Characterisation of Radio Receivers Identified for use in SEARFE Program

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Background of the SEARFE Project

The Students Exploring Australia's Radio Frequency Environment (SEARFE) Project is organized by the CSIRO's Australia Telescope National Facility (ATNF) division. The project is designed to provide high school students with limited practical experience in the field of radio astronomy and an understanding of the value and use of the radio frequency spectrum. The objective of the project is to search for radio-quiet sites in Australia by using either the WinRadio WR-1550e or the AOR AR3000A receiver to measure the radio frequency intensities in the local area of each of the schools in the program. It is hoped that this data will lead to a better understanding of the radio frequency spectrum in Australia and eventually improve Australia's chances of hosting the Square Kilometre Array (SKA).

To support the SEARFE project, Mr Oliver Mather has written software which can control both receivers. The program is called Spectrum Scan, and is able to use either receiver to scan over a specified frequency range and record the output levels of the receiver. It is intended that the students will collect and analyse this data.

1.0 Introduction

Currently, receivers used in radio astronomy are cryogenically cooled to approximately 20°K to reduce the receiver's noise contribution to the system. Cryogenic cooling is an expensive process and is not considered economically feasible for future projects such as SKA, which may be comprised of hundreds of receivers. Accordingly, further research into non-cooled receivers needs to be conducted to determine the effects of increased noise temperature on a receiver system. The purpose of this report is to examine the characteristics of the WinRadio WR-1550e and AOR AR3000A receivers that are relevant for use in radio astronomy and determine ways of measuring these characteristics, in order to determine their usefulness and suitability for the SEARFE project in particular, and radio astronomy applications in general.

2.0 WinRadio WR-1550e

2.1 Specifications

Receiver type	PLL-based triple-conversion superheterodyne	
Frequency range	AM, SSB, FM-N	0.15-1500 MHz
	FM-W	30-1500 MHz
	Note: In some countries certain frequencies may be omitted due to government legislation.	
Tuning resolution	10 Hz (USB/LSB/CW: 1Hz)	
Mode	AM, SSB/CW, FM-N, FM-W	
Image/Spurious Rejection	65dB typ.	
Dynamic range	70dB	
Signal meter linearity	±5dB	
Selectivity	SSB/CW	2.5 kHz @ 6dB
	AM	6 kHz @ 6dB
	FM-N	15 kHz @ 6dB
	FM-W	230 kHz @ 6dB
Scanning speed	AM,SSB/CW	10 channels/s
	FM-N, FM-W	50 channels/s

Sensitivity (AM/SSB/CW 10dB S/N; FM-N/FM-W 12dB SINAD):

Mode	0.15-1.5 MHz	1.5-30 MHz	30-1000 MHz	1-1.5 GHz
AM	25µV	1µV	1µV	1.9µV
SSB	0.9µV	0.3µV	0.3µV	0.4µV
FMN	0.4µV	0.4µV	0.4µV	0.4µV
FMW	-	-	1.0µV	1.0µV

Intermediate frequencies:

f [MHz]	IF1 [MHz]	IF2 [MHz]
0.15-399.999	556.325	58.075
400-807.999	249.125	58.075
808-1113.999	249.125	58.075
1114-1500	556.325	58.075

Mode	IF3 [MHz]
AM,SSB,FM-N	0.455
FM-W	10.7

Frequency stability	10 ppm (0 to 60° C)
Antenna input	50 ohm (BNC connector)
Audio output	0.2W (8 ohm load)

Table 1: (Source: http://www.winradio.net.au/home/1550e-s.htm)

The WR-1550e, is a software controlled external receiver with a frequency range specified to be 150kHz to 1.5GHz. The external unit is connected PC compatible computer via a serial interface cable. The antenna input is a BNC connection.
The receiver operates in 4 modes, AM, FM-N, FM-W and SSB/CW. The receiver gives an output to the computer as number between 0-255. This number is related to the strength of a signal the receiver can pick up at particular frequency.

As the WR-1550e is completely software driven, numerous software programs or “plug-ins” are available and can be downloaded free from WinRadio website. These programs include many features such as scanning and sweeping options, and calibration tables. In order to achieve consistency between the two receivers used in the SEARFE project, the Spectrum Scan program by Oliver Marther, was used to record the results.

2.2 Determining Linearity Characteristics of the WinRadio 1550e

The first test undertaken on the receiver was to determine the linearity of the receiver at different frequencies and signal strengths. From this data the 1dB compression points could also be determined, along with the gain.

The data was collected using a signal generator (Rohde & Schwarz) to supply a signal of known frequency and amplitude into the receiver, (connected to the antenna input). Initially, data was collected for all 4 receiving modes (CW, AM, FMN and FMW) over the frequency range of the receiver, 150KHz to 1.5GHz, varying the amplitude of the input signal for each frequency between -100dBm to -40dBm. The data collected is displayed in Table 2. Figure 1 is a plot for the FMN mode of the output level of the receiver (0-255) versus frequency. From this plot it can be seen that the receiver did not handle frequencies below 10MHz however these frequencies are rarely used in radio astronomy due to absorption of these waves by the ionosphere. This performance was therefore, not considered a problem and only frequencies above 10MHz were studied in detail. No modulation was used when generating signals for the receiver, as the radio signals of interest to astronomers are not modulated.

Freq	-100dBm				-90dBm				-80dBm				-70dBm			
(MHz)	CW	AM	FMN	FMW	CW	AM	FMN	FMW	CW	AM	FMN	FMW	CW	AM	FMN	FMW
0.15	0	0	51	215	0	0	52	215	0	0	53	215	0	0	64	215
1	0	0	22	0	0	0	41	0	0	0	71	0	0	64.5	100	0
10	0	97	108.5	13.5	82.5	170	133	153	165	186	153	185.5	183	205	162	204
20	0	76	103	0	63	163	128	137	157	182	150	182	180	202	161	201
50	0	97	108	50	84	170	133	153	165	186	153	186	183	206	162	204
100	0	75.5	103	0	65	162	128	134.5	157	182	150	181	180	202	161	201
200	0	0	76	0	0	90	106	0	83	168	130	144	165	184	152	183
500	0	82	103	0	96	165	128	138	170	183	150	182	185	203	161	201
1000	0	0	73	0	0	71	102	0	36	160	127	143	145	181	149	183
1500	0	0	76	7	0	77	107	64.5	55	164	129	172	153	182.5	154	194

Freq	-60dBm				-50dBm				-40dBm			
(MHz)	CW	AM	FMN	FMW	CW	AM	FMN	FMW	CW	AM	FMN	FMW
0.15	0	0	91	215	0	135	117	215	123.5	177	143	215
1	52.5	158	126	96.5	151	181	149	176	179	200	160	195
10	203	220	164	218	218	225	164	225	225	227	163	229
20	199	218	163	216	216	225	164	224	224	227	163	228
50	203	220	164	218	219	225	164	225	225	227	163	229
100	200	218	164	216	216	225	164	224	224	227	164	228
200	183	204	161	202	203	219	164	217	218	225	164	225
500	205	219	164	216	217	224	164	223	220	225	164	224
1000	178	201	160	202	196	217	162	217	210	224	162	224
1500	179	202	161	210	198	217	162	222	215	225	162	227

Table 2: Comparison of output levels for all 4 modes over a range of frequencies.

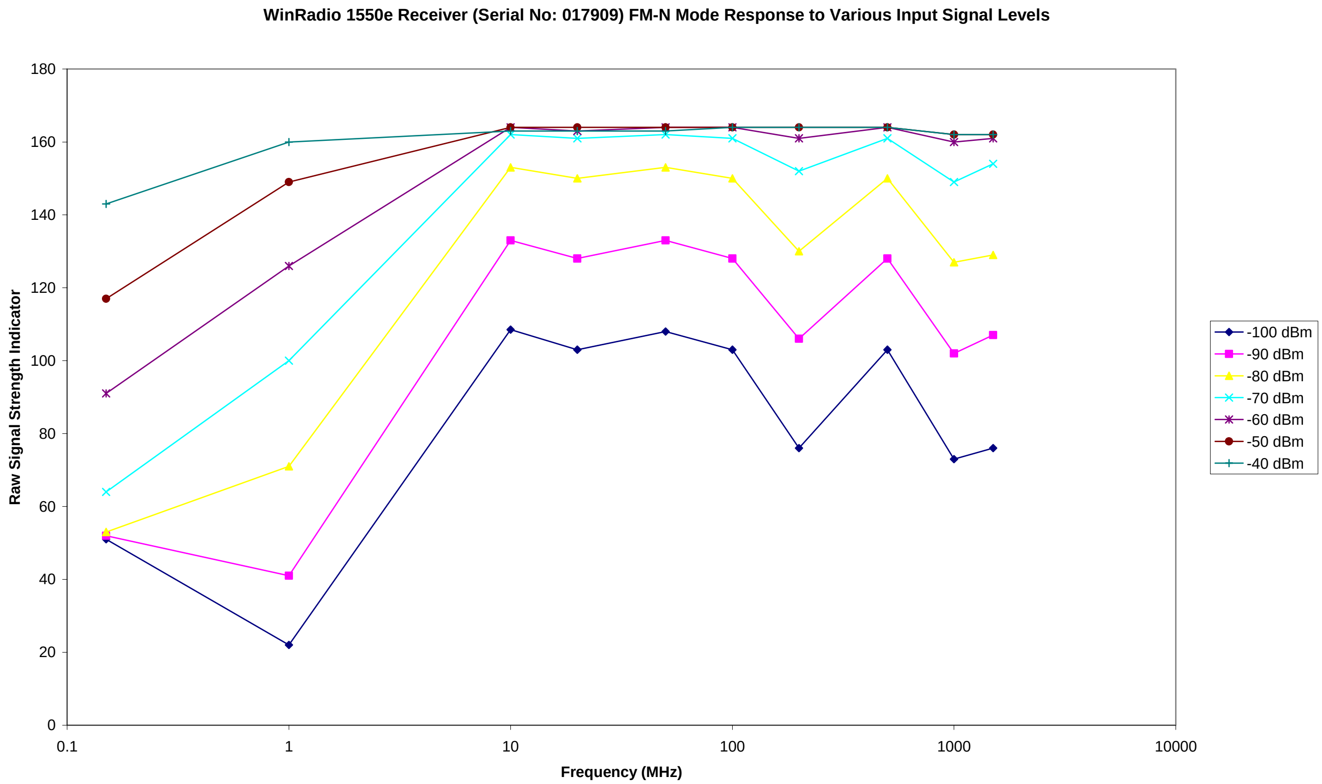

Figure 1: WR-1550e output level vs frequency for FMN.

Since the SEARFE data will usually only be recorded in FMW mode due to the quicker scan time with the wider bandwidth, compared to the time taken for an FMN mode scan, the FMW and FMN receiver modes were analyzed in more detail

Table 3 details the measurements taken in the FMW mode of the output levels, for input signals -100dBm to -40dBm over the frequency range of 10MHz to 1500MHz.

Input (dBm)	10MHz	20MHz	50MHz	100MHz	200MHz	500MHz	1000MHz	1500MHz
-100	14	0	13	0	0	0	0	7
-90	153	137	151	136	2	137	0	65
-80	186	181	185	180	144	181	143	172
-70	204	200	203	199	182	199	183	194
-60	218	216	218	216	202	216	202	210
-50	225	224	225	224	217	223	217	222
-40	229	228	229	228	225	224	224	227

Table 3: WR-1550e output levels for range of frequencies at different input amplitudes for FMW mode.

