Radio Communications By Single Sideband Techniques

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Communications by single sideband techniques will require the use of less power and less frequency spectrum and will bring more efficient use of networks. Also, the communications will be less vulnerable to the effects of radio interference, multipath, and selective fading as compared with communications by conventional amplitude modulation.

The military services, as well as industry, plan to use these advantages to the maximum as soon as practicable.

Ultimately, single sideband communication techniques will replace many of the methods now used for communications in the frequency below 25 megacycles.

Single sideband (SSB) is one of many methods by which radio signals can be modulated or demodulated. It is perhaps unique in that it is the only modulation method that need not contain a redundancy of the original message form.

Most modulation methods are inherently wasteful of frequency spectrum. Ordinary amplitude modulation, for example, requires at least twice the radiofrequency bandwidth of the initial message form. Frequency modulation and phase modulation both require many times the initial message form bandwidth.

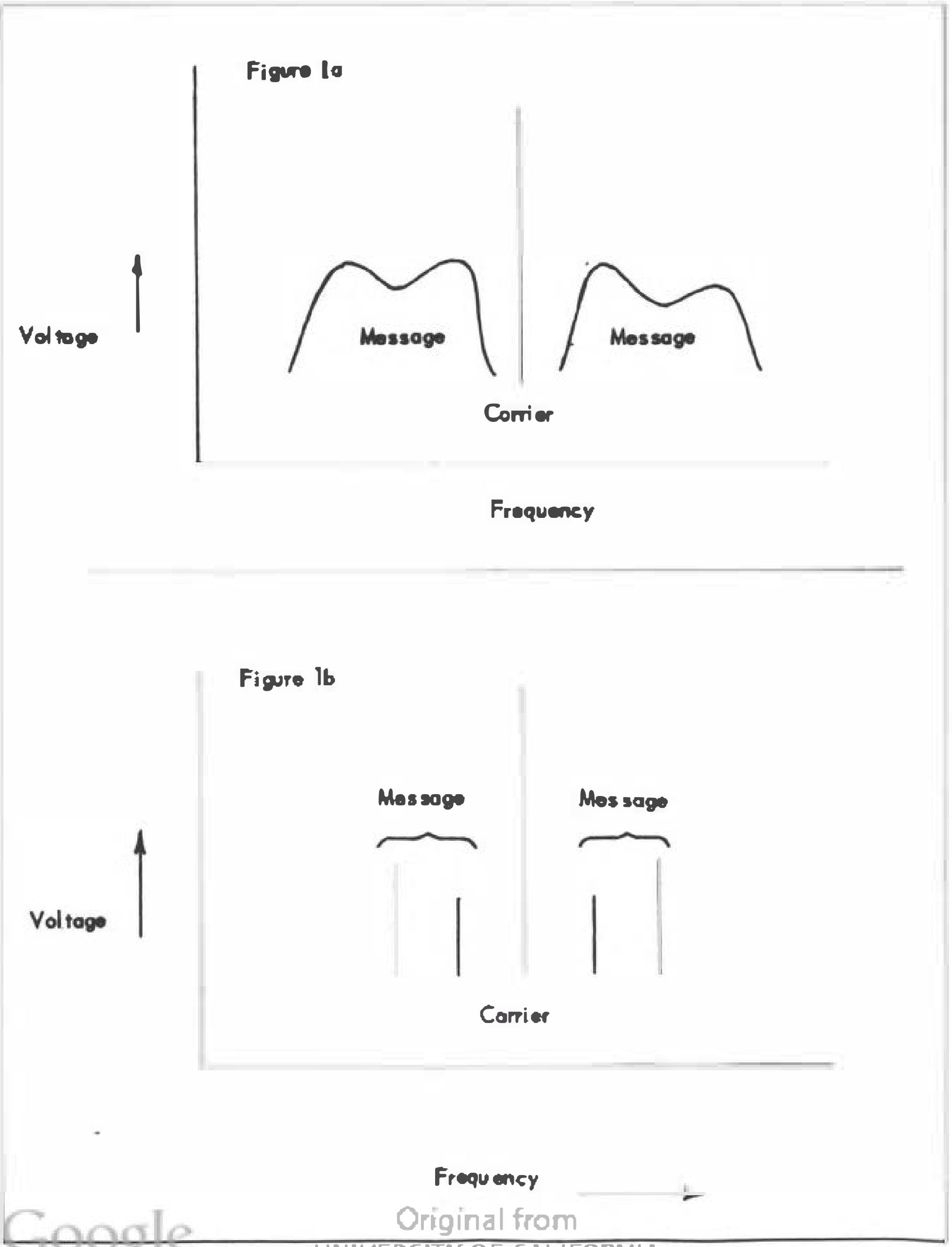
Probably the most widely used and understood process of modulation is amplitude modulation (AM). For this reason, it is used in this article to compare and explain single sideband modulation.

