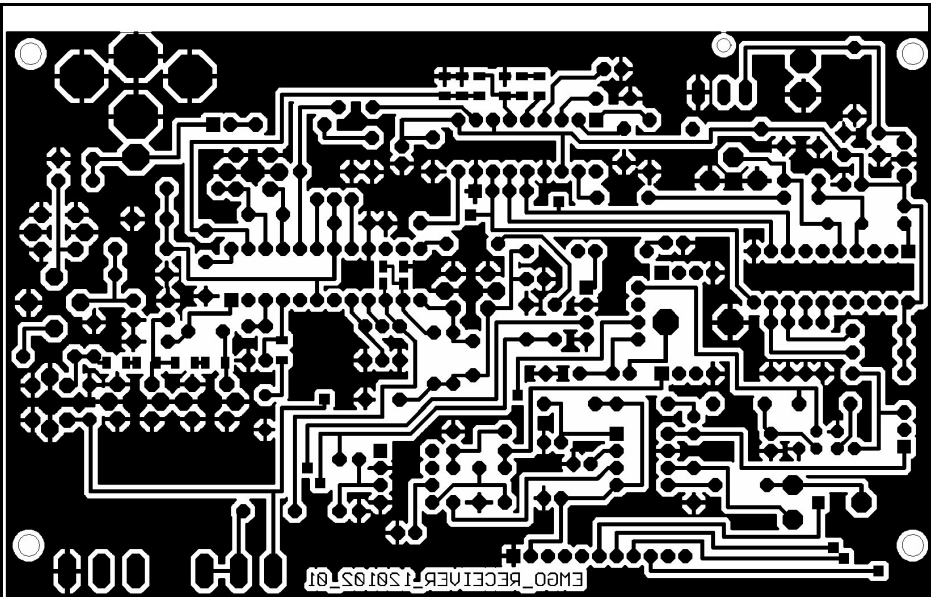
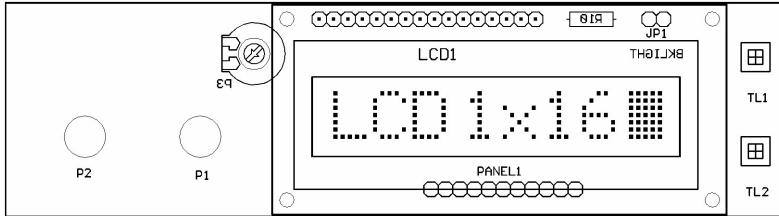


Fig 9 : Bottom side of the main receiver PCB.



**Fig 10 : Component layout of the display PCB.**

connect the shorting pin on the switch JP3. For tuning L1 - L4 at the receivers input and the demodulation discriminator L6 it is best to use a wobbler. Almost same result can be achieved using an rf generator (even an improvised test oscillator 137 - 141MHz with one transistor) a counter and a simple rf diode probe connected to an analogue voltmeter.

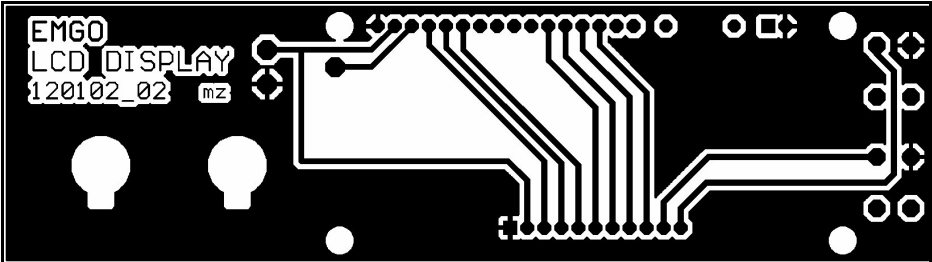
Connect a signal with frequency of 455kHz, preferably frequency modulated by tone of 1kHz, with frequency swing of 30kHz to pin 7 of IC1 using a 1nF capacitor. Connect an oscilloscope to pin 13 of IC1 and tune L6 for maximum amplitude of demodulated signal. By adjusting the value of R6 (a lower value will broaden the linear part of the curve) at least 30kHz of linear demodulation can be achieved. If a signal generator without frequency modulation is used, adjust it in steps 1kHz and plot a graph of the voltage at pin 13 of IC1. It is also possible to determine the value of R6 experimentally by monitoring the image quality (minimum noise, the highest loudness, sharpness of image details, etc.). The recommended value of R6 is 33-56K.

The next step is to fit filter F2 and connect the output signal from a wobbler generator or analyser to the receivers antenna input, connect the wobbler to pin 19 of IC1. This will enable the input selectivity to be adjusted without being affected by capacity of the signal source. Shunt the input coil L1 using a 50Ω

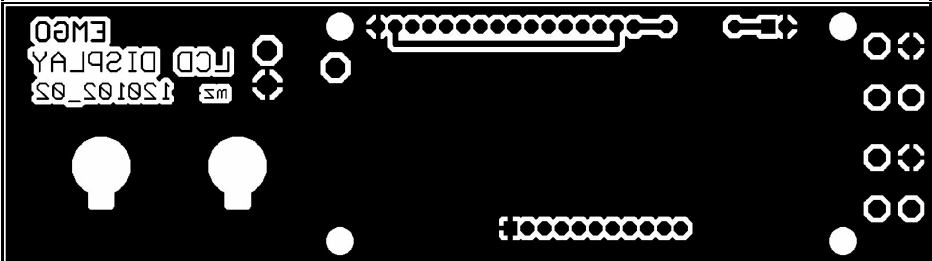
resistor and tune the band-pass filter L2, L3 and L4 to approximately the centre of the band (139MHz) and set the width of band-pass to 4MHz. If you do not intend to use the METEOSAT converter with your receiver, set the input band-pass filter to centre at approximately 137.6MHz. If it is necessary modify C6, C7 and C9, C10 (0.5-1pF) in order to adjust the coupling of the resonant circuits to critical or slightly supercritical. Remove the shunt resistor from L1 and also tune it to the centre of the selected received band, i.e. to 139 or 135.6MHz.

Now fit filter F1 and to insert the synthesiser and microcomputer ICs into their sockets. Switch on receivers power supply and use the trimming resistor on the front panel to set the LCD display contrast so that characters are legible. If turning of trimming resistor to both extremes does not help and no characters appear on LCD display, use an oscilloscope to check communication between PLL IC4 and microprocessor IC3 (pins 8 (CLB), 9 (DLEN) and 11 (DATA) TTL levels). Push any button on the display panel and look for a sequence of impulses, when microprocessor sends new data to the PLL synthesiser. If this is unsuccessful, check that the microprocessors reference oscillator is working.

With the LCD display showing a frequency of 137.5MHz, connect a voltmeter to the pin 23 of IC1 or even better to the test point "UL" and check that the first oscillator PLL is functioning cor-



**Fig 11 : Top side of the display PCB.**



**Fig 12 : Bottom side of the display PCB.**

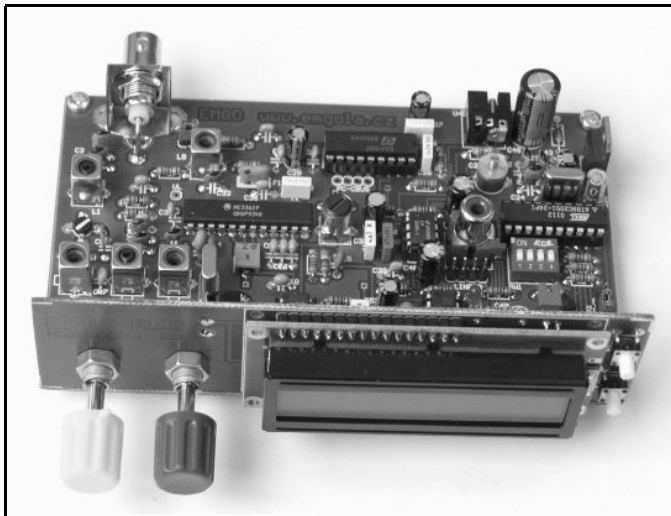
rectly. Start by adjusting the core of L5 using a non-metallic screwdriver and watching the voltmeter for changes in the control voltage of the PLL. The measured voltage should not remain fixed at

either extreme, i.e. 0.2V or 4.3V. If the PLL is working, the tuning voltage should vary smoothly between 0.2V and 4.2V as the position of the core in L5 is changed.



**Fig 13 : Completed receiver in a plastic case.**





**Fig 14 : Picture of the completed receiver.**

If you have wound your own coil L5, you may have to adjust the value of C33. If the tuning voltage reaches the maximum of 4.2V with the core almost unscrewed (minimum inductance), reduce the value of C33 by one step. If the tuning voltage reaches the minimum of 0.2V with the core completely screwed in (maximum inductance), increase the value of C33 by one step. In order to avoid such problems we recommend the use of the specified TOKO coil.

For example, for a received frequency 137.50MHz - satellite NOAA 15 (oscillator of the receiver oscillates at 126.80MHz) set the voltage at the junction of R16, C31 to approximately 2.5V by adjusting the core of the L5. Check the exact frequency of the oscillator using a counter and tune it by slight changing the trimming capacitor C21.

The majority of constructors will probably not have a wobbler or rf signal generator at their disposal. Nevertheless even the modest ham shack equipped with just a probe, a multimeter and "common sense" it is possible to tune the input circuits to the lowest possible noise in the output LF signal. You just have to make a test Colpitts oscillator, working at 137.5 MHz. If you do not have a suit-

able circuit, I will gladly send it to you together with a PCB. You can then tune the resonance circuits, by the following method, to a minimum noise in the output signal. It is not necessary to make direct connection of test oscillator to the receivers input. It is sufficient to insert a cut wire into the antenna connector, a paper clip formed to an "L" shape will do the job. Set SW1-DIP4 to 137.5MHz and tune the frequency of test oscillator to this frequency, i.e. when the noise disappears from the receivers loudspeaker (or at least its intensity is considerably reduced). By touching the coil of test oscillator you can introduce "frequency modulation". At pin 13 of IC1 you can see the signal using an oscilloscope, or by listening to the loudspeaker. First adjust the core of L6 for the lowest noise in LF signal and the loudest volume. Then tune the input circuit, L1 - L4, and gradually shorten the improvised wire antenna (or move the test oscillator away) to give the lowest noise in low-frequency. Do not use a metal screwdriver, make a non-metallic screwdriver from a piece of hard wood (preferably bamboo), or from suitable plastic material.

Note: set the squelch off using potentiometer P1 set to its minimum value.



	Receive freq.	Oscillator freq.	Switch
K0	137.500MHz	126.800MHz	all OFF
K1	137.300MHz	126.600MHz	SW1 ON
K2	137.400MHz	126.700MHz	SW2 ON
K3	137.500MHz	126.800MHz	SW3 ON
K4	137.620MHz	126.920MHz	SW4 ON

**Table 3 : Switch settings for synthesiser.**

When this procedure is complete you can listen for received signals and set the correct squelch level. The synthesiser PLL must be set up before the alternative tuning method is used.

Connect a 137 - 138MHz turnstile antenna [17] to the receiver's input and set the frequency for the NOAA or METEOR satellites by using either switch SW1-DIP4 or buttons TL1/TL2. These satellites should soon appear, consult the current orbit timetable to verify the times. The switch SW1-DIP4 serves as simple memory to store pre-set frequencies after switching on of the receiver. When all the switches are set to the position OFF, the PLL tunes the oscillator frequency to 126.80MHz, thus the received frequency is 137.500MHz (satellite NOAA15). Set the required frequency for the receivers oscillator by switching some of the four switches of the selector switch SW1-DIP4x to the position ON. Table 3 shows the setting of the 4 switches, however all 16 combinations in binary code can be used.

To commission of the low-frequency part of the receiver all that is required is to set the gain of the amplifier for the loudspeaker and sound card using an oscilloscope, or by just listening to the audio output. Set the amplification of IC2 to the required value by adjusting R28 (3R3=74dB, 10R=70dB, 33R=54dB, 105R=44dB, 820R=34dB) with C59 100uF. Set the tone decoder IC7 by adjusting R25 so that the LED diode D1 lights up whenever a tone of 2400Hz is detected in the received signal. The optimum input sensitivity of the decoder has been chosen during development. Should

you have any reason to change it, choose different ratio of resistors R22 and R23. The output from pin 8 is connected using a jumper on JP3 to the input SQOUT of microcomputer. SQOUT can also be connected to the collector of transistor T3, which has a logical value depending on the setting of the squelch and on magnitude of input signal.

### 8.1 The Receivers control function

With a jumper on JP3 position 2-3 (TON), after switching on the receiver will perform a first test for the absence of low logical level on SQOUT. The test is then repeated and if a 2400Hz signal above the set threshold level is detected on any channel, the processor stops tuning. When the signal disappears i.e. when the satellite sinks behind horizon, the test re-starts and re-tunes until another signal is captured. Tuning can be interrupted by pressing the push button UP (TL1) or DOWN (TL2), the receiver is set to the frequency according to the selector switch SW1-DIP4. It is then possible to tune manually from 137 - 141MHz in steps of 10.0kHz. Simultaneous pressing and holding of both push buttons re-starts scanning again. The LCD display will show the current received frequency in MHz. With a jumper on JP3 position 1-2 (SQL), the squelch output is connected to the input of processor SQOUT. The scan function still operates but is now controlled by the level of the squelch, and not the presence of a 2400Hz tone.

## 9.

### How to connect a LF output of the receiver to your personal computer

After demodulation the receiver's low-frequency output is an amplitude modulated tone of 2400 Hz, which can be





**Fig 15 : JVComm32 in action.**

processed by several methods. WEFAX signals used to be processed on older computers without a sound card using JV FAX 7.1a. (operating system Microsoft MS-DOS 3.0-6.22). For those who would like to reminisce, you can study this issue on the web [19]. You will find a description of simple method, which consists of converting the amplitude modulation to frequency modulation. The maximum change of brightness is then expressed by a change of frequency of approximately 1500 - 2300Hz. This signal is connected to the computer's serial port using a simple comparator (EasyInterface) and processed by JV FAX 7.1a. Thanks to the negligible price of obsolete

computers you can make a receiver and decoder at minimum cost and have continuous reception of pictures from meteorological satellites.

Modern fast computers with sufficiently big operation memory give us a possibility to use the most advanced programs. The demodulated 2400Hz signal is connected directly to the input of sound card.

### 9.1 Program for decoding of WEFAX signals using JVComm32

Decoding of pictures by personal computers is supported by many modern programs [26]. I have tested a demonstration version of JVComm 32. This is



an elegant program without the need for an EasyInterface, just connect the low-frequency output of the receiver to the LINE input of your sound card. I finally bought a full licence for use of this program [27]. This program can be, however, only be used on a powerful PC working under Windows 95/W98/W2000/W-NT. The following paragraph describes reception of an image and its decoding by JVComm32 version 1.0 or 1.1.

In 1998 the German author of the JV-FAX, Eberhard Backeshoff, DK8JV (e-mail address: [feedback@jvcomm.de](mailto:feedback@jvcomm.de) and homepage at <http://www.jvcomm.de/>) wrote JVComm32 for decoding of WE-FAX, FAKSIMILE SSTV and other modern modes, he continues to enhance it and extend it. The program requires a common 16-bit sound cards with it's LINE input connected to the low-frequency output of the receiver. A disadvantage of this program is that it requires at least a 75MHz Pentium PC with 16MB of memory, operating system Windows 95, W98 or Windows NT 4.0 and high quality graphic card (High or True Colour) with resolution at least 800 x 600 pixels. JVComm32 on the other hand can work at the background and allows simultaneous processing of received images (viewing, cropping, sending to your friends by e-mail, etc.). The author, nevertheless, recommends for multitasking at least 90MHz Pentium and 32 MB of memory as a minimum.

