REPORT 1059-1

CHARACTERISTICS OF SINGLE-SIDEBAND SYSTEMS IN HF BROADCASTING

(Question 44/10)

(1986-1990)

1. Introduction

This Report has been developed in recognition that consideration is being given to the progressive introduction of single-sideband broadcasting systems into the bands now allocated to the Broadcasting Service at HF. Introduction of this form of broadcasting can be accomplished with greater technical harmony if there is sufficient guidance concerning the technical parameters involved. The following considerations will be concentrated on single-sideband amplitude modulation with synchronous demodulation. With respect to a necessary transition period from DSB to SSB, some consideration must also be given to the reception of SSB signals with reduced carrier by receivers with envelope detection. At the end of the transition, all of the advantages of SSB transmissions could then be realized, as follows:

- a more efficient utilization of the frequency spectrum and a reduction of interference;
- the capability of improving the required protection ratio between adjacent channels in the case of a sufficient carrier reduction;
- the capability of improving the quality of reception, in particular under poor propagation conditions (selective fading), with SSB receivers.

The modulation technique considered most suitable for the achievement of bandwidth saving is some form of SSB system. WARC-79 Recommendation 501 and No. 302 of the Radio Regulations suggest the use of SSB emissions to the maximum possible extent in AM systems. There are two types of such systems, namely single-sideband (SSB) and compatible single-sideband (CSSB).

The CSSB system is not suitable for use in amplitude-modulated sound broadcasting, principally because of its increased distortion; furthermore, a greater radiofrequency bandwidth is needed and adequate suppression of out-of-band emissions is likely to be difficult at HF.

In the event of the introduction of single-sideband amplitude modulation broadcasting, it would seem desirable to use the definitions existing in Recommendation 326.

According to this Recommendation, the carrier component is defined in relation to the peak envelope power P_p of a radio transmitter, by the acceptable intermodulation level D_n.

For single-sideband broadcasting transmitters, the acceptable intermodulation level D_n determines the non-linear distortion (quality), and the out-of-band radiation (adjacent channel interference).

In single-sideband reduced carrier systems, the precision of the locally re-inserted carrier is important for the reception quality.

The system parameters for a future SSB-system for sound broadcasting in band 7 (HF) must be chosen in such a way that the different requirements of the transition period (reception of SSB-signals with receivers using envelope detection) as well as those of the period thereafter, when only receivers with synchronous demodulation will be used, are taken into account [CCIR, 1978-82a].

The system specification of SSB is presented in Recommendation 640.

2. Fundamental technical characteristics of single-sideband broadcasting systems

2.1 Nature of single-sideband (SSB) modulation

References to single-sideband (SSB) frequently are made considering the transmitted signal to be amplitude modulated (AM). However, in fact, the transmitted SSB-signal is a composite of both amplitude and phase modulation. Both components of modulation contain the same information, but differ in phase by 90°. Both the amplitude and the phase information can be recovered independently using a synchronous detector that is phase-locked to the incoming carrier. If the phase of the reinserted carrier is the same as that of the incoming carrier, then the amplitude modulation is recovered. On the other hand, if the phase of the reinserted carrier is shifted by 90° relative to the incoming carrier then the phase information is recovered.

For reasons mentioned above, it can be concluded that:

- additional services (data, etc.) using additional phase modulation are difficult to implement in an SSB-signal;

- an SSB-transmission is less affected by selective fading, compared to a DSB transmission. This improved performance results from the constant level of the regenerated carrier, but also from the fact that the synchronous detector's performance is not degraded with shifts in phase of the incoming carrier (during periods of selective fading) because either or both phase and amplitude components of the SSB signal are used in detection.

2.2 Peak envelope power (P_p)

The nominal power of an SSB transmitter is designated by its peak envelope power Pp. This Pp is specified as the mean power produced during peak conditions employing full modulation. Therefore it is difficult to measure utilizing a thermic power meter connected with a dummy load unless the input signal is sinusoidal.

2.3 *Carrier and sideband power relationships in DSB and SSB systems**

The sideband power P_s of a transmitter, depends on the peak envelope power P_p and the chosen carrier reduction, *a*.

For a single-sideband broadcasting transmitter, the most appropriate value of *a* will depend mainly on the carrier recovery requirements in a low cost single-sideband receiver. To be able to produce the reference carrier for the synchronous demodulator at an acceptable cost, carrier reduction must be restricted to between about 6 and 12 dB, at the transmitter.

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* According to the Radio Regulations (see also Recommendation 326) the following power terms should be used:
- peak envelope power (*PX*);
- means power (*PY*)
- carrier power (*PZ*)

To enable uniform presentation in this Report, which includes a large number of other power and voltage terms the following designations differing from those recommended by the Radio Regulations and Recommendation 326 are used:

$PX = P_p$

$PY = P_m$

$PZ = P_c$

Figure 1 shows the relation between the sideband power P_s and the carrier reduction, *a*, for a given peak envelope power of the transmitter. The indication (1) denotes the values for modulation by a sinusoidal signal and (2) denotes the values for noise or programme modulation. The values of the voltages *U* and the powers *P* are given as percentages related to their peak envelope values. With programme modulation and a carrier suppression of more than 30 dB, the sideband power P_s (2) will be about 10% of P_p. A transmitter operating with a carrier reduction of 6 dB can, when modulated with a programme signal, only radiate a sideband power P_s (2) of about 2.5% of its nominal peak envelope power.

For the calculation of P_s (2) it has been assumed that the ratio of the mean power to the peak envelope power is 0.1 (see Recommendation 326, Table I).

2.4 *Equivalent sideband power*

To replace a DSB transmitter (carrier power P_C) for sound broadcasting in band 7 (HF) with an equivalent SSB transmitter, the sideband power of the SSB transmitter must be double the value of the sum of both sideband powers of a DSB transmitter. This is justified at least during the transition period, when SSB emissions will also have to be received by DSB receivers having a bandwidth equal to $2B_V$, twice as large as necessary for reception of the SSB emission, and also because the coverage of the target area must be the same.

