Simply the Best?

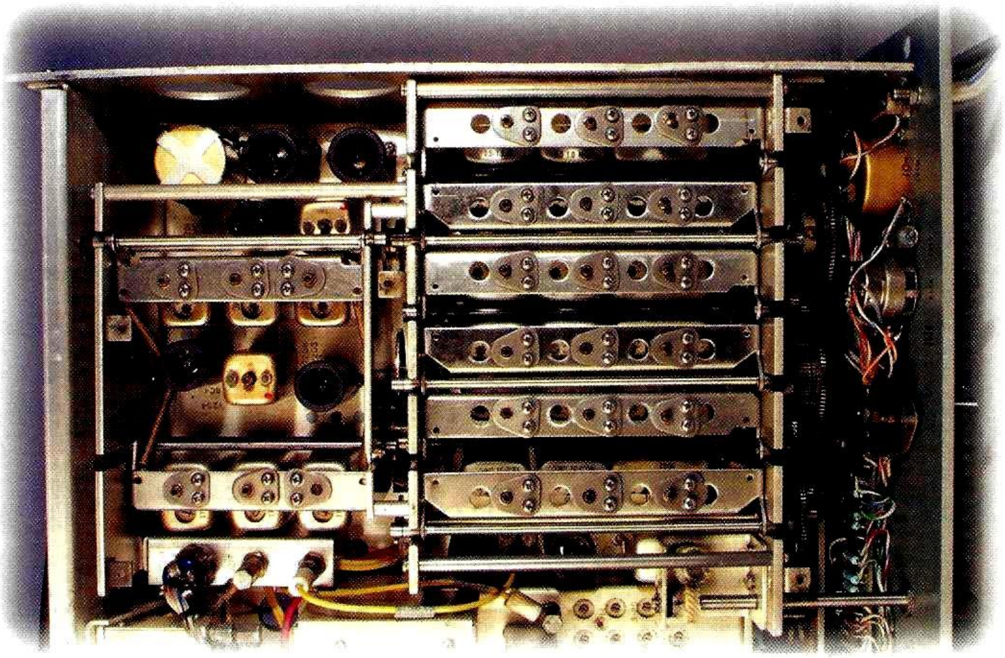
An encounter with one of the giants of the h.f. receiver world. John Wilson gets teary eyed over a Collins classic, the R-390A. It doesn't cloud his judgement or his measurements though.

Anything from the Collins Radio company carries a certain air of mystique, but the R-390A has to be the bearer of the greatest reputation in all the Collins receiver lines. This is the receiver which is reputed to be the finest example of radio engineering of its era, and that stretches from the early 1950s to the late 1980s. Many enthusiasts still rate a good R-390A as the best short wave receiver it is possible to have as a DX listening tool, and I've been waiting to get my hands on one for some time. Patience has its reward, and I was delighted when an enthusiast in the USA who was shipping a fully restored R-390A to a friend in the UK asked me if I would like to review it for *Short Wave Magazine* before final delivery to its new owner. How could I refuse? There is a huge following for the R-390A in the USA, fuelled by the fact that over 50,000 units were made and large quantities are (or were) available on the surplus market. Such is the reputation of the R-390A that several skilled radio engineers have built successful businesses from total restoration of these receivers, and when I say 'total' I mean **total**. The rebuilt R-390s look as close to new as it is possible to imagine, and each sub-assembly has been carefully brought back to full performance specification, every gearbox has received careful attention, every suspect component has been replaced, and lengthy final alignment carried out, usually resulting in performance well in excess of the original Collins specification. Unlike some UK enthusiasts, the American hobbyist accepts that keeping one of these classic receivers in top working order is likely to cost serious money, and is prepared to spend dollars in order to get the best possible quality. How refreshing!

