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Tracking Generator From 1 MHz to 13 GHz for Spectrum Analysers

Expanding an existing spectrum analyser, many of which have very high-precision amplitude and frequency, into a network analyser using a tracking generator is one of the daydreams of many high-frequency technicians. This article is intended to show how such a commercial object can become a DIY project for a modest outlay.

1.

Project Description

The analyser equipment in question consists of four individual components, some of which are more expensive than others.

1. Tracking generator for the basic frequency range of the analyser, which here is 10 MHz to 1.8 GHz;
2. Tracking generator for microwave ranges; here, 1.7 GHz to 13 GHz;
3. Resistive reflectometer measuring bridges for the microwave ranges;
4. Transverter for expanding the network analyser into the low-frequency range, here 100 Hz to 50 MHz

2.

Network Analysis with Tracking Generator

RF technicians regard spectrum analysers rather as doctors do X-ray machines. They make it possible to obtain qualitative and quantitative information on frequencies, amplitudes, subsidiary signals, modulation sidebands, noise fractions, harmonic fractions, spurious oscillations, and many other aspects of active signal sources.

A spectrum analyser is really a highly selective receiver with extremely wide frequency tuning. The result of a frequency scan is not made audible in the loudspeaker, but is documented as an amplitude log on the screen. Modern units have digital image processing with the option of printing out a hard copy.

Large amounts of equipment, most of which is fairly old e.g. from Hewlett Packard, Tektronix, Advantest, Alltek, Marconi, etc. have recently come into the hands of committed radio amateurs. Even if you once needed a mortgage to buy some high-end creations, you can now, in certain circumstances, get them on the second-hand market for the price of a good transceiver. However, we

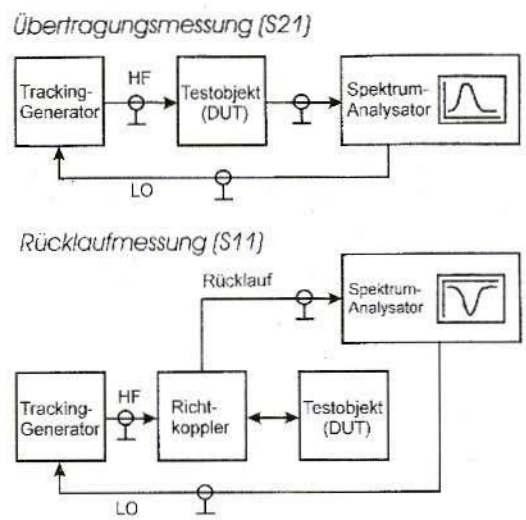

Fig.1: Principle of network analysis for transmission (S21) and reflection (S11) (Übertragungsmessung = Transmission measurement, Testobjekt = Test object, Spektrum-Analysator = Spectrum analyser, Rücklaufmessung = Reflection measurement, Rücklauf = Reflection, Richtkoppler = Directional coupler)

must qualify this by pointing out that the spectrum analyser itself can still investigate only external signals.

A further dimension in RF measurement technology can be opened up through the tracking generator equipment, namely measurements on components which are not themselves oscillating but which are frequency-dependent. For example, the transmission behaviour of filters, selective matching measures, attenuation values, amplifiers, power splitters, repeaters, line resonators, stubs and much else besides can be shown in dB-linear scale on the screen at the same time as the frequency response log, and can be printed out.

Moreover, an additional directional coupler makes it possible to obtain information on the matching and / or return loss of such components within a 50-Ohm system.

3.

Principle of Tracking Generator

The generator presented here corresponds to the expanded HP8569A or B Hewlett-Packard analyser. The frequency and signal levels are tailored for this equipment but must, in principle, be able to work together with all spectrum analysers which have an LO output.

The frequency coverage of the measurement system covers the amateur radio bands over a range extending from 10 MHz to 13 GHz, from shortwave transmissions all the way to the X band. The four overlapping frequency ranges correspond to those of the spectrum analyser and, at least on the HP 8569, are also switched centrally from there. The entire frequency range is available at only one

