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Build this high-performance AM TUNER

For low distortion & wide frequency response

Laser weapons in space! Fact or fiction?

Texas Instruments TI-99/4A computer

How the ABC covered the Games

Digital pH meter

Add a new source to your hifi listening

A high performance AM tuner: Pt. 1

Although many people are aware of the high quality reception available from FM tuners, few are aware that AM radio is also capable of really excellent sound quality. Very few AM tuners take advantage of the full potential of this medium. Our new Playmaster AM tuner is a completely new design which can provide first class sound quality that no AM section in a commercial AM/FM tuner can match, regardless of price.

by JOHN CLARKE

While most high fidelity enthusiasts do not seriously consider AM radio as a hifi medium, a large proportion of the Australian radio audience listens almost exclusively to AM. The audience ratings figures continually bear this out although the FM stations are gaining listeners as time goes on. In many areas too, FM reception is poor or there may be no FM service at all. For people living in these areas a high quality AM tuner would be a boon.

So if you are one of the many who consistently listens to AM in preference to FM, there is now an opportunity to enjoy much improved sound quality. In every respect, whether it be with regard to frequency response, harmonic distortion, signal-to-noise ratio or freedom from mains radiated interference, this new Playmaster design is superior to any currently available AM tuner that we know of.

Modern AM transmitters have an audio bandwidth which is flat to at least 15kHz and many of the better stations broadcast without restricting this bandwidth. However, it is not possible for a practical tuner to have an unrestricted bandwidth. For a start, the 9kHz spacing between AM stations means that 9kHz whistles will become troublesome at night when radio propagation improves. For this reason, the Playmaster tuner has a 9kHz filter with a very deep null.

Apart from the whistle filter the tuner audio bandwidth is rolled off above 10kHz to avoid undue "monkey chatter" which is characterised as a high pitched interference from unwanted stations whose sidebands fall within the bandpass of the tuner. For daytime listening then, the wide/narrow switch is placed in the wide position to obtain excellent listening.

At night time though, some listeners may find that monkey chatter is troublesome even with the bandwidth restricted to around 10kHz. At these times, the wide/narrow switch is set to narrow. This restricts the bandwidth further, to 3kHz. While this may seem rather narrow it is still better than many AM tuner sections in typical AM/FM tuners or receivers and, in any case, the Playmaster in narrow mode is still superior in terms of distortion and noise.

Performance of Prototype

TUNING RANGE	520-1630kHz
FREQUENCY RESPONSE	see graph
HARMONIC DISTORTION	less than 0.6% at 30% modulation
SENSITIVITY	40µV for a 50mV audio output
AUDIO OUTPUT	500mV RMS into 4.7kΩ load at 100% modulation
AGC RANGE	54dB for a 6dB change in audio output
SIGNAL TO NOISE RATIO	65dB with respect to full output

Possibly the most obvious feature of the Playmaster tuner is the 4-digit readout. This reads the tuned frequency to within 1kHz and has been designed to be completely free of the jitter which troubles some digital readouts. Another bonus of the digital readout, as far as the constructor is concerned, is that it makes precise alignment possible without the need for an expensive RF generator. Precise alignment is necessary if best performance is to be obtained and we are very pleased to be able to solve this problem in this fashion.

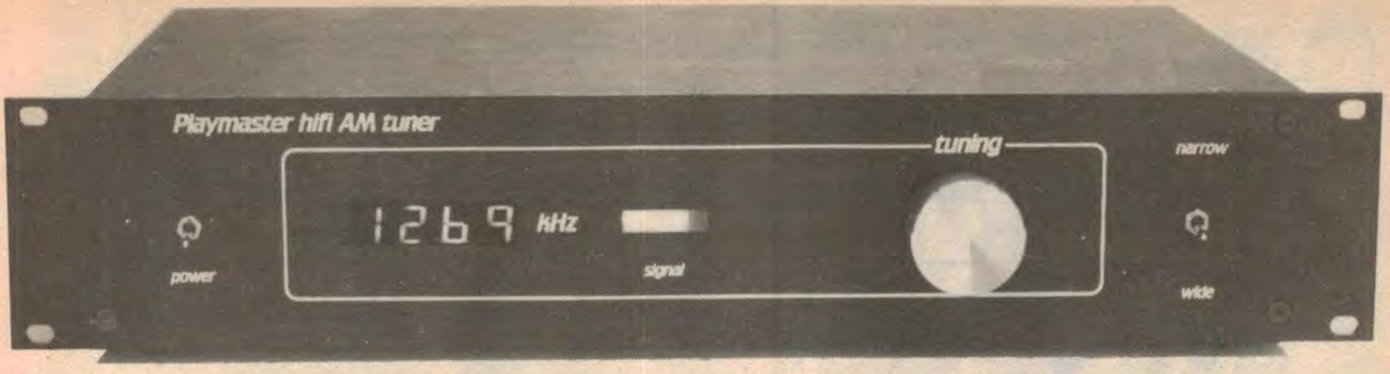
By the way, apart from a multimeter no special tools are required for the alignment procedure. To make the job really easy, we will be presenting a simple CMOS oscillator which will be used in conjunction with the digital readout section.

Also on the front panel is a 12-LED signal strength indicator which is a useful tuning aid, particularly when orienting the loop antenna for best results.

