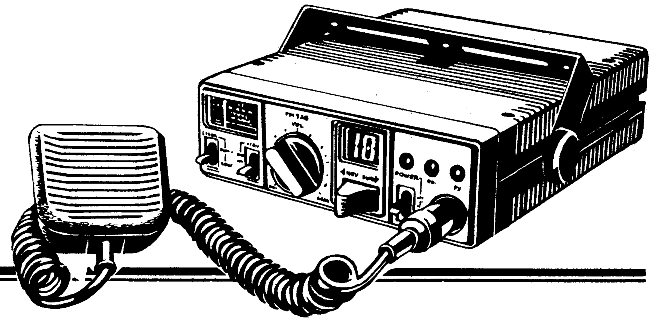


CRYSTALS, SYNTHESISERS AND THE PHASE-LOCKED LOOP — Part 1

Most readers who have scrutinised literature on CB transceivers will have become aware of terms like "crystal control", "frequency synthesiser" and "PLL" ("phase locked loop"). This 2-part article. seeks to impart some insight into these terms, without bogging down in a lot of technical detail.

by NEVILLE WILLIAMS

The exact frequency on which a CB transceiver transmits, along with the stability of that frequency, depends primarily on the in-built transmitter oscillator stage. Similarly, assuming superhet circuitry, the frequency to which the receiver is tuned, and the stability of the tuning, is determined by the in-built receiver oscillator.

The abovementioned terms — crystal control, synthesiser and PLL (phase-locked loop) — all describe the nature of the oscillator circuits in a transceiver and therefore represent an important piece of information about its basic design.

In some transceivers, notably those used on the HF amateur bands, the oscillators use inductors and variable capacitors, and are tuneable across certain specific frequency segments. While the tuneable system has its advantages, it also leaves room for error in the choice of frequencies, either because of inadvertence on the part of the operator, or faulty calibration of the tuning mechanism.

Amateur station operators retain the right to use this kind of equipment only because they have demonstrated basic technical skills by examination, and because they have the means to check dial calibrations from time to time.

Virtually without exception, 2-way radio equipment intended for use by (officially) non-technical operators is licensed on the basis of its operation on one or more specific frequency channels, set aside for the class of service and selectable only by a switch. In fact, the equipment has to meet a whole range of official requirements before it can be "type approved" for use on the air at all.

Equipment intended for use for Citizens Band Radio Service falls into this category.

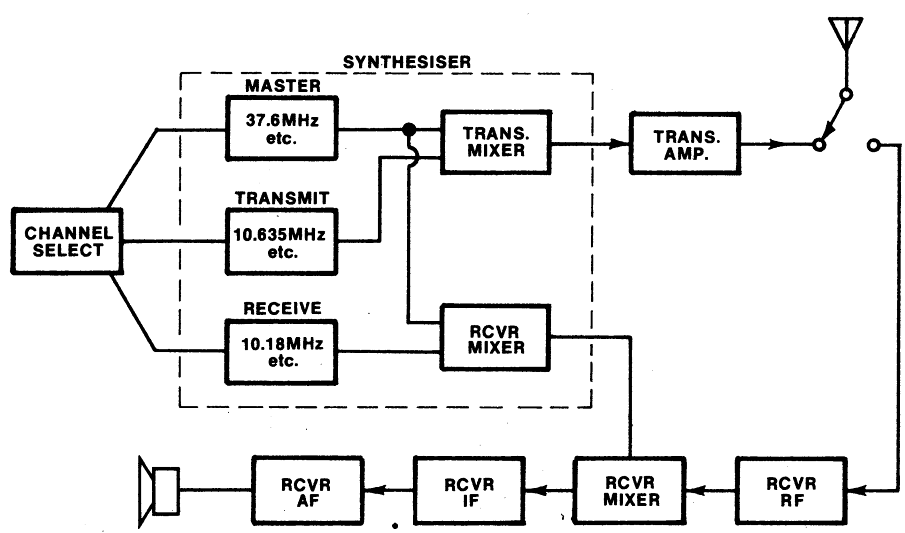
Unfortunately, transmitter and receiver oscillators using ordinary inductance/capacitance circuitry are not sufficiently stable to meet the requirements of a modern 2-way fixed channel system, particularly one operating near or above the top end of the HF band (e.g. at 27MHz or higher).