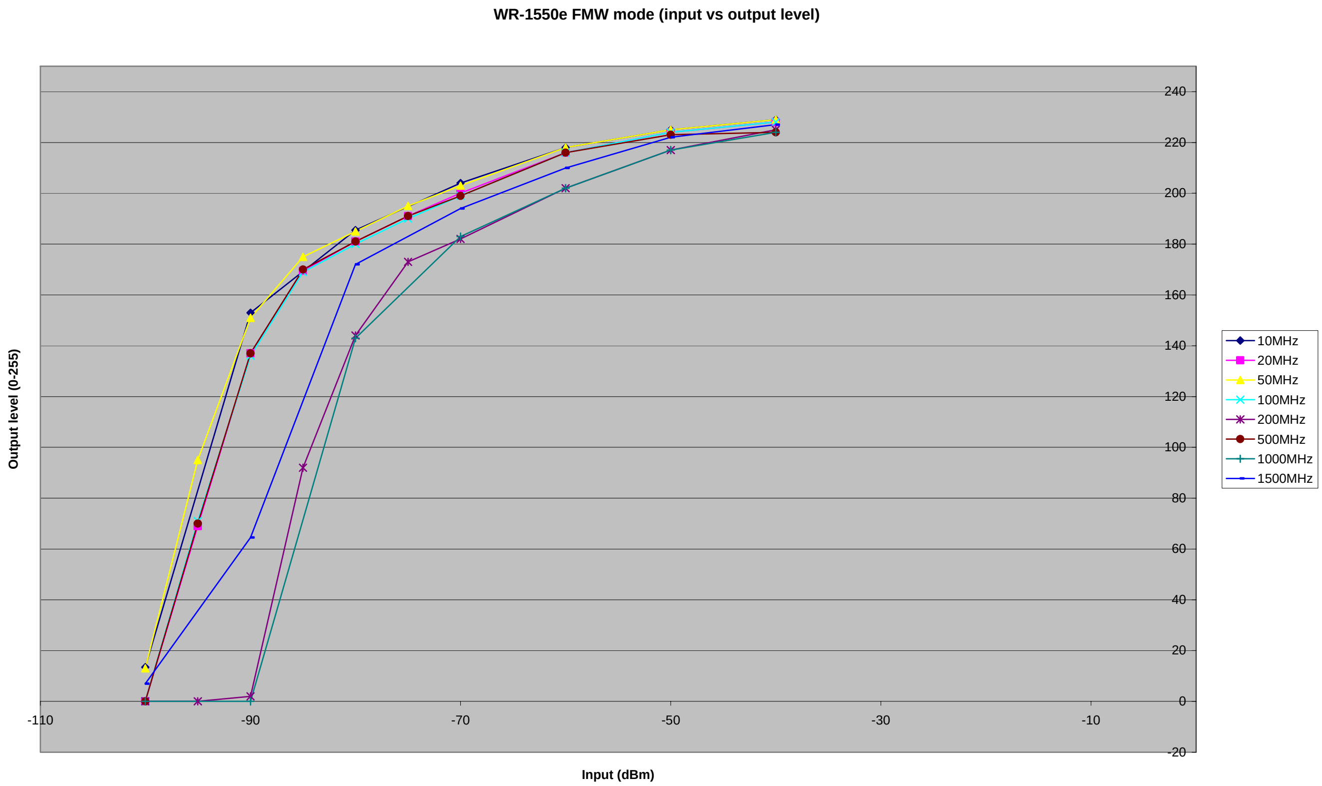

Figure 2: WR-1550e output level vs input amplitude for frequencies 10MHz to 1.5GHz in FMW.

Figure 2 clearly shows that the dynamic range of the WR-1550e in the FMW mode is very small, roughly 10dBm, however its output response is very consistent for the lower frequencies.

The FMN receiver mode was looked at in more detail as it had larger dynamic range, roughly 50dBm, at lower frequencies, which can be seen in figure 3.

Input (dBm)	10MHz	20MHz	50MHz	100MHz	200MHZ	500MHz	1000MHz	1500MHz
-150	17	15	18	17	5	23	23	58
-140	18	17	18	17	6	23	24	59
-130	25	23	28	24	9	28	25	59
-120	50	45	51	46	22	42	27	61
-110	79	75	80	74.5	50	73	41	63
-100	108.5	103	108	103	79	102	71	79
-90	133	128	133	128	109	127.5	100	109
-80	153	150	153	150	131	150	125	134
-70	162	161	162	161	153	160	149	153
-60	164	163	164	164	162	164	159.5	160
-50	164	164	164	164	164	164	162	162
-40	163	163	163	164	164	164	162	162

Table 4: Output levels for range of frequencies at different input amplitudes for FMN mode.

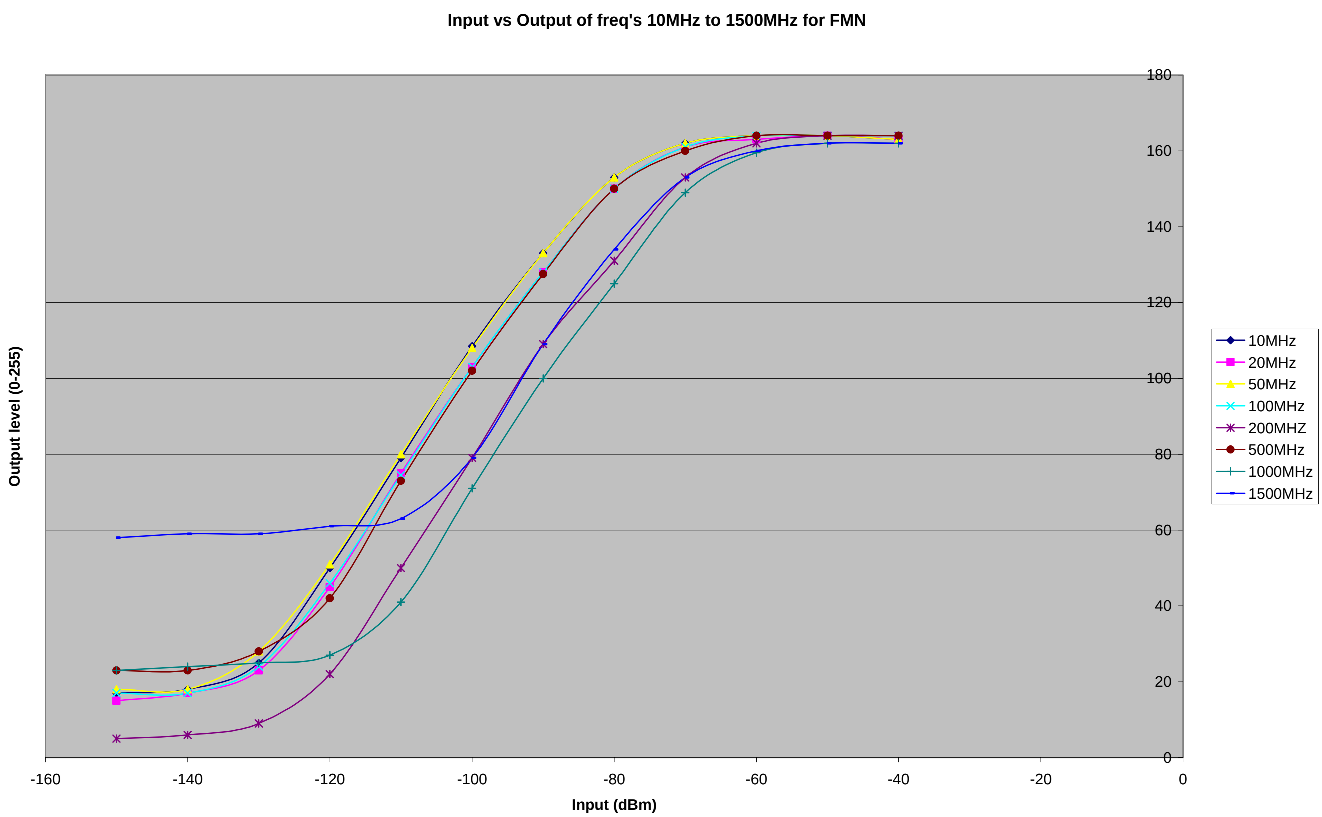

Figure 3: WR-1550e input level vs output level.

Examination of the two receiving modes revealed that FMN mode had a considerably lower noise floor of approximately -130dBm compared to the FMW mode which was approximately -100dBm. From figures 1 and 2 it can also be seen that the FMN mode is more linear with a much larger linear region compared to that of the FMW mode. Both modes had consistent gains and were more linear at the lower frequencies, but behaved quite differently at higher frequencies.

Gain and 1dB Compression Points

The gain and 1dB compression points were only calculated for the FMN mode as the output was more linear and had a larger dynamic range then the FMW mode. In order to measure and calculate these parameters more data had to be collected and added to table 4.

From this data the output level 0-255 was able to be calibrated to give an output in dB. This was done at each frequency by determining the equation of the line using Microsoft Excel for the linear region. By knowing the equation of the line in *y=mx+b* form, the output levels could be converted to dB by dividing each output level by *m* (in which *m* is related to the gain, G).

$$V_o = G \times V_{in}$$

$$20\log(V_o) = 20\log(G \times V_{in})$$

$$20\log(V_o) = 20\log(G) + 20\log(V_{in})$$

The data was again plotted, only this time in the form of input signal versus the new calibrated output signal in dB. Once again the equation of the line of best fit was found for the linear region of each plot at each frequency, (see Table 5 for equations of calibrated data for the linear region of each frequency). From this line the 1dB compression points could be found (see Table 5).

Frequency (MHz)	10	20	50	100	200	500	1000	1500
Original equation	y=2.745x+381	y=2.68+369.6	y=2.67x+373.7	y=2.65x+366.6	y=2.95x+374.3	y=2.725x+373	y=2.95x+365.7	y=2.75x+354.8
m	2.745	2.68	2.67	2.65	2.95	2.725	2.95	2.75
New equation	y=x+138.82	y=x+137.91	y=x+139.96	y=x+138.34	y=x+126.89	y=x+137	y=x+123.95	y=x+129.03
Gain (dB)	138	138	140	138	127	137	124	129
1dB point (dBm)	-85	-81.5	-83.5	-81.5	-88	-83.7	-82.8	-85.5

Table 5: WR-1550e FMN calibrated equations to obtain output for linear regions at each frequency.

Table 6 is the converted output of the FMN mode data from table 4 into dB, found using the method described above, dividing each value by *m* for the corresponding frequency.

Input (dBm)	10MHz	20MHz	50MHz	100MHz	200MHZ	500MHz	1000MHz	1500MHz
-150	6.19308	5.59701	6.74157	6.41509	1.69492	8.44037	7.79661	21.09091
-140	6.55738	6.34328	6.74157	6.41509	2.03390	8.44037	8.13559	21.45455
-130	9.10747	8.58209	10.48689	9.05660	3.05085	10.27523	8.47458	21.45455
-120	18.21494	16.79104	19.10112	17.35849	7.45763	15.41284	9.15254	22.18182
-110	28.77960	27.98507	29.96255	28.11321	16.94915	26.78899	13.89831	22.90909
-100	39.52641	38.43284	40.44944	38.86792	26.77966	37.43119	24.06780	28.72727
-90	48.45173	47.76119	49.81273	48.30189	36.94915	46.78899	33.89831	39.63636
-80	55.73770	55.97015	57.30337	56.60377	44.40678	55.04587	42.37288	48.72727
-70	59.01639	60.07463	60.67416	60.75472	51.86441	58.71560	50.50847	55.63636
-60	59.74499	60.82090	61.42322	61.88679	54.91525	60.18349	54.06780	58.18182
-50	59.74499	61.19403	61.42322	61.88679	55.59322	60.18349	54.91525	58.90909
-40	59.38069	60.82090	61.04869	61.88679	55.59322	60.18349	54.91525	58.90909

Table 6: WR-1550e FMN output levels converted to dB.

The 1dB compression points and gain were found to be almost constant over the frequency range 10MHz to 100MHz, with only slight discrepancies, most likely the result of measurement errors. At low input levels, the output was often not stable and as a result, it was difficult to obtain an accurate reading. The gain was approximately 138 and the 1dB compression point was found to be around -83dBm. More precise output measurements could have been obtained if the output levels where logged over a longer period of time and integrated to obtain a more accurate average of the output level.

2.3 Noise Figure Measurements

Noise Figure calculations were done with the measurements recorded from applying a known noise source into the receiver. A 346C Noise Source which has a range of 10MHz to 26.5GHz, was used. Table 7 contains the recorded data from the output of the receiver at each frequency for the noise figure measurements.

