VHF receiver in DSP

Michael Slifkin, Ziv Mayan and Zachy Globinsky

A DSP VHF FM push-button receiver

Digital techniques are very much the in-thing in electronics, but most radio receivers still use analogue circuitry. Some fully-digital radios are available – as for example advertised on page 801 of this issue – but they are expensive.

The techniques used in digital receivers of this kind are very different from those used in their analogue counterparts. It would be a daunting task even for a very experienced radio ham to design such a receiver. Nevertheless, one who built his first 1-v-1 radio some forty-five years ago has attempted it – with the aid of younger hands.

In this article we discuss digital signal processing, or DSP, techniques in radio and then describe a working push-button VHF FM radio that we have developed and built. A good introduction to DSP techniques can be found at http://www.bores.com/courses/intro/.

Note that this is not a cheap design. While prices of DSP ICs are going down all the time, they are currently still expensive.

Design outline

Controlling the receiver are an EPROM and a programmed microprocessor. If you intend implementing this design, you will need access to an EPROM programmer. Putting the design together is easy since most of the components are ICs.

The circuit diagrams are presented in two sections, the analogue section and the digital section. Using eight voltage regulators may seem rather excessive, but this reflects the rather specialised needs of the various ICs. Note the separation of digital and analogue earths.

Programming can be arduous, but *Electronics World* is supplying the necessary assembly language programs on disk for anyone wanting them.

VHF tuner – outline specifications

Frequency range	88-108MHz
Audio frequency	to 15kHz
Channel width	200kHz
Tuning resolution	0.1MHz
Dynamic range	40dB*

Audio AGC is provided. The default channel at switch on is 101MHz
*See panel entitled 'Dynamic range'

So what's wrong with analogue receivers?

The big question is why would one want to abandon techniques of radio reception which have served us well for over 60 years? Currently the answer would be not to do so because of the high cost. But clearly in the not too distant future, the costs will plummet.

A major advantage of a digital receiver is that changing its programming can alter the entire reception mode, tuning range or channel width. The tuning frequency, bandwidth, mode etc., can all be entered through a key pad, making for very simple use. In addition, a digital receiver's characteristics remain constant throughout its lifetime, resulting in much lower maintenance costs and greater reliability.

By contrast, analogue communication receivers can be difficult to tune. Furthermore, their performance and features cannot be readily changed. In addition, their characteristics can drift, requiring periodic retuning for maximum performance.

In a digital receiver, the use of wide band receivers allows much of the hardware to be shared over all the channels. Thus a completely general-purpose receiver can be built and then programmed to suit the user. It can be changed as conditions and requirements change simply by reprogramming.

Mass production of such radios could

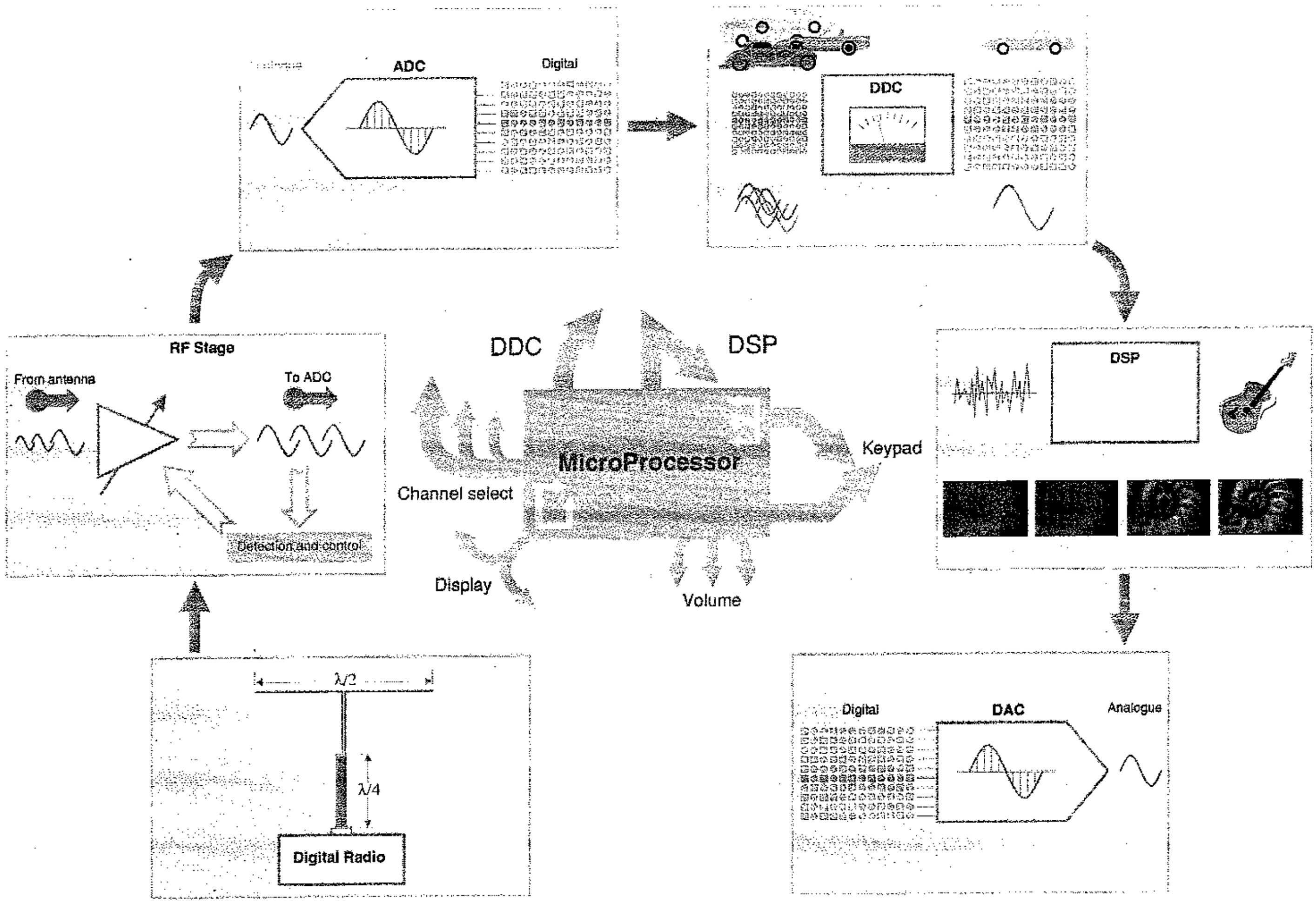


Fig. 1. Schematic Diagram of the DSP VHF FM Receiver

bring the cost to less than that of the analogue communications receiver. In addition to being cheaper, digital radios should offer more versatility and features. An excellent summary of the advantages of digital radio receivers over analogue receivers has been given by B. Brannon.[1]

