THE USE OF SAMPLING TECHNIQUES FOR MINIATURIZED MICROWAVE SYNTHESIS APPLICATIONS

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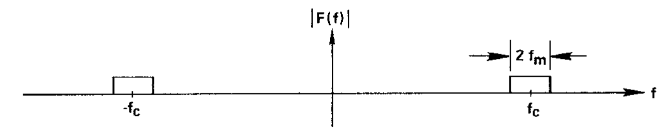
The use of sampling for broadband frequency synthesis is presented. This approach offers several significant advantages over present techniques including reduced size, power consumption, switching speed, and circuit complexity while exhibiting improved synthesis reliability.

Background/Introduction

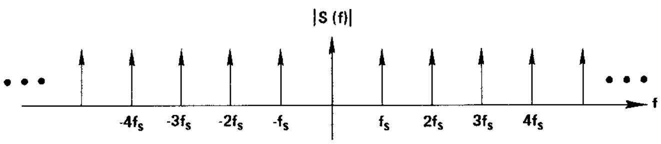
The use of sampling of microwave signals in the past has primarily been limited to instrumentation applications.[1, 2] This paper is concerned with its application in miniaturized microwave synthesis applications suitable for various telecommunication and military requirements. The use of sampling offers several significant advantages over current broadband frequency synthesis approaches. A discussion of sampling theory, circuitry, current synthesis techniques, and synthesis using the sampling technique are presented.

Sampling Theory

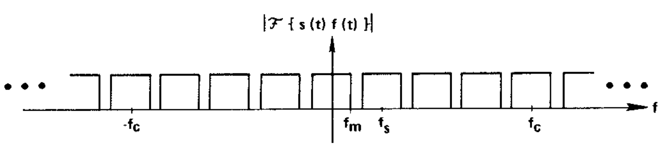
Standard signal sampling[3] is well understood and a highly utilized technique in the area of digital communications and digital signal processing. In such applications the sampling rate, f_s, is required to be at least twice as high as the highest frequency present in the input signal spectrum to avoid aliasing. Less well known and understood is the use of sampling on bandpass signals such as the idealized example in Figure 1a, that have all frequency components higher than f_s.



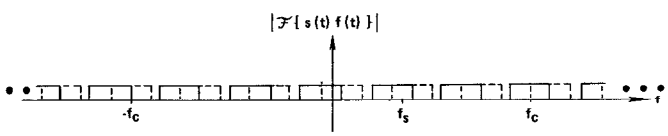
(a) SPECTRUM OF BANDPASS SIGNAL, f (t), WITH $f_m = 0.1 f_c$



(b) SPECTRUM OF SAMPLING FUNCTION, s (t) FOR $f_s = 0.25 f_c$



(c) SPECTRUM OF SAMPLED SIGNAL WITH $f_s = 0.25 f_c$



(d) SPECTRAL DISTORTION CAUSED WHEN $f_s = 0.35 f_c$.
(SEE TEXT FOR EXPLANATION OF FIGURE)

Figure 1. Example of Sampling for a Bandpass Signal

The analysis of sampling for the bandpass case treats the product of the bandpass signal, f(t), with an ideal sampling function, s(t). We shall define the Fourier transform for these functions pictorially in Figures 1a and 1b. It is straight forward to express the fourier transform of the sampled signal

$$\mathcal{F}\left\{s(t)\, f(t)\right\} = K \sum_{n=-\infty}^{\infty} F(f-nf_s) = K\, F(f) + K \sum_{n=1}^{\infty} F(f-nf_s) + F(f+nf_s) \qquad (1)$$

where K is simply a constant of proportionality and $\mathcal{F}\{f(t)\} = F(f)$. Equation (1) shows the effect of sampling is to translate the original spectrum both to the left and to the right, periodically, by multiples of f_s and then summed. The resultant is shown in Figure 1c.

If the sampled signal is passed through an ideal low pass filter with cutoff, f_m, the original signal will have been effectively frequency converted to baseband. Further, because of this periodic translation of the input spectrum, it can be seen that the input signal could have been any of the bandpass spectrums in Figure 1c, which are centered on integer multiples of f_s away from f_c, and also down converted to the same baseband spectrum. This is the fundamental effect that is utilized for the following frequency synthesis application.

Care must be taken in choosing f_s, for a given f_c and f_m, as shown in Figure 1d. Here, frequencies are chosen such that $f_s = 0.35\, f_c$ and $f_m = 0.1\, f_c$. The right hand and left hand spectral components of F(f) (see Figure 1a), that are translated according to Equation (1) are shown in Figure 1d as solid and dashed lines respectively. The spectral components have not been pictorially summed, according to Equation (1), for clarity. It is seen that the sampled spectrum has become highly confused and distorted even though the sampling rate is greater than in the example of Figure 1c.

