PRE-DETECTION CONVERTERS FOR TAPE RECORDERS

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ABSTRACT

RF and IF signals must be down-converted to lower frequencies to allow storage on tape. Pre-Detection converters avoid signal distortion created in later receiver stages, however should not add noise and distortion with their conversion process.

KEY WORDS

Imageless Mixer, Converter, Pre-Detection

INTRODUCTION

Frequency conversion in receivers for purposes of frequency selection and to enable demodulation of the encoded information is achieved through superheterodyne techniques. The carrier frequency is converted to an intermediate frequency (IF) by mixing it with a local oscillator (LO) frequency. LO frequencies and IF frequencies must be selected to ensure that the converted IF frequencies are sufficiently separated from the RF and LO frequencies such that the IF can conveniently be filtered to remove any RF and LO components. Any residual LO and RF components will result in signal distortion (degradation of the encoded information).

Further conversion to frequencies suitable for recording on magnetic tape must also ensure that conversion LO, RF and IF image signals do not affect the converted output. Selection of suitable frequencies for the conversion process can be difficult, if not impossible.

A superior method of down-conversion to tape suitable frequencies is necessary to provide noise-free signals. A circuit topology well suited for this application is called an imageless mixer. An imageless mixer can convert the IF signal to baseband while preserving nearly 100% of the IF bandwidth, and providing excellent amplitude and group delay responses that preserve the characteristics of the original IF signal.

SUPERHETERODYNECONVERSION

A straightforward conversion from the IF to Tape frequency is not generally an advisable circuit topology, due to image fold-over noise. As a typical illustration, refer to the receiver block diagram shown on Figure 1-1.

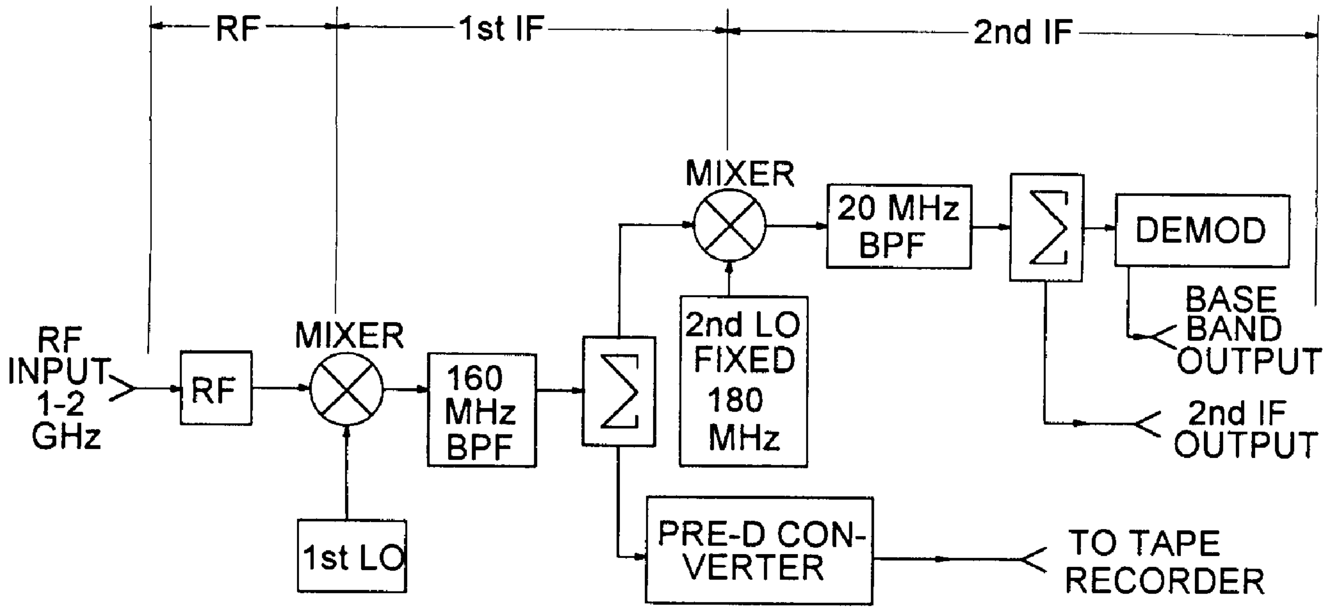

Figure 1-1. Receiver/Pre-D Converter, Block Diagram

A Pre-Detection ("Pre-D") converter is normally connected to the receiver at the earliest practical point to avoid the possibility of signal loss due to receiver failures, or signal characteristic loss due to receiver distortion. If the Pre-D converter were connected to the 2nd IF output shown on Figure 1-1, the signal would be processed through the receiver IF filter on record and once again on playback. Two trips through the narrow filter cause increased signal distortion.

IMAGE FREQUENCY

A simplistic design for conversion of a 160 MHz IF signal to a baseband signal is shown on Figure 1-2. The inherent problem with this scheme is that the circuit has no practical way to reject the image foldover noise. When the image noise is not rejected, the noise of the receiving system is increased by 3 dB and a "0 dB" spurious response instability is created. Both of these characteristics are very undesirable.