When those unacquainted with modulation techniques hear that in single sideband communication the radiofrequency carrier is completely or partially suppressed, they find it difficult to understand what remains for transmission.

Actually, when a radiofrequency carrier is amplitude modulated, mirror image signals are generated, one above and one below the carrier frequency. Each signal contains all the information of the original message (figure 1). The amplitude and frequency of the signals are proportional to the amplitude and frequency of the modulating signal.

A standard method of generating an SSB signal is to amplitude-modulate a low-frequency carrier,

Figure 1a: Plot of voltage versus frequency of a signal amplitude modulated with speech. **Figure 1b:** Plot of voltage versus frequency of a signal amplitude modulated with two tones.



for example 100 kilocycles, in a balanced modulator that suppresses the carrier. This step is followed by several stages of filtering and linear amplification that will, for all practical purposes, remove the carrier and the unwanted sideband.

The removal takes place at low frequencies and at low power levels so that fixed-tuned filters and fixed-frequency balanced modulators can be used to advantage.

In figure 2, a block diagram of an SSB transmitter shows the signal at various points. To obtain the required output power and operating frequency, it is necessary to follow this process with fixed and variable mixing stages and linear power amplifiers.

Generally, the sideband is mixed once more with a higher fixed frequency to bring the sideband to approximately a tenth of the operating frequency and then is mixed with a variable frequency to obtain the output frequency.

There are methods that do not require the use of precise filters to generate a single sideband with which nonlinear amplifiers may be used. However, these methods generally depend on obtaining a precise phase relationship of the sidebands with respect to the carrier or on modulation for the cancellation of the sideband.

Outphasing Techniques

These methods, frequently described as "outphasing" techniques, are complicated and require continuous monitoring and adjustment to maintain a minimum of performance with current components. For this reason, the military services have abandoned them for standard techniques of filtering and linear amplification.

A single sideband signal of one tone modulation, with a totally suppressed carrier, resembles a continuous wave signal (figure 3). A signal with two audio tones, different in frequency and of equal amplitude, is shown in figure 4. The null points are a result of the addition of the two tones when 180° out of phase. If the tones were not of equal amplitude, there would be no null points.

The peaks are a result of the addition of the two tones when in phase. Under conditions of multiple tone modulation or complex modulation forms such as speech, the peaks and troughs or nulls will depend on the amplitude and phase relationships of all the discrete frequencies involved. Therefore, the original message form will not be apparent in the radiofrequency wave form of the sideband signal.

The sideband, however, will in all respects resemble one sideband of a conventional amplitude-modulated waveform in a plot of voltage versus frequency. The peaks referred to previously and the accuracy with which the waveform is reproduced in SSB transmitters and linear power amplifiers are used to describe their ratings.

Peak Power

Therefore, SSB transmitters and linear power amplifiers usually are described as having a certain "peak envelope power" and a certain amount of "linearity."