No matter how carefully the transmitters and receivers were designed and adjusted in the first place, there is every chance, in the course of time, that many transmitters would simply end up outside the selectivity passband of many receivers and not be heard, as a result. With SSB (single sideband) equipment, stability is even more critical, with a drift of even a few hundred hertz being sufficient to render transmissions unintelligible.

For this reason, when a service is planned to operate on one or more specific channels, it is virtually essential that the oscillators determining the transmitted and received frequencies be controlled by precisely ground quartz crystals. This will minimise the risk of transmissions not being heard and, as well, ensure that there will be no off-frequency transmissions to interfere with adjacent services.

Quartz crystals are, in fact, tiny slivers of crystalline quartz which have been very precisely sliced, ground and etched, so that they will oscillate mechanically at an exact nominated frequency, at the same time responding to and producing an equivalent electrical signal.

You've probably came across the appropriate term: the "piezoelectric" effect. It is the same effect which is utilised in (rochelle salt) crystal phono



A typical synthesiser system used in an AM CB transceiver. The significance of the various frequencies is explained in the text. For an AM/SSB transceiver additional provision needs to be made to receive the alternative incoming sidebands.

pickups and "ceramic" pickups.

The vital point is that, in association with a transistor (or valve) a quartz crystal makes possible an oscillator stage which is both precise and stable in terms of frequency — and relatively simple into the bargain.

The crystal may be ground and etched to generate the required frequency directly, as for example in the 27MHz CB band. Alternatively, the equipment may be designed to use crystals ground for a sub-multiple of the desired frequency, with one or more "frequency multiplier" stages following the basic oscillator. Either way, the precision and stability of the end frequency can be of a very high order.

When a transceiver is required to operate on a single channel, it is logical to provide it with two crystals. The one serving the transmitter will produce, either directly or indirectly, a signal corresponding to the nominated channel frequency. The one serving the receiver will produce a signal displaced by a figure equal to the receiver's first intermediate frequency.

Consider, for example, the CB emergency channel on 27.065MHz; the transmitter oscillator circuitry would ultimately have to provide this frequency. If the first IF of the receiver was, say, 2MHz, the receiver oscillator circuitry would have to generate either 25.06MHz or 29.065MHz. For any other receiver IF (intermediate frequency) a different receiver crystal would, of course, be required.

For a transceiver intended to operate on a number of adjacent channels, an obvious option is to provide pairs of crystals — one pair for each channel — selected by a switch. This was common practice in the early days of CB radio and is still used in many hand-held transceivers covering up to about six channels.

The system has a certain simplistic attraction in that other channels can be selected by simply withdrawing some of the original crystals and substituting others of the required frequency. No great feat of mathematics is necessary to work out what the new crystal frequencies should be!

There is one catch, however, which should be mentioned in this context. The input tuned circuits of the receivers and the output tuned circuits of the transmitter have only a certain bandwidth and this may or may not be enough to accommodate a new frequency well away from those for which the equipment was originally adjusted. By way of illustration, crystals can often be bought to shift a CB transceiver on to the boating frequencies of 27.88, 27.89, etc. However, the performance of the receiver in particular will often be very poor, unless the input tuned circuits are re-peaked towards the new signal frequencies.

This problem may be less significant in a more elaborate transceiver, designed from the outset to cover a large number of channels. It could reasonably be assumed that the various tuned circuits would have been arranged to cover a broad band.

In fact, the idea of providing separate pairs of crystals becomes very clumsy for more than a few channels — e.g. 46 crystals for the original American 23 channel system — and a quite untenable 80 for the more recent 40-channel system! Quite apart from the cost and space involved, world crystal resources were just not equal to that kind of demand, especially in the face of a booming CB market.

Other approaches had to be developed.

The first such approach produced what is commonly described as a "synthesiser". The scheme was widely used in American 23-channel transceivers designed in the first half of the 70's and, therefore, in many models which appeared on the Australian market at the start of the local CB era.

In the present context — and without being too pedantic — a synthesiser is a system which creates a group of frequencies indirectly by heterodyning other (usually unrelated) frequencies. We have seen the term used in connection with complex communications receivers, multi-channel military transmitters and so on. Here we are thinking of it purely in connection with CB transceivers, most commonly of the type just referred to.

