A Ku-band low noise downconverter for satellite TV reception

1. Introduction

The frequency band between 10.95 GHz and 12.75 GHz is allocated as a downlink band for many different satellite services. The subband from 10.95 GHz to 11.7 GHz and in particular the two segments from 10.95 to 11.2 GHz and from 11.45 to 11.7 GHz are allocated as the downlink bands for international satellite communications including both telephone circuits and international television distribution. The subband between 11.7 GHz and 12.5 GHz will probably be used by the powerful direct broadcast television satellites. Finally the segment from 12.5 GHz to 12.75 GHz is again being used for national and international satellite communications including telephone circuits, data transmissions and television distribution.

Communications satellites are usually launched into geostationary orbits about 36000 km above the earth's equator. The distance from user stations accessing the satellite is therefore in the 40000 km range. Present satellites only carry rather weak transmitters, the output power per channel ranges from 5 to 40 W for communications satellites and will reach 250 W for high power direct broadcast satellites. Of course weak satellite signals require large receiving antennas. Fortunately satellites transmitting in the Ku-band usually use high gain spot beam antennas of just a few degrees total beamwidth to cover populated areas on the globe, like western Europe, where most user stations are located. Television transmissions coming from these satellites can be received with moderate size antennas, usually parabolic dishes of less than 3 m diameter, and are being used to feed large cable TV networks.

In amateur conditions an excellent noise-free picture can be obtained with parabolic dishes of less than 2 m diameter even from low power communications satellites carrying 10 W or 20 W transmitters like the Intelsat V and V A satellite series, ECS-Eutelsat satellite series and Telecom 1 satellite series.

A satellite TV receiving only station includes a parabolic dish antenna, a suitable receiver and an ordinary TV set or monitor. The first receive downconverter is equipped with a low noise preamplifier and is usually installed directly behind the antenna feed to avoid lossy and expensive microwave transmission lines. The remaining components of a satellite TV receiver are usually installed indoor and include a second, tunable converter for channel selection, a second IF amplifier and FM video demodulator, a sound IF and demodulator, an AM modulator to generate a standard TV signal and a power supply for the complete receiver.

2. Block diagram of the downconverter

The block diagram of the Ku-band low noise downconverter is shown on fig. 1 together with the other outdoor component, a parabolic reflector antenna with a suitable feed for operation in the Ku-band.

Most available Ku-band satellite TV transmissions require a parabolic dish of 1.2 to 1.8 m diameter for noise free reception in western Europe depending on the particular satellite transmitter output power, antenna pattern and transponder mode of operation (half/full). Most available dishes, either new or surplus, have a focal to diameter (f/D) ratio of 0.35 to 0.4. A suitable feed for this f/D ratio is a circular waveguide-horn with a corrugated flange for improved illumination efficiency. Since in the practical construction and alignment the feedhorn is a functional part of the downconverter, it will also be described in this article.

The low-noise downconverter includes three modules: a low-noise amplifier for 10.95 ÷ 11.7 GHz, a block downconverter 10.95 ÷ 11.7 GHz/0.85 ÷ 1.6 GHz and an IF amplifier for 0.85 ÷ 1.6 GHz. The two stage low-noise amplifier uses two 0.5 μm gate length gallium arsenide FETs CFY 18-23 mounted on a 0.6 mm thick glassfiber-teflon laminate.

The block downconverter module includes a fixed tuned FET oscillator at 10.1 GHz, a single ended active mixer stage using an 1 µm gate length gallium arsenide FET CFY 19 and an IF preamplifier stage. The block downconverter module is also built on a 0.6 mm thick glassfiber - teflon laminate.

The IF amplifier module includes three amplifier stages using silicon bipolar microwave transistors and a +5 VDC supply regulator for the other two modules equipped with Ga As FETs.

All the Ku-band connections are made with short lengths of RG-141 3.6 mm diameter semirigid cable and SMA connectors. BNC connectors are used in the IF frequency range.

The low noise downconverter requires a supply voltage of +12 VDC. A practical solution is to feed the supply voltage through the same coaxial cable feeding the IF signal to the indoor unit. The same solution is being used with almost all commercially available low-noise downconverters.

The low noise downconverter was originally designed for the 10.95 ÷ 11.7 GHz satellite band since most satellites transmit in this frequency range. The circuit can also be modified to operate in the 12.5 ÷ 12.75 GHz satellite band and the necessary modifications will be described later in this article. All the values given on the circuit diagrams and the dimensions given on the drawings however apply to the standard 10.95 ÷ 11.7 GHz version!

3. Corrugated horn feed

The corrugated horn feed shown on fig. 2. is made of a short length of circular waveguide, whose open end acts as the horn aperture, a waveguide to coax transition and an adjustable corrugated flange.

To acheive a good illumination efficiency the feed horn should illuminate the parabolic dish surface as uniformly as possible with little spillover. Of course the beamwidth of the feed should be matched to the focal aperture angle of the parabolic dish used. This angle is in turn determined by the dish focal to diameter ratio. The beamwidth of a circular waveguide horn feed is mainly determined by the internal diameter of the waveguide. The dimensions shown on fig. 2. are suitable for parabolic reflectors having a f/D ratio between 0.35 and 0.40.

The corrugated flange improves the illumination uniformity and decreases the sidelobes of the horn feed. The illumination efficiency may exceed 75% and this brings an improvement of between 0.5 and 1dB in the overall antenna gain. In the case of space communications, a decrease of the effective antenna temperature due to the reduced spillover should also be noted. A very simple explanation of the principle of operation of a corrugated surface (flange) is as follows: the corrugated surface enforces two boundary conditions: the tangential electric field should be zero due to the conductive rims and the tangential magnetic field should also be zero due to the λ/4 deep corrugations. between the rims. The combined effect of both boundary conditions is that the field intensity must fall to zero on the flange surface. This produces a rotationally symmetrical flat topped beam with very low sidelobes that is ideal for the illumination of parabolic reflectors.

A corrugated surface is also called a scalar surface in the literature since it behaves exactly in the same way for both magnetic and electric fields. Correspondingly corrugated horns are also called scalar horns.

The position of the corrugated flange along the waveguide should be adjusted for best results. Usually the distance between the open end of the waveguide and the surface of the corrugated flange ranges between zero and λ/4.

A circular waveguide horn can receive and/or transmit arbitrarily polarized waves, including two independent orthogonally polarized waves at the same time. The actual polarization of the horn feed therefore only depends on the waveguide mode launcher used – the coax to waveguide transition. Since most low power satellites use linear polarization, either in a single plane or in two orthogonal planes for frequency reuse purposes, a linearly polarized feed is required. A suitable mode launcher is a simple $\lambda/4$ probe inserted in the waveguide wall about $\lambda_g/4$ from the waveguide shorted end, where λ_g is the wavelength inside the waveguide. Of course the mechanical support structure must allow a smooth and easy adjustment of the feed polarization plane.

High power direct broadcast satellites will probably use circular polarization, both right hand and left hand, between 11.7 GHz and 12.5 GHz. Circular polarization can simply be obtained from a linearly polarized mode inside a circular waveguide by inserting a few tuning screws at 45° with respect to the polarization plane of the linearly polarized mode.

4. Low-noise amplifier

The main function of the low-noise RF amplifier (see fig. 3.) is to improve the overall downconverter noise figure. Beside having a low noise figure it should also have sufficient gain to prevent the overall noise figure being degraded by the noise generated in the following mixer stage.

Only gallium arsenide FETs can provide useable gain values at frequencies above 10 GHz. The main parameter of a GaAs FET that influences its microwave performance is the gate length. 1 µm gate length FETs can still provide about 6 dB of gain at 12 GHz with an associated noise figure of about 4 dB. 0.5 µm gate length FETs are much better: about 10 dB of gain can be obtained with a noise figure of about 2.5 dB. 0.25 µm gate length FETs are of course even better, but they are also very expensive and not yet regularly available on the market.

The CFY 18 transistors used in this project are 0,5μm gate length FETs packaged in the economical "micro-X" package and are manufactured by Siemens. Other manufacturers also supply similar transistors with similar microwave performances and at similar prices.

The parasitic reactances of a transistor package have a considerable effect on the transistor performance in the microwave frequency range. To improve the performances of their products manufacturers usually try to use these unavoidable parasitics to partially compensate the parasitics of the transistor chip at least in the frequency bands where the transistor will most likely be used. It is therefore easier to match a packaged GaAs transistor in the 12 GHz frequency band than at frequencies below 2 GHz!