After the transition period, when only receivers with synchronous demodulation and half the bandwidth of a DSB receiver will be used, theoretically the sideband-power of all SSB transmitters could be reduced to one half of the original value. The signal-to-noise ratio at the output of the receiver, however, would be unchanged only if the spectrum causing the co-channel and adjacent-channel interference within the receiver passband had a uniform power density. Because of the presence of a carrier and the unequal distribution of power in the spectrum of sound-broadcasting emissions, this condition is not met in practice [Gröschel, 1978].

Thus, for the equivalent sideband power P_s of the future SSB transmitters in HF sound broadcasting the following expression might be more suitable:

$$P_s\,(\text{SSB}) \approx (1 \text{ to } 2) \times P_s\,(\text{DSB})$$

A factor nearer to 2 might be realistic.

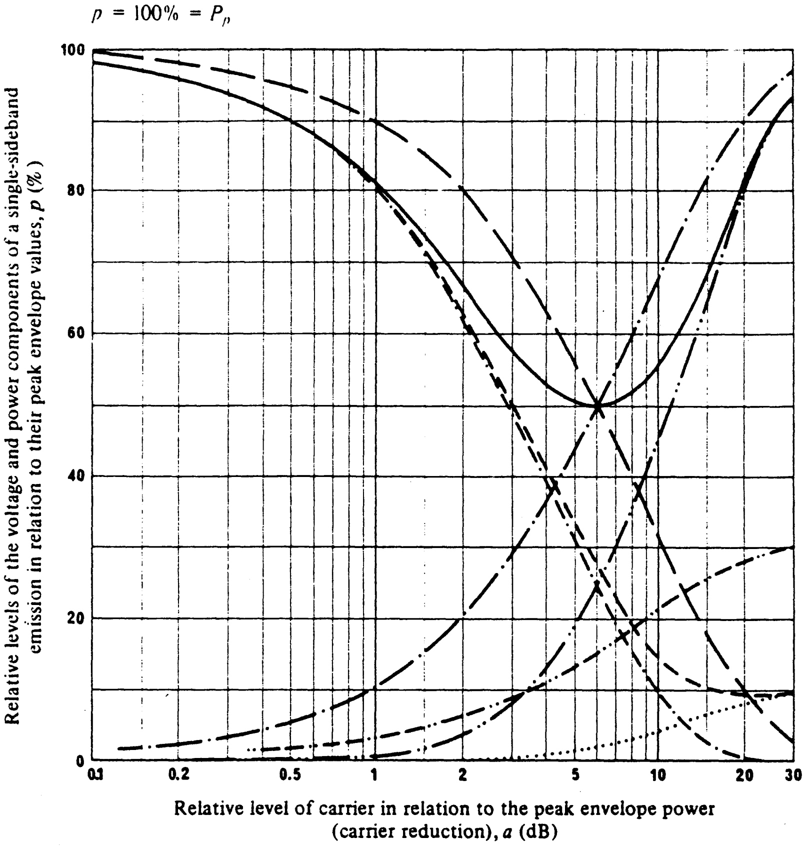

FIGURE 1

	P_p	: peak envelope power of the transmitter (defined by means of the acceptable intermodulation level D_n)
— — —	U_c	: carrier voltage (r.m.s. value)
—·—·—	U_s (1)	: sideband signal voltage for modulation with a sinusoidal signal (r.m.s. value)
··—·· —···	U_s (2)	: sideband signal voltage for programme or noise modulation (r.m.s. value)
-·--·--·	P_c	: carrier power
··—··—··	P_s (1)	: sideband power for modulation by a sinusoidal signal
··············	P_s (2)	: sideband power for programme or noise modulation
————	P_m (1)	: transmitter mean power for modulation by a sinusoidal signal
- - - - -	P_m (2)	: transmitter mean power for programme or noise modulation

Some more details on the necessary peak-envelope power of future SSB transmitters replacing present DSB transmitters in HF sound broadcasting are given in Fig. 2. During the transition period the special receiving conditions will necessitate a peak-envelope power of the transmitter about 4 times higher than will be needed after the transition period [CCIR, 1978-82a].

The WARC HFBC-1987 defined equivalent sideband power in the following manner:

> When the carrier reduction relative to peak envelope power is 6 dB, an equivalent SSB emission is one giving the same audio-frequency signal-to-noise ratio at the receiver output as the corresponding DSB emission, when it is received by a DSB receiver with envelope detection. This is achieved when the sideband power of the SSB emission is 3 dB larger than the total sideband power of the DSB emission. (The peak envelope power of the equivalent SSB emission and the carrier power are the same as that of the DSB emission.)

2.5 *Comparison of power consumption of equivalent DSB and SSB transmitters*

One of the aims of the introduction of SSB modulation in sound broadcasting in the HF bands, apart from a better utilization of the spectrum, is a considerable reduction of transmitter power consumption. Optimum saving of power can eventually be achieved when SSB receivers (having only half the bandwidth of DSB receivers) are in common use, thus permitting a change in carrier level from −6 dB to −12 dB.

