The Simple Spectrum Analyser (SSA) offers reasonable performance over the range 1-90MHz or so, is cheap to build, and utilises almost any oscilloscope as its display. It has selectable, calibrated, frequency sweep-width ranges, accurate logarithmlo signal strength calibration, a dynamic range of over 50dB and a built-in frequency marker generator.

Simple Spectrum Analyser

For most people, a spectrum analyser is way out of reach — but this design by Roger Blackwell, G4PMK, makes a home-brew unit a realistic possibility.

ORIGINS

The original idea for the SSA came from an article by Al Helfrick, K2BLA [1], who described a basic analyser using only three chips. I have added some features contained in an earlier design of his, [2] plus some of my own, based upon a prototype which has now been in use for over a year. Following a certain amount of correspondence [3], and a good deal of information in *Technical Topics* concerning the 'BLA design ([4] and [5]) there was such an overwhelming response, over 120 enquiries, to my offer of further information and numerous requests for PCB layouts, that I decided to write up the project in more detail. The design presented here was developed with home construction in mid therefore uses pre-wound coils and PCB designs which will hopefully ensure fuss-free construction.

Suitable oscilloscopes for use with the SSA, will have a DC coupled Y amplifier offering 100mV/cm sensitivity and an external input to the X amplifier. In practice the majority of modern general purpose oscilloscopes will be suitable.

SPECTRUM ANALYSER OPERATION

Before looking at the circuit in detail, it is worth reviewing the purpose of a spectrum analyser and how it operates. Essentially, it is no more than an electronically tunable receiver, the S-meter output of which is connected to the Y input of an oscilloscope.

If a sawtooth wave-form is connected to the tuning line of the receiver VCO and also to the X input of the oscilloscope, a display of frequency against signal amplitude is obtained over the tuning range of the receiver. If the receiver also has a logarithmic response to input level, then relative signal strengths can be read off the screen. A typical display is shown in **Fig.1**.

Of course, life is just a bit more complicated than that and just as with real receivers, spurious response, selectivity and overload problems occur. The overload problems can be eliminated by specifying a maximum input level (for the SSA it is -20dBm) and by using an attenuator before the analyser input for larger input levels. The necessary selectivity is obtained by using a superheterodyne receiver design in which image problems are minimised by using an Intermediate Frequency (IF) which is higher than the maximum frequency of the analyser - in this case145MHz, which allows a readily available helical filter to be used. Unfortunately the SSA won't cover the 144-146MHz band itself.

OVERVIEW

Fig.2 shows a block diagram of the SSA. After attenuation, the input signal is fed via a low-pass filter to the first (up conversion) mixer, where the input frequency range of 0-90MHz is mixed with the varicap tuned local oscillator which operates over the range 145-235MHz, giving a first IF of 145MHz. This signal is then passed through the helical filter to a second mixer and local oscillator, where it is down-converted to the second IF of 10.7MHz.

The signal next passes through wide or narrow IF filters, a buffer amplifier and a further wide filter, before entering the logarithmic IF strip. This produces a signal-strength output which is proportional to the log of the strip input, hence the display can be calibrated in dBm. This output (usually termed the video output) is then fed to the Y channel of the oscilloscope.

The rest of the SSA is simple. The sweep generator produces a linear ramp sweep voltage, part of which (selected by the sweep width control) is added to a DC voltage from the centre frequency control. Since varicap oscillators do not have a completely linear voltage/frequency relationship, this sweep voltage is passed to the break-point generator, which puts a 'kink' in the sweep where it will attempt to linearise the frequency sweep over the 70-90MHz portion of the range. The output from the sweep oscillator also drives the X axis input of the oscilloscope.

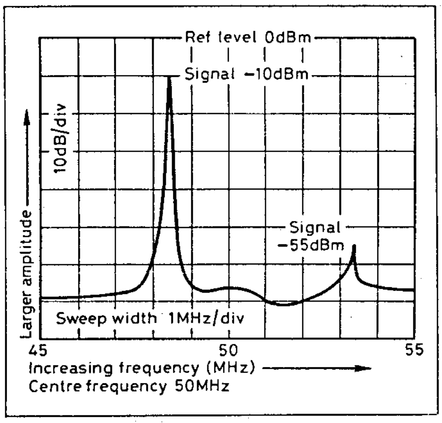

Fig.1 A typical screen display of a spectrum analyser

Not shown on the block diagram is the frequency marker generator, a simple 10MHz crystal oscillator and TTL divider which gives a low amplitude output, rich in harmonics and which is also fed to the analyser input.

CIRCUIT DETAIL

The SSA is divided into three separate boards. The first and most important is the RF unit (**Fig.3**) which is based fairly closely on the original design [1]. The input signal is routed from the front panel 50ohm BNC socket via the two front panel switched attenuators (shown in **Fig.5**), to a fixed attenuator (R1, 2.3), which is designed to limit the maximum input to the analyser to about -20dBm and provide something like a consistent 50ohm input. The signal then passes through an elliptical low-pass filter (C3, 4, 5 and L1) to the first mixer, contained in part of IC1, an MC3356. This remarkable device is one of a family of FM receiver chips such as the MC3357 and MC3359 which contain a local oscillator, mixer, limiting IF amplifier and discriminator - better known from NBFM receiver applications.

