The interfering voice signal was input to TX2 from a tape recorder (Appendix (iii) item 2/11) and in some instances via an audio amplifier. The input levels to the interfering base station were set so as to produce an optimum output level from the transmitters. This optimum voice level was then made repeatable by reference to a 1kHz test tone tape. The following is a list of test tone levels and associated transmitter conditions.

Base Station	**1KHz Test Tone**	**Audio Amp**	**Transmitter Conditions**
FM	800mV	Yes	2.5kHz deviation
AM	105mV	No	80% Mod depth
SSB	105mV	Yes	10V pk to pk at A/D converter input

3.4.2 Co Channel Configuration.

A co channel interfering signal was produced by removing the appropriate base station from the lab and installing it in a second vehicle (the mobile site). The equipment could then be driven to the desired location.

Power was provided by a 2kW petrol generator and RF power radiated from a tripod mounted 5/8 whip antenna. Modulation was again provided by a tape recorder.

This arrangement was found to be satisfactory for the internally synthesised FM and the crystal controlled AM equipment. However, due to the design of the SSB equipment, three external signal references were required. In the final arrangement these were provided by two signal generators, all locked to an Off Air frequency standard. The complete arrangement is shown in Fig 3.10 and Fig 3.11.

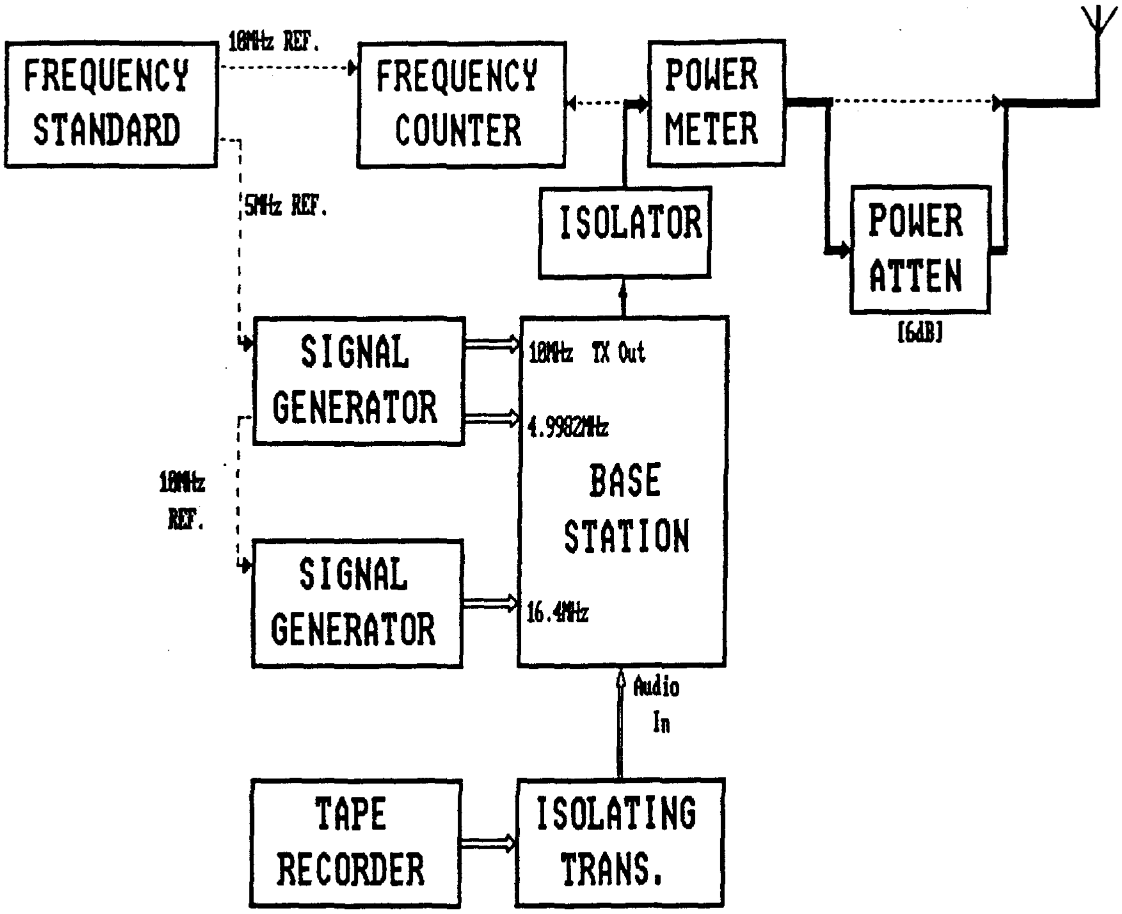


Fig 3.10 SSB Mobile Site Schematic.

Fig 3.11 SSB Mobile Site.

3.4.3 Transmit Mobile Matching.

In order to optimise the performance of each system under test, a careful set up procedure was adopted. The criterion that were used to determine the procedure are as follows:

TX Mobile	Criterion	
	Data	Voice
(1) FM	: 1.5KHz deviation	: 2.5KHz deviation
(2) AM	: 50% modulation depth	: 80% mod depth
(3) SSB	: 7V pk to pk on A/D and	: 10V pk-pk and
	: -17dBm input to audio stages:	25mV

The AM and FM levels were set according to the manufacturers recommendations, but the design of the SSB equipment dictated that the set up criteria was different to that of the other two systems. A very basic block diagram of the input side of the system is shown in Fig 3.12.

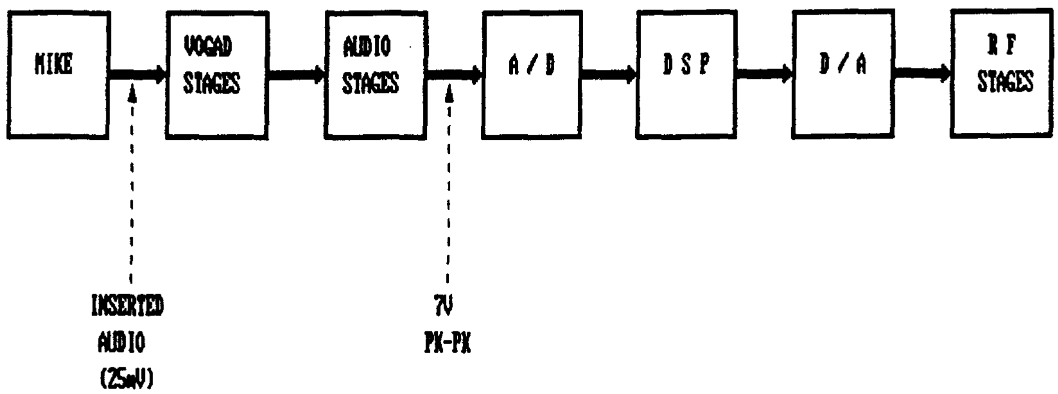


Fig 3.12 SSB Mobile: Tx Side.