Frequency (MHz)	10	100	1000
ENR (dB)	13.16	13.24	13.14
No noise (cold)	19±3	18±4	25±5
Noise (hot)	40.5±5.5	38±5	39.5±5.5
Calibration for dB	1/2.745	1/2.65	1/2.95

Table 7: WR-1550e Noise Figure Measurements.

By dividing the two output levels by *m* from table 5 for the corresponding frequency for when the noise is on and off, P_1 and P_2 can be calculated, (subscript 1 refers to when the device is hot or noise is turned on, while subscript 2 is when device is cold or noise source is switched off). The calculations below are to calculate the noise figure at 10MHz.

$$P_2 = \frac{19 \pm 3}{2.745 \pm 0.005}$$
$$P_2 = 6.92 \pm 1.12\text{dB}$$

$$P_1 = \frac{40.5 \pm 5.5}{2.745 \pm 0.005}$$
$$P_1 = 14.75 \pm 2.1\text{dB}$$

$$\mathbf{Y} = \frac{\mathbf{P_1}}{\mathbf{P_2}}$$
$$Y = 14.75 \pm 2.1\text{dB} - 6.92 \pm 1.12\text{dB}$$
$$Y = 7.83 \pm 3.22\text{dB}$$
$$Y = 6.07 \pm 2.1$$

$$\mathbf{ENR_{dB}} = \mathbf{10\log\left(\frac{T_1 - T_2}{T_2}\right)}$$
$$ENR = 10^{\frac{ENR_{dB}}{10}}$$
$$ENR = 10^{\frac{13.16 \pm 0.05}{10}}$$
$$ENR = 20.70 \pm 1.02$$

$$ENR = \left(\frac{T_1 - T_2}{T_2}\right)$$
$$20.70 \pm 1.02 = \left(\frac{T_1 - 290 \pm 3}{290 \pm 3}\right)$$
$$T_1 = 6293 \pm 361\text{K}$$

$$\mathbf{T_e} = \left(\frac{\mathbf{T_1 - YT_2}}{\mathbf{Y - 1}}\right)$$
$$T_e = \frac{(6293 \pm 361) - ((6.07 \pm 2.1) \times (290 \pm 3))}{((6.07 \pm 2.1) - 1)}$$
$$\underline{T_e = 894 \pm 565}$$

$$\textbf{Noise Figure} = \mathbf{10\log\left(1 + \frac{T_e}{T_0}\right)}$$
$$\text{Noise Figure} = 10\log\left(1 + \frac{894 \pm 565}{290}\right)$$
$$\underline{\text{Noise Figure} = 6.11 \pm 4\text{dB}}$$

The noise figure was calculated to be 6.11dB with an error of ± 4dB. The large error is due to the uncertainty when measuring the output levels. The output levels fluctuated over a large range at such a fast rate that it was extremely difficult to take an accurate reading. These readings could be improved in the same way as previously mentioned, by logging the output over a period of time and taking the average. Further uncertainty is introduced when trying to calibrate these output levels as the gain calculated for each frequency is not entirely accurate for reasons mentioned earlier.

These same calculations were conducted for 100MHz and 1000MHz, the noise figures calculated are represented in the following table (Table 8).

Frequency (MHz)	10	100	1000
Noise Figure (dB)	6.11±4	7.95±6.7	9.91±4
Noise Temperature (K)	894±565	1519±1288	2549±1039

Table 8: WR-1550e Calculated Noise Figures for each frequency.

2.4 Dynamic Range

The rather loose definition of Dynamic Range often results in different values for the same receiver. The dynamic range of a single receiver can also vary markedly depending on the application of the receiver. Generally, the dynamic range is the range of inputs that result in a correct, accurate output from the receiver.

Firstly, the dynamic range was determined by analyzing a plot of the input levels in dBm versus the output levels in dB at 500MHz. A common way of defining dynamic range is to determine the range of the linear region of the graph with the lower limit of the dynamic range being the noise floor, and the upper limit being the 1dB compression point. From Figure 4 below it can be seen that the receiver has a dynamic range of -45.6dBm, this being the size of the linear region of the receiver. In other words, -45dBm is the range of the input that can go into the receiver and give the correct output.

Since this receiver is being analyzed to determine its suitability for use in radio astronomy, it is relevant to consider at the region of input levels that are of similar strength to those from space. As the signals that astronomers would be interested in lie beneath the noise floor, it is important to determine the range of input levels that can be measured without the problem of third order components interfering.

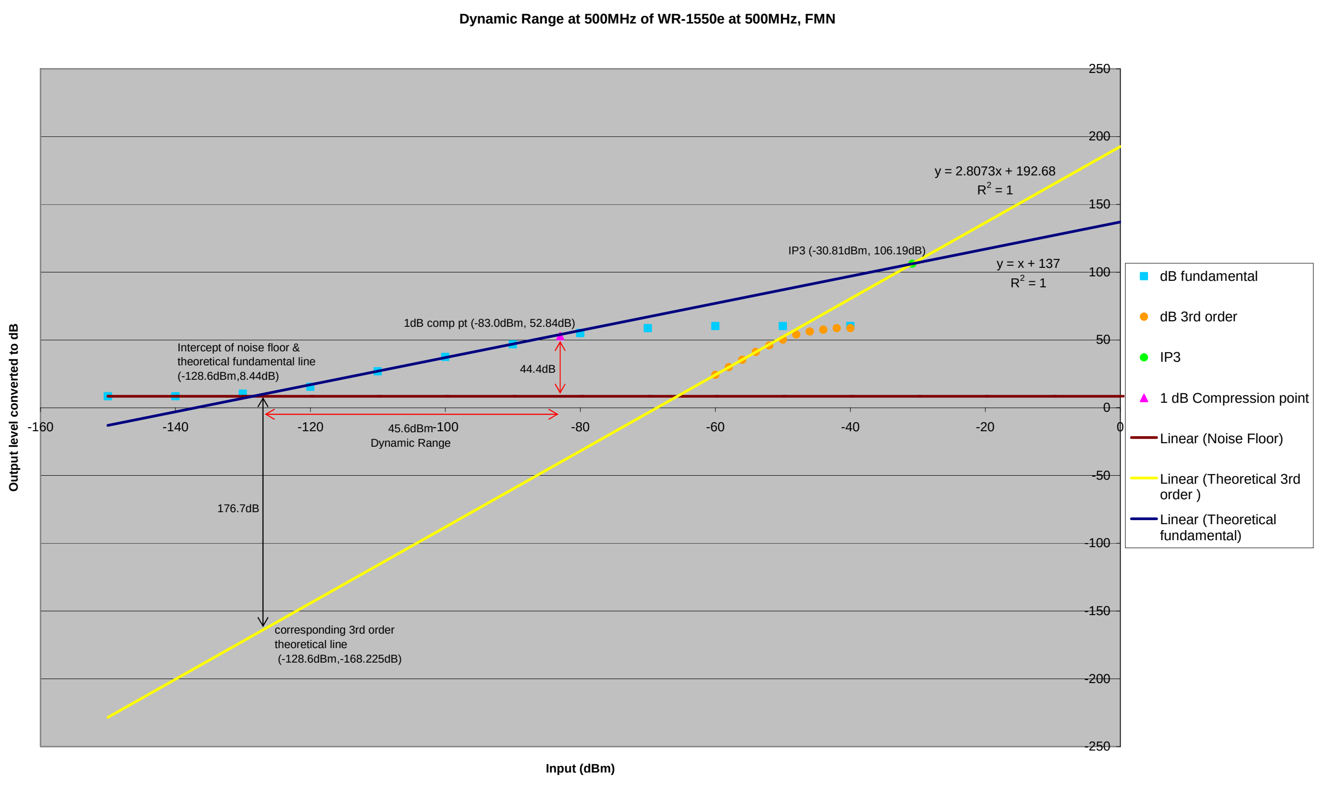

Figure 4: WR-1550e FMN Dynamic Range at 500MHz.

The third order intercept point was determined by mixing 2 signals from 2 separate signal generators into the antenna input of the WR-1550e in FMN mode. The two signals mixed were 500MHz and 510MHz (f_1 and f_2 respectively), which created 3rd order harmonics at 490MHz ($2*f_1 - f_2$) and 520MHz ($2*f_1+f_2$). The receiver was tuned to both 490MHz and 520MHz and the output measurements were recorded for various input levels. These points were plotted on the same graph as the 500MHz output response, and the data was extrapolated to determine the theoretical point were both curves would meet if they were perfectly linear. The range of input levels that can be measured without the problem of third order components interfering, that is, from where the fundamental theoretical output line intercepts with the noise floor, down to the third order output line was 176.7dB, (see figure 4).

2.5 Receiver Selectivity

The receiver specifications state the selectivity of the WR-1550e to be 15kHz at -6dB for FMN and 230kHz at -6dB for FMW. However it was found when measuring these, that the bandwidths were somewhat larger, especially in the FMW mode. The bandwidth was measured to be 17kHz at -6dB for FMN and 313kHz at -6dB for FMW. These measurements were done by applying a -90dBm signal at a 100MHz into the receiver and then tuning the receiver over a series of points on either side of a 100MHz and recording the output strength to get a shape of the band pass filter (see figure 5).

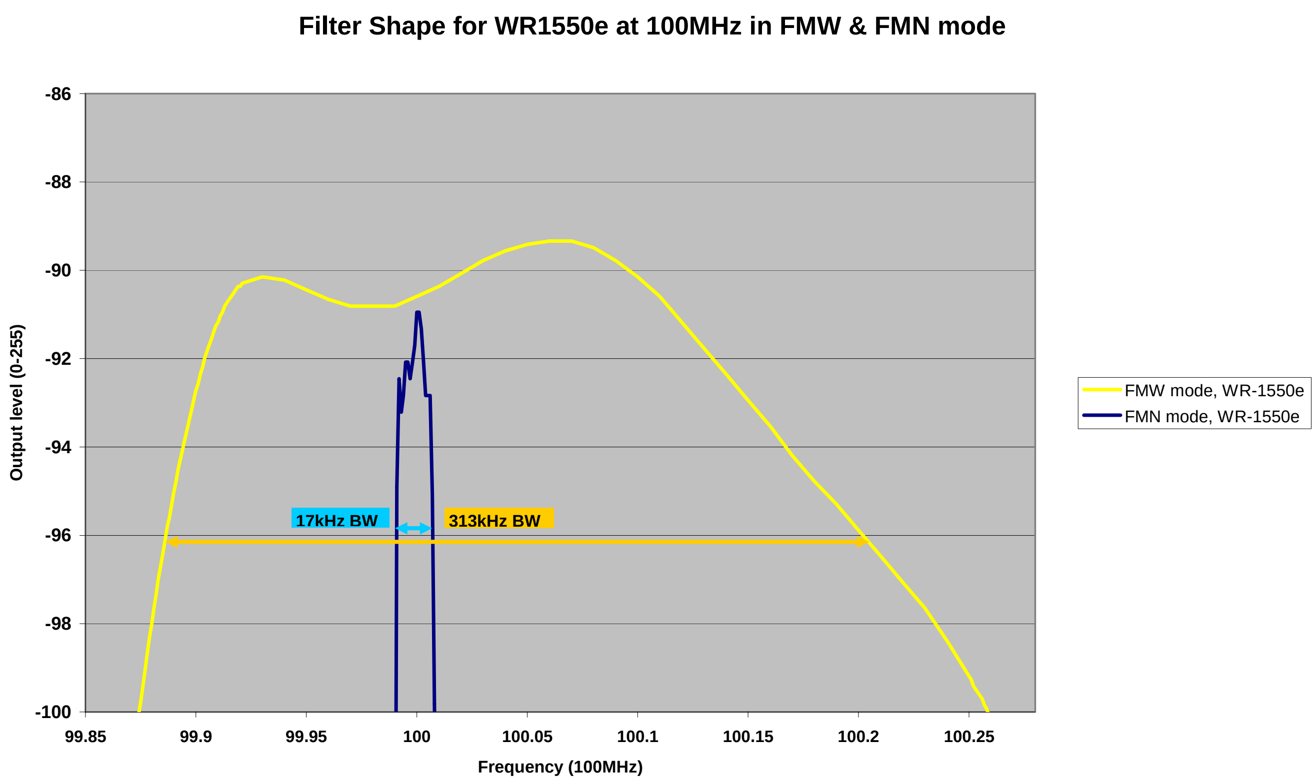

Figure 5: WR-1550e receiver selectivity at 100MHz for FMW & FMN.

