REPORT 899-1

SYSTEMS OF MODULATION WITH HIGH SPECTRUM EFFICIENCY FOR THE LAND MOBILE SERVICE

(Question 7/8; Study Programme 7B/8)

(1982-1990)

1. Lincompex system (linked compressor and expander system)

1.1 *Introduction*

The Lincompex system has been developed for improving the speech quality of HF radiotelephone service. The characteristics of Lincompex equipment for HF fixed telephone service and HF maritime mobile service, specified by Recommendations 455 and 475, are quite satisfactory for practical HF radiotelephone operations.

The congestion in the VHF band for land mobile services is a serious problem in many countries due to the rapid growth of the land mobile telephone service in limited geographical areas. Though the single-sideband technique is undoubtedly the best way for minimizing the occupied bandwidth, with ordinary single-sideband techniques, it is difficult to meet such inherent propagation conditions of the land mobile service as rapid fading and strong impulsive noise in urban areas.

The Lincompex system has high protection features against these conditions in itself.

It is generally understood that the Lincompex system is possibly applicable to the land mobile telephone service with some improvement of basic characteristics of HF Lincompex system.

1.2 *Improved characteristics of Lincompex system for land mobile service*

In order to overcome the inherent propagation conditions of the land mobile telephone service, the following improvements had been applied to the equipment used in trials effected in Japan [Kadokawa et al., 1981]:

- In order to reduce the Doppler effect and the influence of frequency error, the sensitivity of frequency modulation in the control channel is expanded to 6 Hz/dB (three times as large as 2 Hz/dB used in the HF band).
- In order to compensate for the deep and rapid fading, attack and recovery times of the compressor and expander are reduced to about one-third, and also the attack time of the fading regulator to about one-tenth compared with HF Lincompex; the lower limit of the fading regulator range is extended by about 15 dB; the level of the control channel is increased up to the same level of that of the speech channel.
- In order to improve the speech quality, a pre-emphasis circuit with 6 dB/octave characteristic is employed.

1.3 *Test results*

Satisfactory test results were obtained in a field test conducted in Japan. Table I summarizes the results obtained of average field strength corresponding to each grade of evaluation in the field test.

TABLE I – *The measured results of average field strength necessary for each grade*

Grade	Overall rating	Field strength in dB(μV/m)		
		Lincompex	FM	SSB
5	excellent	41	47	(1)
4	good	25	30	37
3	fair	18	22	24
2	poor	18	16	19
1	unusable	(2)	(2)	(2)

(1) Not found.
(2) Not measured.

It is indicated, in the grading range of 3 to 5, that the Lincompex system tested gave the same grade of speech quality even though the field strength is lower by about 5 dB than that of the FM system. When compared with the SSB system without Lincompex, the evaluators for speech quality felt that the Lincompex system was hardly affected by fading and the protection against city noise was almost the same as that of the FM system.

As for the adjacent-signal selectivity, it is noted that the ratio of the level of unwanted radio signal to the level of wanted radio signal is more than 70 dB at the frequency separation of 6 kHz.

1.4 *Future work*

In order to improve the technical characteristics and contribute to the reduction of channel separation, further studies should be undertaken.

Administrations are invited to expedite the study of the reduction of channel separation in the VHF land mobile service.

There are however further factors that directly influence the degree to which Lincompex might contribute to reduction of channel separation. In particular, extremely high frequency stability is necessary to achieve the indicated results. Implementation of such stabilities are presently costly and cause substantial increase in the size of portable equipment and some mobile equipment.

2. SSB system (Yugoslavia)

2.1 *Introduction*

Several thousand VHF, SSB equipments have been used in land mobile applications in Yugoslavia [CCIR, 1974-78] for more than five years.

The performance of SSB was compared with FM by laboratory and also field tests using transceivers which could operate in both modes. The same receiver front-ends and transmitters linear power amplifier were used. The bias of the power amplifier was adjusted separately for the two modes.

2.2 *Equipment characteristics*

The transceiver characteristics are summarized in Table II.