The VOGAD circuitry was designed to maintain the input to the A/D converter at a constant level for a wide range of input levels (10mV to 700mV). In addition, the DSP controlled the RF output power via ALC circuitry. As a result, increasing the audio input level would not necessarily increase the RF output power. Therefore, an arbitrary level of 25mV into the VOGAD circuitry and a voltage swing of 10V pk to pk at the input to the A/D converter were chosen as optimum levels for voice and data was set at

7V pk–pk (the full input resolution of the A/D converter was 10V pk–pk and 25mV was at the low end of the VOGAD range so as to give the best gain/band width product). The 7V pk to pk for data was set as corresponding to 2/3 the level of the voice setting, so as to be consistant with the two other modulation schemes, and so as to be sure that the RF stages were not overdriven.

A matching network was then designed that could be used in all three systems to achieve all three optimum conditions. The network is shown in Fig 3.13 below.

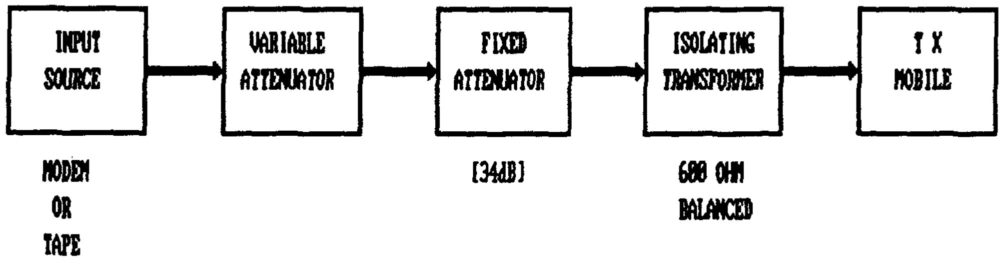


Fig 3.13 Tx Mobile Matching Network.

The same network was used on speech and data for all three systems. Three different DRT tapes were used, hence different attenuator settings were required to accommodate for the different play back levels. The various settings are recorded in Table 3.1.

System	Test Type	DRT Tape	Fixed Attenuator	Variable Attenuator(dB)
FM	Data	-	Yes	24
	Voice	2	Yes	3
		3	Yes	8
		4	Yes	3
AM	Data	-	Yes	17
	Voice	2	Yes	2
		3	Yes	8
		4	Yes	0
SSB	Data	-	No	24
	Voice	2	No	36
		3	No	44
		4	No	38

Table 3.1 Attenuator Settings.

3.4.4 Receive Mobile Matching.

The outputs from the receive mobiles in the vehicle were all taken directly from the audio output stages for both data and voice. The output level for voice was set using the volume controls on the various mobiles and the meter provided on the Nagra tape recorder. This was set for +45dB to +50dB on a slow averaging scale with linear filtering. This level was set at the start of each voice run.

The receive data configuration is shown in Fig 3.14.

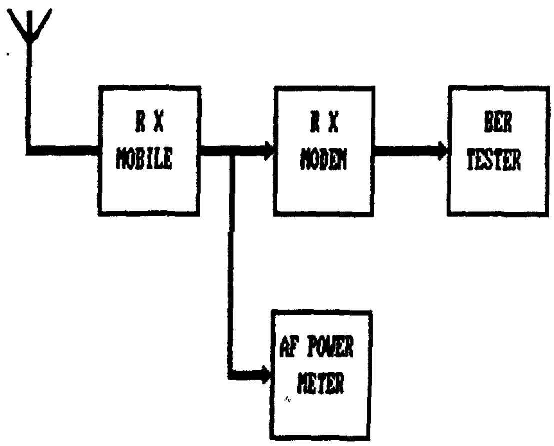


Fig 3.14 Receive Data Configuration.

The output level of the receive mobile was set to give −17dBm, into a 4Ω load representing the loudspeaker, for all three systems. This level corresponds to the output of the transmit MODEM.

3.4.5 RF Power Levels.

The problem with setting the RF power levels for each system was which type of measurement to use. CW and PEP measurements are the same for FM, for AM both vary according to mod depth and SSB has no carrier at all. If a CW measurement is carried out on an SSB transmitter, then a full power pilot test mode is required, which then raises the problem of relating this to the amount of power transmitted under conditions of normal modulation. If a PEP measurement is used then the level recorded will depend on the type of modulation used.

The proposed solution was to set the transmitter power on all three systems to correspond to the same incident field strength at a given point (it is not the absolute level of field strength that is important, but the relative levels of the different systems). The field strength measurements were made with an Anritsu field strength meter and a calibrated antenna (Appendix (iii) item 2/4). The measured field strength and associated RF powers are given below.

System	Field Strength	Power/W	
	dBµV(rms)	PEP	CW
SSB	40.6	2.6	0.7
FM	41.0	1.0	1.0
AM	40.3	1.6	0.6

All power measurements were taken at the antenna feeder and hence equate to ERP. SSB and FM measurements were taken on control channel data transmissions and AM was modulated with FSK data at 50% modulation depth. The relative field strengths and power levels were repeatedly monitored for the duration of the trials.

3.4.6 Channel Frequencies

Two 12.5kHz channels were used for the trials, these being channels 2 and 3 in Fig 3.15 below. The SSB channels are also shown.

