Fig 4.8: Data on SSP with [illegible]

Fig 4.9: Data on FM with SSB co-channel interference

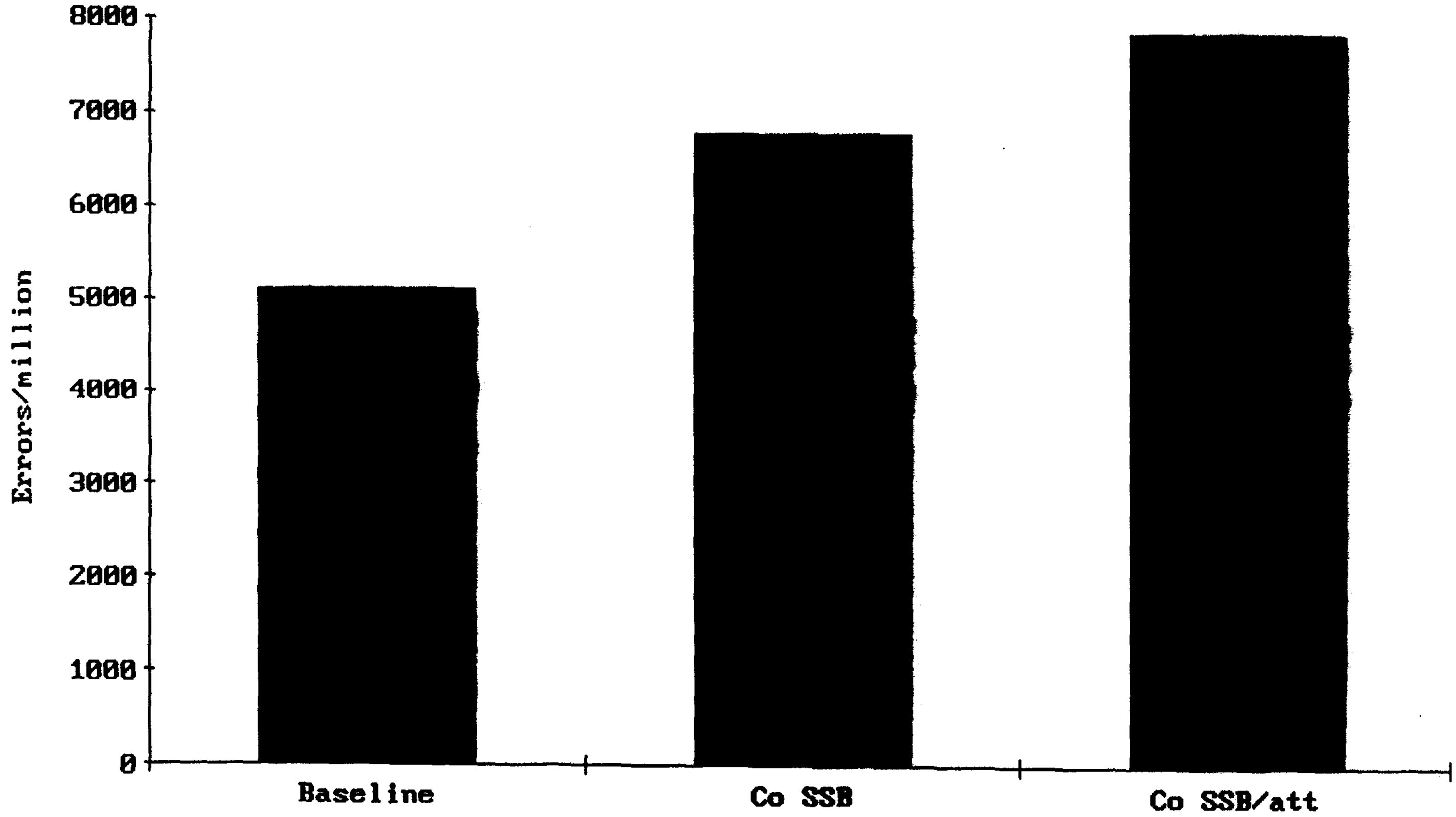
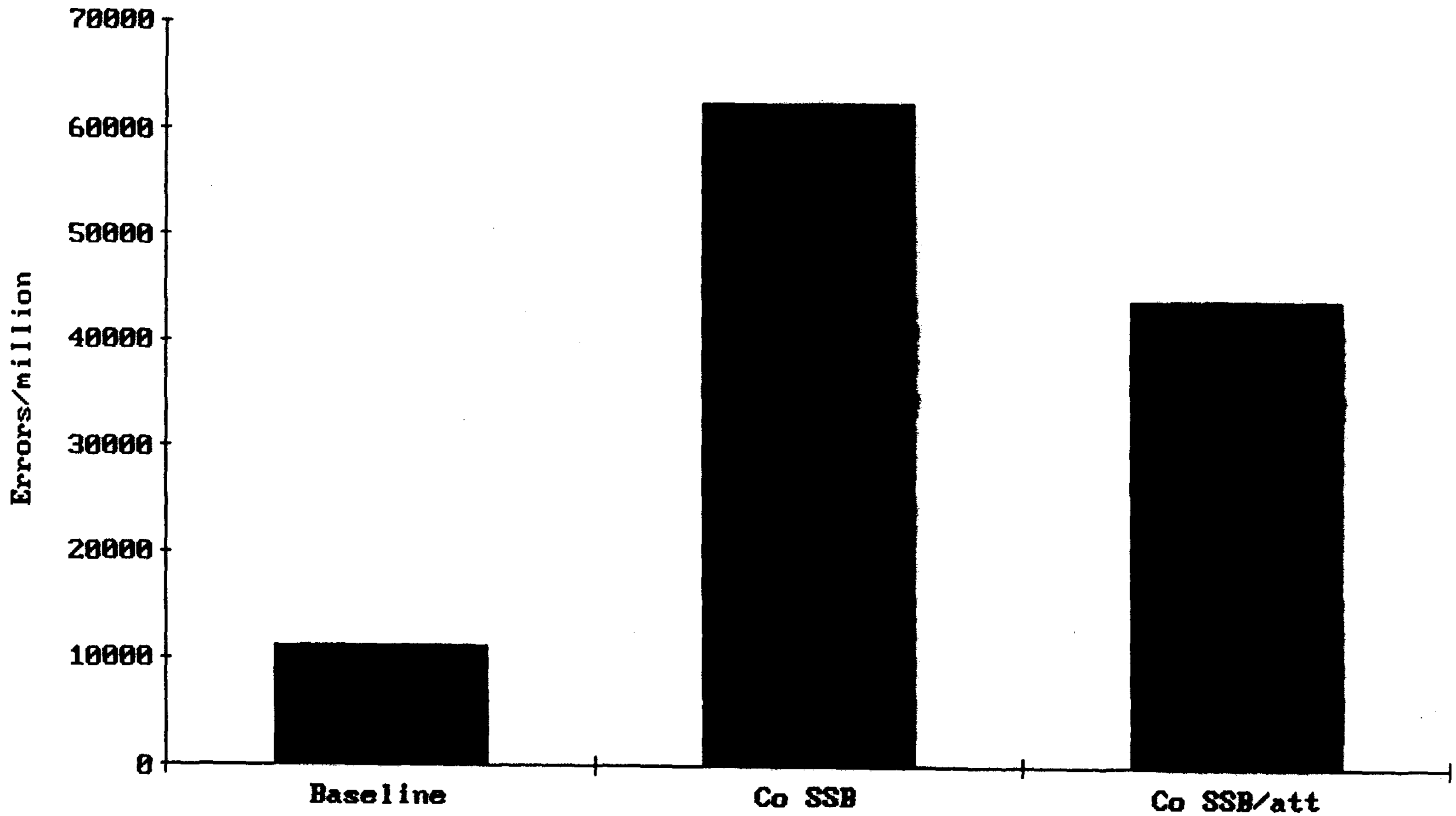