No superheterodyne

The techniques used for DSP in radio reception are quite different from the usual superheterodyne methods used in analogue radio receivers. A DSP receiver works as follows. The signal is digitised after being received on the aerial and will contain all signals in the frequency range. This digitised signal is then down converted to zero frequency – i.e. base band.

The precess so far selects a particular signal at some frequency, which is now at zero frequency but still in the form of the original transmitted signal. A digital signal processor now applies a mathematical algorithm to transform the signal into audio, but still in a digitised form. This digital audio signal is converted to audio sound by a digital-to-analogue converter.

Receiver outline

First we'll describe the general arrangement of the receiver, then the specific stages in more detail.

The radio signal enters the system via the aerial and is amplified by an RF amplifier with a band-pass filter. This amplifier includes an automatic gain control, or AGC, so that the output is about a volt, this being the optimal voltage for the following stage.

Normally of course with a superheterodyne arrangement, AGC is derived from the audio or IF stages, not the RF stage.

This 1V signal now enters a 10-bit analogue-to-digital converter. This converter samples the analogue signal but at a frequency less than the Nyquist frequency – a technique discussed in

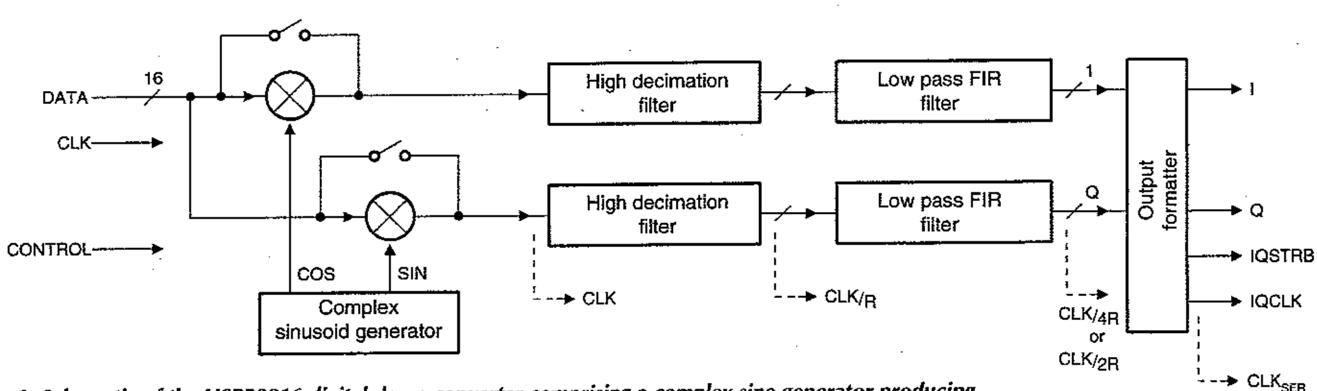
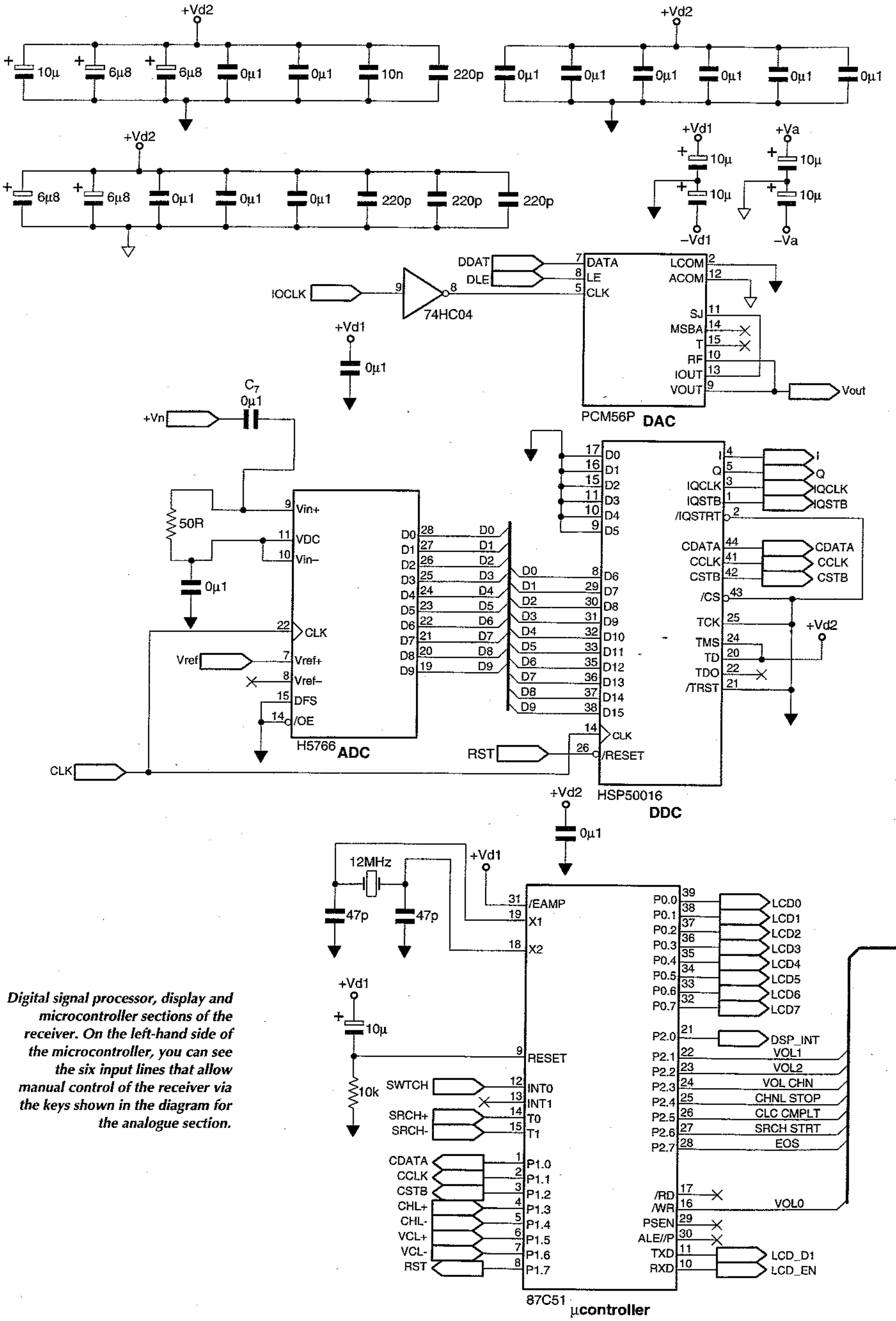
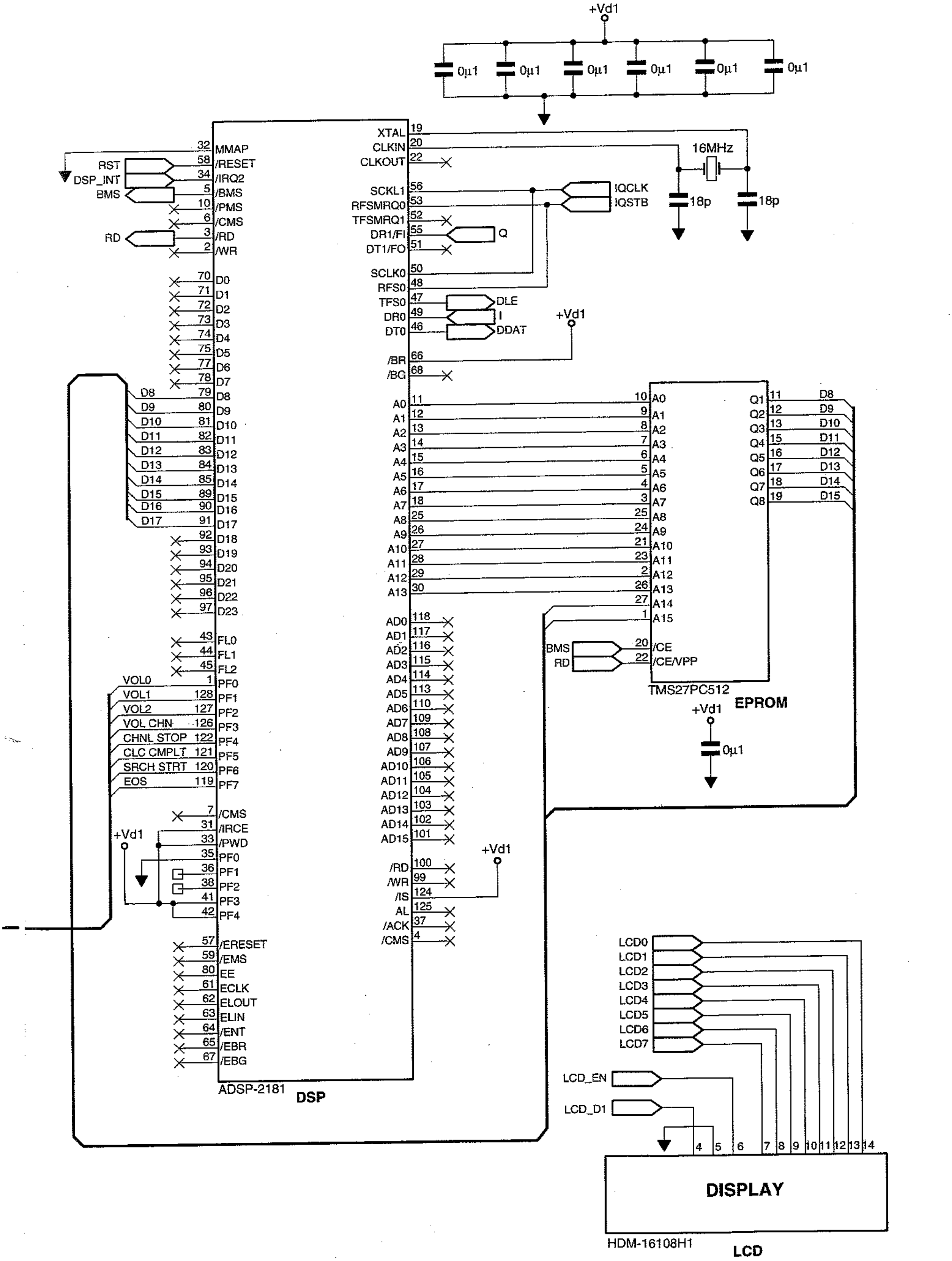
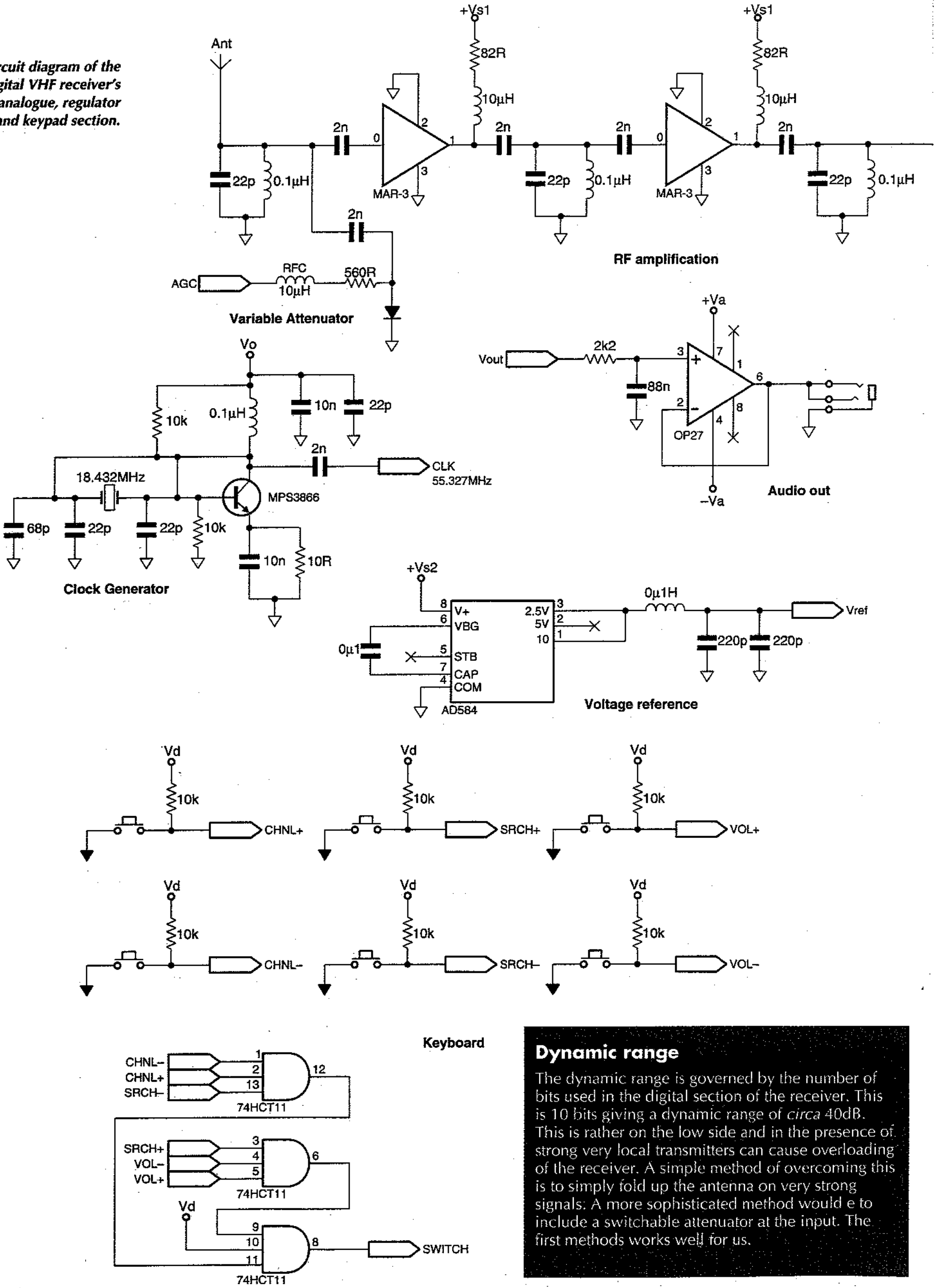


