DIRECT GENERATION OF MSK MODULATION AT MICROWAVE FREQUENCIES

S. Kumar*, W.J. Chudobiak** and J.S. Wight*
*Department of Electronics, Carleton University
Ottawa, Ontario K1S 5B6 Canada
** Avtech Electrosystems Ltd., P.O. Box 5611 Stn. F Ottawa, Canada

ABSTRACT

Direct generation of a modulated signal at microwave frequencies offers considerable simplicity and economy in the transmitter of a microwave communication system. Minimum-shift-keying (MSK) is a digital modulation which yields the same bit-error-rate performance as coherent PSK even though this modulation may be generated as a continuous phase frequency-shift-keying. Utilizing this feature of MSK, this paper describes novel circuits for generation of MSK modulation at microwave frequencies.

Introduction

In the conventional microwave communication systems the modulation is carried out at an intermediate frequency (IF) and the modulated signal is upconverted to microwave frequencies. As compared to this direct modulation at microwave frequencies offers an attractive alternative from reliability and cost considerations. Fig. 1 shows a conventional transmitter and a transmitter which employs direct modulation at microwave frequencies. In the conventional system an IF signal is modulated and the modulated signal is upconverted using a high stability local oscillator. Further, because of the power handling limitations of the upconverter, a microwave amplifier is generally required to feed the requisite power to the antenna. Filtering at microwave frequencies in such a transmitter is limited to suppressing the harmonics of the transmitter frequency; the filtering to limit the spectrum being done at IF.

As compared to this in the directly modulated system, the modulation is carried out directly at microwave frequencies. Filtering to limit the spectrum is also done at microwave frequencies. If a microwave source of sufficiently high power is used, no further amplification of the modulated signal may be required.

Direct frequency modulation at microwave frequencies with analog modulating signals is well known. For direct digital PSK modulation, circuits using p-i-n diodes have been reported (1) (2). In this paper we describe generation of Minimum-Shift-Keying (MSK) type of digital modulation at microwave frequencies. MSK is a digital modulation which may be considered equivalent to either a continuous phase frequency-shift-keying with a modulation index (defined as the ratio of difference between mark and space frequencies to the bit-rate) equal to .5, or as offset keyed QPSK modulation with sinusoidal symbol weighting (3). Coherent matched filter detection of this modulation yields the same ideal channel bit-error-rate performance as the PSK. Compared to coherent FSK this bit-error-rate performance is 3 dB better. Because of its equivalence to continuous phase FSK, it is feasible to generate and amplify MSK at microwave frequencies using circuits such as Injection-locked-oscillators (ILO). In the previous two papers (4) (5) we described the use of the Injection-Locked-Oscillator as a microwave amplifier of MSK modulated signals. In this paper we describe the generation of MSK employing phase-locked microwave osscillators.

Locked Oscillator Circuits for Generation of MSK

A frequency modulated signal may be generated by feeding the modulating signal to the tuning terminal of a microwave voltage-tuned-oscillator. MSK signals may therefore be generated by feeding the digital data to the voltage tuning terminal, the amplitude of the modulating signal being adjusted to obtain a modulation index of .5 required for MSK. However, the frequency stability of the high power microwave oscillator may be of the order of .05 percent. This poor stability is unacceptable as a stability of 1×10^{-6} or better is generally specified for the communication system. A higher stability is achieved by phase locking the oscillator to a frequency reference derived from a high stability crystal oscillator. For analog FM modulation phase locking is feasible for modulating signals where the modulation index is such as to yield a component at the carrier frequency. For the modulation schemes where the modulated signal has no discrete spectral component at the carrier frequency such a phase-locking is not possible. The power spectrum of MSK signal is shown in Fig. 2(a). As may be seen from this figure there is no discrete spectral component. However, squaring the MSK signal results in a modulation known as Sunde's FSK(6). The spectrum has two discrete spectral components separated by half the bit rate from the nominal carrier frequency. The circuit shown in Fig. 3 is based on this feature of MSK. In this circuit the modulated signal is mixed with the reference signal at a frequency Nf_1. The mixer output is squared to generate Sunde's FSK with two discrete spectral lines in its spectrum. One of these components is filtered and the filtered signal is used to lock the loop. The MSK signal is generated by the circuit of Fig. 3 at a nominal carrier frequency of $Nf_1 + \frac{f_1}{2} + \frac{R}{4}$ where f_1 is the reference crystal oscillator frequency and R is the bit rate. The MSK spectrum obtained from this circuit along with the spectrum of the squared MSK signal are shown in Fig. 4. The MSK spectrum of Fig. 4.a agrees very well with the theoretical MSK spectrum of Fig. 2(a). The main lobe in both has a width equal to 1.5 times the bit rate and the first side lobe is about 22.5 dB down from the main lobe. Each side lobe has a width equal to .5 times the bit rate. For large values of (f/R) the spectrum falls off at a rate proportional to $(f/R)^{-4}$.