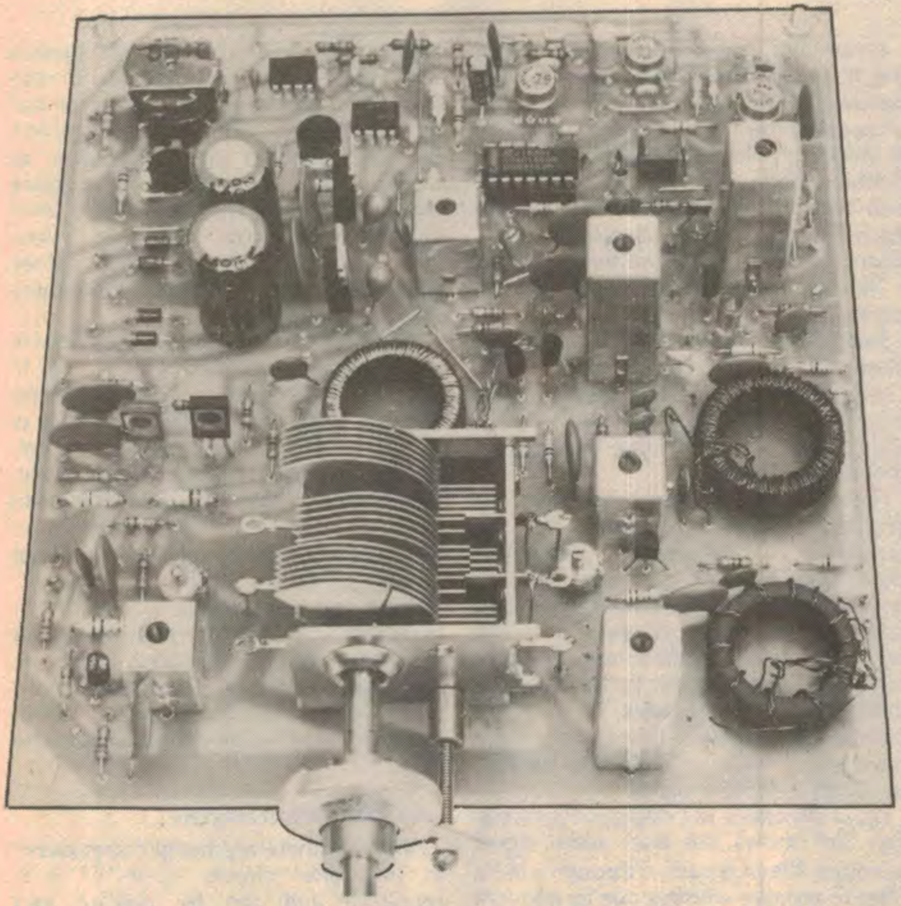
Noise-cancelling antenna

While the circuitry in the Playmaster AM Tuner certainly contains much that is new and innovative, the incorporation of a large loop antenna is probably the most important factor in the low noise reception obtained. Since the loop antenna is a balanced circuit it acts to cut out "common mode" mains radiated interference. This means in practice that there is an almost complete lack of interstation noise and almost no interference at all when tuned to a station. In fact, in many locations where AM reception is normally almost unlistenable due to mains interference, the clean reception provided by the new Playmaster tuner will be a revelation.

The antenna consists of a large single



The new Playmaster AM tuner is built into a rack mounting case and fitted with a silk-screened front panel.



This view shows the main tuner PCB, fully assembled. Note that the version shown is an early prototype – the final version differs in a few details.

loop of hookup wire about 2.5 metres square – the larger the better. It is terminated to a pair of binding post terminals on the rear of the tuner. Associated with these terminals is a screwdriver preset level control which enables the antenna input to be attenuated in very strong signal areas.

Finally, the audio output from the tuner is connected to a pair of RCA phono sockets. This makes it convenient for connection to a stereo amplifier and also provides for a synthesised stereo option which we will publish at a later date.

The performance details of the tuner are summarised in the accompanying panel and graphs. Note that the signal-to-noise ratio and harmonic distortion levels are better than those achieved by many AM transmitters presently in use.

Block diagram

Let us now discuss the general circuit features of the new Playmaster tuner by referring to the block diagram (Fig. 1). Broadly speaking, it is a superheterodyne tuner. As the name suggests, this uses a method of heterodyning or beating two signals together.

The method is as follows: The incoming signal frequency from the broadcast station is "mixed" with the signal from a tunable oscillator. This is called the local oscillator. In some tuner designs the oscillator and mixer functions are provided by one transistor which is known, not surprisingly, as a self-oscillating mixer. The difference between the oscillator and incoming RF signal is known as the intermediate frequency (IF) and this is amplified by one or more IF amplifier stages.

Finally, the intermediate frequency is fed to a detector which recovers the audio frequency modulation which is then fed to an amplifier and loudspeaker.

Incidentally, the term superheterodyne is a contraction of "supersonic heterodyne", although some textbooks state that the word "super" refers to the fact that the local oscillator frequency is greater than the incoming signal.

In the present design, the loop antenna described above feeds the broadcast signal frequencies to a pair of cascaded tunable RF bandpass filter stages which are controlled by two sections of the tuning gang.

The 1st and 2nd bandpass filters allow signals within a defined frequency passband to be amplified while attenuating all other frequencies. In our tuner, the filters pass signals about ±10kHz of the centre frequency, ie, 20kHz wide. By varying the capacitance of the tuning gang, the centre frequency over which the 1st and 2nd RF filter passes the signal can be altered while the bandwidth remains essentially constant.