2.6 Sensitivity

In the FMN receiver mode the sensitivity is specified as 0.4µV over all frequencies and the antenna input is 50Ω. Using those figures the theoretical noise floor was able to be calculated as follows:

$$P = \frac{V^2}{R}$$

$$P = \frac{(0.4\times10^{-6})^2}{50} = 3.2\times10^{-15}\,\text{W}$$

$$P = 10\times\log(3.2\times10^{-15})$$

$$P = -144.95\text{dBW}$$

$$P = \underline{-114.95\text{dBm}}$$

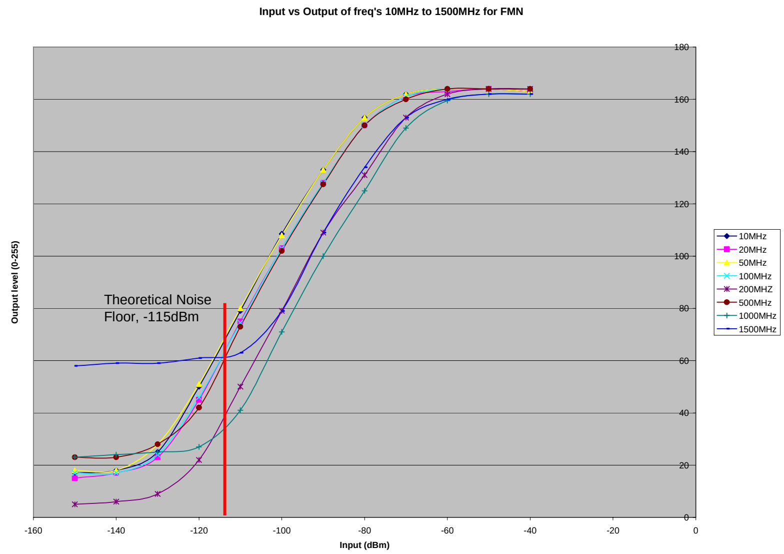

Figure 6: WR-1550e FMN theoretical noise floor.

The noise floor was calculated to be -115dBm, which corresponds to the data collected, though at low frequencies up to 100MHz, it was found that the noise floor was actually lower, at around -130dBm. At the higher frequencies the noise floor was higher as expected, and closely matched the -115dBm noise floor as calculated above (see figure 6 for comparison of measured noise floor and calculated noise floor).

For the FMW mode the sensitivity is specified as 1.0µV for frequencies 30MHz to 1.5 GHz. Once again the noise floor was calculated using the same method as above, which gave the noise floor to be -107dBm. This figure however did not match the measured values. At low frequencies up to about 100MHz the noise floor was estimated to be around 100dBm, which does correspond to the calculated value, however frequencies above 100MHz gave higher noise floor measurements of approximately -90dBm (see figure 7 for comparison of measured noise floor and calculated noise floor for FMW).

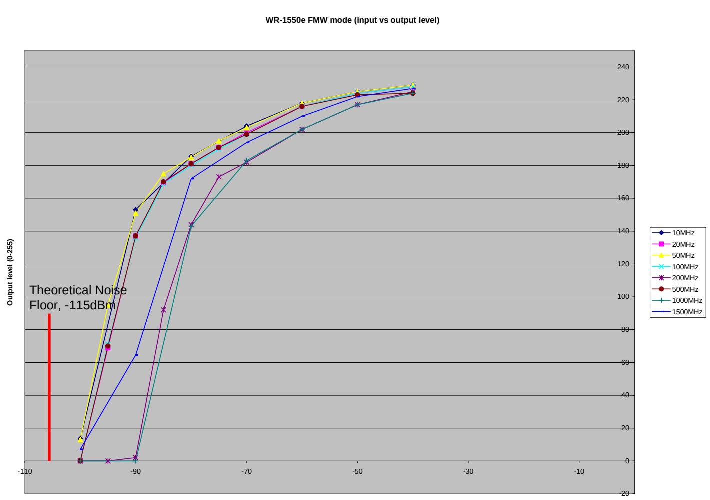

Figure 7: WR-1550e FMW theoretical noise floor.

3.0 AOR AR3000A

The AR3000A is one of the two types of radio receivers used in the SEARFE project. It has range of 0.1MHz to 2036MHz with 6 receiver mode settings, AM, WFM, NFM, USB, LSB and CW. The AR3000A does have a control panel on the front for manual operation of the receiver or alternatively can be controlled/programmed with a computer via the RS232C connection port located on the back. This is how the SEARFE software is able to control the receiver and log the output levels. The AR3000A's output strength is indicated by letters of the alphabet A through P which represent 16 quantization levels, where A is the lowest and P is the highest.

3.1 Specifications

Model	AR3000A
Receiver coverage	100 kHz ~ 2036 MHz
Tuning selection	50 Hz - 999.95 kHz - programmable
Receiving modes	AM, WFM, NFM, USB, LSB & CW
Number of memory channels	400 total (4 x 100)
Number of search banks	Four
Aerial connection	50 OHM BNC
Audio output	0.7 WATTS 8 OHM load @ 10% distortion
Power requirement	External 12V DC @ 0.5A (nominal 13.8V) negative ground approx.
Size	138mm (W) x 80mm (H) x 200mm (D) Approx. excluding projections
Weight	1.2kgs
Receiver Sensitivity	100 kHz – 2.5 MHz: 10 dB S/N 1.0µV SSB, 3.2µV AM 2.5 MHz – 1.8 GHz: 10 dB S/N 0.25µV SSB, 1.0µV AM 12 dB S/N 0.35µV NFM, 1.0µV WFM 1.8 GHz – 2.0 GHz: 10 dB S/N 0.75µV SSB, 3.0µV AM 12 dB S/N 1.25µV NFM, 3.0µV WFM
Receiver Selectivity	USB, LSB, CW: 2.4 kHz/-6dB, 4.5 kHz/-60dB AM, NFM: 12 kHz/-6dB, 15 kHz/-70dB WFM: 180 kHz/-6dB, 800 kHz/-50dB

(Source: http://www.aoruk.com/ar3000a.htm)

3.2 Determining Linearity Characteristics of the AR3000A

The first test undertaken on the AR3000A receiver was to determine the linearity of the receiver at different frequencies and signal strengths.

The process used to measure the linearity characteristics of the AR3000A was the same as used for the WR-1550e. The data was collected by using a signal generator to supply a signal of a known frequency and amplitude into the receiver which was connected to the antenna input. Once again only the FMN and FMW band where analyzed as the SEARFE data is generally collected in the FMW. The FMN was analyzed to compare the differences in the receiver's modes.

Measurements were first undertaken in the FMN receiver mode. The results from this proved the AR3000A was not very linear with a very small dynamic range which can be seen clearly in figures 8 & 9.

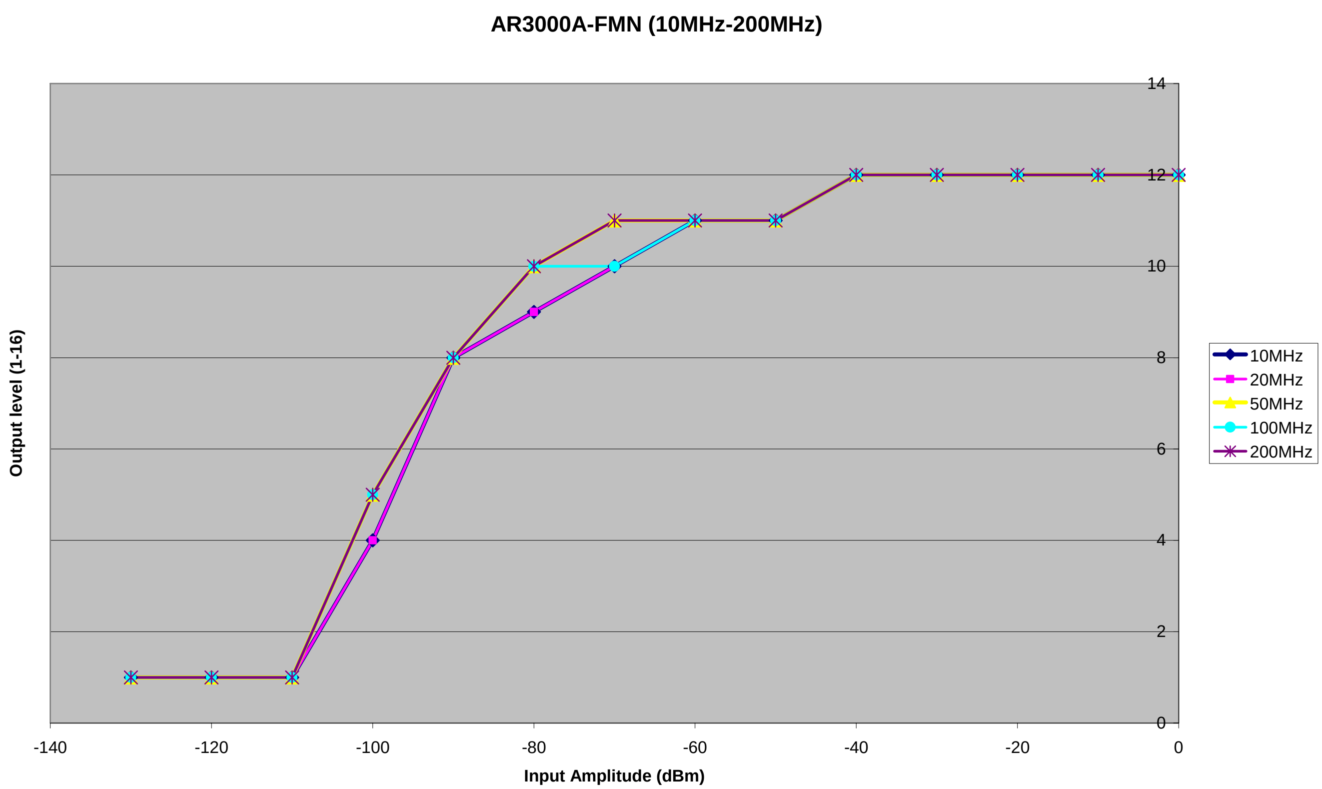

Figure 8: AR3000A output level vs input amplitude for frequencies 10MHz to 200MHz in FMN.