Instead of using 46 separate crystals, each responsible for one distinct frequency, a synthesiser — CB style — used a smaller number of crystals, associated with two or more separate oscillators. These were so arranged that the oscillators would beat, or heterodyne, to create resultants at the specific frequencies needed for the transmitter and receiver. By careful planning, so that each crystal was used several times, the total number required would be considerably less than 46.

Fig. 1 is a block diagram of a typical American CB transceiver for AM operation. The synthesiser section contained a master oscillator served by six crystals generating frequencies 50kHz apart between 37.60MHz and 37.85MHz.

A supplementary transmit oscillator, served by four crystals generated frequencies of 10.635MHz, 10.625MHz, 10.615MHz and 10.595MHz.

A supplementary receiver oscillator, also served by four crystals, generated frequencies of 10.18MHz, 10.17MHz, 10.16MHz and 10.14MHz.

At a function in the Melbourne Zoo, and with a koala to emphasise the Australian theme, the Minister for Posts and Telegraphs, Mr Staley, presented the Australian Design Award to Philips for 1978, for their FM320 transceiver. Operating in the UHF band, it offers CB facilities free from the hassles of 27MHz.

The channel selector switch, together with the transmit-receive switch, combined these various crystals in pairs to produce the required 46 frequencies, but with only 14 crystals — an obvious saving.

The service data for synthesised transceivers commonly used a graphical display to indicate how the oscillators combine, by virtue of the channel switching, to produce specific resultant frequencies. One set of figures should serve to illustrate how the system works out.

Let's say that the transceiver is switched to American channel 9, equivalent to the emergency CB frequency in Australia: 27.065MHz.

The relevant graph shows that, in the process, the master oscillator would be set to produce 37.700MHz. The transmit oscillator would be set to 10.635MHz; the resultant, produced by subtracting one from the other, would be 27.065MHz, as required.

For receive, the same master oscillator would combine with the receive oscillator on 10.180MHz to produce a resultant on 27.520MHz. This frequency would beat with the incoming signal on 27.065 to produce the receiver IF at 455kHz.

Similar figures could be worked out for the remaining 22 channels.

Other quite different combinations of crystals are possible, even necessary, for different receiver intermediate frequencies, and some synthesisers arrive at the desired resultants by adding, rather than subtracting, the component frequencies. However, the basic principles remain the same.

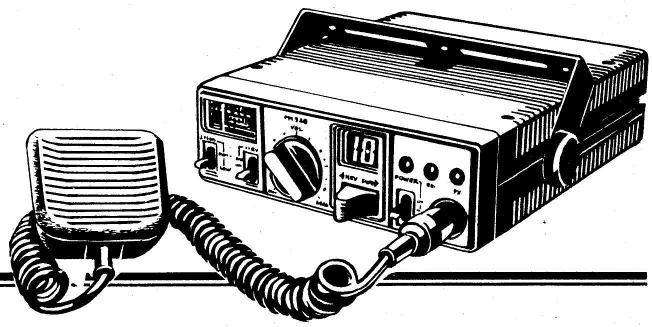
Again, variations occur with the transceivers designed for AM/SSB operation. Here an additional set of four receive crystals may be provided, offset by say 3kHz, to centre the alternative sideband in the IF selectivity passband of the receiver.

But we are in danger of getting into deep waters. The purpose of the article, to this point, has been to explain how a synthesiser works, with a saving of about 70% in the number of crystals required. Having done that, let's stay clear of the intricacies of SSB!

In a following article, we will have a look at the circuitry which displaced synthesisers: the phase-locked loop.

(To be Continued)

The Australian CB SCENE



CRYSTALS, SYNTHESISERS AND THE PHASE-LOCKED LOOP — Part 2

As distinct from direct crystal control, or the synthesisers discussed in part 1 of this article, many modern CB transceivers use a phase-locked loop system to maintain them precisely on the allotted channels. Without getting too involved, this article seeks to explain what the term means.

by NEVILLE WILLIAMS

The phase-locked loop concept has been around for quite some time, certainly since the 1930s. More recently, it found wide application in the horizontal oscillator circuitry of television receivers, where the principle is used to lock the local oscillator to the incoming sync pulses. It is also fundamental to the design of automatic frequency control (AFC) circuitry in modern colour TV receivers and FM tuners.

Basically, a phase-locked loop — called PLL for short — is an electronic servo system which has the capability of producing an output which is frequency (and phase) locked to some external reference signal.

