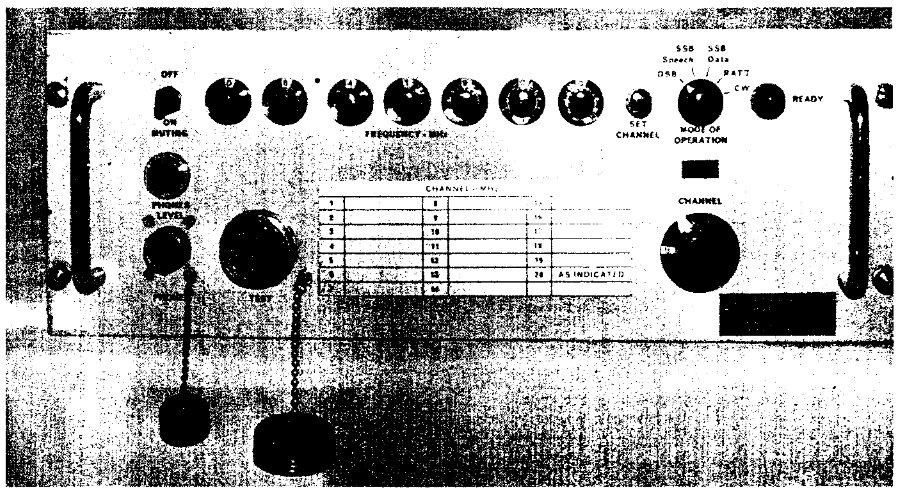
The Great Marconi Mishap and Some Little-known Receivers

by Michael O'Beirne, G8MOB

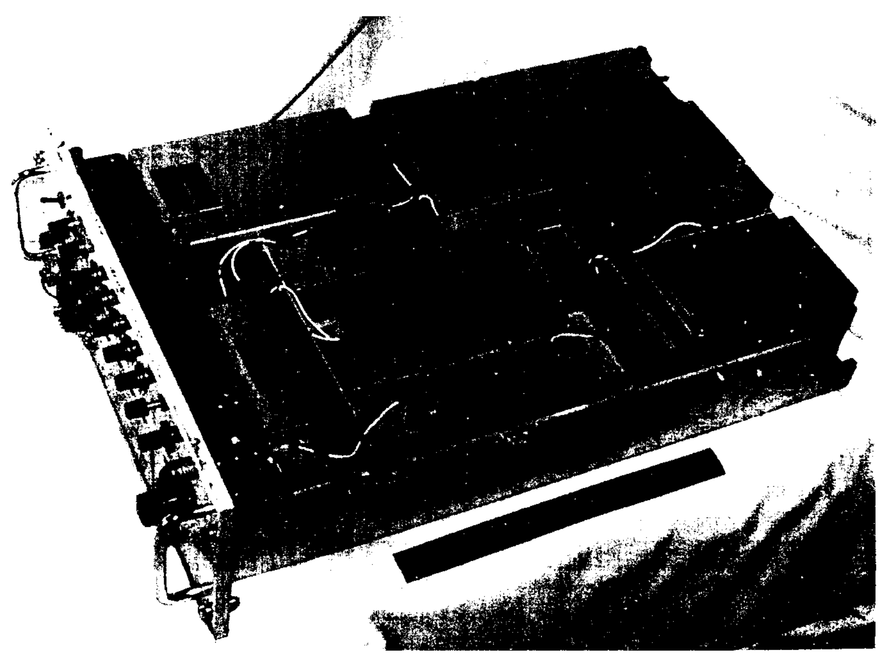
"In the misfortune of our best friends, we find something which is not displeasing to us"
Duc de La Rochefoucauld (1613-1680) *Maximes Supprimées*, **583.**

In January 1974 Marconi's house journal, *Point-to-Point Communication*, published a fascinating paper by the Chief Scientist of their Radio Division, the renown B. M. Sosin, entitled *HF receiver reception failure factor*. This was a massive survey of nine named Marconi and Eddystone receivers (Eddystone, of course, having been within the GEC-Marconi empire for many years) and eleven receivers from other manufacturers identified only by letters from A to L. Details are set out in Table 1.