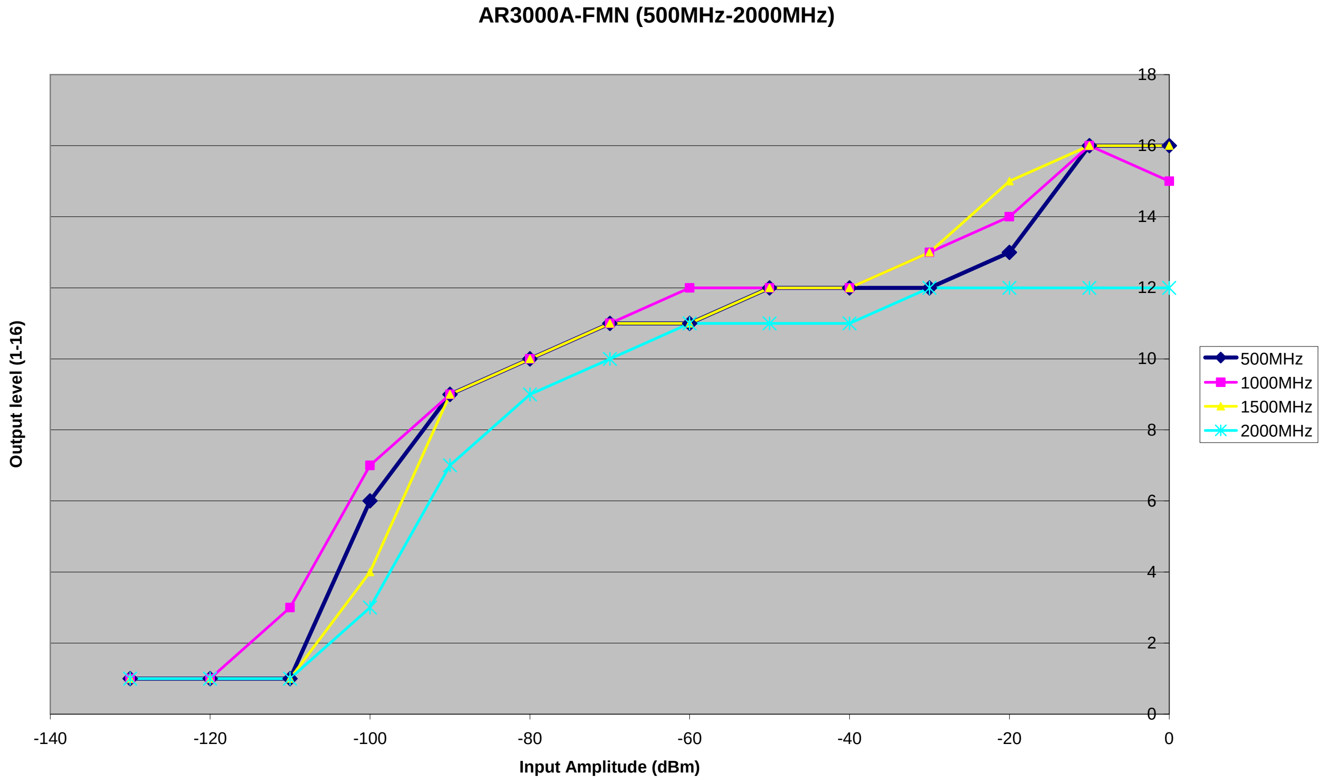

Figure 9: AR3000A output level vs input amplitude for frequencies 500MHz to 2GHz in FMN.

Due to the coarseness of the quantization levels for the receiver output and the fact the receiver proved to have such small linear region, a different approach was undertaken to calibrate the output.

Instead of fitting a line to the linear region of the output for each frequency, the output was characterized by its input signal strength. The measurements were conducted at 100MHz as the lower frequencies were consistent in giving the same output level for the same input level. To determine the transition points from quantization level to the next, the input was increased gradually from -130dBm to 0dBm where the output stopped increasing and flattened out. The input strength and output level were recorded every time the output increased by one level. This was repeated for the FMW receiver mode as well (see figure 10 for graphical representation of the signal strengths range for each quantization level).

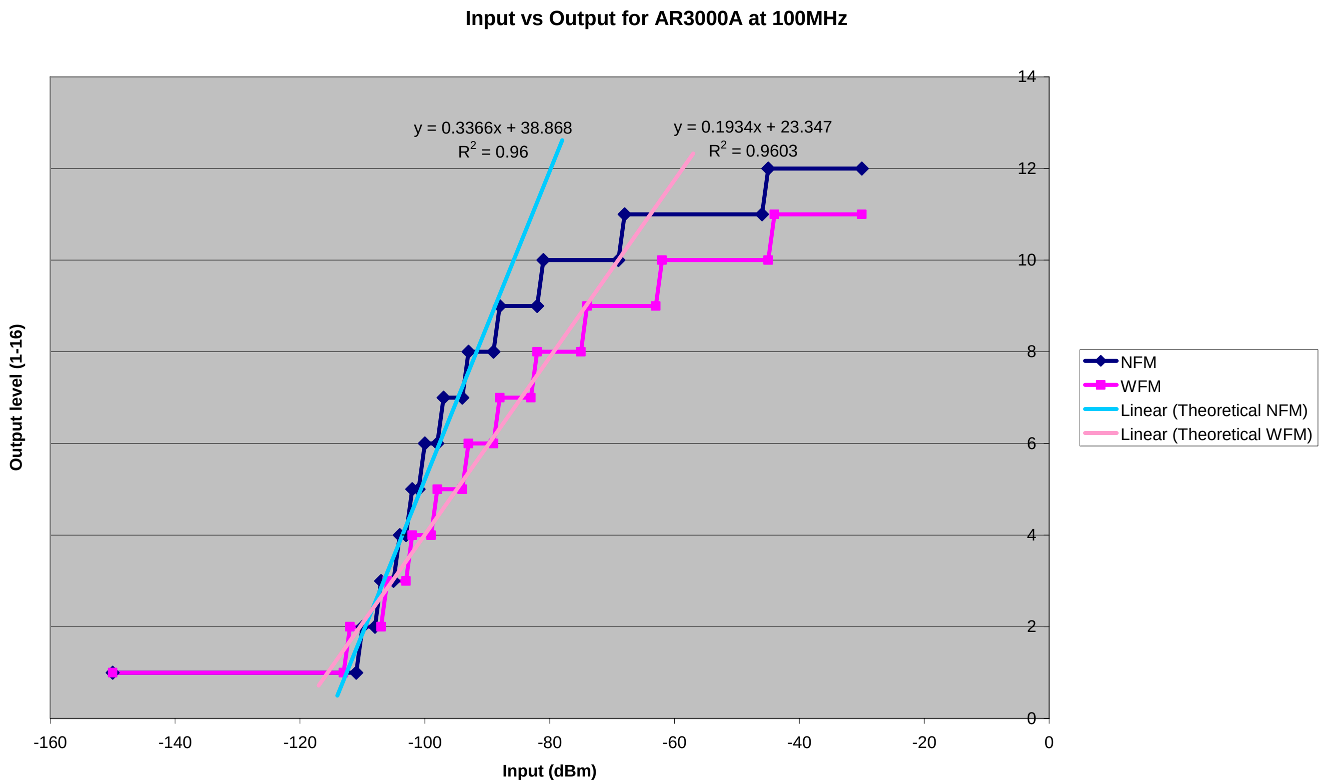

Figure 10: AR3000A output level for corresponding input amplitude in FMW & FMN mode.

The simplest way to calibrate the output when working with such coarse quantization levels was to take the middle value of signal strength range for the corresponding output level. Table 9 below is the calibration table determined from the measurements recorded for figure 9.

Output level		FMN Range	FMN Middle of Range	FMW Range	WFM Middle of Range
A	1	-150dBm to -111dBm	-112.5dBm	-150dBm to -113dBm	-115.8dBm
B	2	-110dBm to -108dBm	-109.0dBm	-112dBm to -107dBm	-109.5dBm
C	3	-107dBm to -105dBm	-106.0dBm	-106dBm to -103dBm	-104.5dBm
D	4	-104dBm to -103dBm	-103.5dBm	-102dBm to -99dBm	-100.5dBm
E	5	-102dBm to -101dBm	-101.5dBm	-98dBm to -94dBm	-96.0dBm
F	6	-100dBm to -98dBm	-99.0dBm	-93dBm to -89dBm	-91.0dBm
G	7	-97dBm to -94dBm	-95.5dBm	-88dBm to -83dBm	-85.5dBm
H	8	-93dBm to -89dBm	-91.0dBm	-82dBm to -75dBm	-78.5dBm
I	9	-88dBm to -82dBm	-85.0dBm	-74dBm to -63dBm	-68.5dBm
J	10	-81dBm to -69dBm	-75.0dBm	-62dBm to -45dBm	-53.5dBm
K	11	-68dBm to -46dBm	-57.0dBm	-44dBm to -30dBm	-37.0dBm
L	12	-45dBm to -30dBm	-37.5dBm		

Table 9: AR3000A calibration table for FMW & FMN modes.

3.3 Receiver Selectivity

The receiver specifications stated the selectivity of the AR3000A to be 12kHz at -6dB for FMN and 180kHz at -6dB for FMW. To measure these bandwidths the same process was used for the AR3000A as was used for the WR-1550e. The AR3000A resulted in closer values to the specifications than the WR-1550e did. The FMN mode's bandwidth at -6dB was measured to be 14.5kHz and the FMW was measured to 184kHz at -6dB (see figure 11).

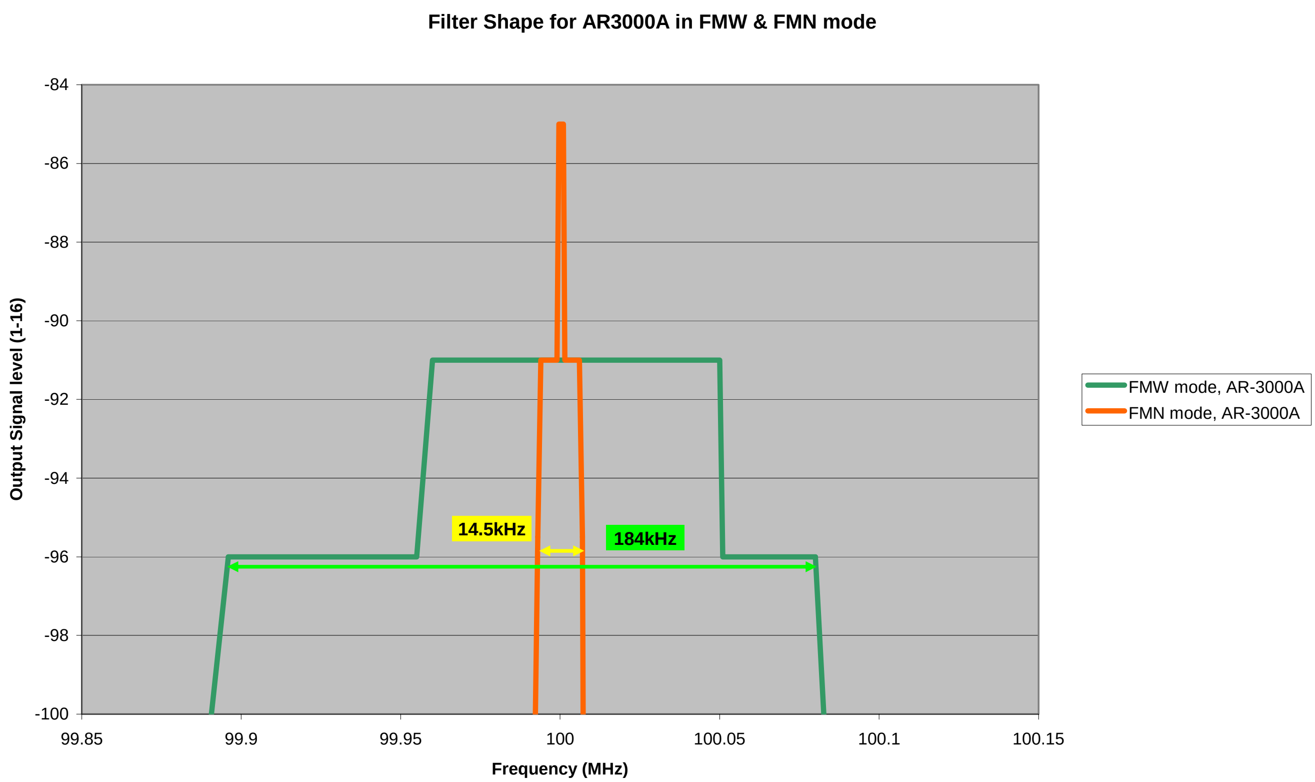

Figure 11: AR3000A receiver selectivity at 100MHz for FMW & FMN.

3.4 Sensitivity

The noise floors again were calculated with the same process as for the WR-1550e. The noise floor in the FMN mode was theoretically -116dBm for frequencies 2.5MHz to 1.8GHz and -105dBm for frequencies 1.8GHz to 2.0 GHz. From analyzing figure 12 below it can be seen that measured noise floor for frequencies 2.5MHz to 1.8GHz (approximately -110dBm) is above the theoretical noise floor calculated whilst for frequencies 1.8GHz to 2.0GHz the measured noise floor (approximately -110dBm) is below the theoretical value.