An SSB signal may be detected simply by reversing the modulation

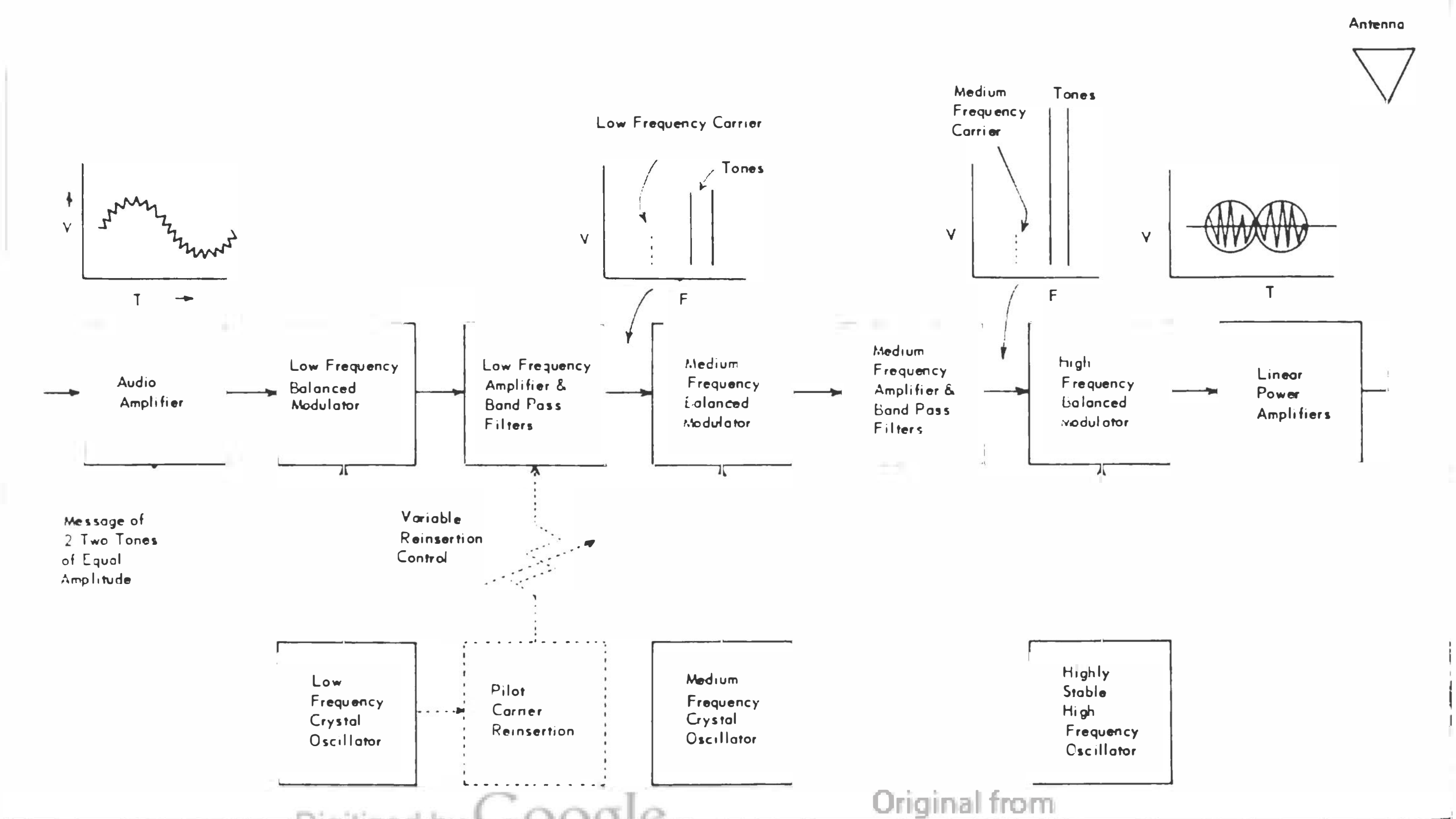


Figure 2. Block diagram of a simple SSB transmitter, showing graphs of the signal voltage plotted against time and frequency. The dotted lines indicate where the "pilot carrier" may be inserted when enough frequency stability is not attainable in the system.

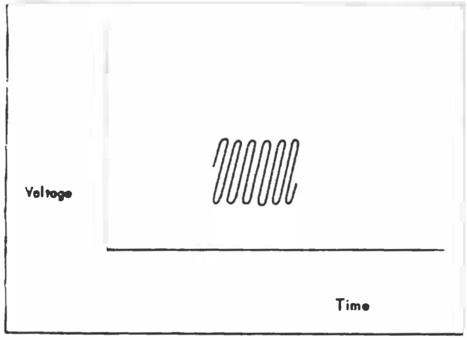


Figure 3. Sine wave.