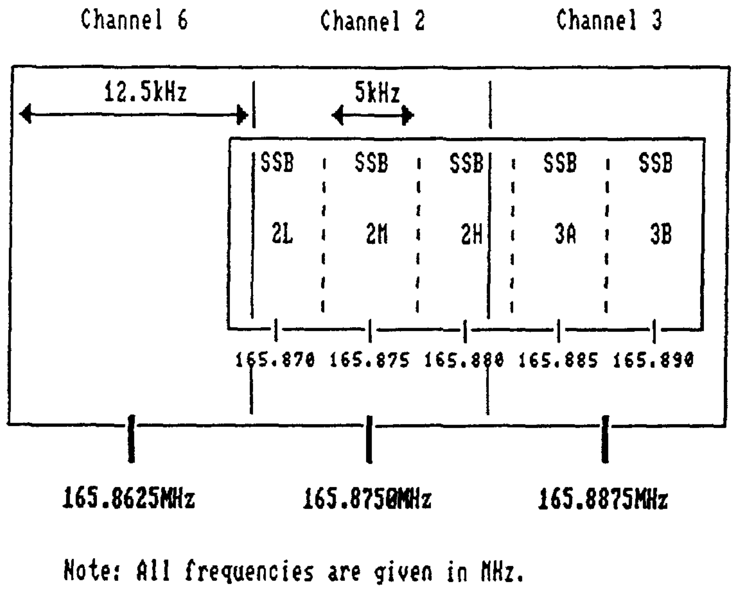


Fig 3.15 Channel Allocations

The frequencies shown in Fig 3.15 are the base station transmit frequencies. The mobile transmit frequencies are 4.8MHz above those shown.

The actual base station frequencies were measured for Channel 2 (and Channel 2M for SSB) and are given below. These results are valid for the mobile site as well as for the fixed site.

FM	165.874,837MHz
AM	165.875,052MHz
SSB	165.875,004MHz

The channels used were taken from the channels approved by the DTI for the purposes of the trial, with channel 2 being used by the AM and FM equipment. The SSB equipment was used on both channel 2 and channel 3 as required, in the slots shown. Table 3.2 below gives the slots used for each measurement.

Measurement	Systems Involved	Channels Used
Co-channel	SSB vs. SSB	2M and 2M
Co-channel	FM/AM vs. SSB	2 and 2M
Adjacent channel	SSB vs. SSB	3A and 3B
Adjacent channel	FM/AM vs. SSB	2 and 3A

Table 3.2 Channels used for tests

4. Results

4.1 Data Results.

The following section presents the data results obtained. All relevant graphs can be found at the end of each section. A complete listing of all raw data is given in Appendix (iv).

All the data results in the following section are given in the form of errors/million bits. (This is equal to the Bit Error Rate (BER) times one million). Obviously, a lower score indicates superior performance.

These results were obtained using a BER meter. The meter is capable of measuring BER's between $1/10^{12}$ and 1/16 (that is, 10^{-6} and 62,500 errors/million bits). This lower limit of 1/16 led to problems under very poor performance conditions, and this is covered more fully in section 4.1.4: Higher Data Rate Results. It should be noted, however, for all results, that 62,500 is the maximum possible value for errors/million and should therefore be read as "62,500 or greater".

A summary of the routes used is repeated below for reference.

ROUTE	FIELD STRENGTH	FADING DEPTH	SPEED
1) A217 (pre-roundabout)	A	shallow	slow, med
2) A217 (post-roundabout)	A	deep	slow, med
3) A2022	B	deep	slow, med

4.1.1 Baseline Data Characteristics.

The baseline data results are given in Table 4.1 and the results are shown plotted for three different speeds in Fig 4.1, 4.2 and 4.3. They are summarised in terms of speed below.

1) Slow.

As can be seen from Fig 4.1, FM would appear to perform better than SSB in high signal strength, shallow fade areas (route (1) – A217 pre) i.e. ideal receiver conditions. SSB performed better under all other conditions. Under worst receiver conditions, in medium/low signal strength areas with deep long and short term fading (route (3) – A2022), the SSB system out-performed FM by a factor of 6 or greater. Of the three modulating schemes, AM gave the highest BER's under all conditions.

2) Medium.

With reference to Fig 4.2, the results show a very similar pattern to those described in (1) above. Again, FM performs best under high signal strength, shallow fading conditions and SSB yields the best BER's in all other cases (again by a factor of 6 under worst receiver conditions). AM is by far the worst and exhibits exceptionally high error rates on routes (3) and (4) of 1 in 10^2 and 2 in 10^2 respectively.

3) Fast.

Although data is only available for one route (route (4) – A3), SSB yielded error rates better than FM by a factor of 5 and better than AM by a factor of 15 (see Fig 4.3).

4) Summary.

FM performs better than either AM or SSB under ideal receiver conditions (route (1) – high signal strength, shallow fades), where as SSB data performance was found to be far better than the other modulating schemes under all other conditions.

Note that this superiority of SSB under non-ideal conditions is not a function of signal strength alone, but is apparently a function of a combination of signal strength and fading characteristic. This is shown by the fact that SSB performs better on Route 2 (A217post) where the signal strength is of a similar level to Route 1 (A217pre) but the fades are much deeper. SSB seems more capable of overcoming fading and this is borne out by the fact that SSB also seems to be the least affected by vehicle speed (see Fig

4.4). By comparison, FM and especially AM showed a marked decrease in performance at increasing vehicle speed.

Table 4.1: Baseline Data Results

		SSB	FM	AM
	Slow			
Route 1	A217 pre	366	103	2289
Route 2	A217 post	240	346	1872
Route 3	A2022	886	5592	13914
Route 4	A3	391	3812	7744
	Med (30mph)			
Route 1	A217 pre	344	27	1627
Route 2	A217 post	68	448	2259
Route 3	A2022	744	5109	11277
Route 4	A3	2316	6512	18752
	Fast (50mph)			
Route 4	A3	1833	8700	27807

