

# THE NEW ZEALAND MADE PACEMAKER TRANSPORTABLE TRANSISTOR RADIO FROM 1957-1960: MIXERS, RF STAGES & IMAGE REJECTION.

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This article examines the heart of the AM Superhet transistor radio, the mixer or mixer-oscillator. In addition it describes the amazing New Zealand made Pacemaker Transportable radio and compares & contrasts some of its features with a very similar looking radio of the time, the Sony TR-72. A separate article on the TR-72 radio is available on: [http://www.worldphaco.com/uploads/THE\\_SONY\\_GENDIS\\_TR-72\\_TRANSISTOR\\_RADIO.pdf](http://www.worldphaco.com/uploads/THE_SONY_GENDIS_TR-72_TRANSISTOR_RADIO.pdf)

The Pacemaker transportable radio has been credited with being one of the world's first commercial transistor radios to have a tuned RF input stage. It may well have been the very first.



Most transistor radios of the mid 1950's (for example the Regency TR1 1954 and the Sony TR72 1956) did not have an active tuned RF stage or any front end RF stage. Most medium wave radios did not have RF stages right into the 1970's. However Short Wave radios often did. Why was this and what would the advantages of the tuned RF stage be?

Nearly all transistor radios employ the common "autodyne" mixer or "converter" circuit or the combined mixer-oscillator circuit sometimes called an "Additive Mixer". This is a misnomer because the important process involves multiplication of the incoming frequency with the oscillator frequency, not addition.

The fundamental principle of the Superhet radio is one of conversion. Meaning the received frequency is converted down to a lower frequency called the intermediate frequency or IF frequency. This is why sometimes mixers were also called converters. For typical transistor radios the IF frequency is nominally 455KHz. The IF amplifier is usually composed of two transistors and three transformers in a typical AM transistor radio. Some radios such as the Pacemaker only have two IF transformers and one IF transistor.

Most of a transistor radio's signal gain and selectivity is in the IF amplifier. While the IF transformers are tuned to a centre frequency of 455KHz, there is still a relative response around this value and a bandwidth wide enough +/- 3KHz to +/- 5KHz to pass audio frequencies to the detector. The converter in the typical radio is either a mixer transistor with a separate oscillator transistor feeding it, or more commonly a single transistor oscillator which also acts as a mixer also and so it is called a "mixer-oscillator".

When the received signal is "mixed" with the oscillator signal the sum and difference of the two frequencies appears in the mixer output, which for a transistor mixer is represented by the circuit currents in the mixer's collector or power supply circuit.

If the received signal frequency is 650KHz and it is mixed with the oscillator signal frequency of 1105KHz, then sum and difference frequencies are generated. The difference being exactly 455KHz which is accepted via the IF amplifier. Example frequencies are shown on the diagram of figure 1 below. In general the oscillator is set to run at the IF frequency (455KHz) above the incoming signal frequency. The oscillator is "ganged" to the antenna circuits tuning by the two gang variable capacitor so that the oscillator signal tracks 455KHz above the received frequencies. The tracking (for reasons beyond the scope of this article) is never perfect and there are "tracking errors" which with good design are zero at the band ends and the band centre.