In its simplest form, as illustrated in Fig. 2, a phase-locked loop involves three basic circuit elements. One is a voltage controlled oscillator, or VCO, whose output frequency is dependent not only on its own circuit constants but on an externally derived DC control voltage. Part of the output signal from the VCO is fed to a phase comparator or detector, which compares it with the incoming reference signal to produce resultants of one kind and another, including a "DC" component whose value reflects any difference between the frequencies being compared. After filtering to remove the original signal components, and possible amplification, the so-called DC component is fed to the VCO.

Assuming that the circuit constants have been suitably arranged, the control voltage will modify the output frequency of the VCO, so that it will lock to the incoming reference frequency. If the latter is absolutely fixed, so also will be the output from the VCO. If the reference frequency varies, for any reason, the output from the VCO will vary with it, provided the time-constant of the control voltage circuitry is not excessively long. In short, the VCO will "track" the reference frequency.

A point to mention in passing is that, while a VCO will lock to a reference signal in terms of frequency, it tends to stabilise with a fixed phase displacement between output and reference signals. It is not important in the present context but will explain why, in some circuitry, a phase difference is noted between the two.

Right: A basic phase-locked loop.

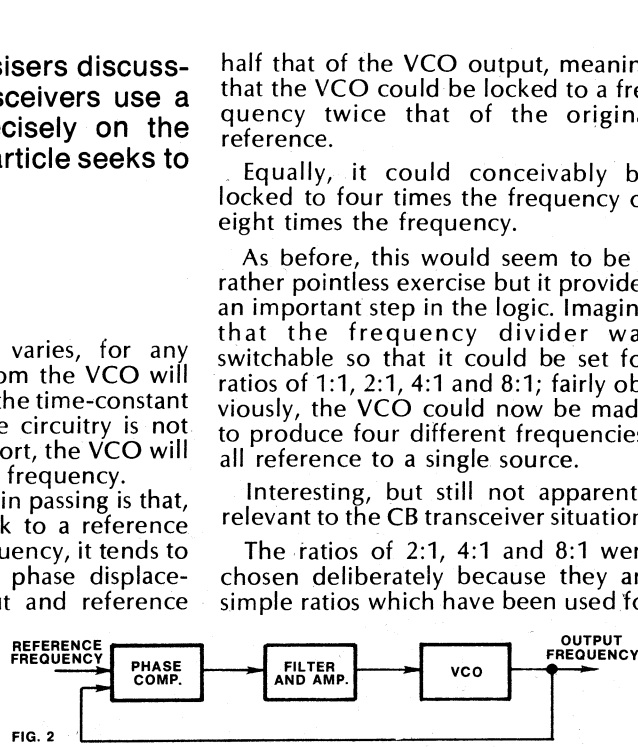


FIG. 2

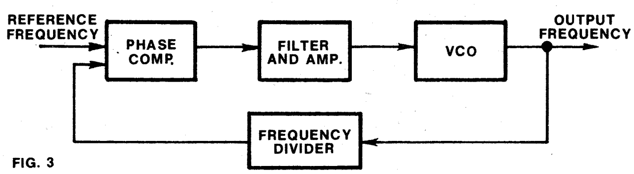


FIG. 3

Left: A basic phase-locked loop incorporating a frequency divider.

To get back to Fig. 2, however, it will be apparent that a VCO could be locked to a crystal source selected for any CB transmit or receive function. The one obvious objection is that it would be a completely pointless exercise. If a crystal source had to be provided for each channel function, it might be as well be used directly!

Fig. 3 contains an important additional circuit function: a frequency divider in series with the feedback path.

Let's say that frequency divider was set for a ratio of 2:1. The frequency fed back to the phase comparator would be half that of the VCO output, meaning that the VCO could be locked to a frequency twice that of the original reference.

Equally, it could conceivably be locked to four times the frequency or eight times the frequency.

As before, this would seem to be a rather pointless exercise but it provides an important step in the logic. Imagine that the frequency divider was switchable so that it could be set for ratios of 1:1, 2:1, 4:1 and 8:1; fairly obviously, the VCO could now be made to produce four different frequencies, all reference to a single source.

Interesting, but still not apparently relevant to the CB transceiver situation!

The ratios of 2:1, 4:1 and 8:1 were chosen deliberately because they are simple ratios which have been used for decades in conventional receivers and transmitters. In fact, up till not so many years ago, frequency division by other than simple ratios was regarded as rather impractical.