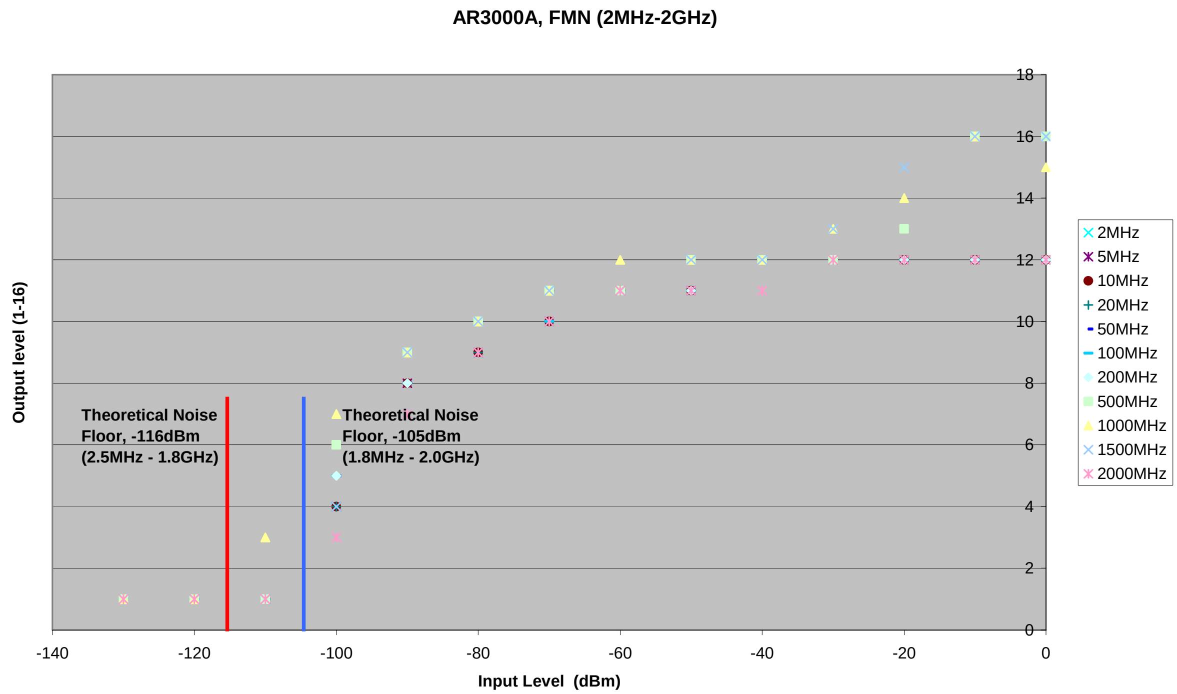

Figure 12: AR3000A theoretical noise floors for FMN mode.

For FMW receiving mode the noise floor calculated for frequencies 2.5MHz – 1.8GHz was -107dBm which once again, was below the actual value which was approximately -110dBm. For frequencies 1.8GHz to 2.0GHz the noise floor was measured to be -97.45dBm.

4.0 Summary of Findings

4.1 WR-1550e

Comparison of 1 dB compression points and the gain for the FMN mode over a range of frequencies

Freq (MHz)	10	20	50	100	200	500	1000	1500
1dB point (dBm)	-85	-81.5	-83.5	-81.5	-88	-83.7	-82.8	-85.5
Gain (dB)	138	138	140	138	127	137	124	129

Table 10: WR-1550e 1dB compression points and gain for each frequency.

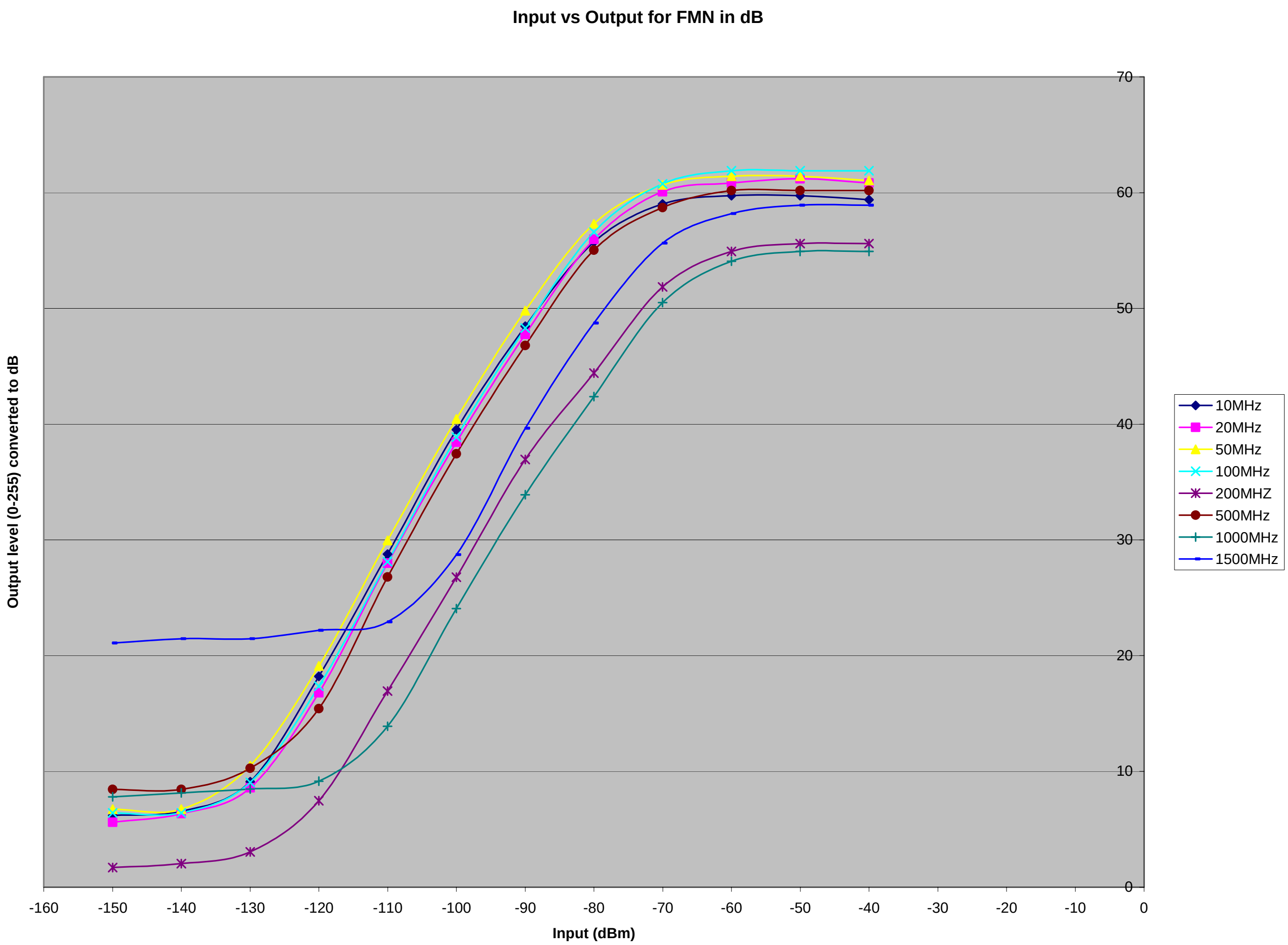

Figure 13: WR-1550e input level vs output level converted to dB.

FMN mode, Frequency range 10MHz to 100MHz

- Receiver behaves linearly for input levels ranging -80dBm to -130dBm.
- The gain is approximately constant at 138 dB.
- The 1 dB compression points are close within the range -80dBm to -85dBm (see table 10).

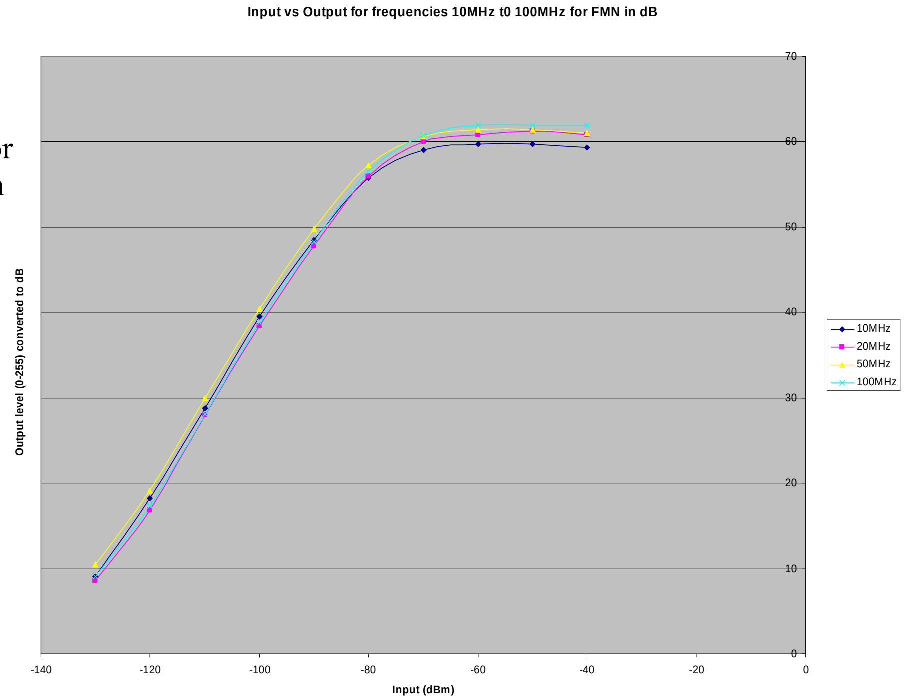

Figure 14: WR-1550e input level vs output level converted to dB for low frequencies.

FMN mode, Frequency range 200MHz to 1500MHz

- Receiver behaves linearly for input levels ranging -80dBm to -100dBm
- The gain is not constant, varying between 124dB and 138dB (see table 10).
- The 1 dB compression points within the range -82dBm to -88dBm (see table 10).

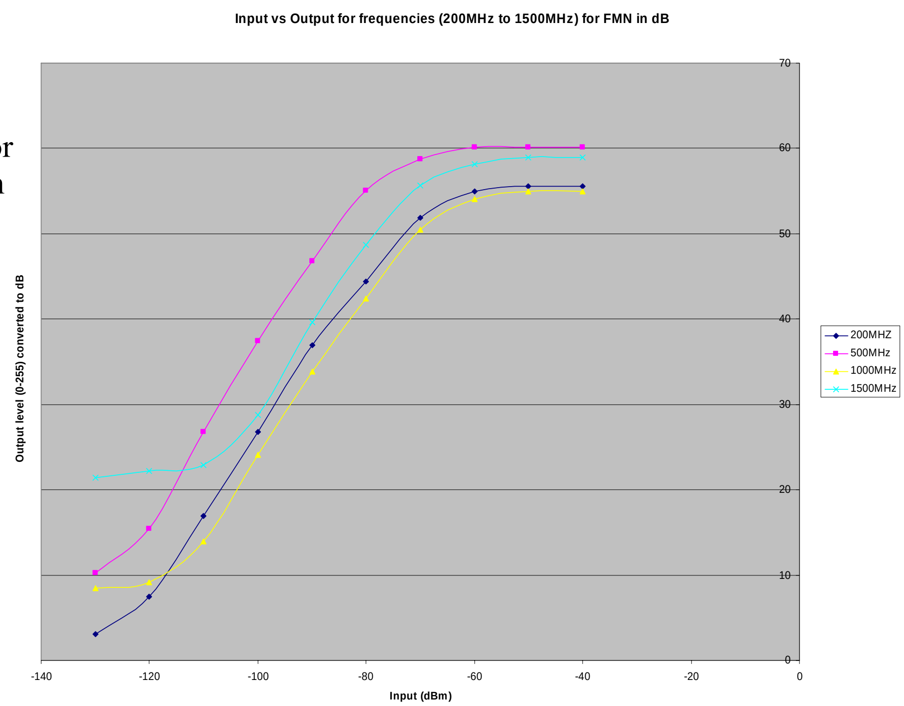

Figure 15: WR-1550e input level vs output level converted to dB for high frequencies.