Fig 4.10: Data on AM with SSB co-channel interference



4.1.4 Higher Data Rate Results.

For the higher speed data runs, two Synchro 96 MODEM's were used (see appendix (iii) item 2/12). This particular piece of equipment was programmable (using the AT command language) and could be configured for various communications formats. The configurations for each format used (2.4kbaud QPSK, 4.8k baud QPSK, and 9.6kbaud QAM, referred to as 2.4Q, 4.8Q and 9.6Q respectively) are given in Appendix (v), along with plots showing the various output spectrum for each modulation scheme. Results in the form of numeric data is contained in Table 4.4.

As can be seen, there are two columns, raw and corrected. This is because the raw data, in some particular cases, can be misleading. Take, for example, FM on route (4) at 2.4 QPSK and 4.8 QPSK. At first, the raw data would suggest 4.8Q performed better than 2.4Q (12449 errors/million and 21382 errors/million repectively). However, when the output of the BERT was examined it was seen that, although the tests were run for the same length of time (9 minutes ±10 seconds i.e 540 seconds) the actual amount of time that the BERT was able to take measurements for was 227s for the 2.4Q and only 88s for the 4.8Q. This then suggests that the "instantaneous" error rate for the 4.8Q system dropped below the 1 in 16 thresehold level (required for the BERT to stay in synchronisation) for longer periods of time than the 2.4Q system. It then follows that the 2.4Q system is more resilient to noise (as conventional theory suggests). Hence, to directly compare the two systems it was assumed that during the time which the BERT was unable to take measurements of error rate for the 4.8Q system but was able to measure the 2.4 system, the error rate of the 4.8 system was 1 in 16. This then yielded the more sensible figures in Table 4.4 (corrected figures). It is important to note that 1/16 is only the lower limit for the BER, and that therefore the number of errors/million could in fact be greater than that shown.

1) Route (2) - A217 post.

The results are shown plotted in Fig 4.13. SSB performed better than FM at 2.4Q by a factor of 3.5, but at 4.8Q FM performed better by a factor of 3.5. The SSB system was found not to work at 9.6Q.

2) Route (3) - A2022.

Again, SSB appeared to perform better than FM at 2.4Q by a factor of 2.4 (see Fig 2.14) but exhibited a worse error rate than FM at 4.8Q by a factor of 2.6. Note the anomaly of 2.4Q FM having a worse BER than 4.8Q FM.

3) Route (4) - A3.

With reference to Fig 4.15, SSB at 2.4Q resulted in a better error rate than 2.4Q FM by a factor of 2.1. At 4.8Q, SSB performed worse than FM by a factor of 1.4 (it must be noted that the last two error rate measurements , SSB and FM at 4.8Q, are very close to the maximum possible on the equipment used).

4) Summary.

In the baseline results detailed in section 4.1.1 SSB performed better than FM on all

Table 4.4: Fast Data Results

	SSB/Raw	FM/Raw	SSB	FM
Route 2:A217				
Baseline	68	448	68	448
2.4D	921	3284	921	15026
4.8Q	2687	1835	18670	16740
9.6Q	MAX	6617	MAX	34801
Route 3:A2022				
Baseline	744	5109	744	5109
2.4D	6906	9099	6906	23153
4.8Q	4757	7292	27549	15429
Route 4:A3				
Baseline	2316	6512	2316	6512
2.4D	10229	21382	10229	23930
4.8Q	29554	12449	60594	44300