The difference between optimum noise match and optimum gain match is small at 12GHz: a CFY 18 matched for maximum gain will only show a 1dB degradation of its noise figure. It is interesting to notice that the source reflection coefficients for optimum noise match and maximum gain match have a similar phase, the magnitude of the optimum noise figure match source reflection coefficient being much smaller than the maximum gain source reflection coefficient. The above is also valid for other similar transistors operating in the 12 GHz frequency range.

However, the specified transistor performance can only be obtained if the transistor is correctly installed into a suitable circuit. Almost all microwave transistors are packaged in cases suitable for installation into a microstrip circuit. At Ku-band frequencies only teflon based laminates can be considered as substrate materials, since alumina, quartz and other suitable materials can not be handled by amateur tools. The preamplifier is built on a 0.6 mm thick glassfiber-teflon laminate having an $\varepsilon_r = 2.6$ so that all the circuit elements have reasonable dimensions.

It is especially important to provide good source grounding/decoupling if the specified gain is to be obtained and other problems to be avoided. Each FET has two source leads and each source lead is bypassed by a leadless ceramic disc capacitor installed in a hole punched in the teflon laminate (fig. 6). Since these capacitors are made of high ε_r ceramic material, they behave practically as metal discs at Ku-band frequencies.

The two stage amplifier uses a 50 Ω etched microstrip line and short capacitive tuning stubs made of thin copper foil to match the two FETs. The tuning is necessary since the transistors and the laminate have tolerances and the amplifier has to be matched to a real world antenna feed and to the following mixer stage, which are not ideal 50 Ω loads. A further advantage of this design approach is that the same printed circuit board pattern can be used between 10 and 13 GHz with just repositioning the tuning stubs. The approximate positions of the tuning stubs for the frequency range 10.95 ÷ 11.7 GHz are indicated on fig. 3.

The supply voltage is fed through $\lambda/4$ chokes and is first bypassed by low value "printed" capacitors so that low frequency resonances of the supply network are dampened by the 56 Ω resistors.

If the amplifier is aligned to cover the 10.95 to 11.7 GHz band it will provide about 22 dB of gain at the band center and about 18 dB at the band edges.

5. Block downconverter module

Both silicon schottky diode and GaAs FET mixers are practical at Ku-band frequencies. The advantages of a schottky diode mixer are a low noise figure, 6 to 8 dB, and little local oscillator drive power required - about 1 mW per diode. GaAs FET mixers using 1 μm gate length FETs acheive a slightly higher noise figure between 10 and 12 dB and require a higher local oscillator drive power, about 10 mW per GaAs FET. Unfortunately the schottky diode mixer noise figure also depends to a large extent on the noise figure of the IF amplifier used. The excellent noise figure specifications are usually obtained with narrowband low noise (1.5 dB) IF amplifiers. Since a satellite downconverter requires a broadband IF amplifier (0.85 to 1.6 GHz) the noise figure of the latter can hardly be held below 5 dB across the whole IF bandwidth and the overall performance of a schottky diode mixer approaches that of a GaAs FET mixer. On the other hand, a FET mixer has a small conversion gain that is sufficient to make its noise figure almost independent of the following IF amplifier.

Packaged mixer diodes have high parasitic reactances that can hardly be tuned out over a wider bandwidth. On the other hand, beam lead diodes only have small parasitic reactances but are very difficult to handle due to their small phisical size. Finally, a GaAs FET is actually cheaper and easier to use than a set of suitable diodes.

The block downconverter module shown on fig. 4. uses a single ended GaAs FET mixer in a grounded source configuration. Both RF and LO signals are applied to the gate of an 1 μm gate length FET CFY 19 and the IF signal is taken from the drain. Note that the actual square law mixing process is actually a vertical process inside the FET structure and is therefore not dependent on the FET gate length. The latter only influences the output IF signal frequency response.

To enhance the mixer performance the gate network should have a low impedance for the output IF signal and the drain network should have a low impedance for the input RF and LO signals. The gate network is a branching filter to couple both LO and RF signals to the mixer gate. The branching network uses tuned $\lambda/4$ open stubs to reject the unwanted frequencies: the RF signal path includes a LO signal trap and the LO signal path includes a RF signal trap. The traps are located at $\lambda/4$ from the branching point to reduce their influence on the desired signal paths. Four $\lambda/4$ chokes are used to reject signals in the IF frequency range and provide a low, resonance free impedance at the IF frequency.

The mixer drain stub operates in a 3/4 λ mode at RF and LO frequencies to enhance the conversion efficiency. For IF frequencies it behaves as a capacitor and builds together with L_1 a low pass filter and an impedance matching network to decrease the mixer output impedance.

The bandwidth occupied by a frequency modulated TV signal transmitted through a satellite transponder is usually between 25 and 36 MHz. A receiver frequency stability of a few MHz is therefore required and this can simply be met by a free running microstrip FET oscillator at 10.1 GHz. An 1μm gate length GaAs FET CFY 19 can provide both the required stability and sufficient output power to feed the mixer stage.

To make oscillate a GaAs FET at frequencies around 10 GHz an external feedback signal path has to be provided from the drain to the gate. Considering the S parameters of a packaged transistor this can be easily acheived by insulating from ground the source leads using two $\lambda/4$ chokes. The oscillation frequency is mainly determined by the gate stub which operates in the 3/4 λ mode including the internal reactances of the transistor chip and package. The drain stubs are required to provide a stable impedance in a wide frequency range and thus prevent oscillations at unwanted frequencies.

The supply voltage is fed through a $\lambda/4$ choke and is bypassed by a "printed" capacitor similarly as in the low-noise amplifier stages.

The block downconverter module includes an IF amplifier stage using a BFQ 69 silicon bipolar microwave transistor. The supply voltage for the mixer and IF amplifier stages is fed through IF chokes L_2 and L_3. Again low value resistors are being used to avoid parasitic resonances.

6. IF amplifier 0.85 ÷ 1.6 GHz and +5VDC regulator

The IF amplifier includes three stages equipped with silicon bipolar microwave transistors (see fig. 5.). Since the gain of bipolar transistors decreases rapidly with increasing frequency in the low microwave region, the broadband IF amplifier should contain suitable networks to compensate the gain rise at low frequencies. A simple solution is to connect the collectors of the transistors to inductive loads (L_4, L_5 and L_6) and couple the signal to the following stage through a small capacitor. In this way the amplifier will have a reasonably flat gain of about 25 dB in the band center and falling about 5 dB at band edges. If more gain is required, for instance to feed a longer cable to the indoor unit, T_7 and T_8 can be replaced by the better BFQ 69 type transistors increasing the overall gain by about 5 dB. On the other hand, at least one stage can be deleted if the coaxial cable to the indoor unit is very short.

The IF amplifier receives the +12 VDC supply voltage through the same coaxial cable from the indoor unit, decoupled by the choke L_7 and a feedthrough capacitor. The supply voltage of +5 VDC for the GaAs FET equipped stages is obtained using a 7805 voltage regulator integrated circuit. Its input and output are bypassed by 1µF multilayer ceramic capacitors to prevent unwanted oscillations.

The IF amplifier is not built on a printed circuit board, the components are directly installed into a suitable metal case. The 7805 voltage regulator IC is installed together with the two bypass capacitors on a small piece of unetched PCB laminate, which also acts as a cooling fin for the 7805. Note that although the current drain at 5V is below 100 mA it is recomended to use an 1A regulator in a TO-220 package to avoid the thermal drift of the 5V supply voltage and as a consequence a drift of the 10.1 GHz oscillator!

7. Construction and assembly of the downconverter

The low-noise RF amplifier and the block downconverter modules are constructed on two double sided printed circuit boards made of 0.6 mm thick glassfiber-teflon laminate having an $\varepsilon_r = 2.6$. The corresponding upper side masters are shown on fig. 8. The lower side should not be etched since it acts as a ground plane for the microstrip transmission lines. Other teflon laminates of the same thickness can also be used: the most standard $\varepsilon_r = 2.55$ laminate without any modifications while other lower ε_r laminates with just a slight repositioning of the tuning stubs.

The teflon printed circuit boards have to be first carefully drilled as shown on fig. 9. Since teflon is a very soft material, only sharp (new!) points are to be used at low speed. Small 1mm diameter holes for the source bias resistors are not shown on fig. 9., in any case these resistors can also be soldered to the walls of the case housing the circuit (fig. 10.) The 100nF bypass capacitor in the block downconverter is installed in the center of the strip used as a support for the +5V supply. The other lead is of course grounded through an 1mm diameter hole in the printed circuit board.

