A SOLID STATE VHF SINGLE SIDEBAND TRANSMITTER

BY

Ermi Roos

B.S.E.E., Newark College of Engineering, 1966

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1.0 INTRODUCTION

Single sideband (SSB) is a very old method of radio communication, and several decades of experimentation have resulted in a standard reliable method of generating SSB power. This is the classical "filter" method where a balanced modulator suppresses the AM carrier, a bandpass filter selects the desired sideband, a mixer selects the desired transmitter frequency, and a linear amplifier develops the required transmitter power. The earliest SSB transmitters were made in this manner, as well as the most recent ones.

This method of generating SSB has the undesired feature that high level sideband power cannot be generated directly, such as with AM, but must be developed with successive linear amplification. Linear amplifiers have low efficiency, are very susceptible to self-oscillation, and tend to generate intermodulation products. If transistors are used, the devices tend to go into "second breakdown" when they are forward biased sufficiently for good linearity. The "second breakdown" effect becomes more severe with increasing frequency, making the design of transistorized VHF SSB transmitters difficult.

A few methods of generating SSB power directly have been developed, but none has been very widely used. One is the "phasing" method, where SSB power may be generated in a final balanced modulator. Such a scheme would be practical only in a single frequency transmitter, because the carrier phase shift network must be set as close to 90 degrees as possible, and networks that would track the carrier frequency would be difficult to adjust. Practical "phasing" transmitters, in fact, use mixers and linear amplifiers. The phasing circuit is simply used as a low-level single frequency SSB source. It is used as a means of eliminating the need for a bandpass filter with a high skirt factor, which was difficult and expensive to make years ago.

An interesting, but almost unknown, method of generating direct SSB was developed by O.G. Villard in 1948.[1] Villard took advantage of the fact that a narrowband phase modulated signal has sidebands that are identical to those of AM, but the carrier signal is 90 degrees out of phase with that of AM. By mixing a signal that is 90 degrees out of phase with the audio signal , with a signal that is phase modulated by the audio signal, one of the sidebands is suppressed. Unfortunately, the carrier remains, and one of the reasons for using SSB is to eliminate the need for generating carrier power. What is unique about Villard's method is that the mixing may be

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[1]O.G. Villard, "Composite Amplitude and Phase Modulation," Electronics, November, 1948, pp. 86-89.

done by amplitude modulating a class C amplifier. The transmitter described in this paper uses a similar method of generating SSB power.

In 1952, Leonard R. Kahn wrote a paper describing the principles of amplifying SSB by envelope elimination and restoration.[2] With this scheme, a low-level SSB signal is infinitely limited, leaving only a phase modulated signal. The phase modulated signal is amplified to a high level with class C amplifiers. A portion of the original SSB signal is envelope detected, and the detector output is applied to an AM modulator that modulates the last class C amplifier. The class C amplifier output is a reproduction of the original SSB signal.

The object of this paper is to demonstrate that the Kahn method provides a practical means of designing a solid-state VHF SSB transmitter. This method exchanges increased complexity in low-level circuits for increased efficiency and ease of design and adjustment of the final power amplifier. Although Kahn's transmitter has not been popular in the past, it will be argued here that the relative cost between low-

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[2]Leonard R. Kahn, "Single Sideband Transmission by Envelope Elimination and Restoration," <u>Proceedings of the I.R.E.</u>, July, 1952, pp. 803-806.

level integrated circuits and high-level RF transistors justifies the use of complex low-level circuits, and simple RF power circuits.

The results of testing an actual envelope elimination and restoration transmitter will be described here. Since a standard VHF transmitter of comparable performance was not designed, strict comparisons between the two methods cannot be made. Nevertheless, the practicality of the envelope elimination and restoration technique will be demonstrated.

2.0 PRINCIPLES OF ENVELOPE ELIMINATION AND RESTORATION SINGLE SIDEBAND

2.1 Basic Theory

The generation of SSB power by envelope elimination and restoration is based upon the fact that any continuous wave modulated signal may be expressed as a product of the detected signal envelope and a phase modulation component. This may be expressed by the equation below.

$$f(t) = E(t)\cos\left[\omega_c t + \phi(t)\right] \tag{1}$$

Where E(t) is the envelope function, ω_c is the carrier frequency, $\phi(t)$ is the phase function, and $\cos\left[\omega_c t + \phi(t)\right]$ is the carrier, or phase modulation component. By separating the envelope function from the phase modulation component, and amplifying the two signals separately, it is possible to recombine the signals in a high power mixer and reproduce the original composite signal.

The phase modulation component in Equation 1 may be isolated by multiplying f(t) by the inverse of the envelope function, which is $\frac{1}{E(t)}$.

$$\frac{f(t)}{E(t)} = \frac{E(t) \cos \left[\omega_c t + \phi(t) \right]}{E(t)} \tag{2a}$$

$$= \cos \left[\omega_c t + \phi(t) \right] = f_{PM}(t) \tag{2b}$$

In practice, multiplication by the inverse of the envelope component is accomplished with a zero-crossing detector, or an infinite limiter. $f_{PM}(t)$ is amplified to the desired level using class C amplifiers, and then multiplied by a signal proportional to the envelope function, $E(t)$, to restore the original signal, (1). $E(t)$ is obtained by AM detecting the continuous-wave modulated signal.

Multiplication of two signals is usually done by the use of a balanced modulator, but, in this case, a standard AM modulator is sufficient. This is because $E(t)$ contains a DC component that prevents negative excursions of $E(t)$. A class C amplifier, which is suitable for amplifying $f_{PM}(t)$, may then also be used for multiplying $E(t)$ with $f_{PM}(t)$.

Accurate restoration of the original signal depends upon correctly preserving the amplitude and time relationships of $E(t)$ and $f_{PM}(t)$. Any errors in either signal will cause distortion in the restored signal.