The MC3356 is intended to be used as a single-chip FSK receiver and has some special features which are exploited in the SSA. Firstly, the IF amplifier has a signal strength output which is proportional to the logarithm of the input voltage and secondly, the local oscillator and mixer will work up to at least 250MHz. The local oscillator is varicap tuned by D1 using the sweep voltage from the sweep/video board, note that two 1n capacitors (C8 and C30) are fitted at the anode end of D1 as a low impedance path is vital here to enable the highest frequency to be reached. Adding C30 to one of the prototypes increased the upper frequency limit by 5MHz!

The 145MHz IF output from IC1a goes to the first IF filter FL1, a TOKO 3-chamber helical type. The IF output from the filter is then down-

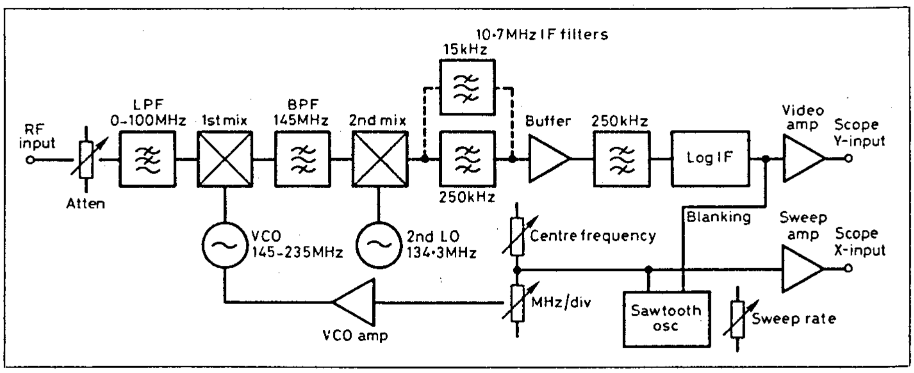

Fig.2 Block diagram of the Simple Spectrum Analyser

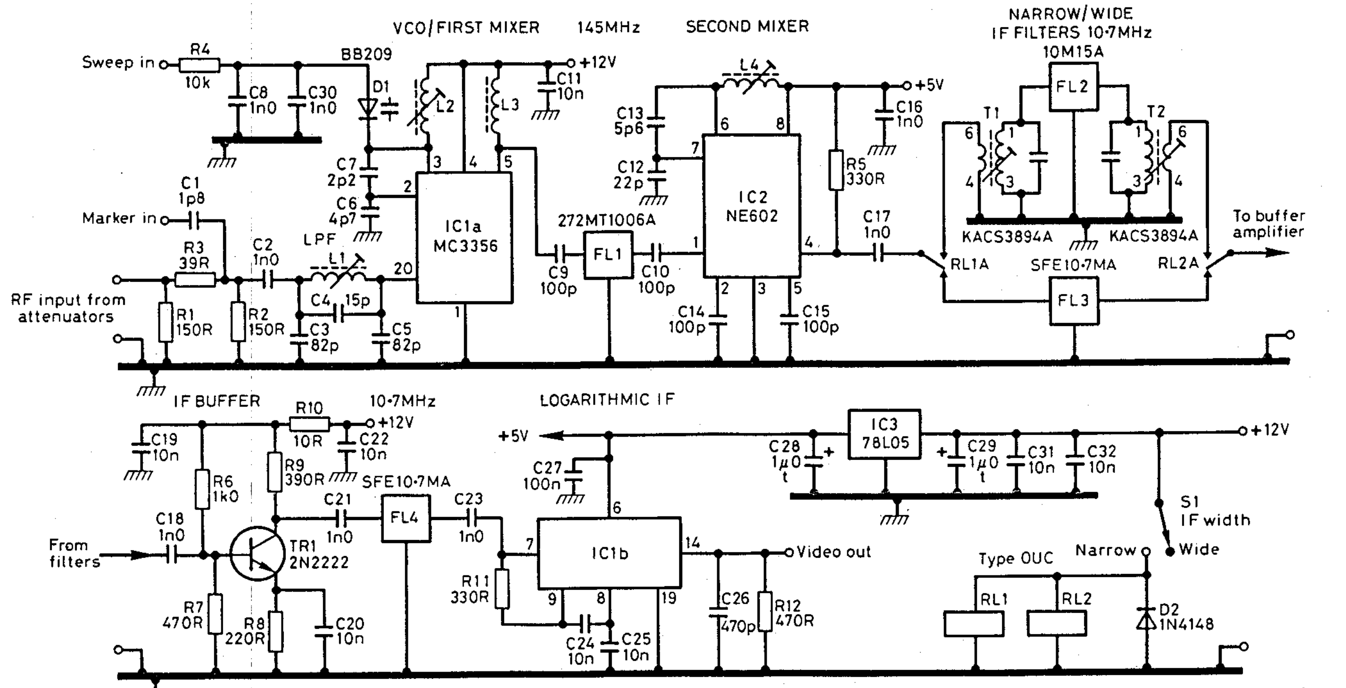

Fig.3 Circuit diagram of the RF board

converted to the second IF of 10.7MHz in IC2, a NE602 oscillator/mixer chip, the LO frequency of about 134.3MHz being set by L4, C12 and C13. Note that there are some differences between the circuit and values shown here and those in references [1] and [6]. The values shown in Fig.3 are correct and the connection of pin 6 to Vcc, together with the capacitor values, is taken from the manufacturer's data sheet.