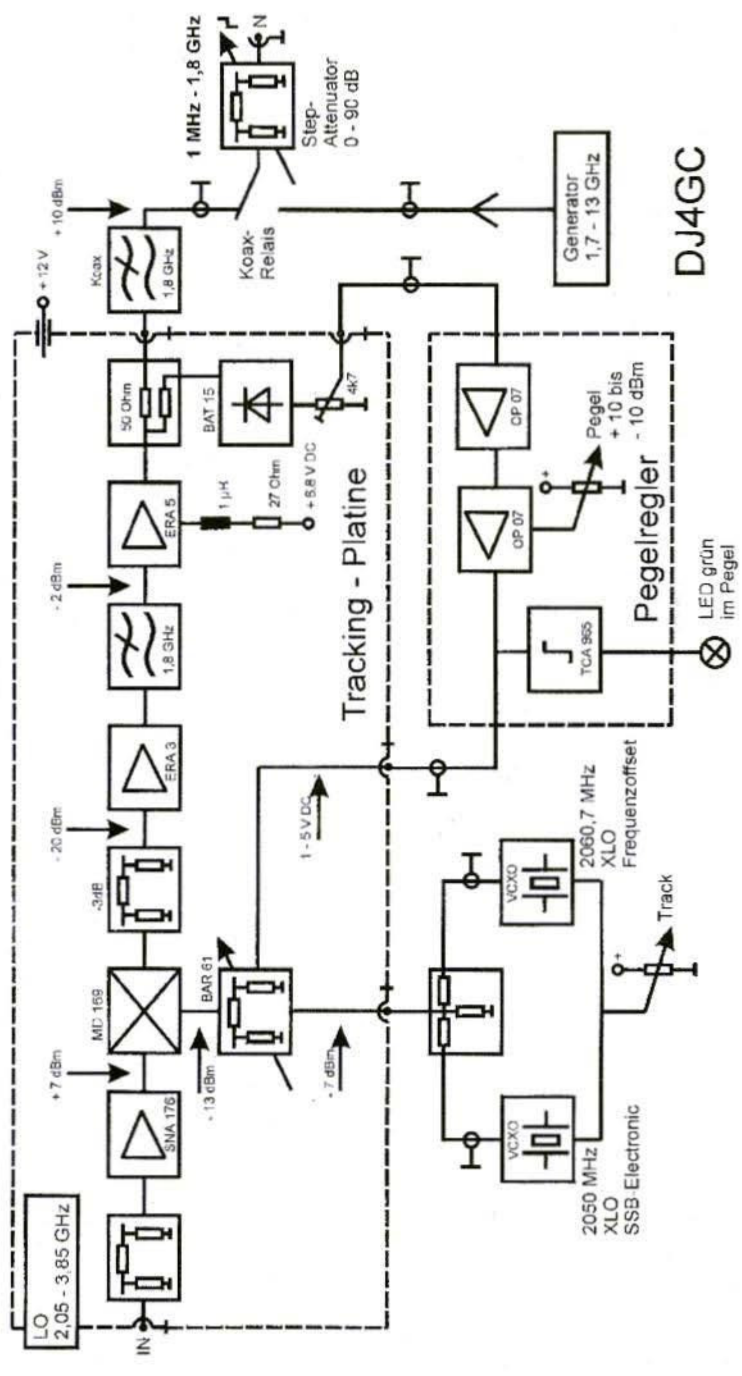

Fig 2: Block Diagram of Tracking Generator for 1 MHz to 1.8 GHz
Tracking Plantine = Tracking PCB, Pegelregler = Level Control, LED grun im Pegel = Green LED within level

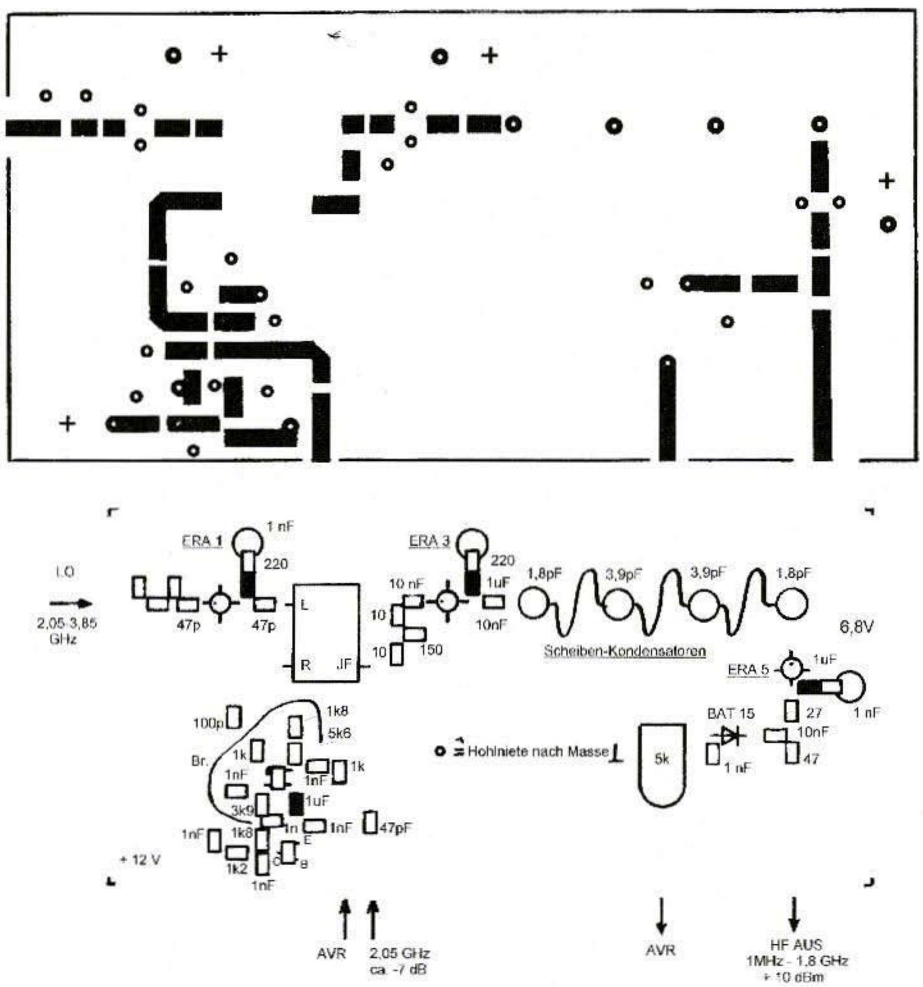

Fig. 3: Layout (100 mm. x 50 mm.) on RT-Duroid, Ultralam or the like
(Scheiben-Kondensatoren = Disc capacitors, Hohlniete nach Masse = Full tubular rivets to earth)