TABLE II – *Transceiver characteristics*

Transmitter

	RF output power (W)	Bandwidth	Speech process
FM	2, 6, 20	±5 kHz deviation	pre-emphasis
SSB	2, 6, 20	2.4 kHz	20 dB-clipper

Receiver

	Sensitivity	IF-bandwidth	Speech process
FM	1 μV/20 dB SINAD	16 kHz/6 dB	de-emphasis
SSB	1 μV/20 dB SINAD	2.4 kHz/6 dB	

2.2.1 *Frequency stability*

A temperature compensated crystal oscillator (TCXO) was used, having the advantages of low power consumption, zero warm up time, and small size.

Frequency variation with temperature: $\pm 1 \times 10^{-6}$ (−30 to +60 °C). This stability is sufficient to provide reliable SSB communication up to 100 MHz.

2.3 *Test results*

2.3.1 *Power consumption*

In portable equipments, the weight, size and power consumption are most important. Comparisons are based on the same SSB and FM RF output power. In Table III, direct comparison of power consumption between FM and SSB in the same equipment is shown.

TABLE III – *Comparison of power consumption of FM and SSB transmitters*

Transmission	RF power output	Power consumption (W)		Intermodulation product level (dB)
		Final power amplifier(3)	Transmitter	
FM	20 W_{rms}	36	52	
SSB-I(1)	20 W_{pep}	22	36	−30
SSB-II(2)	20 W_{pep}	14	22	−30

f = 37 MHz

(1) SSB-I: Two-tone test conditions (CCIR).

(2) SSB-II: Average speech, clipping ratio of 20 dB.

(3) Final RF power amplifier is separately optimized for SSB and FM.

The comparison of power consumption at different RF output power levels can be seen on Fig. 1.

The diagram shows that the power consumption is more than two times greater in a FM system than in a SSB system of equivalent RF output power.

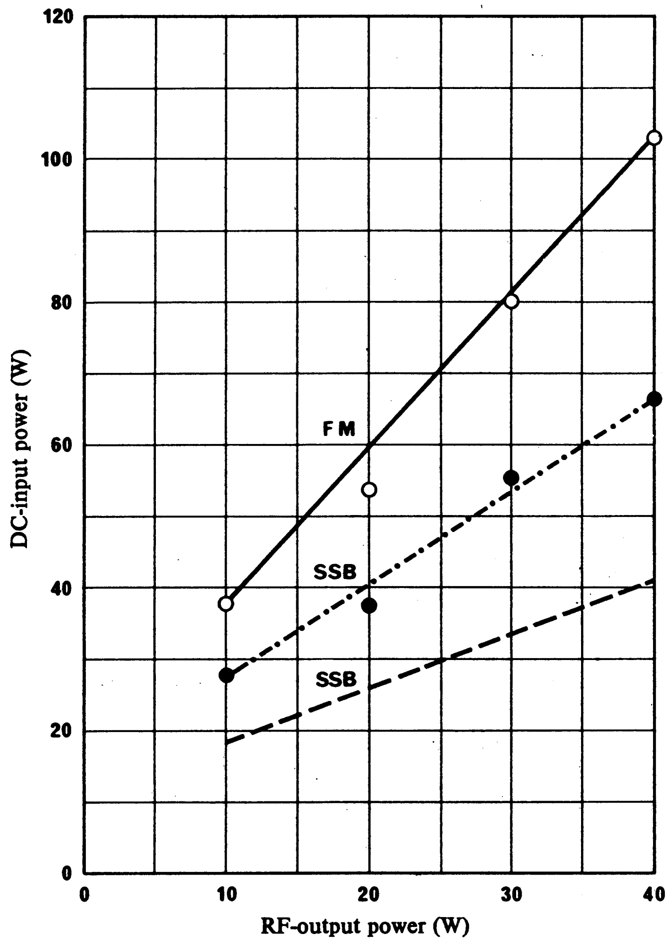

FIGURE 1 – *Comparison of power consumptions at different RF power levels*

——— FM
–·–·–·– SSB 2-tone
– – – – SSB average speech

Intermodulation product level: −30 dB

f = 37 MHz

2.3.2 *Maximum range*

To compare the efficiency of FM and SSB modulation techniques with respect to intelligibility, a logatom articulation method was used. A complete test comprised 2000 logatoms.