Obtaining this broad passband is accomplished by stagger tuning. This involves peaking the 1st RF filter to a higher frequency than the 2nd RF stage, at the low frequency end of the broadcast band (520kHz). Toward the high frequency end (1630kHz) of the broadcast band the stagger tuning is unnecessary and the coils peak at the same frequency. To understand why it is only necessary to stagger tune at the low frequency and not the high frequency end it is necessary to understand the Q of a tuned circuit.

The Q of a tuned circuit is defined as the centre frequency (resonance) divided by the 3dB roll off points. The higher the Q the narrower the frequency bandwidth of the tuned circuit. As the tuned frequency increases, the 3dB points

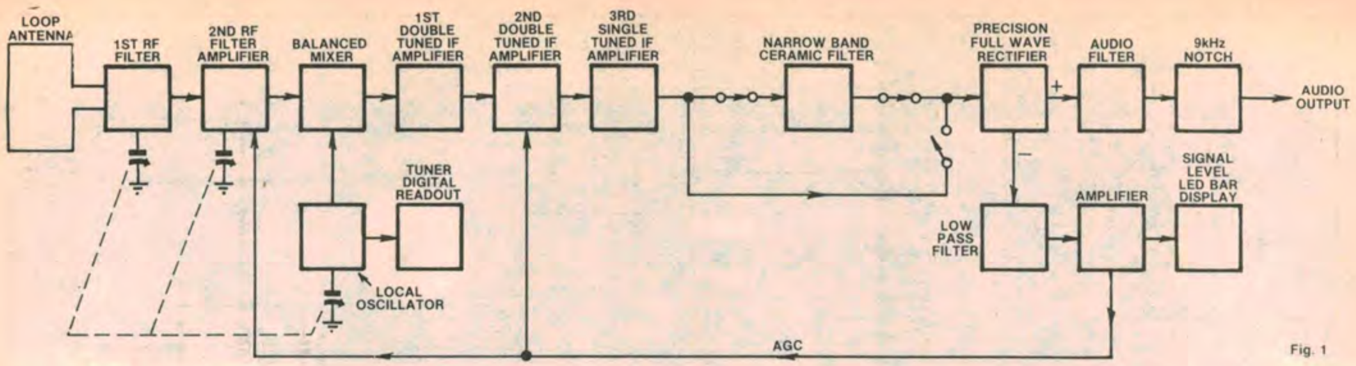


Fig. 1

The circuit is a full superhet design with two RF bandpass filters, three IF stages and a precision rectifier.

become wider for a given Q value and a wider bandwidth is obtained without the need for stagger tuning.

At the high frequency end of tuning, 1630kHz, the capacitor gang is at its lowest capacitance setting. Consequently, with the addition of small trimmer capacitors, the 1st and 2nd RF filters can be peaked to the same frequency by altering the trimmer capacitance by a small amount. At the low frequency end, the capacitor gang is at its largest value and the effect of these trimmers is very small. The ferrite slugs in the RF coils are then adjusted to peak at differing frequencies. As can be deduced, the stagger tuning effect progressively decreases until at the high frequency end the effect disappears.

The balanced mixer performs the mixing function described above except that, because it is balanced, the local oscillator and input RF signals do not appear at the output. The local oscillator is varied by the third section of the tuning gang so that the two RF filters already mentioned and the local oscillator "track" each other, ie they vary in tandem with each other. The mixer output is the intermediate frequency at 455kHz.

The local oscillator is designed to operate over the frequency range of 520kHz +455kHz to 1630kHz + 455kHz. This frequency is counted by the Tuner Digital Readout described in the October 1982 issue. The Tuner Readout subtracts the 455kHz offset from the oscillator signal and displays the tuned frequency.

Three filter stages are used to amplify the IF signal. These each have a wide bandwidth to maintain the response allowed by the RF filters. The 1st and 2nd IF stages provide amplification and are double-tuned, meaning that there are two separate reasonant circuits within each IF stage. The total number of IF filters is therefore five and these provide a sharp roll off at the edge of the passband.

Switching is provided so that a ceramic filter can be inserted in circuit with CMOS analog gates. The ceramic filter provides a narrow bandwidth and a sharp cutoff for night time listening, as mentioned above.

Following the narrow band filter is a precision full wave rectifier. Conventional superhet tuners use a diode as a detector but, since diodes are very nonlinear at low forward voltages, they are a considerable source of distortion. The precision rectifier overcomes the problems of non-linearity by placing the diode(s) in the feedback loop of an operational amplifier. This op amp must have a very wide bandwidth to be able to rectify a 455kHz signal.

Fig. 2 illustrates the detection process. Fig. 2(d) shows the final audio signal resultant after it is passed through a 9kHz filter to remove whistles due to adjacent stations, as mentioned before. The "notch" in the frequency response due to this filter is extremely narrow and so it has negligible effect on program content. For this reason it is permanently in circuit.

Returning now to the detector: this is actually a dual detector which comprises two diodes, one to conduct in the positive direction and the other for the negative signals. The positive direction is used for audio signal detection, as already discussed, and the negative direction for the AGC and signal level display. A very low pass filter, below 1Hz, allows only the negative carrier signal level to be recovered without any impressed audio signal.