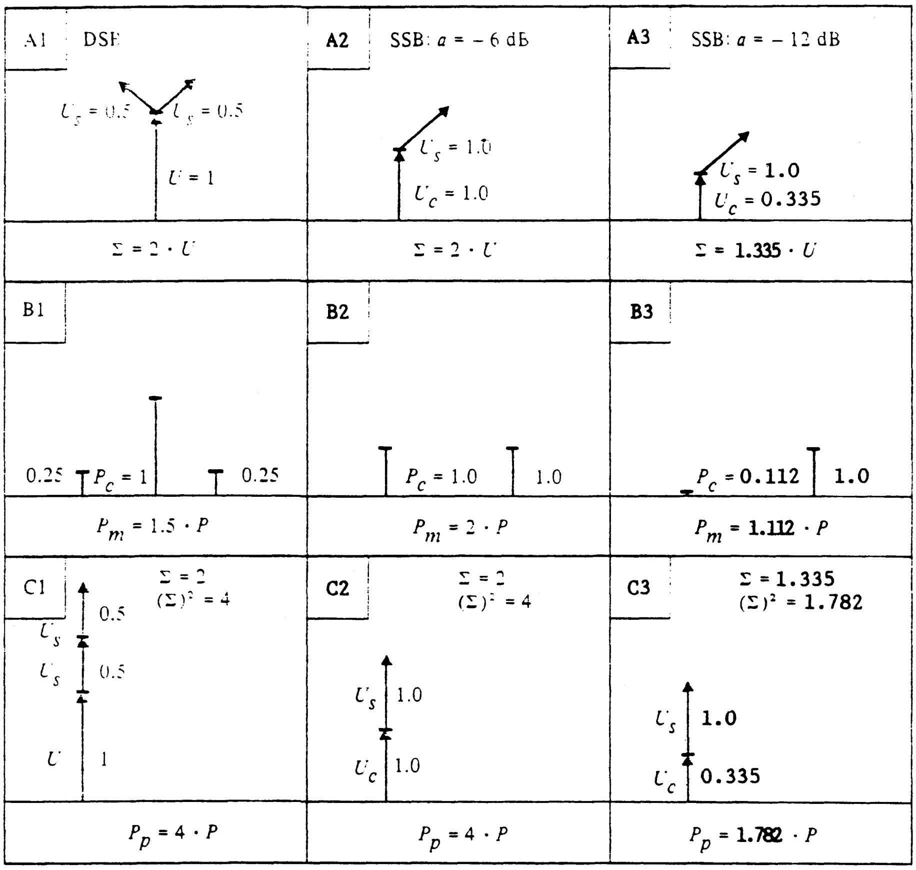

FIGURE 2 – *Relation between carrier- and sideband-levels and powers with DSB and SSB transmission depending on carrier reduction*

(For comparison, carrier power level of the DSB transmitter was assumed to be equal to 1. Full modulation with a single sinusoidal tone.) $P_s(SSB) = 2 \times P_s(DSB)$

A1...A3: level of spectral-components (at the output of the transmitter)
B1...B3: average output power of the transmitter
C1...C3: peak-envelope power at the output of the transmitter
Index 1: DSB signal
Index 2: SSB signal, carrier reduction: − 6 dB (class of emission H3E)
Index 3: SSB signal, carrier reduction: − 12 dB (class of emission R3E)
U: carrier level of the DSB transmitter
U_s: level of sidebands
U_c: carrier level of the SSB transmitter
P: carrier power of the DSB transmitter
P_c: carrier power of the SSB transmitter
P_m: average power
P_p: peak envelope power

On the assumption of programme modulation with 40% effective modulation factor, a value which is reached if the modulation signal is substantially compressed, representative values for the power consumption of transmitters for DSB and SSB modulation with equivalent sideband power have been calculated and are summarised in Tables I and II.

This comparison is based on an overall efficiency factor of 60% for DSB transmitters and of 38% or 60% for SSB transmitters. These values have been derived from existing SSB transmitters. In this case an SSB transmitter with e.g. 12 dB carrier reduction and with an equivalent sideband power (i.e. equal to the DSB sideband power) will have respectively about 40% or 25% of the total power consumption of a DSB transmitter (Figure 2 conditions apply).

During the transition period when reception with DSB receivers must be assumed, a carrier reduction of 6 dB is recommended. In this case an SSB transmitter with double sideband power has respectively about 70% or 7% more power consumption than a DSB transmitter (see Table II).

TABLE I – *Output power ratios*

Carrier reduction	Sinusoidal modulation m_{eff} = 100%	Programme modulation m_{eff} = 40%
6 dB	2.0	1.16
12 dB	1.11	0.27

Average output power of an SSB transmitter relative to DSB carrier power. (m = 100%, conditions as in Figure 2.)

TABLE II – *Power consumption ratio*

Carrier reduction	Sinusoidal modulation m_{eff} = 100%		Programme modulation m_{eff} = 40%	
	SSB efficiency		SSB efficiency	
	38%	60%	38%	60%
6 dB	2.11	1.33	1.70	1.07
12 dB	1.17	0.74	0.40	0.25

Power consumption of an SSB transmitter relative to that of a DSB transmitter. DSB efficiency 60%. (m = 100%, conditions as in Figure 2.)

2.6 *Carrier reduction*

The amount of carrier reduction of an SSB signal determines the additional non-linear distortion that occurs when this signal is demodulated by envelope detection in a conventional DSB receiver. This additional distortion depends both on the carrier reduction *a*, and on the modulation depth. Because of this additional distortion to be expected during the transition period, the carrier reduction should then not be more than −6 dB relative to peak envelope power (class of emission H3E). This conclusion was confirmed by a compatibility reception field test carried out at a distance of 2000 km from a transmitting site in Japan. Subjective assessment of the impairment by distortion of the received SSB programmes was made with reference to the received DSB programmes using the five-grade impairment scale of Recommendation 562. The results are shown in Fig. 3.

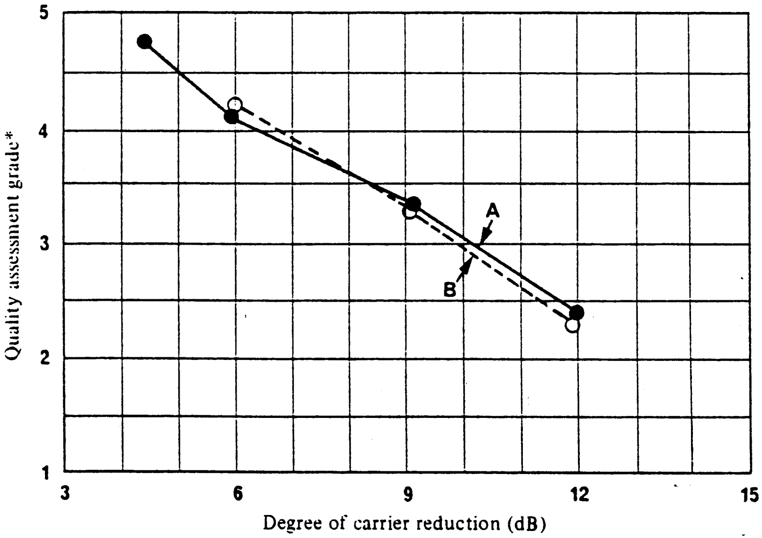

FIGURE 3 – *Assessment in the reception test using conventional DSB receivers for an SSB system*

A: speech

B: light music

* See Table I of Recommendation 562.