N-socket of the generator. In principle, a separate control system for this equipment is therefore not necessary.

In every tracking generator (Fig. 2), a quartz-stabilised oscillator, which corresponds precisely to the first intermediate frequency of the analyser used, is added to the frequency-determining oscillator signal (LO) of the spectrum analyser. The sums or, in general, the differences of the two oscillations then give the analysis and / or tracking frequency precisely.

However, a high degree of isolation,

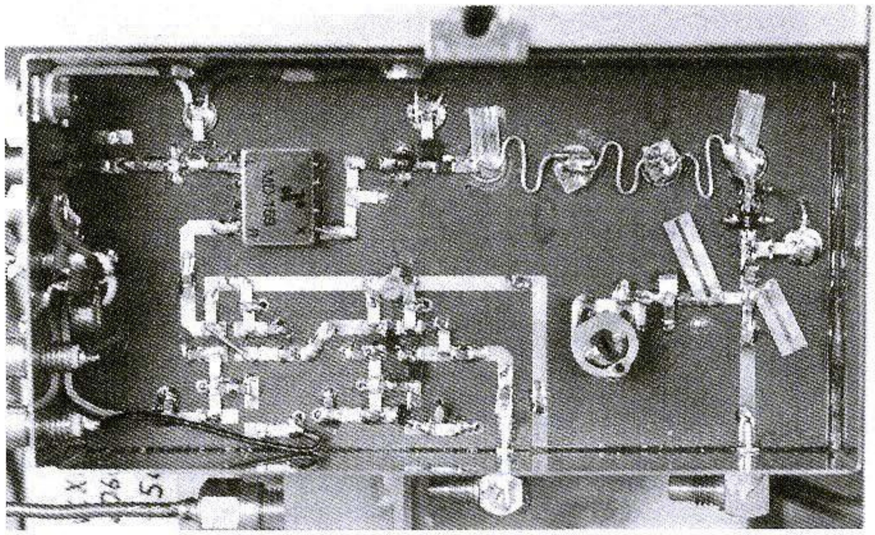

Fig. 4: Generator printed circuit board with PIN controller. The metal lugs serve to optimise the frequency response.

approximately 90 to 100 dB, must be created between this auxiliary frequency oscillator in the tracking generator and the input of the intermediate-frequency amplifier in the spectrum analyser. Such high degrees of de-coupling are difficult to obtain, because the two mixers in the separate units are powered from the same frequency-determining LO source. The degrees of de-coupling of the ring mixers involved (LO intermediate frequency) are nowhere near adequate here. If the isolation values are poor, any residual signals appear on the analyser display, and reduce its dynamic range and sensitivity.

In order to prevent even this intermediate-frequency oscillator signal of the tracking generator from creeping over the Lo circuit into the spectrum analyser, a so-called isolation amplifier is interposed.

Instead of the expensive broad-band circulators and / or one-way circuits which were previously standard, each with approximately 20 dB return loss, here two advantageously-priced modular broad-band amplifiers (ERA 1) are wired up with two attenuators. The forward amplification is sufficiently high at approximately 0 dB over the entire range (approximately 2 to 4 GHz). At the same time, the isolation (attenuation in return direction) still attains 60 dB. Thus, when the tracking generator is connected, the basic noise on the analyser display remains unchanged.

4.

Basic Frequency Range From 10 MHz to 1.8 GHz

The measurement system presented consists in practice of two individual units independent of one another, with some individual components (such as, for example, housings, power supply, DC section of level regulator, together with output-side step attenuator) being operated in common.