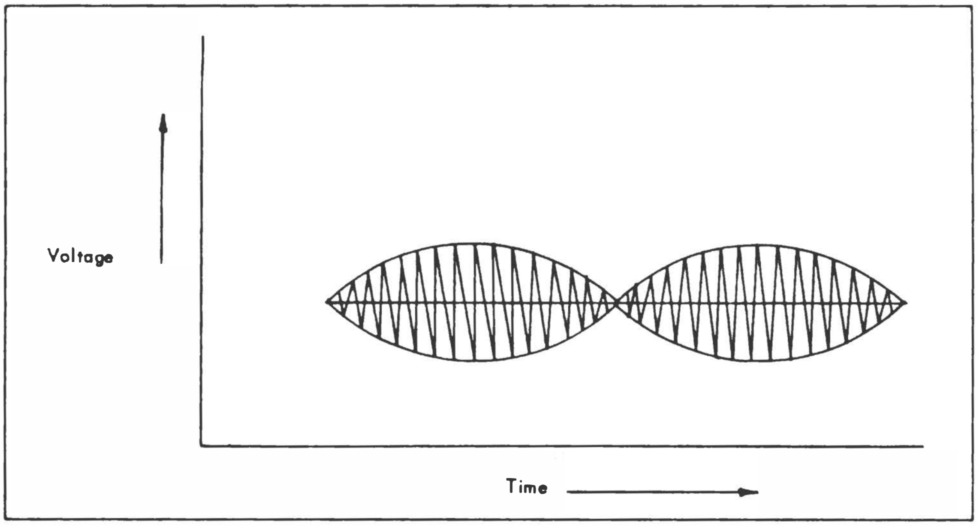


Figure 4. Signal with two audio tones, different in frequency and of equal amplitude.

process and substituting the appropriate mixing frequencies.