Curiously, the much advertised RC410 HF receiver made by GEC (one of the first to have free tuning but with the frequency stability of a 'click-click-click' switched synthesiser) was not included within the columns for the 'home team' or 'the visitors'. Curious because GEC owned Marconi. Perhaps there were elements of internal politics or perhaps its performance was less good than the Marconi products.



The Marconi ICS-3 receiver. It weighs 86lbs and needs a separate PSU. Just look at that massive screening shown below. This receiver had the best performance in Sosin's table



Detailed Specs

This survey was by far the most comprehensive seen to date. A substantial table set out not only the usual specifications such as frequency range and the IFs, IF and image rejection, input impedance, noise factor, frequency stability and third order intercept but also a plethora of the more esoteric aspects such as mean time between failure, synthesiser phase stability, spurious radiation, audio intermodulation, capture time of the AFC system, RF input circuits, any options to fit phase compensated crystal filters and reciprocal mixing performance.

The last mentioned is common enough nowdays but back in the early 1970s this was cutting edge technology. Relatively few RF designers in those distant days had fully engaged with the problems of local oscillator noise.

The Aim of the Survey

The aim of the survey was to try to compare the world's leading receiver characteristics on a common basis, achieved by means of some highly complex calculations to give a 'batting order' of merit, what Sosin described as the 'Reception Failure Factor'. His methodology and calculations are highly complicated and what follows is a précis of my imperfect interpretation.

To understand Sosin's thinking we first need to digress on how receivers behave in the presence of large signals.

Non-Linearities in the Front End

Receivers are reasonably linear up to a critical signal input level. Beyond that the front end behaves in a non-linear fashion and generates additional signals which are entirely spurious in the sense that they were never within the input to the receiver. Take two signals for example on 7MHz and 11MHz. If there are no tuned circuits in the front end both signals will be presented to the RF amplifier and the mixer. Most RF amplifiers are relatively robust to strong signals compared to the mixer which is why so much effort has been expended in improving mixers.

At low levels, our two signals will be treated in the mixer in a linear fashion. If the receiver is tuned to 7MHz then the 11MHz signal will have no effect on the signal accepted by the IF stages since it and the heterodyned signal produced by the local oscillator will fall far outside the passband of the IF filters. If the receiver is tuned to 18MHz then nothing at all will be heard (apart from noise).

At higher signal levels the mixer progressively becomes more non-linear and starts to generate additional frequencies which the receiver treats as external signals. Some of these may be heterodyned into the IF passband and interfere with the on-tune signal. In the case of 'second order non-linearity' the additional signals generated are the sum and difference of the original signals applied to the receiver.

For the inputs mentioned, these spurii will lie at 18MHz and 4MHz. If the operator is listening to a signal on 18MHz, his reception will be affected or possibly obliterated by strong signals simultaneously broadcast on 7MHz and 11MHz or 7.6MHz and 10.4MHz or any other similar combination whose sum or difference produces a signal within a few kHz of the wanted signal. For example, strong enough signals at 7.600MHz and 10.402MHz will produce a spurious 18.002MHz, and an operator listening to 18.000MHz will encounter a nasty 2kHz heterodyne. These second order products are abbreviated to 'IP2'.

Front End Selectivity

It can be seen that one of the unwanted IP2 inputs must lie at least half an octave in frequency away from the wanted signal (11MHz in the case of our 18MHz wanted signal). Accordingly, by providing a fair amount of front end selectivity before the mixer at half an octave away (or less) we can greatly reduce the IP2 spurii. This is the reason why many modern receivers incorporate switched bandpass filters known as 'half-octave' or 'sub-octave' filters. Even better is to have several traditional tuned circuits *à la* AR88, but implementing this in a synthesised receiver is very expensive using motor-tuned variable capacitors and Ledex or relay-switched bands under the control of the synthesiser.