2.2 Linear and Nonlinear RF Amplifiers

If an RF signal has no time-varying envelope, it may be amplified without distortion by either linear or nonlinear amplifiers. This is because all of the distortion products produced by nonlinearity will be centered around the harmonics of the carrier frequency, and they may easily be filtered out by conventional power amplifier tuned circuits. If a signal has an envelope, however, nonlinear amplifier gain will cause the envelope to amplitude modulate the desired signal, resulting in distortion products within the passband of the desired signal. These distortion products cannot be filtered out.

If either linear or nonlinear amplifiers may be used in an application, the nonlinear amplifier is the obvious choice. This is because all active devices are nonlinear by nature, and improvement in power gain linearity is usually obtained by sacrificing amplifier efficiency and increasing circuit complexity. Moreover, nonlinearity is actually required when the envelope function and phase modulation components are finally recombined.

2.3 Intermodulation Distortion as a Design Consideration

2.3.1 General

As with linear amplification, perfect reproduction of an SSB signal also cannot be obtained with the envelope elimination and restoration method. It is the purpose of this section to establish how much distortion is tolerable in a VHF SSB transmitter. It has been observed that the envelope of an SSB signal contains very little information, and the signal remains intelligible even if the envelope is infinitely limited. Distortion of the envelope, however, results in the production of intermodulation products. In commercial practice at HF frequencies, third-order products produced in a two-tone test are held at least 30 db below the level of one of the test tones. Because of the close channel spacing used at HF frequencies, third-order products may fall into an adjacent channel. In the VHF region, however, more frequency space is available, and the channels need not be spaced very close together. Currently, there are no commercial SSB frequency allocations above 50 MHz, and so, information about interference to adjacent channels cannot be obtained from actual experience. As a hypothetical example, it will be supposed here that AM transmitters were eliminated from the 118 through 136 MHz civil aircraft band, and SSB transmtters were used instead.

2.3.2 Practical Considerations in VHF SSB

At HF frequencies, maintaining a narrow bandwidth of transmission is very important because only a small portion of the spectrum is available for communications. At VHF frequencies, however, the stability of the transmitter and receiver is more important than the signal bandwidth in establishing channel spacing. This can be shown by comparing the 118 through 136 MHz aircraft band with the aeronautical mobile bands available at HF frequencies. The 118 through 136 MHz band covers a total of 18 MHz, which is an incredibly large bandwidth compared to the 2.25 MHz allocated for aeronautical mobile operations at HF frequencies. Moreover, the widest single aircraft band in the HF region is only .305 MHz wide. This is particularly important because the frequency band an airborne station will use is usually established by day-to-day propagation conditions. Thus, at any particular time, a large number of pilots may be operating within a single band, while the remainder of the 2.25 MHz will receive little use.

At the present time, 720 channels, spaced 25 kHz apart, have been assigned in the 118 through 136 MHz band. Considering that the maximum range of the transmitters used is approximately 200 miles, this number is more than adequate.

The Federal Communications Commission requires a frequency tolerance of .005% in the transmitters operating in this band, which means that the carrier frequency can deviate as much as 6.8 kHz at the high end of the band. The IF bandpass must be wide enough to receive any signal .005% away from the center of the desired channel. In determining the IF bandpass, the frequency stability of the receiver must also be taken into account. If both the transmitter and receiver have frequency tolerances of .005%, and no fine tuning is used in channel selection, the IF bandpass must be twice .005% the channel frequency in both directions from the center of the bandpass, plus the signal bandwith. At 136 MHz, the total bandpass must be 4 x .00005 x 136000 kHz + 6.8 kHz, or 33.2 kHz. If SSB were used, rather than AM, the required banwidth would only be reduced to 30.2 kHz. This is much too wide for effective SSB operation, because the noise bandwidth is much greater than the signal bandwidth. The IF bandpass for SSB should be only 3 kHz. If tuning is done simply by channel swithing, this would impose a severe restriction upon the frequency tolerance of the transmitter and receiver. Frequency stability would have to be in the order of one part per million. This is certainly possible, but difficult to achieve economically in an airborne transmitter and receiver. A better solution would be to maintain .005% frequency tolerance in both the transmitter and receiver, and to include fine tuning in the receiver. The transmitter could generate a low-level pilot carrier so that the transmitter can be easily tuned in.

2.3.3 Calculation of the Intermodulation Distortion Specification

Let us consider the situation where an SSB transmitter is tuned to exactly 135.975 MHz, and a receiver is tuned to exactly 136.000 MHz. The transmitter is modulated with two equal-amplitude tones at 300 Hz and 3000 Hz, which is the widest frequency spacing possible in many SSB transmitters. The receiver has a bandwidth of 3 kHz. The frequency spacing between one of the test tones of the transmitter, and the edge of the receiver bandpass is 25 kHz - (2.7 kHz ÷ 2) - (3.0 kHz ÷ 2) = 22.15 kHz. (It should be noted that the center of the bandpass of the SSB signal is not the carrier frequency, as in the case of AM, but the center of the transmitter power spectrum.) This means that a total of seven distortion products will appear in the unused frequency space between channels, and the eighth product will appear in the bandpass of the receiver. Because in-band distortion consists entirely of odd-order distortion products (the even-order products appear as harmonics and are filtered out by the tuned circuits of the transmitter), seventeenth order distortion will appear in the bandpass of the receiver. Even if the transmitter signal is infinitely limited, the seventeenth-order product will be 1/17 of the level of one of the test tones, or 25 db down. This fact is demonstrated in Appendix A. This example shows that even the worst-case distortion will not cause severe interference in the adjacent channel under the conditions described. Of course, simply limiting and amlifying the SSB signal will not result in satisfactory operation. The transmission, though still intelligible, will be badly garbled, and the interfering signal should be 30 db down rather than only 25 db down, and it is the thirty-third order product that is that low. This product is 40.5 kHz away from one of the test tones.