The voltage from this low pass filter is amplified and returned to the 2nd IF amplifier and 2nd RF amplifier to control the gain of these amplifiers. The gain is reduced when the carrier signal, representing the strength of the signal, increases. This AGC (automatic gain control) action therefore tends to stabilise the audio output level for a varying amount of signal strength.

The signal level display is also driven from the AGC amplifier and provides a rising level of LED indication for an increasing level of AGC. Consequently the signal level is an indication of signal strength over the operating region of the AGC.

Circuit description

Although there are many components in the tuner circuit, some of it is repetitive and can be divided into separate basic circuit blocks. Three broad sections of the circuit are: the radio frequency section comprising the RF filters, mixer and oscillator; the low frequency areas including the low pass audio filter and notch filter, as well as the AGC; and the power supply.

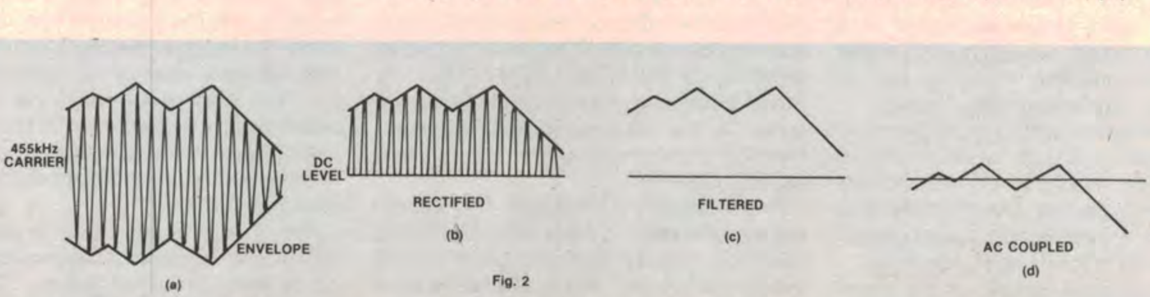
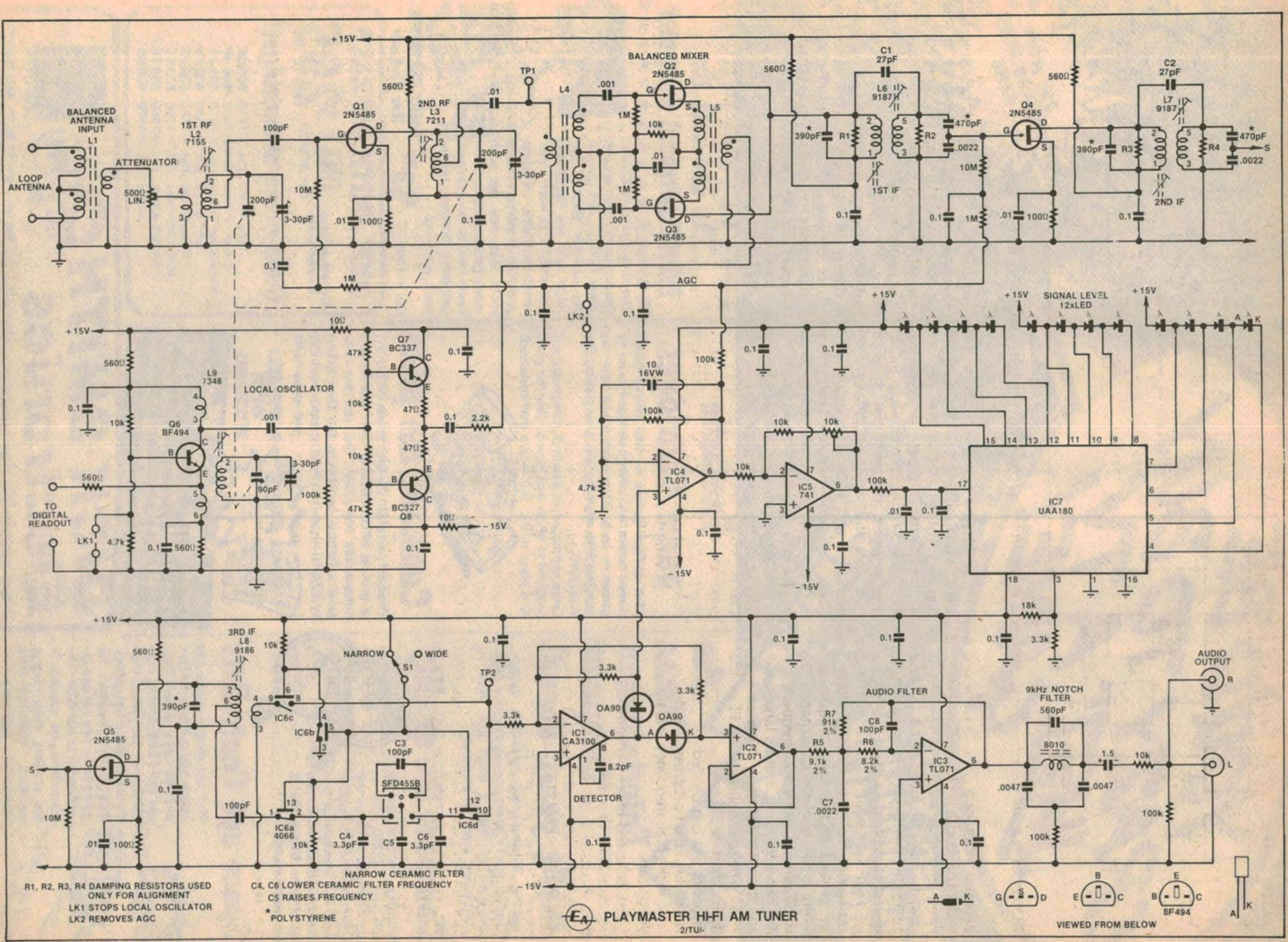


Fig. 2

Fig. 2: The signal detection process in an AM tuner. Fig. 2(d) shows the final signal output.