However, the emergence of digital logic technology has changed all that. It is now possible to arrange circuitry, usually in integrated circuit form, which will count up to any desired number of digits, then automatically reset and start counting all over again. In short, by producing one (reset) pulse after any selected integral number of digits, it can effectively divide by that number.

So, if one should wish to divide by 239, digital counting circuitry can be set up to do just that.

Why pick on 239? Because it provides

a handy example of what we mean.

If we set up digital circuitry to divide by 239 the output from a crystal oscillator set near 2MHz, it will divide its output down to 8366Hz, which is the top "C" note on a typical electronic organ. If we divide the same 2MHz (approx) by 253, we get 7903Hz — equivalent to "B". Divide it by 268 and we get 7460Hz, equivalent to B-flat, and so on down the entire octave.

That kind of complex division involves an integrated circuit especially interconnected internally to provide the integral ratios necessary to produce the notes in a musical octave. It could be described as a "dedicated" IC.

It is possible, however, to produce integrated circuits which will provide a wide variety of division ratios in response to deliberate external manipulation — as, for example, by modifying external connections or voltages by means of a switch. Such an IC is commonly described as a "programmable divider".

Now refer back to Fig. 3 and, in place of the simple divider previously discussed imagine that we insert a programmable divider capable of being set for a variety of ratios no less odd looking (at first glance) but no less deliberate than those nominated for the production of a musical octave.

Fairly obviously, by settling on some appropriate (and fairly low) frequency for the reference, and by setting the programmable divider to a series of critically chosen ratios, the VCO can be made to deliver the range of frequencies required by a CB transceiver, all of them stabilised against the one common reference frequency — logically from a highly stable source.

The foregoing can be expressed in another way, for those who remember their school maths. The design task is to write down the required CB frequencies, determine the highest common factor (which becomes the reference frequency) and set the programmable divider for the relevant ratios.

What of the reference frequency source?

On the assumption that it has to be a relatively low figure, the most practical source is a crystal oscillator whose output is also divided down to the required figure. On this basis, Fig. 3 can be re-drawn as in Fig. 4 to incorporate the reference crystal oscillator/divider.

If the CB channel frequencies were all multiples of 10kHz and all 10kHz apart, the position would be delightfully simple. The crystal derived reference could be 10kHz and, with the programmable divider settable to 2700, 2701, 2702, etc, the VCO would produce frequencies of 27,000kHz, 27,010kHz, 27,020kHz and so on.

But, while the official CB channels are 10kHz apart in most cases, they are not divisible by 10. with figures like 27.015mHz, 27.02MHz, 27.035MHz, etc, the highest common factor is five (or 5kHz) and some measure has to be taken in the design to accommodate this situation.

For example, the reference frequency might be reduced to 5kHz and the programmable divider switching arranged to select only the appropriate 23 or 40 (American) channels or 18 Australian channels.

Again, the PLL could be set up to produce frequencies 10kHz apart, referenced to 10kHz, but heterodyned up to 27.005kHz and so on by beating with a fixed crystal oscillator containing the odd 5kHz. In short, frequency synthesis (see part 1) in addition to the basic phase-locked loop.

In fact, a variety of schemes have been devised to cover this requirement. There is also the need, in receive mode, to provide a VCO output displaced from the channel frequency by a figure equal to the first intermediate frequency. Yet again, for SSB reception, a further increment of about 3kHz must be provided.

In some cases, these various requirements have been met by the provision of additional crystal oscillators to supplement the basic PLL by frequency synthesis. Even so, the need for two or three supplementary crystals is of little consequence when compared with the needs of alternative methods.

SPECIAL PURPOSE ICs

Not surprisingly, however, integrated circuit manufacturers have come up with custom-designed programmable ICs which offer their own in-built answers to the various problems. Referenced to a single crystal, some of these will produce the transmit frequency and the required receiver "oscillator" frequencies for a double-change multi-mode superhet automatically in response to inputs from the channel selector, mode and send/receive switches.

More than that, their "programming" can be rationalised to correspond with that necessary to operate a LED channel readout, and to respond to pulsed rather than hard-wired input.

You find all this confusing?

So does just about everyone else who has not had occasion to work closely with modern multi-channel transceiver design!