The part of the equipment presented

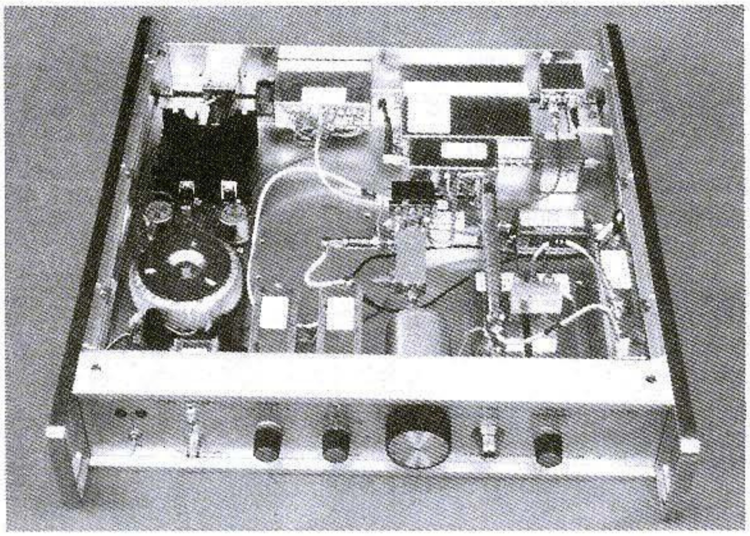

Fig. 5: Internal view of the completed unit

here operates from approximately 1 MHz, but the entire measurement system does not attain high quality until the basic frequency processing range of this spectrum analyser, i.e. from 10 MHz to 1.8 GHz. Thanks to modern, advantageously priced broad band components, this tracking generator can be constructed with amazingly little material and soldering (Figs. 3 and 4). The frequency coverage is suitable for most situations specific to amateur radio.

The frequency determining LO signal of 2.05 GHz to 3.85 GHz supplied to the rear panel of the analyser is mixed with a crystal-stabilised oscillator of 2.05 GHz. This signal injection lies precisely at the first intermediate frequency of the spectrum analyser, and can be adjusted somewhat to balance out a slight frequency drift (VCXO). The difference frequency at the output of the mixer then again lies at the input frequency of the frequency analyser. This combination frequency is amplified again after the ring mixer (here: MD 169 from Anzac), passes through a three-phase low-pass filter with a limiting frequency of 1.8 GHz, and is then amplified once more. At the output of the final stage, a low-barrier Schottky diode (here a BAT 15) detects the level value and feeds it to the level amplifier. This DC voltage amplifier should keep the high-frequency level constant, with the aid of a PIN diode attenuator this corresponds to an internal resistance of ZERO (!). To match the impedance to the circuit system, a chip resistance of approximately 50 Ohms is series wired to the final amplifier. This thus also means the output socket has to have an impedance of 50 Ohms. Even if this resistance uses up a lot of the precious output, it is necessary for matching for correct measurements. Nevertheless, a maximum of + 10 dBm is available for specific measurements with high levels over the entire frequency range.

An electronically controllable variable attenuator, consisting of three PIN diodes in an SMD housing (BAR 61) ensures an automatically levelled output level.

The fixed frequency oscillator at 2.05 GHz is a commercial product. This is a

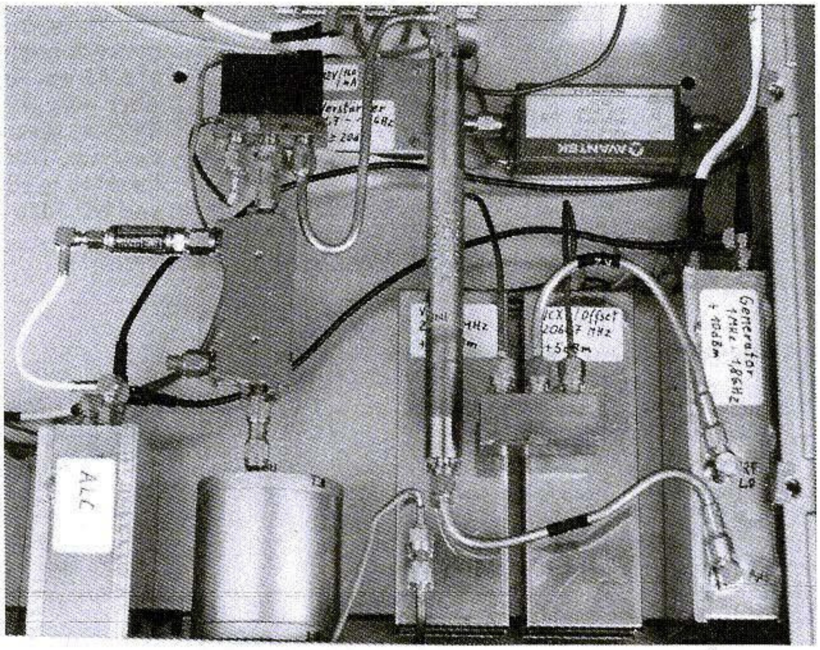

Fig. 6: Section with essential components for basic frequency range up to 1.8 GHz. The long, round, coaxial low-pass filter is in the middle of the picture. The thick, round metal body contains the switchable attenuator. The coax relay, together with the SMA directional coupler and the detector, forms part of the SHF section.

universal oscillator processing (XLO) [1] from SSB-Elektroniks transverter series. This circuit, which can be adjusted for output frequencies between 1.5 and 2.5 GHz, stands out through a high degree of spectral purity. The numerous publications conçerning similar circuits make it superfluous to go over it again at this point. An additional capacity diode in the oscillator circuit of the upper harmonic oscillator creates a pull-in range of several kilohertz. Thus measurements can be better synchronised, with narrow analysis band widths, i.e. low residual noise and high dynamics.