Fig 4.13: Fast Data on A217 at 30mph

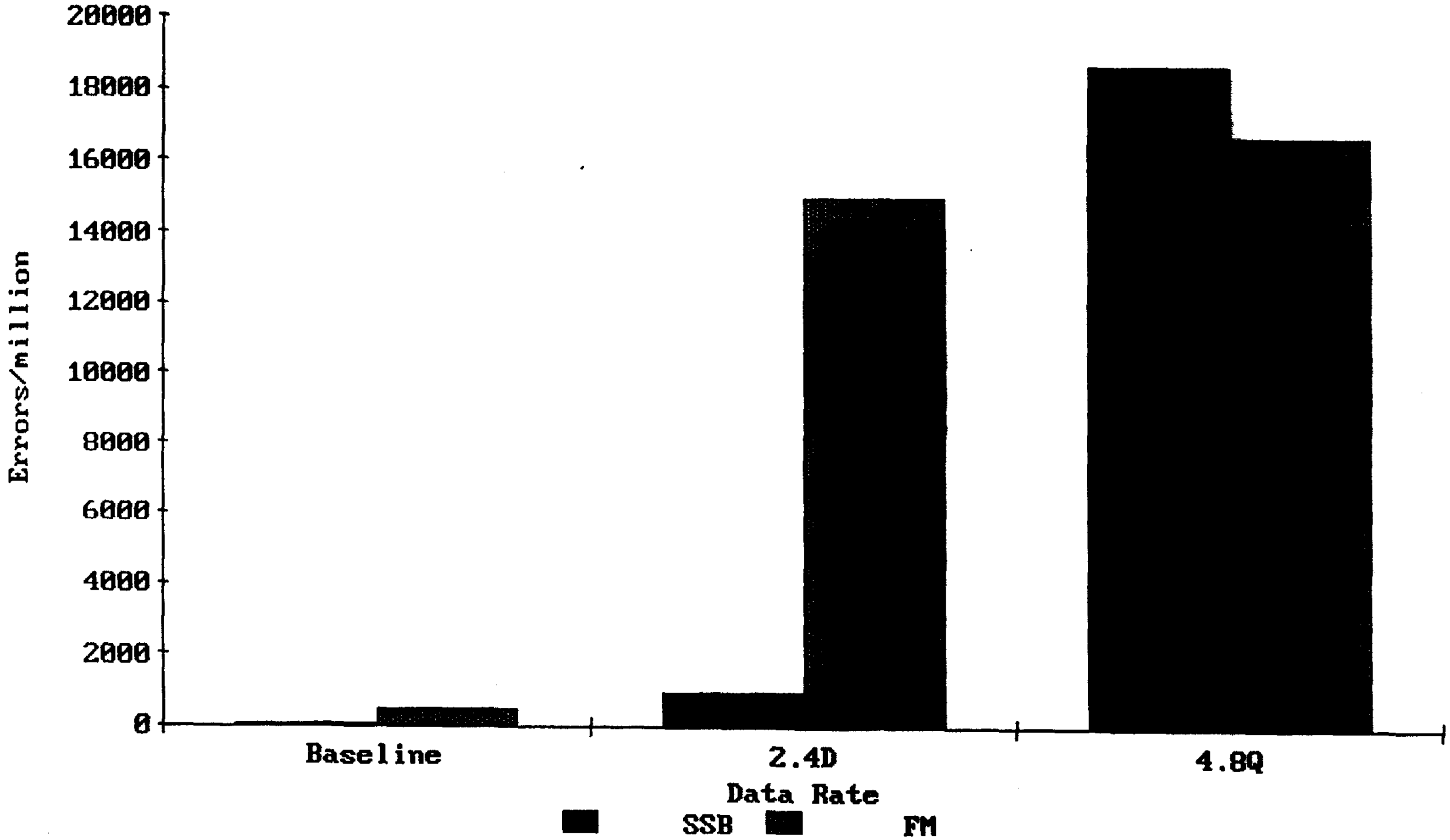


Fig 4.14: Fast data on A2022 at 30mph

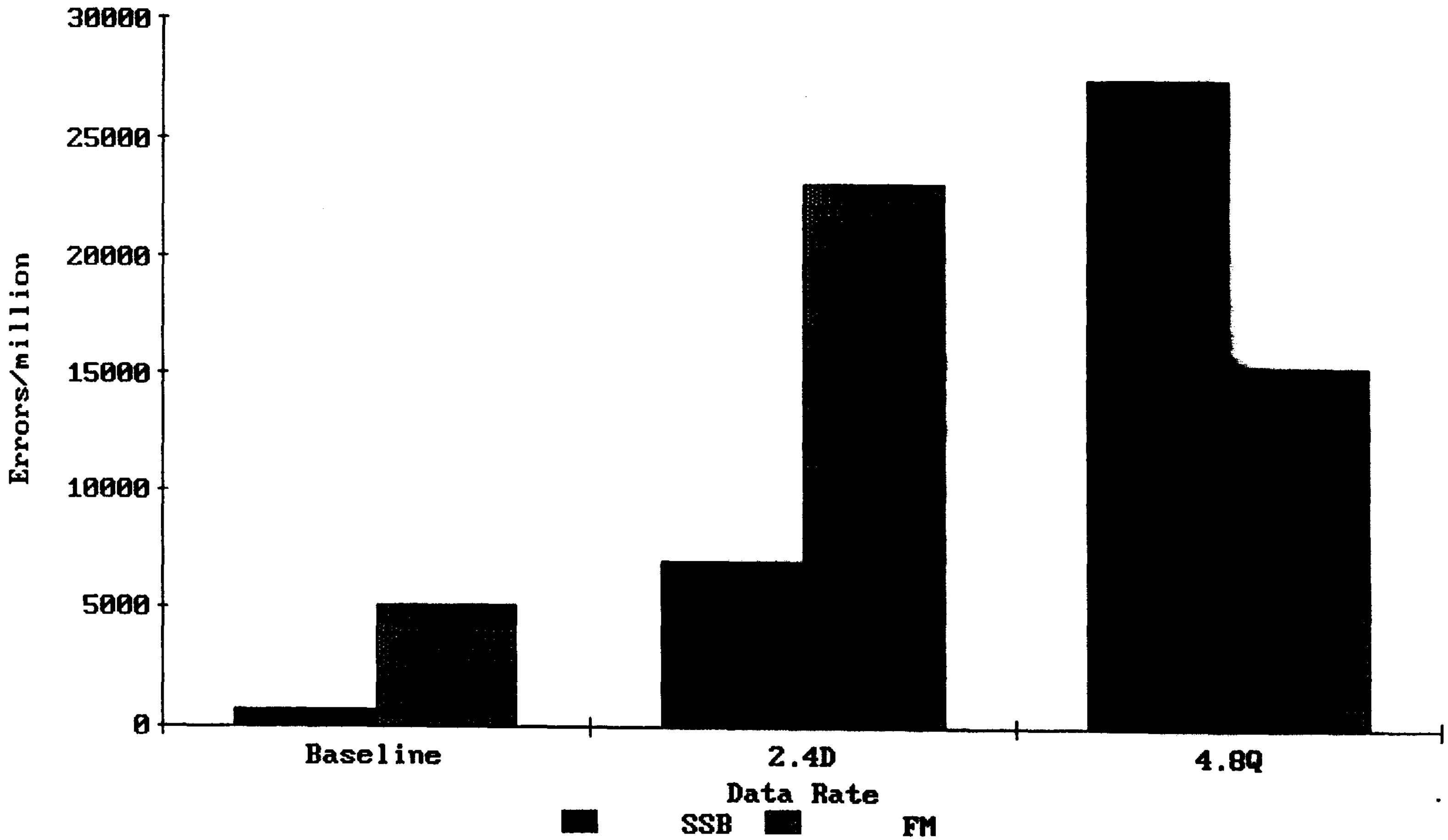
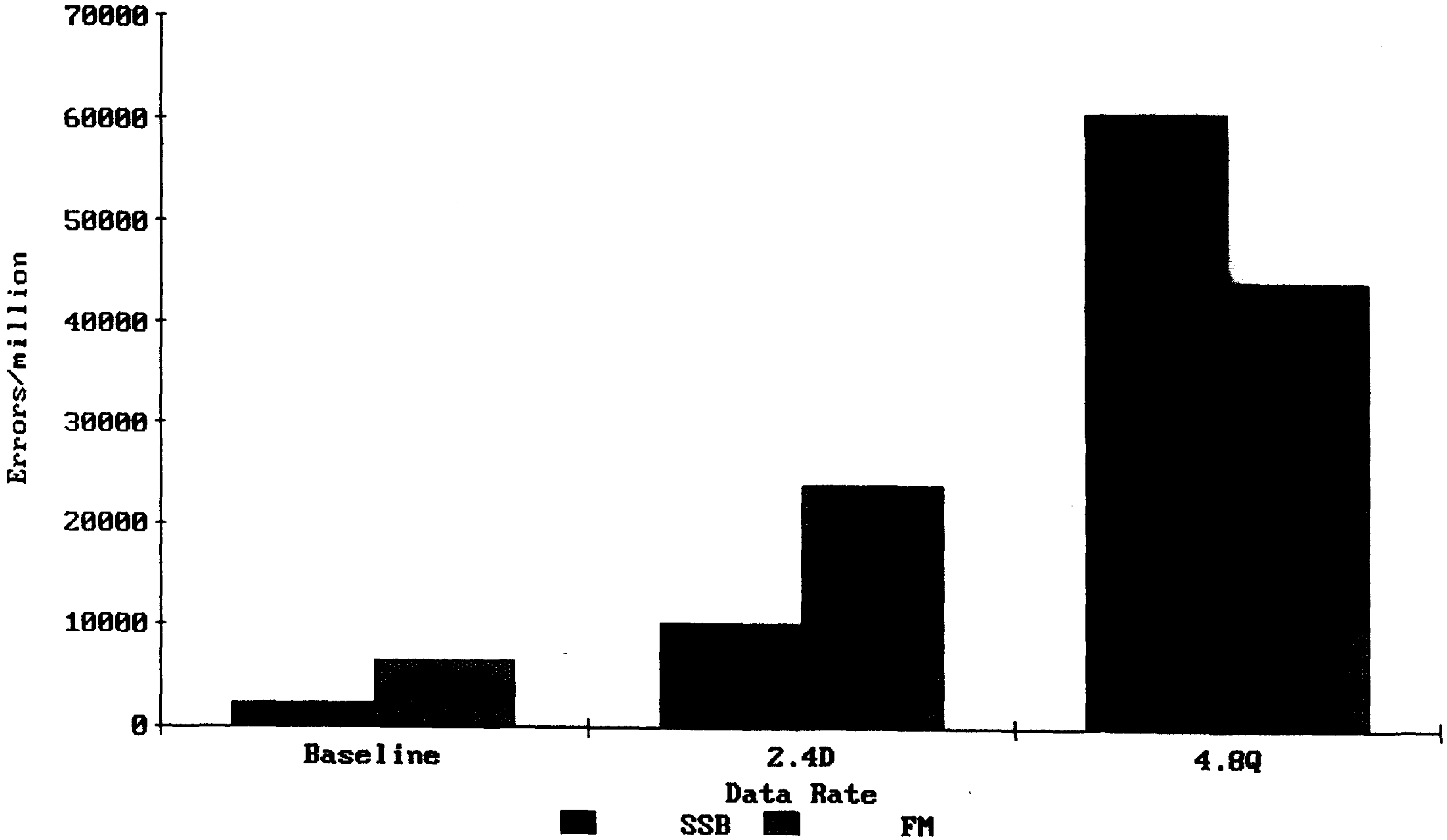


Fig 4.15: Fast Data on A3 at 30mph



4.1.5 Data Results Summary

As far as data transmission is concerned, AM can be ignored as a viable system. Its best performance gives an error rate of 1/615 which is unusable for most purposes, and is certainly much worse than either FM or SSB. Therefore only the effect of SSB on existing AM systems is considered, and only FM and SSB are compared below.

For signals without interference, SSB performs better than FM at data rates upto 2.4kb/s. The only exception to this is under high signal strength, minimum fading conditions, where FM is slightly better. In effect, SSB is better able to cope with any fading.
SSB loses the advantage when faced with higher data rates of 4.8kb/s or more. It should be noted however, that this limit applies only to the use of external line modems, not to the use of specially designed integral modems which have been shown to give much more favourable results. It may even be that better results could be obtained with line modems if a wider crystal filter were used in the RF processing.

Under adjacent channel interference, SSB is virtually unaffected by any form of interference except under very poor receiver conditions. Even then, its performance is better than baseline FM.