The results of laboratory tests are given in Fig. 2, from which it can be seen that in conditions corresponding to maximum range, the FM transmitter must provide 6 to 10 dB more RF output power than the SSB transmitter.

The extensive field tests carried out show that at maximum range conditions the same acceptable quality of communication was obtained at the level of 2W PEP-SSB and 20W FM radio-frequency output power.

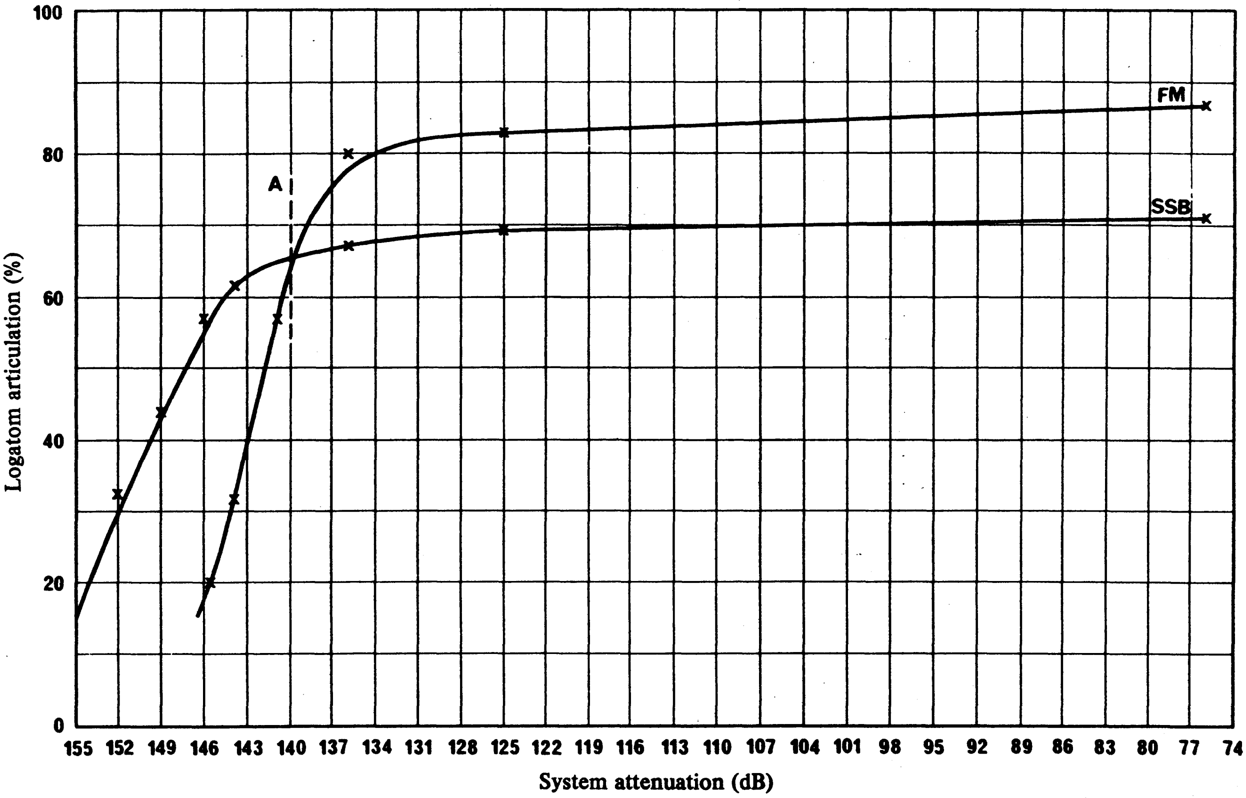

FIGURE 2 – *Logatom articulation versus system attenuation*

A: FM/SSB receiver sensitivity 1 μV/20 dB SINAD

FM: RF output power 2 W

SSB: RF output power 2 W (PEP) and 20 dB clipping

2.4 *Conclusions*

Considerable additional study should be done on:

- adjacent channel selectivity;
- co-channel interference, SSB/SSB and SSB/FM;
- speech processing methods;
- immunity to impulsive noise.

