SSB–Comparison With AM and FM Systems

(PART 2)

This is the second article from the training course written by Collins Radio Company for personnel concerned with single sideband communication systems.

AM System Comparison

Perhaps the most straightforward way to compare the relative performance of AM systems and SSB systems is to determine, under ideal propagating conditions, the transmitter power necessary to produce a given signal to noise (s/n) ratio at the receiver for the two systems.

Signal to noise ratio is a fair comparison, because it is the s/n ratio that determines the intelligibility of the received signal. Figure 1 shows such a comparison between an AM system and an SSB system when 100 percent, single-tone modulation is assumed.

Figure 1A shows the power spectrum for an AM transmitter rated at 1 unit of carrier power. With 100 percent sine-wave modulation, such a transmitter will actually be producing 1.5 units of RF power. There is a 0.25 unit of power in each of the two sidebands and 1 unit of power in the carrier.

This AM transmitter is compared with an SSB transmitter rated at 0.5 unit of peak-envelope-power (PEP).

Peak-envelope-power is defined as the r.m.s. power developed at the crest of the modulation envelope. The SSB transmitter rated at 0.5 unit of PEP will produce the same s/n ratio in the output of the receiver as the AM transmitter rated at 1 unit of carrier power.

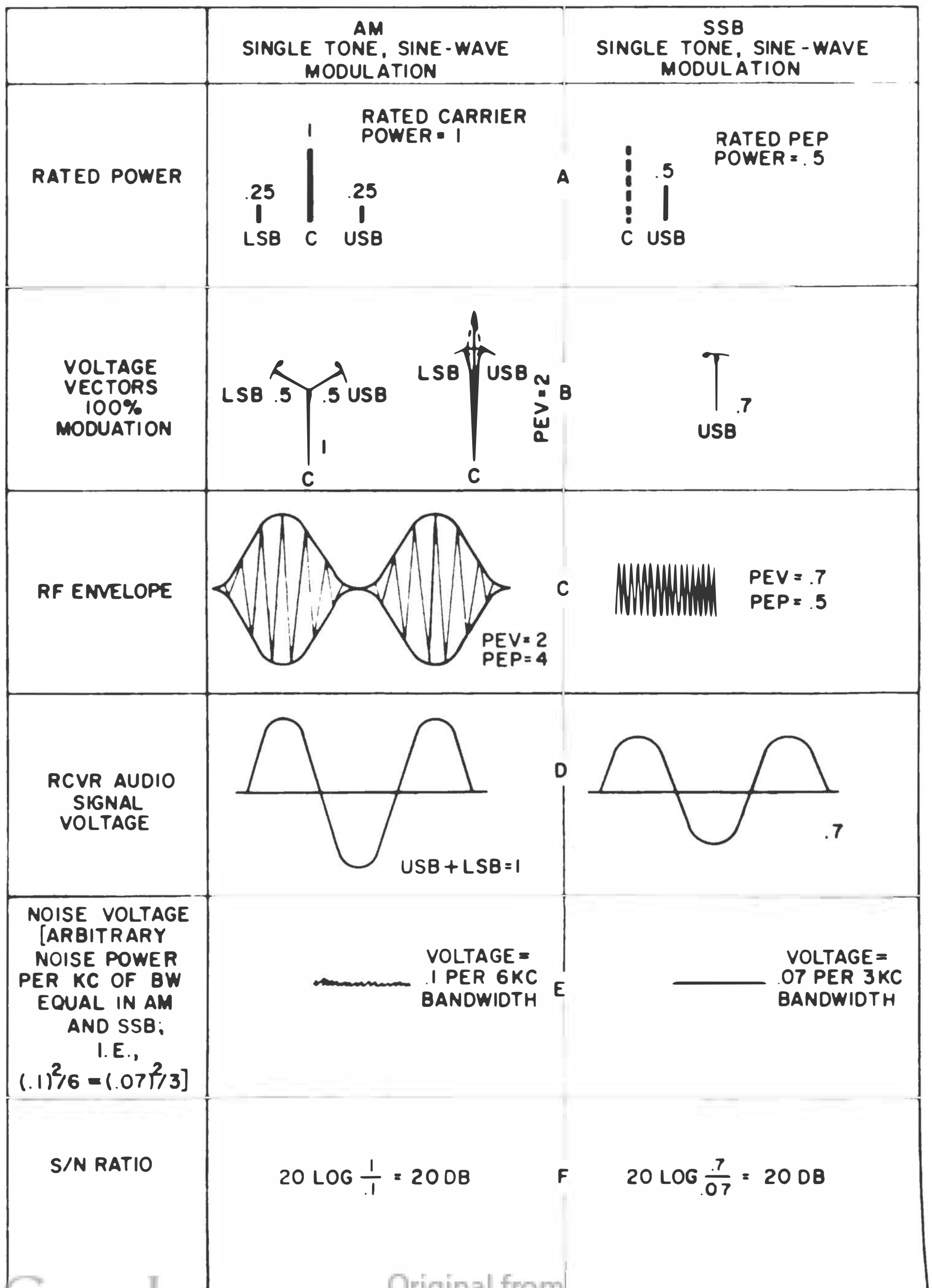
The voltage vectors related to the AM and SSB power spectrums are shown in figure 1B. The AM voltage vectors show the upper and lower sideband voltages of 0.5 unit rotating in opposite directions around a carrier voltage of 1 unit. For AM modulation, the resultant of the two sideband voltage vectors must always be directly in phase or directly out of phase with the carrier so that the resultant directly adds to or subtracts from the carrier.