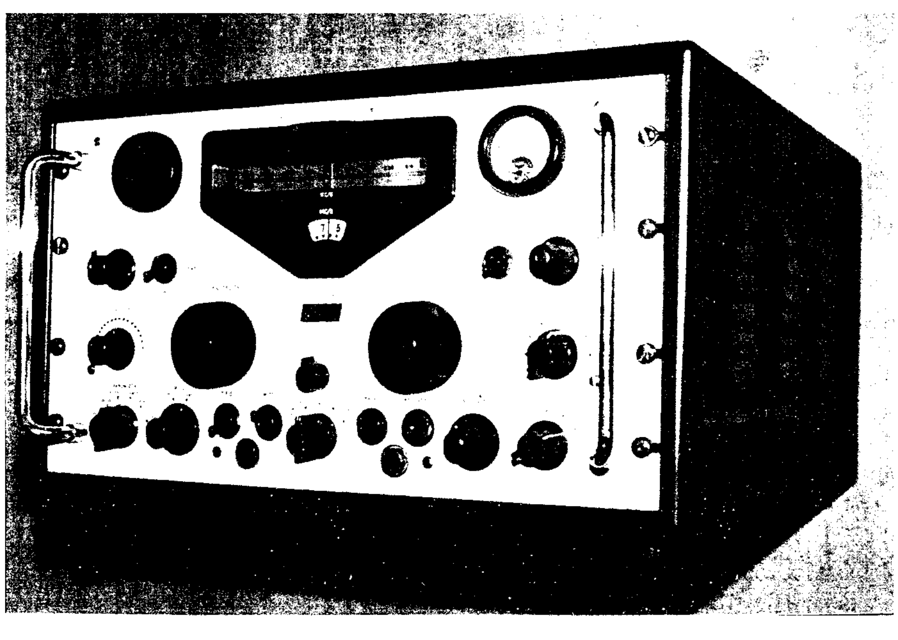
Third Order Intermodulation

IP2 is relatively easy to reduce to minuscule levels using front end selectivity. Third order intermodulation ('IP3') is more insidious. It gives rise to spurious signals which are produced by the sum or difference of one strong signal (F1) and twice the frequency of another strong signal (F2). The spurious IP3 signal lies at F1 + 2 × F2. It also lies at three other points, i.e. F1 - 2 × F2, 2 × F1 + F2 and 2 × F1 – F2. Our original two strong signals of 7MHz and 11MHz are now causing our receiver with a wide open front end to behave as if it were receiving signals on the following additional frequencies:

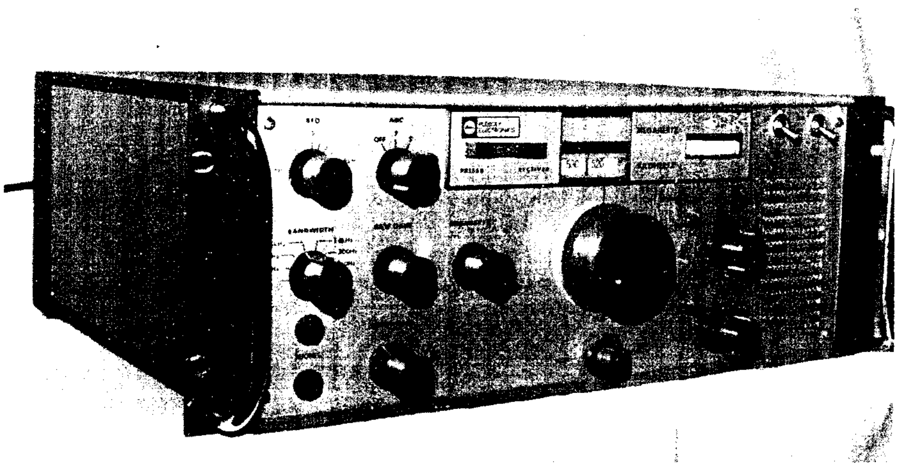
18MHz (an IP2 product, ie 7 + 11)
4MHz (an IP2 product, ie 7 – 11)
29MHz (an IP3 product, ie 7 + 2 × 11)
15MHz (an IP3 product, ie 7 – 2 × 11)
25MHz (an IP3 product, ie 2 × 7 + 11)
3MHz (an IP3 product ie, 2 × 7 – 11).

Higher Order Products

There are also numerous higher order intermodulation products. The fourth order ('IP4') are 2 × F1 + 2 × F2, 2 × F1 – 2 × F2, 3 × F1 + F2, 3 × F1 – F2 and so forth. The fifth order products are 3F1 + 2 × F2 and so on.