Background

Researching the background to the R-390A is made easy by the numerous web sites devoted to this classic receiver, although recent experience serves as a caution not to take what appears on a web page as being necessarily the whole story, rather the opinion(s) of the compiler(s). The receiver was designed by Collins as a lower cost version of the earlier R-390, and the suffix 'A' is important in distinguishing between the two designs. Although designed and first manufactured by the Collins

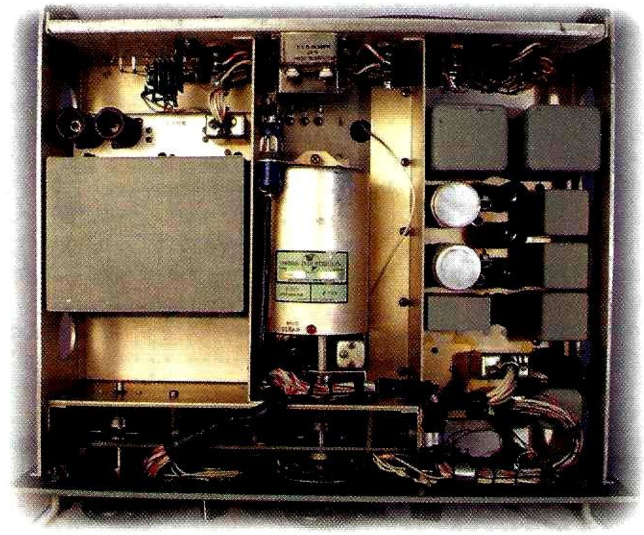
Radio company, other manufacturers were given contracts to build the R-390A under licence, and according to details given by one contributor, Collins actually manufactured just over 6000 units from a total of more than 50,000. The most prolific manufacturer seems to have been the Electronic Assistance Corporation (EAC) with a contract total of over 15,000 units, and the receiver in my hands was indeed made by EAC under contract number FR 36 039-N-6-00189(E), with a serial number of 3830. This places the date of manufacture as 1967, which compares to the first contract placed with Collins back in 1954. The final contracts appear to have been placed with Fowler Industries as late as 1980-84 which means that the R-390A had an astonishingly long production life of some thirty years. That fact is the ultimate comment on the excellence of the original Collins design, and a tribute to the engineering vision which drove the company. Racal and Marconi (and Railtrack?) had that same vision until the 'bean counters' took over and destroyed the engineering ethos in favour of 'profit centres' and 'modern management'. The results are there for all to see.



Rugged Mechanical Construction

One of the reasons for the R-390A's ability to survive is the rugged mechanical construction, based on the use of six separate sub-assemblies bolted to a main frame which is itself mechanically strong. The whole receiver occupies a nineteen inch rack panel of 6U height (10.5 inches for we metric martyrs). Seventeen inches deep, the receiver weighs in at some 85lbs (please don't convert this to kg Kevin!) - (*OK, just this once! - **Ed**.*), making it quite a monster to heave around. Coming to my bench immediately after the Ten-Tec RX320 made the room seem a bit crowded, although I suppose that including the PC in the overall RX320 system redresses the balance. Spare sub-assemblies for the R-390A seem to be readily available in the USA, which must make refurbishment of the assemblies fairly easy, although components are closely packed inside each assembly. The real frightener is the gearbox on the front of the r.f. sub-assembly, which contains more than 200 separate components including substantial cardioid (heart shaped) cams for driving the vertical slug racks up and down. I recall John Thorpe telling me that it was all quite simple when you thought about how these worked, but then he is well ahead of the rest of us in the brain power stakes, and I just continue to marvel and accept that someone at Collins was a minor genius, and the rest of us ought to leave the gearbox well alone unless we have the assistance of a skilled clockmaker.