3. SSB system (United Kingdom)

3.1 *Introduction*

The possibility of using single sideband (SSB) systems to relieve spectrum congestion in the land mobile radio bands below 500 MHz has been investigated in the United Kingdom and a number of laboratory and field tests have been carried out to evaluate the performance of different SSB systems compared to existing AM and FM systems.

3.2 *SSB systems*

In order to meet the automatic gain control (AGC) requirements of SSB systems operating in a land mobile radio environment, where the received signal is subject to rapid fading, a continuous signal must be transmitted with the speech sideband, to maintain the AGC.

The continuous signal may be provided by one of the following systems:

- a pilot carrier;
- a tone in, or at the edge of, the audio passband;
- a Lincompex control subcarrier;
- a data subcarrier.

Studies in the United Kingdom have concentrated on the first of these systems with pilot signals in the range −10 to −20 dB relative to peak envelope power (PEP).

The necessary RF bandwidth is dependent on the audio bandwidth required and the type of pilot signal employed but in general is not greater than 3000 Hz for land mobile applications.

Feedback AGC, using the pilot signal as a reference may be employed at frequencies up to about 200 MHz. For UHF applications a combination of feedback and feed forward AGC may be employed.

3.3 *Channel spacing and frequency tolerance*

An overall system frequency tolerance of 500 Hz will permit the use of 5 kHz channel spacing.

Economic considerations make it advantageous to employ a high stability base station, with a narrow frequency tolerance, and therefore allow a greater frequency tolerance (approaching ± 500 Hz) for the more numerous mobiles.

3.4 *Impulsive interference*

Experiments have shown that an SSB receiver with an i.f. bandwidth of 3 kHz is not unduly sensitive to impulse noise [Gosling *et al.*, 1979]. Although impulses typical of ignition noise are stretched out to a greater extent by the narrow filter of the SSB receiver the total energy passed by the filter is correspondingly less. Side-by-side comparisons with 25 kHz spaced FM equipment in a high noise environment have shown that the subjective effect of ignition noise is approximately the same [Wells, 1978].

3.5 *Co-channel interference*

Subjective tests have demonstrated that under actual mobile-radio field conditions the effects of co-channel interference in an SSB system with 5 kHz channelling are very similar to those encountered by 25 kHz FM systems [Garner, 1980]. In both cases a signal-to-interference ratio of the order of 16 dB is necessary to achieve a quality of reception corresponding to grade 3 in Table II of § 1.4 of this Report.

The range of subjective gradings observed with various co-channel interference ratios is given in Figs. 3*a*, 3*b* and 3*c* for different wanted signal levels and carrier offsets. These curves are based on subjective tests carried out in the United Kingdom [Garner, 1980] in which the wanted and unwanted signals were of the same modulation type. The wanted signal was on tune and the unwanted signal was at a carrier frequency offset of 75 Hz for SSB and 500 Hz for FM, which was considered to give the worst result in each type of system.

Further subjective tests, carried out by the United Kingdom Home Office, have shown that in almost all conditions 25 kHz FM equipment was found to give better co-channel performance than SSB, 12.5 kHz or 12.5 kHz AM. However, in urban and suburban areas SSB was not shown to be markedly inferior to 25 kHz FM and in all conditions SSB performed at least as well as 12.5 kHz FM or AM.

3.6 *Compatibility with existing control signals*

When a pilot signal is used for automatic frequency control most standard signalling systems can be employed.

3.7 *User evaluation trials*

The results of a user evaluation trial carried out in the United Kingdom under typical private land mobile conditions and using speech [Barnes, 1981] have shown that from a users assessment 5 kHz SSB equipment could be used without any loss in quality or intelligibility when compared with 12.5 kHz equipment. Furthermore, in some high field strength situations the quality of the SSB systems would be better than that of existing 25 kHz FM systems.

However, it was judged that under almost all conditions 25 kHz FM equipment would provide a higher quality service.