If the linearity of the system were improved so that the seventeenth-order distorion is 30 db below one of the test tones, the third-order product need be only 15 db down. This is because the amplitude of a distortion product is usually proportional to its order, and the seventeenth-order product is 3/17 of the amplitude of the third-order product. This ratio is approximately -15 db. Since the seventeenth-order product is 30 db down, the third-order product need be only 15 db down.

Unfortunately, a reasonable amount of frequency tolerance must be allowed in the transmitters operating within the band. This means that it will not be always possible to maintain the same amount of frequency space between channels as in the previous example. Let us suppose now that the transmitter that should be operating at 135.975 MHZ is .005% of the channel frequency too high, and the receiver is tuned to a signal .005% of 136 MHz below 136 MHz. There is now 13.6 kHz less unused frequency space between channels than there was before, or only 7.55 kHz. Two distortion products will be in the unused space, and the third will be in the adjacent channel. This will be the seventh-order product. If the seventh-order product is 30 db below one of the test tones, the third-order product will be 23 db down. This is because the ratio of the third-order product and seventh-order product is 7 db.

From the above discussion, it is concluded that the third-order distortion products in the transmitter being described, should be 23 db below one of the test tones in a two-tone test.

2.4 Second Breakdown in RF Power Transistors

2.4.1 General Description of Second Breakdown

Second breakdown is a phenomenon of transistors where high current concentrations become localized in hot spots within the transistor pellet, and cause a regenerative effect where the transistor is unable to sustain the applied collector-to-emitter voltage. Destruction of the transistor usually results. What is particularly disturbing about second breakdown is that it may occur within the primary breakdown and dissipation ratings of a transitor.

While second breakdown can happen in any transistor, it primarily occurs in high-frequency power transistors with reactive loads. The hot spots occur when the transistor is drawing a large amount of collector current, with a high level of collector-to-emitter voltage. If a transistor has a purely resistive load, the peaks of the voltage waveform coincide with the troughs of the current waveform. This is because the transistor collector is a current sink, and its voltage goes down as it sinks more current. Thus, a transistor with a resistive load has a considerable amount of second breakdown protection. If the collector circuit has reactive elements, however, the collector voltage may be sustained at a high level when the collector current is at maximum. This is because the energy-storage elements would delay the collector voltage waveform from what it would be with a resistive load. Regardless of the type of load a transistor has, second breakdown may also be produced by DC biasing a transistor for high collector voltage and current.

The susceptibility of a transistor to second breakdown increases as its gain bandwidth product, f_t, increases. The formula for the current at which second breakdown occurs has been found experimentally to be

$$I_{sb} = K\frac{1}{\sqrt{f_t}}$$

where K is a constant applicable to a particular transistor.[1] VHF power transistors require an f_t of several hundred megahertz to operate effectively, and they are thus very susceptible to second breakdown.

2.4.2 Second Breakdown in Class C and Linear Amplifiers

Figure 1 shows the collector voltage and current waveforms of a properly tuned class C RF power amplifier. Note that the current pulses occur only when the collector voltage is swinging to the minimum value. This phase relationship makes second breakdown very unlikely, and it occurs only if the collector load is resistive at the resonant frequency. If the amplifier is not perfectly tuned, the collector load will be reactive at the operating frequency, and there will be a phase shift in the collector voltage. Under severe

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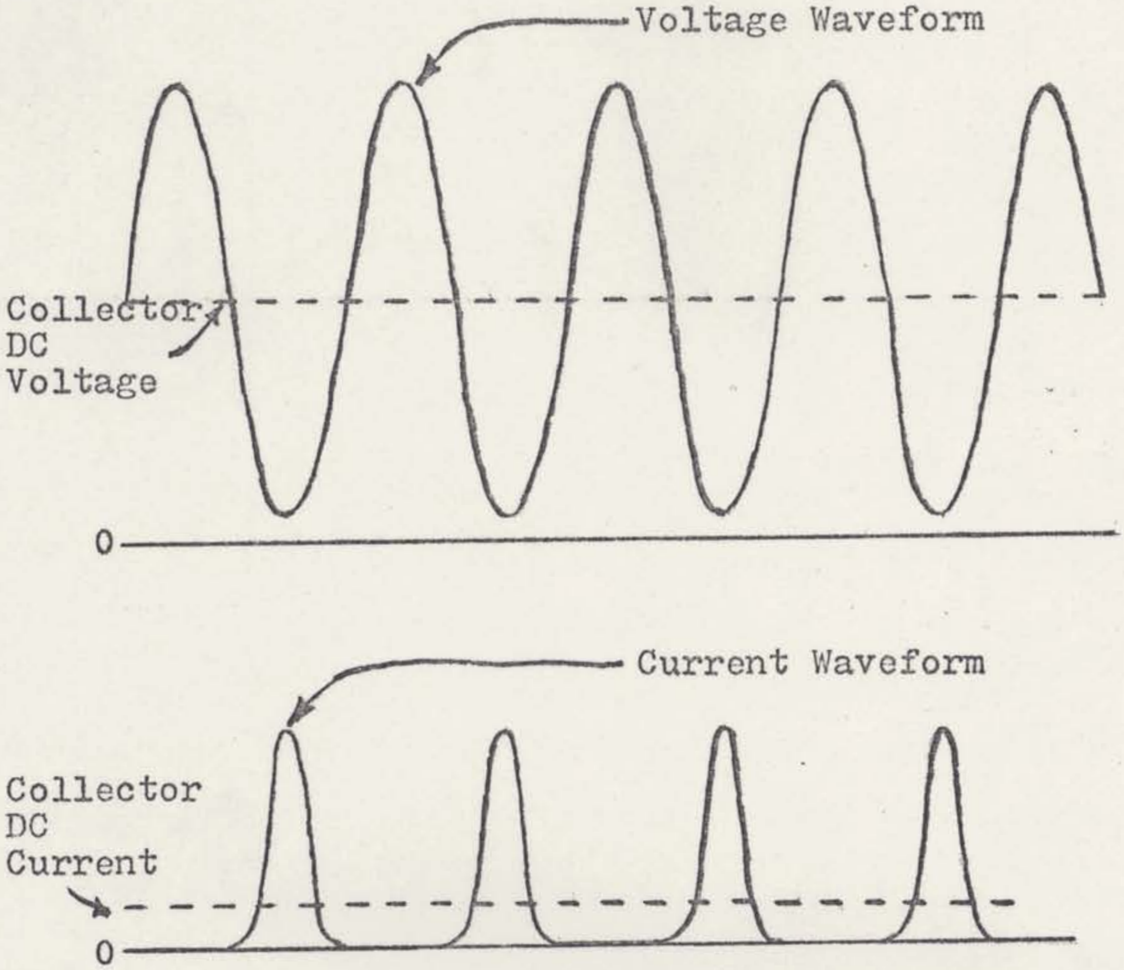
[1]RCA Power Transistor Manual (Sommerville, N.J.: RCA Solid State Division, 1971), p. 14.