The front panel layout owes more to the internal arrangements of the mechanics than to any serious attempt to fit them to the human operator, but at least there is a knob for every function and all clearly labelled as you may see from the photographs. The frequency readout is clear, the MHz digits being driven by the 'Megacycle' knob, with the kHz digits driven by the 'Kilocycle Change' knob. Don't even imagine that these knobs are



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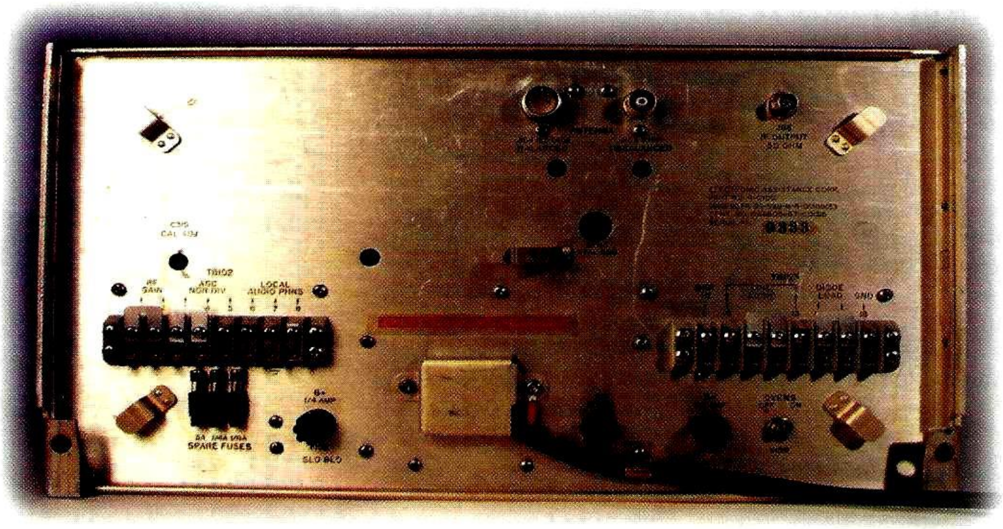
easy to turn. I didn't measure the torque necessary to tune the R-390A, but all jokes about '390A owners having one wrist thicker than the other are true. All is revealed when you take off the top cover and observe just how much mechanical load is placed on the 'Kilocycle' knob by that gearbox and all the cams and levers, although it's interesting to watch it all happen when you turn the knob. Rather akin to watching the drive linkages on a 4-6-2 steam locomotive, or the crankshaft on a single cylinder mill engine and 40 foot flywheel. The astonishing fact about the tuning is the accuracy and linearity that Collins managed to achieve over each MHz segment using mechanical means (and the superb Permeability Tuned Oscillator). All other controls are familiar enough to readers of the magazine, and it is obvious that the R-390A was designed before s.s.b. for communications was a standard feature of receivers, this being catered for by external s.s.b. and i.s.b. i.f. and detector systems. The R-390's c.w. operation is enhanced by the use of a b.f.o. tunable over a ±3kHz range, together with a sharp audio filter centred on 800Hz and having a razor thin passband. Measurements revealed that the R-390A could hardly be bettered by any other c.w. receiver I have encountered.

Switched i.f selectivity is achieved by using Collins mechanical filters at 455kHz, with supplied bandwidths of 16, 8, 4 and 2kHz, each filter showing the excellent shape factor for which Collins filters are renowned. The two narrower bandwidths of 1kHz and 100Hz are provided by a classic single crystal filter. When the crystal filter is being used, the 2kHz mechanical filter is also in circuit which improves the skirt selectivity and minimises i.f. system noise. The use of filters in cascade like this was used in the Lowe and AOR receiver designs by John Thorpe, and by Kenwood in their R-5000 receiver. A good idea is always worth repeating. The a.g.c. system has three decay time constants selected by a front panel control (5s, 300ms and 15ms), and a manual r.f. gain pedestal can be added to the a.g.c. control voltage. A classic peak clipping noise limiter with variable clipping threshold is fitted, and this works to good effect on a.m. and c.w. signals, but causes audio distortion when trying to receive s.s.b. speech, but this is quite normal for this type of noise limiter.