The resultant shown when the upper and lower sideband voltage are instantaneously in phase produces a peak-envelope-voltage (PEV) equal to twice the carrier voltage with 100 percent modulation.

The 0.5 unit of voltage shown in each sideband vector produces the 0.25 unit of power shown in A, 0.25 unit of power being proportional to the square of 0.5 unit of voltage.

The SSB voltage vector is a single vector of 0.7 unit of voltage at the upper sideband frequen-

Figure 1. SSB and AM comparison with equal signal-to-noise ratio.



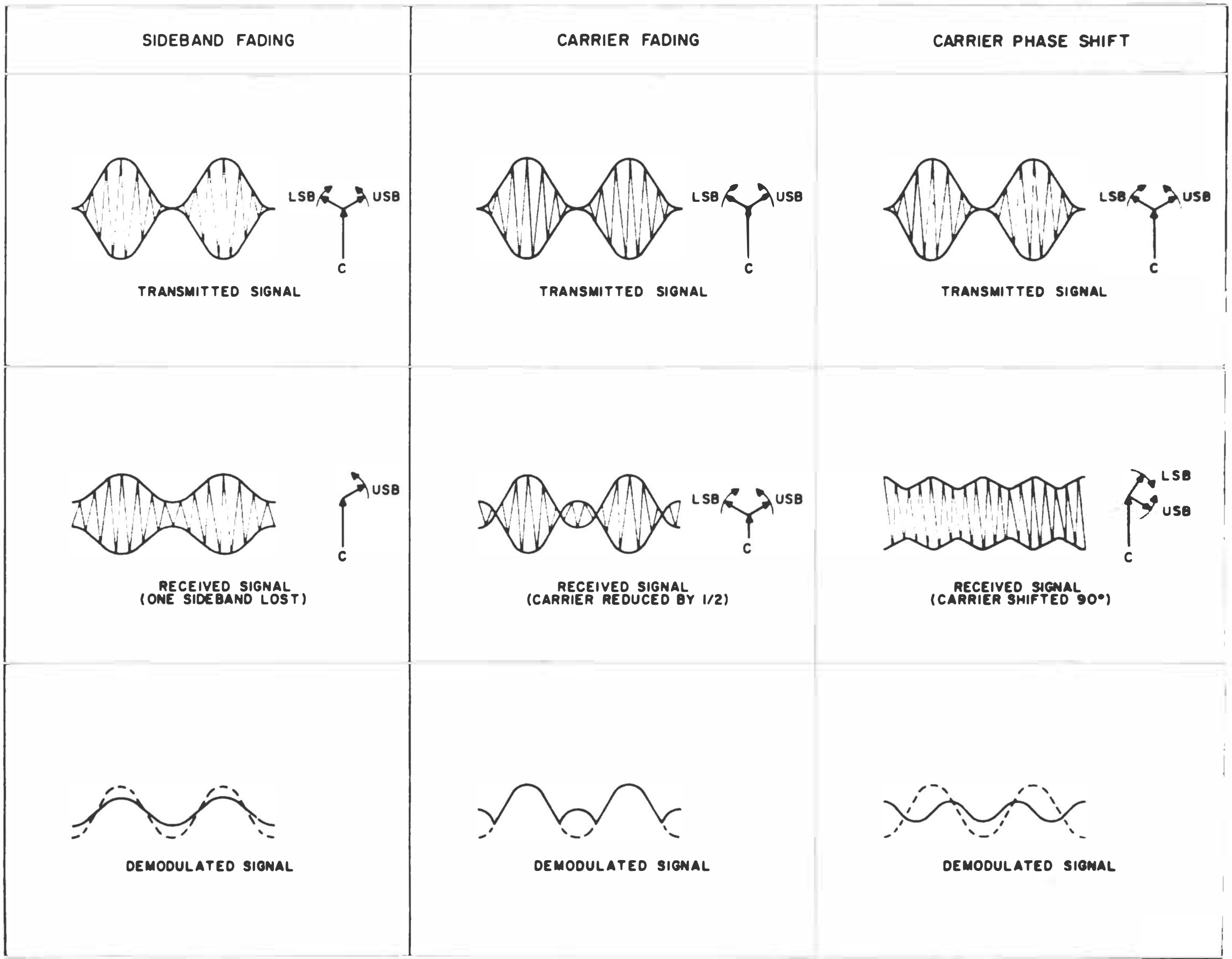


Figure 2. Deterioration of an AM signal with selective fading.

cy. The 0.7 unit of voltage produces the 0.5 unit of power shown in A.

The RF envelopes developed by the voltage vectors are shown in figure 1C. The RF envelope of the AM signal is shown to have a PEV of 2 units, the sum of the two sideband voltages plus the carrier voltage. This results in a PEP of 4 units of power. The PEV of the SSB signal is 0.7 unit of voltage with a resultant PEP of 0.5 unit of power.

When the RF signal is demodulated in the AM receiver, as shown in figure 1D, an audio voltage develops that is equivalent to the sum of the upper and the lower sideband voltages, in this case 1 unit of voltage. This voltage represents the output from the conventional, diode detector used in AM receivers.

Such detection is called coherent detection because the voltages of the two sidebands are added in the detector. When the RF signal is demodulated in the SSB receiver, an audio voltage of 0.7 unit develops which is equivalent to the transmitter upper sideband signal. This signal is demodulated by heterodyning the RF signal with the proper frequency to move the SSB signal down in the spectrum to its original audio position.