Setting the 2nd LO below the first IF removes the 21.4MHz (2 × 2nd IF) spurious response of the original design. The NE602 requires a lower voltage supply than the MC3356 and this is obtained from a 5V regulator, IC3. Narrow (15kHz) or wide (250kHz) first IF filters (FL2 and 3) are selected by means of the miniature relays RL1 and RL2, and the front panel switch S1 (IF BANDWIDTH).

After filtering, the signal is amplified by TR1, which is run at a relatively high standing current so as to provide good dynamic range. Although the stage does not provide the correct terminations for the filters, in practice this is of little consequence. Removing C20 would improve the matching, but with the consequent loss of over 20dB of sensitivity! The signal is then passed via a second filter (FL4) to the main IF signal processing circuit, IC1b. This does one of the most difficult jobs in the analyser - it provides a DC output which is proportional to the log of the IF input voltage. Here, in one fell swoop the 10dB/division Y-axis calibration is achieved, with the (video) output being taken via a screened lead to the sweep/video board. The output from the FM discriminator is not used in this application.

SWEEP GENERATOR

The sweep generator circuit, shown in **Fig.4**, is broadly based on Helfrick's QST article [2], with a few changes for use with this particular VCO. In this circuit 741 op-amps have been used throughout as a) there is no need for anything more sophisti-