The two meters gracing the panel measure audio level to the 600Ω line output and relative r.f. input level. When using manual r.f. gain, the signal level meter is used to show the onset of grid current in the final i.f. amplifier and thus serves to indicate the point at which the receiver is being driven into overload. As I have indicated, the R-390A represents a typical professional communications receiver of the day, and a skilled human operator could have had no



better tool to ply his trade. By comparison, a typical Eddystone receiver of the same period, having similar control functions, would not even be in the same class for weak signal discrimination and overall competence. This is not intended to insult Eddystone, it's just the simple truth that Collins receivers were totally dominant in this field. In fact, my measurements and experience with this particular R-390A gave some truth to the belief that it is still a hard one to beat for ultimate a.m. and c.w. performance, and its following among short wave DXers is well deserved.

Circuit Architecture

In essence the R-390A is a dual conversion receiver tuning the range 8 to 32MHz with (as you might expect from Collins) crystal controlled first conversion down to a tunable i.f. of 3 to 2MHz (it tunes backwards). This tunable i.f. is then mixed with the v.f.o. (p.t.o.) covering 3.455 to 2.455MHz to give a final fixed i.f. at 455kHz where all the selectivity is provided. Well, not entirely true, because there is astonishing selectivity provided by the pre-i.f. tuning, and I will describe this effect later.

Converting the 8 to 32MHz down to the first i.f. calls for oscillator injection of 11 to 34MHz and this on the face of it would need 23 crystals to cover the range. Collins do it with 15 by using harmonics of the lower frequency crystals - clever thinking. What about the ranges below 8MHz? From 500kHz to 8MHz the R-390A becomes a triple conversion receiver by mixing the lower frequency range with a 17MHz oscillator to produce a 17.5 to 25MHz intermediate i.f. with the main receiver then tuning 17.5 to 25MHz as a first tunable i.f. Sounds quite complicated, but the end result is that you have a receiver that employs low phase noise crystal oscillators for all conversions until the p.t.o. is mixed in, and the p.t.o. itself is a low noise optimised design as you will find when I relate the phase noise measurements for you. Even that is not the end of the story because all the tunable i.f.s are tracked with the tuning knob and provide exceptional levels of r.f. selectivity You simply must try to see the mechanical activity inside a '390A when the tuning is rotated - it's most entertaining.

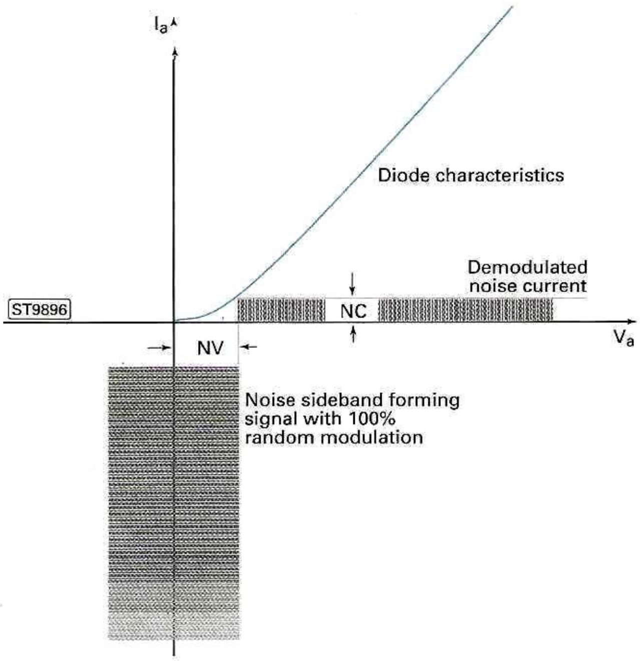
Just about every tuned circuit between the antenna and the first 455kHz i.f. stage is mechanically tracked by the two tuning controls, and when in correct alignment the R-390A has extremely good front-end selectivity. The overall gain distribution, something often ignored by designers, has been optimised to such an extent that the receiver in use has a very low background noise level. The method seems to have been to provide just enough gain in each stage and no more, and one 'tweak' is available in the form of an internal receiver gain preset which my friend Chuck Rippel, an acknowledged USA R-390A expert adjusts to find the 'sweet spot' at which signal to noise ratio hits an optimum setting. He says that it takes a little time to get it right, but when adjusted correctly the receiver is brilliant. Let's see what the measurements in **Table 1** tell us.