Fig. 2. Schematic of the HSP50016 digital down converter comprising a complex sine generator producing two mixing signals, 90° out of phase. It is fully programmable, but rather complicated.



Digital signal processor, display and microcontroller sections of the receiver. On the left-hand side of the microcontroller, you can see the six input lines that allow manual control of the receiver via the keys shown in the diagram for the analogue section.

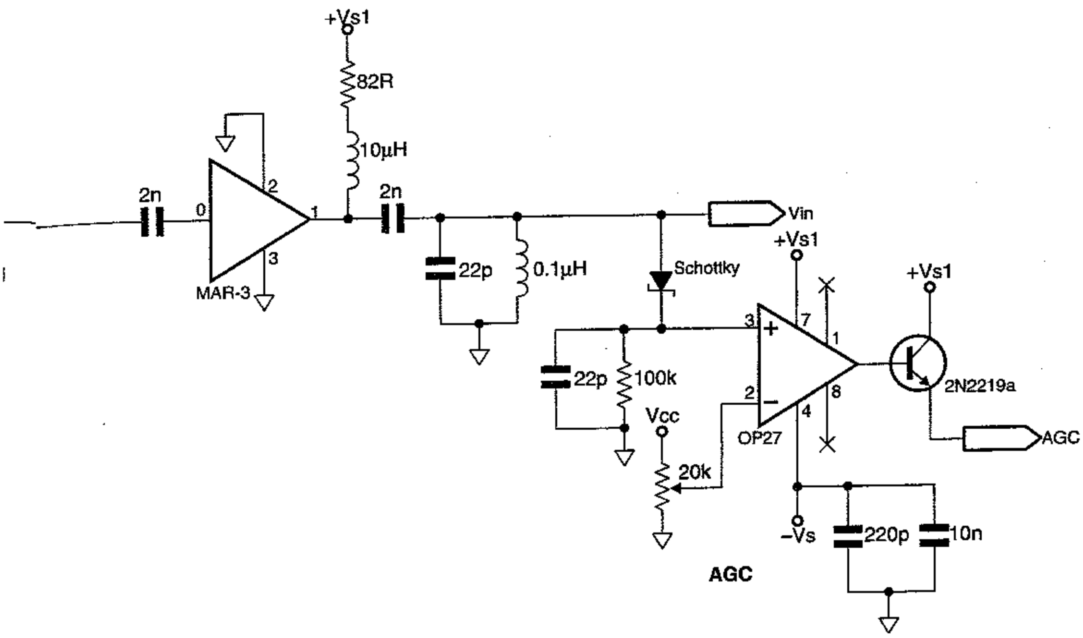

+Vd1
0µ1
16MHz
18p
XTAL
CLKIN
CLKOUT
SCKL1
RFSMRQ0
TFSMRQ1
DR1/FI
DT1/FO
SCLK0
RFS0
TFS0
DR0
DT0
/BR
/BG
IQCLK
IQSTB
Q
DLE
I
DDAT
MMAP
/RESET
/IRQ2
/BMS
/PMS
/CMS
/RD
/WR
RST
DSP_INT
BMS
RD
VOL0
VOL1
VOL2
VOL CHN
CHNL STOP
CLC CMPLT
SRCH STRT
EOS
/IRCE
/PWD
/ERESET
/EMS
EE
ECLK
ELOUT
ELIN
/ENT
/EBR
/EBG
/IS
AL
/ACK
ADSP-2181
DSP
TMS27PC512
EPROM
/CE
/CE/VPP
LCD0
LCD1
LCD2
LCD3
LCD4
LCD5
LCD6
LCD7
LCD_EN
LCD_D1
DISPLAY
HDM-16108H1
LCD



Circuit diagram of the digital VHF receiver's analogue, regulator and keypad section.