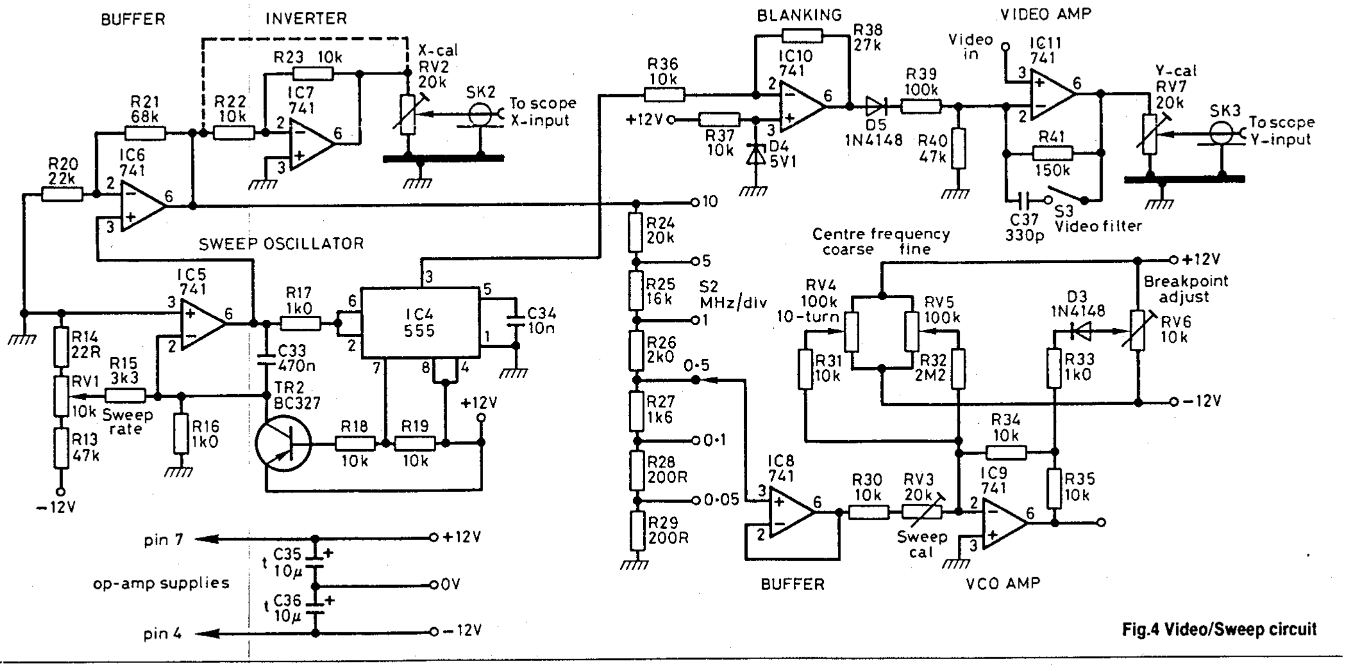

Fig.4 Video/Sweep circuit

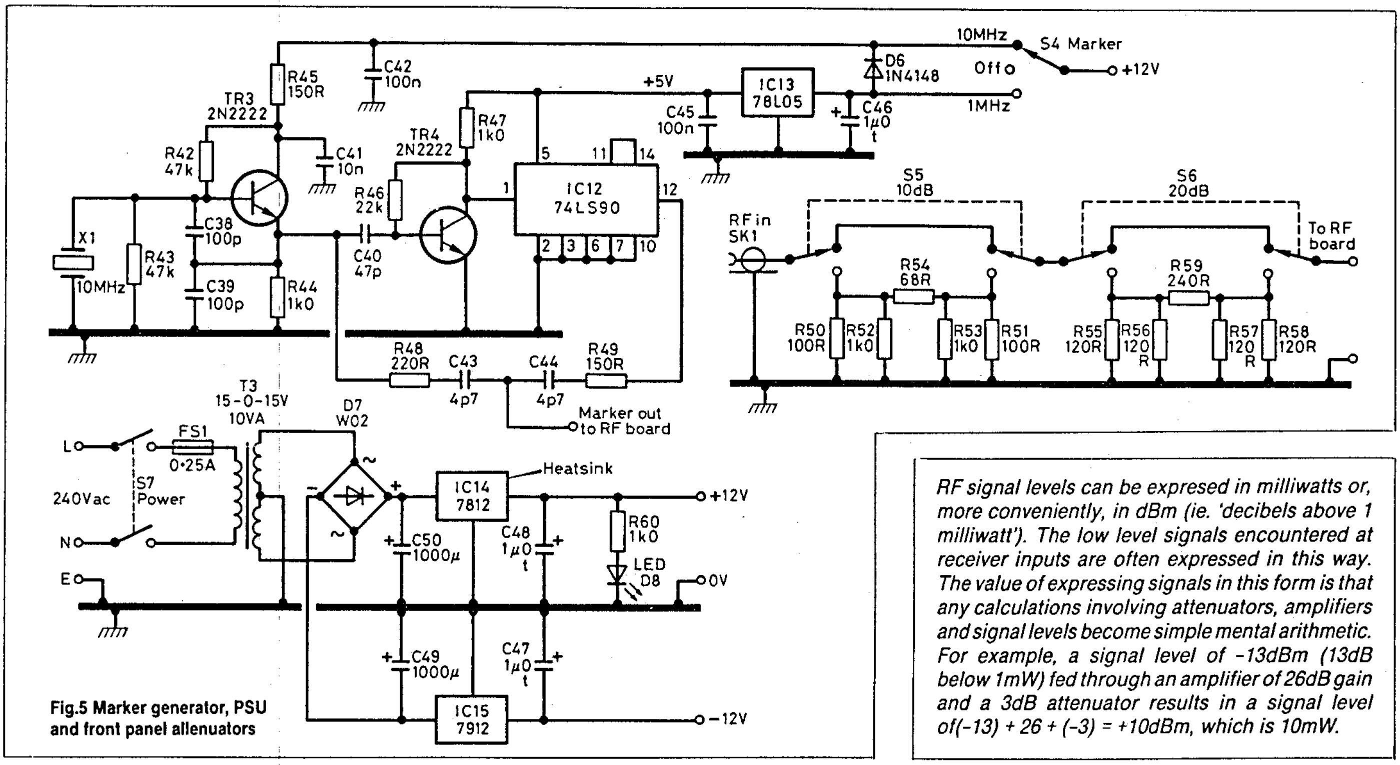

Fig.5 Marker generator, PSU and front panel allenuators

RF signal levels can be expressed in milliwatts or, more conveniently, in dBm (ie. 'decibels above 1 milliwatt'). The low level signals encountered at receiver inputs are often expressed in this way. The value of expressing signals in this form is that any calculations involving attenuators, amplifiers and signal levels become simple mental arithmetic. For example, a signal level of -13dBm (13dB below 1mW) fed through an amplifier of 26dB gain and a 3dB attenuator results in a signal level of(-13) + 26 + (-3) = +10dBm, which is 10mW.

cated and b) they are so cheap that one can be liberal with them!

The sweep ramp is generated by the 555 timer IC4, op-amp IC5 and current source TR2 with the sweep rate being controlled by a front panel potentiometer, RV1. The 555 also provides a fast blanking-pulse output for the video amplifier. The sweep output is buffered by IC6, before being fed to the sweep width front panel switch S2 (MHz/DIV) and to the X output SK2. Depending on the particular oscilloscope, the inverting unity-gain buffer IC7 may not be needed - if a positive voltage applied to the oscilloscope X input deflects the spot to the right, then IC7 can be omitted. In this instance R22 and R23 are omitted pin 6 of IC6 is connected to the top of the X CAL preset RV2, via link LK1 as shown by the dotted line.

The selected sweep voltage amplitude from the wiper of S2 is buffered by voltage follower IC8 before amplification in IC9. In this final stage three important things happen i) the sweep voltage gain is set to allow a calibrated frequency sweep, ii) an adjustable DC offset (the centre frequency) is added by means of a ten turn potentiometer RV4 (CENTRE FREQUENCY COARSE) and RV5 (CENTRE FREQUENCY FINE) and iii) an adjustable non-linearity (break-point) is deliberately introduced into the linear sweep ramp by means of RV6, D3 and R33. This improves the frequency sweep linearity above 70MHz.

VIDEO AMPLIFIER

The video amplifier (IC11) provides a small amount of gain and in conjunction with comparator IC10 provides the retrace blanking by shifting the retrace portion vertically downwards off the screen. Capacitor C37 across the feedback resistor can be switched by S3 (VIDEO FILTER) to provide a little smoothing of the 'grass' on the display if wanted and pre-set RV7 (Y CAL) allows the output of the amplifier to be set to the required 100mV per 10dB of RF input.

The third board, which contains the marker generator and power supply (Fig.5), needs little comment. The marker generator uses conventional techniques to produce a comb of 10 and/or 1MHz markers which can be added to the input signal to allow an easy method of frequency calibration. The power supply uses standard components.