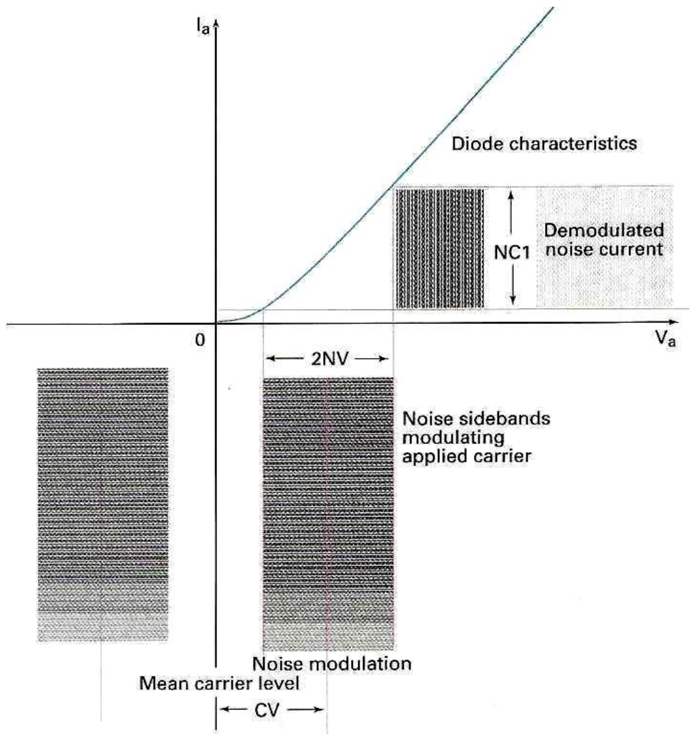
Table 1:

Frequency (MHz)	Mode	Bandwidth (kHz)	Sensitivity (dBm)
14.2	c.w.	2.0	-124
14.2	a.m.	4.0	-116.5
14.2	c.w.	0.1	-136
14.2	c.w.	0.1*	-140
14.2	a.m.	8.0	-110
9.5	a.m.	4.0	-113
6.5	a.m.	4.0	-111
0.9	a.m.	4.0	-110

* plus audio filter

Sensitivity measured as input level in dBm for 12dB SINAD in c.w. mode, 12dB SINAD with 30% a.m. at 1kHz.





Note the amazing sensitivity for the keen c.w. operator when using the 100Hz i.f. filter and the audio filter. In this configuration there was virtually **no** noise in the audio in the absence of a signal, which meant that the moment a signal was applied you could clearly hear it. You do of course need quite keen ears and careful tuning to get the signal into the narrow slot provided by the filters. Now there are sensitivity figures quoted for the R-390A in a.m. with a 4kHz bandwidth which seem to me to be questionable. Sensitivity of 0.2µV for example (-121dBm) for 10dB S/N ratio at 30% modulation depth are bandied about, with even better figures of 0.1µV for 10dB S/N in 4kHz bandwidth having been seen. Clearly, something is adrift, and over the last year I have been trying to get to the bottom of the discrepancy. My conclusion is that many users of the R-390A, together with those who refurbish and align them, are being led astray by the *R-390A Technical Manual* which contains instructions on how to carry out a routine sensitivity check to ensure that the receiver is no worse than its quoted design sensitivity of 5µV - yes, that is five, not half. To do this, the manual instructs you to use a carrier modulated at 1kHz to a depth of 30% and switch the carrier plus modulation on and off whilst looking for a 10dB ratio between on and off conditions. Anyone following these instructions in a attempt to measure the ultimate a.m. sensitivity are not in fact measuring it correctly because the 10dB ratio should actually be measured by leaving the r.f. carrier on all the time and switching only the modulation on and off. Why is this so? I can do no better than quote from a definitive book produced by Marconi Instruments many years ago which gives the simplest explanation I know of.