The RA17L in an original Racal cabinet



The Plessey PR155. This is the 'G' version. Frequency coverage is 15kHz to 30MHz in 30 bands. The kHz scale comprises seven feet of 16mm film giving a frequency accuracy of about 500Hz

the sixth order are 3 × F1 + 3 × F2 etc and on and on *ad infinitem*. It can be shown that spurii lie at the difference between the original strong inputs – i.e. 4MHz, giving responses of 3, 7, 11, 15 etc. Fortunately, the spurii levels decrease as the product order increases, and for practical purposes we only need to concentrate on the IP2 and IP3 products.

The IP3 intermodulation generally starts at a lower level than the other orders of intermodulation. It also lies at a far lower level than the effect caused by receiver blocking from a single strong adjacent signal. The IP3 characteristic largely defines the ability of a receiver to cope with strong signals.

Close-in Signals

When the separation between the strong signals and the wanted signal is large then traditional tuned circuits before the mixer will attenuate these unwanted signals, hopefully to a level where they are of little effect (unless the signals are substantial). But if the large signals are close to each other we have a serious problem. Take strong inputs of 7110kHz and 7130kHz. No amount of pre-mixer selectivity will separate these inputs. Both will hit the mixer and cause IP3 intermodulation at 7090kHz, 7150kHz, 21,350kHz and 21,370kHz. An amateur radio signal on 7,090kHz will probably drown under the spurii.

If the input levels increase further, more spurii will appear as if signals were being received at 20kHz intervals further up and down the band. Now add in many more powerful commercial signals within a few hundred kHz of 7MHz and a veritable cats' chorus of spurii obliterates most of the weak amateur signals on forty metres. There can hardly be an operator who has not experienced this.

Well designed valved receivers tend to be quite resistant to IP3, aided by their considerable pre-mixer selectivity, but despite this selectivity large signals at close channel spacings to the wanted signal will get through and cause intermodulation.

The Importance of IP3

The mixer's IP3 performance is a receiver's Achilles' heel because IP3 spurii will appear before the other forms of spurii. That is why so much effort has been expended in improving mixer performance to the stage where for many sites it is now possible to receive without *any* form of preselection. This obviously reduces the manufacturing cost considerably.

Reference 1 is a seminal article on the whole subject of receiver intermodulation. It discusses why Racal's RA1772, introduced in 1973, did not need any pre-mixer selectivity. It was the first wide-open receiver that could outperform most of the traditional competition.

Measuring Intermodulation

The classic method of measuring intermodulation uses two signal generators and a hybrid combiner to inject two strong signals at defined frequency spacings and amplitudes into the receiver. The level of spurii is measured with an audio output meter, an audio spectrum analyser or with just the receiver's S-meter. Recent ARRL *Handbooks* contain a detailed description of the procedure. Professionals tend to use much stronger test signals than the ARRL's technique. Reference 2 is a valuable discussion on the problems.

Sosin's Concept

We return to Sosin. His view back in the early 1970s was that a two signal test is not good enough because the spectrum contains far more than two strong signals. His aim was to calculate how each receiver under review would behave in a *real live situation* with an aerial input containing a defined spectrum of signals.

In a table he set out the likely levels of signals across the HF spectrum between 2MHz and 29MHz at six quantizised levels between 40dB and 100dB above 1μV per 1MHz span, effectively a snapshot "freeze" of what one might see on the screen of a spectrum analyser connected to an aerial. These are strong signals varying between 1mV and 100mV, the sort likely to upset most receivers then (and indeed nowdays). This RF energy distribution was based upon a well known Swiss analysis, though the levels seem more relevant to a professional aerial system than what most of us can fit into the back garden.

Sosin computed what spurious signals each receiver would give over a span of 1MHz for each of the 333 channels of 3kHz at these quantizised levels. He started the calculated spurii count at quantizised levels of -10dBμV to 0dBμV and continued in 10μV wide bands up to 70 to 80dBμV.