CONSTRUCTION

The RF board is constructed on a double-sided glass epoxy printed circuit board, one side of which is not etched and is used as an earth plane. The component placement diagram (together with drilling details) is shown in **Fig.6**. Most (but not all) of the holes require the copper on the earth plane side to be cleared away around the hole with a counterbore or small drill. Note that the lugs of the shielding cans for FL1 and T1/T2 are used to provide earth paths for tracks underneath the board, and so need to be soldered on both sides of the PCB. The small additional holes on the track layout provide locating holes for the earth plane connections of components - small ceramic capacitors these days seem very prone to disintegrating if one of their legs is bent through a right angle! Note that the varicap diode D1 must be mounted on the underside of the board with its cathode close to the end of L2, as shown.

The video/sweep board component placement is shown in **Fig.8**. This is a single sided PCB where the optional link LK1 (shown dotted) should be fitted instead of R22, R23 and IC7 if you don't need the X output inverter stage, as described earlier. If you do need these components, then omit LK1. Note that the resistors R24-29 are mounted on the rotary switch S2.

The third board, containing the marker generator and the power supply, is also a single sided PCB. The component overlay is shown in **Fig.9**. Sufficient

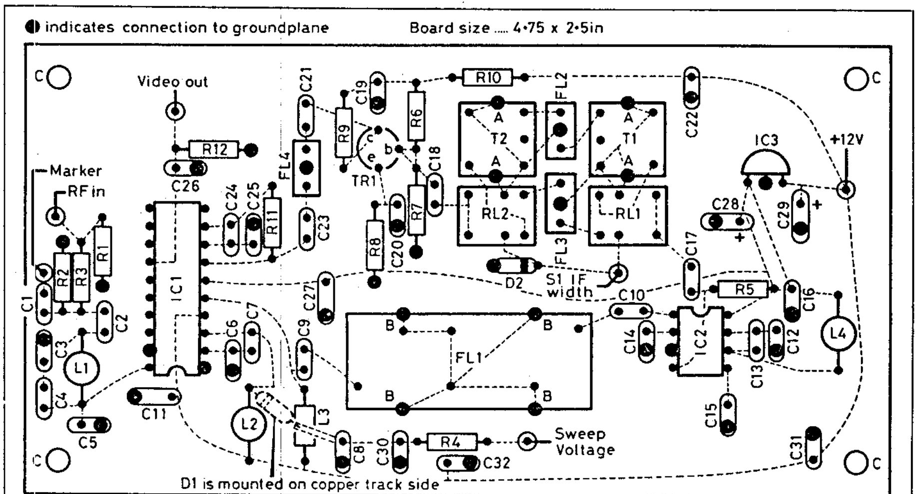

Fig.6 RF board layout (component side) Note that the B8209 D1 is mounted on the underside of the board.

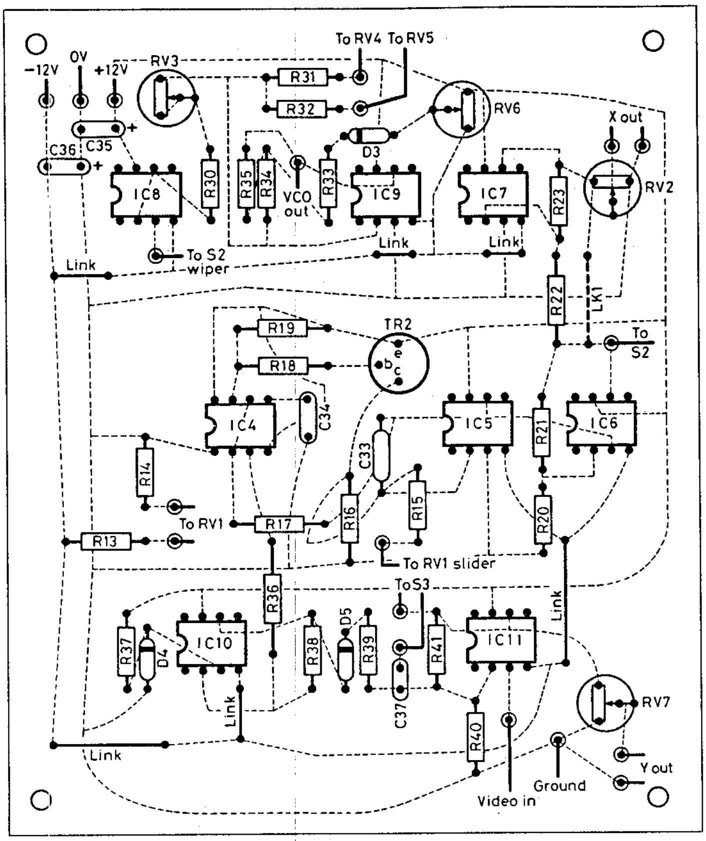

Fig.8 Video/sweep board layout (component side)