R1, R2, R3, R4 DAMPING RESISTORS USED ONLY FOR ALIGNMENT
LK1 STOPS LOCAL OSCILLATOR
LK2 REMOVES AGC

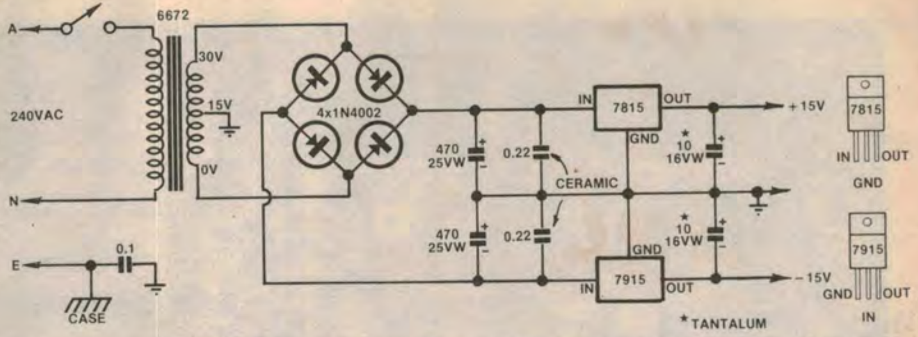
C4, C6 LOWER CERAMIC FILTER FREQUENCY
C5 RAISES FREQUENCY

*POLYSTYRENE

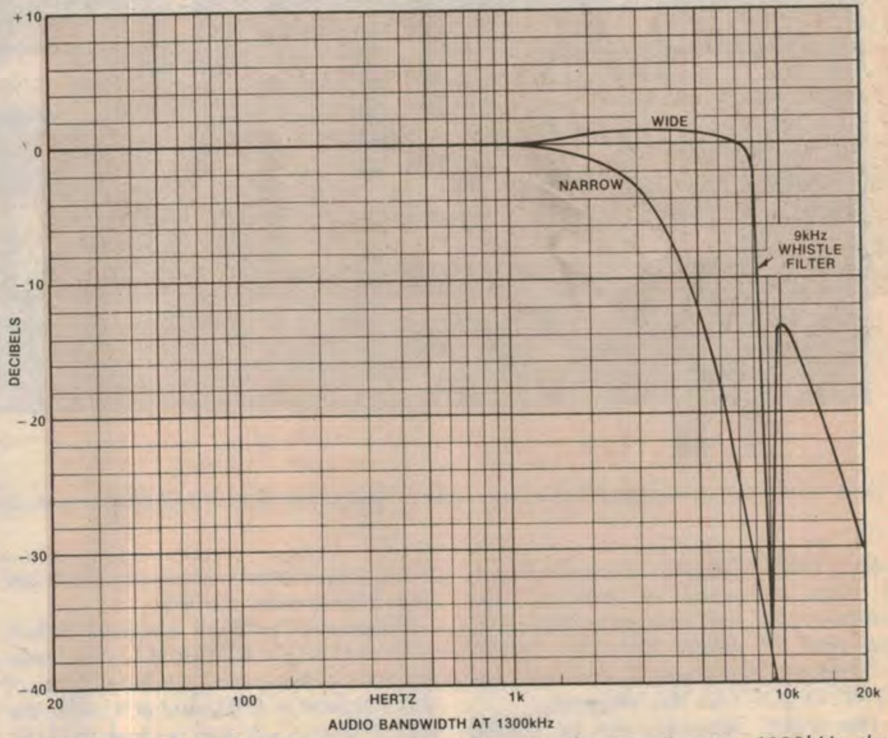
EA PLAYMASTER HI-FI AM TUNER

2/TU/-

Playmaster hifi AM tuner



The power supply is conventional and consists of a centre-tapped transformer, a bridge rectifier and positive and negative three-terminal regulators.



Although this graph plots the audio bandwidth when the tuner is set to 1300kHz, the response is virtually identical over the entire tuning range.

The balanced antenna input comprises a toroidal transformer wound so that common mode signals are shunted to ground. Signal attenuation is provided by the preset potentiometer at the secondary of the transformer and the pot wiper connects to the antenna coil of L2, the 1st RF coil. The secondary winding of L2, in conjunction with the 200pF variable capacitor and trimmer, forms the RF tuned circuit. Q1, an N-channel FET, is capacitively coupled to the tap of L2.