If a broadband noise level is chosen as 0.1 unit of voltage per 6-kilocycle bandwidth, the AM bandwidth, the same noise level is equal to 0.07 unit of voltage per 3-kilocycle bandwidth, the SSB bandwidth. This is shown in figure 1E.

These values represent the same noise power level per kilocycle of bandwidth; that is, $0.1^2/6$ equals $0.07^2/3$. With this chosen noise level, the s/n ratio for the AM system is 20 log s/n in terms of voltages or 20 decibels.

The s/n ratio for the SSB system is also 20 decibels, the same as for the AM system. The ½ power unit of rated PEP for the SSB transmitter, therefore, produces the same signal intelligibility as the 1 power unit rated carrier power for the AM transmitter. This conclusion can be restated as follows:

Under ideal propagating conditions but in the presence of broadband noise, an SSB and an AM system perform equally (same s/n ratio) if the total sideband power of the two transmitters is equal. This fact means that an SSB transmitter will perform as well as an AM transmitter of twice the power rating under ideal propagating conditions.

Antenna Voltage Comparison

Of special importance in airborne and mobile installations, where electrically small antennas are required, is the peak antenna voltage. In these installations, it is often the corona breakdown point of the antenna that is the limiting factor in equipment power.

Figure 1C shows the RF envelopes of an SSB transmitter and an AM transmitter of equal performance under ideal conditions. The PEV produced by these two transmitters is shown to be in the ratio 2 for the AM transmitter to 0.7 for the SSB transmitter. This indicates that for equal performance under ideal conditions, the peak antenna voltage of the SSB system is approximately ⅓ that of the AM system.