Fig 4.1: Data Baseline - Slow Speed

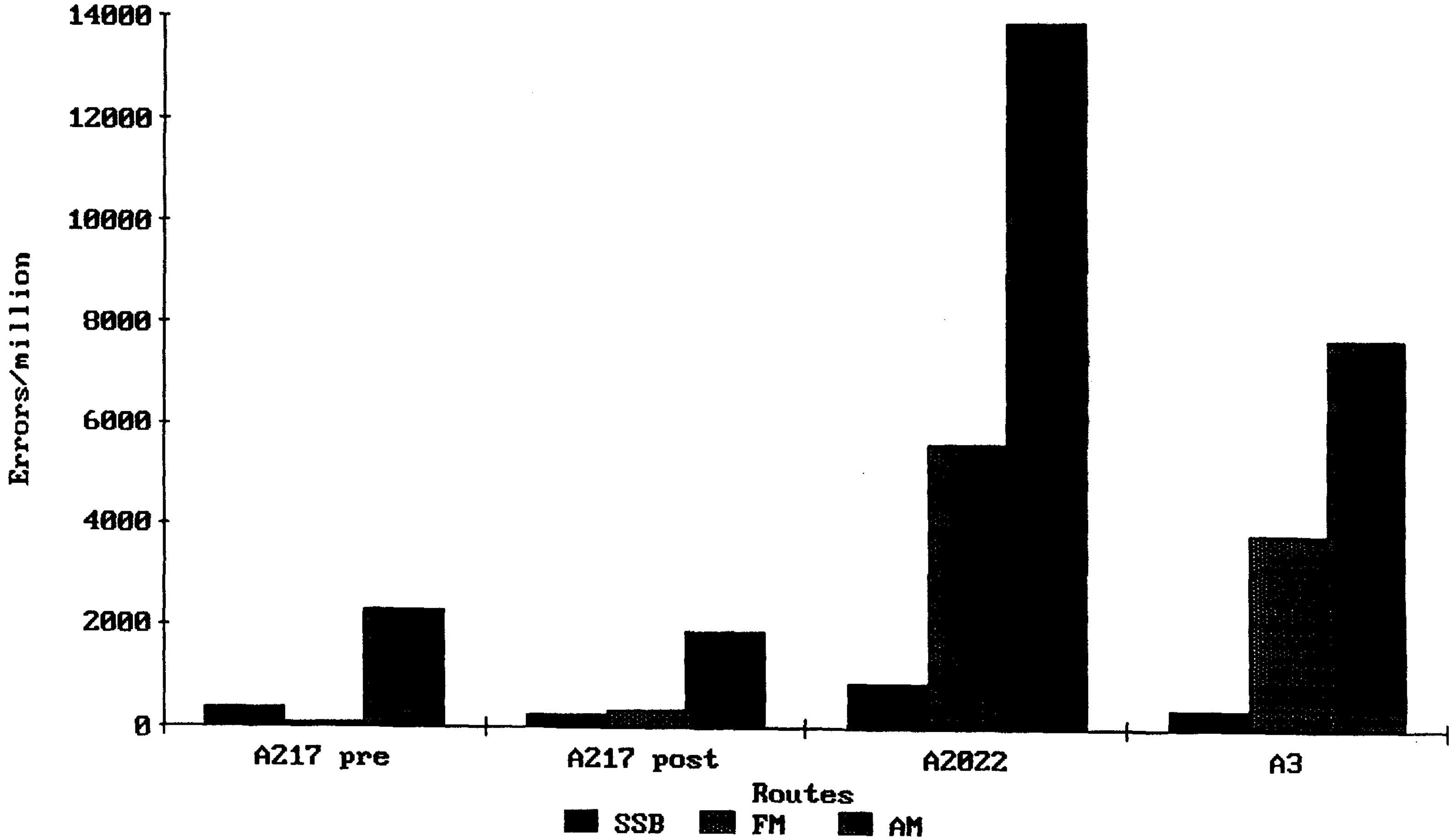


Fig 4.2: Data Baseline - Med. Speed

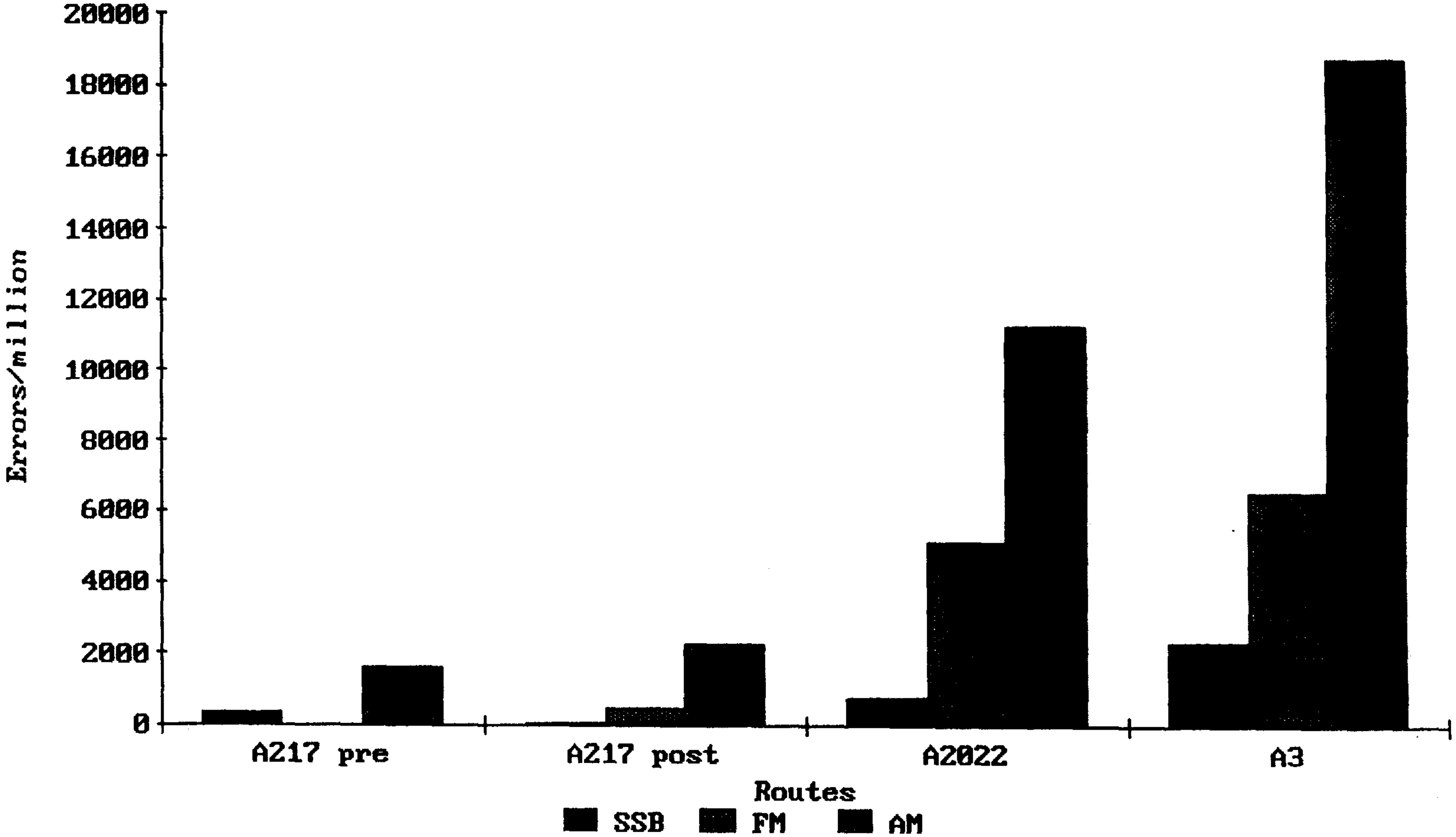