The $\lambda/4$ chokes are grounded through 2 or 2,5 mmØ holes using small pieces of thin copper foil cut to the same width as the microstrips to be grounded and wrapped around the hole edge to provide the shortest possible grounding path. Then these holes may be tapped using small square pieces of tinned copper foil (see fig. 7.).

The leadless source bypass disc capacitors should be pressed into the respective 5mmØ holes. Both the copper cladding around these capacitors and the copper foil to be added should be well tinned to ensure good solder wetting and therefore a low grounding inductivity (see fig. 6.)

The 1.5pF coupling capacitors are small rectangles of thin teflon laminate as shown in fig. 7. Due to the small thickness of the insulation these capacitors should be immediately checked for shorts after installation. At Ku-band frequencies the virtual capacitive value of these capacitors is larger due to resonance effects.

The remaining components can now be installed. Of course the GaAs FETs will be installed last. GaAs FET manufacturers generally state that their product may be damaged by improper handling during installation due to electrostatical discharges through the very small area junctions. The handling procedures they suggest are however usually not very clever nor sufficient to protect the delicate microwave semiconductors. Grounding oneself's body might be fatal for an operator if there is an accidental fault in the electrical installation of the laboratory!

Therefore I am going to describe here a simple and safe procedure, both for the GaAs FETs and for the operator:

1. Work on an ordinary wooden table sitting on a wooden chair. Wood is an insulating material however its conductivity is sufficient to prevent the build up of large electrostatic charges.
2. Disconnect the soldering iron from mains when soldering even if you are using a separation transformer since electrostatic charges are directly proportional to the capacities of the charged bodies.
3. Before each soldering operation touch with your finger both the tip of the soldering iron and the ground plane of the printed circuit board to equalize the potentials.

Following these simple rules I have not yet destroyed even a single GaAs FET although I have soldered more than twenty GaAs transistors during the developement of the described downconverter. Many of these have even been soldered several times since the original prototypes did not work satisfactorily. Of course any soldering operation should only be done with the DC power switched off and the circuit disconnected from other circuits and/or test equipment. Electrical equipment that produces induced charges like CRT displays or induced voltage or current spikes should also be switched off during the installation of GaAs FETs.

Following the assembly the low-noise amplifier printed circuit board can be immediately installed in a suitable metal box as shown on fig.10.

The block downconverter printed circuit board should be first roughly aligned, especially the oscillator frequency, before installation in a suitable metal case. The walls of the housing are 22 mm wide strips of thin brass plate, the cover is made from 0.5 mm thick aluminum plate and the bottom is the same printed circuit board. Feedthrough capacitors are soldered into holes made in the walls of the metal case. The 5V6 1W overvoltage protection zener diodes are installed externally. Each module requires its own zener diode since voltage spikes can also be induced in the 5V supply wiring for example due to accidental short circuits.

A piece of absorber foam has to be installed below the cover to dampen the unwanted parasitic resonances of the housing.

Ku-band frequencies require SMA connectors. SMA connectors are usually used together with short lengths of 3.6 mm Ø semirigid cable. To increase the mechanical strength of the assembly a M4 brass nut is screwed onto the cable end and then soldered to the case. The internal diameter of the M4 thread has to be slightly enlarged with the aid of a small round file to fit the outer jacket of the semirigid cable. If suitable SMA connectors are available these can also be directly soldered onto the case.

BNC connectors are suitable for the IF frequency range between 0.85 and 1.6 GHz. Female BNC connectors can be directly soldered onto the metal cases as shown on fig. 11.

The components of the IF amplifier are installed in a 55 mm long, 20 mm wide and 15 mm high box made of thin brass sheet (see fig. 11. and fig. 12.)

8. Alignment and testing of the downconverter

There are many different possible alignment procedures depending on the instrumentation available. Since most amateurs only have little microwave instrumentation available, an alignment procedure that requires a minimum amount of professional instruments will be shown, using simple home-made instruments like a wideband noise generator and equipment an amateur already has like a 1296 MHz converter and a receiver with a disconnected AGC for noise figure / gain measurements.

The three stage IF amplifier does not require any adjustment. Reasonable values of DC currents (around 15 mA) flowing through the transistors T_6, T_7 and T_8 already ensure that the amplifier is operating correctly. The +5VDC voltage regulator should also be checked before connecting the two modules with Ga As transistors.

The block downconverter module should now be connected. The operation of the 10.1 GHz FET oscillator should be checked and the frequency aligned to the desired value. When T_3 is oscillating correctly, its current drain should be around 15 mA (to be measured as a voltage fall on the source bias resistor). Touching the drain and gate stubs at the same time with your finger should block the oscillations and the current drain should fall to about 10 mA. If similar values are not obtained (tolerances of ±20% are allowed) then the value of the nominally 100 Ω source bias resistor should be modified. Note that a wide spread of the transfer curve $I_{ds} = f(U_{gs})$ is normal for GaAs transistors.

The frequency of the oscillator can be adjusted by the T_3 gate stub length. As etched on the teflon printed circuit board this stub is slightly too long and the oscillation frequency is generally 300 to 400 MHz too low. The grounding strip should be carefully removed and the gate stub shortened using a small file producing a 3mm wide cut in the laminate. Since the gate of the FET is not connected during this operation observe all the handling precautions as when soldering the Ga As FETs. The gate stub should be shortened by about 1 to 1,5 mm to obtain 10.1 GHz. Fine frequency corrections can be made by a small capacitive tuning stub – a small piece of thin copper foil soldered about in the center of the gate stub.

Unfortunately it is not easy to measure the frequency of the local oscillator with amateur instruments. The ideal solution is a spectrum analyzer or a sensitive microwave frequency counter connected to the input of the module. If the signal is not sufficient, then the LO trap resonator has to be temporarily detuned, but this will also shift the oscillator frequency by about ±50MHz. Alternatively a schottky-gunn module, well known from the early amateur microwave activity, can be used to downconvert the FET oscillator signal to the VHF / low UHF range where it can be monitored easily. Even the famous Lecher wires, although spaced by 1 cm, are still very accurate at 10GHz, but a cheap and sensitive detector is not readily available. Absorption resonators are also accurate, but they need a sensitive detector too.

Actually it is sufficient to bring the oscillator frequency to within ±50 MHz, fine adjustments can be done later. The block downconverter printed circuit can now be installed in a suitable case as shown on fig.10. The voltage on the source of T_4 (mixer transistor) should now be checked on the mixer test point. With the LO drive signal applied the current through T_4 should be within 7 and 10 mA to obtain the best mixer noise figure. Disabling the oscillator as described earlier the T_4 source voltage should fall by about 500mV. The source voltage increase in an active FET mixer when applying the LO drive signal has precisely the same meaning as the rectified current of diode mixers: it does provide an insight into the nonlinear mixer operation and an estimate of the mixer efficiency.

The mixer and the low-noise amplifier should now be aligned for the maximum available gain in the desired frequency band between 10.95 and 11.7GHz. A simple noise generator can be used as the signal source. An inversely polarized B-E junction of a BFQ69 transistor is a simple and efficient noise source; at 12GHz it can supply over 30dB ENR with a zener current of about 5mA. Since many suitable designs were already published in this and other magazines, the construction of a noise source will not be discussed here.

If a noise generator is being used as the signal source then a sensitive receiver is required to detect the signal at the IF output of the block downconverter module. A suitable IF value is 1296 MHz since it falls almost in the center of the IF passband 0.85 to 1.6 GHz and converters are readily available for this frequency. The 1296 MHz converter should be connected to a (possibly wideband) receiver equipped with a linear detector and the AGC disconnected. A noise figure measurement set receiver is ideal for this purpose. Of course, the receiver should be equipped with a manual gain control (attenuator) to adjust the signal level to obtain a suitable output indication on the S-meter.

If a wideband noise generator is used as a signal generator, care should be taken not to tune the low-noise amplifier and the block downconverter to the image frequency. A fool proof solution is to build two horn feeds (see fig. 2., the corrugated flanges are not yet necessary). One horn is connected to the input of the low-noise amplifier or block downconverter to be aligned and the other is connected to the output of the noise generator. The lowest cutoff frequency of the waveguide (mode TE_{11}) is around 9.75 GHz for the given internal diameter of the horn. This is of course below the wanted frequency range 10.95 ÷ 11.7 GHz but above the image frequency range 8.5 ÷ 9.25 GHz. Therefore the horn feed is a simple and very efficient image rejection filter.