A typical sampling circuit is not the ideal form described above, but rather of the sample-and-hold type. This circuit accomplishes the same desired frequency conversion with a somewhat more complicated spectrum resulting from the low pass "holding" feature of the circuit.

Sampling Circuit

Evolution of sampling circuits operating at microwave frequencies has been from complex mechanical structures[1] to planar hybrid circuits realized in thin and thick-film.[4, 5] The circuit for this application uses thin-film construction with microwave transmission line and transition techniques employed in microwave mixers.[6] Figure 2 shows a block diagram of the sampler circuit with Figure 3 a photograph. In the diode off state the input RF signal propagates on microstrip and the odd mode of a coplanar transmission line[7] terminated in 50 ohms. The sampling operation begins when the diodes are pulsed on, allowing the RF signal to pass through sampling capacitors, C_s, to the coplanar odd mode ground. This capacitance is such that the time constant allows the capacitors to quickly charge to the input voltage. The same sampling pulse that turns the diodes on, propagates down the even mode of the

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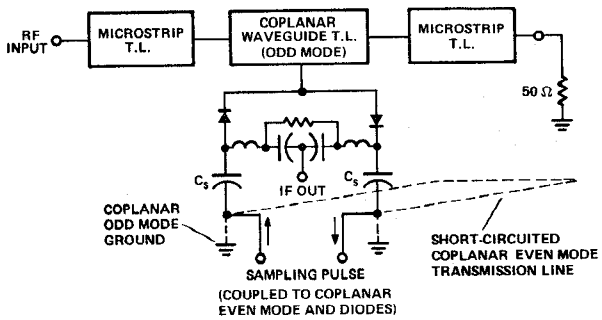

Figure 2. Block Diagram of Sampler Circuit

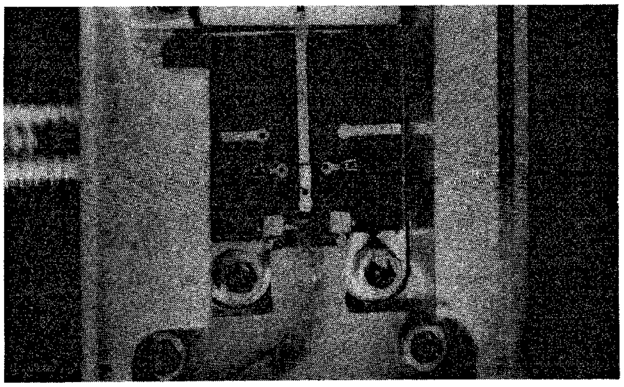

Figure 3. Prototype Sampler Circuit

coplanar transmission line to short circuits which reverse pulse polarity and reflect it back to the diodes, turning them off. This round trip time interval sets the maximum RF frequency of the sampler. The important portion, therefore, of the sampling pulse is its leading edge and is commonly generated by a negative going pulse from a step-recovery diode circuit, which is an integral part of the typical sampler assembly. Finally the voltages held on the sampling capacitors are allowed to discharge into a combiner circuit, shown in Figure 2, and then amplified.

Current Synthesis Techniques

There are currently two basic approaches to the generation of microwave signals. In what may be termed an up conversion approach, a low frequency reference signal (possibly synthesized) is multiplied up to the desired output frequency. This is the basic concept behind direct synthesizers and while workable for narrowband, low resolution requirements, it can become quite complex. The primary approach for broadband requirements is therefore to phase lock a fundamental microwave oscillator as depicted in the block diagram of Figure 4. This concept requires a means of down converting a sample of the microwave output signal to a lower frequency range where it may be processed with conventional digital phase lock circuitry.

One accepted means to perform this down conversion has been to use a frequency reference (say 100 MHz) and a YIG multiplier, as pictured in Figure 5a, to generate a stable microwave signal which is mixed against the RF sample to yield the IF output. An alternate method shown in Figure 5b was described by Krehbiel[8] and utilizes a narrowband UHF synthesizer, an SRD harmonic generator and a mixer to produce the IF signal. In comparison to the YIG multiplier approach, this technique provides improved reliability and requires considerably less volume. While these two methods have been the mainstay of microwave frequency synthesis for several years, they both exhibit shortcomings which sampling down conversion eliminates.