Connecting the receiver to the input of computer sound card is very easy. From connector LINESB of the receiver connect the low-frequency signal to the connector LineIn or microphone input of the sound card. Fig15 shows JVComm32 in action, when a map is received in background for, the pictures received from the satellite NOAA are loaded from the folder, Picture files, to the desktop:

## 9.2 Description of software

Configuration of the program for recep-

tion of satellites NOAA or METEOSAT is very simple. Set the mode to NOAA or METEOR, and the Interface type to Sound Card. The help with this program is also very user friendly, you will find all the details of setting and operation.

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## 10.

### Kits

The author has produced kits for hams for several years and therefore knows very well that successful completion of a project is often hindered by tiny problem. No matter how good a verbal description is, it's information capability is always much lower than visual and/or audio information. That is why kits are supplied with a CD containing complete information. Kits contain a set of printed circuit boards and parts. Fully assembled and tuned modules are also available for a slightly higher price.

You can get more detailed information at the following contacts:

[emgo@vuhz.cz](mailto:emgo@vuhz.cz) or [emgo@iol.cz](mailto:emgo@iol.cz) or <http://www.emgola.cz/>

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## 11.

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## 12.

### Parts list

#### Capacitors

1pF	4 ceramic (SMD 0805)	C6,C7,C9,C10
3p3	1 ceramic	C2
5p6	1 ceramic	C12
6p8	1 ceramic	C3
10pF	1 ceramic	C33
12pF	3 ceramic	C5,C8,C11
1.8 - 22pF	1 trimming capacitor	CKT1 8-22pF
33pF	3 ceramic	C22,C23,C24
47pF	1 ceramic	C14
47pF	1 ceramic	C19 (used if not included in L6)
150pF	1 ceramic	C13
2n2	1 foil WIMA	C25
4n7	1 foil WIMA	C37
10nF	1 ceramics	C35
10nF	2 foil WIMA	C26,C49
47nF	5 ceramic	C4,C30,C32,C36,C39
47nF	1 foil WIMA	C38
100nF	9 ceramic	C1,C15,C16,C17,C18,C34,C43,C44,C47
220nF	1 foil WIMA	C31
330nF	1 foil WIMA	C28
2M2/50V	1 radial electrolytic	C20
10M/50V	1 radial electrolytic	C45
47M/12V	2 radial electrolytic	C27,C29
100M/10V	1 radial electrolytic	C46
100M/15V	1 radial electrolytic	C40
1000M/15V	1 radial electrolytic	C48

#### Resistors and potentiometers

2R2	1 R20	
47R	1	R3
180R	1 R14	
120R	1 R10 (for LCD with back light)	
3k3	3 R8,R9,R11	
4k7	2 R17,R18	
10k	4 R5,R7,R16,R19	
22k	1 R4	
39k	1 R6 (39K - 56K see text.)	
47k	2 R12,R13	
50k/G pot	1 TP160, shaft 4mm P2	
100k/N pot	1 TP160, shaft 4mm P1	
100k	2 R1,R2	
100k trim	1 PIHER PT6VK100 P3 (setting of contrast of LCD display)	
180k	1 R15	

#### Transistors and diodes

BF981	1 Dual gate MOS FET T1
BC238	2 NPN universal TO92 T2,T3

Red LED	1 Any LED diode D1
1N4007	1 Rectifier diode 1A D2

#### Integrated circuits

MC3362	1 RX FM 2x MF IC1
LM386	2 LF amplifier IC2,IC6
89C2051	1 With program RX137141DIP4LCD IC3
SAA1057	1 PLL up to 160MHz IC4
LM7805	1 Stabiliser +5V IC5
SE567	1 Tone decoder IC7
LCD-DV-16100	Single line display LCD1

#### Coils

7MC455kHz	1 TOKO 455kHz/600µH L6
Choke 560nH-1 µH	2 axial, TLM2
0.1µH inductance	5 TOKO or 2.75 turns, see text L1, L2, L3, L4, L5

#### Other

X-TAL 10.245MHz	1 Quartz X2
X-TAL 4.000MHz	1 Quartz X1
F 455 kHz/30kHz	1 Ceramic filter F2
10.7MHz	1 Ceramic filter F1
Socket DIL8	1 low Pro IC2
Socket DIL18	1 low Pro IC4
Socket DIL20	1 low Pro IC3
BNC connector	1 Antenna connector F
Spacer	4 M3x5 mm
Nut M3	4 Fe/Cd
Con. SCD-016A	1 power supply socket 12V-2.5mm
Con. SCP-2009C	1 power supply plug 12V-2.5mm
CINCH SCJ-0363	1 GM Elektronik, REP connector.
Switch DIP 4x	1 GM Elektronik, DIP1 connector.
Push butn. P-B1720	2 GM electronic, display board TL1, TL2,
Push butn. P-B1720	2 GM electronic, main PCB TL1
Knob	2 GM electronic, for 4mm shaft for P1 and P2
Pin S1G11W	1 GM Electronic, to connect the base of the receiver to LCD display
Loudspeaker	1 Conrad Electronic
PCB1 DISPL	1 138 x 37mm
PCB2 M-BOARD	1 138 x 88mm



*Wido Schäk*

# The Transmission Of Electro-Magnetic Waves In Rectangular Waveguides

**The waveguide is considered to be the most important transmission element for low loss transmission of electro-magnetic waves and signals from 1GHz upwards. At frequencies below 1GHz, coaxial cable can be more economically used for the transmission of broad band signals, however as the frequency increases the transmission losses play a larger and larger role. The article below takes a closer look at the transmission of electro-magnetic waves in waveguides.**

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## 1.

### Introduction

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In principle, the transmission of high frequency signals should take place with as little loss as possible. For signals of up to 1GHz, this can be dealt with entirely by using modern, low loss coaxial cables. Above 1GHz, however, transmission losses play a larger and larger role, due to cable attenuation.

This disadvantage is often accepted for amateur radio use on grounds of cost. This means a high degree of attenuation in feeders to antennas (parabolic reflector, horn radiator, etc.) if the coaxial cable used is not designed for high frequencies.

For this reason, waveguides are predominantly used in commercial equipment for frequencies above 1GHz (e.g. radar and broad band directional radio), in order to achieve the lowest loss possible.

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## 2.

### Wave propagation in waveguide

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When using waveguides, you must take into account the fact that the cross sectional area and the shape determine the frequency response of waveguides. Mismatches between the waveguide input and output are particularly important, as are discontinuities, e.g. poor flange couplings. These can lead to reflections and to the formation of standing waves, and can make it increasingly difficult to predict the wave propagation pattern.

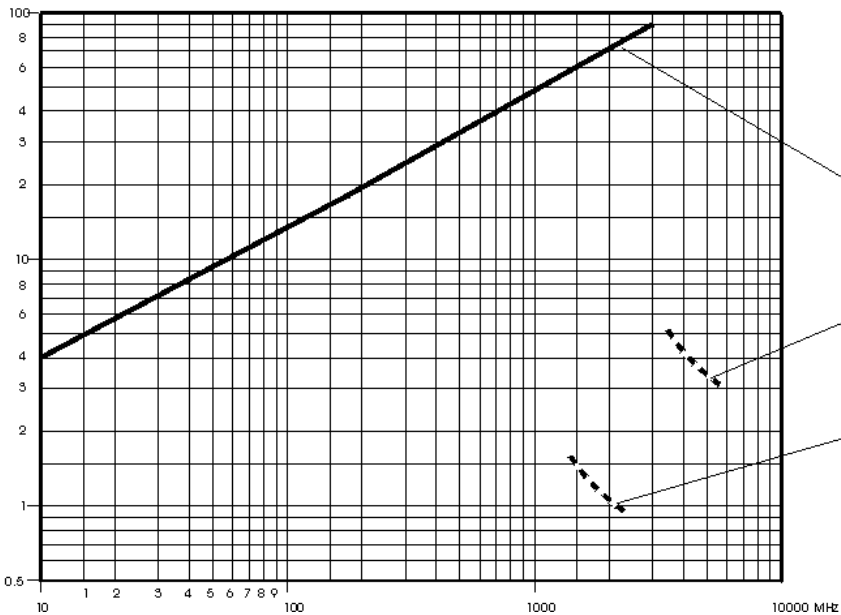
#### 2.1. Significance of lower limiting frequency for waveguides

When signals are transmitted using waveguides, the frequency, the power of the signal being transmitted and the bandwidth, determine the shape and waveguide cross sections. Rectangular, round and ridge waveguides are of importance here.

So that we can understand wave propagation in waveguides, we must now intro-



db / 100 m



**Fig. 1: Attenuation curve of coax cable in comparison to waveguides:**  
**Curve 1: RG 55B/U 50-Ohm coax cable, material solid PE**  
**Curve 2: Rectangular waveguide type 40 AL**  
**Curve 3: Rectangular waveguide type 18 AL**

duce a few simplifications, but these will nevertheless produce sufficiently accurate results.

- The dielectric material in the waveguide is always considered as being loss free, so that  $\epsilon = 1$  (e.g. air).
- Only Joules heat loss due to the skin effect occurs, reflection losses due to mismatches between the transmitter output and the waveguide do not amount to anything significant.

## 2.2. Wave propagation in rectangular waveguide

Fig. 2 shows the wave propagation in a rectangular waveguide.

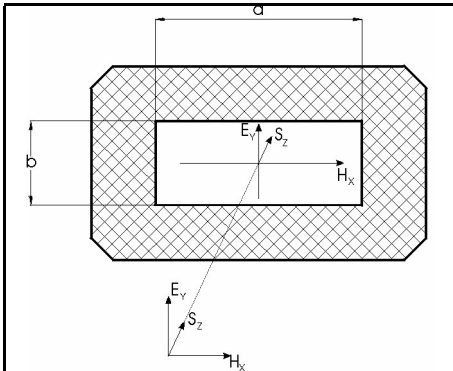
The following assumptions are made in

the analysis below. A linear polarised electro-magnetic wave acts on the waveguide, and the transmitted wave is polarised parallel to the smaller side wall  $b$ .

It is further assumed that the wave acting on the waveguide always has a magnetic,  $H_x$  field component, and an electrical,  $E_y$  field component, that are perpendicular to one another. This gives rise to a resulting directional vector,  $S_z$ , which makes the wave move into the waveguide and generate an interference field in its interior, depending on the frequency of the signal.

Let us assume that a linear polarised wave, parallel to side  $b$ , is acting on the aperture of the waveguide, with the frequency at the aperture being lower than





**Fig. 2: Incidence of a wave into a rectangular waveguide.  $S_z$  = resultant directional vector, vertical to plane of drawing.**

the limiting frequency,  $f_g$ , of the waveguide. The current generated in the waveguide wall due to the low wavelength simply short circuits the electrical field. This field is called an attenuation type.

If we now slowly increase the frequency of the wave until the critical limiting frequency,  $f_g$ , of the waveguide is reached, a stable electrical field wave is finally created, and a displacement current flows between the a sides. At this limiting frequency, the wavelength of the

wave corresponds to double the length of the a side of the rectangular waveguide.

$$\lambda \leq 2a$$

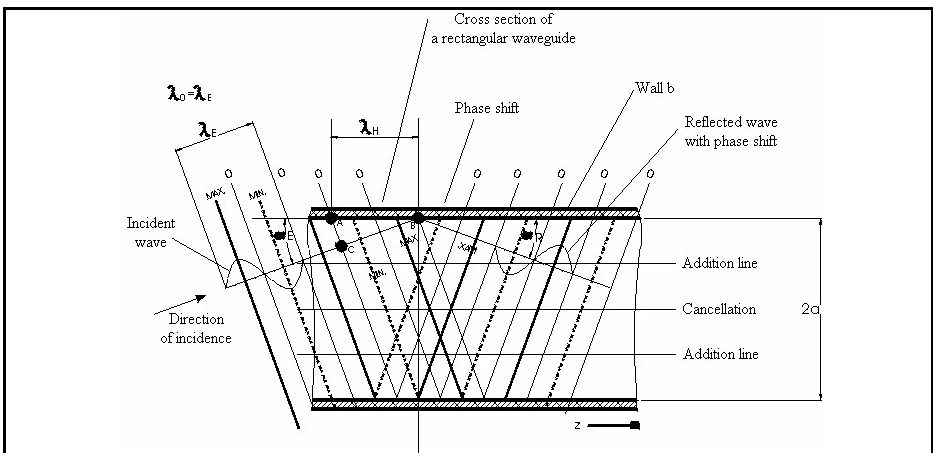
From this frequency onwards, this electro-magnetic wave can enter the waveguide. The zig-zag reflection of the wave on the side walls of the waveguide now generate an interference field (Fig. 3).

Due to the reflection of the incident wave on the side walls of the waveguide, an interference field arises in the waveguide. There are now field areas in this interference field in which the fields of the incident and reflecting waves are added together. There are likewise field areas in which the amplitudes of the two waves cancel each other out. To make this easier to understand, the illustration in Fig. 3 looks at the special case in which  $\lambda_E = 2a$ . In this case, this frequency,  $f_0$ , derived from  $\lambda_E$ , is the limiting frequency,  $f_g$ , explained above.

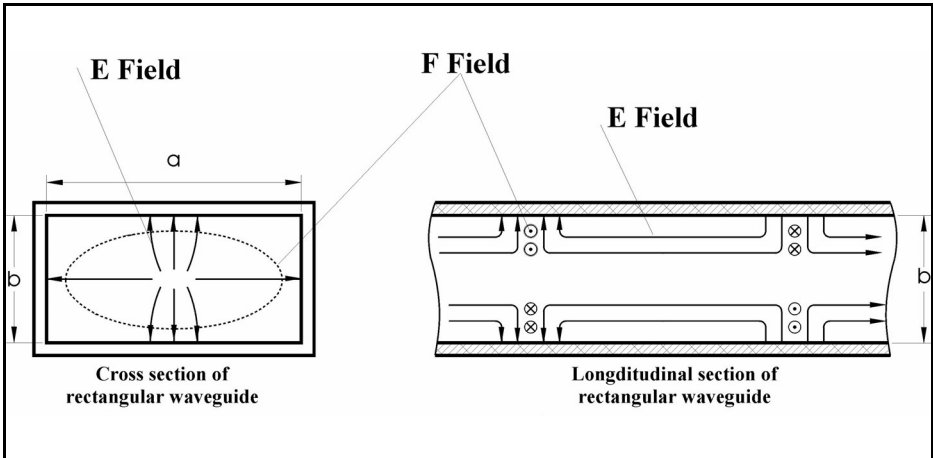
$$f_0 = f_g \text{ in Fig. 3}$$

It is also significant that a resulting new wavelength,  $\lambda_H$ , with the directional vector z, arises in the waveguide, due to the wave reflection of the incident wave.

The value of  $\lambda_H$  depends on the angle of



**Fig. 3: Interference of a wave in waveguide.**



**Fig. 4: TM wave in rectangular waveguide.**

incidence, E, with which the incoming wave is reflected on the waveguide wall (see also Fig. 3).

Angle of incidence  $\alpha_E$  = Angle of reflection  $\alpha_R$

The wave component,  $\lambda_H$ , can easily be derived from the geometry shown in Fig 3:

$$\text{The section AC} = \lambda_H$$

$$\text{And the section BC} = \lambda_0$$

$$\lambda_H = \frac{\lambda_0}{\cos \alpha_E}$$

The angle of reflection of the wave front is dependent on the frequency,  $f_0$ , of the incident wave.