The noise generator signal level can easily be adjusted by the distance between the two horn apertures. The low-noise preamplifier can be tuned to the actual horn feed impedance since the overall system noise figure is the only important parameter.

As first the adjustment of the block downconverter module alone should be completed. If suitable instrumentation is available the LO signal trap should be tuned for minimum LO leakage at the input connector. Otherwise it should not be touched since it is already etched very close to the required dimensions. Then the noise generator signal should be fed to the input as described above and the position of the tuning stub should be found. The tuning stub is a small piece of copper foil, about $2 \times 3\,mm^2$, to be moved along and across the 50 Ω microstrip using a thin rod of insulating material and finally soldered in the position that gives the maximum conversion gain. This operation may both shift the oscillator frequency by a few ten MHz and slightly increase the voltage at the mixer test point. However both these effects have almost no influence on the performance of the converter.

Now the low-noise amplifier can be inserted between the horn feed and the block downconverter module. The source bias resistors should be adjusted to obtain a drain current of about 15 mA. Without any tuning a gain of 12 to 14 dB can be expected from the S parameters of the transistors. As first the interstage match should be optimized for maximum gain. Then the output match should also be optimized for maximum gain. Finally the position and length of the input tuning stubs for the maximum gain should be found. The input tuning stubs are however not yet soldered in this position, since we actually want the optimum noise match. This can simply be obtained leaving the tuning stubs in the same position and shortening them to get 1 to 2 dB less gain. Alternatively the effect of a tuning stub can be decreased by bending up the open end of the copper foil.

The CFY 18 transistors are selected by the manufacturer according to the noise figure indicated by two numbers. The CFY 18-23 selection is specified to have a 2,3 dB noise figure at 12 GHz. Considering the contribution of the following stages a 3 dB noise figure is the theoretical minimum. Various losses between the horn feed and the first transistor will increase the noise figure to about 4 dB in the band center and a few decibels more at band edges. The above estimate was found in good agreement with practical carrier to noise ratio measurements on satellite signals, considering the satellite EIRP, the free space insertion loss and the receiving antenna gain.

A tuned low noise amplifier has some selectivity. This is useful to prevent the noise figure degradation due to amplifier noise in the image frequency range, since the mixer input network is not very selective. On the other hand, sometimes it may be necessary to optimize the alignment later to cover the whole 10.95 ÷ 11.7 GHz band better.

Of course the waveguide horn feed provides a very high image rejection if the waveguide is not too short. Although the length of the waveguide horn is not critical, 70 to 80 mm is a practical value.

9. Modifications for other frequency ranges and other semiconductor components

Although the described low-noise downconverter was designed for the 10.95 to 11.7 GHz segment, it can be tuned for almost any Ku-band satellite downlink segment. The IF frequency band can hardly be changed, the choice 0.85 to 1.6 GHz representing the best compromise considering available semiconductors, reasonably priced cables, connectors and standardized indoor units. The oscillator frequency has to be tuned to the required value first (by adjusting the gate stub length). The drain stubs should not be shortened by more than 1 mm each otherwise there is danger of parasitic oscillations in the 8 to 9 GHz range. Then the LO signal trap should be adjusted, the RF signal trap and finally, after positioning the tuning stub, also the short compensation stub should be corrected. The low-noise amplifier can be adjusted in the same way as explained earlier, however the positions of the tuning stubs will be quite different from those indicated on fig. 3.

As a practical experiment I have tuned a prototype for the 12.5 to 12.75 GHz frequency band to receive the two french Telecom 1A and 1B satellites. Beside a slightly lower gain due to the higher frequency of operation no other problems were noted. Of course the horn feed had to be redimensioned: a 16 mm inner diameter tube was used, the probe length was reduced to 4.7 mm while the spacing from the shorted waveguide end remained 12 mm (see fig. 2.)

A number of manufacturers actually supply suitable GaAs FETs, both 0,5μm gate length and 1μm gate length types with similar S-parameters as the CFY 18 and CFY 19 types. Although these were not yet practically tried, no major problems should be expected except for the obvious repositioning of the tuning stubs. Of course the FETs should be packaged in suitable microwave packages. Ceramic packages still offer a better performance to price ratio than plastic packages, which are also more sensitive to improper handling and high temperatures encountered during the soldering operations.

10. Conclusion

Ku-band downconverters for small television receive-only satellite earth stations are already a standard product on the professional equipment market. These downconverters usually use the same IF band, generally between 900 and 1700 MHz (±100MHz). The input connector at Ku-band frequencies is a waveguide flange and a suitable horn feed is usually supplied separately. To decrease the effect of the feed mismatch on the noise figure of the low noise preamplifier, a low loss circulator with one port terminated with a matched load (isolator) is usually inserted between the waveguide to microstrip transition and the first amplifier stage. A circulator is a difficult to get and an expensive item but fortunately in amateur conditions each converter can be individually aligned and a small degradation of its performances will only be noticed at band edges.

Professional Ku-band downconverters also use oscillators stabilized with dielectrical resonators. These are some orders of magnitude more stable than the free running oscillator shown in this article. Such a high stability is required in cable television headend stations, where a number of receivers must operate unattended reliably for months. An amateur receiver is usually hand tuned and any downconverter drift can immediately be corrected. In the practical use it was difficult to notice this instability, since it follows the ambient day/night temperature cycle while the receiver was usually tuned from one channel to another much more frequently. The receiver was not equipped with an AFC circuit!

All the Ku-band downconverters have a fixed tuned local oscillator and convert at the same time the whole Ku-band segment down to the relatively wide IF frequency band. A tunable downconverter would be a better technical solution for single channel reception, however it seems that suitable components to build Ku-band VCOs are not readily available.

Although the antenna gain and the downconverter noise figure are considered the most important parameters of a satellite receiving station, the performance of the IF circuits and in particular the wideband FM demodulator is equally important. Amateurs usually only have small antennas. Regardless of the size of the available antenna there will always be some signals at the margin of the system sensitivity. Since the satellite wideband FM video signal contains a lot of redundancy it is possible to extend the treshold of a FM demodulator even beyond the theoretical values. Therefore a suitable IF tuner / demodulator, usually referred as the indoor unit, will also be described in a future article, including a treshold extension demodulator adaptable to different signal to noise ratios, a tunable audio IF to receive most of the standards used and of course a modulator to feed the signal directly to the antenna connector of a PAL or SECAM TV set.

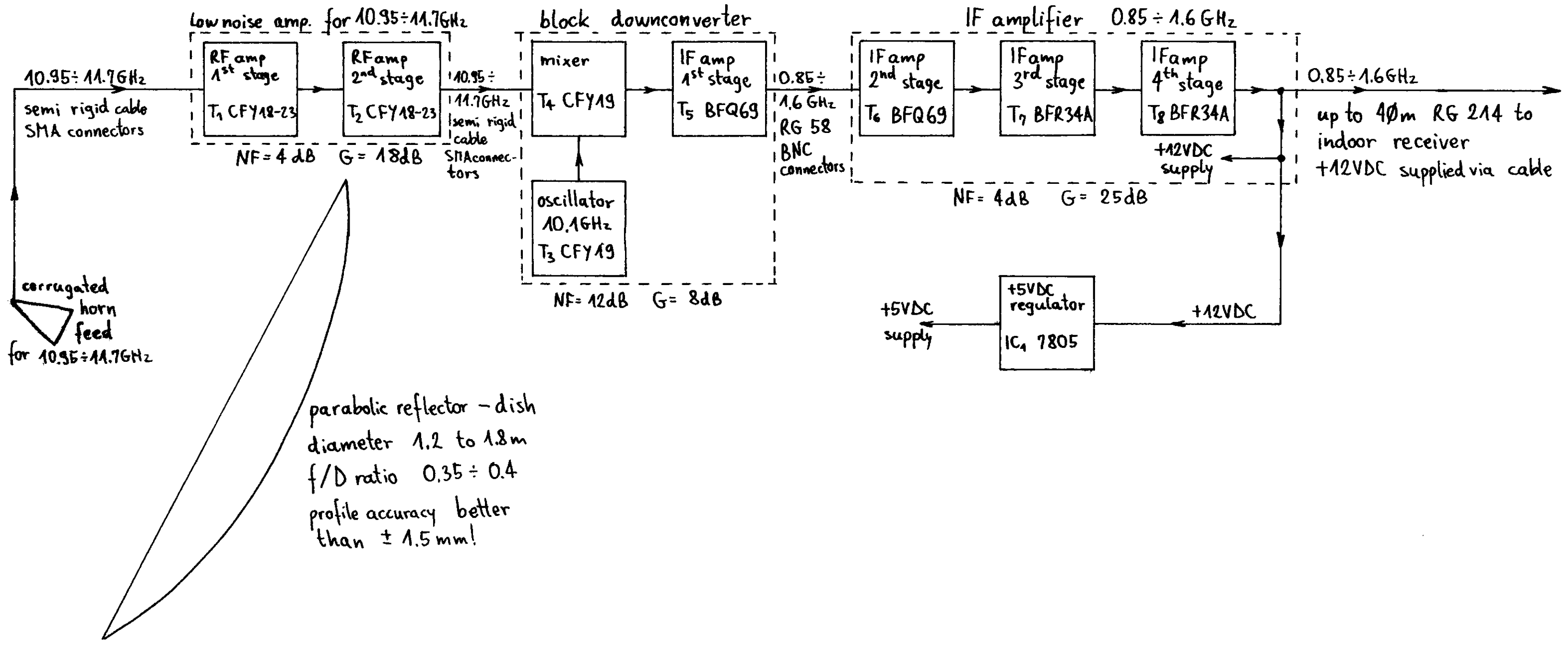


Fig. 1 — Block diagram of the Ku-band satellite TV receive only station - outdoor units.