Thanks to modern, advantageously priced broad band modules, the entire high-frequency processing system (without an XLO) fits into a small tinplate housing measuring 53 mm. x 100 mm. (Fig. 4). In principle, the level amplifier and its four ICs could also be fitted in using SMD technology. Some improvement in the measurement dynamic (a few dB) can be obtained by externally fitting a coaxial 1.8-GHz low pass filter with a very high cut off gradient (Fig. 6). Thus the harmful injection signal on the first intermediate frequency (2.05 GHz) at below 90 dBc in the output spectrum is no longer displayable.

Thermally measured, the amplitude of the tracking signal varies by a maximum of only ± 0.5 dB around the set value. This amplitude ripple is thus less than the actual frequency response of the spectrum analyser. However, the HP 8569, like most of todays equipment, has digital image conversion, through

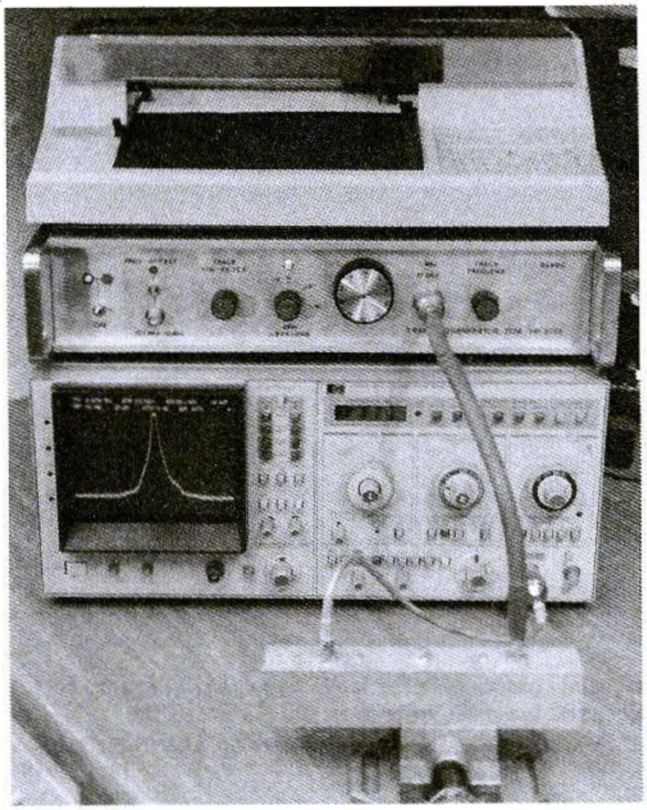

Fig. 7: Scalar network analysis of a 13-cm. finger filter with HP 8569(A) spectrum analyser, DIY tracking generator and HP 7470 A plotter

the useful special function of standardisation, which enables the reference level (0 dBc) to be made into a straight line in the centre of the screen. In this way, all the units inherent ripple is eliminated. Although this is only a digital image conversion, the interpretability of the print-out is recognisably improved, especially in the microwave ranges. Amplifications appear above the screen centre and attenuations below.

The HP 8569 is equipped with an HP-IB interface. Even if this operates in a slightly leisurely fashion by present-day standards, splendid hard copies can be created with the help of an HP 7470A plotter. The documentation appended was put on paper in this way.

5.

Details of Signal Processing

The four MD 169 (Anzac) ring mixers used here are certainly relatively expensive, but they and all their data are within the frequency range of this measurement system. It was obviously developed for similar applications. Other mixers such as, for example, TFM 42 from Mini-Circuits, certainly display a slightly higher amplitude ripple at the output, together with a rather higher LO disruptive breakdown, but apart from this they are also suitable.

The resistive attenuator at the LO input of this printed circuit board is calculated in such a way that the mixer approxi-

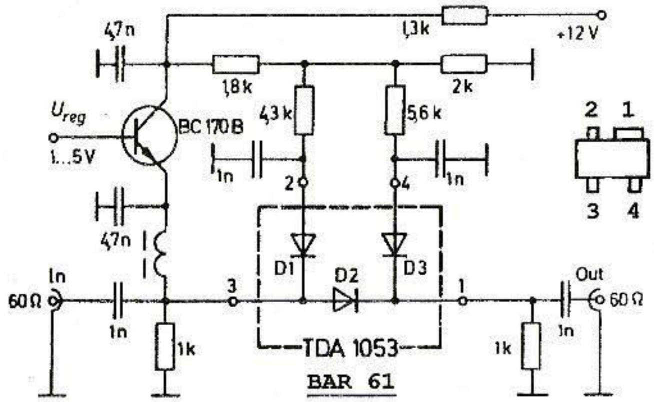

Fig. 8: Circuit of PIN diode controller for adding frequency of 2,050 MHz. The peripheral circuit with a transistor developed by ITT is suitable for all types of PIN diodes

mately attains its rated level of + 7 dBm. The mixer output level at the intermediate frequency port is approximately 30 dBm. This very low amplitude is a favourable compromise between the dynamics of the signal (useful signal to basic noise) and the lack of distortion. It is well known that the distortion spectrum of ring mixers, which grows rapidly with relatively high output signals, generates so-called amplified spurious signals (non-harmonic ghost signals), which can no longer be removed by filtration measures.