The new wave,  $\lambda_H$  arising from the interference field, with direction z, has an altered propagation speed,  $v_g$ , compared with the wave,  $\lambda_0$ .

$$v_g = c \cdot \cos \alpha_E$$

$$c = \frac{1}{\mu_0 \cdot \epsilon_0} = f_0 \cdot \lambda_0 [\lambda_0 = \lambda_E]$$

### 3.

### Classification of wave types in waveguides

Dependent on the excitation of the incident wave entering the waveguide (polarisation of the wave), we distinguish between two basically different wave types:

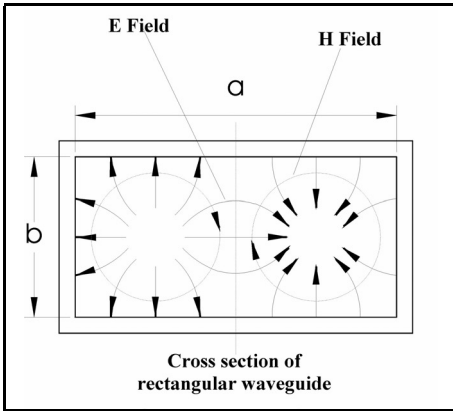
Wave type 1 TM wave

Wave type 2 TE wave

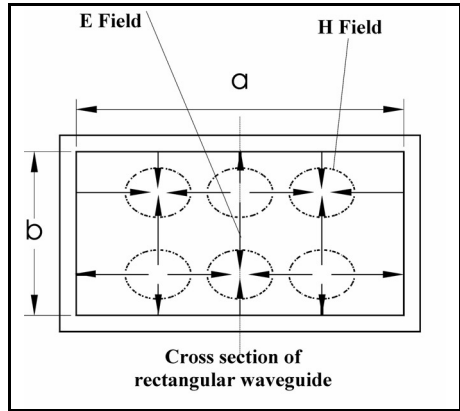
We refer to a TM wave if the directional vectors of the electrical field lines are vertically to the direction of incidence of the incident wave (see Fig. 4). The resulting vector product,  $E \times H$ , then gives an E field strength in the propagation direction of the wave, and we therefore refer to it as an E wave. This would be clearly visible if we split the waveguide in the longitudinal direction and examined the two resulting field components, E and H.

An example field pattern is shown in Fig. 4. The resulting H field lines are circular and vertical to the plane of propagation. The electrical fields are parallel to the





**Fig. 5a:Field image of a  $TM_{21}$  wave in rectangular waveguide.**



**Fig. 5b:Field image of a  $TM_{32}$  wave in rectangular waveguide.**

longitudinal axis of the waveguide. This means that the resulting E field strength causes an E wave to be propagated in the longitudinal direction of the waveguide. We can see the circular magnetic H field in the cross sectional representation in Fig. 4. By contrast, the electrical fields terminate at the internal walls of the waveguide.

However, in the middle of the cross section there is no conductor where the electrical E fields can terminate, they therefore bend round in direction z and thus determine the propagation direction of the E wave. This is called an  $E_{11}$  wave.

The following statements are thus valid for understanding wave propagation in waveguides:

- Magnetic H field lines are closed and run tangential to the waveguide walls.
- Electrical E field lines are either closed or terminate vertical to the inner walls of the waveguide.
- Electrical and magnetic field lines are always vertical to one another.

The following naming convention has been adopted and applies to both main groups H waves and E waves:

H waves  $TE_{mn}$  waves  
 E waves  $TM_{mn}$  waves

We can therefore determine the type of wave within the two main groups, the number of closed field areas of the H fields and/or the E fields in the cross section of the waveguide is counted (see Figs. 5a and 5b).

### 3.1. E waves

This does not pose any problems with the various TM waves, as can be seen in Figs. 6a and 6b.

The number of H fields is counted along side a (direction x) and along side b (direction y) of the waveguide.

In Fig. 5a we see two closed H fields along side a (direction x) and one row of H fields, in relation to side b (direction y).

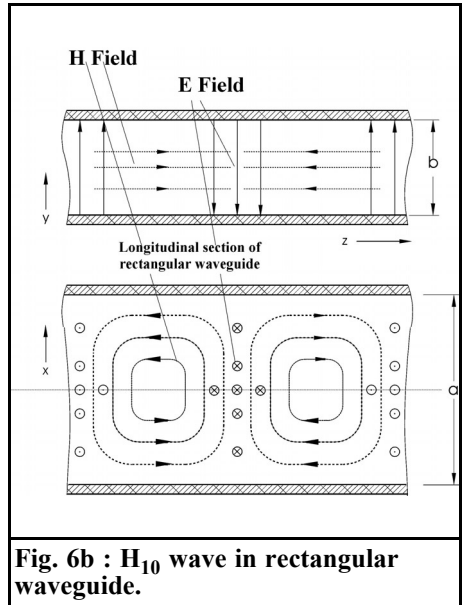
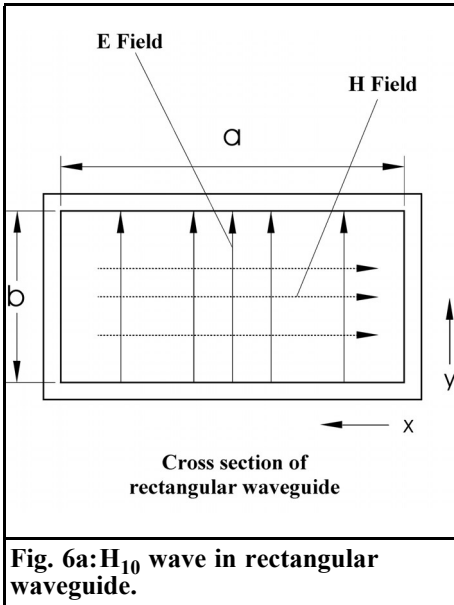
This gives us:

$$m = 2$$

$$n = 1$$

Therefore were dealing with a  $TM_{21}$  wave here.

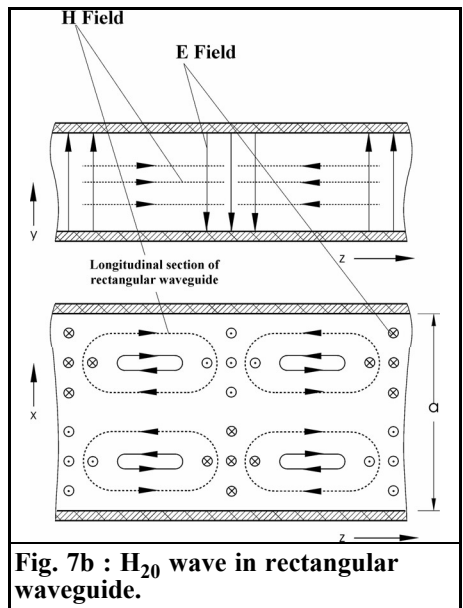
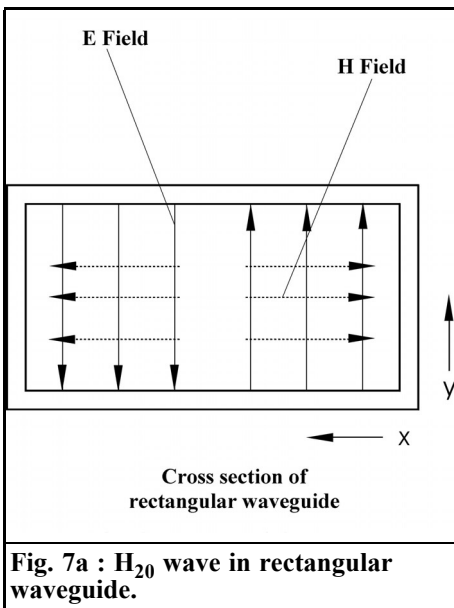
In Fig. 5b we observe three H fields along side a and two complete field areas lying on top of each other along side b. This gives a  $TM_{32}$  wave.

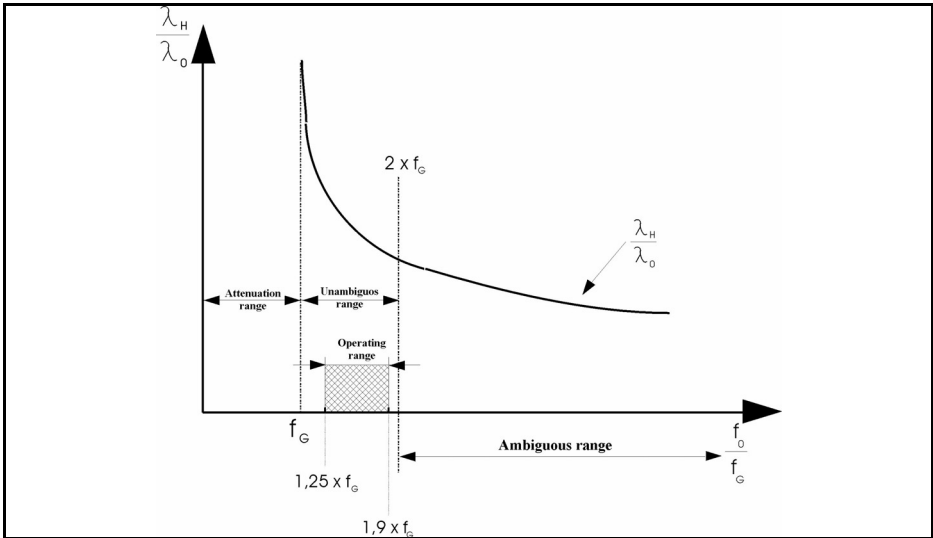


**3.2. H waves**

Lets go on to the H waves (TE waves). Figs. 6a and 6b show an  $H_{10}$  wave. It can be seen from Fig. 6b that the field lines of the H fields are orientated in direction

$z$  of the waveguide, and we can therefore refer unambiguously to an H wave. Figs. 7a and 7b give an example of an  $H_{20}$  wave, here two closed H fields are orientated in direction  $x$ , and shift into direction  $z$  with the changing polarity.





**Fig. 8: Frequency and application ranges of rectangular waveguides.**

**4.**

**Wall currents in the waveguide**

So far we have examined only the various field distributions of the magnetic H fields and the electrical E fields in the waveguide. For a comprehensive understanding of wave propagation in waveguides and of their construction, we must also consider the wall currents in the waveguide.

The occurrence of electrical wall currents on the surface of the internal walls of the waveguide can be explained by the fact that alternating magnetic alternating (tangential H fields) cause a surface current in a conductive body. Here the current flow is orientated vertically to the polarisation of the magnetic field and thus vertically to the concentric field lines of the H field. If we now look once again at the field distribution in the  $H_{10}$  wave (Fig. 6), we recognise that  $H_{10}$  wall currents can thus always be found in the vicinity of H field lines, with their directional vectors being orientated vertically

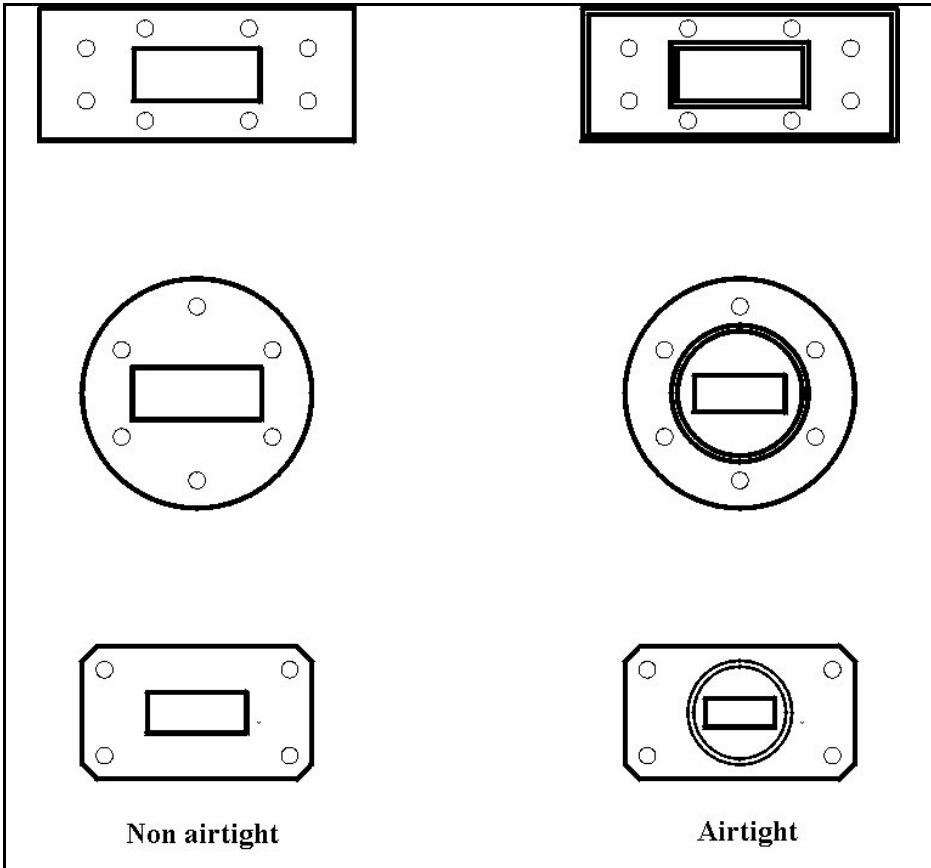
to the circle of the concentric field lines.

In accordance with this definition, the complex wall currents can also be derived for any other wave types of E waves and H waves. What is of interest here is that the wall current generated penetrates only to a depth,  $\delta$ , into the internal waveguide wall (skin effect). Thus, particularly in very high frequency applications ( $f > 20\text{GHz}$ ), the waveguides internal walls are often electro-plated with a layer of gold, silver or copper in order to obtain a high degree of conductivity for the waveguide surface.

**5.**

**Phase velocity and frequency response in rectangular waveguides**

For the transmission of high frequency waves in waveguides, the high degree of dependence on the frequency (in contrast to coax cables) must be taken into ac-



**Fig. 9: Basic forms and constructions of waveguide flanges.**

count. The signals fed into the waveguide display a phase velocity that varies with the frequency. The phase velocity's dependence shows itself, in particular, in the vicinity of the lower limiting frequency, fg. For broadband, high frequency transmission, this leads to a frequency dependent distortion of the signal in phase and amplitude. So an "unambiguous range" is defined with a specified upper and lower transmission frequency for the waveguide section. The lower frequency is set to exceed  $1.25 \times fg$  and the upper cut off frequency is set at  $< 19 \times fg$ .

## 6.

### Guide wave impedance in waveguides

The fact that waveguides display a high degree of dependence on the frequency has already been mentioned. This property must also be taken into account for the matching of waveguide sections to standard terminating impedances, e.g. for  $50\Omega$  power amplifier stages. By contrast to coax cable, which is matched to the transmitter through its constant characteristic impedance, complicated circum-



stances are present for waveguides, since E fields and H fields are transmitted. The peak values of these fields now determine the maximum transmitted rf output, P.

Note: The maximum transmittable continuous wave power and rf peak power are dependent on the cross sectional area, A, of the waveguide, and are also dependent on the breakdown field strength, which is dependent on the pressure, temperature and relative humidity.

For waveguides the wave impedance is introduced as a replacement for the characteristic impedance, defined as the quotient of the peak value of the electrical field,  $E_y$ , and the peak value of the magnetic field,  $H_x$ . But its level is also dependent on the frequency of the signal, feeder wave.