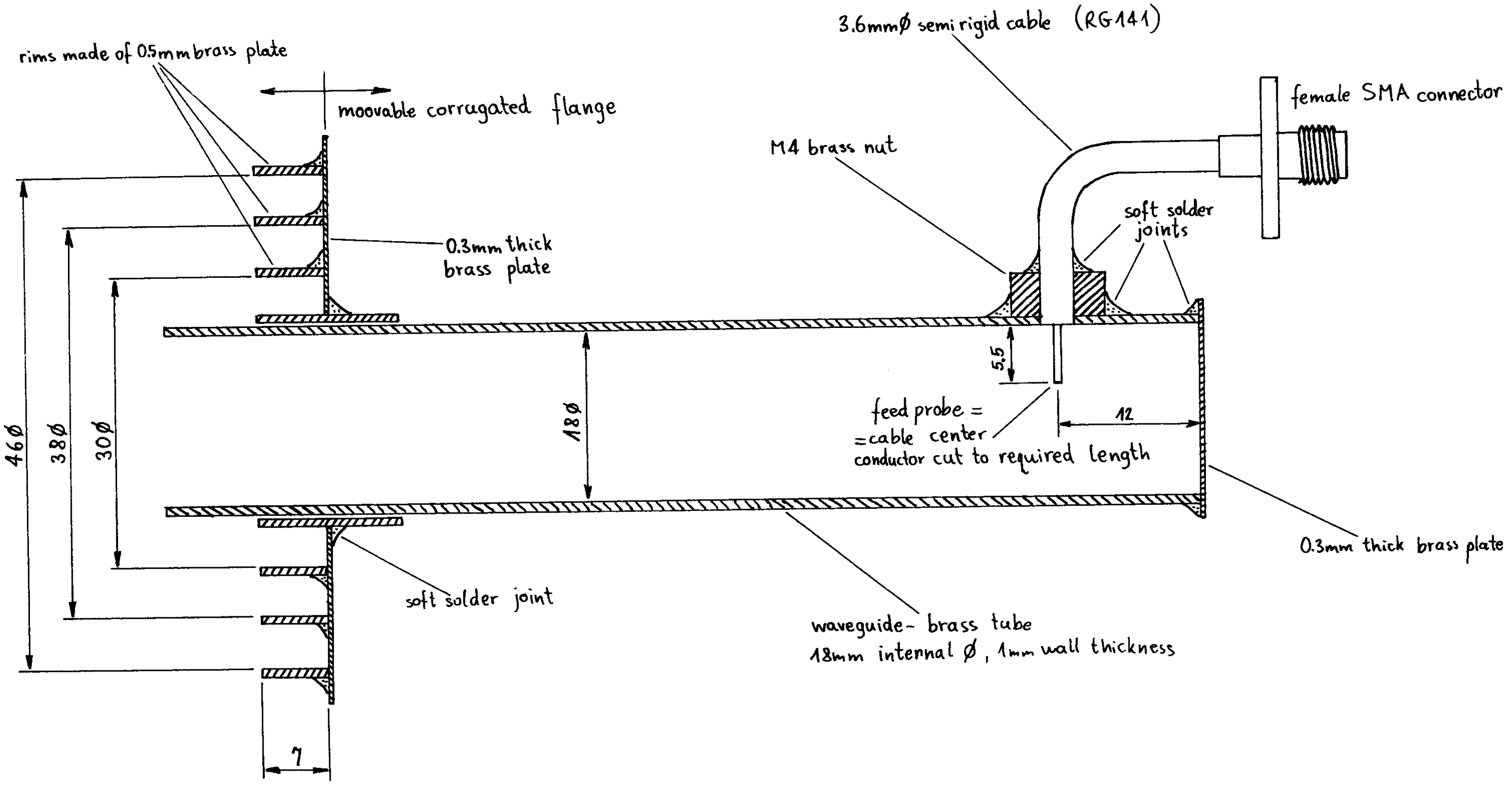


Fig. 2 - Corrugated horn feed for 10.95 to 11.7GHz.

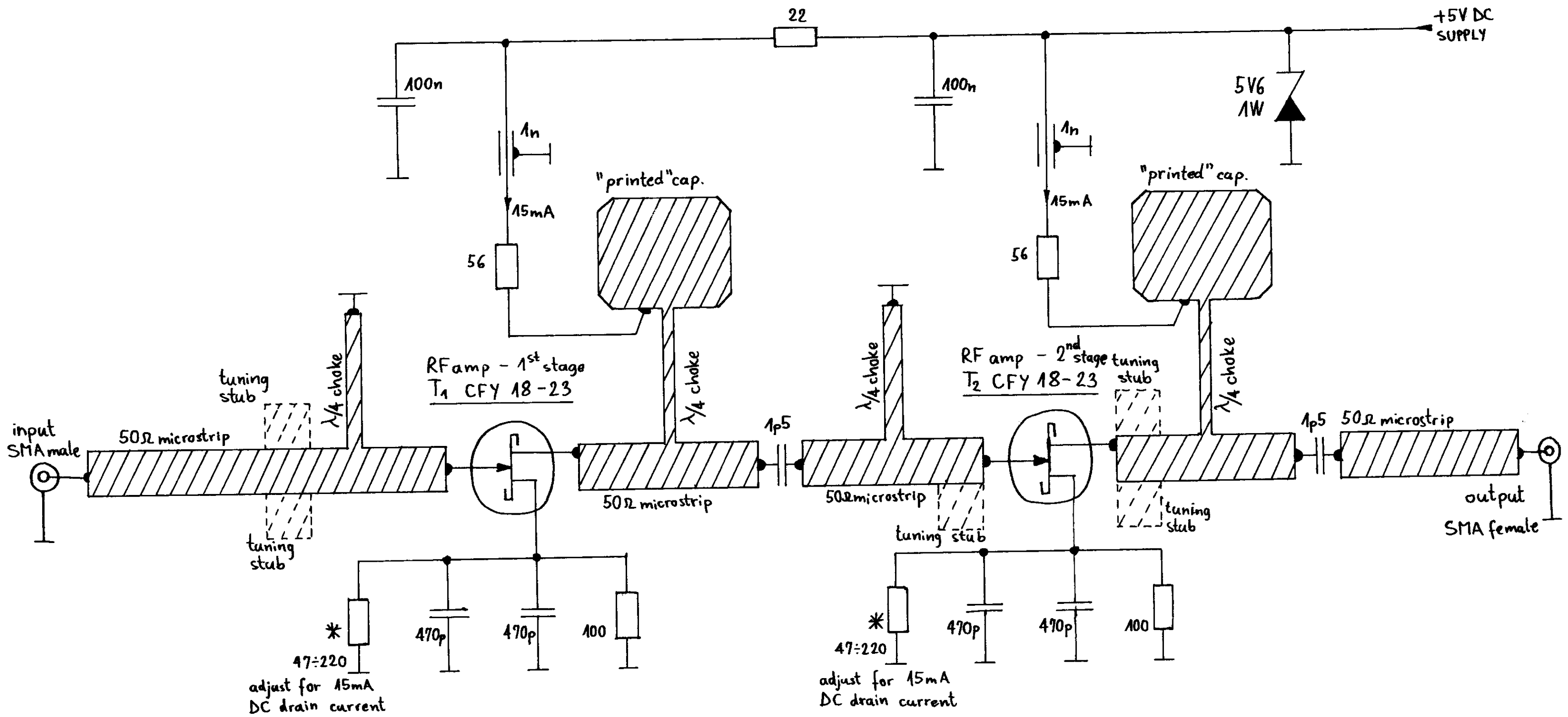


Fig. 3 — Low noise amplifier for 10.95 ÷ 11.7 GHz.