The PIN diode regulator used here (BAR 61 from Siemens) provides an infinitely variable attenuation of up to 20 dB. The design parameter of this newly developed SMD module is above 30 dB at 2.05 Ghz. It is thus considerably better than the old TDA 1065, UTF 025, or 3 BA 379 units, which were designed for the UHF television ranges, these still display approximately 10 dB of control coverage at this frequency, but with poor matching. This is naturally not sufficient for exclusive levelling at a constant output level.

In a departure from normal practice, it is not the fixed-frequency, but the variable LO signal from the spectrum analyser which is high-gain and drives the mixer.

Since ring mixers react very tolerantly to level inputs at the LO port, relatively small levels break through to the intermediate-frequency output.

At this point, the useful signal is subjected to a ripple of maximum 2 dB over the entire range. The 3 dB attenuator at the mixer output represents a kind of circuit hygiene. It certainly feeds on the useful signal but, on the other hand, it ensures a certain level of matching between the mixer and the amplifier.

The three-stage low-pass filter is designed for the highest output frequency of the generator. At the limiting frequency of 1.8 GHz, the input and output capacitors have a value of 1.8 pF. The two central capacitors have double this value 3.6 pF. Suitable disc capacitors available also small-format chip capacitors are also suitable. The capacitors can be mounted on the board surface but the disadvantage is that their height has a tendency to cause surface resonances. The three inductances can each be calculated to be 4.4 nH, they consist of 0.5 mm. thick silver-plated wire, which is bent in an S-curve with a length of

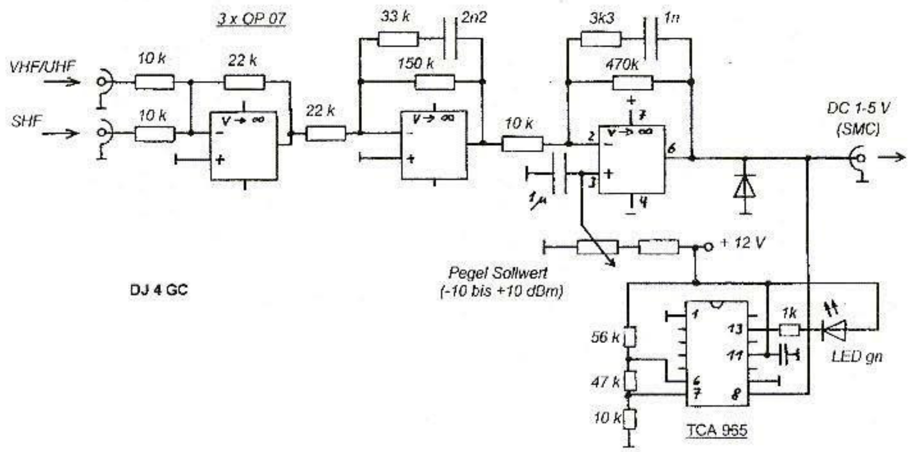

Fig. 9: Control amplifier for controlling PIN diode controller with two inputs and window comparator for level monitoring

(Pegel Sollwert = Rated level value, Bis = To)

approximately 8 mm. (see Fig. 4).

To reduce the ripple levels in the transmission band, the inductances are slightly adjusted by being slightly bent, and the capacitances with the help of metal lugs.

Naturally, a computer-optimised, self contained filter could also be used. A low-pass filter is necessary because the other signals at this point, such as image frequencies or the LO affect the automatic level control and would lead to considerable control errors.

To terminate this low-pass, the final stage must display a continuously good input matching. This demanding task is undertaken by the monolithic ERA 5 broad band amplifier from Mini-Circuits which gives a guaranteed +10 dBm output with a 50 ohm input impedance. Thus even ring mixers can be measured with this equipment.

For practical measurement operation a level of approximately 10 dBm is advantageous. In these circumstances, the tracking generator generates 0 dBm with low distortion. To improve the broad band output matching, 10 dB attenuation is used from the step attenuator. The power then remaining, of 100 micro Watts (- 10 dBm) will admittedly not make any DX connections possible, but is a signal at the limit of the spectrum analyser receiver. Depending on the level set, and on the analysis bandwidth, a measurement dynamic of at least 70 dB is available on the display. With skilled use of the measurement level, with the help of the two stage reducers, dynamic differences of markedly more than 100 dB can be measured.

The wobble measurements which were previously used, with broad-band diode receivers, give quite considerably lower dynamic values. For very broad-band measurements, the detector diodes also generated harmonic distortions, which produced false readings.