Q1 is a self-biased common source amplifier with the tuned circuit formed by coil L3 and its associated 200pF variable capacitor and trimmer as the drain load. The 100Ω source resistor provides self bias while gate circuit current is allowed to flow through the 10MΩ and 1MΩ resistors to the AGC. A 0.1μF capacitor connected to the 10MΩ resistor shunts AC signals to ground. Circuit gain is increased for AC signals by placing a bypass .01μF capacitor across the 100Ω source resistor. Decoupling for the power supply comprises the 560Ω resistor to the supply and 0.1μF capacitor to ground.

The tap from L3 capacitively couples to the primary of L4, a toroid transformer.

Two opposite phase signals are obtained from the separate secondary windings of L4 and are fed to FETs Q2 and Q3. Q2 and Q3 comprise the balanced mixer. These RF signals then cancel at the commoned drain connections. The local oscillator signal is applied via the toroid transformer L5 and two out of phase signals are obtained at the secondaries of the L5 transformer. These are injected into the sources of Q2 and Q3 respectively.

The local oscillator Q6 is fairly conventional and uses a tuned circuit formed with the main winding of L9, a 90pF variable capacitor and the associated trimmer. The oscillator is decoupled from the power supply with a 560Ω resistor and 0.1μF capacitor. A complementary symmetry buffer amplifier comprising Q7 and Q8 follows the oscillator, and drives coil L5 and the reflected impedances in the source terminals of FETs Q2 and Q3 in the mixer.

To maintain the broad bandwidth developed in the RF stages, overcoupling is used between double-coupled IF transformers L6 and L7. As well as inductive coupling, these transformers have capacitive coupling between the two coils. Each coil is peaked at a different frequency so as to broaden the bandwidth. This method allows sharp skirt selectivity but with the disadvantage of a double hump in the frequency response.

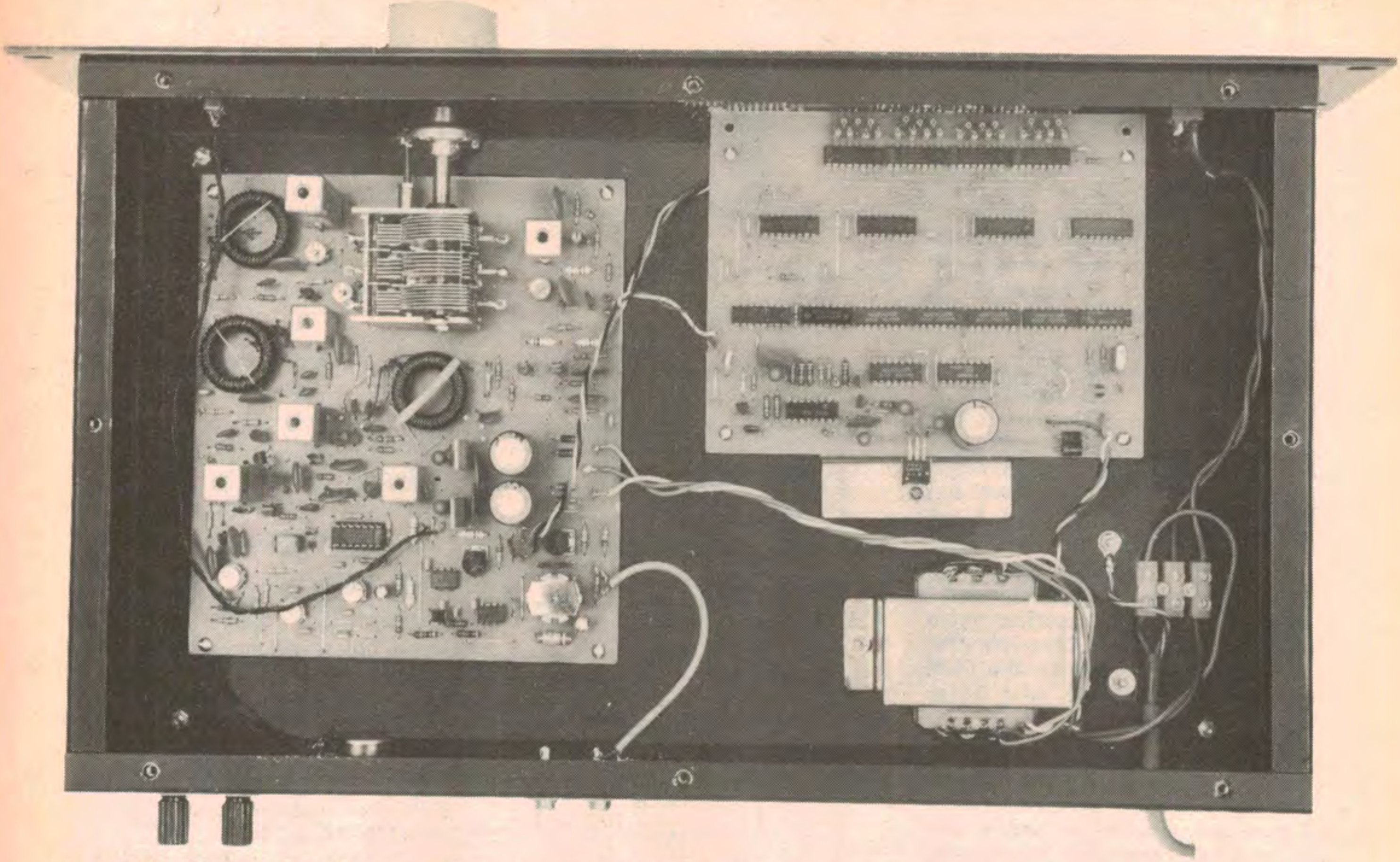
This double humping is caused by the peaks of each coil resonance differing to such an extent that a trough occurs in the centre of the passband. This causes peaking at the high end of the audio frequency response. To counter this, a further single IF stage is used to even out the trough at the centre of the passband and reduce the peak at the edges of the passband.