Dynamic range

The dynamic range is governed by the number of bits used in the digital section of the receiver. This is 10 bits giving a dynamic range of *circa* 40dB. This is rather on the low side and in the presence of strong very local transmitters can cause overloading of the receiver. A simple method of overcoming this is to simply fold up the antenna on very strong signals. A more sophisticated method would e to include a switchable attenuator at the input. The first methods works well for us.

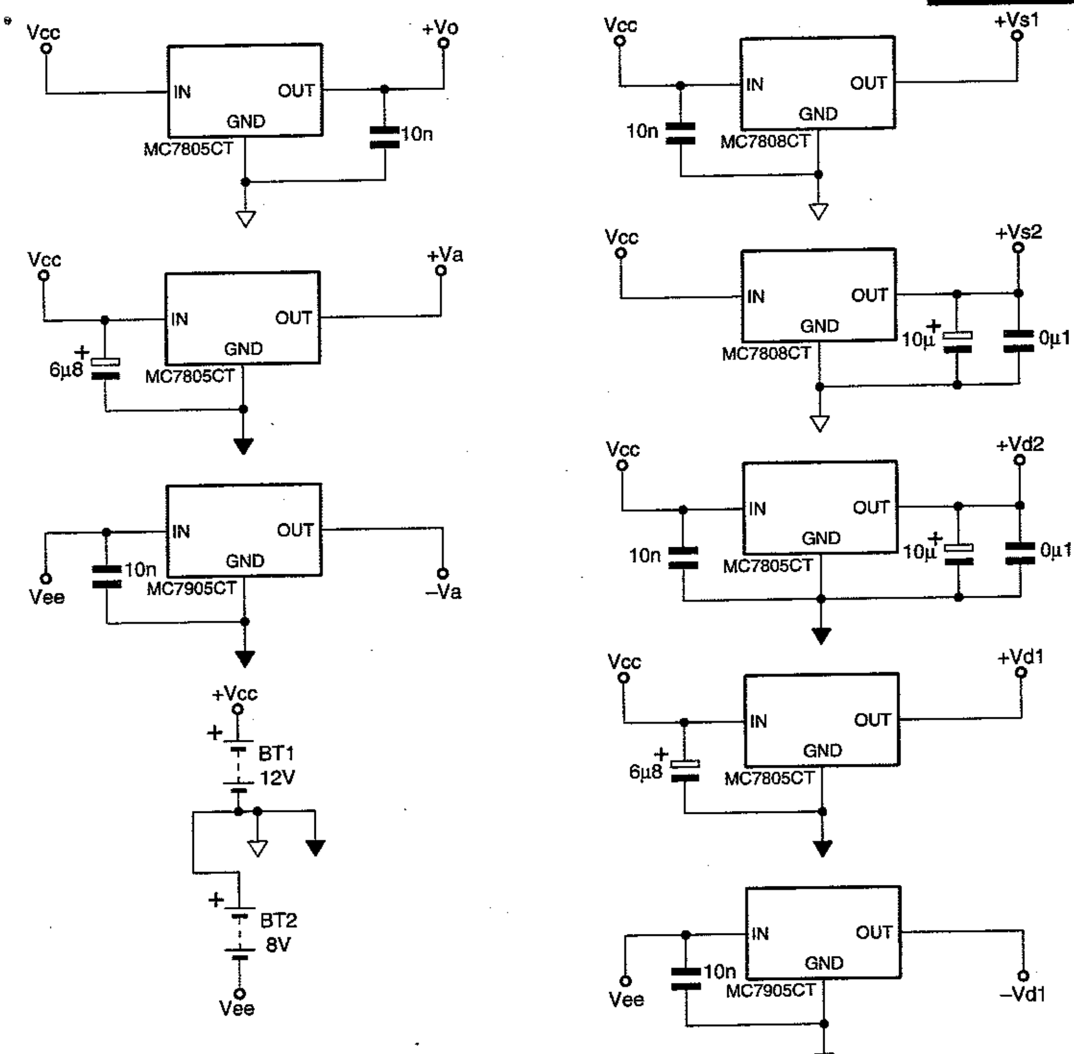


AGC

Software availability

If you want the object code in electronic form, e-mail jackie.lowe@rbi.co.uk and it will be forwarded to you as text embedded in an e-mail. It will not be sent as an attachment to avoid distributing viruses. If you want the object code on disk, again free of charge, send us a PC formatted 3.5in floppy with a protective self-addressed envelope and enough stamps to allow us to return the disk to you. Post it to the Quadrant House address below

For those of you wanting to exploit the design further, the source code is available on disk, or as an e-mail attachment, for £25 fully inclusive. E-mail the above address with your credit card number, expiry date and card-holder address or fax 0181 652 8555 with the details. Alternatively, send your order to Receiver software, Electronics World Editorial, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS.