A comparison between the SSB power and the AM power that can be radiated from an antenna of given dimensions is even more significant. If an antenna is chosen that will radiate 400 watts of PEP, the AM transmitter that may be used with this antenna must be rated at no more than 100 watts. This is true because the PEP of the AM signal is four times the carrier power.

An SSB transmitter rated at 400 watts of PEP, all of which is sideband power, may be used with this same antenna. Compare this with the 50 watts of sideband power obtained from the AM transmitter with a 100-watt carrier rating.

Selective Fading

The power comparison between SSB and AM given in the previous paragraphs is based on ideal propagation conditions. However, with long-distance transmission, AM is subject to selective fading which causes severe distortion and a weaker received signal. At times this can make the received signal unintelligible.

An AM transmission is subject to deterioration under these poor propagation conditions, because all three components of the transmitted signal (the upper sideband, lower sideband, and carrier) must be received exactly as transmitted to realize fidelity and the theoretical power from the signal. Figure 2 shows the deterioration of an AM signal with different types of selective fading.

The loss of one of the two transmitted sidebands results only in a loss of signal voltage from the demodulator. Even though some distortion results, such a loss is not basically detrimental to the signal, because one sideband contains the same intelligence as the other.

However, since the AM receiver operates on the broad bandwidth necessary to receive both sidebands, the noise level remains constant even though only one sideband is received. This is equivalent to a 6-decibel deterioration in s/n ratio out of the receiver.

Although the loss of one of the two sidebands may be an extreme case, a proportional deterioration in s/n ratio results from the reduction in the level of one or both sidebands.

The most serious result of selective fading, and the most common, occurs when the carrier level is attenuated more than the sidebands. When this occurs, the carrier voltage at the receiver is less than the sum of the two sideband voltages.

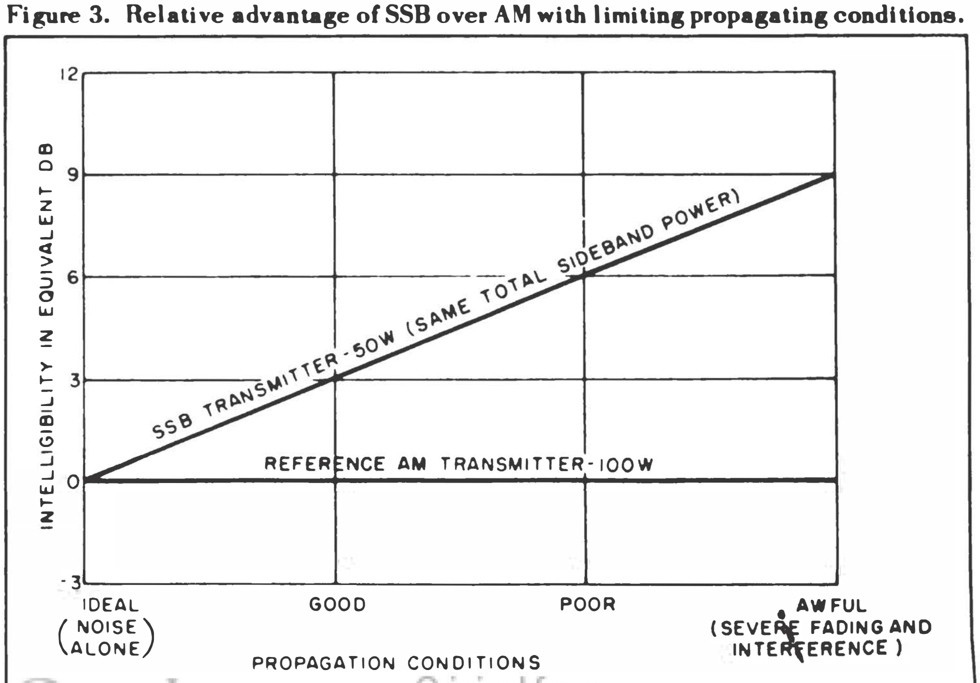
When the carrier is attenuated more than the sidebands, the RF envelope does not retain its original shape, and distortion is extremely severe upon demodulation. This distortion results upon demodulation because a carrier voltage at least as strong as the sum of the two sideband voltages is required to properly demodulate the signal.

The distortion resulting from a weak carrier can be overcome by the use of the exalted carrier technique whereby the carrier is amplified separately and then reinserted before demodulation. In using the exalted carrier, the carrier must be reinserted close to its original phase.