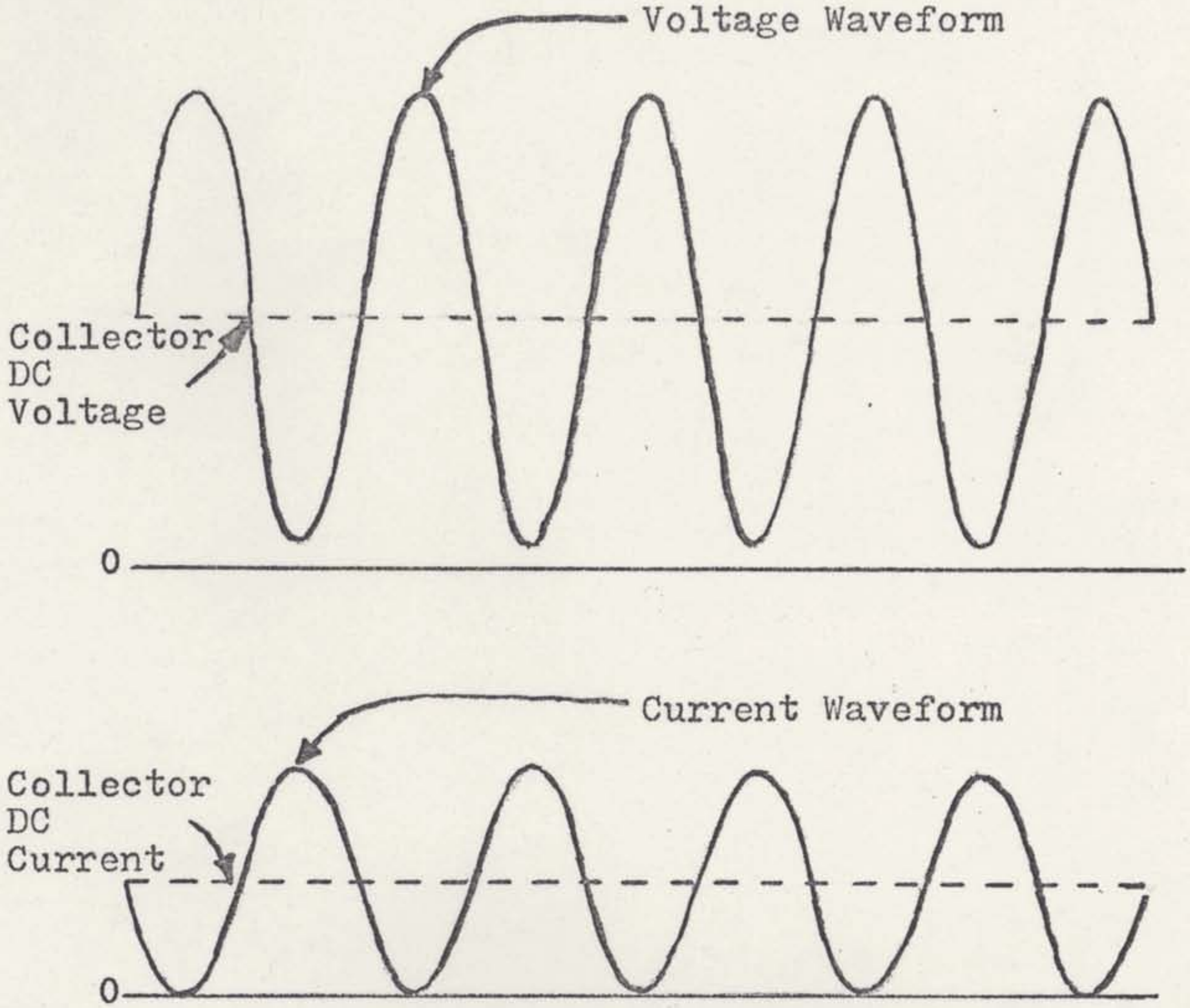
Voltage and Current Waveforms of a Class C Amplifier

Figure 1

load mismatch conditions, the phase shift can be large, and both the voltage and current can be high simultaneously. This can cause second breakdown to occur. RF power transistors of the "overlay" type are designed to prevent the current concentrations that cause second breakdown. They have a large number of emitter sites with small integrated "ballast" resistors in each site. If a hot spot tends to develop at an emitter site, the ballast resistor will cause emitter degeneration which reduces the amount of current at the site.