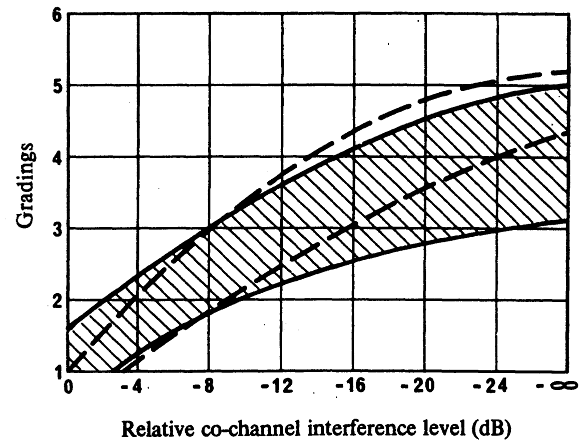

FIGURE 3a

——————— : SSB

— — — — : FM

Wanted signal: 10 μV
Carrier offset: zero

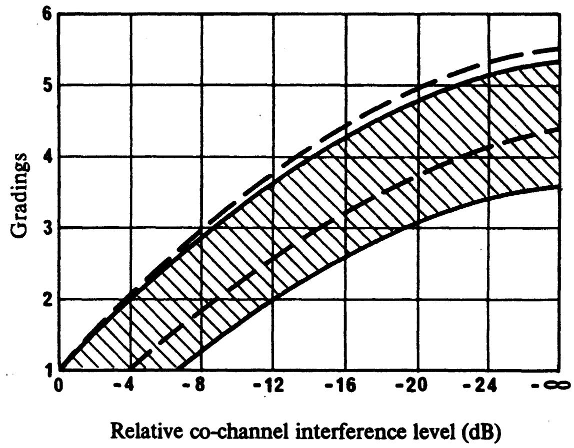

FIGURE 3b

——————— : SSB

— — — — : FM

Wanted signal: 3 μV
Carrier offset: 75 Hz for SSB
500 Hz for FM

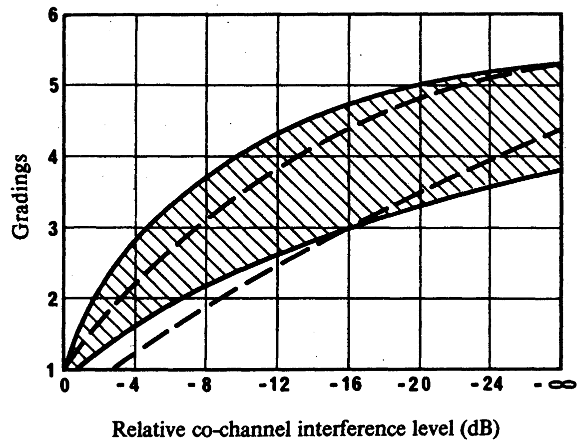

FIGURE 3c

——————— : SSB

— — — — : FM

Wanted signal: 10 μV
Carrier offset: 75 Hz for SSB
500 Hz for FM

4. SSB system (United States of America)

4.1 *Introduction*

Laboratory experiments have been conducted in the United States on the use of Amplitude Companded Single Sideband (ACSB) VHF radios for mobile communications. ACSB radios employ both Amplitude and ACSB Companding and audio pre-emphasis and de-emphasis voice processing. Some comparisons are made with FM, AM and ACSB receivers.

4.2 *Tone and voice co-channel tests*

The following type of receivers were tested:

- ACSB: For 3K00 R3E emission with 4:1 expander and 12 dB/octave de-emphasis
- 25 kHz FM: For 16K0 F3E emission 6 dB/octave de-emphasis
- 12.5 kHz FM: For 11K0 F3E emission 6 dB/octave de-emphasis
- AM: For 6K00 A3E emission

The reference sensitivity of each receiver was measured in accordance with IEC Publication 489 and adjusted for equal noise figure of 10 dB. The reference sensitivity of the four receivers are as follows:

	dB (μV) at receiver input
ACSB	– 6.0
25 kHz FM	–12.5
12.5 kHz FM	–15.0
AM	– 3.0

The range of the SINAD performance between –20 dB (μV) and 10 dB μV signal input to each receiver is given in Fig. 4. These results do not necessarily reflect system performance under other than constant tone modulation.