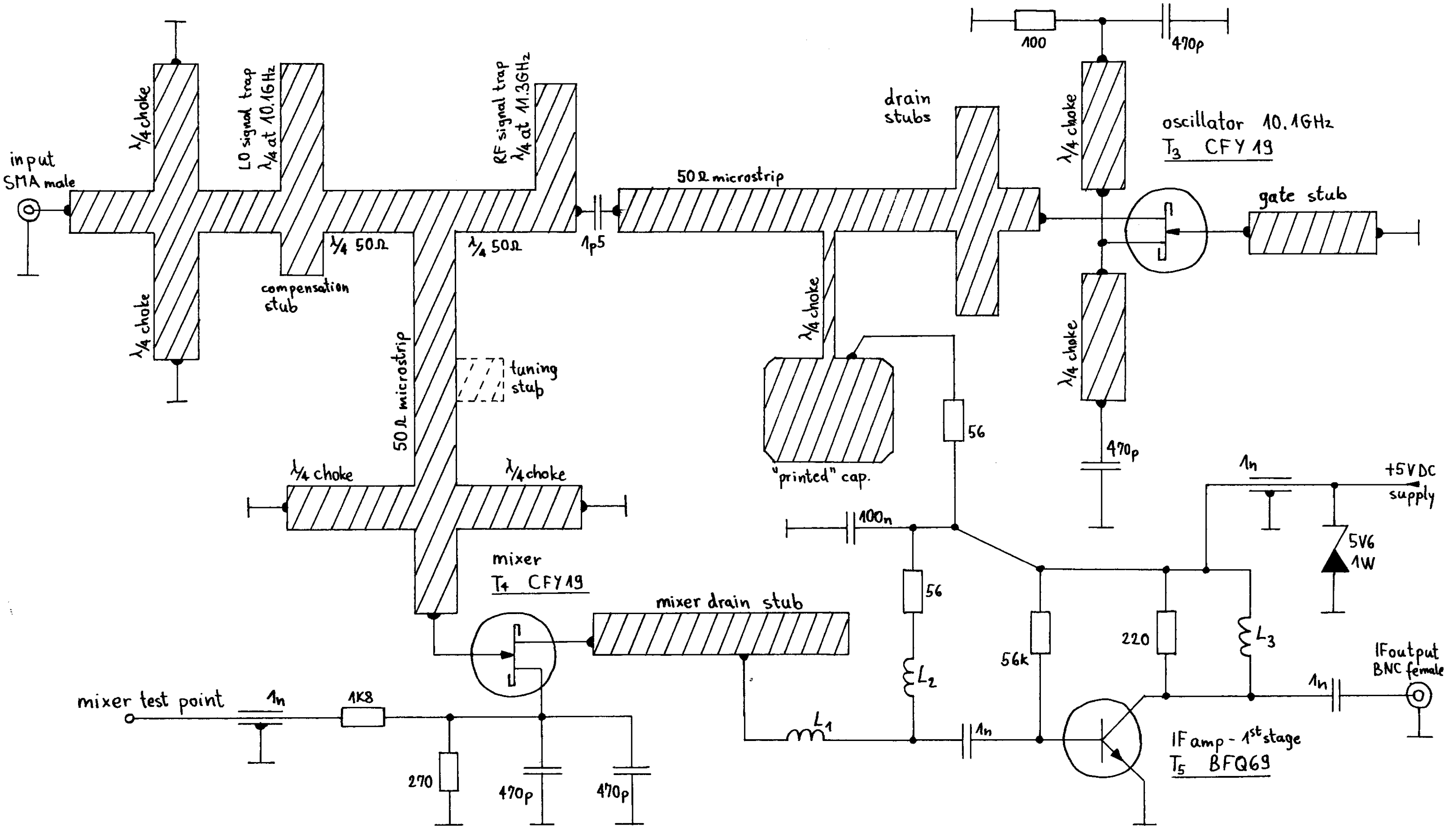


Fig. 4 - Block downconverter 10.95 ÷ 11.7GHz to 0.85 ÷ 1.6 GHz.

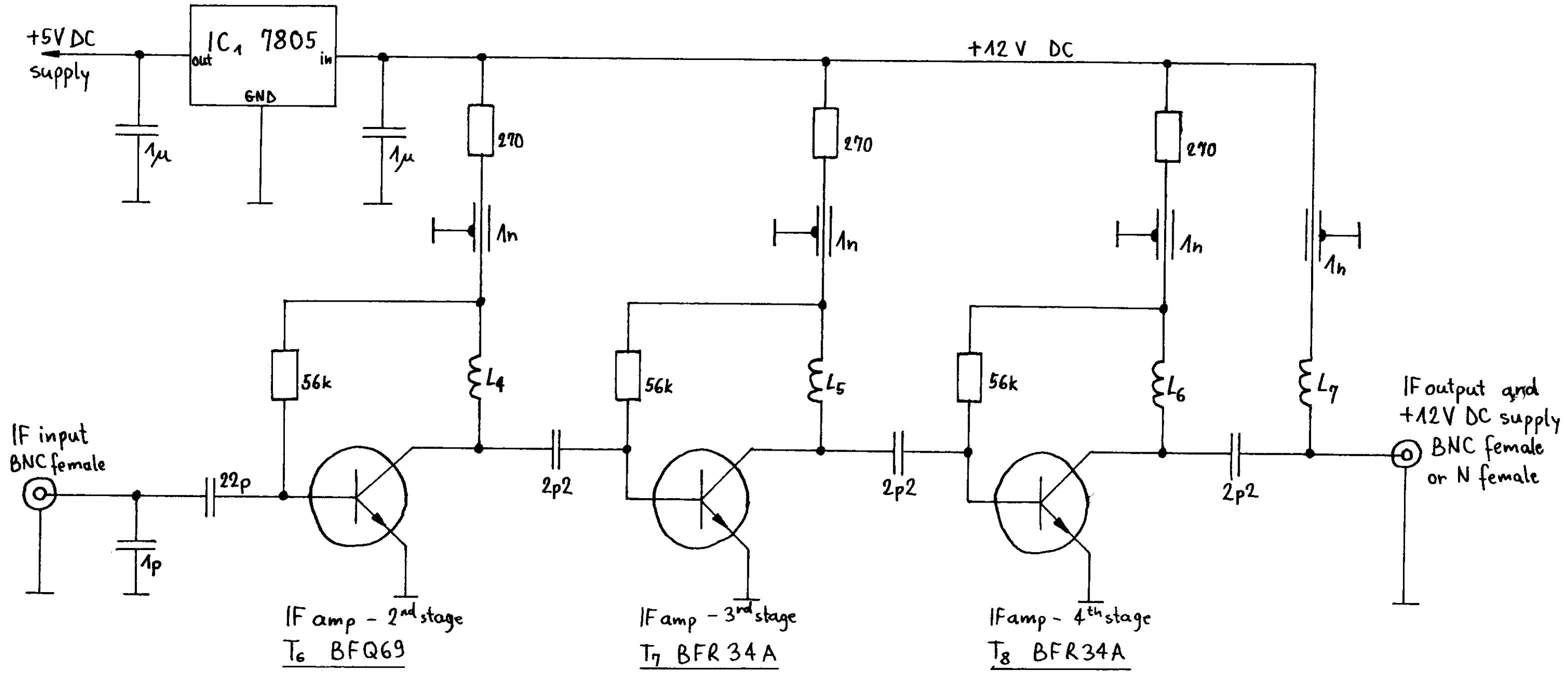
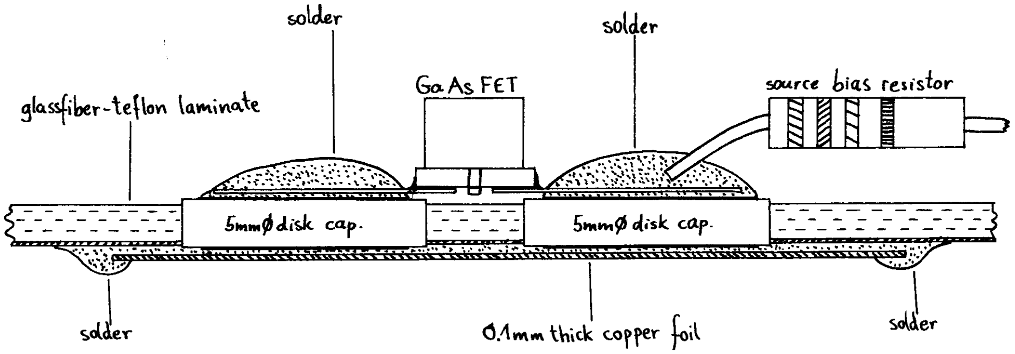
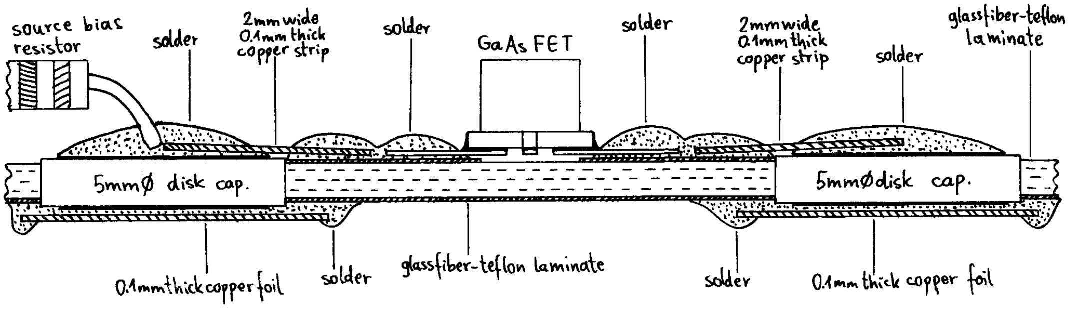