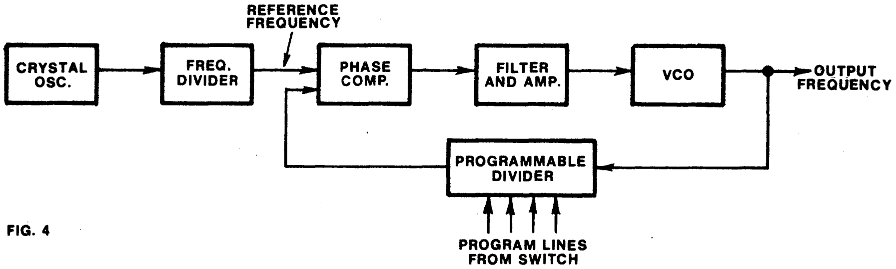
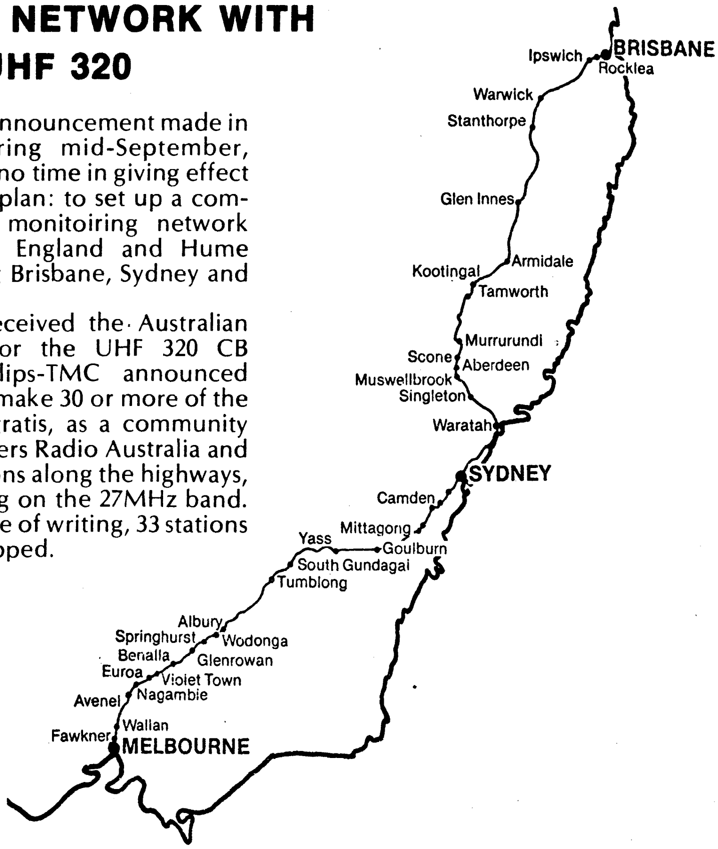


FIG. 4

But, leaving aside these refinements and complications, you will hopefully have gained what we set out to impart — an appreciation of how a voltage controlled oscillator can produce an array of precise frequencies, aided by a reference crystal, a phase-locked loop and a programmable divider.

HIGHWAY NETWORK WITH PHILIPS UHF 320



Following an announcement made in Melbourne during mid-September, Philips have lost no time in giving effect to an ambitious plan: to set up a complete UHF CB monitoiring network along the New England and Hume highways linking Brisbane, Sydney and Melbourne.

Having just received the Australian design award for the UHF 320 CB transceiver, Philips-TMC announced that they would make 30 or more of the units available gratis, as a community service, to Truckers Radio Australia and Big Wheels stations along the highways, already operating on the 27MHz band. In fact, at the time of writing, 33 stations have been equipped.

The main role of the stations is to assist and cooperate with professional drivers using the highways — a task which is often made difficult on 27MHz by noise and interference and by CB "idiot" behaviour. The new UHF FM equipment offers substantial relief from these problems, with an exceptional degree of speech clarity as a further bonus.

Mr Graham Evans, National Director of Truckers Radio Australia, says that his organisation is keen to promote the exclusive use of UHF channel 40 (477.400MHz) for highway communication, primarily by professional drivers. However, TRA stations would cooperate with responsible private drivers on the highway channel, in respect to road conditions, directions and emergency situations.

"In return for that service on the highway, TRA will beg the indulgence of UHF users to leave channel 40 alone in the cities for the use of truckers".

"So we offer a service on the highway, and they give us a go in the city".