For the purpose of illustrating the undesirable characteristics of the simplistic design, let signals on the high side of the LO from 159 MHz + 10 kHz to 159 MHz + 2 MHz be the desired IF signals. The signals below the LO from 159 MHz - 10 kHz to 159 MHz - 2 MHz are then the undesired or image signals. Unfortunately for this topology, the mixer responds equally well to signals on either side of the LO. The image signals should be rejected, otherwise the so-called image "fold-over" noise will increase the receiving system noise figure by 3 dB. Increasing the system noise figure can be a very harmful result, but even worse is a "0 dB" spurious response to signals in the image band. That is, the mixer responds equally well to both desired and undesired signals, providing a 0 dB amplitude difference between the signals.

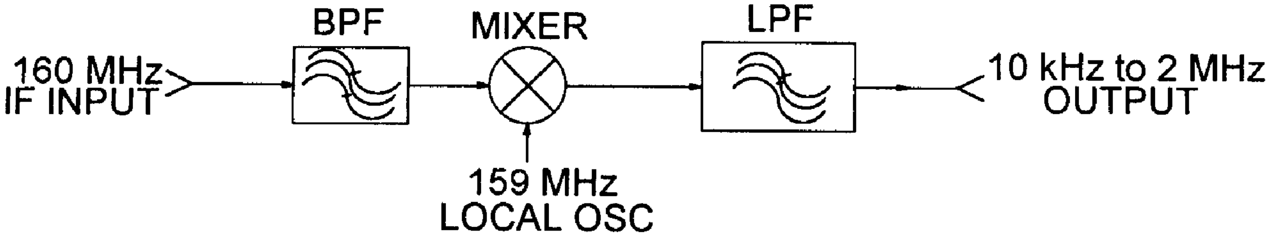

Figure 1-2. Simple Converter, Block Diagram

Changing bandpass filter characteristics on Figure 1-2 is not considered to be an effective way to eliminate image signals because of the extreme shape factor required to reject the image. The shape factor is 1.01 from the 3 dB bandpass to the 30 dB rejection bandwidth. Constructing such a filter is not a very practical solution. Using a suitable bandpass filter in this scheme can be made to work, but the output signal bandwidth must be decreased considerably, contributing to signal distortion. However, there is no good reason to use a variation of this simplistic design because of the availability of imageless mixers.

IMAGELESS MIXER

Figure 1-3 shows a typical imageless mixer scheme used to Pre-D convert IF signals. The circuit uses the Σ_1 and Σ_3 quadrature phase splitters/summers to provide a feature unique to imageless mixers. The IF signals from M_1 and M_2 that are above the LO at 159 MHz are combined at the mixer output. The signals below the LO are rejected. This is shown on Figure 1-3 as a signal vector or phase diagram.