The common drain load for the mixer FETs is the coil winding of the 1st IF filter and a 390pF capacitor across the coil tunes the circuit. Power is derived from the associated 560Ω resistor decoupled by the 0.1μF capacitor. A 27pF capacitor top-couples the first coil to the second coil which is also tuned with 390pF, which in this case is a 470pF and .0022μF capacitor in series. The reason for using two capacitors is to provide a lower voltage tap from the winding to Q4.

Q4 provides impedance matching from L6 and amplification in the 2nd IF stage, as well as AGC action. The second IF stage is virtually identical to the 1st IF stage and together they provide very sharp roll off at the edges of the passband.

Q5 buffers the capacitively coupled output from L7 and provides gain in the 3rd IF stage. Two outputs are taken from this IF transformer, one from the tap off the main winding and the other from the secondary winding. A CMOS gate package (IC6) is used here to switch the signal either directly to the input of IC1 or via the ceramic filter. These separate taps compensate for the fact that the ceramic filter has a signal loss of about 9dB.

The ceramic filter consists of two ceramic tuned circuits which are top coupled with C3. This capacitor can adjust the bandwidth of the filter from 2kHz with a 27pF capacitor up to 5.2kHz



View inside the assembled AM tuner. Full constructional details will be given in next month's issue.

with a 150pF capacitor. We settled upon a 100pF capacitor. As supplied, the ceramic filter has a centre frequency tolerance of within 2kHz (ie, 455kHz ±1kHz) and consequently provision has been made to trim the frequency.

The centre frequency can be shifted low by adding C4 and C6 and making C5 a link. Alternatively, the centre frequency may be shifted high by adding C5 and omitting C4 and C6. The suggested values for these three capacitors will be noted later.

Precision rectifier

IC1 is a CA3100 operational amplifier suitable for wideband applications and in fact has an uncompensated open loop gain of around 50dB at 455kHz. The amplifier is used here as a precision rectifier with unity gain. The amplifier is basically arranged in an inverting amplifier configuration, with feedback via two separate resistors each in series with a diode. Now there are two feedback paths, one for positive swings of the op amp and the other for negative swings. Tapping the signal at the anode of one diode and cathode of the other will result in detection of the negative and the positive rectified signals respectively. Lag compensation with the 8.2pF capacitor ensures stability.

The positive rectified waveform is buffered with IC2, a TL071 BiFET operational amplifier. The unity gain bandwidth of this amplifier is 3MHz and at 455kHz the typical open-loop gain is close to 20dB. This amplifier is only satisfactory at these frequencies when used as a unity gain buffer. Buffering is required since any loading on the rectifier causes distortion of the rectified waveform.

A 40dB per decade Butterworth filter (IC3) is used to filter the rectified waveform and has a passband gain of 10. The following notch filter provides a very sharp null at 9kHz and is adjustable by rotating the ferrite cup to open or close the integral air gap.

At this stage the output of the filtered audio signal has a DC component, and capacitive coupling with the 1.5μF capacitor provides a signal referenced about ground. The 100kΩ resistor to ground allows a path for the coupling capacitor to charge if there is no load on the output. The 10kΩ resistor in series with the output prevents any undue loading effects by the amplifier stage which could possibly reduce the depth of the notch.

> We estimate that the current cost of components for this project is approximately
>
> **$250**
>
> This includes the cost of a pre-punched case with silk-screened front panel, plus sales tax.

Automatic gain control

Meanwhile, the negative rectified signal output from IC1 is buffered and integrated by IC4. This heavily filtered signal has a negligible audio component since the integrator rolls off signals above one Hertz.

After further filtering with a 100kΩ resistor and two 0.1μF capacitors, the signal is virtually a DC level which varies according to the carrier level. This signal is then used to apply AGC to the two FETs in the RF amplifier and 2nd IF stage (Q2 and Q4). The more negative the AGC, representing a higher carrier signal, the less gain the FETs provide, thereby rendering the 455kHz signal level relatively constant for a wide range of input signal strengths.

Parts List for the Playmaster AM Tuner

Chassis and Hardware

1 aluminium rack cabinet, 430 x 255 x 88mm, with pre-punched front panel and artwork
1 large knob to suit
1 power transformer, A&R 6672 or equivalent
2 SPDT mains switches
1 mains cord and plug
1 grommet to suit mains cord
1 mains cord cable clamp
4 rubber feet
5 19mm brass standoffs
4 25mm brass standoffs
1 dual RCA panel output socket
1 500Ω linear potentiometer
2 binding post terminals

Main Tuner PCB

1 printed circuit board, code 82qr12a, 161 x 178mm
3 Neosid ferrite ring cores, 4328R/2 F14
18 metres 0.4mm (26 B&S) enamelled copper wire
1 Jabel 7155 antenna coil
1 Jabel 7211 2nd RF coil
2 Jabel 9187 455kHz double-tuned IF transformers
1 Jabel 9186 455kHz IF transformer
1 Jabel 7348 oscillator coil
1 Jabel 8010 whistle filter coil
1 Roblan SM3P padderless gang
1 reduction drive assembly
1 SFD455B Murata ceramic filter