Formulae:

$$Z_F = \frac{E_Y}{H_X} = \frac{Z_{F0}}{\sqrt{1 - \left(\frac{\lambda_0}{2a}\right)^2}}$$

Where wavelength of signal:

$$\lambda_0 = \frac{C_0}{f_0}$$

And characteristic wave impedance:

$$Z_{F0} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$$

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## 7.

### Coupling high frequency signals into rectangular waveguide

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The rf input is fed to the waveguide either by means of a special waveguide flange connection on the transmitter output or through a broad band  $50\Omega$  coaxial connection, which then feeds the rf into a waveguide adapter. These adapters can

be obtained for all types of cable and all standard coaxial plugs.

Finally, a few other basic waveguide flange constructions are illustrated in Fig. 9 in airtight and non-airtight versions.

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## 8.

### Literature

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Strips and waveguides, Walter Janssen, Hüthig Verlag, 1992



Sigurd Werner, DL9MFV

# Amplifier For 47GHz Using Chip Technology

The article below describes a project to construct an amplifier for the 47GHz microwave band. The two stage amplifier uses semiconductor chips from United Monolithic Semiconductors, S.A.S. and gives at least 26dB gain. Anyone actually constructing this power amplifier must have access to bond technology.

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## 1.

### Introduction

---

The non-thermal effects of pulsed high frequencies are being examined as part of certain research projects [4]. Of particular interest are the effects of high frequencies on the activity of protein based bodies (enzymes). Since molecular resonances are to be expected in the range from approximately 42 to 46GHz, the experiments began in this range.

In addition to a generator and measuring equipment for this frequency range, we needed (among other things) a good stable power amplifier. This article shows that the amplifier designed and assembled is also suitable for use on the amateur radio frequency of 47,088MHz. This description could prove a stimulus for people with projects of their own.

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## 2.

### Selection of semiconductors

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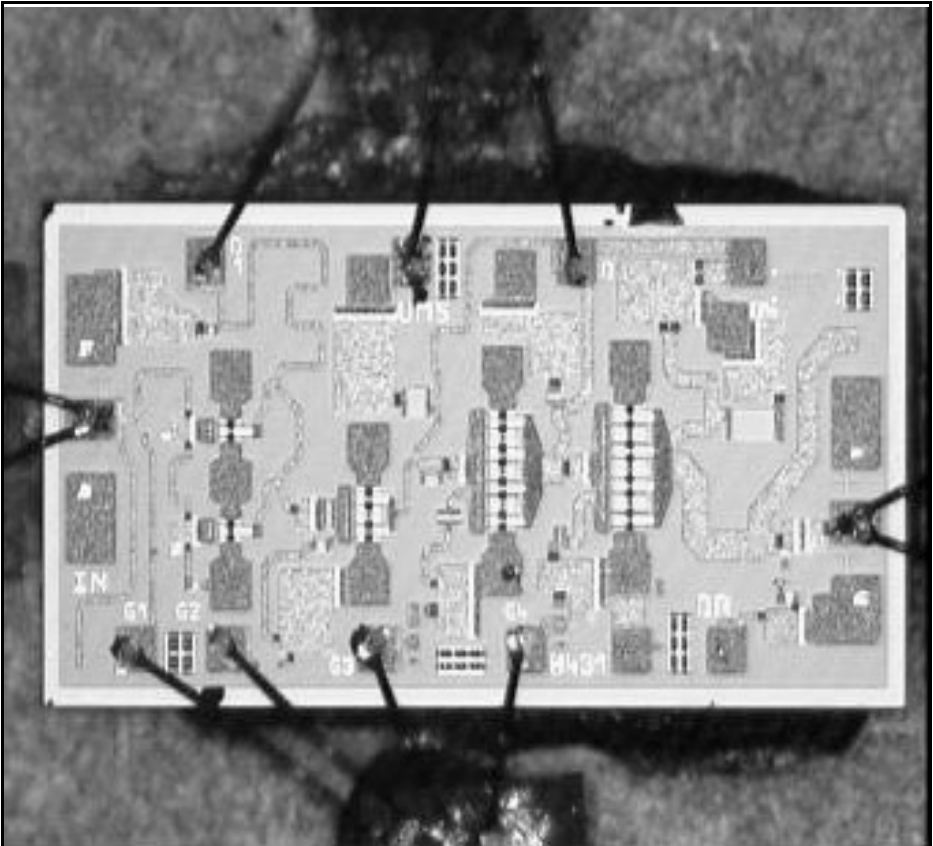
The use of discrete semiconductors in the GHz range referred to is always very expensive for radio amateurs and is combined with considerable design expenditure. An alternative is the use of suitable semiconductor chips, which are glued onto a carrier material, and their connections bonded.

Unfortunately, there are no ready made chips for this frequency range, so some DIY work is called for.

After an examination of the data sheets from various chip manufacturers, the CHA3093c from UMS (United Monolithic Semiconductors, S.A.S.) was chosen.

In the data sheet, this chip is specified for frequencies between 20 and 40GHz, but when the S parameters were studied, they were listed for up to 50GHz, the amplification value for 47GHz was found to be at least 17.3dB.

However, this applies only to measurements on the wafer but with a good construction, values of approximately 14 to 15dB can be attained. The input matching is -11.1dB, which is an acceptable value. A saturated power of 22dBm, approximately 150mW, is specified (3dB



**Fig. 1: Magnified illustration (x 120) of CHA 3093c chip from UMS.**

compression). Fig. 1 shows the chips, greatly magnified. The four groups of cascaded semiconductors can be clearly recognised.

### 3.

#### Circuit design

The design is relatively simple. A driver chip feeds two chips in parallel through a Wilkinson divider. The power is combined again through a second Wilkinson divider. The same chips (type CHA 3093c) are used for all three devices.

### 4.

#### Mechanical and electrical construction

The housing for the prototype was milled from brass (60 x 30 x 9 mm.) and gold plated. The depth of the cavity is 4.8mm. K plugs (2.4 mm.) were mounted at the input and output of the amplifier circuit. Fig. 2 illustrates the construction of the amplifier.

The carrier substrate is a thin ceramic plate made from aluminium nitride (AlN,  $\epsilon=9.0$ ) which is only 0.254 mm. thick.





**Fig. 2: Assembly of two stage microwave amplifier in gold plated milled housing; the Wilkinson dividers can be easily recognised.**

The microstrip lines have each been connected to the chip surfaces through a co-planar spacer. Thanks to the good thermal conductivity of the aluminium nitride, the chips can be glued directly onto the substrate.

The power leads for the gate and the drain are decoupled using 100pF capacitors, for longer paths there are also 1nF single layer capacitors and 100nF ceramic capacitors. These are fed through the housing base using soldered in feedthrough capacitors.

The chips were bonded by means of thermo-compression (including ultrasound support), using 17.5 $\mu$ m gold thread. Chips, capacitors and substrate were attached using a single component silver conductive adhesive [2] hardened at 150°C. Figs. 3 and 4 show details of the construction.

The gate bias of the first semiconductor stage on the driver chip was provided separately. Its drive is intended to test the use of the driver chip as a multiplier. A connection to the monitor diode of the chip was dispensed with for the prototype.

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## 5.

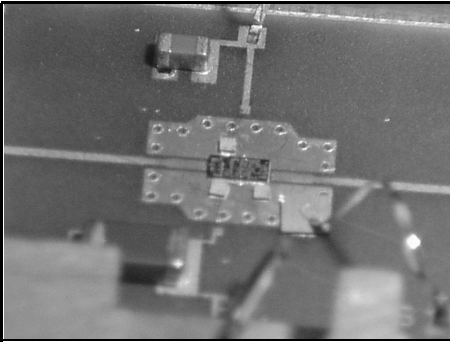
### Results

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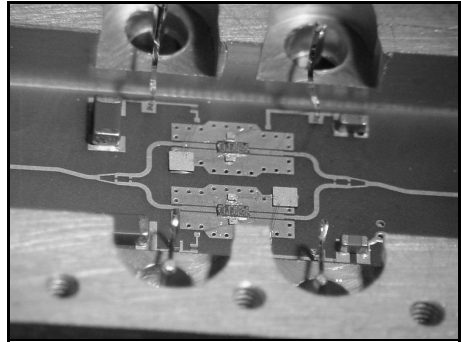
The drain current per chip (at 3.6V) was set at 360mA. This requires a negative gate voltage of approximately 0.6 - 0.5Volts. A heat sink is necessary for continuous operation, since the power consumption is almost 4W.

The amplifier was initially driven using a CW signal (47,088MHz) of 200 $\mu$ W. The power level of approximately 20mW





**Fig. 3: Details of driver assembly.**



**Fig. 4: Details of second stage with parallel wired amplifier chips.**

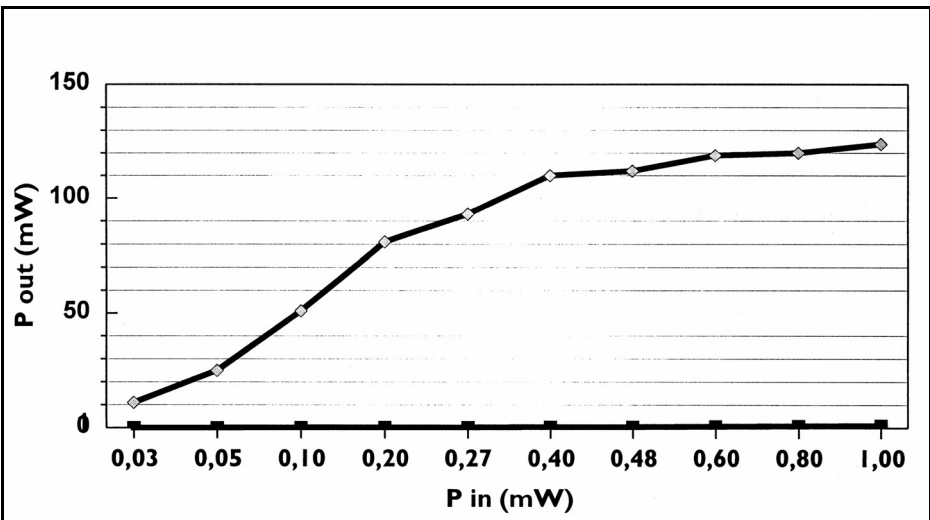
measured at the output which could be raised to 80mW by rough optimisation. In the output area of the chip there was a marked mismatching (the S22 parameter is only 5.8 dB!).

The calculated amplification is approximately 26dB, i.e. 13dB per stage. The -3 dB compression point is at approximately 20.7dBm.

With suitable drive, a saturation power exceeding 120mW can be attained (Fig. 5). This means that the values specified in the data sheet were not attained. This

applies, in particular, to the saturation power reached for one chip of only 17.8dBm. This could be because the semiconductors are designed for pulsed mode operation.

The amplifier is particularly sensitive to heat, even with a moderately warm housing, the output drops by 15 to 20%. A generously dimensioned heat sink must therefore be used. To counteract waveguide effects, absorption material should be applied in the input and output areas before the metal cover is fitted.



**Fig. 5: The output of the amplifier plotted against the driving power, measured with a CW signal at 47088 MHz.**



6.

## Outlook and acknowledgements

This article indicates the options for modern chips, and is intended to act as a stimulus for further experiments.

Some other interesting types of chip have recently come onto the market, these are just waiting to be tested. The price of a chip is somewhere around one Euro, depending on the source of supply. At the VHF/UHF Congress in Munich at the beginning of March, Michael Kuhne (DB6NT) introduced a project for a 47GHz preamplifier. A particularly low noise chip is used, type CHA 2157 from UMS [3].

In conclusion, I would like to thank several helpful people who have supported me in word and deed, namely Konrad Hupler (DJ1EE), Walter Ludwig (DL6SAQ), Mrs. Astrid Habel (Technical University, Munich) and Mr. Wilhelm Hohenester of Rhode & Schwarz, Munich.

7.

## Literature references

[1] Data sheet from United Monolithic Semi-conductors, S.A.S.; Ref.: DSCHA30930207, 26. 7. 00

[2] Technical Data Sheet, Ablebond 84-1 LMI from Ablestik

[3] Michael Kuhne, DB 6 NT Manuscript for VHF / UHF 2002, 14th Congress, Munich 2002

[4] Institute for Physiological Chemistry of University of Munich



## The UK Six Metre Group

[www.uksmg.org](http://www.uksmg.org)

With over 1000 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 60-page quarterly newsletter 'Six News' and through its web site [www.uksmg.org](http://www.uksmg.org), 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.

Why not join the UKSMG and give us a try? For more information, contact the secretary Iain Philipps G0RDI, 24 Acres End, Amersham, Buckinghamshire HP7 9DZ, UK or visit the web site.



Bernd Kaa, DG4RBF

# Precision Directional Coupler For Matching Measurements

**Directional couplers are frequently required in high frequency measurement technology. They are used, not only in standing wave measurement equipment, but also in high quality test rigs and network analysers. A directional coupler is described below, it has high directivity and can be used from approximately 120MHz up to 1,500MHz.**

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## 1.

### Introduction

---

If we want to carry out wobbled matching measurements, then, among other things, we need a good directional coupler with high directivity. The directivity is the measurement of how well the directional coupler can distinguish the forward transmission from the reverse transmission.

To be able to carry out meaningful measurements, even on high quality components and good DIY circuits, the directivity should be as high as possible, exceeding 30dB. However, as industrially manufactured directional couplers are used in high tech equipment, the price of a new one is too high for most radio amateurs, and they are scarcely found on the surplus market.

There are numerous publications dealing

with the construction of directional couplers, but some of them are designed for simple applications only, e.g. for SWR meters, the directivity is frequently only 25dB.

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## 2.

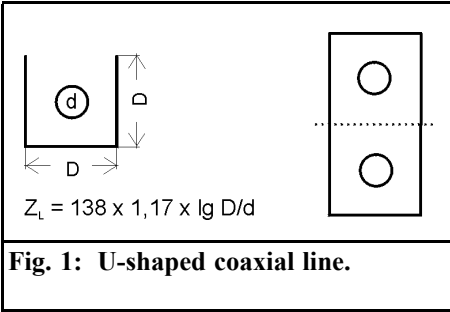
### Requirements

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If you want to build a directional coupler with a high directivity, then the following points must be given consideration during construction:

- Maintenance of 50 $\Omega$  impedance in the main and secondary lines
- Precise 50 $\Omega$  termination for all lines
- Discontinuities should be as slight as possible where there is a transition from the lines onto the coaxial connectors and the dummy load
- Trimming option for secondary line for maximum directivity

Experiments with coupled semi-rigid lines have already provided usable results, but they have not led to the desired directivity of 40dB. Precise impedance can be achieved using the solid sheath cable, but it is badly influenced by the long windows ( $\lambda/4$ ).



**Fig. 1: U-shaped coaxial line.**

On the basis of these experiments, attempts were made to find a way to produce two coupled lines running parallel, with  $50\Omega$  impedance.