4.2 AR3000A

The AR3000A was found to be not very linear and therefore, to have only a small dynamic range. At lower frequencies (0.2MHz to 200MHz) it was quite consistent in that the output responses were nearly all the same for the same input signal over the range of frequencies.

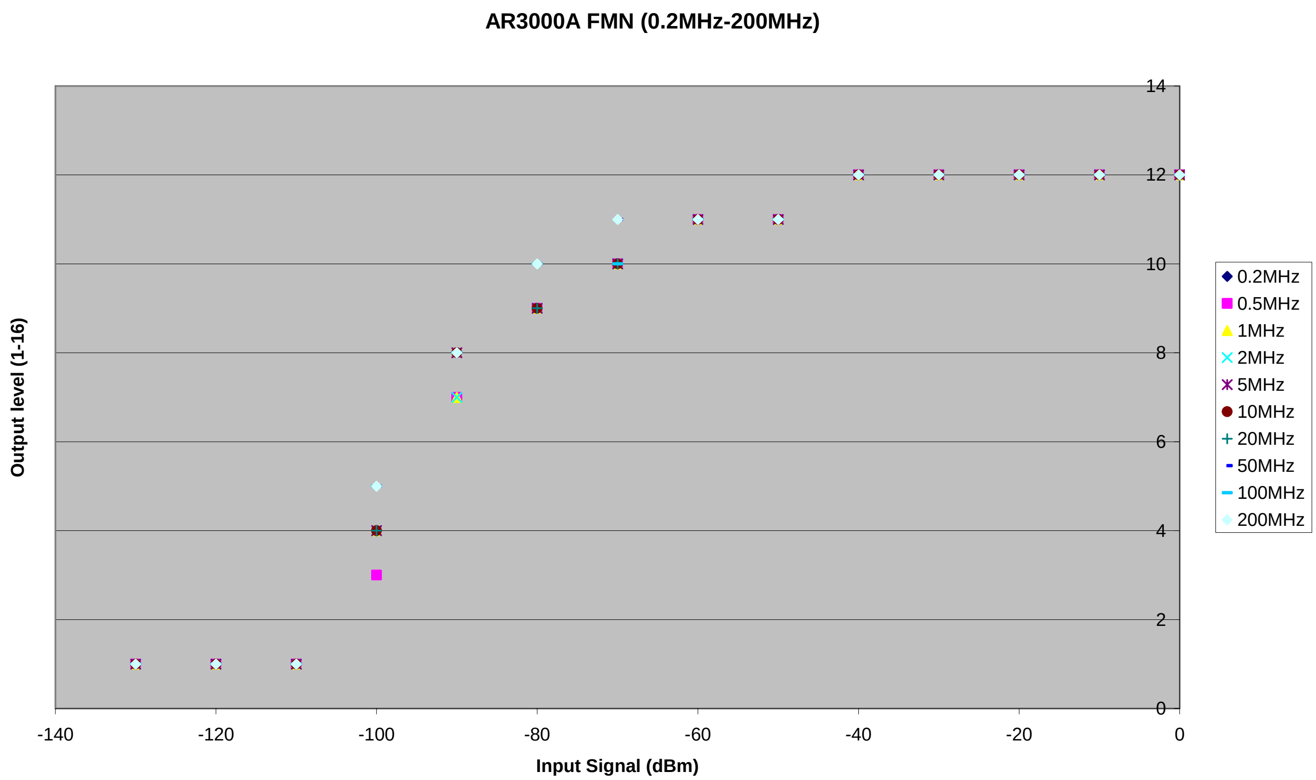

Figure 16: AR3000A output level vs input amplitude for frequencies 0.2MHz to 200MHz in FMN.

The receiver was able to be roughly calibrated into dBm, due to this consistency between the frequencies with the output response.

Output level		FMN Calibrated o/p	WFM Calibrated o/p
A	1	-112.5dBm	-115.8dBm
B	2	-109.0dBm	-109.5dBm
C	3	-106.0dBm	-104.5dBm
D	4	-103.5dBm	-100.5dBm
E	5	-101.5dBm	-96.0dBm
F	6	-99.0dBm	-91.0dBm
G	7	-95.5dBm	-85.5dBm
H	8	-91.0dBm	-78.5dBm
I	9	-85.0dBm	-68.5dBm
J	10	-75.0dBm	-53.5dBm
K	11	-57.0dBm	-37.0dBm
L	12	-37.5dBm	

Table 11: AR3000A calibration table for FMW & FMN modes.

5.0 Conclusion

Characteristics of the WR-1550e and AR3000A radio receivers relevant for use in radio astronomy were analyzed. Neither receiver was considered suitable for use in radio astronomy as they were not particularly linear, they did not possess a sufficiently large dynamic range, nor did they have the sensitivity required for detection of mJ signals.

Whilst unsuitable for use in radio astronomy, both receivers were considered entirely suitable for the purposes of the SEARFE project, as the main focus of the program is to educate students in the use of the radio frequency spectrum and to gather data to aid the search for radio-quiet sites in Australia.

6.0 SEARFE Results

Some SEARFE results had been submitted from Abbotsleigh High School, Sydney, New South Wales and Kimba Area School, Kimba, South Australia. Both of these schools scanned the radio frequency spectrum from 30MHz to 300MHz in WFM mode using the AR3000A receiver. A comparison of their results is represented graphically in figure 17. below.

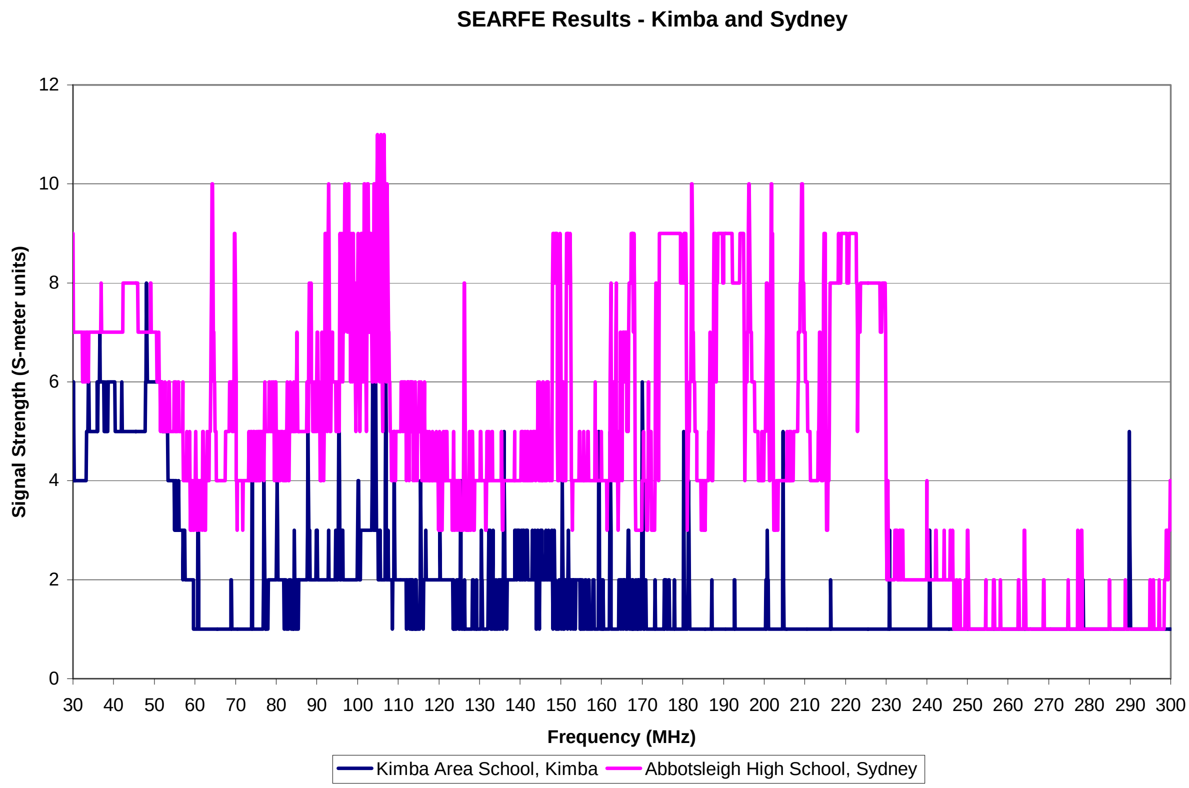

Figure 17: AR3000A WFM mode results from Kimba Area School and Abbostleigh High School.

This data was able to be converted to dBm from the calibration table constructed from previous tests on the AR3000A and is displayed at Figure 18.

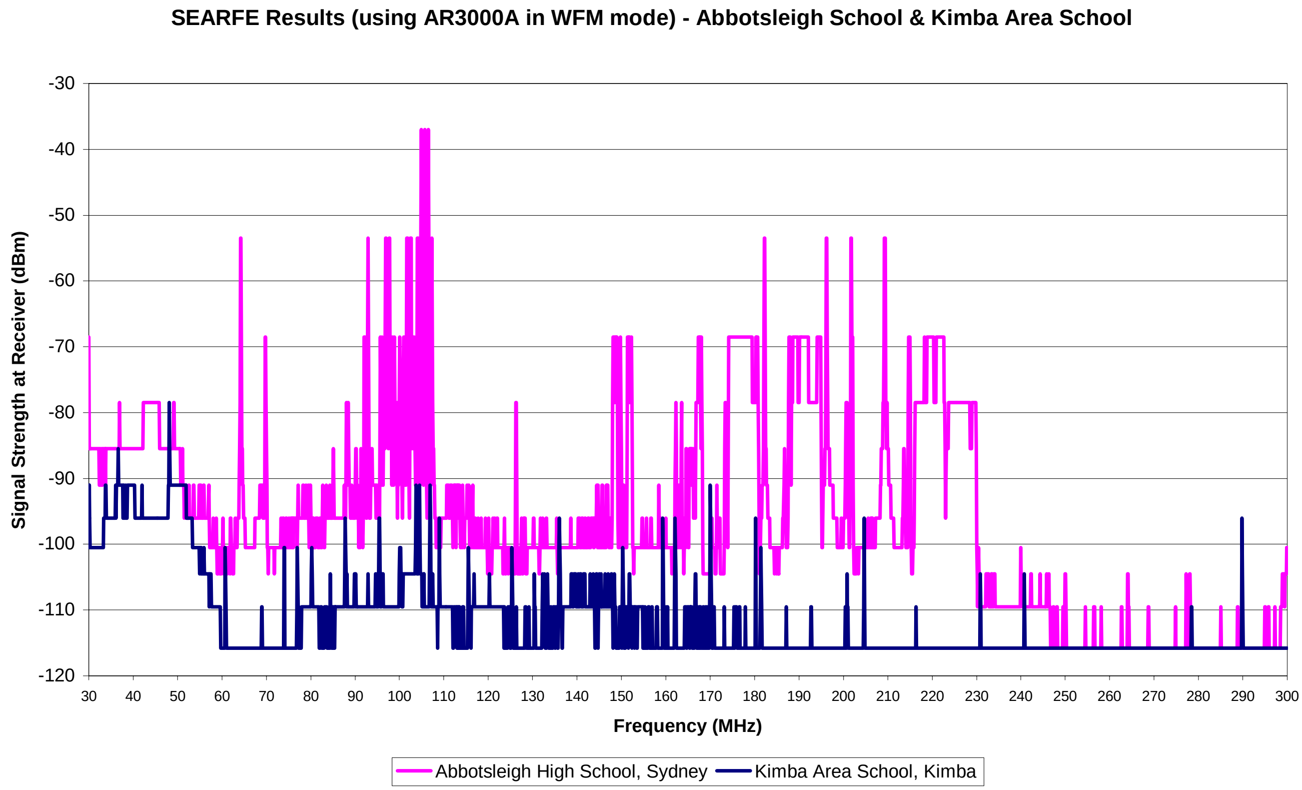

Figure 18: AR3000A WFM mode results from Kimba Area School and Abbostleigh High School converted to dBm.