At a carrier reduction of 6 dB, the average impairment of reproduced SSB signals with reference to the DSB signals was slightly higher than grade 4 [CCIR, 1982-86a].

In this case, intermodulation distortion is the prevailing cause. The amount of distortion reached with full modulation is quite large. In practice, with average modulation factors 35 to 45%, this distortion will be smaller.

2.7 *Acceptable intermodulation level in SSB transmitters*

The value for the acceptable intermodulation attenuation of D_N will largely depend on the required quality of the transmission with respect to non-linear distortion. Theoretical considerations based on a mathematical model for the calculation of adjacent-channel interference in SSB systems [Gröschel, 1978] show that with respect to adjacent-channel interference the intermodulation attenuation D_N of SSB broadcasting transmitters need not be better than 20 to 25 dB. In the future SSB system the acceptable intermodulation level therefore must be determined according to the wanted quality of the received signal. A range of D_N = 26 dB (≈ 6.5% harmonic distortion) to D_N = 35 dB (≈ 2.3% harmonic distortion) seems to be suitable for future SSB sound-broadcasting transmitters depending on the type of the prevailing programme (speech, music).

2.8 Demodulation

AM-based signals can be detected by two different methods; with conventional envelope detection or by mixing the input signal with an internally generated injection carrier. Envelope detection uses peak rectification which accurately follows the envelope of the modulated waveform.

In the mixing method the frequency of the internally inserted carrier must be equal to that of the carrier of the incoming SSB or DSB signal in which case the RF sideband information will be transferred into the audio range. Demodulation by mixing is normally referred to as product demodulation in a case where the frequency of the inserted carrier is nearly the same as that of the incoming carrier. In the case of these carriers being phase locked to each other, demodulation is referred to as synchronous or coherent demodulation.

DSB (A3E) or DSB with changing carrier level can be detected by envelope or synchronous demodulation.

Product demodulation is possible only with a SSB receiver, where the other sideband and carrier are cancelled or suppressed by filtering before demodulation.

SSB (H3E, R3E) signals can be demodulated by product or synchronous demodulation. SSB H3E (-6 dB) allows for envelope detection. The audio quality achieved is, however, marginal and therefore this method should be considered only during the transition period with old receivers.

Synchronous demodulation has the following advantages compared with product demodulation:

- locking function leads to less stringent requirements of the frequency stability in receiver oscillators;
- proper tuning is more easily accomplished by unskilled operators;
- allows both A3E and SSB detection;
- less sensitive to marginally adjusted transmitters (AM-PM conversion).

Because of the above advantages, synchronous demodulation should be recommended for new receiver designs as a standard demodulator and the system parameters should be based on this concept.

2.9 The influence of selective fading on demodulation systems

Broadcasting in the HF bands is based almost exclusively on sky-wave coverage. Because of selective fading, the reception of sky-wave signals with double sideband (DSB) modulation and envelope (linear) detection at the receiver, suffers severely from non-linear distortion. This degradation may largely be avoided when synchronous or product demodulation (see also 2.1 and 2.8) is used.

Test transmissions in band 6 (MF) using sinusoidal modulation (800 Hz) have been analyzed to determine the non-linear distortion occurring with envelope detection (A3E) and with synchronous detection (R3E).

The results are shown in Fig. 4. They show clearly that the non-linear distortion caused by effects of ionospheric propagation, such as selective fading, will be greatly reduced by the use of product demodulation in the receiver. The same improvement would be possible, even with class A3E emissions, if synchronous demodulation were used. No improvement will be achieved in compatible single-sideband (CSSB) emissions [CCIR, 1978-82b].