Ballasting degrades the RF performance of a transistor, somewhat, by decreasing transistor gain and increasing saturation voltage. Therefore, the minimum amount of ballasting to ensure adequate second breakdown protection should be used.

Figure 2 shows the voltage and current waveforms of a perfectly tuned class A linear amplifier. A transistor RF amplifier may also function in a linear fashion in the class AB mode. The voltage and current phase relationships of Figure 2 are the same as in Figure 1. The major difference between the two diagrams is the time duration of collector conduction. The longer conduction time of linear amplifiers causes the transistor to draw more current at high collector voltages. This makes second breakdown more likely. Poor load mismatch



Voltage and Current Waveforms of a Class A

Amplifier

Figure 2

will have the same effect in linear amplifiers as in class C amplifiers, but with more severe results.

Special transistors have been designed for linear SSB operation in the HF region. They employ a large number of ballasted emitter sites, and they require high bias current for good linearity. The bias current has to be well regulated to prevent the destruction of the transistor. These transistors are only suitable for use up to 30 MHz.

2.5 The Basic System

Figure 3 shows the basic envelope elimination and restoration system as described by Kahn in his classic paper.[1] The output of the SSB Generator is limited, leaving a phase modulated signal. The Mixer and Oscillator establish the transmitting frequency of the system. The phase modulated signal is amplified to the desired level by a series of class C amplifiers. At the same time, the output of the SSB Generator is envelope detected, amplified, and applied to an AM modulator. The modulator and last class C amplifier mix the phase modulation and envelope components of the original SSB signal, and the output of the amplifier is a reproduction of

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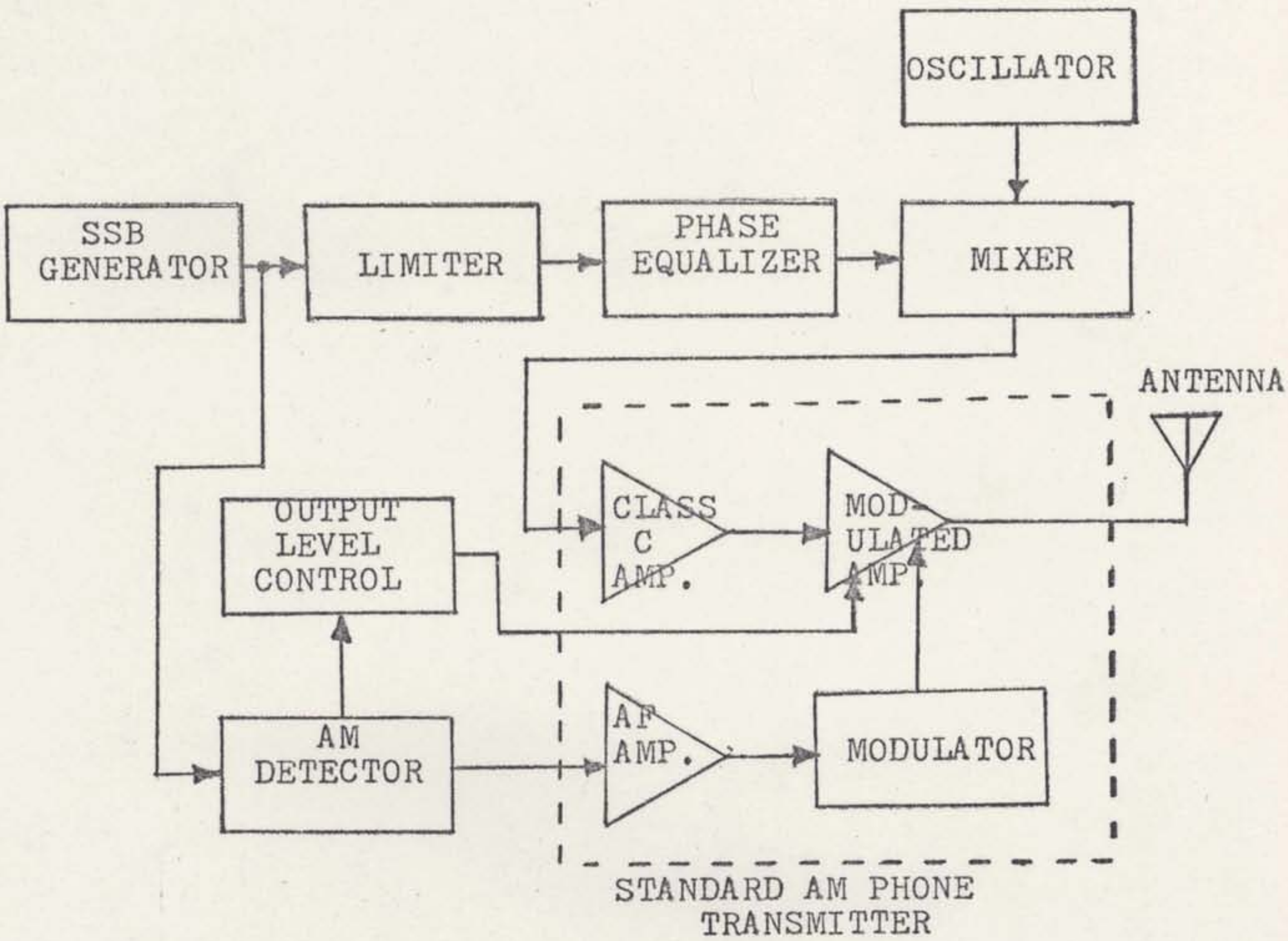
[1]Kahn, op. cit.



Basic Envelope Elimination and Restoration System

Figure 3

the SSB Generator output.

A particularly appealing feature of the Kahn method is that an AM transmitter can be used to generate SSB. It appears, at first glance, that SSB power can be generated with the same ease as AM. Unfortunately, this is not the case. There are fundamental differences between the envelopes of AM and SSB that cause difficulties in the implementation of the system.