Voltage supply

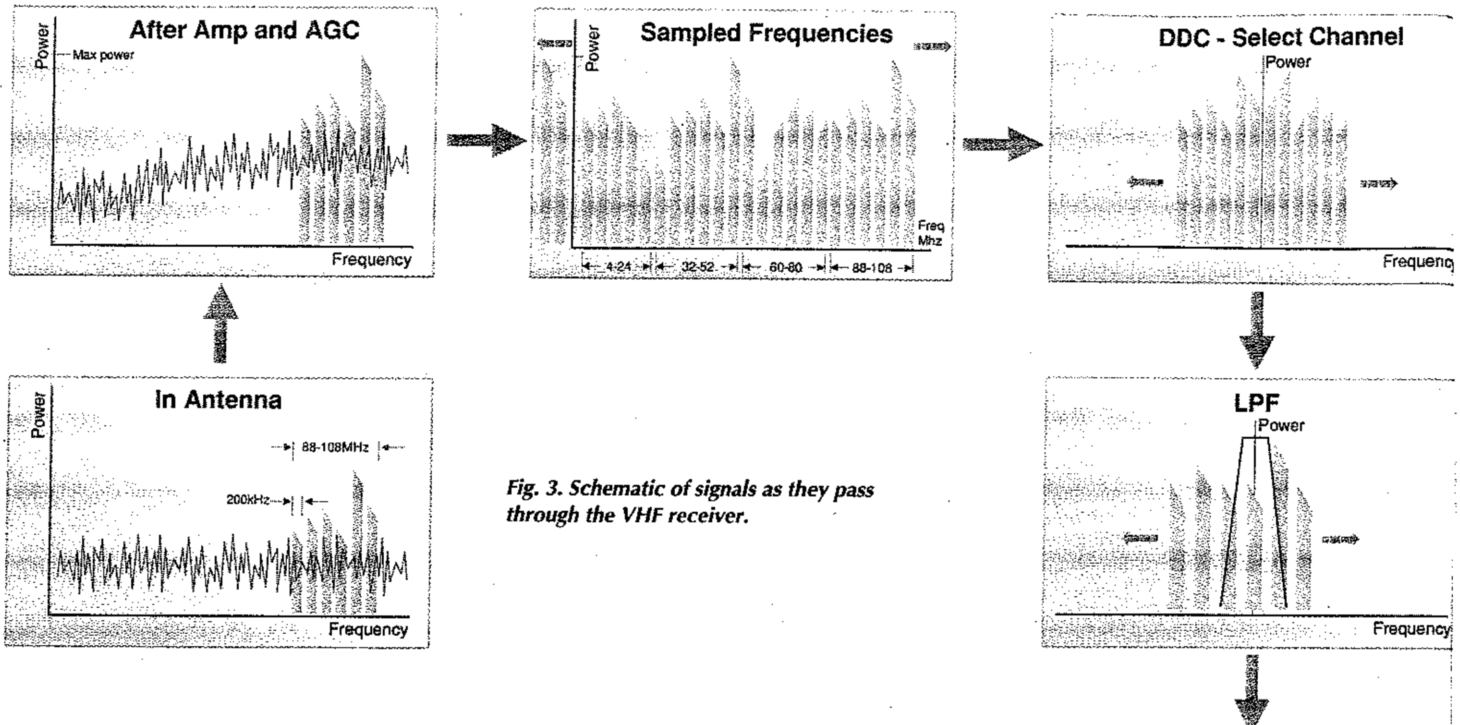
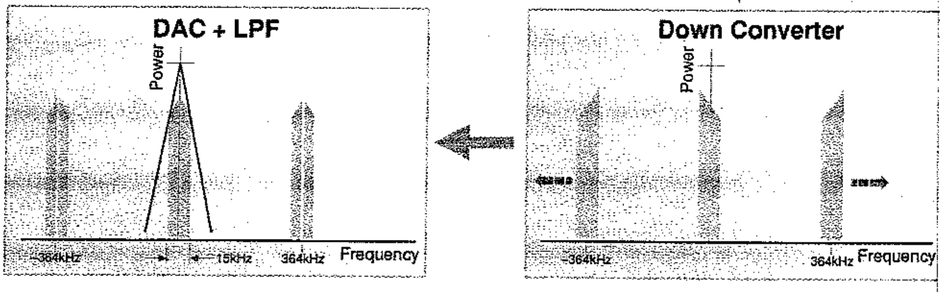


Fig. 3. Schematic of signals as they pass through the VHF receiver.



What is under sampling?

Most of you will be familiar with the Nyquist criterion, which states that if one samples a signal at less than twice the highest frequency found in that signal then the restored signal will be distorted – a phenomenon known as *aliasing*.

A well-known version of this is seen at the cinema when the stagecoach rolls into town and the wheels appear to be moving backwards. This occurs because each film piece is shown at 24 times a second. When the spokes are rotating at more than 12 times a second, the wheel appears to be moving backwards.

The stroboscope works on the same principle by flashing a powerful light at a frequency just slightly lower or higher than that of some repetitive motion. This makes the motion appear to move very slowly backwards or forwards or be stationary.

However, where you have a band-pass limited signal – in our case we are looking at signals in a 20MHz range from 88 to 108MHz – then it can be shown that you only need to sample at very slightly more than twice this bandwidth. This means that you sample at 40MHz, rather than 217MHz, without distorting the reconstructed signal. This technique is known as under sampling.

the box entitled 'What is under-sampling'.

Containing digitised components lying within a 20MHz bandwidth, the sampled signal is down converted using a special digital IC called a digital down converter, or DDC. This device converts the signal in the frequencies between 88 and 108MHz down to DC.

Note that this is not a simple down conversion as used for instance in the synchrodyne receiver as described recently in *Electronics World*.[2] Instead, in this IC there is a complex process in which the incoming digital signal is mixed with a local oscillator which has both sine and cosine components.

After some processing, the mixed signal becomes an output which is a digitised FM signal at DC. This is then passed through a low-pass filter to minimise the bandwidth.

Now, the FM signal has to be demodulated using a digital signal processor to reform the original signal in a digitised form. This signal is then passed through a 16-bit digital-to-analogue converter to produce an analogue audio signal, which is passed through a low-pass filter to the speaker.

Control of the receiver is by an on/off switch and a simple six-key touch pad. There are up and down buttons for volume. In addition, a frequency up/down button moves up one FM channel or down one FM channel. There is also a button that searches up, and one that searches down. When a signal is encountered the search then stops.

The whole process is controlled by a microcontroller, which also functions as a user-interface. This microcontroller is responsible for getting the desired radio frequency by sending the mixing frequency to the DDC and outputting the frequency to an LCD display. It also searches for active channels and enables volume control.