**BASIC SUPERHET & THE  
IMAGE PROBLEM:**

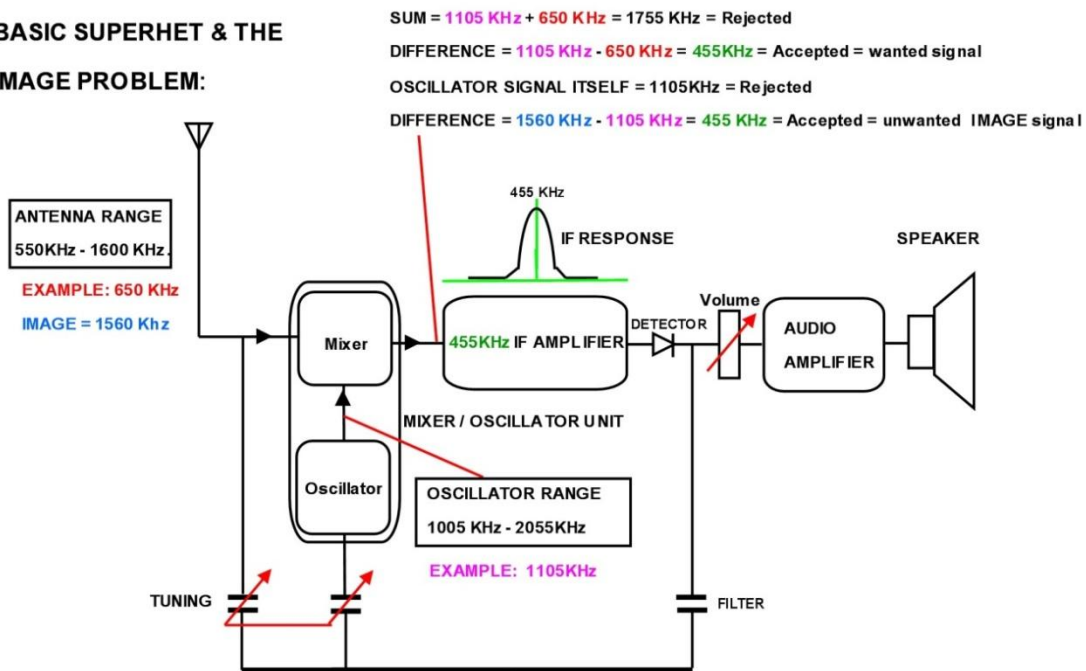


FIGURE 1.

As noted in figure 1, there is another frequency known as the “image” frequency that would also be accepted. This image frequency or potential interfering radio station will have a lower signal level than the wanted signal because the tuned coil in the antenna circuit (or on the ferrite rod in the transistor radio) is tuned to the wanted signal. However if the image frequency was strong enough it could break through. The IF amplifier rejects all signals and accepts the difference signal when the oscillator frequency is 455KHz above the received frequency. However the “image” frequency which is  $2 \times 455\text{KHz} = 910 \text{ KHz}$  above the wanted received frequency (or 455KHz above the oscillator) is at risk of breaking through as its difference frequency with respect to the oscillator is again 455KHz.

For the AM radio band then, most of the possible image frequencies above 790KHz tuning on the dial are in fact out of the MW band are above 1700KHz where there are no(few) stations transmitting. However this is not the case on the Shortwave bands where there are many stations transmitting 910KHz above the received frequency.

One solution to the image problem is to have a tuned “preselector” or radio frequency stage (RF stage) requiring an extra transistor and coil prior to the mixer. This stage

helps to select the wanted frequency and attenuate other frequencies further away such as the image frequency. It has the effect of improving the radios selectivity and also it provides some additional gain (sensitivity) and provides additional signal level to the mixer potentially helping to lower the noise generated in the mixer itself. This was done in the Pacemaker Radio.

### **How the transistor radio mixer works:**

The mixer/oscillator stage is the most interesting stage in the Superhet radio. This stage is unassuming looking and “simple looking” with a single transistor, however it performs an extraordinarily complex and interesting role. This sort of complex functionality created by apparent simplicity and a paucity of components is the type of electronics circuit that I find very impressive.

Exactly how the mixer is working is often glossed over in many texts on transistor radio circuits however it is critical to the function of the simple AM transistor radio.

In order to generate sum and difference frequencies of two periodic waveforms such as sine waves (or cosine waves) the two signals must in fact be multiplied together. It will not work if the signals are simply added. So how does a single transistor mixer stage or mixer-oscillator stage multiply two signals? Firstly looking at two cosine waves of angular frequency  $\omega_1$  and  $\omega_2$  Radians per second:

(Note that  $\omega = 2\pi f$ , where  $f$  is the frequency in cycles per second. Multiplying the angular frequency  $\omega$  by time  $t$  yields the angle in radians. Therefore the electrical or magnetic component of a radio wave has the general form  $Y = A.\cos(\omega t)$  where  $Y$  is the amplitude varying with time and  $A$  is the peak amplitude and the frequency  $f$  is  $\omega/2\pi$ ).

If we multiply the two angular frequencies together we have:

$$\cos(\omega_1 t) \cdot \cos(\omega_2 t) = \frac{1}{2} \cos(\omega_1 + \omega_2)t + \frac{1}{2} \cos(\omega_1 - \omega_2)t$$

This trigonometrical identity is available from many texts. So something quite remarkable has happened. Multiplying the two waves has resulted in two other frequencies which are the sum of the two initial frequencies ( $\omega_1 + \omega_2$ ) and the difference of the two frequencies ( $\omega_1 - \omega_2$ ). They both have half the amplitude of the original waves.