Fig. 5 – IF amplifier 0.85 ÷ 1.6 GHz and +5VDC regulator.

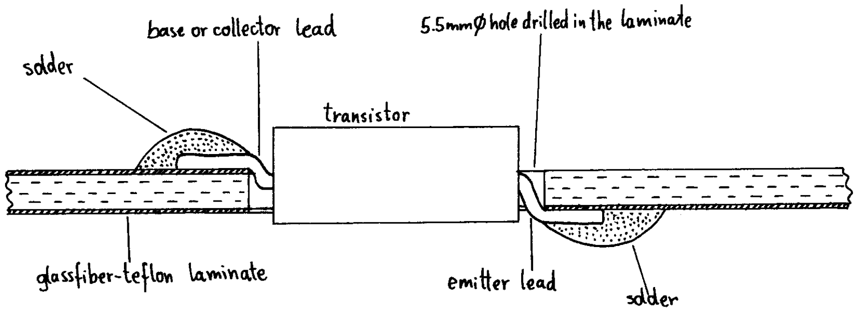


Installation of the amplifier / mixer Ga As FETs (T_1, T_2 and T_4)

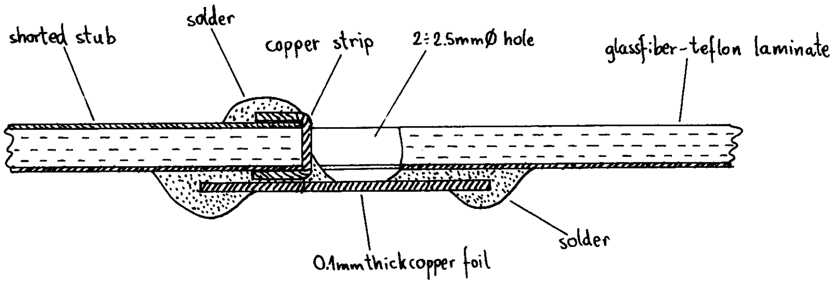


Installation of the oscillator Ga As FET (T_3)

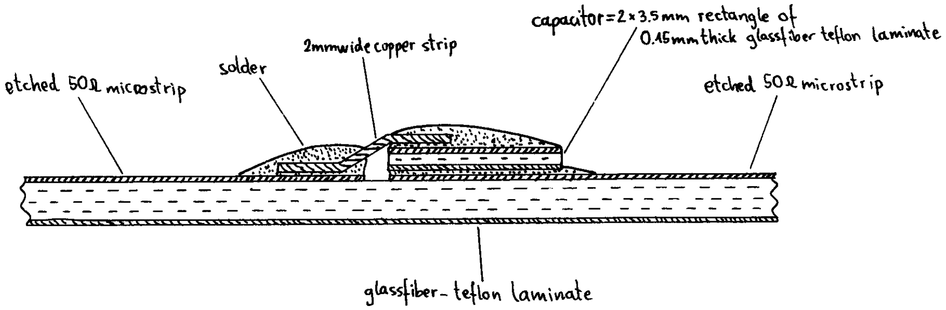
Fig. 6 - Installation of the Ga As FETs and corresponding source bypass capacitors.



Installation of the 1st IF amp transistor (T_5).



Grounding shorted stubs.



Installation of the 1.5pF coupling capacitors.

Fig. 7 – Installation details of other components.

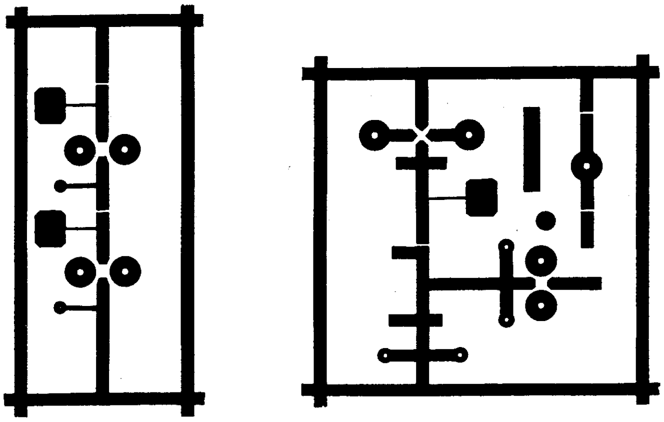


Fig. 8 – PCB masters, upper side. Lower side not etched, 0.6mm thick glassfiber-teflon, $\varepsilon_r = 2.6$.

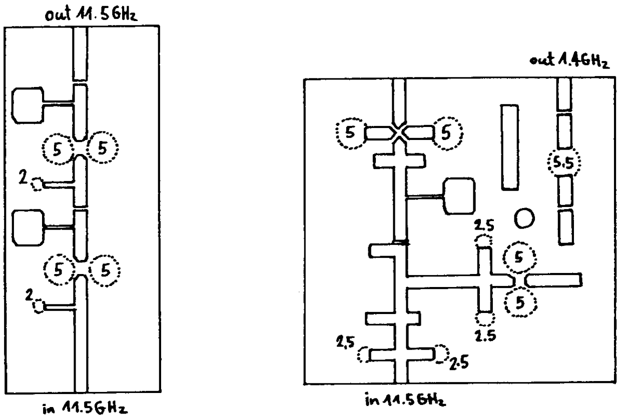


Fig. 9. – PCB drilling plan. Numbers indicate hole diameters in mm.

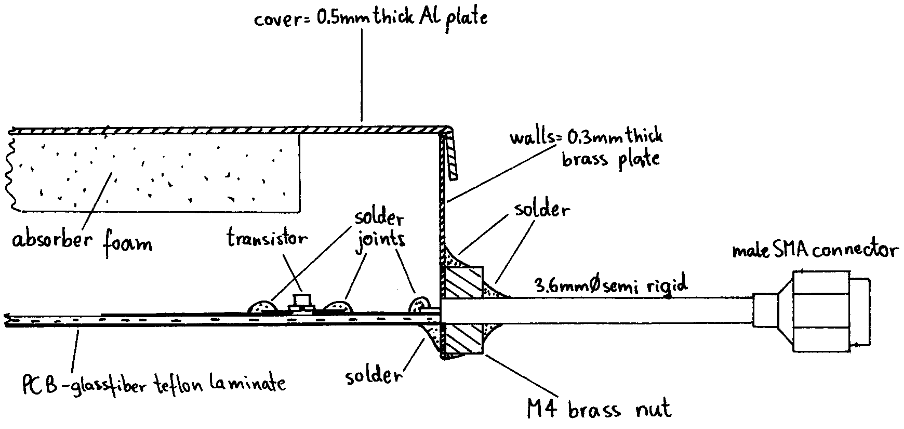


Fig. 10 - Installation of the printed circuit boards.