Here are some reflections on this. A  $50\Omega$  line can consist of a round external conductor with a round internal conductor, or of a square external conductor with a round internal conductor. There is also a formula for calculating a  $50\Omega$  line that consists of a U shaped external

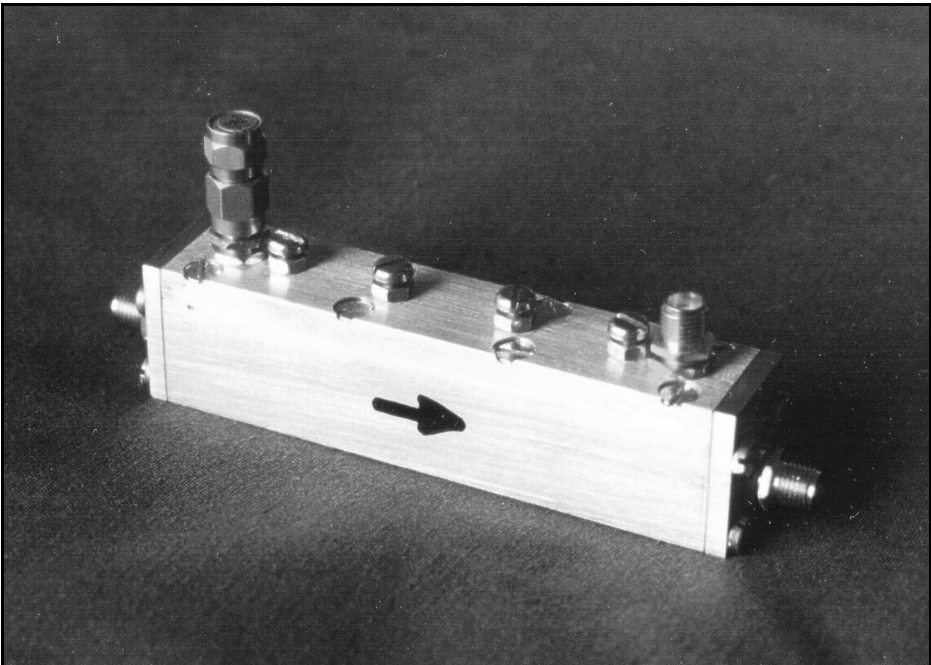
conductor with a round internal conductor:

$$Z_L = 138 \times 1.17 \times \lg D/d$$

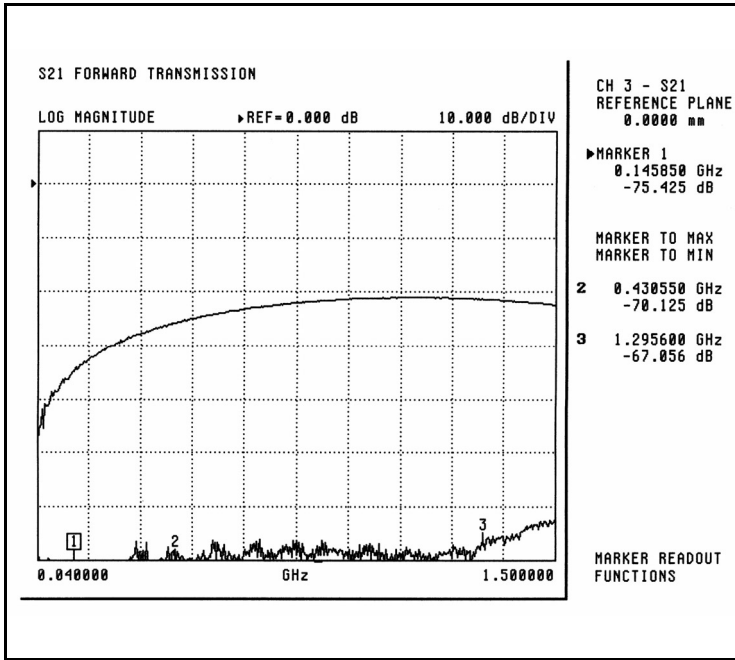
If we use two of these U shaped coaxial lines and join them at the open sides, then we obtain two coupled  $50\Omega$  lines (Fig. 1).

This led to the directional coupler illustrated in Fig. 2, with a directivity exceeding 45dB together with a good band width. The measurement of the forward and reverse transmission in the frequency range of 40MHz to 1,500MHz was carried out using a Wiltron network analyser (Fig. 3). The good directivity values of 45 to 48dB can be read off from the measurement curve.

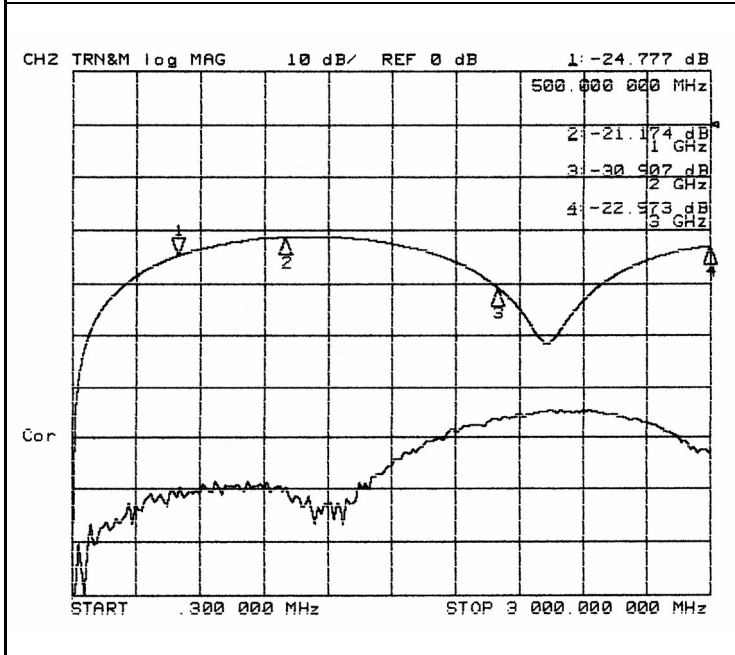
Fig. 4 shows the measurement results up to 3GHz, which were measured using a Rohde & Schwarz network analyser. Here too, we can see the extremely high



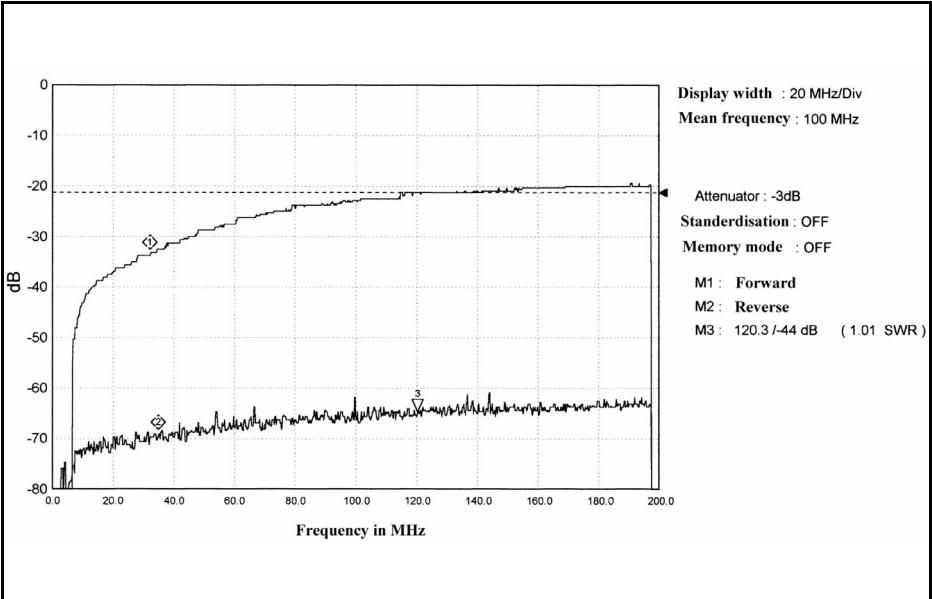
**Fig. 2: Ready-to-operate specimen of directional coupler, made from brass, with SMA jacks for main and secondary branches and with calibration screws in cover.**



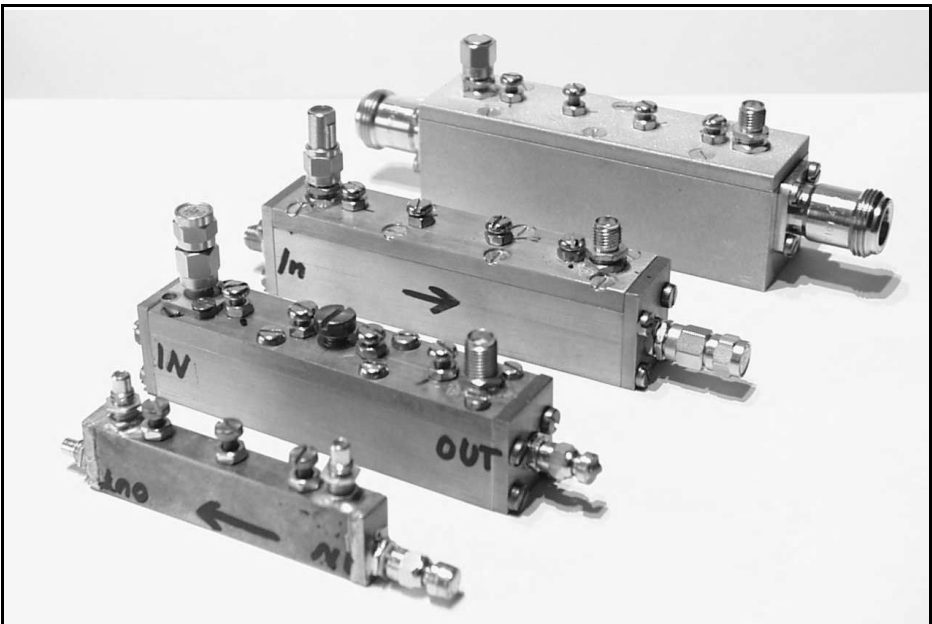
**Fig. 3:** Measurement of forward and reverse transmission in range between 40 and 1,500 MHz shows a directivity of approximately 45dB.



**Fig. 4:** Measurement results up to 3 Ghz.

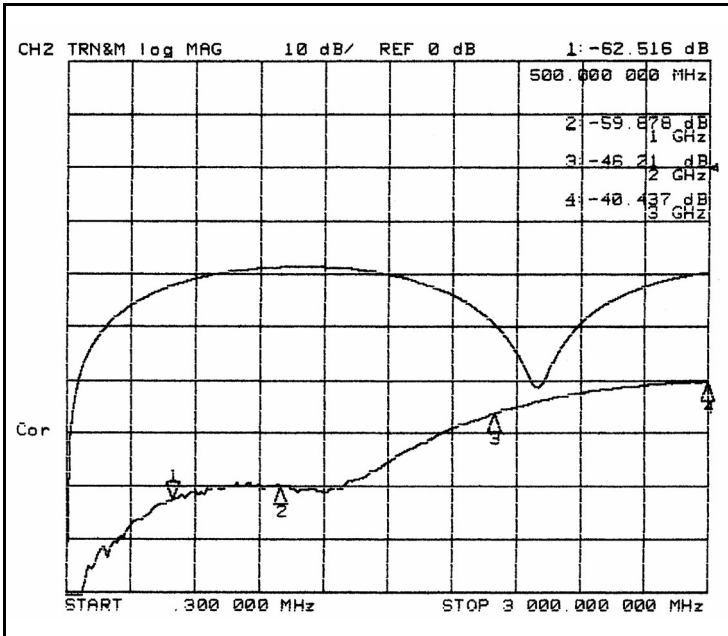


**Fig. 5: Good directivity (44db at 120MHz) even in lower frequency range to 200 MHz.**



**Fig. 6: Specimen assemblies of various directional couplers in different sizes, with SMA or N jacks in the main branch.**





**Fig. 7: The measurement curves show the somewhat poorer values when N jacks are used.**

directivity levels, which go all the way up to 1,500MHz. If calibrated for narrow band, even higher values of directivity could be attained, exceeding 50dB (!).

Fig. 5 shows the forward and reverse transmission for the directional coupler in the lower frequency range up to 200MHz. It can be seen from this that the directional coupler, in conjunction with sensitive wobble systems, can be used with a good directivity even at low frequencies (44dB at 120MHz).

Several directional couplers with various connection jacks were assembled in accordance with this concept (Fig. 6). It became clear from this how important it is to use high quality coaxial jacks. It is extremely important to have as few rf discontinuities as possible in the transition onto the coaxial jacks. The best results were attained with good SMA and SMC jacks. Somewhat lower directivity values were attained from assemblies using N jacks (Fig. 7). So only precision jacks with small flanges from reputable manufacturers should be used.

If we move into directivity values exceeding 30dB, we likewise need a high value 50Ω termination on the secondary and main lines. It is best if two equal dummy loads are used. You can not do without high quality industrially produced dummy loads but they can be obtained at acceptable prices.

### 3. Assembly

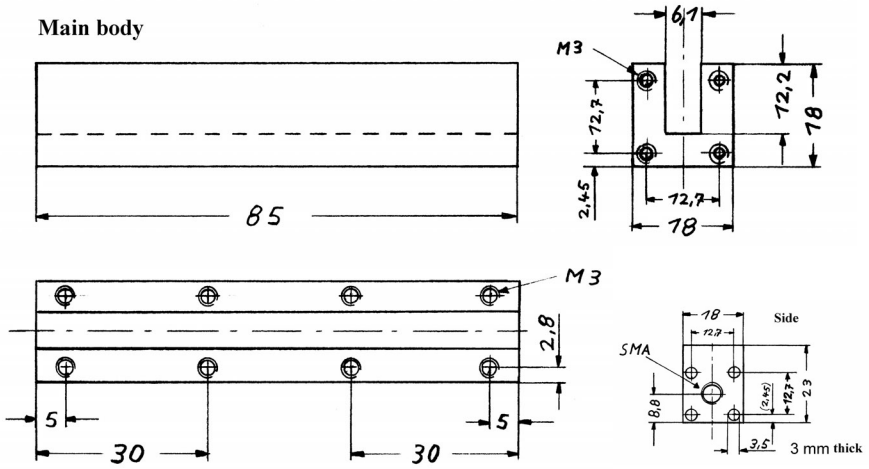
The mechanical components of the directional coupler are all made of brass (Fig. 8). The main body consists of an 18mm. x 18mm. square bar with a milled groove 6.1mm. wide and 12.2 mm deep. An 18mm. x 5mm. piece of brass flat material is used as a cover. Incorporated here, among other things, are 4 tuning screws (M3), to tune the secondary line.