AM has constant average power, and therefore, its detected envelope has a constant DC level. For this reason, AM modulators may be AC coupled to the modulated amplifiers, because the level of the DC component (i.e., carrier power) may be established by a DC power supply. AC coupling cannot be used with SSB, however, because its average power changes rapidly with time. For this reason, the Modulated Amplifier in Figure 3 is modulated by two separate signals that are derived from the detected SSB envelope. One signal is the Modulator output, which is transformer coupled to the plate of the final power amplifier tube. This signal contains the AC component of the envelope detector output. The other is a DC voltage that follows the DC level of the envelope detector output. The Output Level Control contains a low-pass filter that eliminates the AC component of the envelope, and a DC amplifier that applies a signal that is proportional to the average level of the envelope to one of the grids of the final power amplifier tube.

One difficulty with using two modulation paths is ensuring that the two signals complement each other well enough so that the detected envelope is accurately reproduced. The levels have to be carefully balanced, and the upper cutoff frequency of the Output Level Control should be the same as the lower cutoff frequency of the Modulator. If a transistorized RF power amplifier is used, only a single modulation path is necessary, because a modulator can be readily DC coupled to the final power amplifier.

In order to accurately reproduce SSB, the AM transmitter must be capable of 100 percent downward modulation. This is because the SSB envelope frequently crosses zero. 100 percent modulation is easier to obtain with tube transmitters than with transistorized transmitters. This is because the drive power of a transistor can feed through to the output even if the collector voltage is zero. By modulating several stages at once, however, a high percentage of modulation can be obtained.

The Phase Equalizer in Figure 3 is intended to balance the time delays between the phase modulation component and envelope componet during signal processing so that the original SSB signal is faithfully reproduced once the two components are recombined. The Phase Equalizer, however, is shown in the wrong place in the diagram. It should be located between the AM Detector and AF Amplifier. Kahn was probably aware of this, but failed to pick out the error on the printer's proof sheets. To prove that the Phase Equalizer should be in the AF path rather than the RF path, Appendix B will show that the phase delay in the RF path will not cause any distortion in the recombined SSB signal.

Modulators containing transformers and coupling capacitors have appreciable phase delays that can cause spurious outputs in the envelope elimination and restoration system. These delays must be equalized. The need for phase equalization is eliminated if the modulator has a sufficiently wide frequency response so that there are no appreciable phase delays within the passband of the detected envelope. This means that the modulator must be flat well into the supersonic range. This was not possible with vacuum tube modulators, but can be easily done with integrated operational amplifiers.

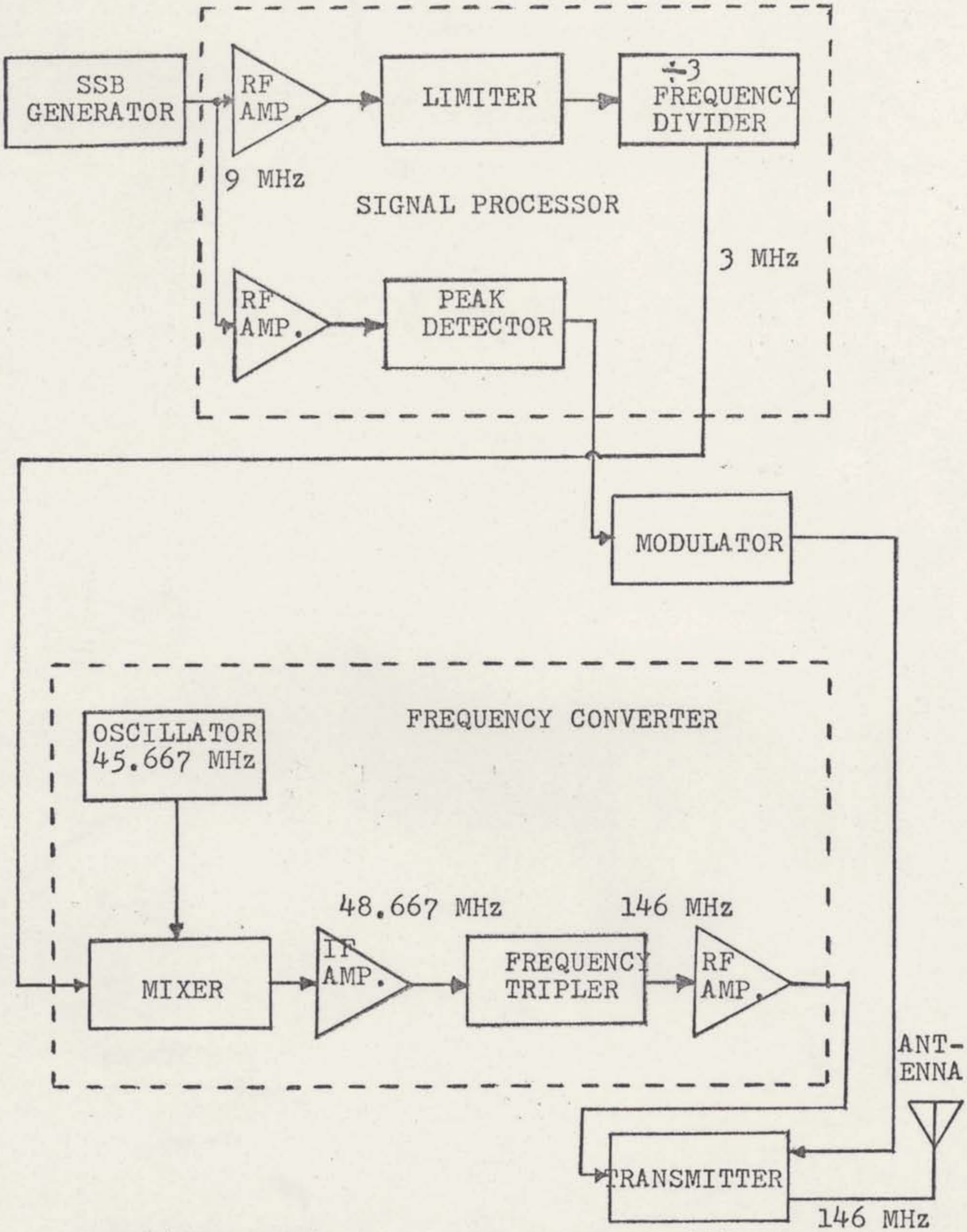
Another important consideration in the envelope elimination and restoration system is the linearity of the modulator. AM transmitters function well even if the envelope of the transmitter output is not a good reproduction of the audio signal applied to the modulator. This is not the case with the system under consideration. Nonlinearities in the modulation would cause spurious frequencies in the transmitter output.