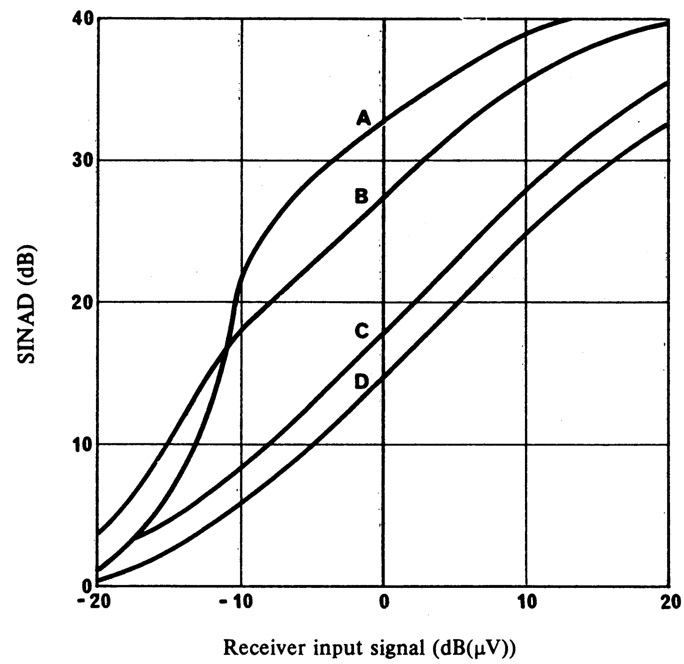

FIGURE 4 – *Receiver sensitivity*

A: FM – 25 kHz
B: FM – 12.5 kHz
C: ACSB
D: AM

Co-channel interference tests using voice modulation were performed on three of the four receivers.

The protection is based on the ratio (dB) of the mean wanted signal to the mean interfering signal required to prevent an impairment of speech quality. The wanted signal was modulated with extracts from an English language news broadcast and the interfering signal was modulated by a female speaker reading Harvard sentences.

Each signal was passed through a separate multipath simulator and adjusted in level as described above. During the tests the wanted signal mean value was set at a fixed level, and the listener was instructed to set the interfering signal to the highest level and yet not impair speech quality. The results, shown in Fig. 5, were averaged for a team of 5 persons.

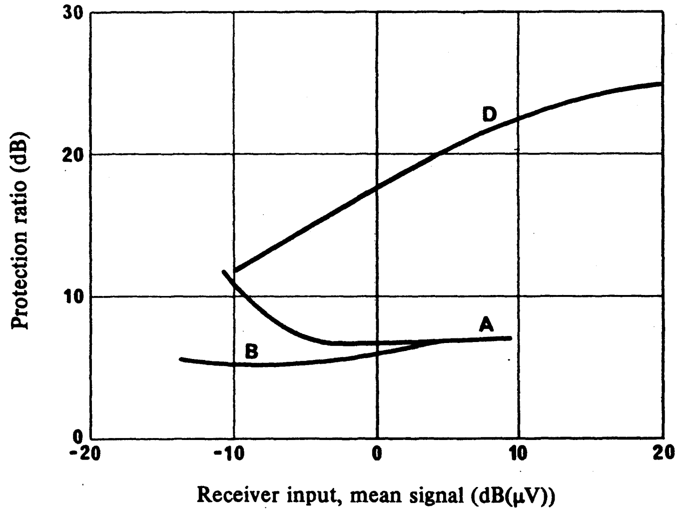

FIGURE 5 – *Co-channel protection ratio voice modulation, Rayleigh fading*

A: FM – 25 kHz
B: FM – 12.5 kHz
C*: ACSB
D: AM

* Complete test results for the ACSB receiver are not yet available, but will be added at a later date.

4.3 *Wanted signal voice tests (ACSB receiver)*

The attached Fig. 6 illustrates how pre-emphasis, de-emphasis and amplitude companding improves the signal-to-noise ratio of certain types of syllables as compared to an SSB transmitted and received signal without the use of audio processing.

Meaningful measurements of ACSB radio performance have been difficult to obtain using standard objective test procedures because these procedures may not account for the use of voice processing. Subjective tests (diagnostic rhyme test) have indicated that ACSB performance is better than implied by objective tests. Such conclusions must be interpreted with care.