On the other hand, FM suffers slight degradation under lower signal strength conditions, but worse deterioration with strong signal strength. The relative reduction in performance is less than the worst case for SSB, but the FM absolute performance is nearly three times worse. It is in fact generally true to say that FM is more resistant to interference

The limiting factor on introducing an SSB system into an area with an existing FM system is therefore likely to be the effect of FM interference on SSB. With the higher power interferer, SSB is seriously affected by FM, but attenuating the interference by 6dB leads to a 30% improvement, indicating that a more reasonable protection ratio, such as the 30dB suggested by the laboratory test of section 2.2.8 is likely to lead to much more acceptable results, and may even be an overestimate in practice.

The same remarks apply to AM in terms of its effect on SSB, but the effect of SSB interference on AM was much more serious than that on FM and brought the level of measured BER close to, and even above the maximum possible measurable level of 1/16. The effect of SSB interference on SSB was less severe, bringing the SSB performance standard roughly in line with that for baseline FM. However, there is much less reduction in the BER due to the increase in wanted-to-unwanted signal ratio than for FM or AM interference, and it is therefore likely that a similar level of co-channel protection ratio will be required within an SSB system to that between an SSB and an FM system.

4.2 Voice Results

The following section presents the voice results obtained. All relevant graphs can be found at the end of each sub–section. Appendix (vi) contains the results statistics.