Selective fading can also result in a shift between the relative phase position of the carrier and the sidebands. An AM modulation is vectorally represented by two counter-rotating sideband vectors which rotate with respect to the carrier vector. The resultant of the sideband vectors is always directly in phase or directly out of phase with the carrier vector.

In an extreme case, the carrier may be shifted 90° from its original position. When this occurs, the resultant of the sideband vectors

Figure 3. Relative advantage of SSB over AM with limiting propagating conditions.



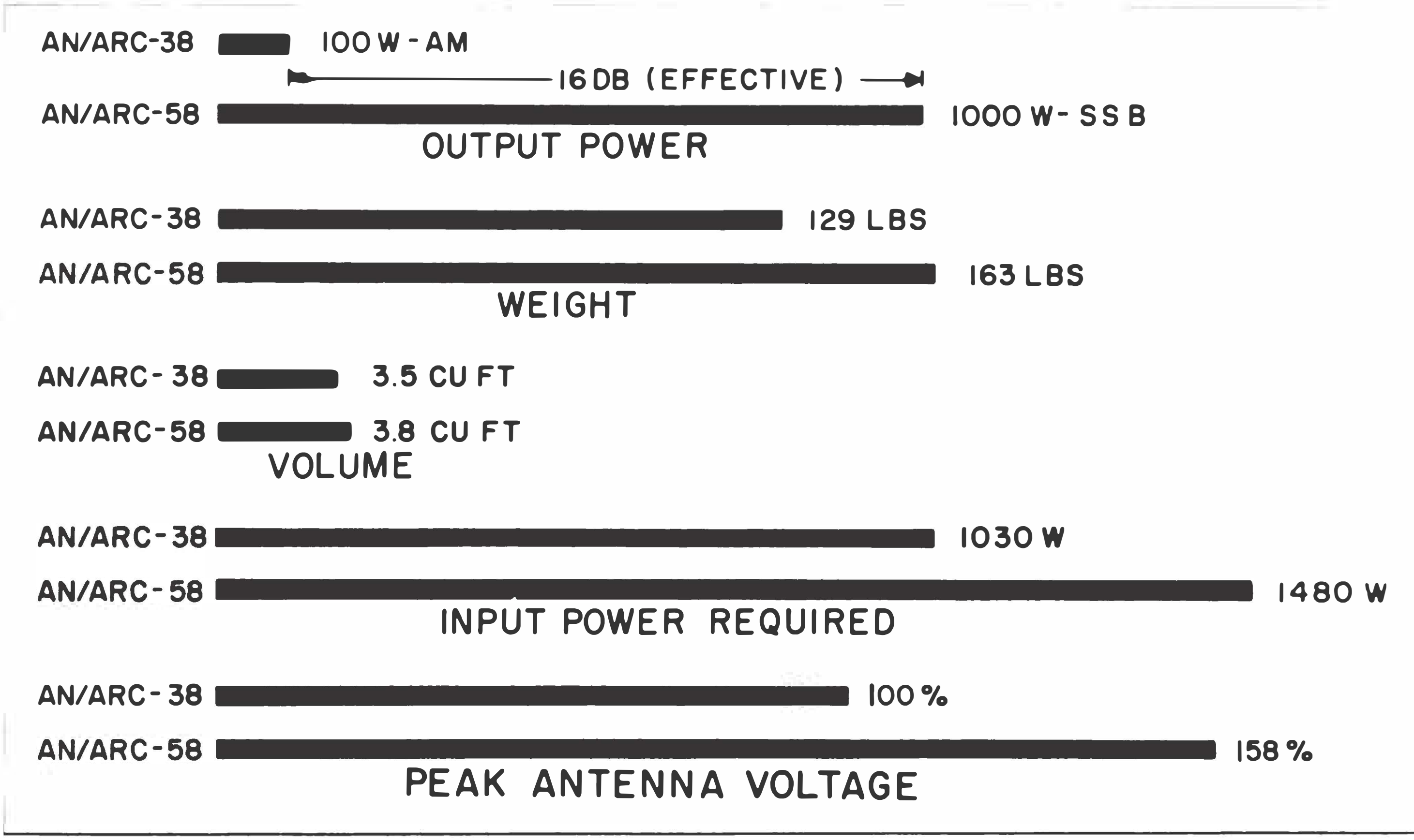


Figure 4. AN/ARC-38 and AN/ARC-58 comparison.

is ± 90° out of phase with the carrier vector. This results in converting the original AM signal to a phase modulated signal. The envelope of the phase modulated signal bears no resemblance to the original AM envelope and the conventional AM detector will not produce an intelligible signal.