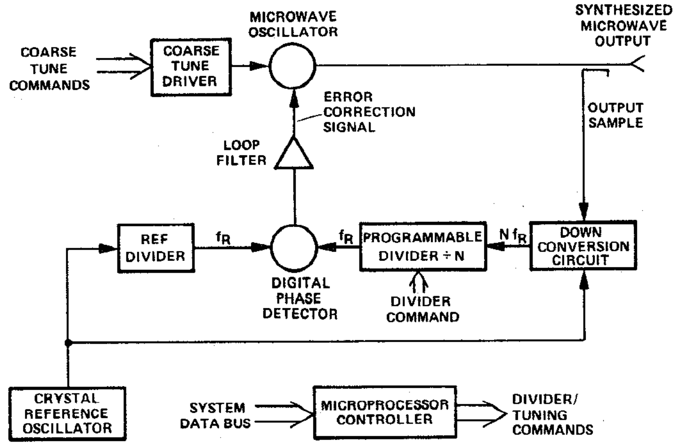

Figure 4. Microwave Synthesizer Block Diagram

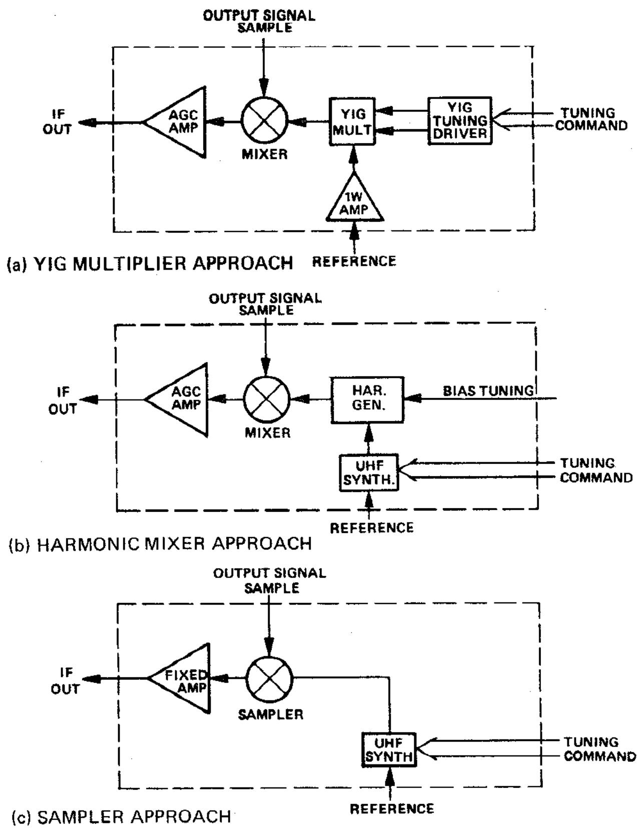

Figure 5. Alternate Down Conversion Block Diagrams

Synthesis Using Sampling Technique

The use of the sampling down conversion method diagramed in Figure 5c offers several advantages. To appreciate these advantages it is helpful to describe the limitations of the current approaches described above. The YIG multiplier approach requires a 1 watt 100 MHz reference signal, must be tuned to the desired RF frequency range, and dissipates large amounts of heat. The size and weight of the YIG and the associated 100 MHz amplifier limit usefulness in miniature applications, while long term YIG frequency drift and reliability can be a problem in any application. In the alternate UHF synthesizer-mixer approach reliability is greatly improved, but a microprocessor routine is required at each frequency point to optimize the frequency conversion via an SRD bias adjustment. In broadband requirements both approaches tend to exhibit great variations in output signal amplitude which, in turn, dictates the need for AGC amplification before the IF is digitally processed.

Virtually all of the above problems are overcome by utilizing sampling to perform the down conversion process. This approach is really the same as the UHF-harmonic mixer method, with the sampler being substituted for the conventional harmonic generator and mixer combination. Because the sampler is specifically designed to have an extremely flat broadband response, no AGC amplification is necessary greatly reducing the amount of associated circuitry. Furthermore, no microprocessor interaction is required to optimize the frequency conversion at any point, simplifying synthesizer interface and control problems and minimizing the time required to switch frequencies. The output spectrum of a YIG oscillator locked to 10 GHz with this circuitry is shown in Figure 6.

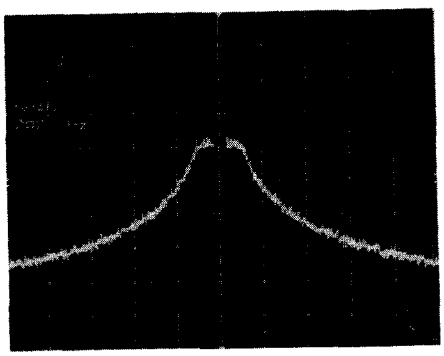

Figure 6. 10-GHz Synthesized Signal

Conclusion

The sampling technique has been successfully utilized in a production 2-20 GHz synchronizer which eliminates many of the problems of conventional microwave synthesis techniques while occupying a volume of only 33 in^3 and weighing less than 2 lbs.

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