All the results are given in the form of percentage unintelligibility. For each individual listener, this is the number of DRT test words which were heard and marked incorrectly during the test, expressed as a percentage of the total number of words recorded during the test run. The presented result is the average value of the scores obtained by the listeners for each test. The range of the DRT unintelligibility score is thus from 0% (all words correct) upto 50% (the average score if all the words were randomly chosen).

Listeners were also asked to fill in a comments sheet and some of these results are given in each sub–section. This was of help in assessing factors other than intelligibilty, such as naturalness and level of background noise, which are also relevant to the performance of a voice system.

Between eight and thirteen listeners were used to assess each tape. Both male and female listeners were used and all listeners were inexperienced in using PMR systems.

During the voice tests, a number of problems arose regarding the performance and reliability of the SSB system. These are fully covered in the relevant sections, but it should be borne in mind that the SSB system was a development model and its performance is not fully optimised. One particular problem was the VOGAD circuit previously mentioned, which was found to display an inadequate response time. This led to a distortion of the beginnings and ends of words much commented upon by listeners, which is likely to have had a considerable effect on the intelligibility score of SSB, particularly in poorer receiver conditions. It is felt important that this factor in particular should be considered in relation to the following results, since an easily applied remedy could improve the scores of SSB by an appreciable factor.

Fig 3.8 gives the standard base station configuration used for the tests, but some additional baseline test runs were carried out with a different configuration. This omitted the hybrid combiner and both sets of cavity filters in the transmit path, leaving only the isolator between the single transmitter (all that is needed for baseline measurements) and the duplexer. This arrangement gave an additional 8dB of output power and of measured field strength.

The results obtained with this high field strength arrangement will be considered first, and then compared with those results obtained with the normal lower field strength configuration with all filters in place. The performance under interfering conditions will then be considered.

4.2.1 High Signal Strength Baseline Voice Results

The baseline results for the higher field strength configuration are shown in Table 4.5 and the results are shown plotted for three different speeds in Fig 4.16, 4.17 and 4.18. The results are summarised below.

1) Slow

Fig 4.16 shows the results at dead slow speed. Excluding the route (3) – A2022 results, FM and SSB have very similar levels of performance on each route, with a maximum difference of 1.1% and a mean level of 8.3%. In addition, their performance changes very little on the different routes.

The exception to this is in medium/low signal strength, deep fade areas (route (3) – A2022) where SSB has a much worse performance than the norm for the other routes. To jump ahead slightly, this can be seen to be repeated in the results for medium speed, in Fig 4.17, and no explanation for this behaviour could be found. The DRT scores were re-checked and found to be reliable, but a particular phenomenon was noted on the tape concerned. A buzzing could be heard during the words on the tape which distorted and obscured the words. This buzzing was limited to the single tape, on which the results for the SSB route (3) – A2022 slow and medium runs and the SSB route (4) – A3 medium and fast runs were recorded. The A3 fast results could be compared with the results from a repeat run taken later, and were found to be nearly 5% higher than the score from this second tape which is the result shown in Fig 4.18. It is considered, therefore, that a fault arose with the SSB equipment for this set of runs, and that the results for the SSB route (3) – A2022 slow and medium runs and the SSB route (4) – A3 medium run are unreliable.

The AM performance is better than, or equals the performance of the other systems except in the low signal strength area (route (4) – A3), where its performance markedly deteriorates. Fading does not seem to have a seriously deleterious effect on AM at this slow speed, shown by the improvement on the strong signal strength, deep fade route (route (2) – A217 post) over the strong signal strength, shallow fades route (route (1) –

A217 pre).

2) Medium

Fig 4.17 shows the high signal strength medium speed results. These show a fairly unchanged relative pattern from the slow speed results, but while the scores for the strong signal strength areas (route (1) - A217 pre and route (2) - A217 post) remain virtually unchanged, those for the lower signal strength routes deteriorate with increased speed. AM seems most resistant to this deterioration.

The fact that the results for slow and medium speed are virtually unchanged for high signal strength areas indicates that fading has little effect under these conditions, but this is not true in lower signal strength areas.

As explained in the previous section, the results for SSB route (3) - A2022 run and the SSB route (4) - A3 run are considered unreliable, and their real performance is likely to be better by a factor of perhaps 5%.

3) Fast

As before, Route 4 - A3 is the only route on which fast 50mph tests can be carried out. Fig 4.18 shows these results. Again the pattern is of FM and SSB having similar performance levels, with AM having a worse result in the low signal strength area of Route 4.

4) Comments

The comments for SSB were fairly consistent for all routes and were in the main rather negative. The voice heard was repeatedly referred to as "tinny" and "unpleasant" and in one case compared unfavourably with a Dalek. However, it should be borne in mind that an altered audio frequency response could be engineered, by changing the audio filtering, which might improve the listener response to SSB.

Reference was made in several cases to the fact that the beginning (and in a couple of cases the end) of words was difficult to distinguish. This problem, as previously noted, is due to the response time of the VOGAD circuit being too slow. Again, this problem could be corrected.

AM gained a much more favourable response than SSB, as far as subjective comments were concerned, with typical quotations being "clear" and "comfortable to listen to". However, this response was limited to strong signal strength routes, and in weaker signal strengths, the high level of background noise was much noted.

The comments for FM were fairly favourable, with the voice quality being perceived as better than SSB and more consistent than AM, although it was not considered to equal the best performance of AM. However, background noise was considered more of a problem than with SSB, particularly at higher speeds.

5) Summary

AM performs better than both SSB and FM in high signal strength conditions and gradually deteriorates as the conditions become less favourable. The performance of SSB and FM, on the other hand, remains fairly constant and approximately equal, at about a 92% intelligibility level, over most conditions considered. This indicates that signal strength is not a large contributing factor to SSB and FM voice performance, within certain limits, and this is confirmed by the results in the following section.