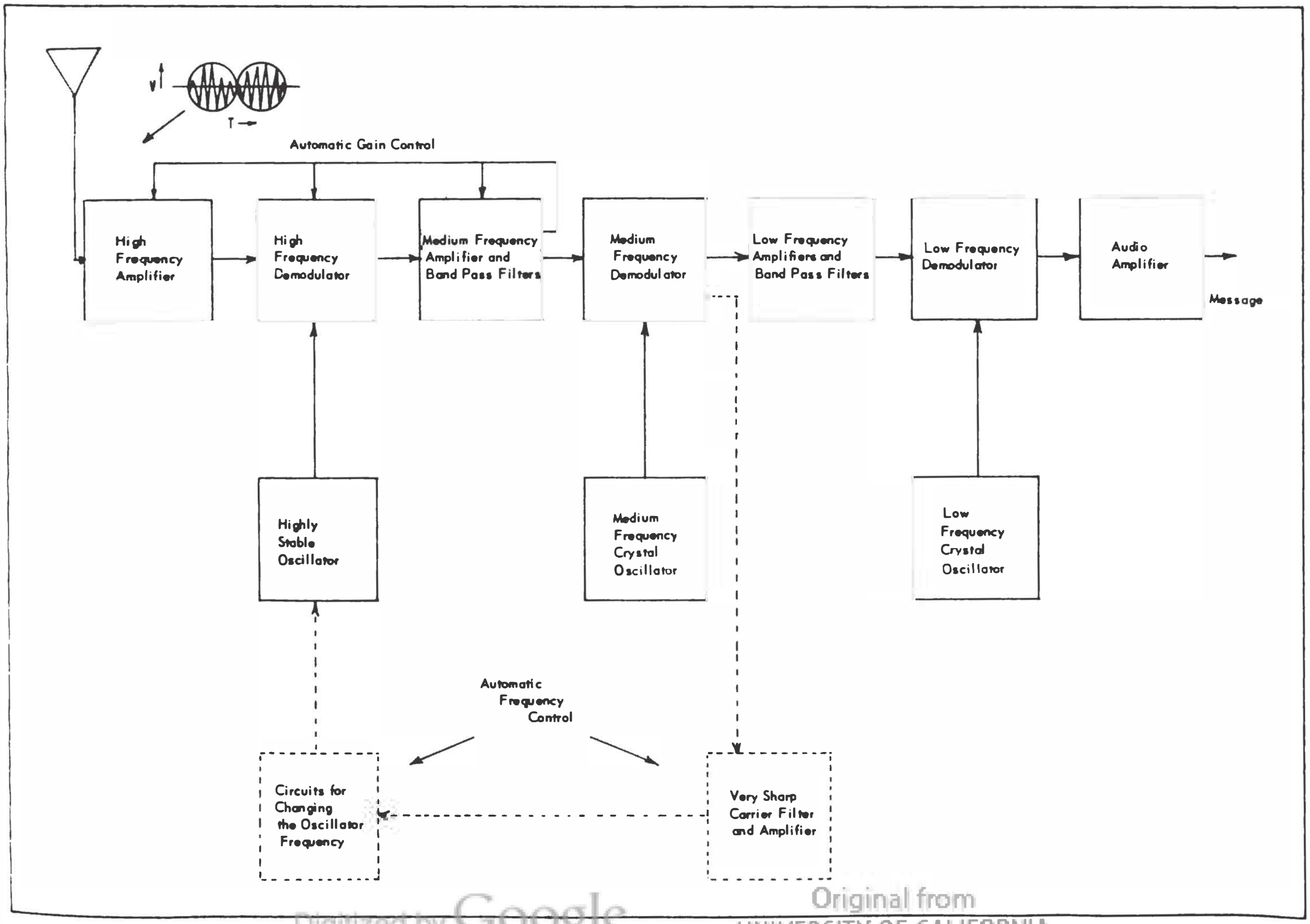
Permissible Inaccuracies

Figure 5 is a single sideband receiver block diagram. For proper reception, the mixing frequencies must be tuned very closely to the transmitter frequency. The inaccuracies permissible vary with the type of message form and the tolerable amount of distortion resulting from the message form, as well as the signal-to-noise ratio at the received point.

When enough frequency stability cannot be obtained otherwise, the transmitter may be designed to transmit a "pilot" carrier, and the receiver designed to have automatic tuning circuits to keep it in tune with respect to the pilot frequency.

Although the pilot frequency need

Figure 5. Block diagram of a simple SSB receiver. The dotted lines indicate where the automatic frequency control may be inserted when enough stability is not otherwise obtainable.



be only a small fraction (1/10 or 1/20) of the total sideband power, its transmission is not desirable for network communications of the type used by the military services, because of interference. However, the transmission of a "pilot tone" in point-to-point circuits has been used successfully for many years.

The tuning of the automatic frequency control (AFC) circuitry in the receiver is guided by the pilot frequency, so that errors contributed by the transmitter and the receiver are compensated in the receiver. Although this process will align the transmitter and the receiver, it has serious defects.

When interference is received within the capture range of the AFC circuitry, the receiver will tune to the strongest signal. The reception, therefore, is vulnerable to intentional or unintentional interference.

Two or more transmitters cannot be successfully operated on the same frequency, as in totally suppressed carrier SSB communications, since in the absence of modulation the pilot frequencies of other transmitters could interfere at the received point in a conventional network operation. Although a transmitter and receiver can be maintained on the same frequency, both may be considerably off the assigned frequency.

For these reasons, such systems will be limited to special applications, such as fixed, point-to-point, long-range communications.

SSB Not New

History shows that SSB is not as new as many suppose, but is one of the earliest forms of radio communications. It was used in the early days of radio in the low and medium frequencies because of the narrow antenna bandwidths available and the required use of low frequencies and groundwave propagation.

Single sideband techniques were not widely known, and following the discovery of skywave propagation and the use of the high-frequency spectrum for long-range communications, SSB techniques were abandoned for the conventional AM techniques now in use.

At that time, it was difficult, if not impossible, to obtain enough stability in the high frequencies without crystal oscillators that were not yet available or to generate a single sideband by the use of the components then in use.