The controller sends the volume control data to the signal processor, which is responsible for the output amplitude. Other than that, a program stored in the EPROM controls the signal processor.

Elements of the receiver

Figure 1 shows the various stages of this receiver in a pictorial form. The first stage is the antenna, a conventional ribbon dipole VHF aerial, which often comes with a music centre but can be bought from any radio shop.

The following RF stage is conventional. It consists of three *MAR3* monolithic broad-band amplifiers and four band-pass filters to give good selectivity.

Each filter has 3dB points at 80 and 145MHz. While consistency might demand that we use only digital filters, this option provides us with the simplest and cheapest solution to get the correct selectivity and gain.

Automatic gain control is derived from the output of this stage via the Schottky diode, the *OP27* operational amplifier and the *2N2219A* transistor.

The derived voltage is fed back to the first *MAR3* in the chain to maintain the output at around 1V peak to peak. The RF chokes are used as high pass filters to remove higher frequencies and maintain stability in the amplifier chain.

The RF signal is next fed to the a-to-d converter for digitisation. The converter is a Harris *HI5766* with a 250MHz full-power input bandwidth and a maximum 60MS/s sampling rate. The sampling frequency of 55.296MHz is obtained as the third harmonic (second overtone) signal from an 18.432MHz crystal.

Next, the digitised signal is fed to the DDC. This is a Harris *HSP50016*, made to be compatible with the a-to-d converter, having a maximum 75MS/s input data rate.

The DDC is fully programmable and is rather complicated. It consists of a complex sine generator to produce two mixing signals, 90° out of phase.

When two signals are mixed together in a non-linear device, i.e. mixer, the sum and difference of the two frequencies are obtained. Thus, one of the results of mixing two signals of the same frequency is an output riding on DC plus a signal at double the original frequency.

Frequency-modulated signals are rather complex. One cannot simply down convert by mixing with a frequency the same as the carrier, as with AM or SSB signals. Instead in-phase (I) and quadrature (Q) signals have to be produced and recombined to reform the FM, as is done in this device. The block diagram taken from the manufacturers data sheet is shown in **Fig. 2**.

To prevent the doubled frequency produced in the mixing process breaking through, a low-pass filter has to be added. This is accomplished with a decimation filter followed by a fixed finite-impulse-response filter.

The decimation filter is not quite as lethal as it sounds. It passes every *N*th pulse, not every tenth pulse, as its name implies. Its effect is to divide the clock frequency by *N* and to reduce the bandwidth by this ratio.

Output from the DDC is a digitised FM signal at DC. The signal processor performs the mathematical operation on this signal to convert it to a digitised audio signal. The signal processor is an *ADSP-2181* from Analog Devices. It is a microprocessor optimised to carry out all kinds of arithmetical functions.

This signal processor is the heart of this receiver and it is only with the introduction of such devices that a digital receiver becomes possible. These devices are of course fully programmable. The software can be altered to operate on any kind of signal

Object code for the microcontroller.

```
:0600000002002B0200CEFD
:01000B0032C2
:0100130032BA
:01001B0032B2
:0100230032AA
:10002B00C29775401FD540FDD29775A805758805F9
:10003B007581607520041202EA12007812025612C2
:10004B0001D712022BD2AF80FED291D292C291C2B3
:10005B00927830754005E60875410833D29192903D
:10006B00C291D541F6D540EED291C29122C2927582
:10007B00507B7551E77552EC7558AC755988755AAC
:10008B00A2755B177544009000B075420675430569
:10009B007830E54493F6080544D543F61154D54220
:1000AB00EC753A4722380000001500000000007048
:1000BB00000000000900000069B002DA0B01D01DB7
:1000CB00524003C0D0C0E07545FF309518309622E2
:1000DB0030934F30943C30B40630B50602013D02EC
:1000EB0001A202016C7407B5200302013D05200239
:1000FB000106E520603C1520020106D2A3A2029264
:10010B00A2A20192A1A20092B6D2A0C2A0D2A0023A
:10011B00013D74C9B53A06753A0102013A053A0236
:10012B00013A7401B53A06753AC902013A153A1209
:10013B0002561201D712022B8545407541FF7542BD
:10014B0001D542FDD541F7D540F17545403095952 8
:10015B0030969F3093CC3094B9758805D0E0D0D0D1
:10016B0032C2A3C2A7D2A0C2A0D2A0000000C2A6D6
:10017B00D2A630A5FD20A41B74CAB53A0B753A0064
:10018B00D2A7C2A6D2A680D9053A120256C2A6D2CF
:10019B00A680DF153A8098C2A3C2A7D2A0C2A0D274
:1001AB00A0000000C2A6D2A630A5FD20A41AE53AF5
:1001BB00700B753ACAD2A7C2A6D2A680DA153A122C
:1001CB000256C2A6D2A680E0053A213AC374C9955D
:1001DB003A75F00A8485F03B245875F00A8485F053
:1001EB003C75F00A8485F03DF53E12032DD2B1E546
:1001FB003E6005243002020574201202FCE53D240A
:10020B00301202FCE53C24301202FC742E1202FC6C
:10021B00E53B24301202FCC2B190034512031322BA
:10022B0012033290035112031 3D2B1AB200B743D66
:10023B001202FCDBF97408C39520FB74201202FC3C
:10024B00DBF9C2B190035612031322E53AC3F553FF
:10025B008550F0A4F54685F047E5538551F0A4F59C
:10026B004885F049E5538552F0A4F54A85F04BC318
:10027B00854657E5472548F556E549354AF555E492
:10028B00354BF554C3E5572558F557E5563559F514
:10029B0056E555355AF555E554355BF554D291D2A3
:1002AB0092C291C2927430754104 33D2919290C232
:1002BB0091D541F67854754004E60875410833D260
:1002CB00919290C291D541F6D540EE7410754104D0
:1002DB0033D2919290C291D541F6D291C29122C262
:1002EB00B174381202FC740E1202FC74011202FC7F
:1002FB0022F580D2B012033CC2B012033C22D2B121
:10030B0051FCC2B112033C22D2B1E4FB93B4000303
:10031B00C2B122C083C08251FCD082D083EB048057
:10032B00EA22748051FC2274C051FC22740151FCEE
:10033B00227F017E10DEFEDFFA224D487A20464DE9
:0F034B002020202020000564F4C20002020200092
:00000001FF
```

for which a mathematical method for detection is available.