(Immediately this result is recognisable as the frequency spectrum of Amplitude Modulation itself, with a central carrier and a side band on either side with  $\frac{1}{2}$  the amplitude. Mixers are in fact also Modulators).

In specialised mixer integrated circuits (such as the MC1496) the multiplication of two waves is exactly as per the equations above. This IC is a “voltage multiplier”. However in the case of the single transistor mixer or combined single transistor mixer-oscillator in the typical transistor radio the situation is a little different.

Figure 2 below shows what happens when two different signals, a and b, are added and then amplified either by a linear amplifier in one example or a “square law” amplifier in the other. As can be seen linear amplification results in simple scaled up amplitudes of signals a and b. On the other hand if the amplification obeys a square law then the product of the two signals a and b appears as the term “2ab”: see figure 2 below:

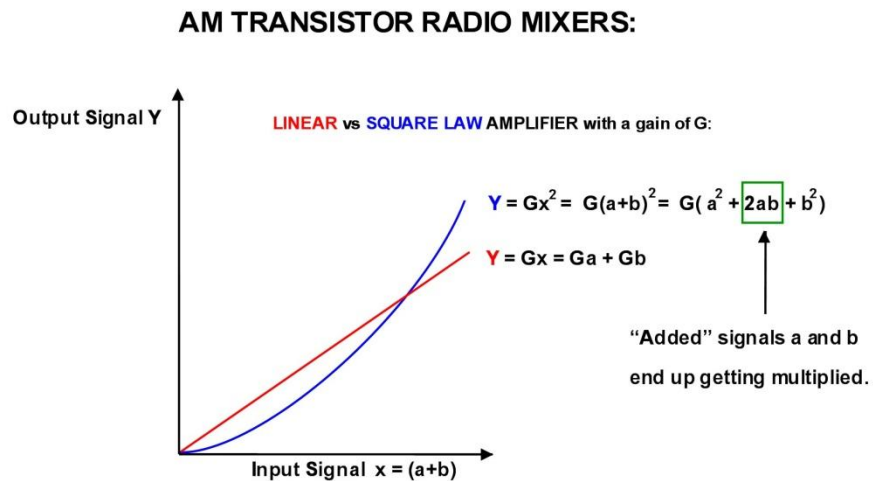


FIGURE 2.

The signals a and b have been multiplied by square law amplification. Also other signals appear which are equal to the square of signal a, also the square of signal b. If we represent these signals as cosine waves instead we find out what happens when two added waves get squared:

$$(a + b)^2 = (\cos(\omega_1 t) + \cos(\omega_2 t))^2 =$$

$$1 + \frac{1}{2} \cos(2\omega_1 t) + \frac{1}{2} \cos(2\omega_2 t) + \cos(\omega_1 + \omega_2)t + \cos(\omega_1 - \omega_2)t$$

Again the sum and difference of the two waves has appeared, but this time the amplitude of those is not halved. The “1” represents a DC component. Also along with that yet two more frequencies  $2\omega_1$  and  $2\omega_2$  which are twice the frequencies or second harmonics of the original cosine waves. So squaring a cosine (or sine) wave doubles its frequency. (This is one easy method of frequency doubling in radio engineering by passing a sine wave through a squarer circuit).

Therefore the current in the mixer circuit or the “mixer current” in the simple transistor mixer stage consists of a “cocktail” of different signals:

- 1) The received radio station frequency.
- 2) The oscillator frequency.
- 3) The sum of the oscillator and received station frequency.
- 4) The difference between the oscillator and received station frequency.
- 5) Twice the received radio station frequency.
- 6) Twice the oscillator frequency.
- 7) The transistor’s DC bias currents.

Also for anything other than perfect square law amplification there will be more frequencies or harmonics in the mixer’s output current or output signal. In fact the transfer curve could be represented by a polynomial of the form:

$$ax^1 + bx^2 + cx^3 + dx^4 \dots\dots\text{etc.}$$

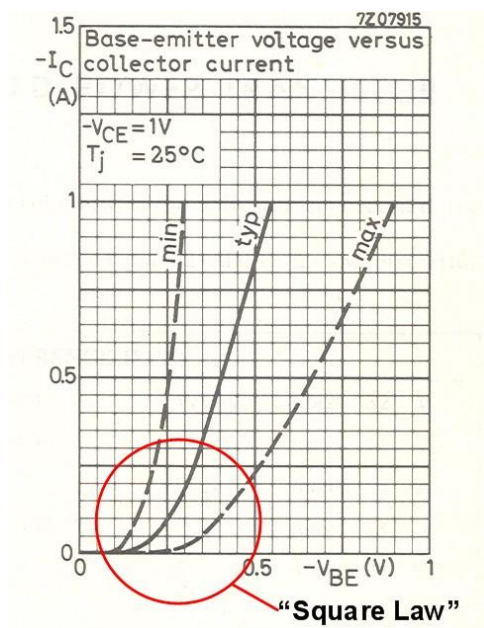
It turns out that “cubing” a sine wave for example results in a 3<sup>rd</sup> harmonic or 3 times the frequency. This means there can be 2<sup>nd</sup> 3<sup>rd</sup> 4<sup>th</sup> 5<sup>th</sup> etc frequency harmonics of the

oscillator & received frequency at the mixer output. These signals are rejected by the IF amplifier which only amplifies 455KHz +/- about 3 KHz.

A single transistor operating at a low bias level has a voltage amplification response curve which is non linear and very similar to the blue  $x^2$  curve in figure 2. This is not obvious from most transistor data sheets because the transistor's base-emitter voltage is not often plotted against collector current. More often than not the base current is plotted against collector current which looks more linear and the slope at any point is the small signal current gain.

When considering the voltage operating across the transistor's base-emitter junction, the function or response is very similar to a simple diode. The collector currents are converted to a voltage by the impedance in the collector load circuit. So the transistor, at low bias levels, when considered as a voltage amplifier is a "Square Law" amplifier. So are field effect transistors too. An MPF102 junction FET for example also makes a good mixer or mixer/oscillator. The following graph figure 3 is of base-emitter voltage vs collector current for a PNP germanium transistor from a Philips manual:

FIGURE 3.



The lower part of the curves are non linear and "square law" in basic character, especially in the zone of base-emitter voltages less than 0.5V.

The circuit of figure 4 below shows a typical transistor radio self oscillating mixer stage called an "autodyne converter" such as that used in the Sony TR-72 for example. The mixer in the Pacemaker has a slightly different configuration.

The mixer stage's total current, containing all of the signal components passes through the primary of the first IF transformer, which like the other IF transformers in the radio is tuned to a centre frequency of 455 KHz. The first IF transformer's primary winding is simply in series with the mixer circuit's total current so it can be placed as convenience dictates as shown in the diagram. The position in series with the transistor's collector circuit is used in the Pacemaker Radio and the position in series with the ground connection is used in the TR-72. There are many versions of single transistor self oscillating mixers; often the feedback to sustain oscillations is from the oscillator coil to the transistor's Emitter, not the Base. In essence they all have the same in functionality and require that the transistor is mildly biased and operating in its non linear region.

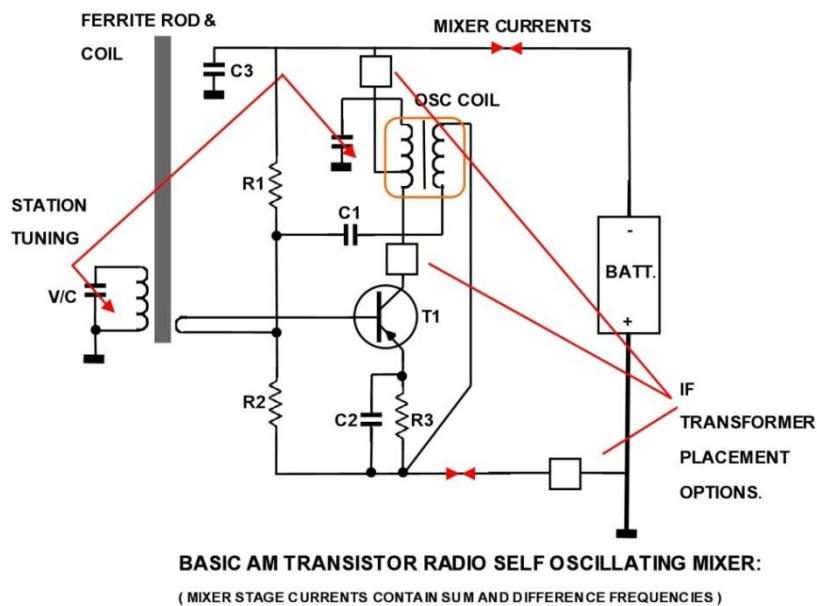


FIGURE 4.