There are two main drawbacks in the circuit of Figure 3. Any small variation in the amplitude of the modulating data signal or the voltage tuning characteristics of the VTO will result in the modulation index to change from a value of 0.5. Further if the free-running oscillator frequency drifts too much with temperature the PLO may lock to the second spectral line in the Sunde's FSK signal. A second circuit which is free of these problems is shown in Fig. 5. In this implementation of MSK generation, both the data clock and high frequency reference are derived from a common crystal oscillator of requisite frequency stability. A low power PLO is locked to the reference frequencies signal. From the clock signal, a signal at a frequency of clock/4 is obtained by using a divide by four counter. The PLO output signal is multiplied with the clock/4 signal in a DSB modulator (a double balanced mixer) to obtain two spectral lines which differ in frequency by clock/2. These spectral lines correspond to mark and space frequencies for the MSK signal. Further, since the data clock and the PLO were derived from the same crystal oscillator, the phase continuity will be maintained when these frequencies are selected by the mark and space in the data. This selection of frequencies by the data is accomplished by injecting the DSB signal at the mixer output into a high power voltage tuned microwave oscillator. The bias at the voltage tuning terminal is adjusted to bring the free-running frequency of the oscillator to a value midway between the mark and space frequencies. The data is superimposed over this bias to bring the oscillator frequency near the mark or space frequency corresponding to a mark or space in data. This results in the injection locking of the oscillator to the desired frequency. The MSK signal is generated at the output of the high power oscillator.

Conclusion

Digital MSK modulation is attractive for direct generation at microwave frequencies because of its equivalence to continuous phase FSK. Two circuits for implementing generation of MSK at microwave frequencies using locked oscillators have been presented in this paper. The obtained MSK signal power spectrum compares very well with the theoretical MSK spectrum.

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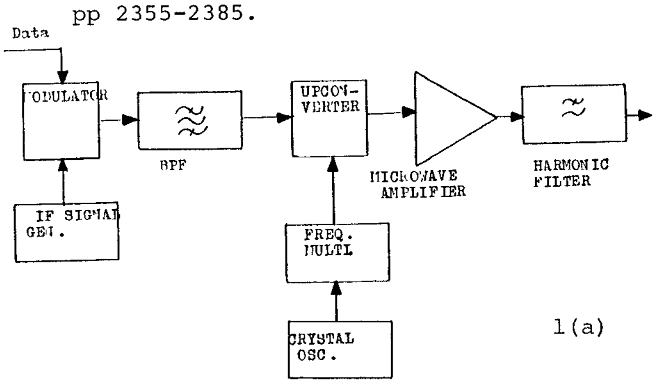
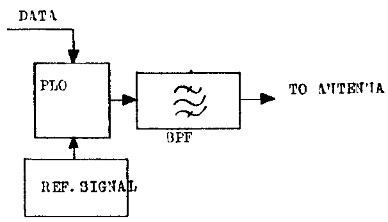


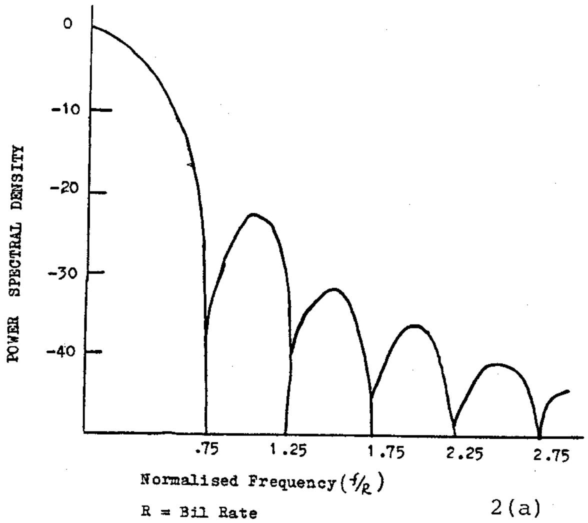
1(a)