Finally, we have an audio signal, but in digitised form. The last stage is to convert the signal back to analogue form using a d-to-a converter. For this task, we chose the *PCVM56P* from Burr Brown.

Analogue output from the d-to-a converter is finally passed through a low-pass filter and an *OC27* op-amp to the speaker. Controlling the output from the signal processor controls the volume. We included a liquid crystal display, which shows both the frequency and volume magnitude.

All of these operations are supervised by the microcontroller. This is an 8C751 eight-bit controller. This device has an-board EPROM, into which the control program is loaded.

The control program for the signal processor is stored in a *TMS27PC512* EPROM. Both programs were written in assembly language on a PC. When they had been thoroughly checked and debugged, they were downloaded to their respective EPROMs.

Writing the programs is the most difficult part of this design. There are over 400 lines of source code. It is not possible in this article either to discuss it or present it. However, copies of the two programs are available from *Electronics World*. The algorithm controlling the signal processor has already been published.[3]

Diagrammatic depictions of the signals as they pass through the receiver are shown in **Fig. 3**.

Further work

The receiver performs very well and has been the subject of much favourable comment.

The present limitation to a general purpose DSP receiver extending to the highest frequencies is the full-power bandwidth of the sample-and-hold circuit located at the front end of the analogue-to-digital converter, together with its aperture jitter. At the time of writing, it is at yet not possible to build a DSP receiver for the very popular 900MHz band. ■

References

1. Brannon, B, 'Wide Dynamic Range A/D Converters Pave the way for Wide Band Digital Receivers,' *EDN*, 7 November 1996.
2. Slifkin, M and Dori, N, 'Synchrodyne and homodyne receiver,' *Electronics World*, Vol. 104, No 1751, Nov. 1998.
3. Shima, JM, 'FM Demodulation Using a Digital Radio and Digital Signal Processing,' MSc Thesis, University of Florida 1995.

Object code for the DSP chip's eprom in S format.

```
S22500000040060093FE2040020093FE1040000093FE3040087093FE403C008C0000003C0083EF
S22500002102800018020F0000000000000000000000000000000000000000000000000000000E
S2250000420000000000000000000000000000000000000A001F0000000000000000000000006F
S22500006300000000000000000000000000000000000000000000000000000000000000000077
S22500008400000000000000000000000000000000000000000000000000000000000000000056
S2250000A500000000000000000000000000000000000000000000000000000000000000000035
S2250000C600000000000000000000000000000000000000000000000000000000000000000014
S2250000E7000000000000000000000000000000000000000000000000000000000000000000F3
S225000108000000000000000000000000000000000000000000000000000000000000000000D1
S225000129000000000000000000000000000000401F5093FE2040000093FE1040008093FE30EE
S22500014A40125093FE400280000000000000000000000000000000000000000000000000009A
S22500016B0000000000000000000000000000000000000000000000000000000000000000006E
S22500018C0000000000000000000000000000000000000000000000000000000000000000004D
S2250001AD0000000000000000000000000000000000000000000000000000000000000000002C
S2250001CE0000000000000000000000000000000000000000000000000000000000000000000B
S2250001EF0000000000000018030F0000000000000000180D8F0A001F0A001F0A001F0A001F68
S2250002100A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F05
S2250002310B000F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001FF3
S2250002520A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001F0A001FC3
S2250002730A001F0A001F0A001F0A001F0A001F0A001F3C017443E1F093FF6043E1F093FF20F2
S22500029447B30093FE603805A03812413800053800193812323800063800123812233800007B3
S2250002B538001B34001034000434001850000A23380F6800A034000234000634001A403240CC
S2250002D668000A3400213400053400194032402 3380F6800A541C1F093FFF040000240000393
S2250002F74FFFF83C220302010F18058F0D03B80D03CA3FFF060E7B0F0E7C0F0D03A622621F0C
S2250003180D009A0E430F0D006F0E440F0D007F0D0C860D0CA728889821810F2E7C5C180A24AB
S22500033920800F51096A527CB518089356EC45526CCA0612000712000712000712000712006A
S22500035A0712000712000712000712000712000712000712000712000712000712000712006A
S22500037B0D002421800F0E340F0D0CBE0D03280D033A0A001FCB2C5A566CCF06120007120095
S22500039C07120007120007120007120007120007120007120007120007120007120007120028
S2250003BD0712000712000712000D006421800F0E340F0D0CBE0D03280D033A0A001F20800F2C
S2250003DE51096A527CB5180BF3566C4562ECC0061200071200071200071200071200071200F2
S2250003FF0712000712000712000712000712000712000712000712000712000712000D0024AD
S22500042021000F0E340F0D0CBE0D03280D033A0A001FCA6C5A672CC506120007120007120081
S22500044107120007120007120007120007120007120007120007120007120007120007120082
S2250004620712000712000D006421000F0E340F0D0CBE0D03280D033A0A001F3C007483FE5A43
S2250004832382DF1811B1380E0040000A93FE5A0A001F40000440000E40200540200F380E6045
S2250004A40A001F83FE5A238A9F180E6140000A93FE5A83FE5A238A9F180E90238ADF18110193
S2250004C540000040000120980F26105F380F600A001F0D03280D033A27100F18103021001F04
S2250004E6180FFC21011F180FFC0A001F22611F0D001A20980F0A001F0D000C22EF0F181132F3
S22500050718109422E60F18113522E90F1811321810E422E00F18113540030A93FE5A3805A098
S2250005283C01740A001F0D00F50D00E40D00510D004040020A93FE5A380E600A001F83FE5A54
S22500054940007423820F2262BF0D008A3C01740A001F096C000C9000000000FFFFFFFFFFFF65
S9030000FC
```