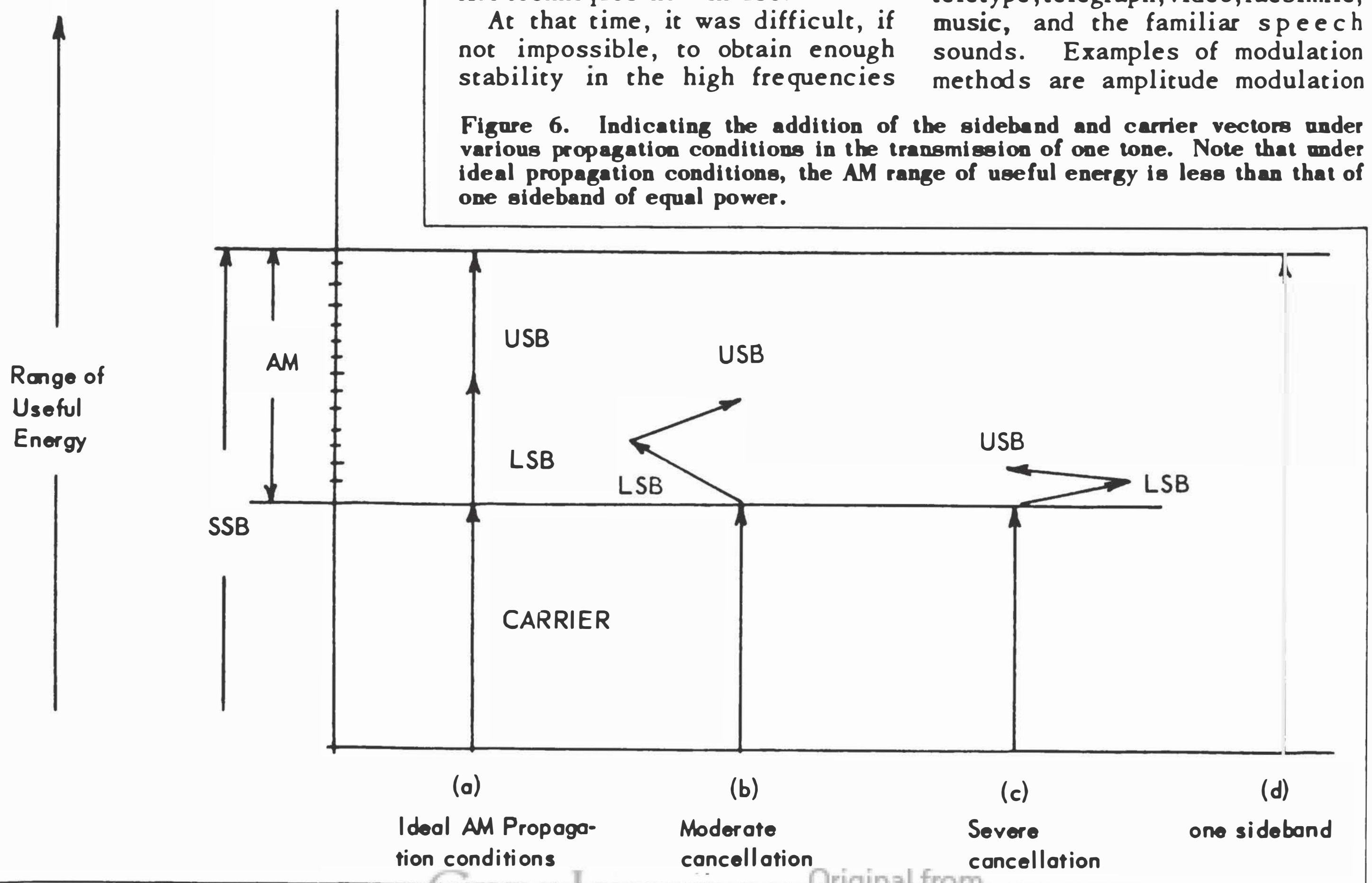
Over a relatively short period of time, the growth of radio communications and the many branches of electronics that followed them have crowded out unused areas in the radiofrequency spectrum completely. The best estimates indicate that demands for the use of the radiofrequency spectrum will continue to multiply.

The communications people are merely leading the way in the now most important conservation of the radiofrequency spectrum.

The most desirable band for long-range communications, and therefore the most crowded, is the high-frequency band, 3 to 30 megacycles or approximately 2 to 32 megacycles for the military services. In this band, the predominant means of modulation is conventional amplitude modulation. Amplitude modulation defines the process of modulation, not the message form.

Examples of message forms are teletype, telegraph, video, facsimile, music, and the familiar speech sounds. Examples of modulation methods are amplitude modulation

Figure 6. Indicating the addition of the sideband and carrier vectors under various propagation conditions in the transmission of one tone. Note that under ideal propagation conditions, the AM range of useful energy is less than that of one sideband of equal power.