The side components are made from 3mm. thick brass. The cover and side components are each screwed onto the

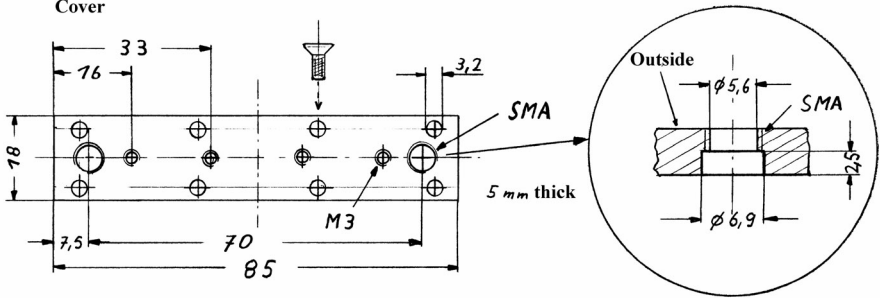




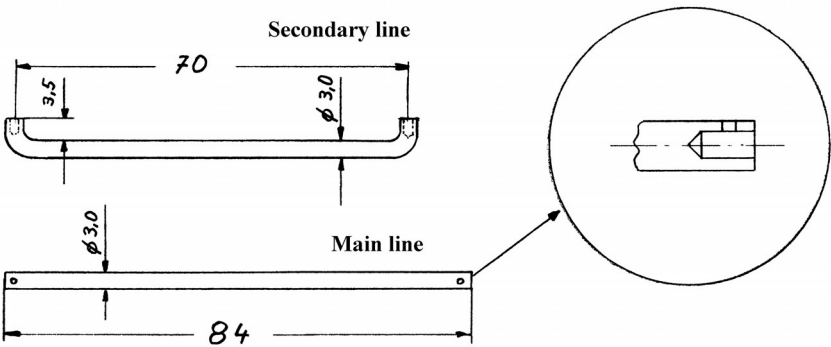
Main body



Cover



Secondary line



Main line

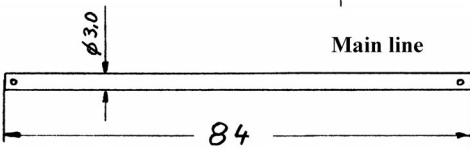
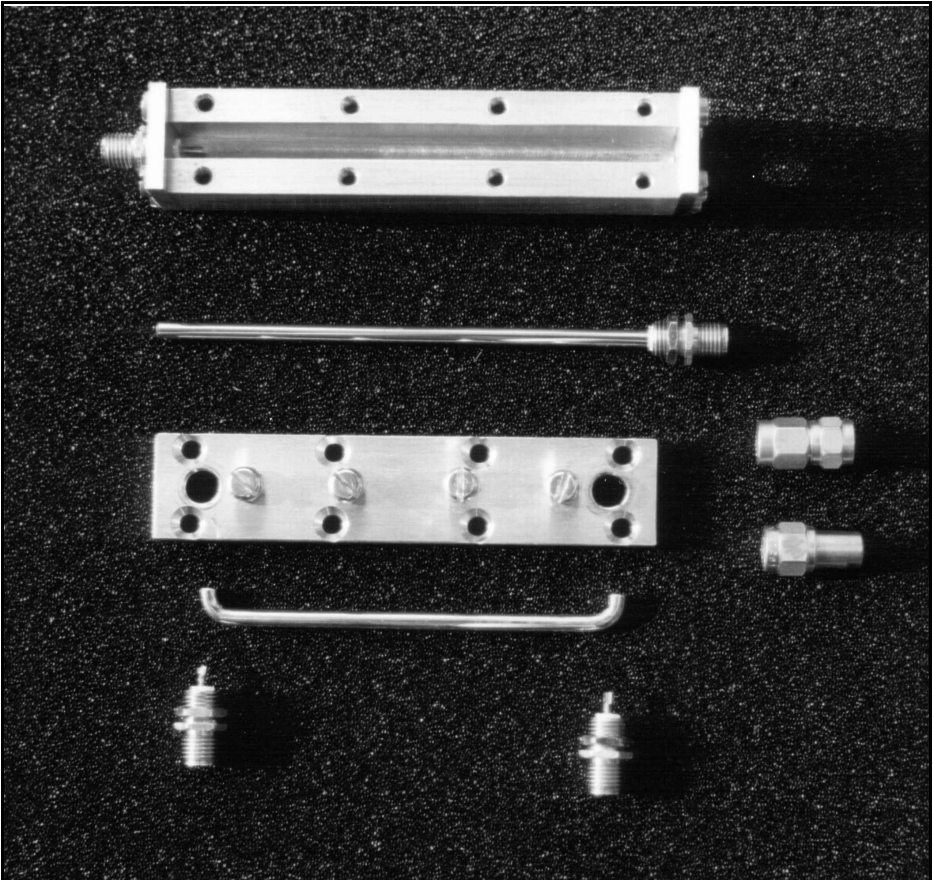


Fig 8 : Details of the mechanical components.



**Fig. 9: Individual components of directional coupler: 18 x 18 mm. coupler, with side components, main coupling line made from round bars, cover with tuning screws and holes for SMA jacks, secondary coupling line and SMA panel jacks.**

main body with M3 brass screws.

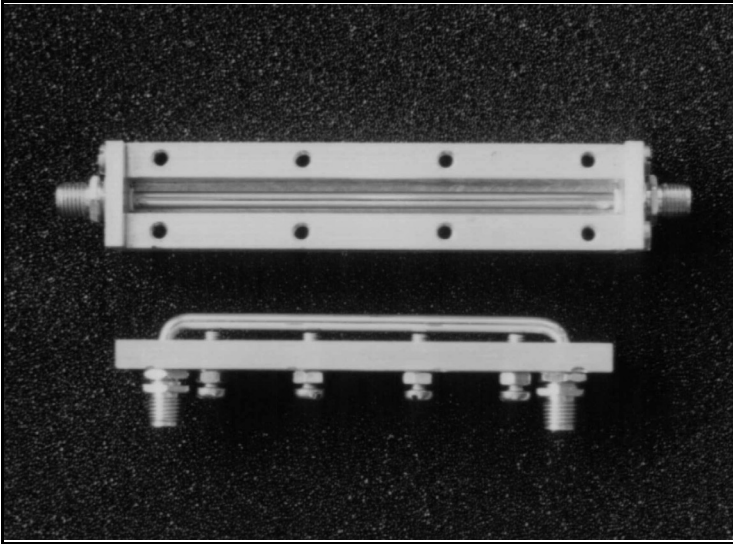
The internal conductors of the main and secondary lines are each made from 3mm. round pieces of brass. Small holes at the ends support the internal conductor of the SMA jack. The bore diameter is dependent on the type of the jack used. A 1mm. transverse hole is used to improve soldering.

The dimensions and units are shown on the drawings shown in Fig. 8. The two internal conductors should be polished, to reduce skin effect.

A thread is cut in the cover and in each side component for the SMA jacks. These threads are described as  $\frac{1}{4}$ " 36 UNS-2A. But it is difficult to get hold of taps with this thread. A  $\frac{1}{4}$ " 32 NEF tap can be used for short threads. These can be obtained in many model shops, since this is the thread size for heater plugs in model glow plug engines. Fig. 10 shows the directional coupler when opened.

### 3.1. Coaxial jacks

Quality SMA single hole jacks are used as connecting jacks. In order to keep the



**Fig. 10:** The fully assembled directional coupler opened up; the tuning screws in the cover can be easily recognised.

rf discontinuities as small as possible, the Teflon inserts, which project at the rear end of the jacks, are shortened to 0.7mm. This compensates for the discontinuities that arise during the transition from the 3mm. thick internal conductor of the directional coupler to the thinner internal conductor of the SMA jack (Fig. 11).

### 3.2. Final assembly

Once all the components have been



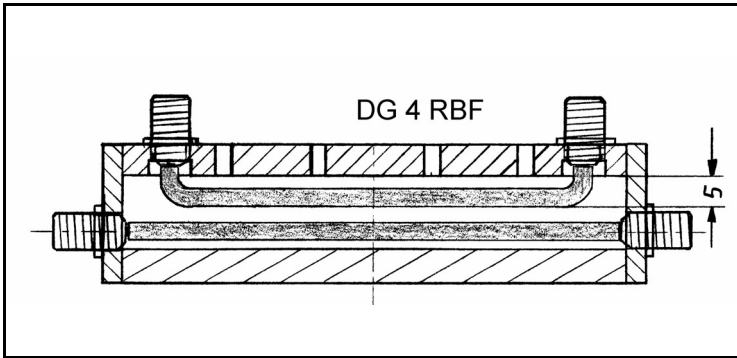
**Fig. 11:** SMA jacks with unshortened (top) and shortened Teflon edge (below).

manufactured and matched, the main body is assembled, with the side components and the straight internal conductor of the main line. The precise position of the internal conductor can be aligned again while the side components are being screwed on. The four tuning screws must be filed flat before they are fastened in the cover with a lock nut.

The curved internal conductor of the secondary line is fastened to the cover with the two SMA jacks. A guide dimension for the distance from the lower edge of the internal conductor to the cover is 5mm. (see Fig. 12).

The distance between the two coupling lines can be adjusted, depending on how far you screw the two SMA jacks into the cover. This influences the coupling. The best alignment was obtained with a forward transmission of approximately 20dB at 1,200MHz. The SMA jacks are fixed externally using lock nuts.

With this construction it is possible to alter the distance of the coupling lines, even after assembly. Arranging the lines at an angle is also possible.



**Fig. 12: Details for assembly of body, cover, side components and coupling lines.**

4.

### Calibration

The fully assembled directional coupler is best calibrated with the wobble system with which it is to be used. But calibration can also often be carried out using a fixed signal source (radio equipment) and a sensitive mW meter.

Calibration is carried out with the 4 trimming screws at the best directivity, i.e. with minimum reflection and a dummy load of precisely  $50\Omega$ .

In order to guarantee a broad band calibration, the directional coupler should be calibrated in at least one lower and one upper frequency range. A broad band calibration can naturally be carried

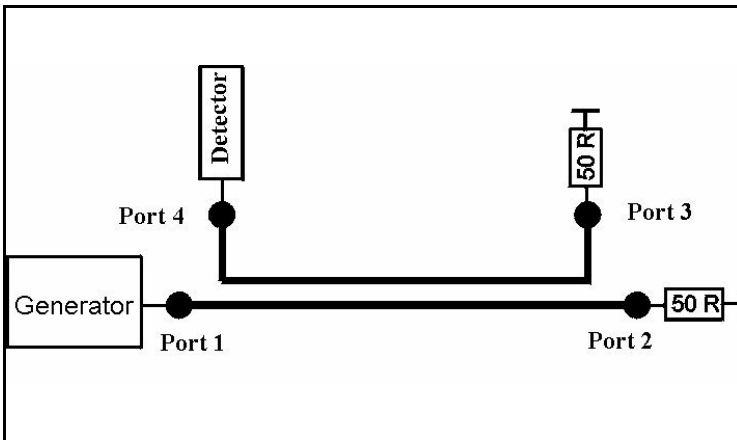
out most easily using a wobble system.

5.

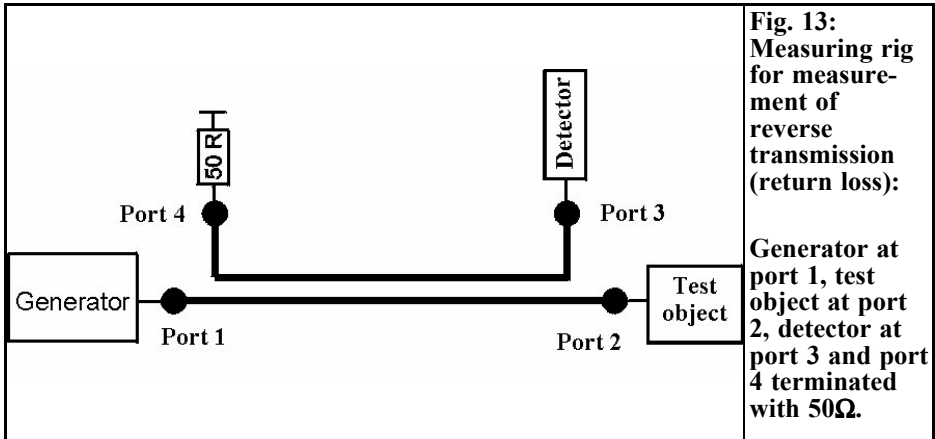
### Range of application

Directional couplers are designed, in particular, for matching measurements in conjunction with wobble measurement systems. The directional coupler is very suitable, in conjunction with the rf synthesiser, up to 1,450MHz [2], for spectrum analysers with tracking generators or for scalar network analysers in frequency ranges from 140MHz to 1,500MHz.

This directional coupler concept can be modified and assembled for other frequency ranges by changing the length.



**Fig. 13: Measuring rig for measurement of forward transmission:**  
  
Generator at port 1, detector at port 4, port 2 and port 3 terminated with  $50\Omega$ .



6.

### Set-up of measuring instruments

First the forward transmission curve is determined and stored. To this end, port 2 is terminated with a 50Ω dummy load and the detector is connected to port 4 (see Fig. 13). The curve determined in this way is the start point for the subsequent reflection measurement.

To measure the reverse transmission, the detector connected to port 3 and the test object is connected directly to port 2 (Fig. 13). The difference between the forward transmission and the reverse transmission can then be used for calibrating the test object.

7.

### Literature

[1] Carsten Vieland, DJ4GC Microwave directional coupler with high forward / reverse ratio made from semi-rigid lines, VHF Communications 1992/3 pp 130 - 139

[2] Bernd Kaa, DG4RBF, HF synthesiser up to 1,450MHz, VHF Communications 1998/2 pp 103 - 121 and 1998/3 pp 159 - 181



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Wolfgang Schneider, DJ8ES

# CW Modulator Using Pin Diodes

**This article describes a CW modulator for radio applications which is simple and uncomplicated from the rf technology point of view. The call sign and additional data are encoded and stored in an EPROM.**

## 1.

### Circuit description

The pin diode modulator originates from an application note by Hewlett Packard [1]. The combination of pin diodes (BA479) and resistors offers optimal matching (SWR) of the input and output in both switching positions, "On" and "Off". This guarantees good matching for the master oscillator and the later frequency multiplier stages.

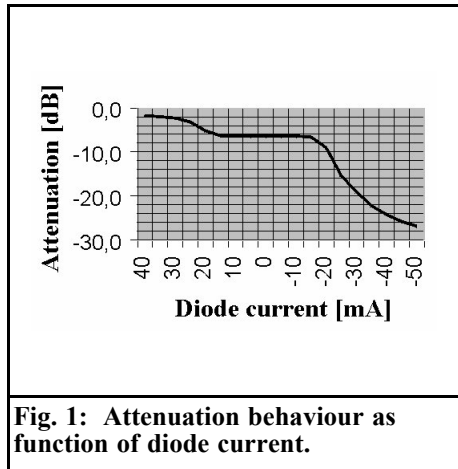
Because of its attenuation behaviour and the impedance matching is dependent on the diode current, the circuit is usable only as an rf switch and not as an amplitude modulator. The graph in Fig. 1 gives a visual representation of the attenuation performance. The circuit was used as a broadband modulator for an SWR indicator [3] as long ago as 1984 by Wilhelm Schürings (DK4TJ).

The 3 pole high pass filters at the input and output, attenuate the pulses from the control circuit so that they do not affect

the oscillator and the frequency multiplier. It is a Chebyshev filter with 0.01dB ripple in its transmission range. With the specified values, at  $2 \times 1\mu\text{H}$  and  $270\text{pF}$ , a lower limiting frequency of approximately 10MHz is obtained.

The control circuit consists of an EPROM with the text data and a drive stage (IC5, T2, T3). The operational amplifier controls the switching current for the pin diodes (D1 to D4) through the two transistors: +40mA in the switching position "On" and -40mA for "Off". The transistor T1 acts as an inverter.