"Measurement on a.m. receivers. The noise generated in the early stages of an a.m. receiver is not normally sufficient to drive the diode detector to the linear part of its characteristic. This is why we usually find that when an unmodulated carrier at a level below the a.g.c. threshold is applied to the receiver, the noise output increases as compared with the noise when no signal is applied.

The explanation is as follows: when no carrier is applied, the noise voltages affect the detector as an infinite number of random sidebands of constant mean amplitude. This, in effect, a very small signal having random modulation at a mean depth of 100%. It is represented in figure 3.5(a) as a block of noise having an effective peak voltage of NV.

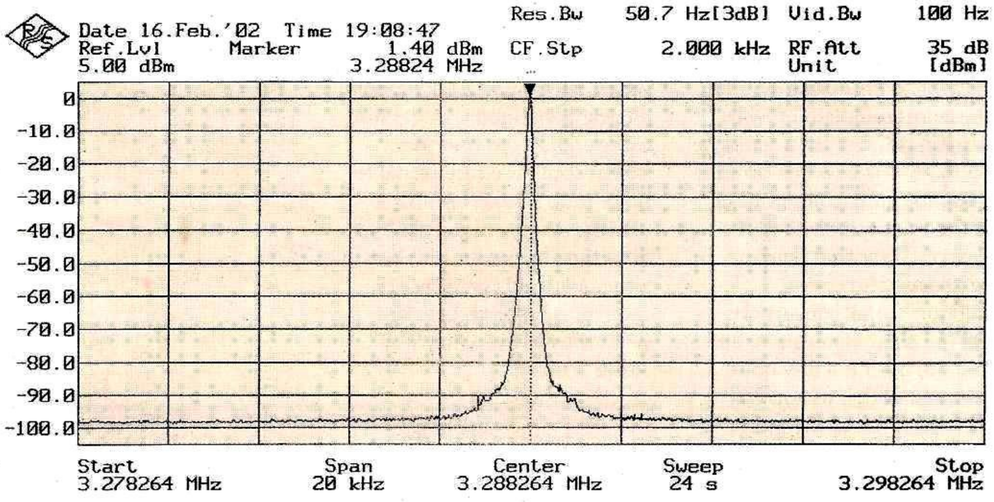


Fig. 1: The R-390A selectivity between the antenna connector and the mixer at 14MHz.