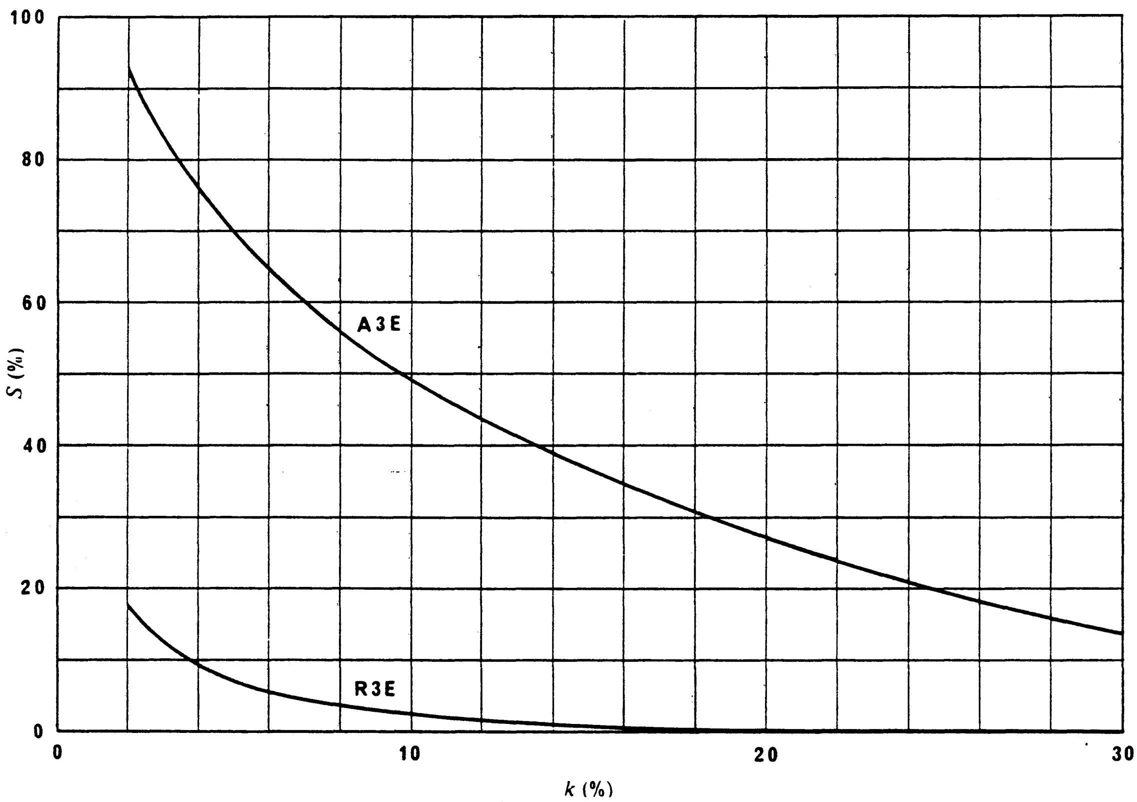

FIGURE 4 - *Cumulative probability (S) of the non-linear distortion (k) averaged over the whole measuring period. Comparison between A3E (envelope) and R3E (synchronous) detection*

2.10 *The precision of the locally re-inserted carrier in SSB receiver*

In single-sideband reduced carrier systems, the precision of the locally re-inserted carrier is important for the reception quality. Comprehensive subjective listening tests have shown [Thiessen, 1973] that the effects of non-linear distortion and inaccuracy of the re-inserted carrier superimpose and can be described by:

$$\Delta Q = (k_2/10\%)^2 + (k_3/6\%)^2 + (\Delta f/12\ \text{Hz})^2 \qquad (1)$$

where

ΔQ: impairment of quality on the basis of a 6-grade scale,

k_2, k_3 : distortion factors of the 2nd and 3rd harmonics,

Δf: frequency error, (Hz), of the re-inserted carrier.

A maximum value ΔQ_{max} = 0.25 appeared to be just tolerable. Values of k_2 = 2.9%, k_3 = 1.7% and Δf = 3.5 Hz would be jointly admissible if the disturbing effects are assumed to be evenly distributed.

2.11 *Further factors to be taken into account*

2.11.1 The suppression of the same sideband (upper or lower) would have to be adopted within each broadcasting band. The present state of research indicates that, in the technology of intermediate-frequency and audio-frequency filters, suppression of the lower sideband is preferable. It is therefore suggested that for broadcasting the upper sideband should contain the full audio-frequency modulation.

2.11.2 The degree of carrier reduction should not exceed 12 dB. This was confirmed from the performance point of view of an SSB receiver by a reception field test carried out in Japan over a distance of 2000 km from the transmitting site, using experimental SSB receivers developed by incorporating synchronous detectors in conventional commercially available HF receivers.

Figure 5 shows the subjective assessment of the quality of the reproduced sound with the experimental SSB receivers using the seven-grade impairment scale of Recommendation 562, with reference to reception by DSB receivers with envelope detection.

The reception quality of SSB signals was worse than that of the DSB signal in cases where carrier reduction exceeded 12 dB because much distortion was caused within the SSB receiver due to difficulty in proper carrier extraction.

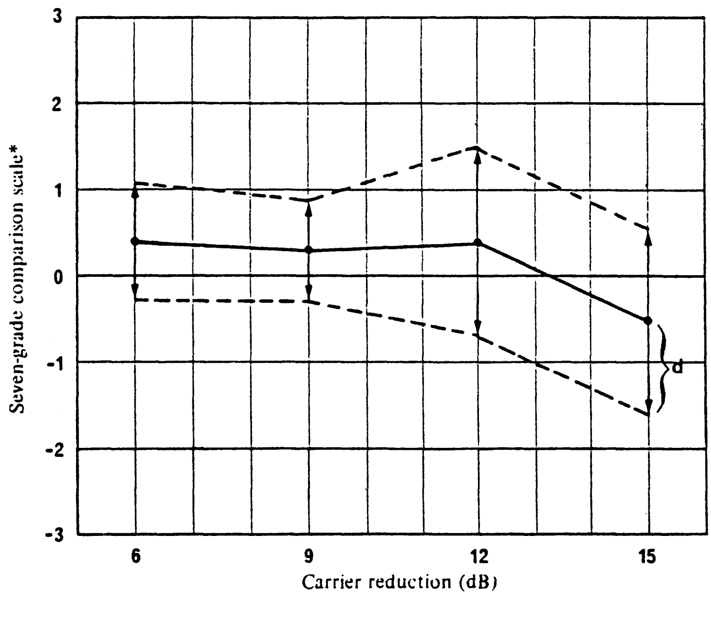

FIGURE 5 – *Assessment in the reception test using the experimental SSB broadcast receiver*

d: standard deviation

* See Table II of Recommendation 562.

2.11.3 The audio-bandwidth transmitted should be related to the carrier spacing. (The precise bandwidth cannot be given, the fraction of the channel spacing might well approach unity.)

3. **Transition period**

1987	31.12.1990	2000	31.12.2015
Start of transition period SSB: 6 dB carrier reduction	New transmitters should be capable of SSB Low cost receiver should be equipped with synchronous demodulation Review of the final date of cessation of DSB	Latest review of the final date for introducing SSB	End of transition, SSB with 12 dB carrier reduction

FIGURE 6 – *Organization of the transition period from DSB to SSB*

During the transition period, which is shown in Figure 6, SSB transmissions will be mainly received by conventional DSB receivers using envelope detection. In order to avoid undue deterioration of reception quality, it will be necessary to operate SSB transmitters with a carrier reduction not exceeding 6 dB. This, on the other hand, will have some consequences on the necessary output power of SSB transmitters if the same loudness level is required. To obtain with a conventional DSB receiver using envelope detection the same loudness level with both SSB and DSB, the sideband power of the SSB emission has to be 3 dB larger than the total sideband power of the DSB emission. Alternatively, if the sideband power of the SSB emission cannot be increased, one has to accept some reduction of the coverage area. One way to reduce this difficulty is to group together the SSB transmissions.