Fig 4.3: Data Baseline - Fast Speed

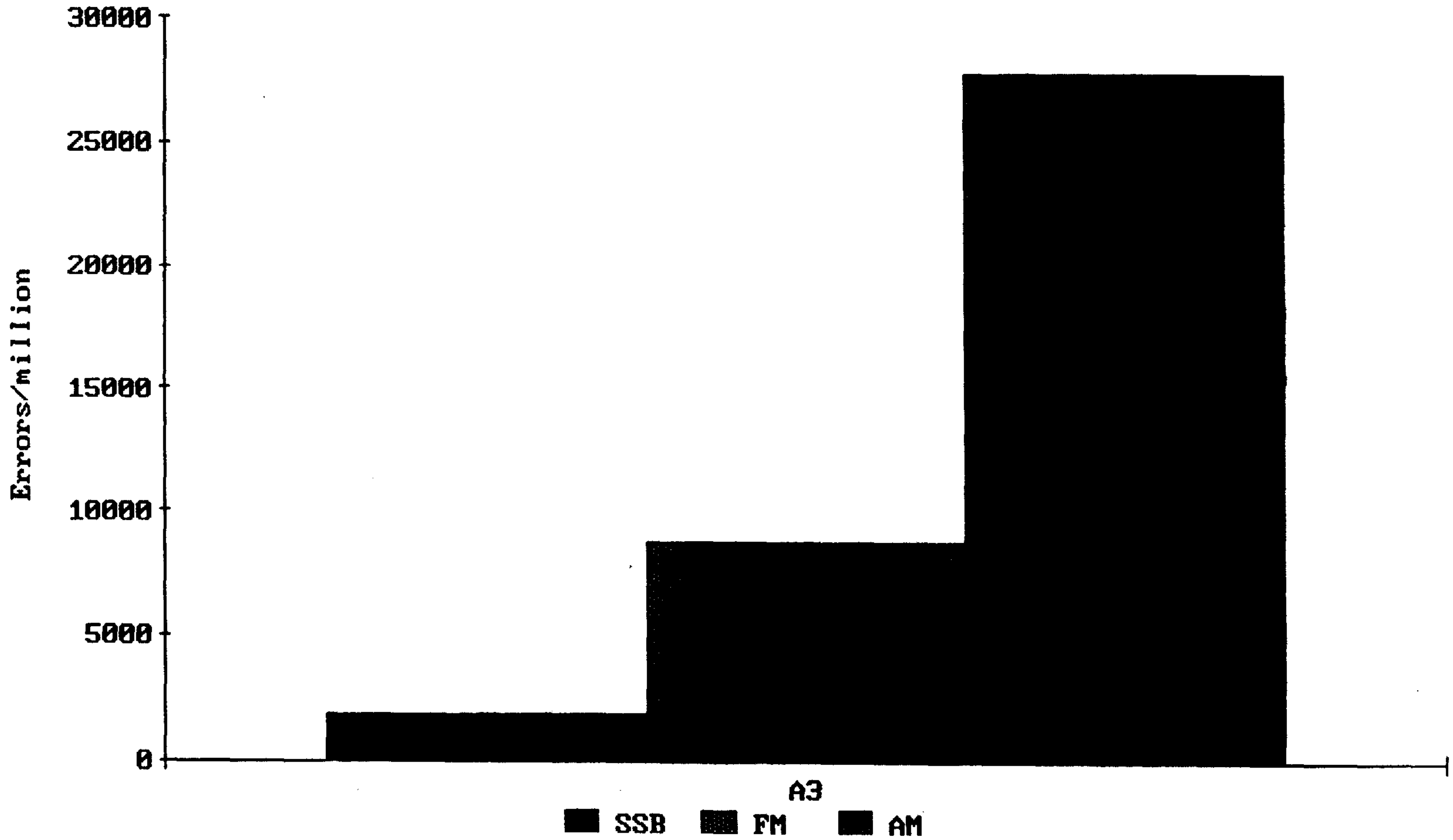
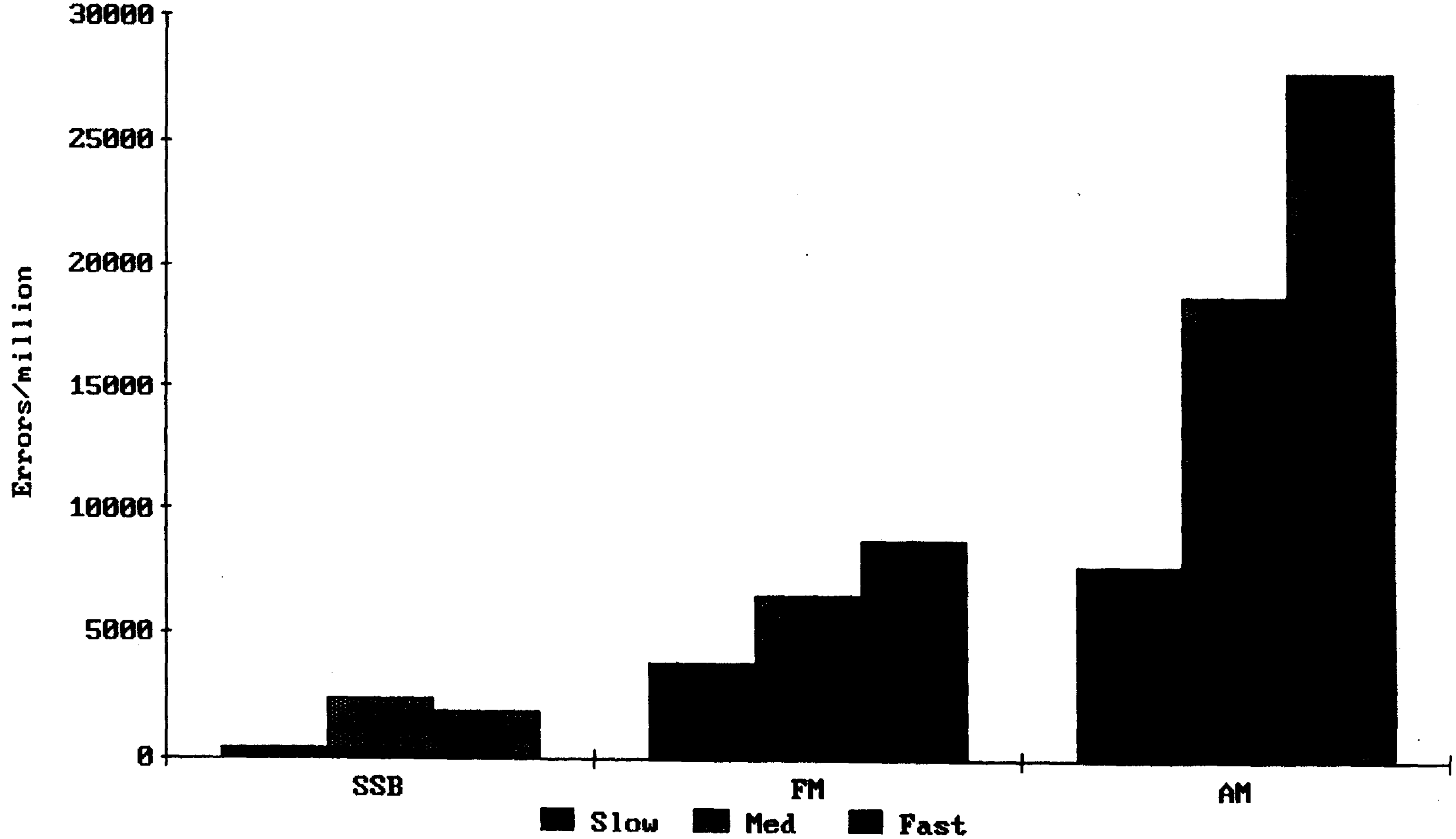