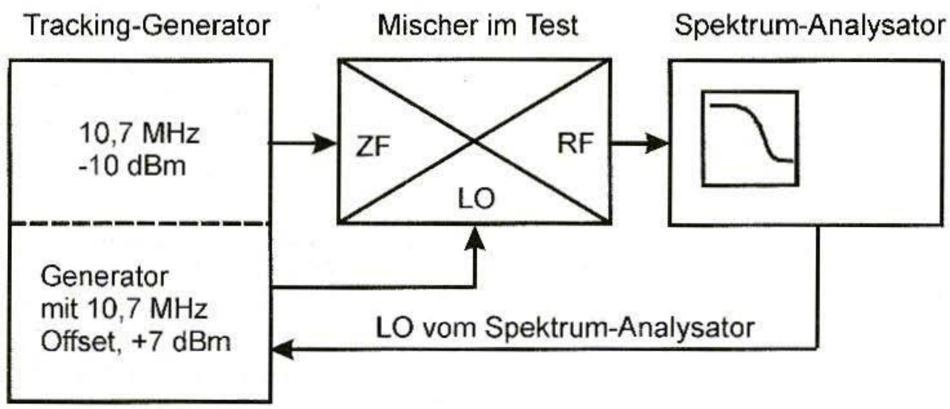

Fig. 10: Measurement of conversion loss readings (gain values) from frequency mixers

(Mischer im Test = Mixer in test, Spektrum-Analysator = Spectrum analyser, Mit = With, Vom Spektrum-Analysator = From spectrum analyser, Messung

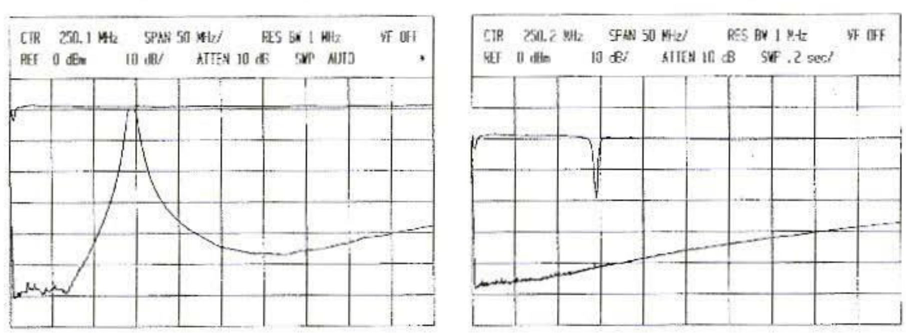

Fig. 11: Measurement on an LC two-circuit filter for 145 MHz:

a) S21 transmission behaviour from 0 500 MHz

Top curve: reference level 0 dBc

Bottom curve: filter curve (attenuation in app. 1 dB transmission band)

b) S11 reflection behaviour

Top curve: reflection loss of two-circuit filter (app. 20 dB)

Bottom curve: sharpness of directivity of measurement system

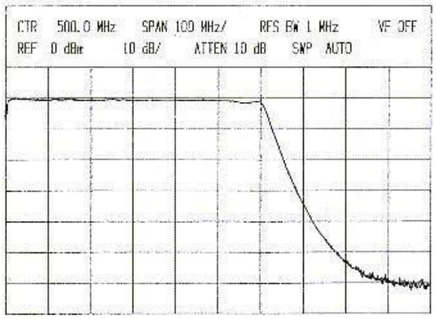

Fig. 12: Coaxial low-pass filter with a limiting frequency of 600 MHz. Up to 800 MHz, the attenuation increases by 50 dB.

6.
Control Amplifier

The circuit of the PIN diode controller, developed back in the seventies for television purposes, requires DC control of between approximately 1 and 4 Volts (Fig. 8). Its design is equally suitable for all low-signal PIN diodes. The rectified voltage at the diode port of the generator printed circuit board is measured and kept constant, as far as possible, due to the automatic control. Approximately 100 mV rectified voltage can be expected for an output level of 1 mW (0 dBm).

A three-stage OP amplifier processes the control voltage. Although in principle this is a DC voltage, level differences during rapid wobbling must be controlled within a few micro-seconds. On the one hand, such control paths must be rapid, but on the other hand they must not bring dynamic errors due to over shoots. The RC frequency response compensation on both OPs prevents both sorts of anomalies.

A summing amplifier at the input processes the detector level of both the VHF / UHF section and the SHF generator, without switching. The 4.7 k-Ohm trimming potentiometer at the detector output of the generator printed circuit board described here makes it possible for the level to be matched to the SHF section.

An externally operated potentiometer

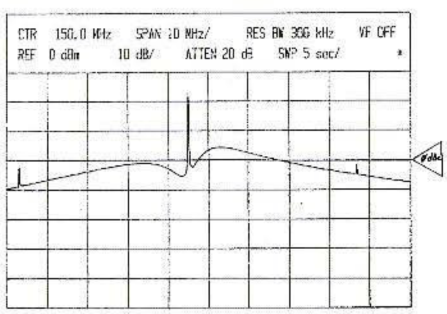

Fig. 13a: Highly-selective 2-m. pre-amplifier with quartz resonator wide selection between 100 and 200 MHz

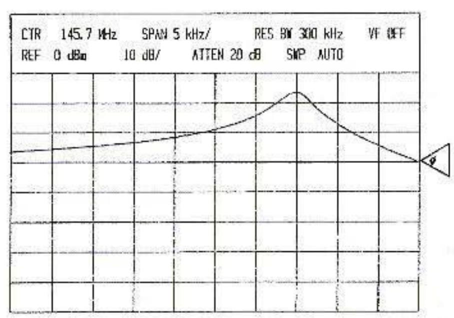

Fig. 13b: Same amplifier at high frequency resolution. The main resonance of the quartz is only 3 kHz wide.