The text data is stored in the 27256 EPROM (IC2). This memory chip is organised for 32k x 8 bits. Only the most



**Fig. 1: Attenuation behaviour as function of diode current.**



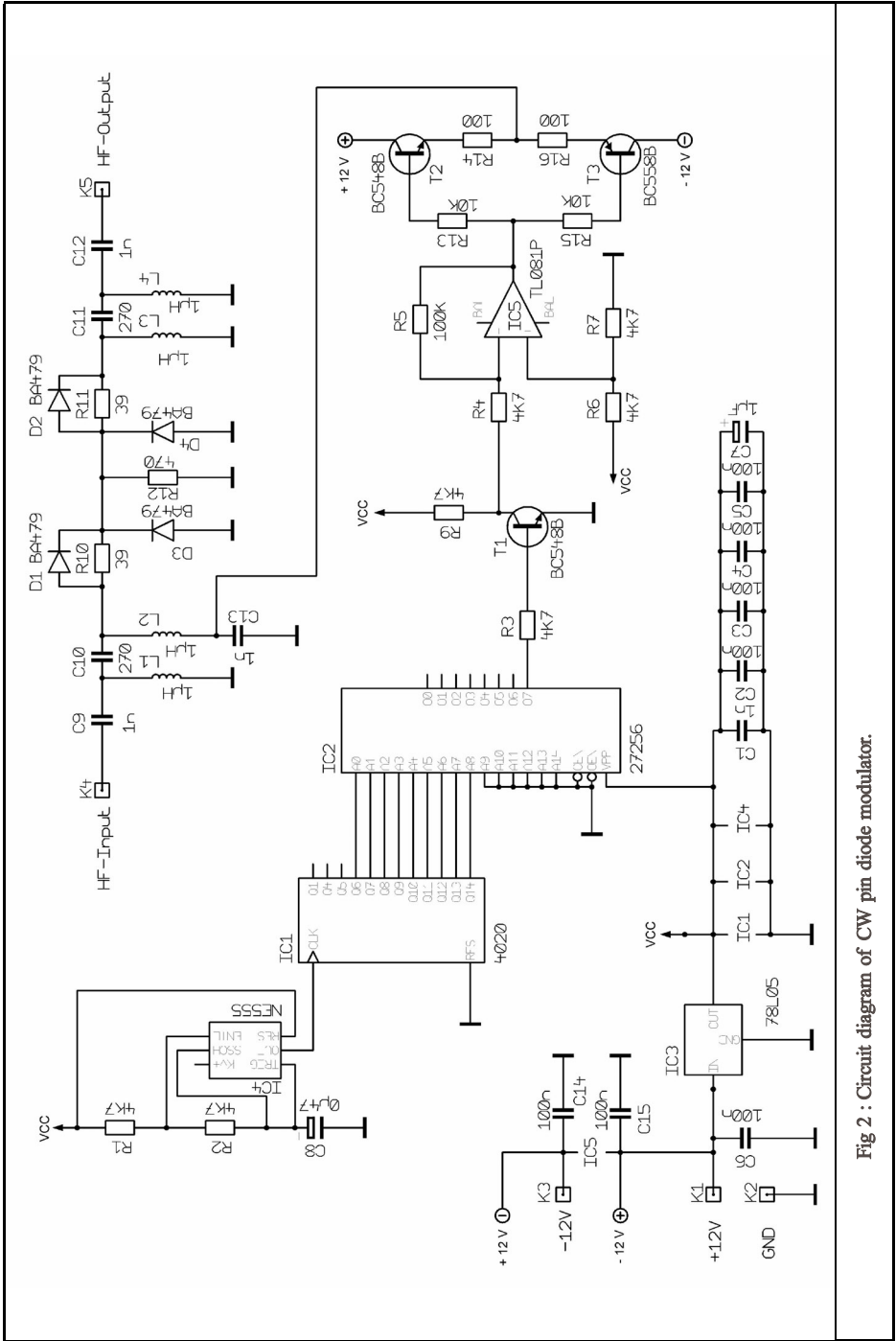
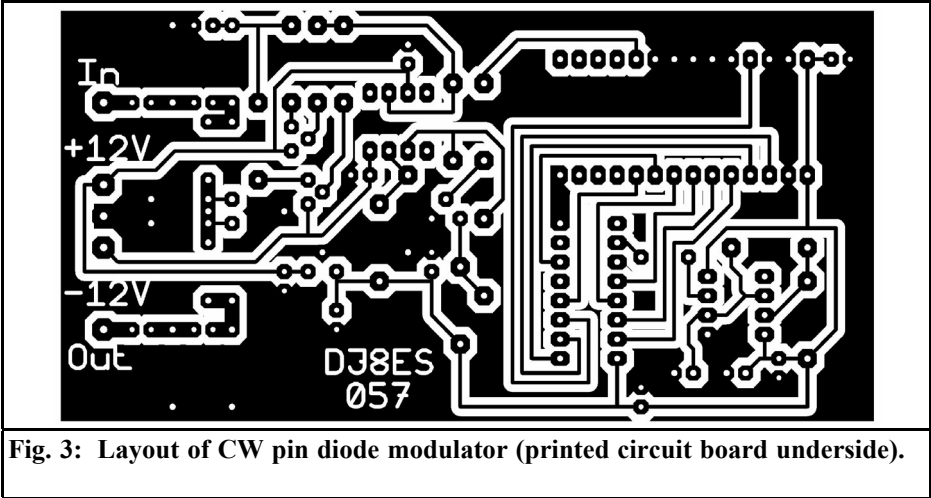


Fig 2 : Circuit diagram of CW pin diode modulator.



**Fig. 3: Layout of CW pin diode modulator (printed circuit board underside).**

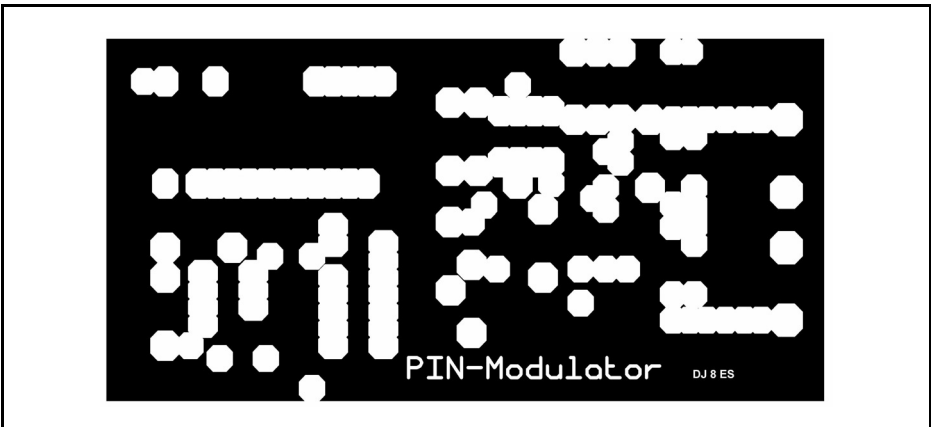
significant data bit, Q7, is used to save the CW text in the above circuit. If the data bits Q0 to Q7 are switched round, 8 different CW texts can be stored.

The CW characters are serially fetched, the EPROM is addressed through its address circuit. This is achieved by a CMOS IC 4020 (IC1). This is a 14 bit binary counter, in which the 9 low value bits are used to address the EPROM.

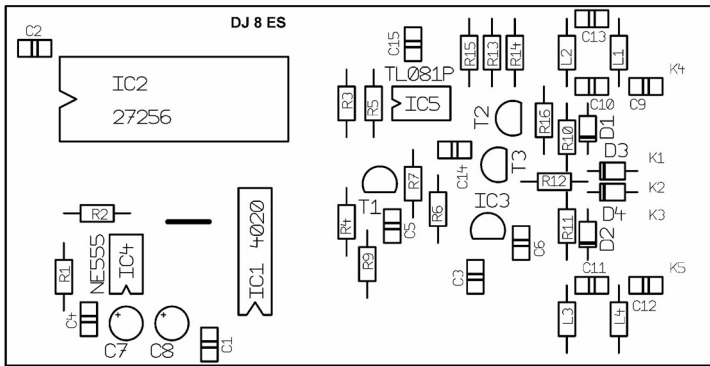
The programmed CW text should be outputted at a rate of 60BpM. The clock frequency can thus be calculated to make

available a storage area of 512 bits at 273Hz. The address area begins at 0000H and ends at memory address 01FFH.

A standard circuit using an NE555 timer IC (IC4) is used as a clock circuit. The output frequency is defined by the RC combination of 2 x 4.7k $\Omega$  and 0.47 $\mu$ F. One of the two resistors can be replaced by a potentiometer for the precise setting of the speed if applicable.



**Fig. 4: Earth side of CW pin diode modulator printed circuit board.**



**Fig. 5: Components layout of CW pin diode modulator.**

**2.**

**Assembly instructions**

The CW modulator with pin diodes is assembled on a double-sided epoxy printed circuit board with the dimensions 54mm. x 108mm.. The circuit thus fits into a standard tinfoil housing with the dimensions 55.5mm. x 111mm. x 30mm.. The earth surfaces are soldered to the housing all round on both sides.

The components are inserted in no particular order in accordance with the components drawing in Fig. 5. All earth connections are soldered on both sides.

It is useful if a precision IC socket is used for the EPROM, so that the EPROM can be replaced for text amendments at any time. The photo (Fig. 6) shows the modulator before fitting into the housing.

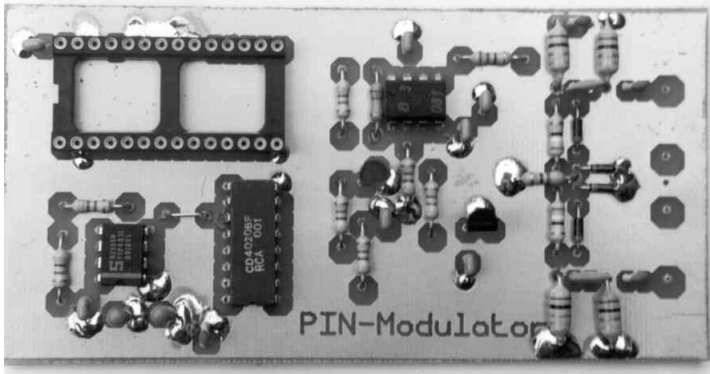
**3.**

**Parts list**

T1, T2	BC548B transistor
T3	BC558B transistor
IC1	4020 CMOS counter
IC2	27256 E-prom
IC3	78L05 voltage regulator
IC4	NE555 timer IC
IC5	TL081 operational amplifier
D1, D2, D3, D4	BA479 pin-type diode
L1, L2, L3, L4	1µh, axial, RM 10 mm
C7	1µF/25V, RM 2.5 mm tantalum electrolytic
C8	0.47µF/16V, RM 2.5 mm tantalum electrolytic

Ceramic capacitors EGPU, RM 2.5 mm.:

2 x	270pF
4 x	1nF



**Fig. 6: Specimen assembly of CW pin diode modulator.**

7 x 100nF

Resistors ¼ W, RM 10 mm.:

2 x 39Ω  
 2 x 100Ω  
 1 x 470Ω  
 7 x 4.7kΩ  
 2 x 10kΩ  
 1 x 100k

#### 4.

### Putting into operation and operational experiences

The CW modulator assembly with the pin diodes can be put into operation following assembly and a final inspection of the components. No calibration is needed.

A stabilised voltage  $\pm 12V$  power supply is required. The peak current consumption is approximately 50mA, depending on the actual switching position.

The CW modulator described above has been in constant use for a year now in the DB0GHZ beacon in Penneberg/Appen near Hamburg (locator JO43UP). The

beacons crystal oscillator (approximately 108MHz) is keyed through the pin diodes.

#### 5.

### Literature references

- [1] H.Vifian, F.K.David, W.L.Frederik: A Voltmeter for the microwave engineer, HP-Journal 11/72
- [2] Vishay Telefunken: Data sheet BA 479, Document Number 85527, Revision 2, 1. 4. 99, [www.vishay.de](http://www.vishay.de)
- [3] Wilhelm Schürings, DK4TJ: The SWR indicator, VHF Communications 3/84 pp 171 - 180
- [4] Wolfgang Schneider, DJ8ES: CW call sign transmitter, VHF Communications 3/93 pp 158 - 161



Winfried Bakalski DL5MGY and co-authors

# Baluns For Microwave Applications Part 1

**In applications involving mixers and push-pull rf power amplifiers, baluns are used for the transition from the symmetrical to the asymmetrical section. Whilst for short-wave applications a transformer can be used, many different techniques are used for UHF applications.**

---

## 1.

### Introduction

---

In rf technology, baluns (balanced to unbalanced) play an important role. In antennas, we need to guarantee a transition from the coaxial line to the symmetrical two-wire system with as little reflection as possible. The same is needed in the rf electronics itself, i.e. in the designing of mixers and, in particular, in push-pull power amplifiers. A good overall view of various types of balun (even if it is not complete) can be found, among other things, in [1-3].

A balun has to have the following characteristics:

- As precise a 180° phase shift as possible must be maintained between the two terminals of the symmetrical port.
- In power amplifiers, the impedance

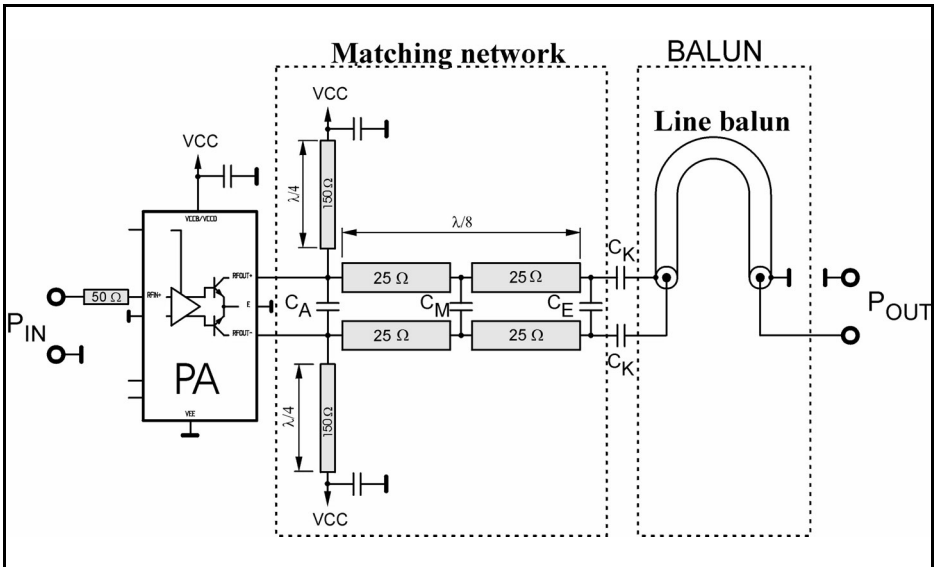
presented to the symmetrical port must be equal. If this is not the case, then there will be a decrease in the efficiency.

- The symmetrical port must be well isolated from earth. This is especially important for power amplifiers, since parasitic oscillations can occur.
- The insertion loss should be kept as low as possible.

When power amplifiers are used in class C, not only is an optimal loaded impedance needed at the operating frequency, but a very low-impedance load is needed at the second harmonic, with an open circuit at the third harmonic, in order to obtain optimal amplifier efficiency [1].

The basic idea behind the construction of a balun can easily be outlined. Two signals 180° out of phase (symmetrical port) are “synchronised” in their phases and their outputs are added. Many designs involving  $\lambda/4$  phasing lines (90°) and  $\lambda/2$  phasing lines (180°) have crystallised out of this basic idea.

Over time, a large number of designs have been collected. This article, though, will concentrate on designs that can be realised using no more than double-sided printed circuit boards, and that are used for applications in push-pull power amplifiers. Naturally this implies the use of microstrips and discrete components



**Fig. 1: Line balun with matching network.**

such as coils and capacitors. A line based solution will be discussed first followed by the LC balun and its further developments.