2.6 The Proposed System

2.6.1 General

Figure 4 contains a block diagram of the proposed experimental solid-state VHF transmitter. It has an operating frequency of 146 MHz, and it is capable of developing 4 watts PEP. A transistorized AM transmitter is used as the modulated power amplifier. The Modulator is DC coupled to the Transmitter, and therefore, no "output level control" is necessary. The Modulator also has a sufficiently wide frequency response so that no phase equalization circuits are needed in the system.

The proposed system uses a unique frequency conversion technique that eliminates the need for multiple mixer-oscillator circuits. Because the output of the Limiter is a phase modulated signal, it may be frequency multiplied or divided without any distortion in the transmitted information. Only the modulation index changes by the factor of the frequency multiplication. Figure 4 shows that the 9 MHz output of the Limiter is divided in frequency by three to



Proposed Solid State VHF SSB Transmitter

Figure 4

give a 3 MHz phase modulated output. The modulation index of the Frequency Divider output is one third that of the Limiter. Frequency tripling the IF Amplifier output results in a 146 MHz signal that has the same modulation index as the Limiter output. Thus, the 9 MHz Limiter signal is frequency converted to 146 MHz by the use of only a single mixer-oscillator circuit. A system similar to this was proposed by Karl Meinzer in 1970.[1]

The experimental transmitter was designed only to demonstrate the new technique, and not for any particular practical application. For this reason, the transmitter was made as simple as possible, and contains no circuits that are designed only for operator convenience. The use of only a single frequency of operation particularly helped to simplify the design. The use of 146 MHz places the operating frequency at the center of the 2-Meter Amateur Band. This frequency is far from the normal activity on the band, and allows unlimited testing of the transmitter without harmful interference to others.

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[1] Karl Meinzer, "A Frequency Multiplication Technique for VHF and UHF SSB," QST, October, 1970, pp. 32-35.

2.6.2 The Frequency Converter

The frequency conversion technique presented here is similar to one described by Karl Meinzer in an amateur radio magazine.[1] Meinzer's total system deviates considerably from the one developed by Kahn. Figure 5 shows that modulat-ion is not applied to the final power amplifier, but to the Frequency Divider output. This signal is then applied to a Mixer-Oscillator that heterodynes the signal to one third the desired frequency of operation. A Linear Amplifier develops the signal to a higher power level, and a varactor Frequency Tripler generates SSB power at the desired operating frequency.

This sort of transmitter must have a high level of intermodulation distortion because a varactor frequency tripler is certainly not a linear amplifier. Nevertheless, Meinzer reports that his signal was perfectly intelligible, and the third-order intermodulation products were 25 db down. Apparently, the varactor tripler followed the envelope of its input signal remarkably well. Meinzer operated his transmitter at 1296 MHz, where interference to adjacent channels is not a problem (largely because there is very little

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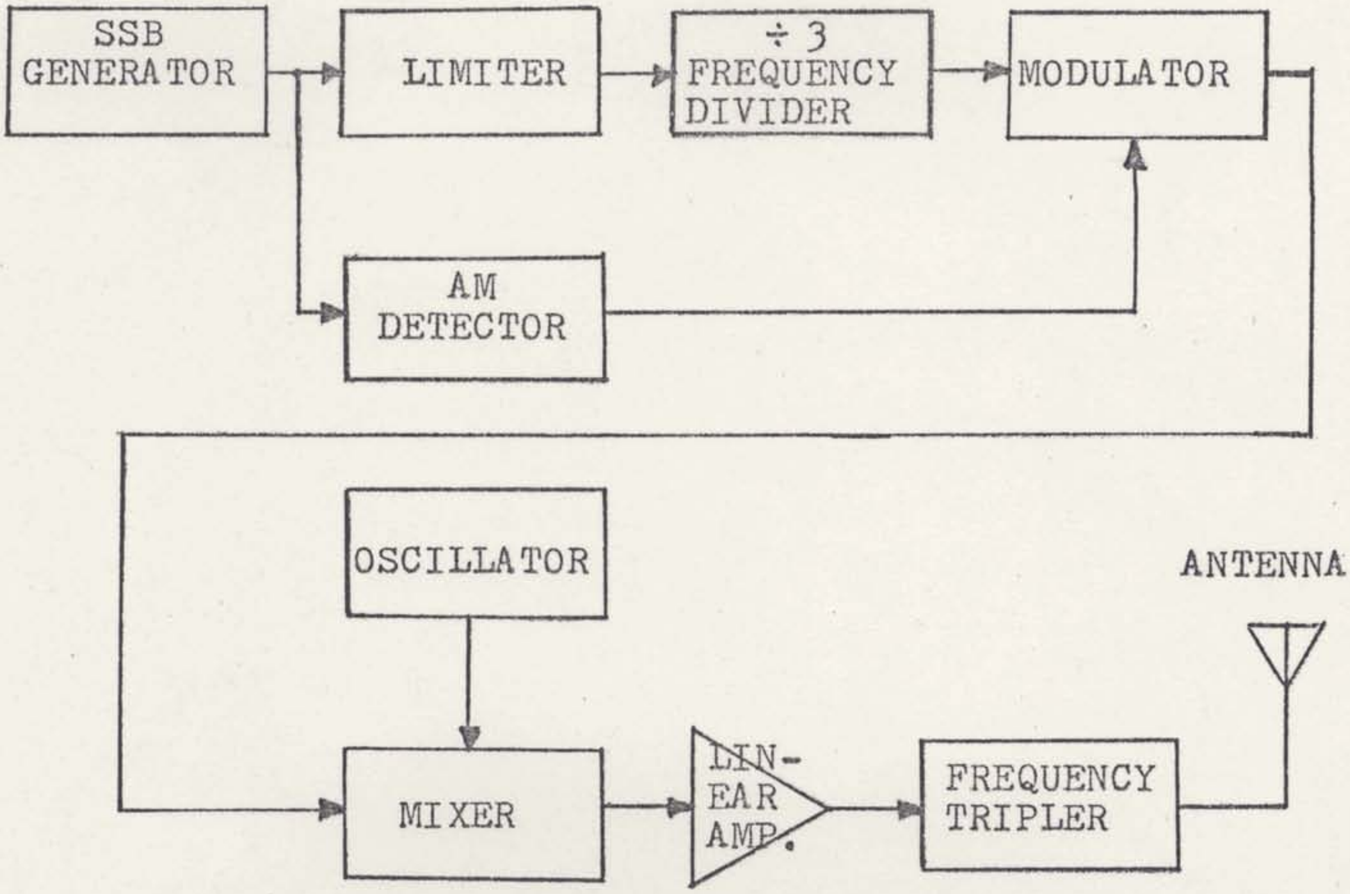
[1] *Ibid.*