To check that the results from these schools were accurate or at least reasonable, the experiment was repeated in the SKA lab at Marsfield with the same model discone antenna (D130J) over the same frequency range using the AR3000A receiver. The signal strengths recorded in the SKA lab were of similar strengths of those recorded by Abbotsleigh High School, indicating that the SEARFE data was reliable and had been measured correctly (see figure 19.). The Kimba Area School data produced much lower signal strengths, however this could be expected as there are less radio transmitters located in that area and therefore, less background noise.

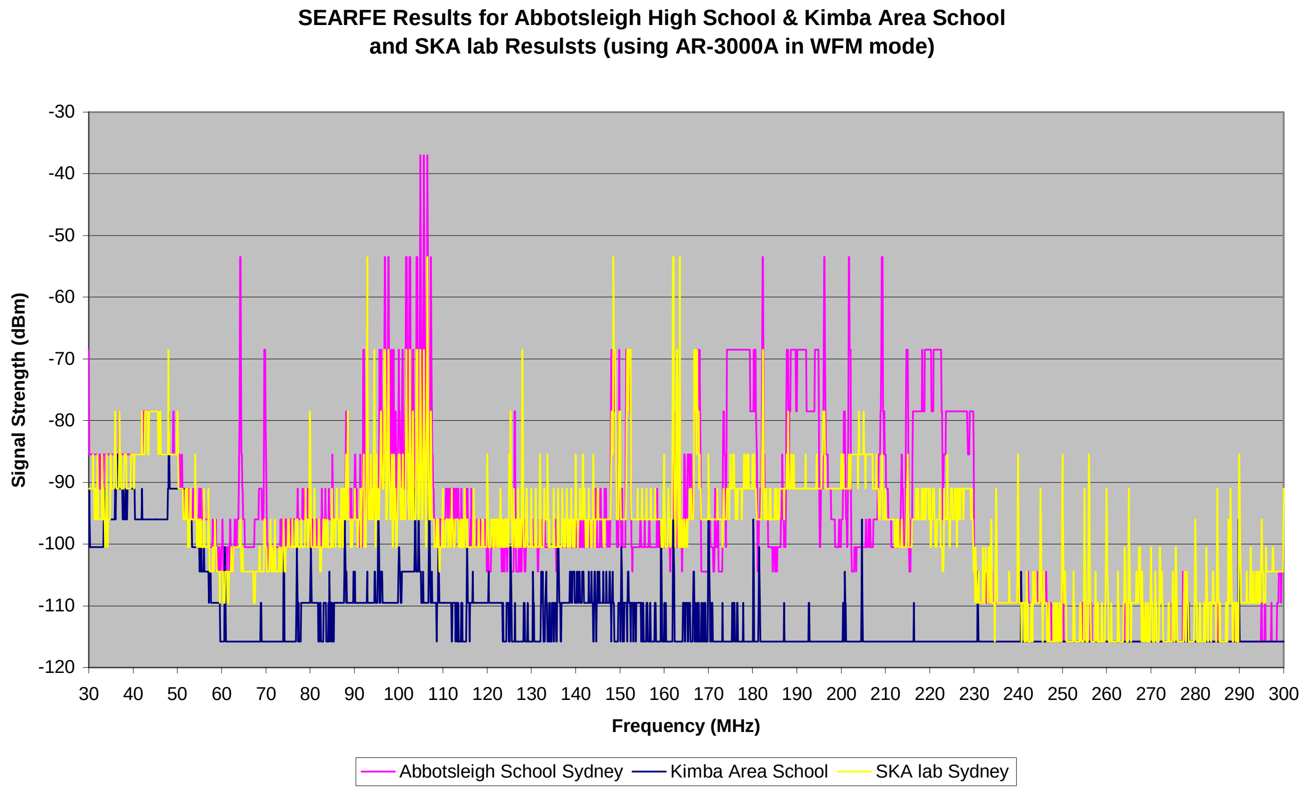

Figure 19: AR3000A WFM mode results from Kimba Area School, Abbostleigh High School and SKA lab converted to dBm.

To check that the calibration adjustments to the data were accurate, the results from the spectrum scan in the SKA lab using the AR3000A were compared to scans conducted with a calibrated spectrum analyzer (Anritzu) with the same discone antenna. Two scans were conducted with the spectrum analyzer, one with a bandwidth of 100kHz and the other with a bandwidth of 10kHz. Both of these scans were conducted over the same frequency range as with the AR3000A, 30MHz to 300MHz. This test confirmed the accuracy of the calibration tables for the AR3000A, as the signal strengths of the data from the AR3000A scan were of similar strengths to those measured with the spectrum analyzer. This test also proved the AR3000A was detecting signals accurately as the over all scan shape matched that of the spectrum analyser, picking up the same signals at each frequency with similar strengths however, it is clear from figure 20 that the AR3000A has a lower noise floor than the Anritsu.

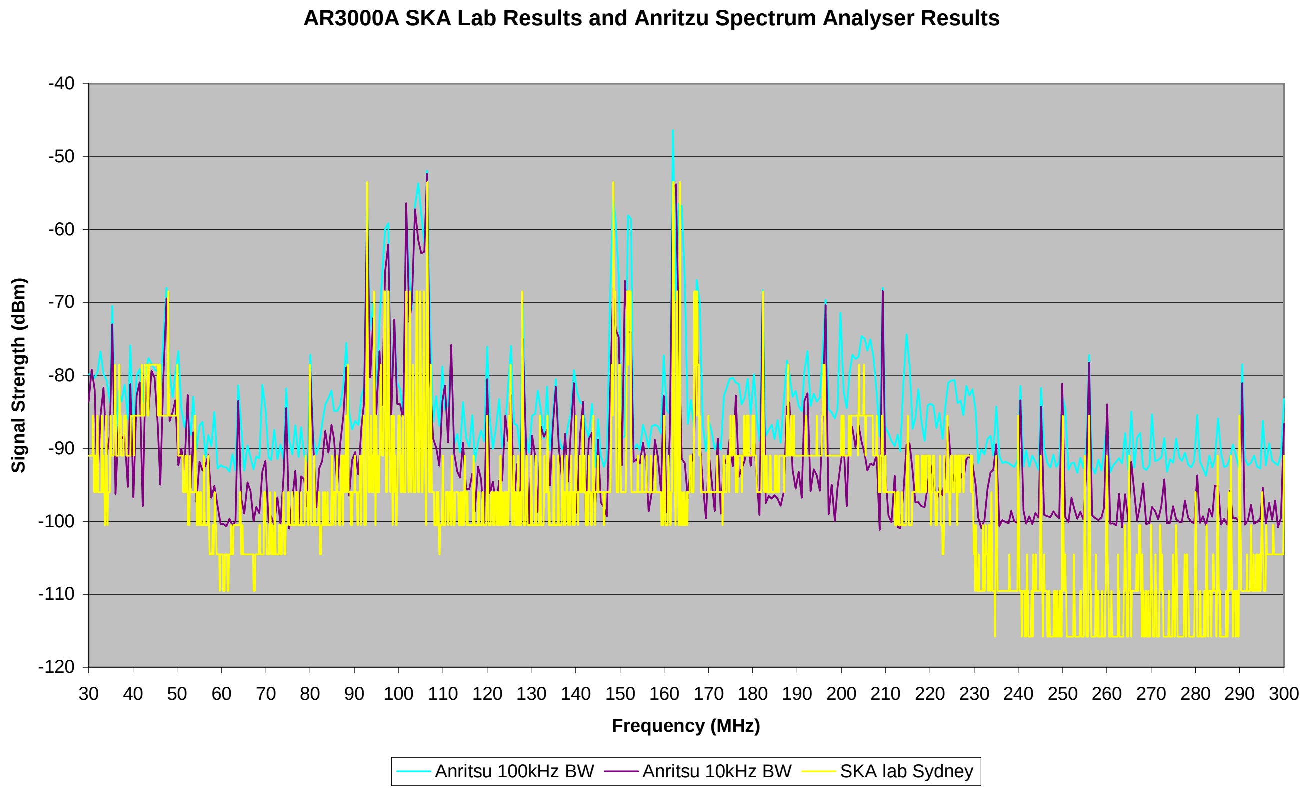

Figure 20: AR3000A WFM mode results for SKA lab converted to dBm and Anritzu Spectrum Analyzer scans.

After it was established the results received from the SEARFE program were reasonably accurate, it was possible to convert the data into more useful units, such as flux density ($dBW/m^2/Hz$).

The Area calculation assumed for a discone antenna was;

$$A = \frac{\lambda^2}{4\pi} D \text{ ,} \quad \text{(D was assumed to equal 1)}$$

The AR3000A WFM mode flux density of Abbotsleigh High School and Kimba Area School results are displayed at Figure 21.

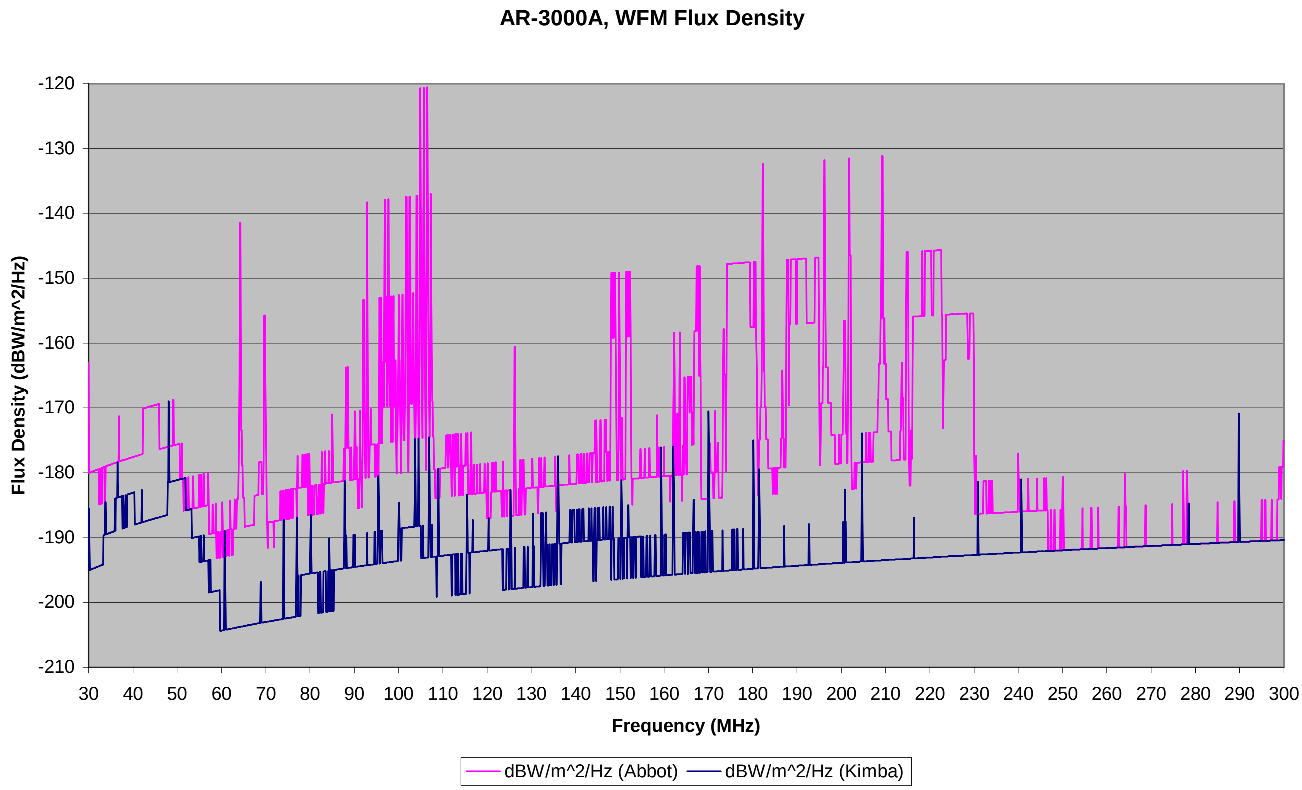

Figure 21: AR3000A WFM mode flux density of Abbotsleigh High School and Kimba Area School.

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