Fig 4.4: Data Baseline Results for A3



4.1.2 Adjacent Channel Data Results.

All experiments were carried out at 30mph on routes (2), (3) and (4). The numeric results are given in Table 4.2.

1) SSB with Adjacent Channel Interference.

Results showing an SSB wanted signal with SSB, FM and AM interfering signals are given in Fig 4.5. In general, SSB is not seriously affected by interference on Route 2 (A217) and only slightly more on Route 4 (A3). These are routes with strong signal strength with deep fades, and medium signal strength without deep fades respectively. Indeed, on the A217, SSB would appear to perform better with an SSB or FM interfering signal than with no interference. However, the difference is slight and is almost certainly due to experimental error introduced by differing atmospheric propagation conditions, varying road traffic conditions and possible local RF interference.

This apparent near immunity to interference does not extend to the worst receiver conditions on Route 3 (A2022) where the effect of all three types of interference is to increase the error rate by a factor of between three and four. A gradual deterioration in interference rejection in lower signal strength areas is indicated, and this is reinforced by the slight performance deterioration noticed on Route 4.

2) FM with Adjacent Channel Interference

As can be seen from Fig 4.6, FM behaves in a different manner to SSB under interfering conditions. In this case, the worst affected signal is on Route 2 (A217) whereas the effect of interference on the lower signal strength routes is considerably less.

3) AM with Adjacent Channel Interference

AM repeats the pattern shown by SSB, in that the worst effects of interference are seen under worst receiver conditions on Route 3 (A2022). However, AM shows greater resistance to interference than SSB on the A2022. The anomaly of a wanted signal performing better with interference than without is repeated on Route 4 (A3), but the same explanation holds.

4) Summary

In general, SSB performs well under adjacent channel interference except in very poor receiver conditions. AM performs similarly and is in fact even more resistant to interference, although of course, its absolute performance is much worse. FM is, on average, also relatively more resistant to adjacent channel interference than SSB, but again its absolute performance is worse.

It is interesting to note that on each route, SSB performs better with any form of interference than does either FM or AM without interference.

Table 4.2: Adjacent Channel Data Results

	SSB	Baseline	SSB Int	FM Int	AM Int
Route 2	A217	68	59	34	113
Route 3	A2022	744	2775	2203	2566
Route 4	A3	2316	3372	3404	2110

FM		Baseline	SSB Int
Route 2	A217	448	1092
Route 3	A2022	5109	7687
Route 4	A3	6512	8152

AM		Baseline	SSB Int
Route 2	A217	2259	2379
Route 3	A2022	11277	21426
Route 4	A3	18752	17444