Table 4.5: High Signal Strength Baseline Voice Results

	SSB	FM	AM
Slow			
A217 pre	9.2	8.6	5
A217 post	7.3	7.7	3.2
A2022	13.1	4.4	5.3
A3	7.9	9.1	14.8
Med (30mph)			
A217 pre	7.8	8.5	5.6
A217 post	7.9	8.7	3.8
A2022	14.3	6.8	8.6
A3	12.7	12.9	17.3
Fast (50mph)			
A3	10	11.8	15.9

Fig 4.16: Voice Baseline - Slow Speed
(X - Unreliable Result)

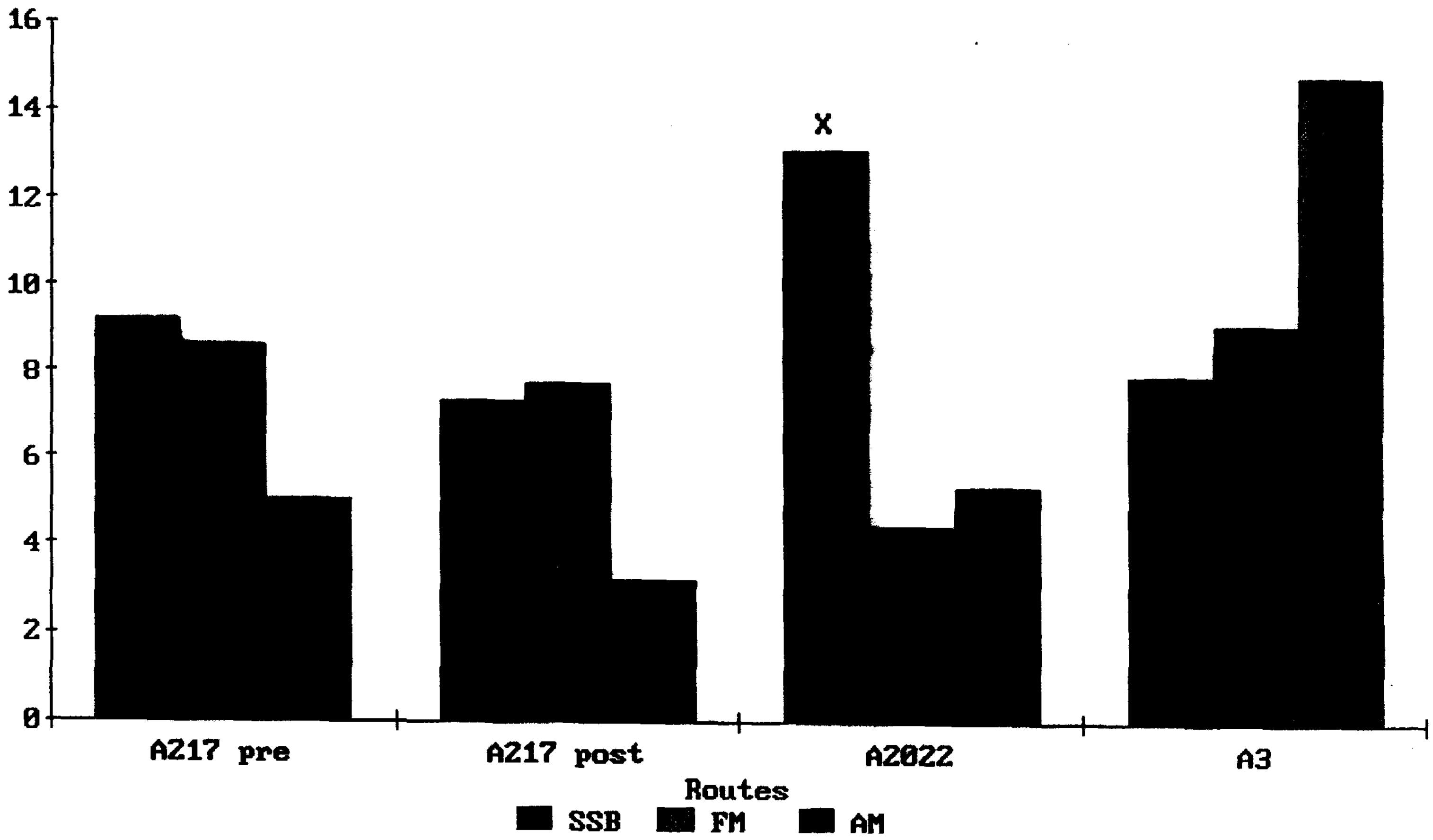


Fig 4.17: Voice Baseline - Med. Speed
(X - Unreliable Result)