His calculation of the spurii appears to have been based on four parameters – the noise factor, the front end and IF filtering, the third order intermodulation product ('IP3') and the images rejection in the published specifications for each receiver. Separate calculations were done for a notional 20dB aerial attenuator switched in. Many readers will know that an aerial attenuator has a profound effect on the IP3 performance and dynamic range. (In simple terms, introducing an attenuator

Table 1 – Summary of Sosin's table of Reception Failure Factors

Receiver	Relative Cost £	Noise Factor dB	IP3 level at 10kHz spacing dB	Reception Failure Factor dB	Author's Notes
Marconi receivers					
CR24A	–	5-7	75	8	7ft cabinet.
ICS–3	6.4	17	99	0.4	Was the Royal Navy's warship HF receiver
H2900	9	10-15	75	1.6	
MST	11	12	65	13.1	Two 7ft cabinets. Very expensive
N2001	3.8	10	65	10.5	Known as *Hydrus*. Weighs 270lbs
N2020	9.3	10	65	9.8	Replaced in Royal Navy by ICS–3
N2050	2.5	17	70	10.3	Known as *Apollo*. Replaced the *Atalanta*
H2311	1.8	17	60	12.7	Modified Eddystone EC958
1830/6	0.55	12	60	10.3	Eddystone
Non–Marconi					
A spec	5.5	10-15	90	4	
A actual			80	9.4	
B spec	2.3	11	88	9	Clearly the Racal RA1772
B actual			80	17	
C	1	7	70	35	Clearly the RA17L
D	9 ?	10	63	–	
E	1.5	8	70	26	Clearly the Plessey PR155
F	–	10	75	–	
G	2.9	10	75	–	
H	3.3	10	75	10.8	
J	3.3	14	75	13.4	Probably the Collins 651J–1
K	1.9	10	68	20	Clearly the Redifon R551
L	2.0	16	69	12.4	Possibly the Drake MSR–1

between aerial and radio of 20dB will reduce the signal level by 20dB and reduce the IP3 products by 60dB. If these IP3 interfering signals are at a level of 60dB above the receiver noise level then switching in the attenuator should eliminate them.)

Further calculations produced an estimate of how many of the 333 channels per 1MHz spectrum span were occupied with the receiver's own spurii and thus preventing reception. This was then compared with the natural level of ionospheric noise at the frequencies used for the earlier calculations using the same notional aerial, commonly called the 'atmospheric limit'. The factor in dB by which the average level of spurii exceeded the atmospheric limit was defined as the "Reception Failure Factor".

Reception Failure Factor

Sosin's premise was that if the receiver's spurious responses which were occupying the wanted channel exceeded the natural ionospheric RF levels then the receiver had 'failed' to the extent of the excess. That was a measure of the receiver's 'goodness': basically its ability to receive in the presence of a wide spectrum of substantial signals that one would find at a professional receiving site.

Sosin's methodology attempted for the first time to see what would be the effect of a large number of other strong signals present within the spectrum fed to the receiver. It also took account of the effect of front end tuning. The results are summarised in Table 1. The IP3 figure is the input signal level above 1μV EMF to produce an intermodulation product of 1μV EMF at a signal spacing of 10kHz.

Results

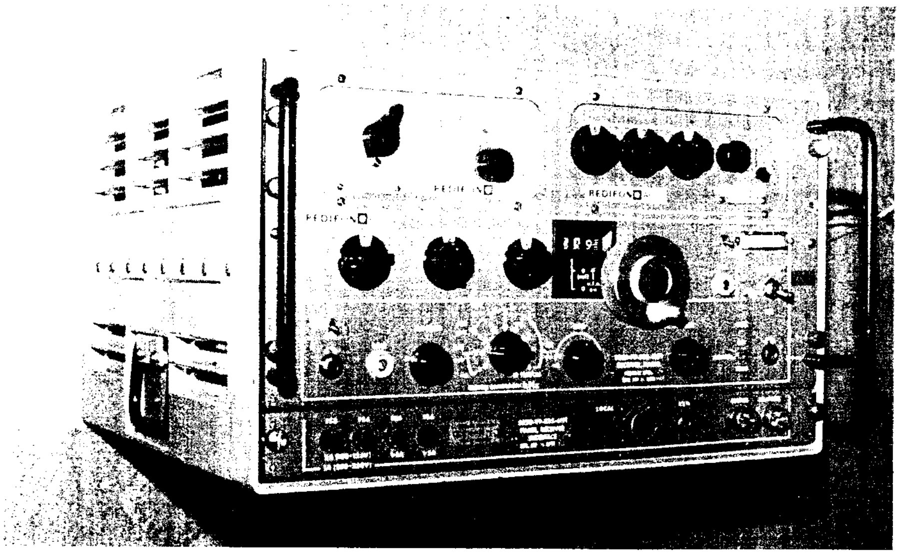
It has to be said that the methodology produced excellent figures for the Marconi and Eddystone receivers and less good figures for nearly everyone else. This approach may have favoured Marconi and Eddystone receivers which had masses of traditional front end selectivity in contrast to sets from the opposition most of which used much wider half-octave filters or were broadband.