Any shift in the carrier phase from its original phase relationship with respect to the sidebands will produce some phase modulation with a consequential loss of intelligibility in the audio signal. Such a carrier phase shift may be caused by poor propagating conditions. Such a carrier phase shift will also result from using the exalted carrier technique if the reinserted carrier is not close to its original phase, as previously mentioned.

An SSB signal is not subject to deterioration because of selective fading which varies either the amplitude or the phase relationship between the carrier and the two sidebands in the AM transmission. Since only one sideband is transmitted in SSB, the received signal level does not depend on the resultant amplitude of two sideband signals as it does in AM.

Since the receiver signal does not depend on a carrier level in SSB, no distortion can result from loss of carrier power. Since the receiver signal does not depend on the phase relationship between the sideband signal and the carrier, no distortion can result from phase shift.

Selective fading within the one sideband of the SSB system only changes the amplitude and the frequency response of the signal. It very rarely produces enough distortion to cause the received signal or voice to be unintelligible.

Limiting Propagating Conditions

One of the main advantages of SSB transmission over AM transmission is obtained under limiting propagating conditions over a long-range path where communications are limited by the combination of noise, severe selective fading, and narrow-band interference.

Figure 3 illustrates the results of an intelligibility study performed by rating the intelligibility of information received when operating the two systems under varying conditions of propagation.[1] The two transmitters compared have the same total sideband power.

That is, a 100-watt AM transmitter puts one-fourth of its rated carrier power in each of two sidebands, while a 50-watt SSB transmitter puts its full rated output in one sideband.

This study shows that as propagation conditions worsen, and interference and fading become prevalent, the received SSB signal will provide up to a 9-decibel advantage over the AM signal. The result of this study indicates that the SSB system will give from 0- to 9-decibel improvement under various conditions of propagation when total sideband power in SSB is equal to AM.

It has been found that 3 of the possible 9-decibel advantage will be realized on the average contact. In other words, in normal use, an SSB transmitter rated at 100 watts (PEP) will give equal performance with an AM transmitter rated at 400 watts carrier power.

It should be pointed out that in this comparison the receiver bandwidth is just enough to accept the transmitted intelligence in each case and no speech processing is considered for SSB transmission.

Comparing Airborne HF Systems

Figure 4 shows a comparison in weight, volume, input power, effective output power, and peak antenna voltage between radio set AN/ARC-38 and radio set AN/ARC-58. These sets are both airborne transceivers operating in the 2- to 3-megacycle, high-frequency range. The AM set, AN/ARC-38, is rated at 100 watts RF output, and the SSB set, AN/ARC-58, is rated at 1,000 watts RF output.

The effective output power of the SSB transceiver is shown to be 16 decibels higher than the AM transceiver. This 16 decibels is equivalent to a power advantage of 40 to 1, which is an enormous advancement in the communication ability of an airborne system. In addition to the power advantage of the SSB system of significance in airborne equipment is the more efficient use of the antenna with the SSB system.

Summary of AM Comparison

The foregoing paragraph on SSB comparison with AM systems may be briefly summarized. For long-range communications in the low-, medium-, and high-frequency ranges, SSB is well suited because of its spectrum and power economy and because it is less susceptible to the effects of selective fading and interference than is AM.

The principal advantages of SSB result from the elimination of the high-energy AM carrier and from improved performance under unfavorable propagating conditions.

On the average contact, an SSB transmitter will give equal performance to an AM transmitter of four times the power rating. The advantage of SSB over AM is most outstanding under unfavorable propagating conditions.

For equal performance, the size, weight, power input, and peak antenna voltage of the SSB transmitter is significantly less than the AM transmitter.

Comparison with FM Systems

Although much experimental work has been done to evaluate the performance of SSB systems with AM systems, very little work has been done to evaluate the performance of SSB systems with FM systems.