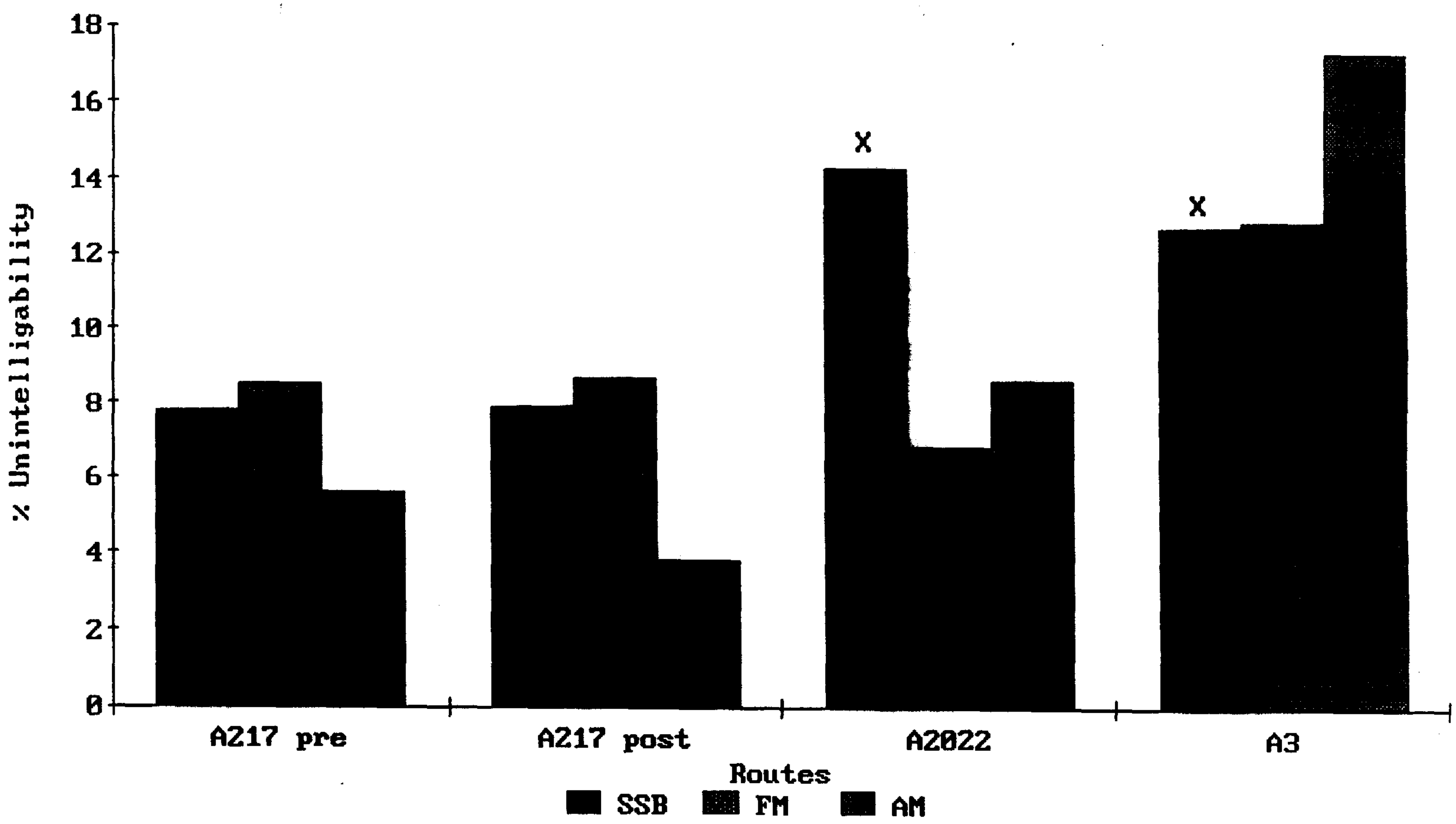
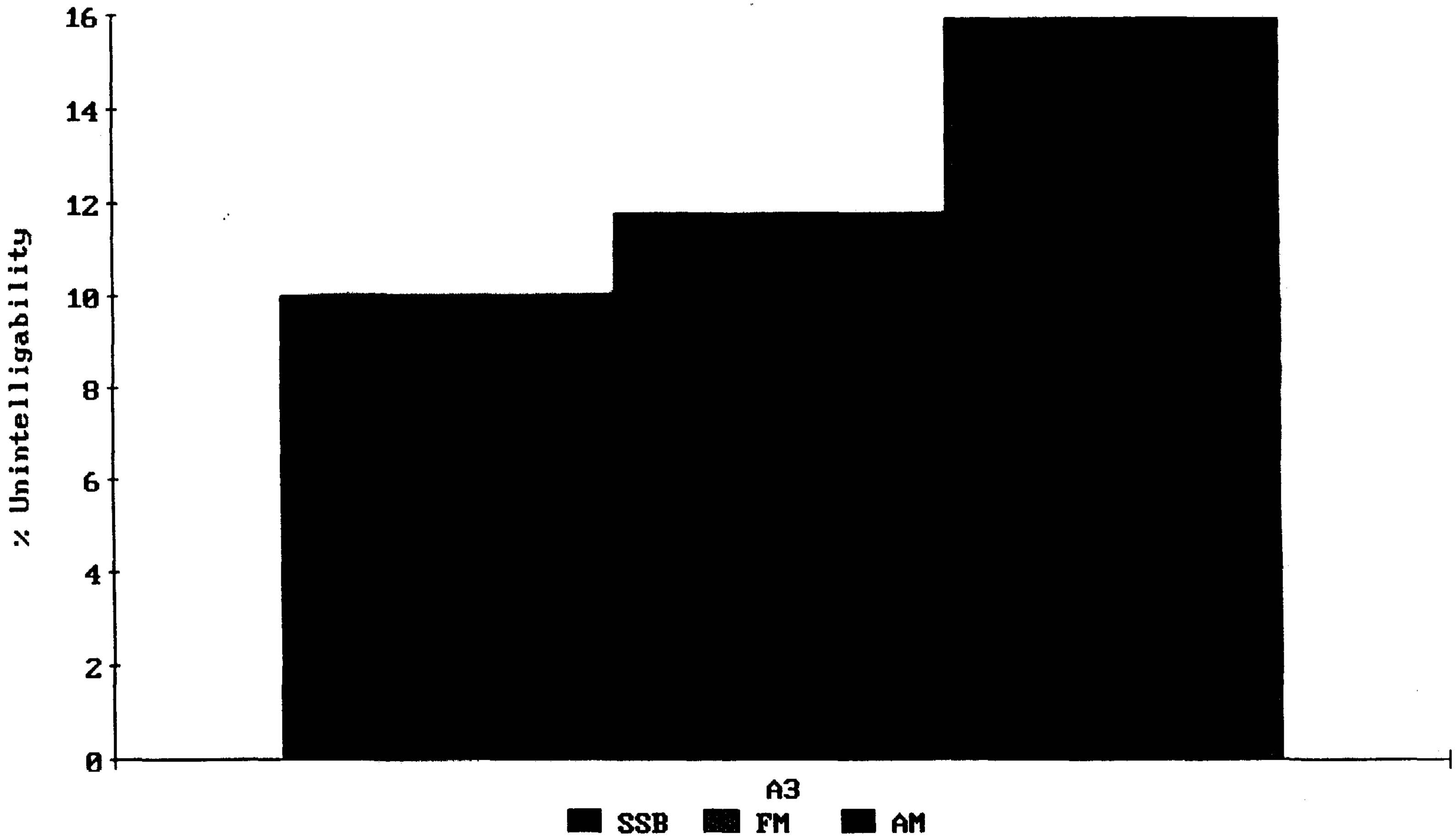


Fig 4.18: Voice Baseline - Fast Speed



4.2.2 Low Signal Strength Baseline Voice Results

Table 4.6 shows the low signal strength baseline results, and Fig 4.19 shows these results plotted. Note that these results are for signal strengths 8dB below that for the previous set of results. As can be seen, these tests were run on the three routes used for interference tests: route (2) - A217 post, route (3) - A2022 and route (4) - A3, all at medium speed.

1) Results

In the strong signal strength areas, the SSB and FM results are all similar in level, and are in fact marginally below the results for the higher signal strength tests. (This may be due to the advantages of filtering on the transmit path.) This reinforces the view that for FM and SSB, signal strength has little effect on voice quality. This is not true for AM, and for the lower signal strength tests, its performance deteriorates to a level much worse than SSB and FM.