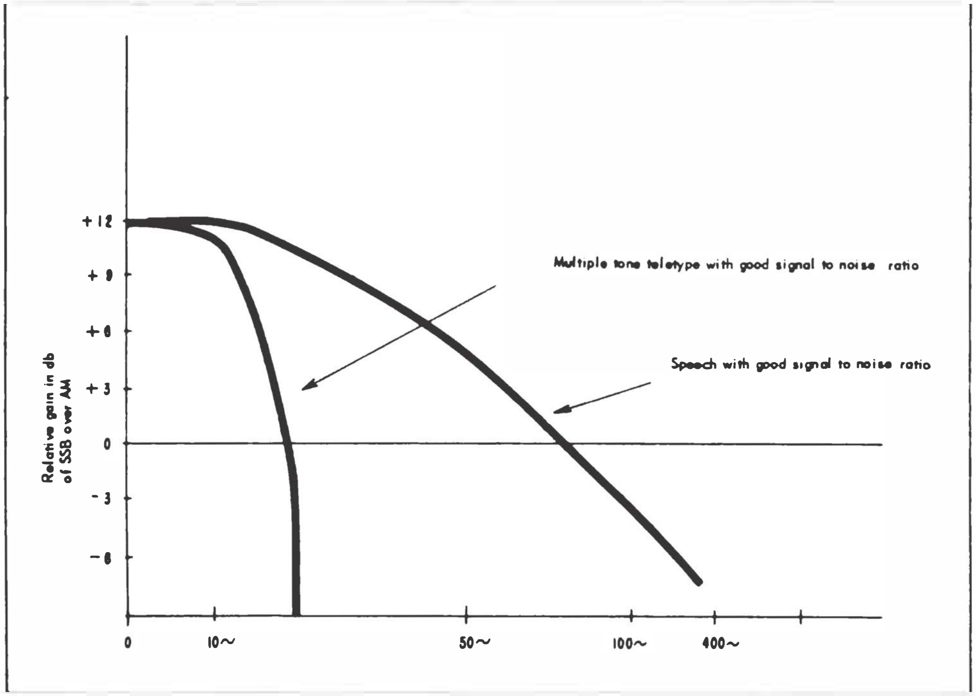


Figure 7. A rough indication of the effect of frequency errors, showing frequency difference between the SSB transmitter and the receiver.

(AM), frequency modulation (FM), phase modulation (PM), pulse time modulation (PTM), and single sideband modulation (SSB), the last being a modified method of AM.

Amplitude modulation, as in all modulation methods except SSB, is a redundant form that requires at least twice the original message bandwidth in frequency spectrum. By comparison, an SSB signal requires only the same bandwidth as the initial message. By substituting SSB modulation for other modulation methods, it would be possible to double at least the amount of communication capacity in the band.

A comparison between AM and SSB systems shows that an SSB transmitter need have only 1/8 to 1/16, that is 9 to 12 decibels less, depending on propagation conditions, of the peak-envelope power rating of an AM transmitter to get the same performance as the AM system for any given distance. To understand this fact, a brief review of elementary AM theory is given here.

Crest Voltage

In a transmitter, amplitude modulated 100 percent by a single tone, the radiofrequency envelope, composed of the carrier and two sidebands, has a crest voltage of two times the carrier and, therefore, has power peaks of four times the carrier power. The transmitter will also have a total average output power, over the modulation cycle, of one and a half times the carrier power.

For example, an AM transmitter, with a carrier rating of 100 watts modulated 100 percent by a single tone and without amplitude distortion, will have envelope peaks of 400 watts and a total average output power, over one modulation cycle, of 150 watts.

Therefore, the AM transmitter should be designed to handle a peak-envelope power of 400 watts and an average power of 150 watts. Of the 150 watts of average power, only 25 watts can be used in each transmitted sideband.

By comparison, to transmit the same intelligence, a single sideband transmitter need only be designed for a 25-watt peak power output. Therefore, at the transmitter, the SSB equipment need have only 1/16, or 12 decibels less, the peak-envelope power output.

For a complete system analysis, the receiver and the propagation medium must be considered.

At the AM receiver, if the voltages generated as a result of each sideband are added with the proper phase relationship, an effective gain of four times the power (or 6 decibels) may be credited to the AM system. On the other hand, since the SSB receiver needs only half the bandwidth, a signal-to-noise gain of two (or 3 decibels) should be credited to the SSB system.

Ideal Conditions

Thus, under ideal propagation conditions for the AM system, a net gain of 8 times the power (or 9 decibels) favors the SSB system.

The foregoing is only an approximation because, for simplicity, certain assumptions have been made with regard to the relationship of noise to receiver bandwidth and also with regard to the method of detection in the AM receiver.

Under practical conditions of communications, the sidebands at the receiver in an AM system can seldom be properly added because of the propagation phenomena of multipath. The effects of multipath propagation can cause the sideband components to vary out-of-phase relationship with respect to each other or the carrier, and cause cancellation of the sidebands partially or totally in the process of detection by conventional means.

Signals arriving from a reflected path will arrive out of phase from a signal traveling over a direct path or a different reflected path, and the vectorial addition of the various signals will disrupt the proper phase relationship of the sidebands in the AM signal.

Figure 6 shows the results of the effects under various propagation conditions when a message of one tone is transmitted. When more than one tone is transmitted, such as multitone teletype without diversity, the various tones in the sidebands will be less likely to add properly or yield the maximum useful energy.