The possibility of conversion of DSB transmitters to the SSB mode is described in § 5.3.

3.1 *Evaluation of compatibility aspects of a proposed SSB system*

One of the major aspects to the implementation of SSB broadcasting in the HF bands is the fact that suitable SSB receivers will not yet be at the disposal of most listeners. Therefore, during the transition period, SSB transmissions should be receivable with adequate quality on conventional receivers using envelope detection. Among other parameters, e.g. audio-frequency bandwidth and compression, the dominant parameters controlling the compatibility are the amount of carrier reduction and the sideband powers. In addition to the transmission characteristics, the reception quality depends on the type of receiver and its tuning, as well as on propagation conditions such as, for example, type and intensity of fading.

3.2 *SSB receivers*

The WARC HFBC-87 decided that the immediate introduction of SSB is to be encouraged and also decided the procedure of transition from DSB to SSB (Resolution No. 517 HFBC-87). This transition has the following consequences with respect to receiver development.

- Conventional receivers employing only envelope detection should no longer be produced.
- New receivers to be used during the transition period, and afterwards, should be equipped with a synchronous demodulator, and use for carrier acquisition, a method whereby the carrier is regenerated by means of a suitable control loop which phase locks the receiver to the incoming carrier. Such receivers are expected to work equally well with conventional DSB transmissions and with SSB transmissions having a carrier reduced to 6 or 12 dB relative to peak envelope power.

There are essentially three reasons for recommending such synchronous demodulators:

- They permit the introduction of spectrum-saving SSB techniques without impairment of tuning ease.

- They permit the reception of both DSB transmissions and SSB transmissions having carrier reductions of 6 dB and 12 dB, respectively.
- They generate less distortion in the case of selective fading, which occurs frequently in present-day receivers with envelope detection.

In order to attain the best reception quality achievable with the new SSB system, the new SSB receivers should have an AF bandwidth of about 4 kHz and a much improved selectivity, with a slope of attenuation of the order of 35 dB/kHz. They can be readily manufactured using modern ceramic IF filters. It is also possible to have somewhat less selectivity, but then only at the expense of audio bandwidth.

3.3 *RF protection ratios in the transition period from DSB to SSB*

In the following discussion, it is assumed that the transmitter passband has a width of 4.5 kHz (see Annex I to Recommendation 639), that its passband is limited with a slope of attenuation of 40 dB/kHz, that its modulation signal is subject to a high degree of compression (see Recommendation 560) and that in the case of an SSB emission the carrier reduction is 6 dB, and the upper sideband is used.

The high audio compression used would result in a short-term r.m.s. modulation factor of about 50%.

3.3.1 *RF co-channel protection ratios in the transition period*

Due to the need to increase the radiated sideband power by 3 dB in the case of equivalent SSB emissions, there is a consequent need to make an allowance of the same 3 dB in the co-channel protection ratio for the case of a wanted DSB signal interfered with by an SSB signal, if the same quality of reception is to be maintained. Practical tests carried out in Japan have confirmed that an increase is necessary. One way to reduce this difficulty is to group together the SSB transmissions.

3.3.2 *Relative RF protection ratios in the transition period*

- It is first assumed that a wanted DSB signal is received by a conventional DSB receiver with envelope detection which is intefered with by an SSB emission with equivalent sideband power.

  The resultant RF protection ratio of the wanted DSB signal in the lower adjacent channel at for example $\Delta f = -5$ kHz would be impaired by about 1 dB, while under the same conditions reception of the wanted DSB signal in the upper adjacent channel at $\Delta f = +5$ kHz would be impaired by about 4 dB in comparison to the present RF protection ratios, as specified in Recommendation 560.

  If the tuning of the receiver is offset slightly, however, equal impairments of about 2.5 dB on both sides can be obtained.
- For the case of a wanted SSB signal interfered with by a DSB signal, the results obtained practically coincide with the values specified in Recommendation 560 (curve D). In this case reception of the wanted SSB signal will not be degraded during the transition period.
- In the case of a wanted SSB signal interfered with by an SSB signal, the results are the same as for a wanted DSB signal interfered with by an SSB signal, because in both cases the receiver is the same and the sideband powers are equivalent. In this case, therefore, the same impairment will occur as with a DSB signal being interfered with by an SSB signal.

The results described above show that during any transition period the protection ratios at $\Delta f = \pm 5$ kHz are impaired by about 2.5 dB in the case where SSB interferes with either SSB or DSB. When SSB is interfered with by DSB, it will need the same protection ratios as are valid now for DSB interfered with by DSB.

It can be expected that new SSB receivers which are suitable also for the reception of DSB signals will become available during the transition period, and that reception of DSB signals will be improved by their advantages (such as a reduction in harmonic distortion due to selective fading and better selectivity with enlarged AF bandwidth).

3.4 *RF protection ratios after the transition period for SSB operation with reduced carrier*

According to the proposed technical parameters for a future SSB system, a carrier reduction of 12 dB is assumed while all other assumptions made in § 3.3 for the transmitters are maintained. Both wanted and interfering signals are SSB signals.

Figure 7 shows a set of RF protection ratios calculated with the above assumptions for different SSB receivers which have different bandwidths and slopes of attenuation.

In Fig. 7, the relative RF protection ratios, A_{rel}, are given with respect to the frequency difference Δf between the wanted carrier f_w and the interfering carrier f_i:

$$\Delta f = f_w - f_i$$

Thus, negative Δf describes interference from the upper adjacent channel.

Curve ① is valid for an SSB receiver whose frequency response corresponds to that of the EBU reference receiver (B_R = 4 kHz) and the now obligatory tuning offset leads to an effective receiver AF passband of 4 kHz. Reception in the lower adjacent channel at $\Delta f = -5$ kHz is impaired by about 7 dB while the improvement in the upper adjacent channel would be almost 17 dB.