However, figure 5 shows the predicted result of one such study based on a mobile FM system as compared with a mobile SSB system of equal physical size.[2] The two systems compared also operated with the same output tubes to their full capacity so that the final RF amplifiers dissipated the same power during normal speech loading.

The study is complicated by evaluating the effects of speech processing, such as clipping and preemphasis, with resultant distortion. Such speech processing is essential in the FM system but has little benefit in the SSB system.

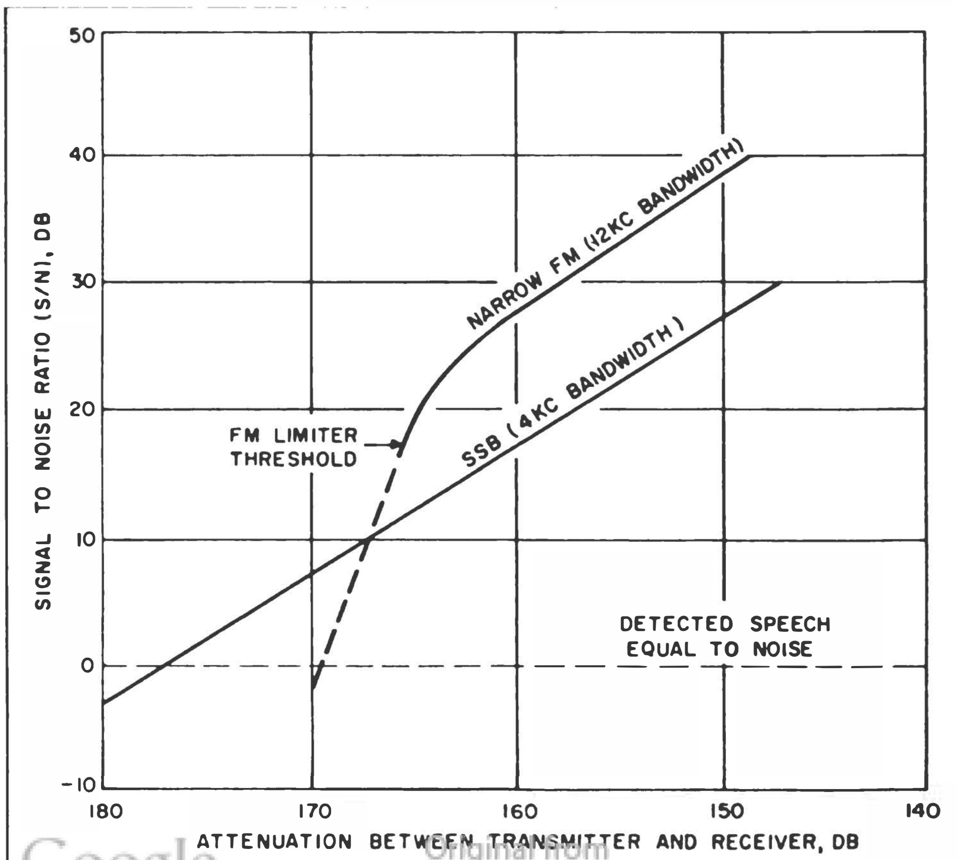
Figure 5 shows the s/n ratio in decibels on the y-axis and the attenuation between transmitter and receiver in decibels on the x-axis. This graph indicates that with between 150 and 160 decibels of attenuation between the transmitter and receiver, a strong signal, the narrow-band FM system provides a better s/n ratio than the SSB system.

Under weak signal condition, from 168 and higher decibels of attenuation between transmitter and receiver, the s/n ratio of the FM system falls off rapidly, and the SSB system provides the best s/n ratio. This fall-off in the FM s/n ratio results when the signal level drops below the level required for operation of the limiter in the FM receiver.

The conclusions that can be drawn from figure 5 are as follows:

1. For strong signals, the FM system will provide a better s/n ratio than the SSB system. However, this is not an important advantage because when the s/n is high, a still better s/n ratio will not improve intelligibility significantly.
2. For weak signals, the SSB system will provide an intelligible signal where the FM system will not.
3. The SSB system provides three

Figure 5. SSB performance compared with FM.



times the savings in spectrum space as the narrow-band FM system.

The third article in the SSB series will describe the generation of the different SSB signals: The single-tone waveform, the single-tone waveform with carrier, the two-tone waveform, the square waveform, and the voice waveform.