Sosin's conclusion was that all the receivers gave factors worse than the atmospheric limit. In other words the limit to communications was the receiver, not the ionosphere. For example Marconi's star performer, the ICS-3 (designed for the Royal Navy and I believe still in use), had an average failure factor of just 0.4dB. It actually gave a positive factor at LF frequencies and was only marginally worse than the atmospheric limit above about 14MHz. The H2900 came in at 1.6dB, the H2311 at 12.7dB and the 1830/6 at 10.3dB. The commercial opposition was less impressive. The best, 'A', was 4dB and the worse, 'C', with a whopping 35dB.

Expressed in a different way, a radio path using receiver C to achieve a designated performance target would need 35 – 0.4 dB (i.e. 34.6dB) more power at the transmitter output to achieve the same performance as the ICS-3. Thus if the ICS-3 needed 100W, receiver C would theoretically need around 250kW on the basis of the presentation.

Practical Experience

Many of us would regard some of these calculated figures as not supported by practical experience. I find for example that there are few signals received at my QTH on a much more



The Royal Navy's version of the Redifon R551. The ARU18 module on the top left is a passive preselector and the module top right, the ARU11, provides full frequency synthesis in steps of 100Hz. It is very heavy. This version was sold to about 20 navies

modern Marconi receiver (the H2540 made in the mid-1980s) that I cannot also hear on my refurbished RA17L plus RA218 SSB converter built in the early 1960s, though I accept that the tuning rate, stability, phase noise and selectivity are nothing like as good as with the H2540.

I have to say that Sosin's calculations are way beyond me. I draw comfort from the fact that none of the professional RF engineers who have seen and discussed Sosin's original paper with me understand the calculations either!

In the context of a house journal with considerable circulation to customers and other reaches of industry, the cynics among us might well be forgiven for suggesting that the motives for all this incredibly hard work might not have been entirely in the interests of science.

Identifying the Other Receivers

Matters might have rested there and Marconi might well have scored a commercial uplift but for the fact that many of the opposition's receivers could be identified from the details in their specifications, particularly the IFs and dimensions. Take receiver 'C'. The IFs given are 40MHz, 3MHz to 2MHz and 100kHz. It needs an adaptor for SSB. It has a free-running VFO with a frequency increment of 1000Hz and six bandwidths with no crystal filters. Its dimensions in inches (converted from the metric details in the table) are 19W × 10.5H × 19D, it weighs 67lbs and consumes 120 watts. I would expect that most readers aged over 40 would swiftly recognise the Racal RA17L. I also identified the Racal RA1772 ('B'), Plessey PR155 ('E'), Collins 651S-1 ('J') and Redifon R551 ('K').

Errors and an Unhappy Racal

Some minor details of the RA17L were wrong. It states that there is no automatic frequency control facility (true) but ignores the excellent AFC facility when using the RA98 ISB converter. The details of the IF filtering also omit the effect of an SSB converter that would be used with the RA17L at a professional station.

What upset Racal were the figures for receivers 'A' and 'B'. Receiver 'A' I cannot identify but receiver 'B' was clearly Racal's new wonder rig, the RA1772 which had recently appeared on the market and which had a third order intercept considerably higher than *any* of the receivers reviewed other than the ICS-3 and 'A', as Table 1 vividly shows. It has to be said that the ICS-3 has an inferior sensitivity with a noise factor of 17dB which has a substantial effect on the IP3.

The RA1772 is still an industry benchmark for receiver quality with an IP3 measured in one of John Wilson's reviews in *Short Wave Magazine* at a hefty +31dBm. The close-in dynamic range of the RA1772 is vastly better than that of the H2311/Eddystone 958, yet the H2311 scores a far better reception failure factor of 12.7dB compared with the RA1772's of 17dB.

To compound the product defamation, the paper stated boldly that receivers 'A' and 'B' did not match up to the specification. As a result the table sets out two columns per receiver – one for the spec and one for the 'actual'. The reception failure factors given to the RA1772 were 9dB 'spec' and 17dB 'actual'.