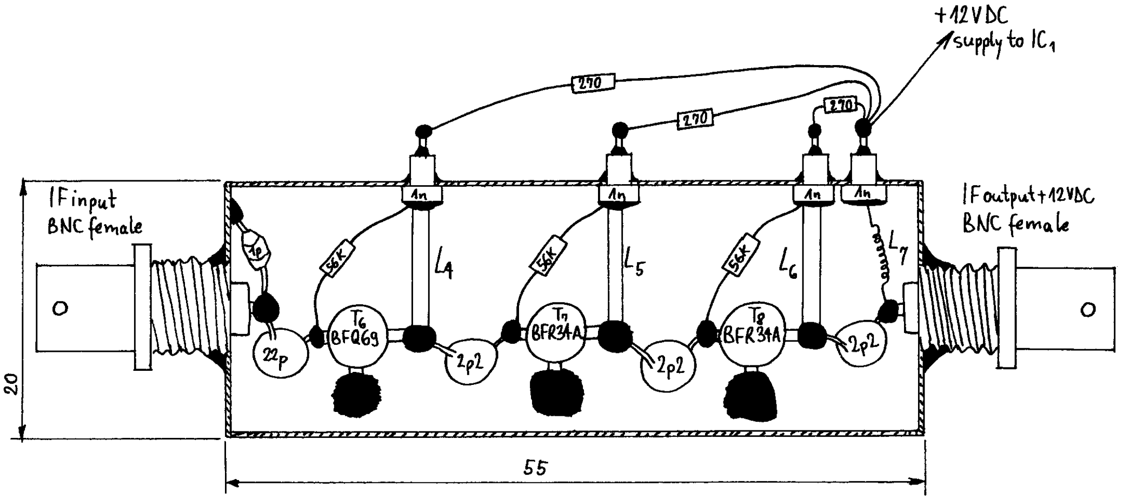
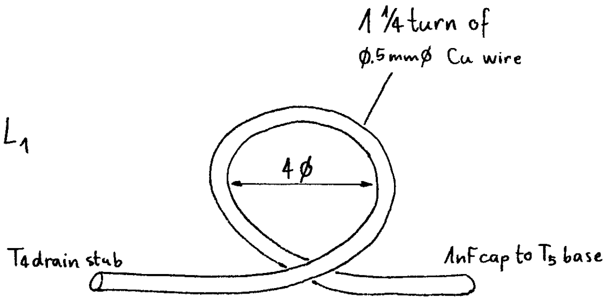


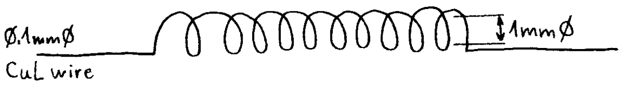
Fig. 11 - Construction of the 0.85 ÷ 1.6GHz IF amplifier

L_1



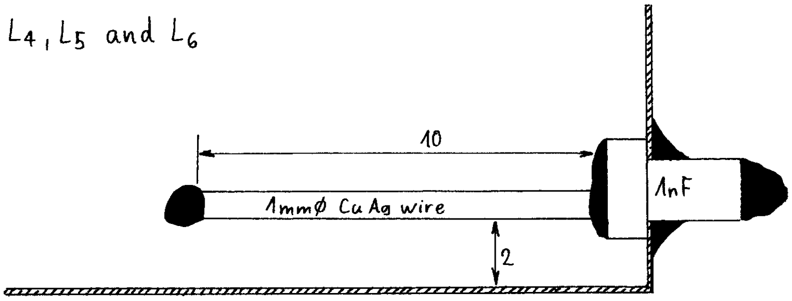
Note that L_1 is soldered about 5 mm ($\lambda/4$ at 11GHz) from the open end of the mixer drain stub.

L_2, L_3 and L_7



L_2, L_3 and L_7 are IF $\lambda/4$ chokes. Total wire length = 65 mm. The exact number of turns (about 10) is not important.

L_4, L_5 and L_6



L_4, L_5 and L_6 are straight lines soldered between the transistor collector terminals and the feedthrough capacitors.

Fig. 12. – Construction details of L_1 to L_7.

Fig. 1. - The 90 cm diameter dish pointed to Intelsat V A at 27.5° W.

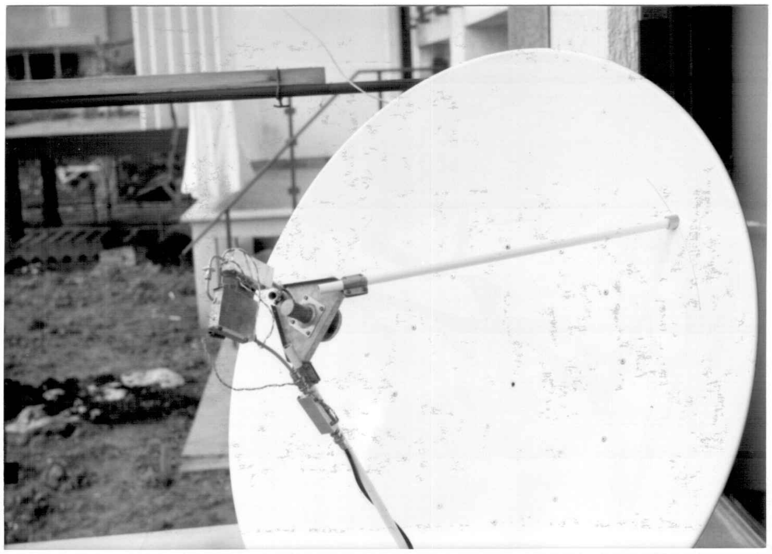


Fig. 2. - The "outdoor" unit. The polarization of the feed is adjusted to receive "CNN".

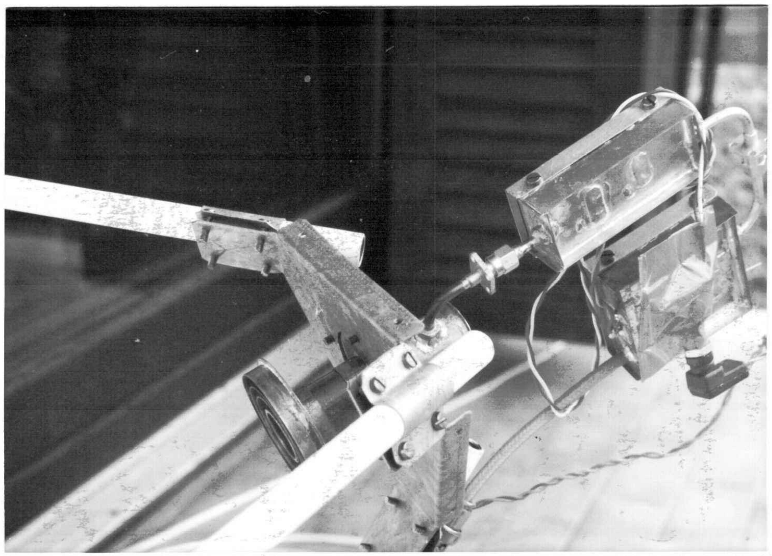


Fig. 3. - Detail of the feed, preamplifier and first downconverter.

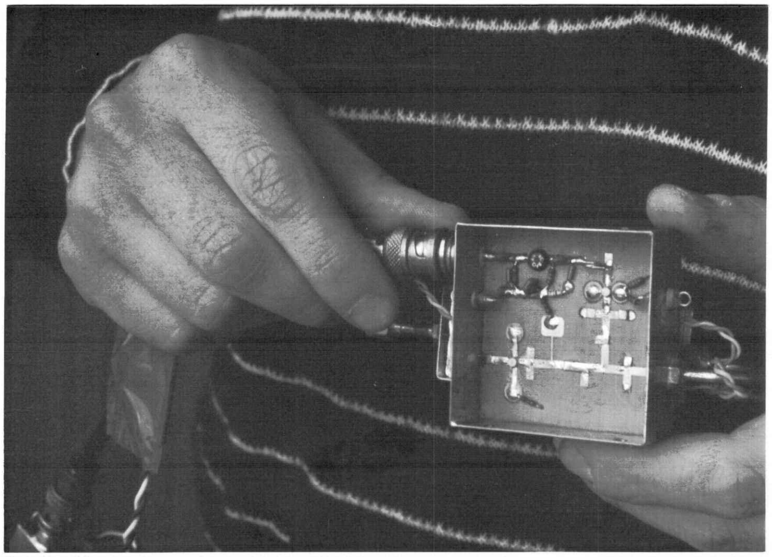


Fig. 4. - Inside of the downconverter (another prototype)