If a receiver with the skirt selectivity of the EBU reference receiver is to be used after the transition period, this receiver should not lead to any reduction in the relative RF protection ratio in the lower adjacent channel beyond the value now reached, according to CCIR Recommendation 560, and its AF bandwidth could be increased to 3 kHz (Fig. 7, curve ②), which would mean 50% more AF bandwidth than at present (2 kHz).

It would, however, be much more desirable to take advantage of the necessary introduction of SSB receivers and improve their selectivity. A considerable improvement of the relative protection ratio could be reached by using a ceramic IF filter with a skirt selectivity of about 35 dB/kHz. The corresponding protection ratios for receiver passbands of 4.4 kHz, 3.7 kHz and 3.0 kHz are given in Fig. 7 by the curves ③, ④ and ⑤, respectively. With 4.4 kHz bandwidth, protection would be improved by about 7 dB in the lower adjacent channel and by more than 40 dB in the upper adjacent channel. As can be seen, even a receiver bandwidth of 3.8 kHz would be achievable with at least 27 dB protection ratios in the lower and the upper adjacent channels. This example clearly shows the great advantage of an improvement of the skirt selectivity of the receiver.

3.5 *Conclusions*

Table III summarizes the effects of the introduction of SSB emissions with 6 dB carrier reduction during the transition period and with 12 dB carrier reduction in the final situation. These effects relate to the use of receivers with the EBU reference receiver frequency response during the transition period and an SSB receiver equipped with a ceramic or mechanical IF filter having a bandwidth of about 4 kHz and a slope of attenuation of 35 dB/kHz.

If an existing DSB transmitter has been converted to SSB operation, the achievable sideband power will be lower than the equivalent sideband power. This will result in an AF signal-to-interference ratio about 3 dB lower in comparison to DSB.

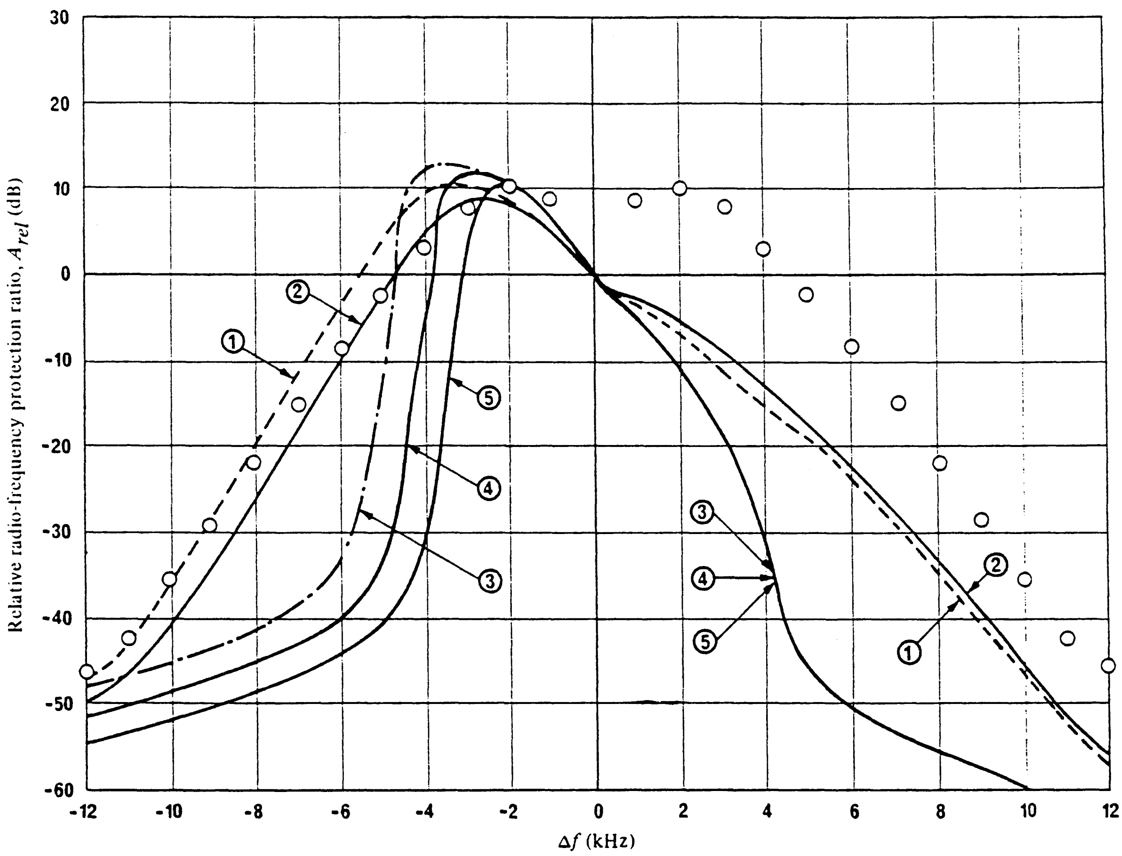

FIGURE 7 – *RF protection ratios after the transition period*

Wanted signal: SSB; interfering signal: SSB

Receiver:

- - - - ①	EBU	B_R = 4 kHz;	slope 8 dB/kHz
——— ②	EBU*	B_R = 3 kHz;	slope 8 dB/kHz
— - — ③	ceramic filter	B_R = 4.4 kHz;	slope 35 dB/kHz
——— ④	ceramic filter	B_R = 3.7 kHz;	slope 35 dB/kHz
——— ⑤	ceramic filter	B_R = 3.0 kHz;	slope 35 dB/kHz
O O O	values of CCIR Recommendation 560, curve D		

$\Delta f = f_w - f_i$ B_R: receiver RF bandwidth

f_i always coincides with $\Delta f = 0$

* Offset by 1 kHz.