Fig 4.5: Data on SSB with adjacent channel interference

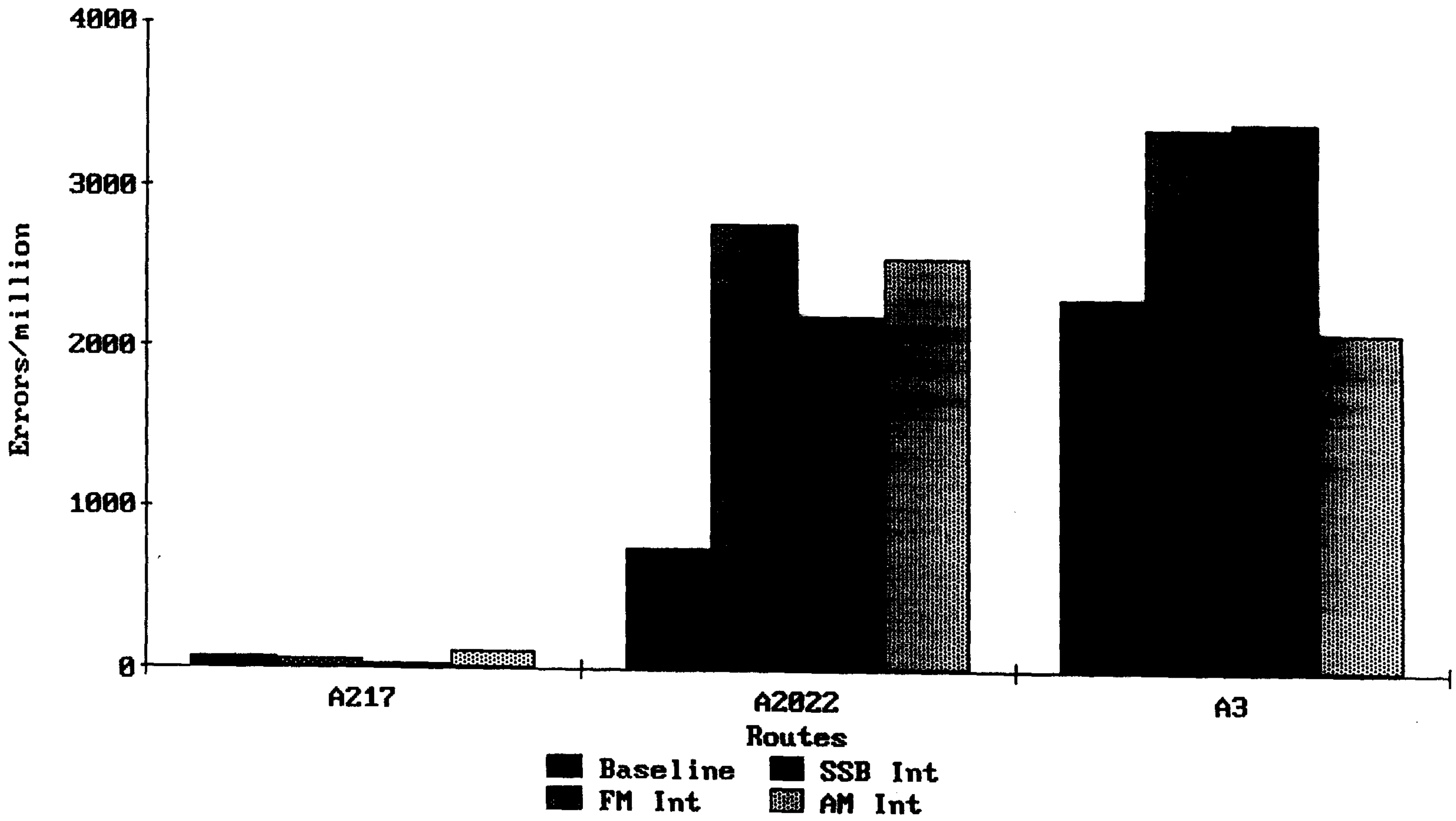


Fig 4.6: Data on FM with SSB adjacent channel interference

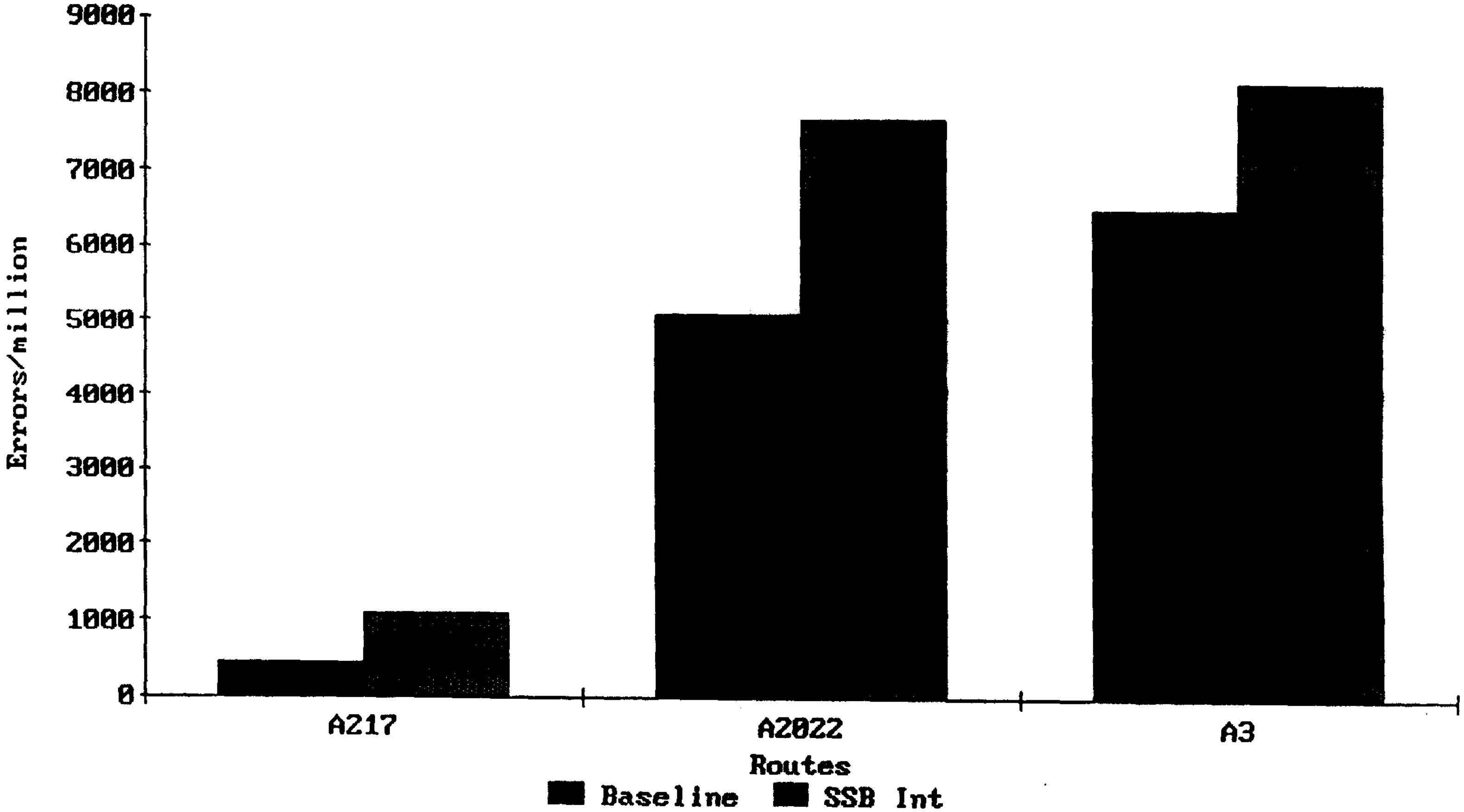
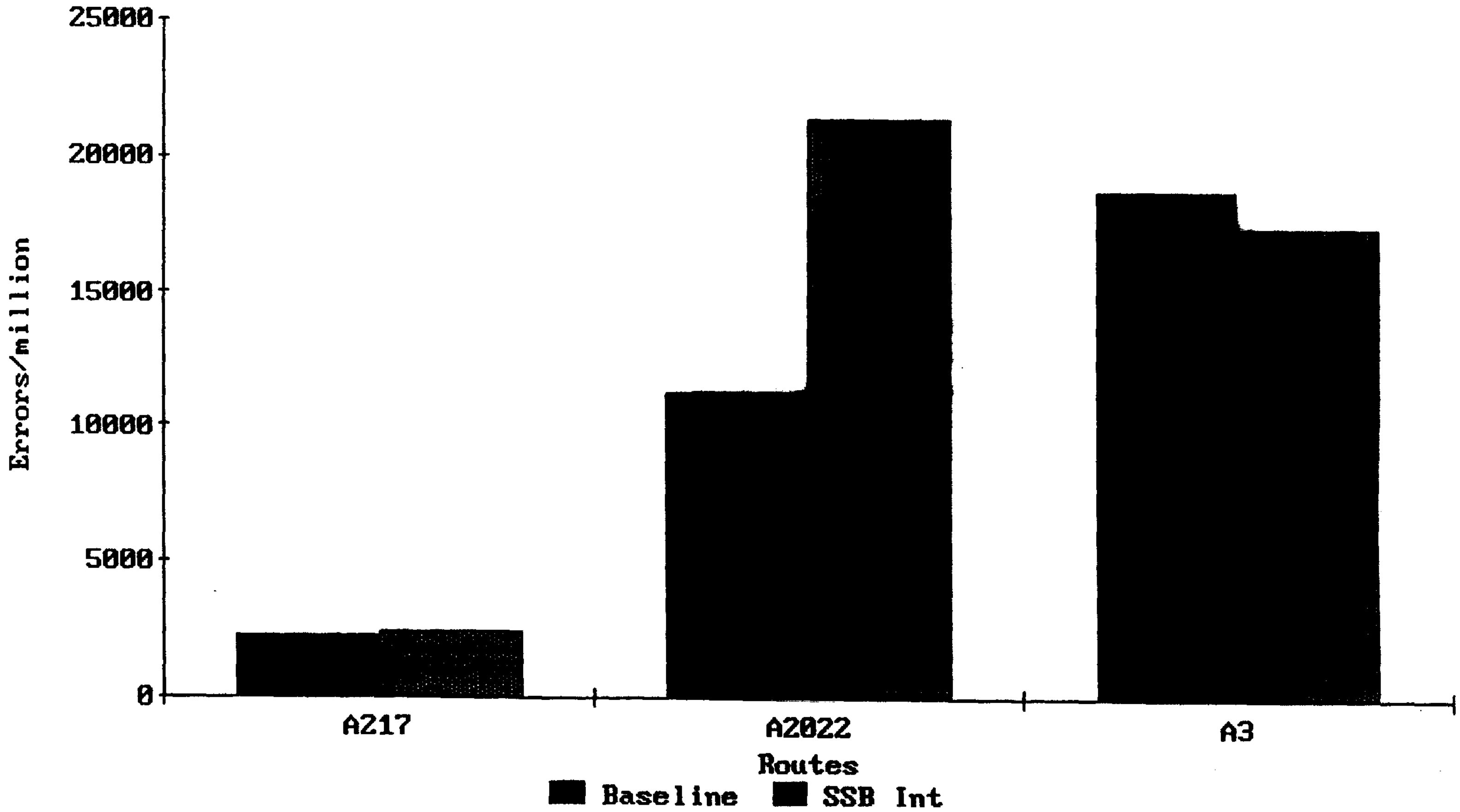