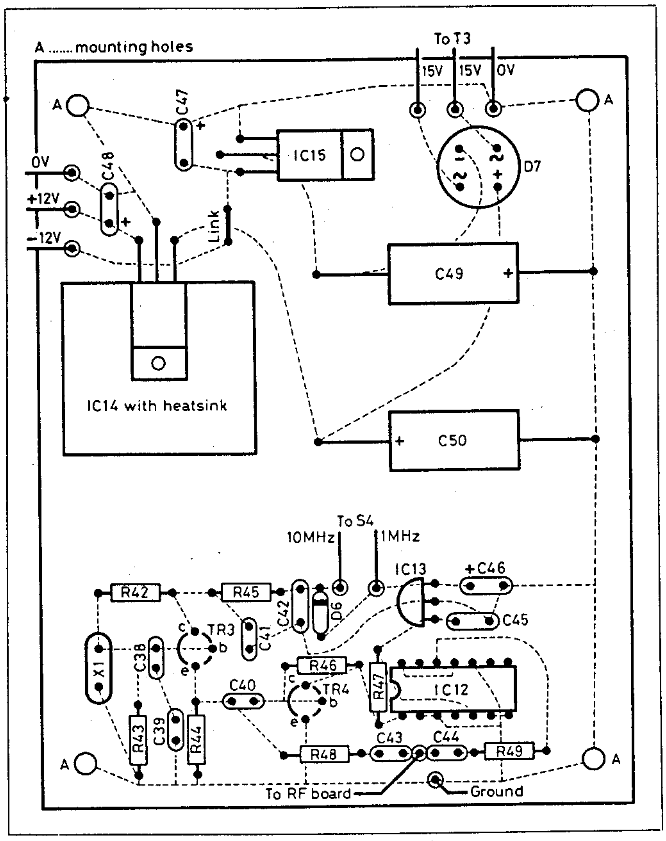

Fig. 9 Marker generator and PSU layout (component side)

space for a small heatsink for IC14 has been provided on the board.

The analyser needs to be constructed in a metal case to provide the necessary shielding from stray signals but when choosing or making a case and installing the boards, remember that the pre-sets on both the RF and sweep boards will need adjustment. This means that the boards should be mounted so that there is easy access to both boards. The input attenuators are constructed on the slide switches S5 and S6 using short leads, and could well be fitted with a grounded screening box made of double-sided PCB.

For the coarse centre-frequency control, choose a good ten-turn potentiometer and fit it with a large knob which has a cranked handle, this will save a lot of wear and tear on your fingers! The fine control needs a good quality single-turn carbon-track potentiometer. The connections to the RF board from the front panel attenuators and the marker generator should be with miniature coaxial cable such as RG174. The video and sweep connections, as well as those to S2 and the X and Y output sockets, should be made with small diameter screened (audio) cable.

Test the boards on the bench before finally assembling them in the case. One of the prototypes spent its first few weeks in this state simply because I could always find something to look at with it which seemed more interesting than the prospect of drilling holes in the front panel! Final setting up of the RF board should be done when it is fixed in the case.

ALIGNMENT

Start by testing the power supply and marker generator. The latter can be easily checked by listening to its harmonics on an HF receiver, or use an oscilloscope on the input and output of the decade divider. Next test the sweep and video board. It should be fairly easy to check the operation of this with the oscilloscope which will be used for the display. Don't set it up at this stage, merely confirm that the sawtooth waveform is available at the analyser X output, and that an attenuated version (with a DC offset dependent on the centre frequency controls) is available at the VCO sweep voltage output.

When the RF board is complete, connect power to it and ground the tuning input. Then connect the video output to the oscilloscope (which for the moment can have its conventional timebase operating) and select wide IF bandwidth. If a 145MHz source (eg. a 2m handheld with a dummy load) is brought close to the input side of the 145MHz filter, the trace should deflect upwards, showing that the second mixer, oscillator and log IF strip are working. Adjust L4 for maximum response, reducing the input signal as required.

Now complete all the interconnections, set the oscilloscope to external X operation, and connect the X output of the SSA to the external X input of the oscilloscope. Adjust RV2 (X CAL) (and perhaps also the oscilloscope X gain) so that the available sweep is just wider than the screen. Set S2 to 10MHz/DIV, connect the video ouput of the SSA to the oscilloscope Y input (set to 100mV/cm, DC coupling) and switch on the 10MHz markers. At this stage, a few blips on the screen should be seen. When the VCO is correctly aligned, one of the blips will not disappear when the markers are switched off - this is the lower limit of the coverage - in other words 0MHz.

The next stage requires patience! Set RV4 (CENTRE FREQUENCY COARSE) to about mid travel and unscrew the core of L2 so that it is about half way out of the coil - by now a few marker blips should be seen if all is well. Adjust L4 for maximum amplitude of the blips, noting that there will be two positions where this occurs - choose the position where the core is further inside the coil, as the other corresponds to the LO being on the high side of the first IF. By careful adjustment of the VCO coil L2 it should be possible to see marker blips every 10MHz up to 90MHz, whilst still keeping the 0MHz blip. If necessary adjust L4 slightly. L1 does not need adjustment - just leave the core as supplied.

Adjust RV3 (SWEEP CAL) and RV6 (SET BREAK-POINT) to give a linear display (as near as possible) over the bottom 70 or 80MHz or so, with one marker appearing at every horizontal division on the screen. You will find that careful setting of RV6 will substantially improve the frequency linearity above 70MHz. These adjustments interact somewhat, so it is worth repeating them. Check, with the aid of the 1MHz markers, the operation of the MHz/DIV (Sweep Width) switch.