The variable capacitor (V/C) tunes the ferrite rod (aerial) circuit and is ganged to a second capacitor which tunes the oscillator coil. In most transistor radios (like the Sony TR-72) the gang which tunes the oscillator is smaller in total value to allow proper tracking of the oscillator frequency with the tuning of the received frequency on the ferrite rod coil so they remain close 455KHz apart and minimise tracking errors.

In some radios (such as the Pacemaker) where the tuning gangs of the oscillator and other tuning capacitor gangs have the same value then an extra capacitor called the "Padder" capacitor is placed in series with the oscillator capacitor to reduce its value by the correct amount so that the tracking errors are minimised.

In figure 4, R1 and R2 are the transistor's bias resistors which set the transistor's DC conditions. The incoming radio station signal from the small coupling coil on the ferrite



rod assembly is mixed into the transistor's base circuit along with the oscillator feedback signal via C1 which maintains the self oscillations. The Ferrite rod coil has a relatively small number of turns feeding the transistor's base circuit so the main tuned winding on the ferrite rod is not heavily loaded. C2 and R3 help the transistor maintain a stable DC bias condition. The polarity of the oscillator coil windings is such that the feedback is positive to sustain oscillations. Capacitor C3 bypasses any radio frequencies on the battery supply voltage.

## The Pacemaker Transportable schematic:

I was unable to locate the original manufacturer's schematic, so it was traced out from the radio which might be a 1960 version. The circuit design has some interesting features, figure 5.

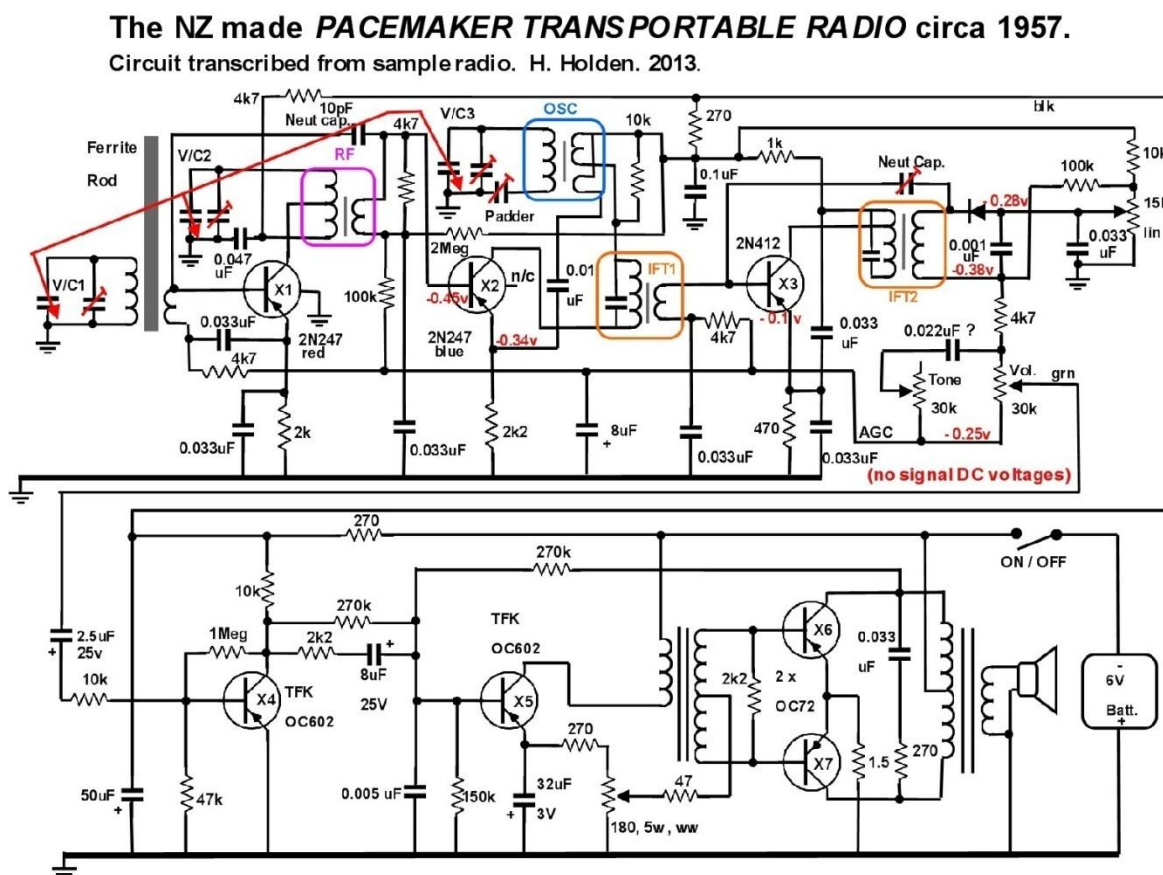


FIGURE 5.