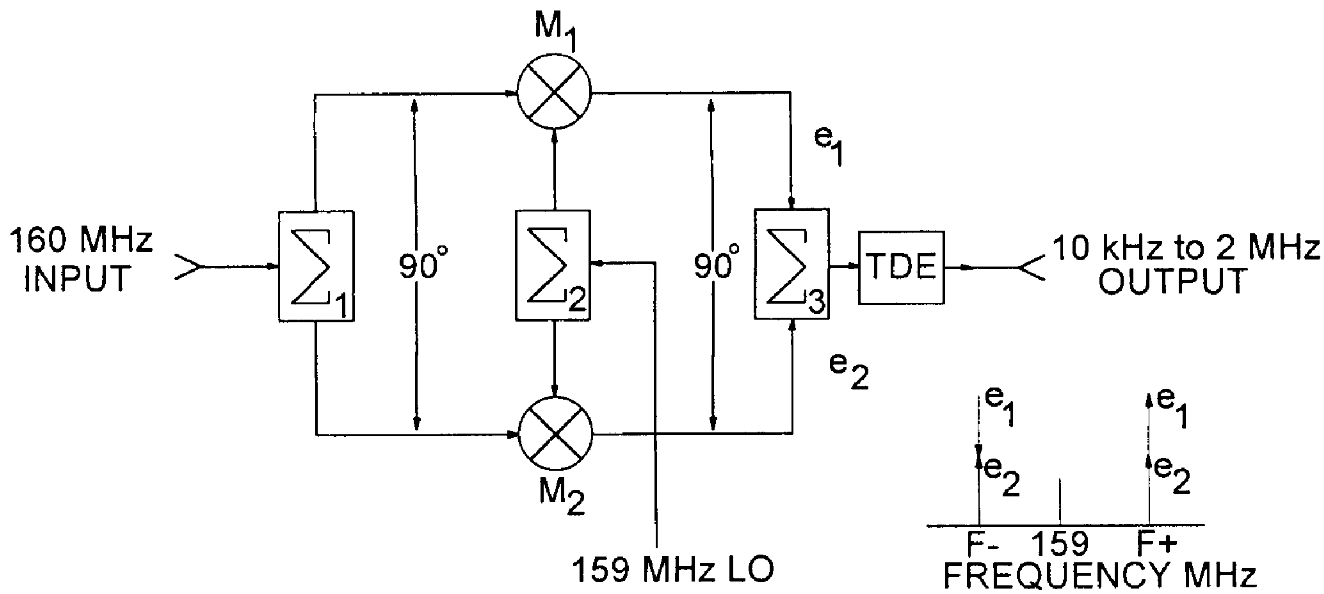

Figure 1-3. Typical Imageless Mixer, Block Diagram

To show this mathematically we inject two signals, P and Q, that are 1 MHz above and 1 MHz below the LO frequency respectively so that the composite signal at the converter input may be expressed as:

$$e_t = \mathrm{P}\sin(\omega_0 t + \omega_p t) + \mathrm{Q}\sin(\omega_0 t - \omega_q t)$$

where:

t = time.

e_t = instantaneous voltage at the input to Σ_1 at time t.

P = amplitude of the upper modulating signal.

Q = amplitude of the lower modulating signal.

$\frac{\omega_p}{2\pi}$ = frequency offset of P from the LO (1 MHz).

$\frac{\omega_q}{2\pi}$ = frequency offset of Q from the LO (-1 MHz).

$\frac{\omega_0}{2\pi}$ = frequency of the LO (159 MHz).

Since splitter Σ_1 is a quadrature splitter, the output to mixer M_1 will be e_t as above and the output to mixer M_2 will be delayed by 90 degrees, so that the output of the two mixers after mixing with the LO will be..

These two equations may be expanded to:

$$e_{m1t} = P\left[\cos\omega_p t - \cos\left(2\omega_0 t + \omega_p t\right)\right] + Q\left[\cos\omega_q t - \cos\left(2\omega_0 t - \omega_q t\right)\right]$$

$$e_{m2t} = P\left[\sin\omega_p t + \sin\left(2\omega_0 t + \omega_p t\right)\right] + Q\left[\sin\left(-\omega_q t\right) + \sin\left(2\omega_0 t - \omega_q t\right)\right]$$

Since we are only concerned with base band frequencies and all mixer products that are above 2 MHz will be removed at a later stage by low pass filtering we can eliminate the higher frequency terms from the above two equations to yield:

$$e_{m1t} = P\ \cos\omega_p t + Q\ \cos\omega_q t$$

$$e_{m2t} = P\ \sin\omega_p t - Q\ \sin\omega_q t$$

Adding the two mixer outputs in quadrature summer Σ_3 will give us the imageless mixer output:

$$e_{ot} = 2P\ \cos\omega_p t$$

where

e_{ot} = the instantaneous voltage at the output of the imageless mixer at time t

It is clear that the Q signal that was below the LO frequency has been canceled out by the final summer. Although two single signals were used to demonstrate the imageless mixer function, the above would apply to the general case where any signal (or noise) that is below the LO frequency would be removed from the output.

One major technical problem is maintaining quadrature balance and amplitude over a 200-to-1 output frequency ratio. This is done to the extent that the image is rejected by more than 1,000-to-1 (30 dB). A rejection of 30 dB is equivalent to an increase in the noise figure of less than 0.004 dB. Another potential technical problem is that the Σ_3 summer introduces a time delay error. This can be corrected by a time delay equalizer. A frequency response variation of less than 1 dB and a time delay variation of less than 200 nsec are realizable in the 2 MHz bandwidth of the circuit shown on Figure 1-3.

The receiver IF input to the Pre-D converter is generally at a very early stage of the receiving system. Therefore, the converter typically provides its own AGC capable of operating over a range of approximately 70 dB.

The other half of the pre-detection problem is to convert the tape playback signal back up to the receiver IF frequency. In this case the undesired mixer product must be rejected. This is accomplished by rearranging the components shown on Figure 1-3. The undesired mixer products are rejected by an imageless mixer, but the problems associated with the simplistic design remain when the components on Figure 1-2 are rearranged.

CONCLUSION

APCOM makes wideband pre-detection converters using the imageless mixer circuit topology. The imageless mixer is a good complexity/performance compromise since it is very flexible with regard to different IF signal and IF bandwidth requirements. The imageless mixer provides excellent amplitude and group-delay responses. At this time, APCOM is routinely producing converters with ±90% (of the output center frequency) amplitude bandwidth (the "data bandwidth") and ±80% group delay compensated data bandwidth.

The group delay variation is typically less than ±100 nsec divided by the output center frequency in MHz, i. e. , for a 1 MHz output center frequency, the typical group delay variation is less than ±100 nsec. Data bandwidths of 8 kHz up to 100 MHz are in production at this time. In the future, APCOM intends to expand the amplitude bandwidth to +100%/-99% of the output center frequency and the compensated group delay bandwidth to ±90% of the data bandwidth.