## 2.

### The line balun with matching network

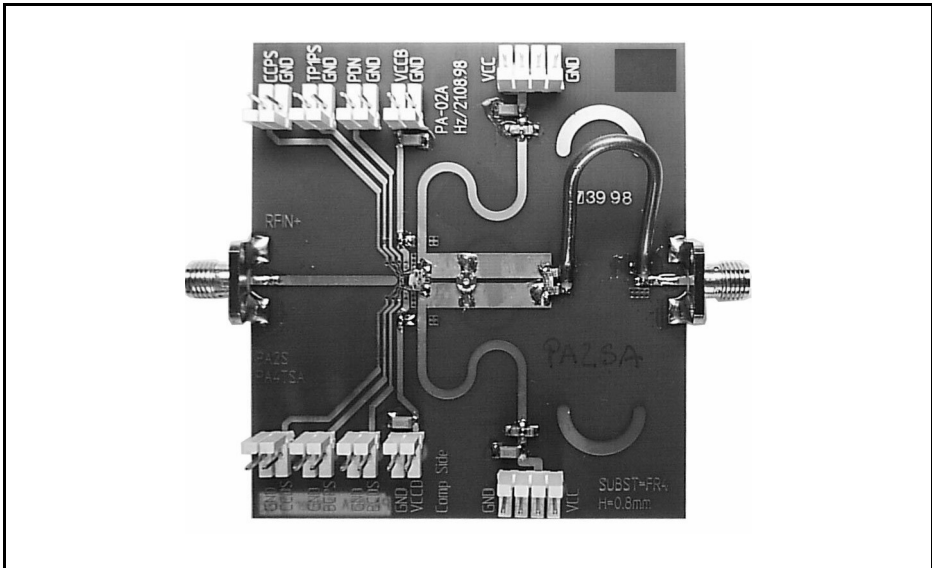
Fig. 1 shows the optimal design for a power amplifier balun in the range from approximately 400MHz to 1.5GHz.

The actual balun is in this case a  $\lambda/4$  long line section with a series connected matching circuit. The line balun described in [1, 3] (called a bazooka balun in [3]), we are normally dealing with a semi-rigid line with  $Z_w = 50\Omega$ . The length is precisely  $\lambda/4$ . As a rule we can still not achieve optimal matching with the line balun alone, an additional matching network is connected to it in series. This consists of a microstrip, with an impedance,  $Z_w$ , of  $50\Omega$  and trimming

capacitors.

Since power amplifiers are usually matched with a low load impedance, this results in a  $Z_w$  which must be lower than  $50\Omega$  (cf.  $\lambda/4$  transformer equation). The precise impedance can thus be selected to have another value, depending on the desired input impedance of the balun. With  $C_M$  and  $C_E$ , the real and imaginary components of  $Z_0$  can be set. The capacitors,  $C_K$ , act as DC block capacitors. The DC feed comes through two  $\lambda/4$  transformers. This gives a short-circuit, at the second harmonic, at the two collectors of the rf transistors, because the  $\lambda/4$  transformer transforms a short-circuit into a short-circuit again at double the fundamental frequency,  $2f_0$ .

An open circuit is achieved on the collectors of the rf transistors by means of a resonant circuit with  $C_A$  at third harmonic,  $3f_0$ . This circuitry is required to achieve a high efficiency in non-linear operation. Fig. 2 shows a 900MHz power amplifier with an integrated circuit. This IC contains a push-pull power amplifier that is set to a  $50\Omega$  output using the



**Fig. 2: A 900-MHz GSM power amplifier module with line balun.**

circuit described above.

This design has two disadvantages:-

- The electrical length of the  $\lambda/4$  line section must be guaranteed within narrow tolerances.
- The design requires manual calibration.

The length of this  $\lambda/4$  line also represents the limit for the application at low frequencies, since this becomes longer as the frequency decreases.

If the frequency exceeds 1.5GHz, it is apparent that trimming capacitors are practical up to a maximum of 1.5GHz, since better microwave trimming capacitors have their resonant frequency at 1 to 2GHz. Thus this design is unusable for frequencies exceeding approximately 1.5GHz. On the other hand, it offers an optimal load impedance, among other things, for the amplifier in that, even for the non-linear application case (class C) even the harmonic load can also be matched. Thus this design can be used to achieve very high efficiencies, which is

not possible with fundamental frequency matching alone.

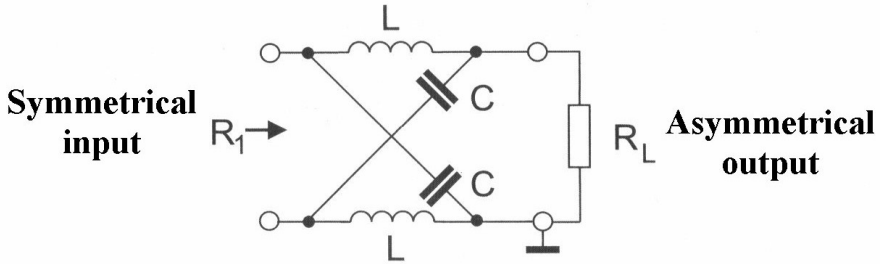
### 3.

#### The LC Balun

The LC balun [2, 5] is actually a bridge circuit (Fig. 3) and is also referred to in English speaking countries as a “lattice-type” balun. It made its first appearance in a patent document from 1934 (C.Lorenz AG Berlin, Tempelhof) [5]. It consists of two capacitors and two inductances, which create a phase displacement of  $\pm 90^\circ$  for each connection of the symmetrical input.

One very good characteristic of the balun is the ability to match any symmetrical input impedance and any asymmetrical real output impedance. Moreover, it is outstandingly suitable for integration, and is therefore also used for smaller power amplifiers (Fig. 4). We should also look at the power supply of rf





**Fig. 3: The LC balun bridge in classical representation.**

transistors. If the whole assembly is mounted on a double-sided printed circuit board, then the rf shunt can be replaced by a radial stub [6-8] and the choke by a  $\lambda/4$  transformer with an impedance as high as possible.

For calculation:

1. First all impedances and the operating frequency are determined. Using the formula to calculate the circuit frequency:

$$\omega = 2\pi f$$

Subsequently, the characteristic impedance of the bridge circuit can be determined using the expression:

$$Z_c = \sqrt{R_1 \cdot R_L}$$

where  $R_1$  is the symmetrical input resistance from Fig. 4 and  $R_L$ .

2. Now the component part values are determined. For the typical case in which real impedances are used:

$$L = L_1 = L_2$$

and:

$$C = C_1 = C_2$$

For the inductances,  $L$ , we obtain the expression

$$L = \frac{Z_C}{\omega}$$

and for the capacitances

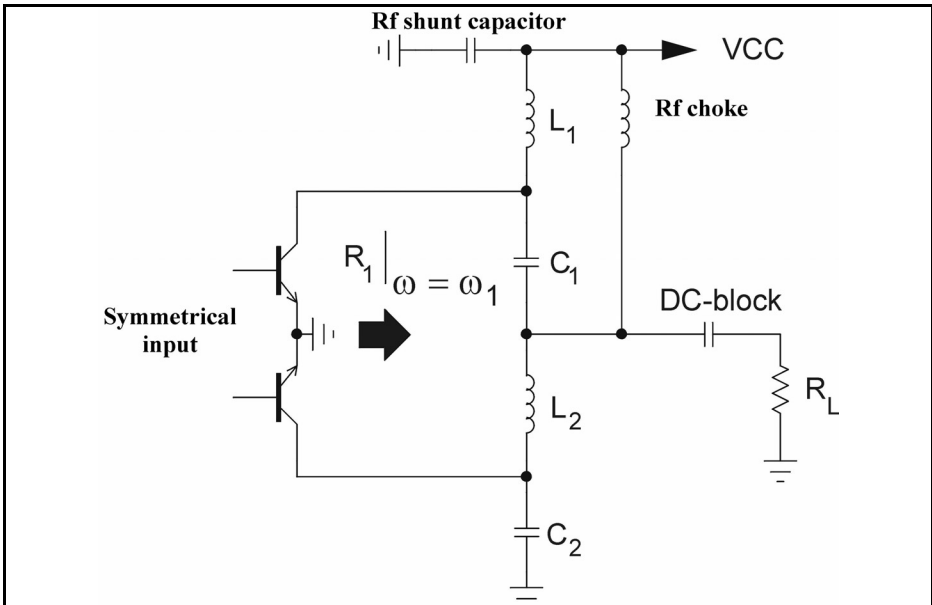
$$C = \frac{1}{\omega Z_C}$$

The important thing about this calculation is that we are assuming that the components are ideal and, more importantly, that the connection lines are infinitely short. If we now construct such a bridge for high frequencies (from 500MHz), we should also take the connection lines into account. With a simulation tool such as Ansoft Serenade [S1] or Eagleware Genesys [S3], this is done by inserting the appropriate microstrips (for tracks) and/or inserting computed inductances (1mm wire 1nH).

We should also take care that the load impedance actually corresponds to reality (is the connection line, for example, actually 50 $\Omega$ ? what happens if a DC block is used?) otherwise the above equations will not apply.

When selecting component parts, we should take care that we are operating below their resonance frequencies which becomes more and more difficult as the frequency increases. So it is recommended to use the S-parameter files from the component part manufacturer. We soon understand here that the lumped component parts used put an upper frequency limit on the design.

Using microstrips as a replacement for



**Fig. 4: The LC-balun for a push-pull power amplifier.**

the lumped component parts can be a solution:-

An inductance can be realised by selecting an appropriate ratio between the line impedance and the length. Likewise, a capacitance can be realised by using an open circuit microstrip. A good rf short-circuit (rf shunt) can be created using a radial stub [6-8].

#### 4.

### The Microstrip Based LC Balun [9]

With the knowledge that we can replace lumped component parts by microstrips, we can design a balun that makes use of these features. Fig. 5 shows such a balun:-

In comparison with an LC-balun using discrete component parts, this type of design has a number of advantages:

Saving on expensive microwave component parts

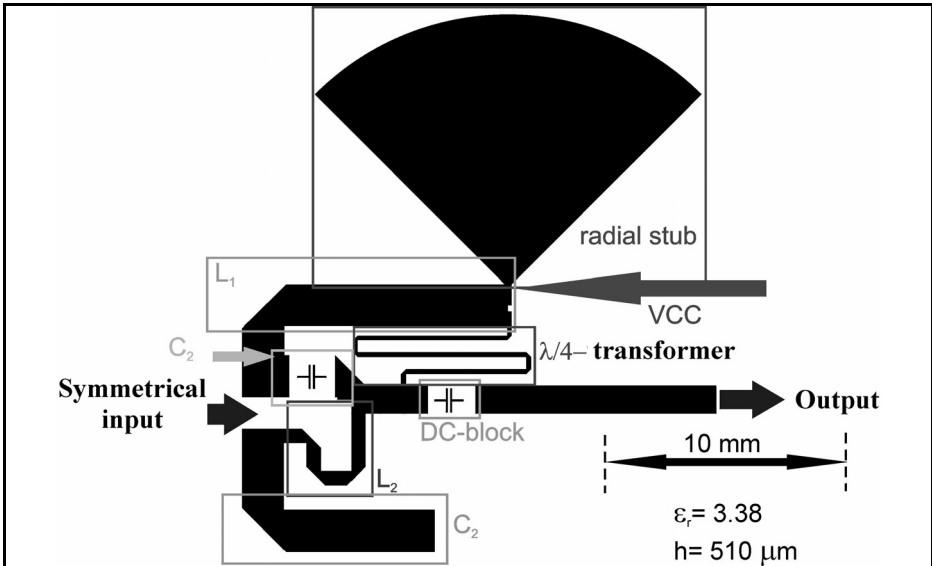
Greater freedom to design with a simulator (every microstrip is defined in terms of length and width). We can also obtain a low load impedance for the second harmonic and an open circuit for the third harmonic.

A direct power supply feed for the power transistors of a push-pull amplifier is made possible through the line structure.

The radial stub fulfils two tasks here:-

- Rf shunt for the power supply
- Defined shunt for the inductance L1

A method for the calculations of this balun is available when using the example of Ansoft Serenade. The above balun has been calculated and simulated for an operating frequency of 2.45GHz and symmetrical input impedance of  $28\Omega$ . The substrate used was Rogers RO4003, with a substrate thickness of  $510\mu\text{m}$  and  $\epsilon_r = 3.38$ .



**Fig. 5: Microstrip LC balun for the 2.45GHz ISM band with a differential input impedance of  $28\Omega$  . (Substrate: Rogers RO4003 with  $\epsilon_r = 3.38$  and a thickness of 0.510mm.).**

To determine the track widths it is best to use the “Transmission Lines” tool from Serenade, or something similar such as, for example, Appcad [S2]. We obtain a width of approximately 1.15mm. for a  $50\Omega$  line.

(To be continued)

## A1.

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[9] W.Bakalski, W.Simbürger, H.Knapp, A.L.Scholz, Lumped and Distributed Lattice-type LC-baluns, Proceedings of the International Microwave Symposium (IMS2002) Seattle, June 2002

[S3] Eagleware Genesys: <http://www.eagleware.com>, Not to be confused with the Eagle CAD program from Cadsoft. You can also, from time to time, find a demo version of the Eagleware Genesys Suite on this page

## A2.

### Software on the internet

[S1] Ansoft Serenade 8.5: <http://www.ansoft.com>, A restricted student version is available

[S2] Appcad 2.0: <http://www.agilent.com/>, This is a freely available tool for all possible calculations involving electrical engineering and metrology

## A3.

### Co-authors:

Winfried Bakalski DL5MGY, Herbert Knapp OE1RNC, Werner Simbürger OE6RUD, Arpad L.Scholtz OE4SZW

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The sectors giant and the inventor of TTL technology has made a discovery. High quality analogue technology is also important, and has a big future in con-

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Naturally, the themes are essentially concerned with every conceivable OPV application, but rf communications engineering and the analogue components required in DSP systems are also appreciated.

Address:

<http://www.ti.com>

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### Appcad

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The earlier DOS program package from the good old HP days can now be obtained free of charge once again in the most recent Windows version from the successor company (Agilent) and can be downloaded from the Internet.

Various aids are on offer for the committed rf and microwave developer (e.g. a stripline calculator or a coil calculation program or operating point calculations, etc.). They support, not only circuit simulation, but also the simulation of complete systems. So no developers PC



should be without this.

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<http://www.hp.woodshot.com>

## Alpha Industries

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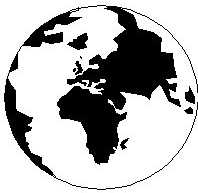
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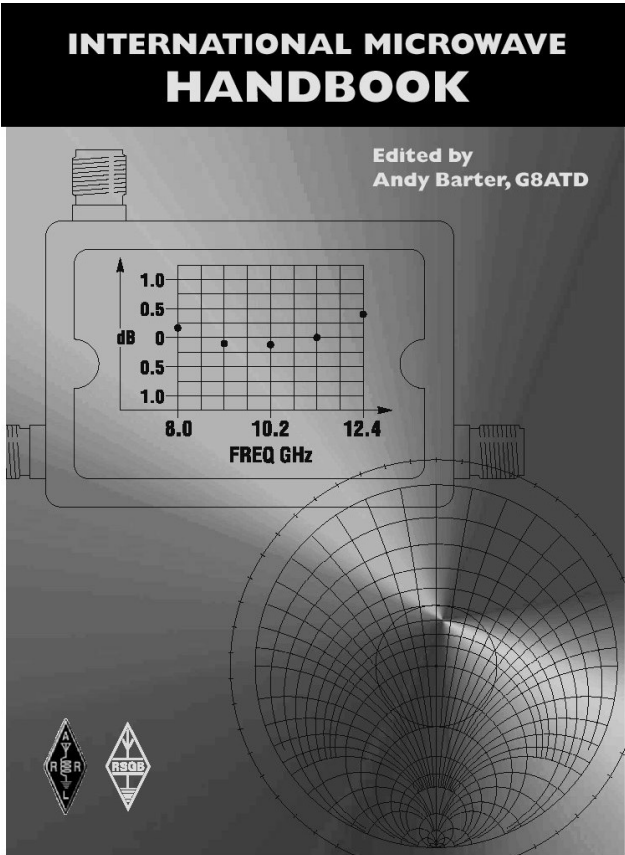
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