One immediate difference, the Pacemaker uses PNP germanium transistors while the Sony TR-72 uses NPN's

### **RF stage or Preselector stage:**

This is based on transistor X1 a 2N247 and one gang of the 3 gang tuning capacitor. The RF stage has neutralisation with a fixed 10pF capacitor. This is a requirement for stability because the tuned circuits in the base and collector stage of X1 are tuned to the same frequency and would otherwise exchange energy with each other via the transistor's Miller capacitance and this stage would burst into oscillation as a result. The 3 gang tuning capacitor (V/C) has the same values per gang and looks like the type of V/C seen in tube radios of the time.

### **The IF Amplifier:**

The radio has one less IF amplifier stage than the typical transistor radio of the time and one less IF Transformer. The loss of gain and selectivity is compensated for by the gain provided by the tuned RF stage of transistor X1. The net overall gain and selectivity is similar to a standard radio, however due to the selectivity of the RF stage the image rejection is substantially improved and possibly there is lower mixer noise.

### **The Mixer- Oscillator:**

The 3 gang tuning capacitor has the same values per gang so the gang allocated to the oscillator section VC3 must have a series Padder capacitor to average the tracking errors of the oscillator tuning range with respect to the received frequency range. The mixer-oscillator stage has in phase feedback from the oscillator transformer to the transistor's emitter to sustain oscillations, unlike the mixer circuit of the Sony TR-72 for comparison where the out of phase feedback is fed to the transistor's base.

### **The Detector:**

The diode was not labelled, it is probably an OA90 or similar. The detector has been arranged to have bias control. Due to the fact that the detector diode cathode is at the AGC voltage value, which is about -0.38V, even in the absence of signal this tends to

excessively forward bias the diode. So another negative voltage (developed across the 15k preset) is added to the diode anode. In my set this was -0.28v which leaves a residual 100mV forward bias. This value was possibly the factory setting. A small detector forward bias can help to demodulate weak signals.

### **Automatic gain control, AGC:**

Agc is applied to X1, X2 and X3. Less AGC range is applied to the mixer-oscillator X2 as it is sourced from the divider comprising the 100k and 2 meg Ohm resistors. There is the risk that high agc levels could deactivate the oscillator and it is thought not wise to apply the agc to the mixer-oscillator by some. This is probably the reason for the 2 meg Ohm resistor which assists X2's bias so X2 still stays in oscillation even with high agc levels, yet it still subject to some agc.

### **Audio Amplifier Stages:**

The audio amplifier design in this set has some interesting features too. The input stage X4 has a grounded emitter and is DC stabilised by collector to base feedback via the 1 meg resistor. There is direct coupling from X4's collector circuit to establish the bias on the driver stage X5, whose emitter current sets the output transistor's bias current via the voltage developed across the wire wound adjustable resistor in X5's emitter circuit. This arrangement is very unusual. It means that the output stage's bias (the OC72's) current stability is controlled by the input transistor's (X4's  $V_{be}$ ) base-emitter voltage characteristic, which is very dependent on temperature.

As the radio heats up X4's  $V_{be}$  drops and X4 turns on harder. This lowers the voltage on X4's collector circuit and lowers the base voltage to X5, therefore X5's emitter voltage drops, tending to turn off the output transistors. So it would appear the designers have used the audio input transistor X4 as a "temperature compensation device" for the output transistors.

There is also a small amount of low frequency and negative DC feedback from the collector of X6 via the 270k resistor which slightly aids the DC stability but this effect is limited due to the relatively low resistance of the output transformer's primary windings. This could also possibly be some sort of anti motor-boating network as its AC frequency response is such that it is only active below about 100 to 200 Hz. Again this arrangement is very unusual. There is no conventional audio AC negative feedback in the Pacemaker radio such as seen around the audio stages of radios such as the Sony

TR-72. Normally feedback is from the speaker itself to the driver transistor's emitter circuit. The following photo figure 6 shows some other features inside this unique radio:



FIGURE 6.