The Meinzer Method

Figure 5

activity at these frequencies). The transmitter described in this paper makes use of the frequency division-tripling idea, but AM modulation is still applied to the power amplifier, as in Kahn's transmitter.

The advantage of first dividing the phase modulation component by three, and finally tripling it, may not be obvious at first, but a little thought will reveal that it is easier to heterodyne a 3 MHz signal to 48.667 MHz, than a 9 MHz signal to 146 MHz. The ratio of the oscillator frequency (f_o) to the input signal frequency (f_s) remains the same in both cases, but suppression of undesired mixer products is easier at the lower frequency than the higher. An important mixer product that must be suppressed is the oscillator signal, or carrier. In an unbalanced mixer, the carrier level is normally much higher than that of the desired signal. With the f_o/f_s ratio used here, f_o is very close to the desired output signal, and a considerable amount of filtering is ordinarily required to attenuate the carrier. The best solution would be to make a balanced mixer that would suppress the carrier. Obtaining effective carrier balance is very difficult at 146 MHz because the phase shifts due to reactive elements in transistors are appreciable at this frequency, but a considerable amount of carrier suppression is easily obtained at 48.667 MHz. Another problem is that the third-order mixing product, $f_o + 2f_s$, is just as close to the desired signal as the carrier. This product can only be eliminated by good filtering. Tuned circuits are more effective at 48.667 MHz than 146 MHz, because there are less losses due to skin effect and radiation, and higher Q's are possible.

In order to obtain a complete understanding of the system requirements of the frequency converter, the output of the Frequency Divider for a two-tone modulated SSB signal, is calculated in Appendix A.

2.6.3 The Transistorized Transmitter

A class C RF power amplifier is used to develop SSB power in the experimental transmitter. The advantages of using class C amplifiers to generate SSB, rather than class A or AB amplifiers, have been pointed out earlier in this paper. It should be stated here that it is not necessary to modulate the collector to obtain linear amplification with class C amplifiers. A sort of base modulation is now used in transistor linear amplifiers for AM operation in the 225 to 400 MHz military aircraft band.[1] A feedback control system is

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[1]Russel A. Gilson "A Simple High-Performance Feedback Modulation System," Research and Development Technical Report ECOM-3224 (Fort Monmouth, N.J.: United States Army Electronics Command, January, 1970).

used, which is similar to the automatic level control (ALC) systems now used to correct nonlinearities in SSB linear amplifiers. The dynamic range and gain of this feedback system is much greater than that of ordinary ALC, because the nonlinearities of class C amplifiers are much more severe than those of amplifiers already designed for linear operation. The nonlinearities are corrected by modulating the input of the final power amplifier with the error signal of the feedback system.

This system is used for AM, which does not have as critical linearity requirements as SSB. It is capable of only up to 85% modulation, while the SSB envelope has 100% downward modulation. The system also requires an appreciable amount of drive power which must be generated by linear amplifiers at the operating frequency. Further details of this system are given in Appendix C.

3.0 CIRCUIT DESCRIPTION

3.1 General

This chapter contains an explanation of the circuits used in the experimental transmitter. The schematic diagrams (Figures 6 through 11) are divided into sections that correspond to the blocks in Figure 4.

Such incidental circuits as DC power line filters, and other circuits used to suppress interference within the system, have been omitted from the discussion.

3.2 SSB Generator

The SSB Generator (Figure 6) is the source of the low-level SSB signal that is frequency converted and amplified by the transmitter described in this paper. Oscillator Q1 develops the carrier signal used by the SSB Generator. It has an operating frequency of 8.9985 MHz, and it is applied to Balanced Modulator U1. An audio signal from a microphone is applied to U2, which acts as a high input impedance buffer amplifier for the microphone. U2 has unity voltage gain. Voltage amplification is obtained with U3, and the gain is adjusted by R12. DC offset of U3 is adjusted with R20.