TABLE III – *Summary of the effects of the introduction of SSB transmissions with 6 dB carrier reduction during the transition period, and with 12 dB carrier reduction afterwards*

	Transition system		Final system
Transmitter carrier reduction	6 dB		12 dB
Total transmitter power	With constant carrier: more power With floating carrier: less power (comparable to final system)		Less power
Transmitter capital cost	More than for conventional DSB		Less than DSB
Transmitter operating cost	More than for conventional DSB		Less than DSB
Transmitted bandwidth	DSB: ± 4.5 kHz/SSB: +4.5 kHz		SSB: +4.5 kHz
Receiver selectivity characteristics	DSB: EBU	SSB: ceramic filter	SSB: ceramic filter
Receiver AF bandwidth	2 kHz	3.7-4 kHz	3.7-4 kHz
Receiver RF bandwidth	4 kHz	3.7-4 kHz	3.7-4 kHz
Slope of IF filter	8 dB/kHz	35 dB/kHz	35 dB/kHz
Receiver costs	No change	Initially more expensive	Less expensive than during transition
Channel spacing	10 kHz		5 kHz
Spectrum usage	No saving, slightly less efficient		Up to twice the number of emissions
Relative adjacent-channel protection ratio	Worse by 2.5 dB	Better	Better approx. 25 dB
Quality	Slightly worse	Better	Better

4. Relative values of RF protection ratio

The WARC HFBC-87 considered using the following relative values of RF protection ratio.

TABLE IV

Relative RF protection ratio values with reference to the co-channel RF protection ratio for DSB wanted and unwanted signals (dB)[1] for use in the HF bands allocated exclusively to the broadcasting service

	Wanted signal	Unwanted signal	Carrier frequency separation f unwanted − f wanted, Δf (kHz)								
			−20	−15	−10	−5	0	+5	+10	+15	+20
1	DSB	SSB (6 dB carrier reduction relative to P_p)	−51	−46	−32	+1	3	−2	−32	−46	−51
2	SSB (6 dB carrier reduction relative to P_p)	DSB	−54	−49	−35	−3	0	−3	−35	−49	−54
3	SSB (6 dB carrier reduction relative to P_p)	SSB (6 dB carrier reduction relative to P_p)	−51	−46	−32	+1	0	−2	−32	−46	−51
4	SSB (12 dB carrier reduction relative to P_p)	SSB (12 dB carrier reduction relative to P_p)	−57	−57	−57	−45	0	−20	−47	−52	−57

[1] Frequency separations Δf less than −20 kHz, as well as Δf greater than 20 kHz, need not be considered.

The values of relative RF protection ratio given in Table IV should be used whenever SSB emissions in conformity with the specification in Appendix 45 to the Radio Regulations are involved in the use of the HF bands allocated exclusively to the broadcasting service.

The values given refer to the case of co-channel DSB wanted and unwanted signals for the same reception quality.

For the reception of DSB and SSB (6 dB carrier reduction relative to peak envelope power) wanted signals, a conventional DSB receiver with envelope detection designed for a channel spacing of 10 kHz is assumed.

For the reception of a SSB wanted signal (12 dB carrier reduction relative to peak envelope power), the reference receiver as specified in Appendix 45, Part B, section 3, to the Radio Regulations is assumed.

SSB signals with 6 dB carrier reduction relative to peak envelope power assume equivalent sideband power as specified in Appendix 45, Part B, section 1.2, to the Radio Regulations.

The figures for case 2 in Table IV relate to a situation where the centre frequency of the intermediate frequency pass-band of the DSB receiver is tuned to the carrier frequency of the wanted SSB signal. If this is not the case, the value for a difference of +5 kHz may increase to -1 dB."

5. Transmitter technology

5.1 DSB transmitters

Modern high power double-sideband transmitters are still using a valve in the final amplifier stage for generating the high radio-frequency power. Amplitude modulation is generated using a digital modulator which modulates the plate voltage by means of pulse width of pulse step modulation. This DC-coupled method enables the use of a dynamic carrier level operation or generating SSB-signals using a class C radio-frequency power amplifier.

Typical transmitter efficiencies for modern DSB transmitters in the range of 100 - 500 kW are between 65 and 75%, with a modulation depth of 100%. Decreasing modulation depth decreases these values by only a few per cent.

5.2 SSB transmitters

In the modern transmitters SSB can be generated by either of the two following methods:

a) low level SSB generation followed by linear class AB or B power amplification;

b) low level SSB generation followed by separation of the amplitude information and the phase information. The amplitude information is amplitude modulated by an anode modulator as described in § 5.1. The frequency source for the transmitter is phase modulated by the derived phase information. The composite signal, available at the transmitter output, resembles the SSB signal. This method is known as Kahn method.

The first method yields a total transmitter efficiency around 40% with full P_p, i.e. 100% modulation, by using additional energy saving circuitry. With 100% modulation, the second method reaches 65-75% efficiency which is similar to the DSB value. With a 40% average modulation level and -12 dB carrier reduction the total efficiency for the Kahn method decreases by 10%, resulting in a 55-65% efficiency. This reduction in efficiency results from the fact that the mean RF output power is reduced while the input power requirements of the transmitter (cooling, heaters, etc.) remain the same.

The maximum P_p, achievable for SSB is less than the maximum P_p of DSB for transmitters operatable for both DSB and SSB modes. For the method of linear amplification the P_p reaches 0.25 times the DSB value. The P_p generated using the Kahn method reaches 0.5 - 0.75 times the DSB value.

Keeping P_p constant, the change from -6 dB to -12 dB in carrier level can be utilized for the increase of wanted sideband power up to 3.5 dB.

5.3 Possibilities for conversion of existing DSB transmitters to SSB

The majority of existing DSB transmitters apply anode modulation using a modulation transformer and a modulation choke. The anode modulator is AC-coupled to the final radio-frequency stage and therefore only the linear amplification type of SSB generation is possible. The accompanying modifications are significant. Resulting SSB P_p cannot exceed original DSB carrier power.

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[1978-82]: **a.** 10/41 (Germany (Federal Republic of)); **b.** 10/11 (Germany (Federal Republic of)).

[1982-86]: **a.** 10/7 (Japan).