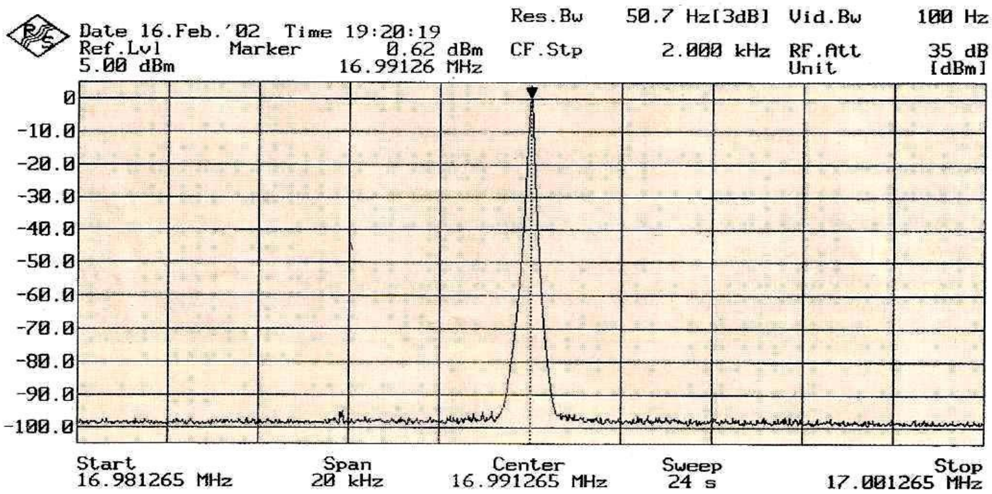


Fig. 2: Good phase noise results, the spectral purity of the conversion oscillator, a classic crystal oscillator.

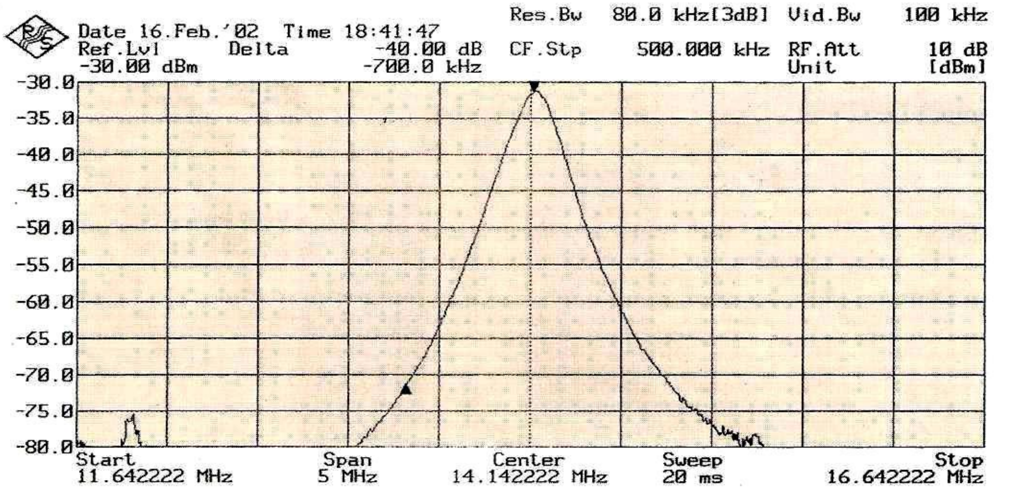


Fig. 3: The Collins v.f.o. (p.t.o.) is almost as clean as a crystal and hugely better than most synthesisers.

When this is applied to a diode detector the demodulated noise current has the effective peak-to-peak amplitude of NC, which is quite small because the noise voltage is not large enough to drive the diode to the steep part of its characteristic.

When a carrier having a peak voltage of CV is applied to the diode, as shown in figure 3.4(b), it is modulated by the noise sidebands to the depth (NV+CV/NV). The diode is then presented with a noise modulated voltage of 2NV centred about the level CV, so that the demodulated noise current becomes NC1 which is very much larger than NC. Once the applied carrier becomes large enough to bring the whole of the noise modulation on to the linear part of the diode characteristic, small changes in carrier level do not affect the noise output from the receiver.

It is obvious, then, that when we measure the signal to noise ratio of an a.m. *receiver we must measure the noise with the carrier applied; so an unmodulated carrier at the specified level is first fed to the receiver from the signal generator, and the level of noise output power Pn is noted. Standard modulation is then applied to the signal and the increased output power Pt is noted. This second power output is the signal plus the noise, so that Pt = Pn + Ps where Ps is the signal power. The signal to noise ratio is* Ps/Pn which is equal to (Pt/Pn) - *1. However, the usual signal to noise ratio requirements is of the order of 20dB or 100:1. For ratios of this order Pt can be regarded as Ps and the calculation simplified. This is rather more convenient when using a power meter calibrated directly in decibels. The ratio expressed in decibels is, of course, 10.logPs/Pn."*
Thus spake Marconi!