References:

1. J.F. Honey, "Performance of AM and SSB Communications," Tele-Tech, September 1953.

2. H. Magnuski and W. Firestone, "Comparison of SSB and FM for VHF Mobile Service," Proceedings of the IRE, December 1956.

SONAR DIRECTIVES

The accompanying directives that apply to the installation and maintenance of sonar equipments were listed in the enclosure to Bureau of Ships instruction 9674.25 of 7 August 1957.

Additional copies may be ordered in accordance with Bureau of Supplies and Accounts instruction 5604.3.

Number	*Date*	*Title*
4750.1	5/8/57	Non-painting of AN/SQS-4 domes.
9110.16A	1/18/56	AN/UQS-1—Installation and Maintenance Notes.
9190	3/19/57	Zinc exterior to sonar domes.
9670.89	1/24/57	Testing electron tubes.
9674	6/25/57	Ground straps for AN/SQS-4 transducers.
9674.2	4/20/55	Marking of conductors in.
9674	4/1/57	AN/SQS-4 type quantitative measurements.
9674	5/1/57	AN/SQS-4 type quantitative measurements.
9674.3A	1/23/56	60-inch rubber domes—installation program.
9674.6	9/11/52	Transducer filling fluid.
9674.9	10/3/52	Bathythermograph repair.
9674.11	1/2/53	AT-200B/UQN-1A and 1B transducer lugs.
9674.12A	11/28/56	Transducer repair.
9674.13C	12/10/56	Recaulking of 60-inch rubber domes.
9674.14S1	8/24/53	Hydrophone fairings.
9674.15A	5/31/55	Galvanic protection of sonar hoists and domes.
9674.16	8/18/53	JT, AN/BQR-3, BQR-3A, BQS-3 cable allowance.
9674.17	8/27/53	Transducers handling.
9674.18A	4/16/56	Transducers—installation inspection sheets; discontinuance.
9674.19	12/2/53	Transducers antifouling painting.
9674.21	1/8/54	Antifouling painting.
9674.22	2/2/55	Transducer—reusable shipping container.
9674.24	9/18/56	AN/UQS-1 domes—Replacements.
9674	9/20/57	Sonar sweep generators, repairing of.
4900.11	7/22/55	WQA-1 keyers for MSC and MSO, MDAP ships.
9070.8	11/8/55	Docking plans and vertical clearance for sonar domes.
09674	9/17/57	SQS-4/UQN-1 interference.

RADIOACTIVE TUBES—CORRECTION

In the Bureau of Ships Journal December 1957, in the list of tubes containing radioactive material, page 28, wherever Ce 137 appears, it should be Cs 137: In column 1, third and fifth items from bottom of page and in column 2 at top, items 1, 2, 3, 4, 6, and 8.

TEST EQUIPMENT...

(Continued from page 28)

The output pulse will be displayed approximately 1,000 microseconds after the input pulse at a precise multiple of the reference delay. Because of the sweep multiplication provided by using two sweeps per delay interval and because any error in beacon delay is allowed to accrue through the many delay intervals in the 1,000 microsecond period, any small error in the timing of the overall zero distance radio beacon delay will cause a noticeable shift in the superposition of the input and output pulse pairs displayed on the oscilloscope.

By checking superposition at multiples of the 49.8 and 50.2 microsecond reference delays, it may readily be seen whether the beacon delay is between these two figures. If it is, then it is within tolerance.

Video Zero Distance Delay. The video zero distance delay is measured exactly by the same technique as the overall distance delay described above. The reference delays used for checking video delay are changed to 42 and 44 microseconds, by the crystal selector switch. At the same time, contacts of the crystal selector switch transfer the mixer input to the video input and output points on the beacon.

Position 4

When the test function switches are placed in position 4, the input connections of the oscilloscope are removed. Each one of the test units may then be used as an independent piece of test equipment.

The oscilloscope sweep and signal circuits may next be adjusted by means of front panel controls for observing any desired waveform in the equipment. Signal and sync voltages may be fed to the oscilloscope by means of flexible test leads.

With this arrangement the number of operating tests may be extended to include any other tests which may arise later, also the test equipment may be used as an aid in troubleshooting the radio beacon.