The Outcome

The outcome was predictable. The lawyers got going, the brown stuff hit the proverbial and before long Marconi had withdrawn the entire January issue. Pat Hawker's TT column in *RadCom* in April 1994 quotes the following letter sent out by Marconi's editor to all recipients of the January issue:

"In the edition of Point-to-Point Communication *dated January 1974 in an article entitled "HF reception failure factor", an account was given of the specification and performance of various types of receiver as compared with the manufacturers' specifications.*

"We are now informed that certain of the specifications in relation to the receivers listed in the graphs and in Table 1 as A and B respectively, and in fact manufactured by Racal Communications Limited, were incorrectly quoted to the disadvantage of such receivers.

"Further it has been suggested that those receivers did not reach the performance claimed for them in the specifications. We are glad to take this opportunity of withdrawing this imputation which was unfounded.

"We have now obtained directly from Racal Communications Limited the relevant specification figures for a revised article which will be sent to you as soon as possible. In the meantime we ask you as a matter of importance to withdraw the existing edition of Point-to-Point Communication *totally from circulation.*

"We apologise for the inconvenience and embarrassment which has been caused".

Readers in the legal business will recognise the statement as the sort likely to have been drafted by the gentlemen in wigs who work at The Temple and Lincoln's Inn. The outcome was without doubt a serious self-inflicted wound for Marconi.

The Missing Issue

Professional readers will appreciate why there may a gap in their technical library's collection of *Point-to-Point Communication*. However, as in most aspects of life, not all is lost if one perseveres. There is one public copy still intact – it is the copyright edition deposited with the British Museum Library and held for many years at the Patent Office Library in Chancery Lane which was the source of my information. To gain access you will now have to visit the new British Library at St Pancras armed with a reader's ticket. The original shelf reference was HC65.

Later in 1974 *Point-to-Point Communications* printed an amended version of the article and a revised table. It should provide a valuable overview of the state of the art of receiver technology at that time.

Plea for Help

It would be interesting if any professional readers could throw some light on the 'goings on' following publication and what happened to Sosin's concept of Receiver Reception Failure Factor. He was arguably the first to appreciate fully the vital importance of intermodulation in receiver design, and his influence on the thinking of younger engineers has been considerable. However, it seems to me that the exercise in his paper was doomed to fail to an extent because receiver specifications are written on many different bases. Eddystone often quote a "typical response". Racal's tend to be understated. The calculations seem not to take account of the effect of AGC, one aspect that is particularly hard to get right. AGC is highly subjective and it will make or break a receiver no matter how robust its front end might be.

A Batting Order of Receiver "Goodness"

Trying to assemble a batting order of 'goodness' also inevitably invites the questions of 'good for what and for whom?'. A reasonably modern Marconi H2540 receiver (first marketed in about 1978) has a most impressive spec. With its very expensive optional phase-compensated crystal filters it is excellent for fast HF data links but has no AM facility, and the CW performance is only so so. For AM, I connect the output of the second mixer to an old GEC BRT402E tuned to 1.4MHz (the H2540's second IF). I tune on the H2540 and listen on the BRT402E rather like a Q5'er.

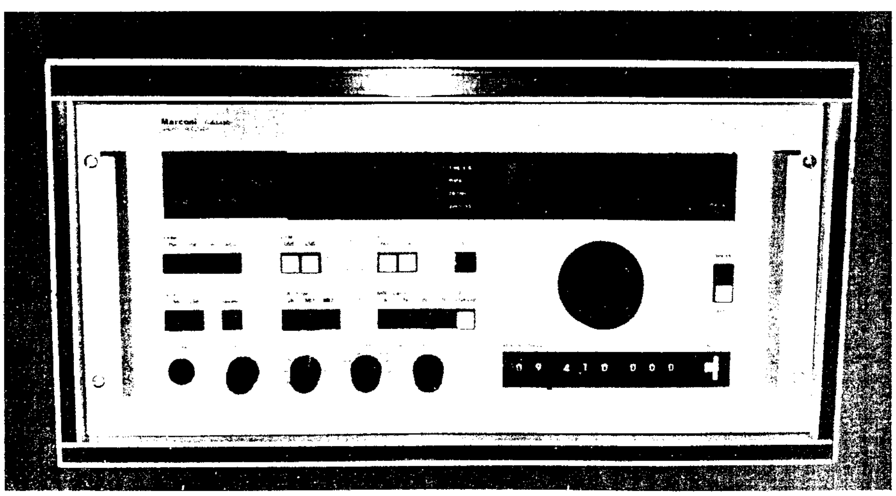
This combination works well but it's a massive lump of metal occupying a vertical space of 19.75 inches in a rack cabinet. A modern AOR 7030 would run rings round it for amateur purposes if only I could cope with the AOR's dreadfully unfriendly front panel.