You may have to read that a couple of times, but all it describes is the well known effect in a.m receivers using diode detectors (such as the R-390A) that tuning to a weak unmodulated carrier results in a rise in receiver audio output, but this is not the same thing as measuring the true a.m. signal to noise ratio, which has to be done by first applying the carrier and then measuring the ratio between modulation on/modulation off to give the true S/N ratio. Just for interest, I measured the S/N ratio using the *R-390A Technical Manual* method and for a 10dB increase in audio output I needed an input signal of 0.211µV, but when I checked the **true** signal to noise ratio at 0.211µV by switching the modulation on and off, the ratio was actually 3dB. In other words I was measuring the m.d.s. (minimum discernible signal) level of the receiver, and the **true** signal to noise ratio at 10dB was given at -116dBm, which is 0.35µV, much more in line with what one might expect - actually, for an a.m. receiver it is still very good indeed. Finally, remember that all this waffle relates to diode detectors and not necessarily to other type such as synchronous or homodyne systems.

Third order intercept point at 20kHz spacing measured as -30dBm with an apparent dynamic range of 69dB, but this I suspect is intermodulation in a later stage than the first mixer, because when re-measured at 50kHz spacing the intercept point rose to +2dBm at a dynamic range of 90dBm, probably as a result of selectivity between the first and subsequent mixers. In this respect, the R-390A is a relatively poor performer when compared to more modern offerings such as the Racal receivers from the RA1770 series onwards. However, with all that front-end selectivity the second order intercept point measured with my standard input signals at 6.5MHz and 7MHz, resolving the product at 13.5MHz was an excellent +91dBm with a dynamic range of 112dB. Take a look at **Fig. 1** which shows the selectivity between the antenna connector and the mixer at 14MHz. The pass band response is an amazing 40dB down at only 700kHz from the tuned frequency, and I have not seen anything like it before

I expected good phase noise results from looking at the spectral purity of the conversion oscillator (**Fig. 2**), a classic crystal oscillator, but look at **Fig. 3** which shows that the Collins v.f.o. (p.t.o.) is almost as clean as a crystal and hugely better than most synthesisers. The reciprocal mixing measured out as follows:

Tone spacing (kHz)	**Phase noise** (dBc/Hz)
5	-126
10	-130
20	-142
50	-152
100	-152

The low noise at 50 and 100kHz surprised me when I compared them to my best reference which is the Kenwood TS-900 which flattens out at -149dBc/Hz but is slightly better than the R-390A closer in, but I then realised that the exceptional r.f. front-end selectivity of the 390A was affecting the measurement, and when I checked I found that a signal 100kHz away from the frequency on which I was measuring was already attenuated by some 3dB, and allowing for this changed the results at 50kHz and 100kHz to -149dBc which is precisely what the TS-900 showed. Figuring that the R-390A front-end would be less selective in absolute terms at a higher frequency, I repeated the measurements at 21.1MHz and sure enough the results were in line with the TS-900. Don't misunderstand me, I'm not saying that the results affected by the front-end selectivity are suspect, it's just that I wanted to know why the '390A appeared so good - it appeared good because it **is** good.

Overall

The R-390A is an impressive receiver and deserves the reputation it has earned among the a.m. DX enthusiasts. 'Tuning around' is not a strong point because of the heavy mechanical action of the tuning mechanism, but if you want to get in amongst the noise and dig out weak stations, then the '390A is still a formidable weapon in the armoury. For listening (as I do) to s.s.b. utility channels it is less satisfactory than something like an RA1792 or AR7030, because it simply wasn't designed for that purpose (rather like the RA17) but would perform well if you could find an outboard s.s.b. demodulator. No collection of classic receivers could be considered complete with a R-390A, but would I buy one in preference to something a bit younger? Probably not, because my listening is of a more general nature, but if I could afford to have one to play with, I would be more than happy. Collins really did produce the very best in h.f. equipment, and no-one can deny it.

Happy listening!

SWM