Fig 4.7: Data on AM with SSB adjacent channel interference



4.1.3 Co-Channel Data Results.

These tests were run on route (3) at 30mph with a 6dB attenuator being used for the lower power level runs. All relevant field strength plots are given in Section 3.3, and the average protection ratios for the two runs were 2dB and 8dB. The numeric results are given in Table 4.3.

1) SSB with Co-Channel Interference.

A problem was encountered during the co-channel interference tests with a wanted SSB channel. Two SSB transmitters were required to carry out the co-channel tests, and a different transmitter was used at the fixed site (for the wanted channel) than had been used for all the previous tests. This was because the second transmitter could not be made to work reliably at the mobile site with signal generators providing the required clock signals and a petrol generator providing power. Therefore, the second transmitter, originally planned to be the source of the interfering channel, was instead used as the wanted channel source. However, it was found that this had a much worse baseline performance than the original, mainly due to different tolerances on the crystal filter. This means that Fig 4.8, which shows the effect of interference on SSB, must be viewed in isolation and cannot be directly compared with the previous and following results. The illustration it gives to the effect of interference is however still valid and comparable in terms of relative ratios with the other results. The figure for the baseline measurements, given in Table 4.3, is not a real-time measurement, but an estimate based on stationary data measurements made later and comparative measurements made between the two transmitters. It can therefore only be considered accurate to within ±20%.

As can be seen from Fig 4.8, the effect, on an SSB wanted signal, of co-channel interference at both levels of interference ratio is considerable. This is particularly true of FM and AM interfering signals, while SSB has a lesser effect. On the other hand, reducing the level of the SSB interferer has little apparent effect on the level of signal degradation, unlike the case with AM or FM interference where a 30% improvement in BER results.

2) FM with Co-Channel SSB.

Referring to Fig 4.9, the effect of a co-channel SSB signal is not particularly great, increasing the BER by around 25%. However, the anomaly of the lower power level of interfering signal causing a greater BER must be noted, although the difference is slight, and the small effect of SSB interference is merely reinforced by the result.

3) AM with Co-Channel SSB.

The result of introducing an (attenuated) interfering signal (see Fig 4.10) was an increase of the BER by factor of 4. It was found that the full power interfering signal made any measurements impossible (implying that the BER was greater than 1 in 16). This level of 1/16 (or 62,500 errors/million bits) is that shown in Fig 4.10, although the real figure may be higher.

4) Summary.

On the whole, FM is strongly resistant to SSB interference, in stark contrast to AM which is catastrophically degraded.

SSB is also badly affected by interference, although it performs noticeably better with SSB interference than with AM or FM. It should be noted that the performance of SSB with SSB interference is at a very similar level to the performance of baseline FM.

The result that FM has a more detrimental affect on SSB than either AM or SSB, as can be seen on Fig 4.8, has a possible explanation. In the FM case, a strong carrier is sweeping across the full bandwidth of the SSB signal. When it is within the notch provided for the SSB pilot, it will cause frequency jitter on the wanted SSB signal, as the receiver switches lock from one "pilot" to another. This will have a serious affect on a FSK data signal (see section 2.2.8 Co-Channel TTIB Tone Test).

Table 4.3: Co-Channel Data Results on Route 3 - A2022

SSB

Baseline	2500	±500
Co SSB	5563	
Co SSB/att	5122	
Co FM	11940	
Co FM/att	8406	
Co AM	10983	
Co AM/att	8090	

FM

Baseline	5109
Co SSB	6781
Co SSB/att	7847

AM

Baseline	11277
Co SSB	62500
Co SSB/A	44042