SEMICONDUCTORS
3 TL071, CA3140 or LF351 BiFET op amps
1 CA3100 wideband op amp
1 741 op amp (can be TL071)
1 µAA180 12-LED bar graph display driver IC
5 2N5485 N channel FETs
1 BF494 high frequency NPN transistor
1 BC337 NPN transistor
1 BC327 PNP transistor
2 OA90 germanium diodes
4 1N4002 1A rectifier diodes
1 7815 positive 15V 3-terminal regulator
1 7915 negative 15V 3-terminal regulator

CAPACITORS
2 470µF/25VW electrolytic
1 10µF/16VW electrolytic
2 10µF/16VW tantalum
1 1.5µF/16VW electrolytic
2 0.22µF ceramic
13 0.1µF ceramic
12 0.1µF monolithic ceramic
1 0.1µF metallised polyester
6 .01µF ceramic
2 .0047µF metallised polyester
2 .0022µF ceramic
1 .0022µF metallised polyester (C7)
2 .001µF ceramic
1 560pF polystyrene
2 470pF polystyrene
3 390pF polystyrene
4 100pF ceramic
2 27pF ceramic
1 8.2pF ceramic
2 3.3pF ceramic (see text)

RESISTORS
(¼W, 5% unless specified)
3 x 10MΩ, 4 x 1MΩ, 6 x 100kΩ, 1 x 91kΩ 2%, 2 x 47kΩ, 9 x 10kΩ, 1 x 9.1kΩ 2%, 1 × 8.2kΩ 2%, 2 × 4.7kΩ, 3.× 3.3kΩ 1 × 2.2kΩ, 6 × 560Ω, 3 × 100Ω, 2 × 47Ω, 2 × 10Ω, 1 × 10kΩ small horizontal mounting trimpot.

Main Readout PCB

1 printed circuit board, code 82fc8a, 160 x 125mm
1 4MHz series mode crystal

SEMICONDUCTORS
1 MC10116 triple differential line receiver
5 74LS90 decade counter/dividers
1 74LS93 divide-by-eight counter
1 74LS04 hex inverter
4 4029 presettable decade counters
4 4511 BCD to 7-segment decoders
1 4017 decade counter/divider
1 7805 3-terminal 5V regulator plus insulating hardware
4 1N4002 1A silicon diodes
1 2N5485 VHF FET
2 2N4258 PNP transistors

CAPACITORS
1 1000µF/25VW PC electrolytic
1 10µF/25VW PC electrolytic
1 10µF/25VW tantalum
2 10µF/10VW tantalum
4 0.1µF monolithic
2 0.1µF ceramic
1 .01µF metallised polyester
1 47pF polystyrene
1 39pF NPO ceramic
2 27pF NPO ceramic

RESISTORS
(¼W, 5% unless specified)
1 x 1MΩ, 5 x 1kΩ, 2 x 1kΩ 1%, 8 x 470Ω, 29 x 270Ω, 1 x 220Ω, 1 x 100Ω, 1 x 22Ω.

LED Readout PCB

1 printed circuit board, code 82qr12b, 146 x 33mm
4 FND500 common cathode displays
12 rectangular LEDs, 8 red, 4 green
2 0.1µF monolithic capacitors
1 18kΩ ¼W 5% resistor
1 3.3kΩ ¼W 5% resistor

MISCELLANEOUS
Rainbow cable, hookup wire, machine screws and nuts, solder, etc.

NOTE: Components specified are those used in the prototype. Components with higher ratings may generally be used provided they are physically compatible.

Links LK1 and LK2 and resistors R1-R4 are used only during the alignment procedure. Note that only one 4.7kΩ resistor is required for R1-R4, since the same resistor is used at each position in turn.

Signal strength indicator

The output of IC4 also drives IC5 which is an inverting amplifier with gain adjustable by means of a 10kΩ trimpot. In turn, IC5 drives IC7 which is the signal strength indicator. This has 12 LEDs to provide a logarithmic display. The range over which the LEDs operate is set by the 18kΩ and 3.3kΩ resistors connected to pin 3 of IC7.

In all cases, bypassing of the power supply at each active device is affected with 0.1µF capacitors. This bypassing reduces the possibility of feedback being applied through the power supply and causing instability of the circuit. Ceramic capacitors are used for all bypassing involving RF, and small monolithic ceramic capacitors used for the audio stages.

The power supply is a conventional centre tapped full wave rectified circuit with positive and negative 15V three terminal regulators. The reservoir capacitors are 470µF/25VW electrolytics and, as these are not suitable for suppressing high frequency noise, 0.22µF ceramic capacitors are also used. The regulators are bypassed at the output with 10µF tantalum capacitors to improve transient response and further bypass the supply lines.

Although the 1A capacity of the 6672 transformer is far more than is used by the circuit, the transformer was selected for the 30V secondary voltage necessary for the two 15V regulators.

A 0.1µF capacitor is used to shunt high frequency noise from the ground of the circuit to the chassis.

That completes the description of the circuit of our new AM tuner. Next month we shall continue with the assembly of the three printed circuit boards. These comprise the main tuner PCB, the main display PCB (which is similar to that described in the October issue), and a new companion LED readout board.