FINAL ADJUSTMENT

Now is a good time to finally adjust the filters on the RF board. Using an internal marker blip, carefully adjust the 145MHz filter for maximum signal amplitude. Select the narrow IF, and adjust the cores of T1 and T2 for maximum amplitude and best shape - what is displayed is the actual IF response of the analyser. When using the narrow IF, remember to reduce the sweep rate. If a marker is put at the centre of the screen with the centre frequency controls, reducing the sweep width with S2 should not result in the marker moving - if it does, then try adjusting the oscilloscope X shift slightly and re-centering the marker.

Finally, the calibration of the log vertical scale must be set using a 50ohm signal source, such as a signal generator connected to the SSA RF input socket. Using the oscilloscope Y shift, position the base line near the bottom of the screen. With the attenuators switched out, and the oscilloscope Y amplifier set to 100mV/cm, adjust the signal amplitude to give a peak of 4 divisions or so. Now adjust the Y cal pre-set so that when attenuation is switched in, the peak falls in amplitude by 1cm per 10dB. If you have access to an accurate signal source, you can set the oscilloscope Y shift so that the top of the screen corresponds to -20dBm (in a commercial instrument this is termed the reference level). The noise floor of the analyser is about -85dBm but note that the lowest vertical division doesn't quite correspond to the 10dB per division calibration of the rest of the screen.

PRACTICAL HINTS

Bear in mind the limitations of the analyser - remember that it has a maximum input of -20dBm (+10dBm with both attenuators in), and will start to show its own shortcomings if you overload it - the dynamic range of the analyser is over 50dB. Whilst the absolute sensitivity will vary across its range by 6dB or so, the relative calibration of 10dB per vertical division remains unchanged for any given frequency. When using the narrow IF, slow the sweep down - watching the display whilst you do will soon show you why this is necessary. Incidentally, although not shown on the circuit diagram, one addition I recommend is a good RF filter on the mains input, to keep the entry of RF to the approved route only, via the front panel input socket!

Whilst you won't find the SSA suitable for making Intermodulation Distortion measurements or looking at oscillator noise, many useful and interesting tasks await it. By connecting a few feet of wire to the input, a fascinating picture of the HF spectrum emerges - try it during the day and then have another look at night, when the 7MHz broadcast stations are in full swing. Use the 10 and 1MHz markers to find your way about the spectrum.

You should find that the upper limit of the analyser is over 95MHz, and that if you live in a good signal strength area, Band II VHF radio signals are visible. Connecting a good antenna should enable a watch to be kept for 28 or 50MHz openings. If your HF rig has a mixer VFO, try looking at the output - and be prepared for a shock such as I had when I looked at mine! A photograph of a typical display using a very short antenna can be seen in **Fig.10.**

Whilst it doesn't quite have the performance of a commercial unit (or for that matter the same price tag!), when used with a modicum of care it is a very useful tool. I hope you'll find that, once you have built it, the SSA rapidly becomes indispensable for all kinds of jobs around the shack. □

ACKNOWLEDGEMENTS

First, thanks should go to Al Helfrick, K2BLA, whose inspirational design started this all. Second, to the many people who expressed interest in my original design mentioned in TT (I'm sorry I couldn't reply to you all); to G3SEK for reading the draft, and finally to G8HAJ who provided material assistance with the early development.

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[1] A Simple Spectrum Analyzer. A Helfrick, *RF Design* January 1988 35-37. Details also given in Technical Topics, *Radio Communication*, April 1988.

[2] An Inexpensive Spectrum Analyzer for the Radio Amateur. A Helfrick, K2BLA, *QST* November 1985 23-29.

[3] Technical Topics, *Radio Communication* July 1988.

[4] Technical Topics, *Radio Communication* August 1988. These notes are very definitely no longer available!

[5] Technical Topics, *Radio Communication* September 1988.

[6] Technical Topics, *Radio Communication* November 1988.

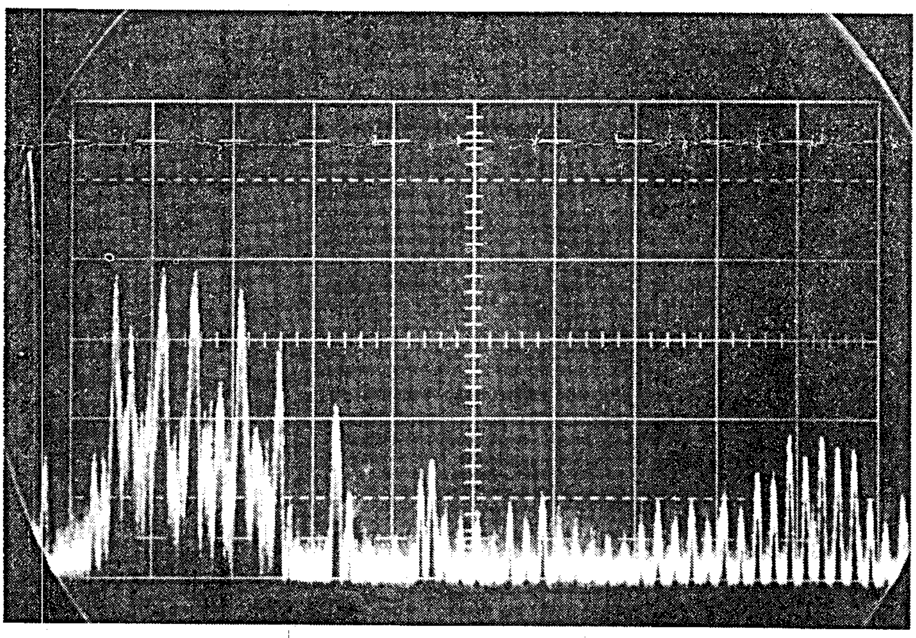

Fig.10 Typical SSA display with short antenna. Sweep width is 5MHz/DIV, the frequency range shown is 5 to 55MHz with 30MHz at the centre of the screen. HF broadcast stations dominate the left portion on the display. Just left of centre are two CB transmissions. Clock frequency harmonics from a microprocessor operating a few feet away can be seen from 30 to 55MHz.