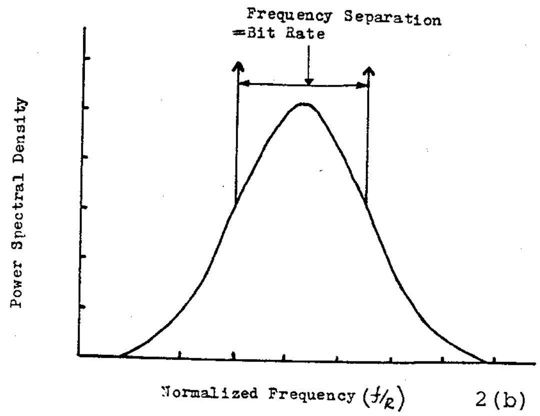
1(b)

Fig. 1(a) Transmitter Portion of a Conventional Microwave Communication System.

1(b) Transmitter for a Directly Modulated System.



2(a)



2(b)

Fig. 2(a) Theoretical Power-spectral-Density of MSK signal.

2(b) The Power Spectrum of Sunde's FSK obtained by squaring the MSK signal.

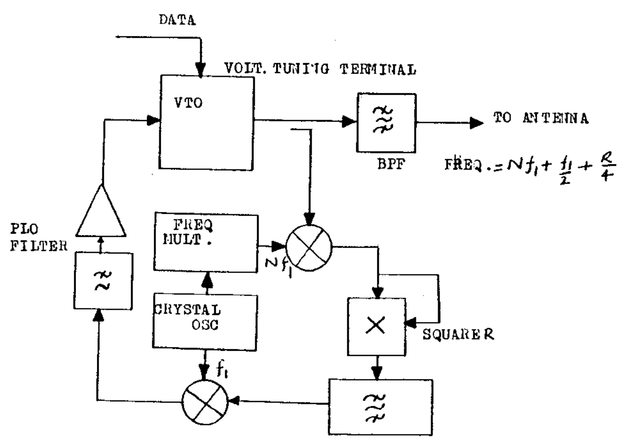
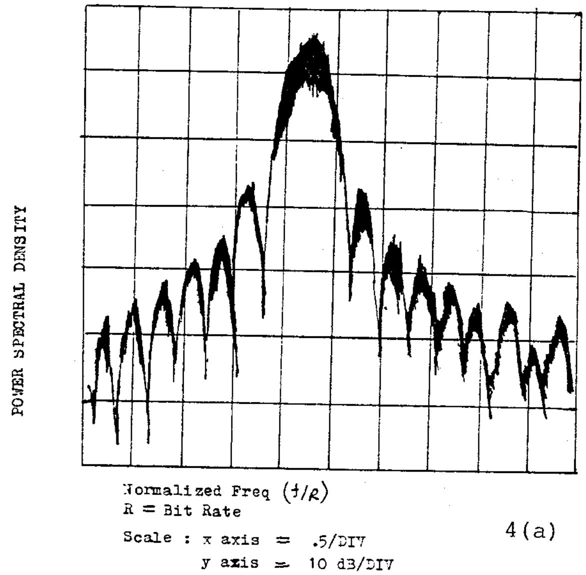
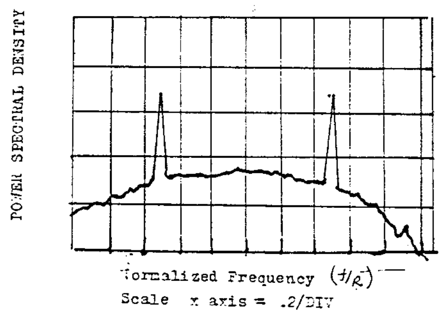


Fig. 3 Direct MSK modulation circuit.



4(a)



4(b)

Fig. 4(a) The Power Spectrum of MSK signal obtained from circuit of Fig. 3.

4(b) The spectrum of the squared MSK signal in Fig. 3.

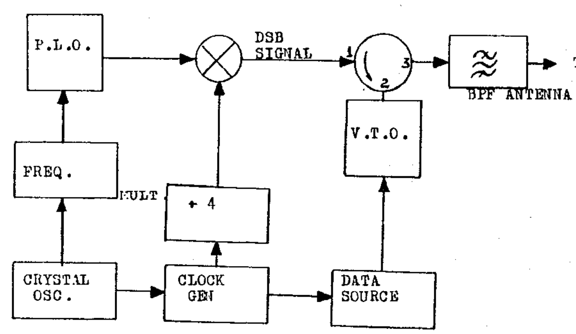


Fig. 5. An Improved Circuit for Generation of MSK Modulation.