In the lower signal strength areas, the performance of AM continues to worsen. On the other hand, the performance of SSB remains fairly constant under all conditions, as would be expected if SSB is resistant to long term field strength variations. This is also true of FM except under low signal strength conditions on route (4) - A3 where the performance is markedly worse.

2) Comments

In general, the opinion of listeners was not much changed by the reduction in signal strength. The major difference noted was an overall increase in the level of background noise for all three systems, particularly in low signal strength areas, and in the case of FM, on the high signal strength route as well.

The particularly favourable response to AM in high signal strength areas disappeared, and the comments made were fairly neutral.

SSB was again described as "tinny", but for the same route was also described as "clear" and "excellent". This illustrates the essentially split opinion of listeners on SSB. They found the SSB voice to be generally highly intelligible but also unpleasant in tone. The problem of the beginning of words being masked or distorted was again noted.

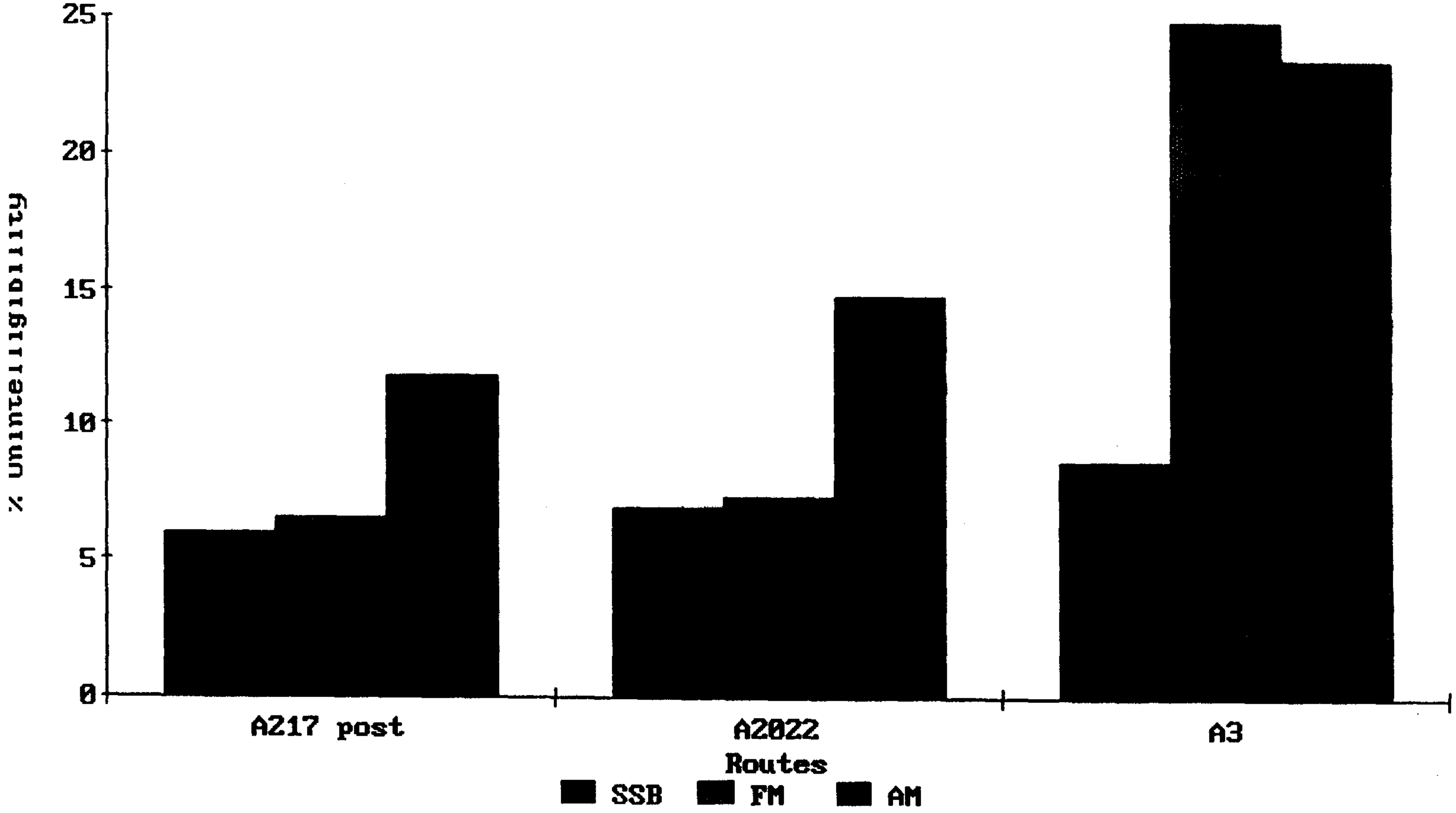
3) Summary

SSB performs at a constant level of 92% intelligibility. This is also true of FM down to a signal strength threshold level, beyond which its performance is rapidly degraded. AM's performance, on the other hand, deteriorates steadily with reducing signal strength. In no case does fading appear to have any great effect on voice performance.

Table 4.6: Lower Signal Strength Baseline Voice Results

	SSB	FM	AM
Med (30mph)			
A217 post	6	6.5	11.8
A2022	6.9	7.3	14.8
A3	8.6	24.8	23.4

Fig 4.19: Lower Signal Strength
Voice Baseline - Medium



4.2.3 Adjacent Channel Voice Results

Table 4.7 gives the results for adjacent channel interference tests, and Fig 4.20, 4.21 and 4.22 show these results in graphical form. It should be noted that these adjacent channel tests were carried out with the normal, low signal strength transmitter configuration, with all filtering in place.

1) SSB with Adjacent Channel Interference

On all routes, SSB interference has little noticeable effect on the SSB wanted channel. As can be seen in Fig 4.20, in some cases the baseline result is better than the result with interference, and in some cases worse. However, the difference is limited to less than 1%, and can be explained by experimental error. Thus the conclusion can be drawn that SSB is highly resistant to SSB adjacent channel interference.

This resistance also extends in a slightly lesser degree to FM interference, except in weak signal strength areas where the performance is degraded by about 2%.

AM interference has the most serious effect on SSB, decreasing the intelligibility to a fairly constant level of around 90% on all routes

2) FM with SSB Adjacent Channel Interference

As can be seen from Fig 4.21, SSB had a varied effect on FM. No explanation for this