The experiments seem promising. Development and field testing continue in the United States.

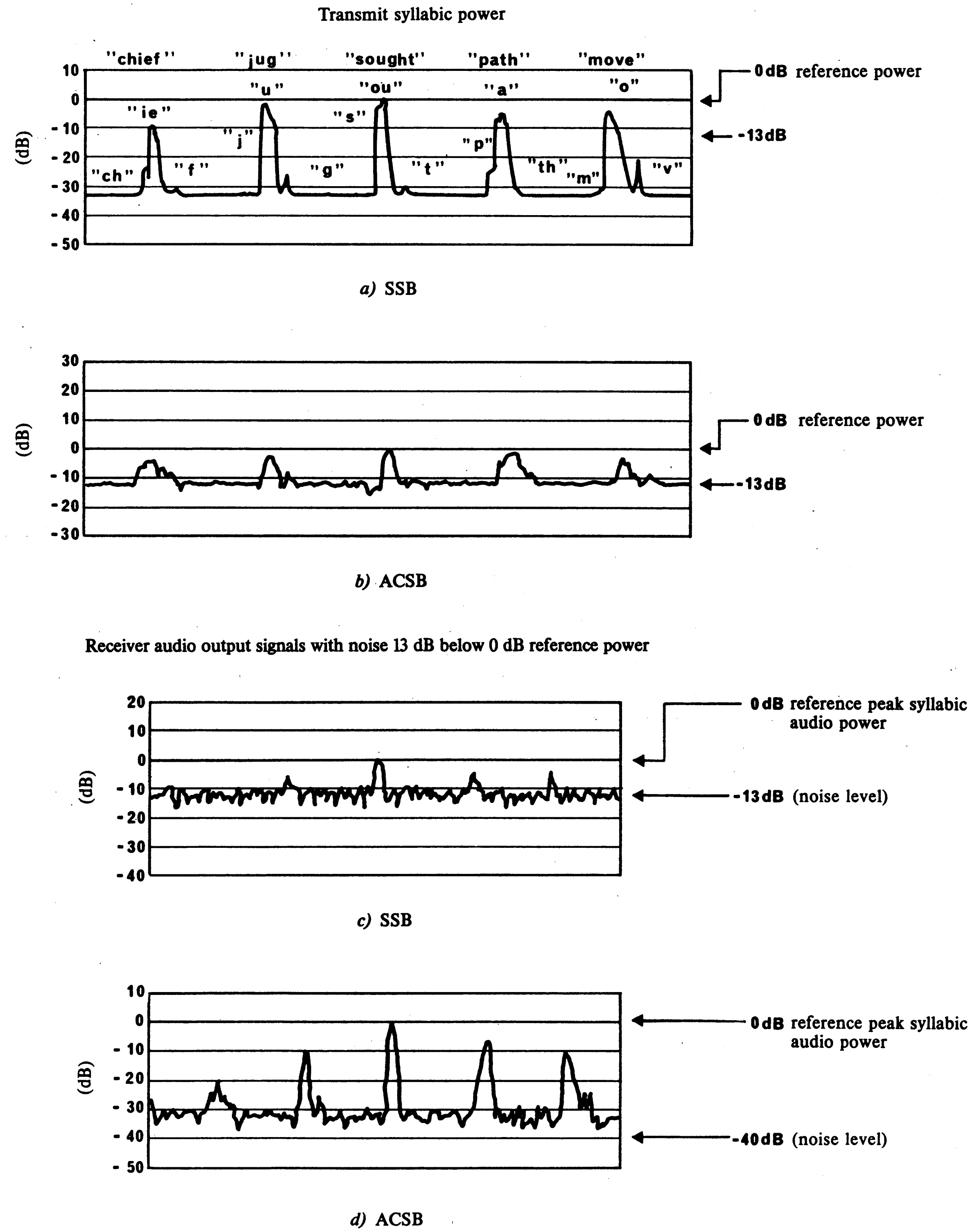

FIGURE 6 – *Performance of SSB and ACSB radios on English language test words in the absence of multipath fading*

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