Selective fading, another propagation phenomenon, is caused by the ionosphere reflecting frequency components on the transmitter signal in unequal amounts. When this phenomenon occurs, it is in effect like a filter that may attenuate certain frequency components in the composite signal. When the radiofrequency carrier of an AM signal fades, the signal, if detected by standard techniques, will include harmonics and cross modulation products of the intelligence in the upper and lower sidebands.

Although signal variations (from multipath and selective fading) of 10 to 100 times the received voltage—that is, 20 to 40 decibels—are not uncommon on AM transmissions, the same circuit with SSB techniques would show little, if any, adverse effects, since the carrier and the other sideband are not there to distort and cancel the signal.

Since the adverse effects are random in nature, it is difficult to determine exactly what the gain of the SSB system has above the figure of 8 times (or 9 decibels) the derivation of which has already been quantitatively explained in this article.

A feature of SSB techniques, used to advantage by radio amateur groups, is that of network operations.

Multiple Party Line

The ideal network of radio communications would be similar to a multiple party line telephone circuit, which can be simulated in network operations by the use of proper SSB equipment.

In a conventional AM communications network, if two transmitted carriers are on or near the same frequency, the message carried by either is not usually intelligible at any received point in the net. This condition is caused either by a participant trying to "break in" to the net, or by a transmitter that has drifted out of an assigned frequency on another circuit.

The inadequate frequency stability of present equipment and the crowded condition of the high-frequency spectrum are largely responsible for the condition. Therefore, much indoctrination is required to establish an orderly network of communications by AM techniques.

When there are two or more simultaneous transmissions on an SSB network, the messages will not be distorted nor combined as one in the process of detection. The average person, when hearing two undistorted speech sounds, can mentally select, listen to, and understand the one desired.

In SSB communications, the only indoctrination normally required is that of common courtesy and intelligent behavior, that will give more message time and remove the possibility of complete message distortion by simultaneous communications. This represents a considerable gain over standard AM or FM techniques now in use.

Unfortunately, to obtain a successful network of SSB communications or even a one-way circuit requires either a high order of frequency stability in the equipment or continuous monitoring by the operator. In SSB, when speech is the message form, a difference in transmitter and receiver frequencies of approximately 10 cycles will cause a loss of original clarity.

Differences of 30 to 400 cycles will cause a complete loss of intelligibility, depending on many factors, including the signal-to-noise ratio at the received end. Other more efficient message forms, such as multitone teletype, require an even higher stability, with an error limit of 3 to 10 cycles.

Figure 7 indicates what may be expected with various frequency stabilities.

Until a few years ago, the advantages to be gained by the use of SSB techniques in the high-frequency spectrum have been offset by the exacting technical requirements of equipment design and by the heavy investment in the present systems.

Also, the possibility of refinement of the established AM systems and the modest cost of design improvements have been more attractive than the prospects of investing in a different and relatively untried system.

However, it has now become apparent that the AM systems cannot adequately handle the expected requirements, either in capacity or in reliability and range. Therefore, the Bureau of Ships has sponsored research and development to provide designs for interim and standard equipment for SSB communications from ships and shore stations.

To require a change in a short period of all high-frequency communications to SSB techniques would be economically unsound. Therefore, of necessity, the planning for a successful implementation of SSB techniques must include an interim type of equipment that will operate with equipments now installed.

Interim Equipment

The interim equipment will be in the form of conversion kits for present AM equipment with a service life of 5 years or more, as well as for newly developed equipment that can carry both AM and SSB communications. The prototypes for the interim type of equipment are nearly completed and will be ready for laboratory and service evaluation soon.

Shortly after installation of the interim equipment starts, standard and special SSB communications systems should be available for testing and evaluation. The installation of the equipments, which have maximum data handling capacity to meet the requirements of a modern communications system, should make possible a gradual and orderly transition to the use of SSB communication techniques.

Electronic Countermeasures Cable Failures

Recently several installations of ECM equipment have become temporarily inoperative because interconnecting cables failed through overheating.

The cables that failed included heat-resistant cables; however, they were run through heat concentration areas. In one case the cable was run adjacent to a steam line.

Wherever possible, electronic cables should not be run through high temperature locations, such as in machinery spaces, laundry spaces, and galleys. Nor should they be run unnecessarily near stacks or in areas exposed to stack gases.

If it should ever be necessary to run cables through spaces such as those listed, the cables should not be placed adjacent to high heat surfaces.