From the rear there is little to see and most of the parts are protected from the owner's prying fingers. The radio runs from a 6V lantern battery which is extremely long lasting in this application. The radio's current drain is only about 10mA. The Ferrite rod assembly, the audio driver and output transformers are visible along with the elliptical Rola speaker and the 3 gang variable capacitor that characterises this radio.

Figure 7 shows the internal arrangement with the chassis removed from the cabinet and the speaker removed:

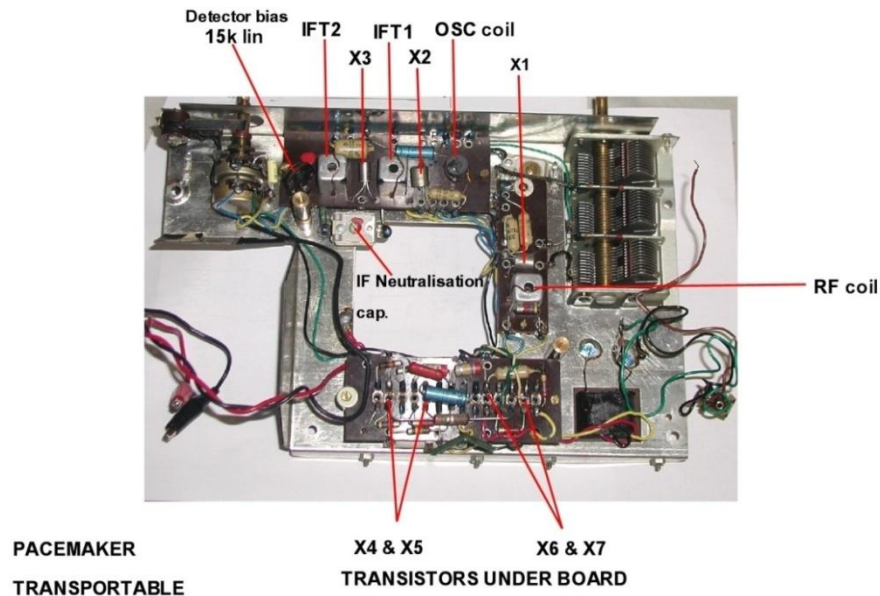
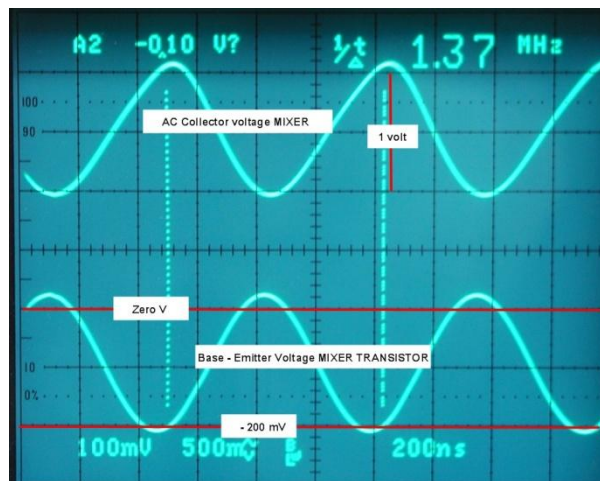


FIGURE 7.

## The Mixer- Oscillator in the Pacemaker radio:

Measurements across this stage in the radio confirms as expected that the mixer-oscillator transistor X2 is operating in its non-linear region. The following recording was taken (under no received signal conditions) of the voltage across X2's base-emitter connections with the scope channel on DC and 100mV/cm. The AC collector voltage of X2 was recorded at the same time (upper trace) and as can be seen it is not a linear representation of the base-emitter voltage. When a radio station signal is received the waveforms becomes a very complex arrangement with many frequencies and harmonics.



Remember that this set is a *positive ground* unit so that an increasing negative deflection of the scope's beam corresponds to increasing absolute voltage. At times during the cycle of oscillation the transistor X2 is actually cut off as the base-emitter voltage is zero volts or a little positive. Although the collector voltage is a little distorted, the sine wave voltage across the oscillator tank circuit of VC3 and the padder capacitor is undistorted, as is the feedback voltage to X2's emitter. The recording confirms that the mixer transistor operating over a base-emitter voltage range of about -200mV and is therefore operating in its non linear area as it is required to behave as a "mixer".

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