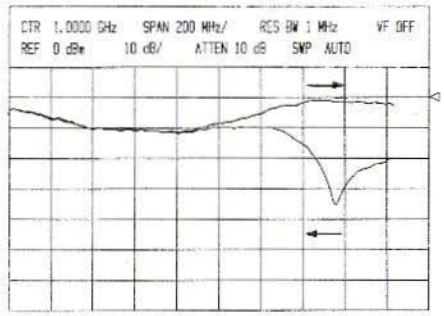

Fig. 14: Transmission behaviour of a commercial directional coupler in transmission and non-conducting directions from 1 to 1.8 GHz. The optimal operating frequency is 1.6 GHz.

pre-sets a freely adjustable DC reference value with which the rectified voltage, already amplified, can be balanced. Since no frequency dependency of any kind has to be taken into account at this point, the potentiometer can be directly calibrated in RF output levels (- 10 dBm to + 10 dBm). With only very slight deviations, this scaling also applies to the microwave ranges for which this DC controller is also used.

A window comparator (TCA 965) monitors that the pre-selected output is being maintained. All that this requires is for the DC voltage fed to the PIN diode controller to be monitored to ensure that the limiting values are maintained. Voltage values of between 1 V and 4 V mean that the PIN diode controller is being controlled within its rated range; this is indicated by a green LED. Above approximately 4 Volts, the LED goes out and alerts the user to a malfunction. The same thing happens if the voltage fall below approximately 1 Volt.

7. Measurements on Frequency Mixers

This tracking generator has an interesting additional option. The fixed-frequency oscillator required for mixing at the first intermediate frequency of the spectrum analyser used can be switched up to 10.7 MHz upwards, i.e. from 2,050 MHz to 2,060.7 MHz. This task is undertaken by a second XLO [1]. This makes it possible to investigate the attenuation and frequency response of frequency converting four pole networks such as ring mixers. The two oscillators are brought together into a small coaxial housing through two 50-Ohm resistances onto a summation line (Fig. 6). A crystal-stabilised 10.7 MHz oscillator with a calibrated level of 10 dBm is incorporated into the equipment as an auxiliary signal. It is automatically activated when the frequency shift is switched on.

Naturally, only mixers, or else complete converter systems, with intermediate

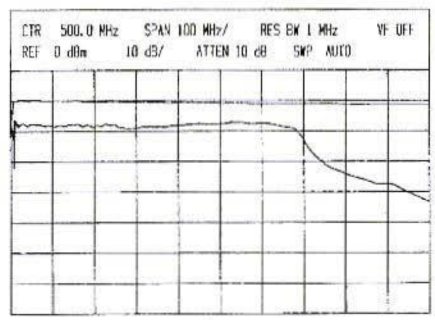

Fig. 15: Conversion loss of a 500-MHz ring mixer in range between 0 and 1,000 MHz. The top curve indicates the reference level of 0 dBc.

ports which can take 10.7 MHz can be measured. The maximum tracking output level of + 10 dBm is sufficient for most ring mixers as a direct oscillator signal. The cost of a second XLO is considerable, of course; moreover, it is needed only for mixed systems. However, this measurement option, which is met with nowhere else except in high-end network analysers, provides valuable insights into the field of RF. technology when required.

In Fig. 15, the mixed attenuation curve for the M1B ring mixer (Watkins & Johnson) is documented, as an example, over a range of 0 to 1,000 MHz. The measurement procedure is as follows:

First, a reference line is stored in the screen memory of the spectrum analyser with the tracking generator over the entire frequency range for a level of 10 dBm

Using the second quartz oscillator mixed together with the variable LO signal in the tracking generator, the output signal is shifted upwards by 10.7 MHz. The analyser no longer reacts to this new tracking frequency, since it always displays 10.7 MHz frequency offset to the reception frequency in question. However, a crystal-stabilised 10 dBm signal source is available for precisely this difference frequency, which is fed into the intermediate-frequency port of the mixer to be investigated.

The difference frequency of both the mixing products generated in this way falls precisely on the individual analysis frequency and is represented as a continuous line on the screen.

The conversion loss can easily be read off on the display or on the hard copy, with high precision, as the differential between the current and reference lines from the memory. The high selectivity of the analyser prevents faulty measurement products involving other mixed products.

8.

Conclusion

Only the mixer printed circuit boards, an XLO and the control amplifier are required for a minimal version of the tracking generator described here. At a constant output level (for example, 0 dBm), the television PIN diodes which can still be found in many DIYers toolboxes can be called up for active service.

However, the expensive SHF stage reducer, the rare coaxial low-pass and the second XLO add a touch of luxury to the project.

9.

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