Most experienced users will confirm that operational convenience in a receiver is just as important as the numbers in the specs. In a similar way, not too many of us would welcome the 270lbs mass of the Marconi *Hydrus* in the shack, despite its excellent RF qualities. There might also be some opposition from the spouse and the floorboards.

Where are the Marconi Sets?

The irony is that while the second hand professional receiver market is awash with RA17s, RA1772s, PR155s and Redifon R551s (and I have owned each one at some time), I have in thirty five years of radio activity only ever seen *one* of the named Marconi receivers, the ICS-3, and that one is here in my shack awaiting a PSU and

Racal's RA1772 receiver covering 10kHz to 30MHz in 30 bands. It has excellent strong-signal performance



The Marconi H2540 receiver covers 10kHz to 30MHz. It is designed for full remote control. It dates from the late 1970s/early '80s and is about 26 inches deep!

Table 2 – Summary of the unidentified receivers

Specification	A	D	F	G	H	L
Remote control	Full	Full	Full	None	Full	None
First production year	1973	1967	1970	1972	1972	--
Price index (referenced to the price of an RA17)	5.5	9	–	2.9	3.3	2
Frequency scale/increment	digital 1Hz	digital 10Hz	digital 100Hz	digital 100Hz	digital 100Hz	digital 100Hz
Frequency tuning	digital	digital	digital	digital	digital	continuous
Frequency range (MHz)	0.05-30	3-27.5	1.8-28	0.2-30	0.1-30	0.1-30
IFs (MHz)	68.1 1.6	39.3 34.3 10.7 0.1	71.6 1.6	71.6 1.6	139.3 10.7 0.2	not given
Crystal filters	8	varies	varies	4	4	4
AFC	option	option	option	none	none	none
Size (W x H x D) in inches	three of 19 x 5.25 x 16	large cabinet	–	19 x 5.25 x 21.6	19 x 5.25 x 16	19 x 5.25 x 13.8
Weight (lbs)	103	–	–	53	39.6	35.2

manual. At 86lbs weight (plus outboard PSU) and a depth of 25 inches, it is not easy to install in a domestic QTH. Eddystone 1830s are around but what ever happened to the rest of the Marconi receivers? Perhaps they were too specialised and costly to be of interest to the surplus dealers. The Marconi MST for example is marked at eleven times the price of the RA17L. I also note with a wry chuckle that the RA17L was selected as the base price comparison and that well over 10,000 were manufactured. Perhaps the market is telling us something.

The Unidentified Receivers

Curiosity requires identification of Sosin's remaining receivers. These are set out in Table 2 above. All apart from G provide independent sideband, i.e. they have separate IF filters, amplifiers, detectors and outputs for USB and LSB.

Receiver 'A' is a Racal receiver. Receiver 'D' is placed beside 'E' which is a Plessey PR155 and has similar IFs indicating that it is probably also a Plessey product. It occupies a substantial rack cabinet. Receivers 'F' and 'G' are clearly related. I wonder if they are German, by Telefunken, Siemens or Rohde & Schwarz, or perhaps the specialised receivers made by the Dutch company Van der Heem for submarines. Receiver 'L' fits the price and many of the specs of the professional maritime Drake MSR-1 but seems to be too heavy. I have scoured the literature including Fred Osterman's masterly *Short Wave Receivers Past and Present* without success. Can any reader help please?

RB

Acknowledgement

I am grateful to Pat Hawker G3VA for his help and researches at the Science Museum Library in tracking down Sosin's revised paper.

References

1. R. F. E. Winn: *Synthesised Communications Receiver* – *Wireless World* October 1974.
2. John Thorpe: *Intermodulation Testing of High Performance Receivers* – AOR's website at http://www.aoruk.com/comments.htm.