COMPONENTS LIST

RF BOARD

RESISTORS	
R1, 2	150
R3	39
R4	10k
R5, 11	330
R6	1k0
R7, 12	470
R8	220
R9	390
R10	10
CAPACITORS	
C1	1p8
C2, 8, 16, 17, 18, 21, 23, 30	1n0
C3, 5	82p
C4	15p
C6	4p7
C7	2p2
C9, 10, 14, 15	100p
C11, 19, 20, 22, 24, 25, 31, 32	10n
C12	22p
C13	5p6
C26	470p
C27	100n
C28, 29	1μ 35V Tant Bead
SEMICONDUCTORS	
D1	BB209
D2	1N4148
TR1	2N2222)
IC1	MC3356)
IC2	NE602
IC3	78L05
MISCELLANEOUS	
FL1	272MT1006A CBT 145MHz helical filter
FL2	10M15A 2 pole 10.7 MHz crystal
FL3, 4	SFE10.7MA 10.7MHz ceramic filter
L1, 2	TOKO S18 coil 1.5t white 301SN0100
L3	4.7μH RFC TOKO FL4 348LS4R7
L4	TOKO S18 coil 4.5t yellow 301SN0400
T1, 2	TOKO KACS3894A IFT
RL1, 2	Minature relay type OUC
S1	SPDT min toggle IF BANDWIDTH

MARKER GENERATOR

RESISTORS	
R42, 43	47k
R44, 47	1k0
R45, 49	150
R46	22k
R48	220
CAPACITORS	
C33, 39	100p
C40	47p
C41	10n
C42, 45	100n
C43, 44	4p7
C46	1u 35V Tant bead
SEMICONDUCTORS	
TR3,4	2N2222
D6	1N4148
IC12	74LS90
IC13	78L05
MISCELLANEOUS	
X1	10MHz HC18U
S4	spdt centre off toggle MARKER

SWEEP AND VIDEO BOARD

RESISTORS	
RV1	10k lin SWEEP RATE
RV2	20k cermet preset X CAL
RV3	20k cermet preset SWEEP CAL
RV4	100k 10-turn COARSE CENTRE FREQ
RV5	100k lin carbon FINE CENTRE FREQ
RV6	10K cermet preset BREAKPOINT ADJ
RV7	20k cermet preset Y CAL

(RV2 and RV7 can be any value in the range 10 - 100k; similarly RV4 and RV5 can be 10 - 200k)

CAPACITORS	
C33	470n polyester layer
C34	10n
C35, 36	10u 25V Tant bead
C37	330p
SEMICONDUCTORS	
TR2	BC327
D3, 4	1N4148
D5	5V1 zener
IC4	555
IC5-11	741
MISCELLANEOUS	
S2	1 pole 6 way wafer MHz/DIV
S3	SPST or SPDT toggle VIDEO FILTER
SK2, 3	BNC panel socket

POWER SUPPLY

RESISTORS	
R60	1k0
CAPACITORS	
C47, 48	1u 35V Tant Bead
C49, 50	1000u 25 or 35V elect
SEMICONDUCTORS	
D7	W02 bridge rectifier
D8	red panel mounting LED
IC14	7812 with small heatsink
IC15	7912
MISCELLANEOUS	
T3	15-0-15V 10VA mains transformer
S7	dpst ON OFF
F1	0.25A fuse and holder

FRONT PANEL ATTENUATORS	
R50, 51	100
R52, 53	1k0
R54	68
R55-58	120
R59	240
S5,6	dpdt slide switch 10dB (S5) 20dB (S6)
SK1	BNC panel mount socket

All resistors are 0.25W 5% or better, capacitors are miniature ceramic plate type unless otherwise noted.

PRINTED CIRCUIT BOARDS, COMPONENTS AND PCB OVERLAY AVAILABILITY

PCBs

Please note that PCBs for this project are not available as yet. Arrangements are being made for these to be included in our forthcoming PCB service — see the RSGB Mail Order Price List in forthcoming issues of RadCom for details.

PCB OVERLAYS

Photocopies of the PCB track details are available from RSGB Headquarters, please send a stamped, self-addressed envelope of foolscap size and clearly mark your envelope 'Spectrum Analyser'.

COMPONENTS

Although this project contains commonly available components, readers may wish to make use of a components kit being made available by Bonex. The kit contains all the components required with the exception of PCBs, case and control knobs. The price of the kit is £48 including both VAT and postage and packing. Please send your orders direct to Bonex at:
12 Elder Way,
Langley Business Park,
Slough, Berks SL3 6EP.
Tel: 0753 49502.