APPLIED MICROWAVE & WIRELESS

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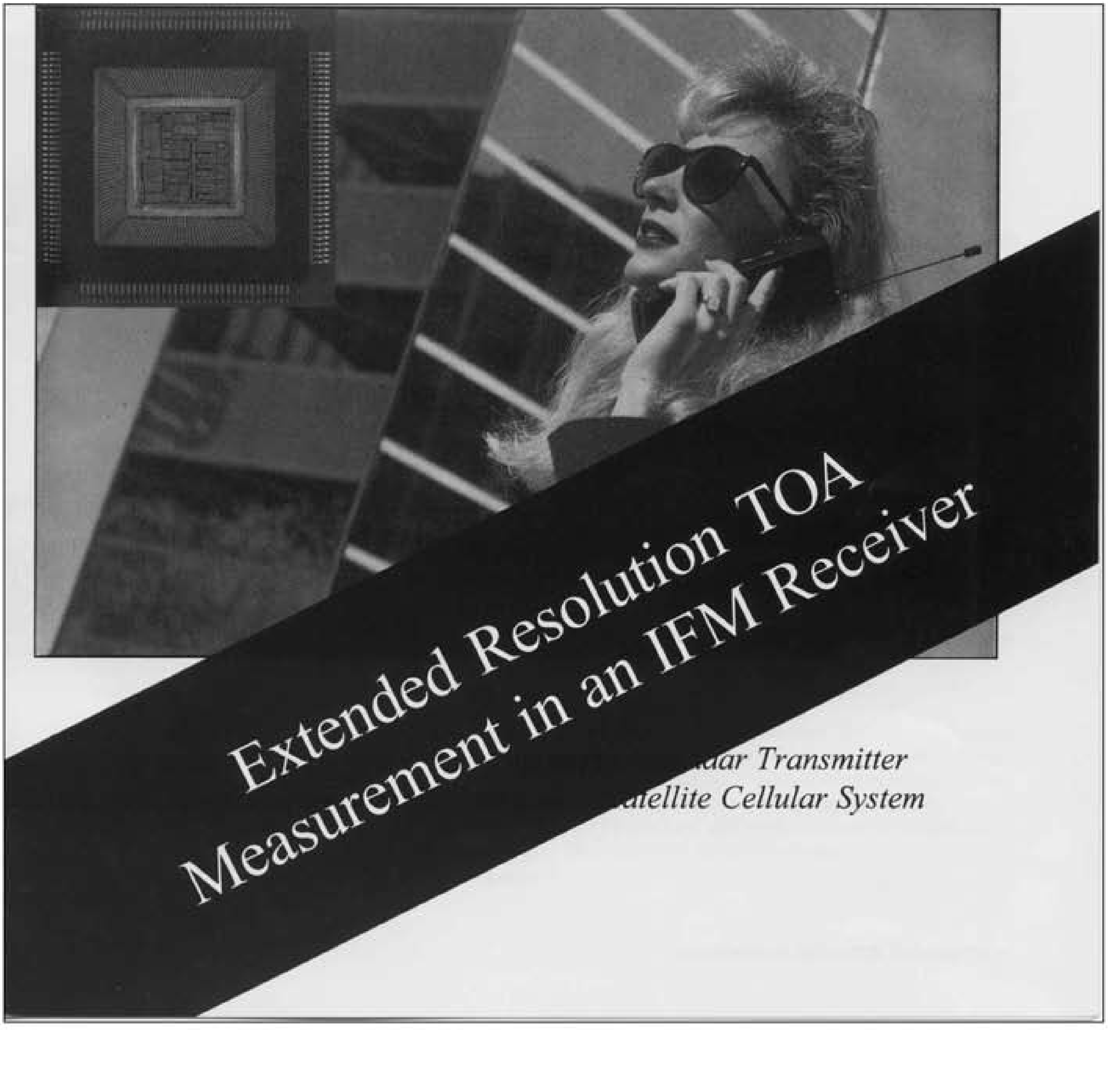

Extended Resolution TOA Measurement in an IFM Receiver

Time of arrival (TOA) measurements define precisely when an RF signal is received, necessary in the identification of type and mode of RF and radar emitters. The author describes a method by which resolution can be improved from 25 or 0.3 nanoseconds without a concurrent increase in receiver complexity.

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Time of arrival (TOA) measurements define the exact time when an RF signal is received. This data is of substantial utility in the identification of the type and mode of an RF emitter. Many current Radar Warning Receivers (RWRs) employ TOA data to sort and identify the emitter, analyzing the TOA of each sequentially received RF pulse to establish the Pulse Repetition Interval (PRI) and, thereby, identify the emitter. TOA data can also be used, in a multiple receiver application, to locate an emitter geographically.

The present technology for TOA measurement is limited, for basic systems, to the receiver system's internal clock period, usually 50nS or 100nS for 20MHz and 10MHz clocks respectively. For more complex systems, the combination of a narrow RF bandwidth, a very high speed (100MHz to 500MHz) sample clock, and a short observation time is often employed. This latter approach is referred to as a "Snap Shot Digitizer". The Snap Shot Digitizer samples the RF amplitude envelope at a very high rate for a short time period, then stores this data in a large buffer memory for further processing. The high sample rate provides the TOA resolution and the short time interval is due to the large block of data being stored.

Because of the requirement for post-processing of a large amount of digital data, the Snap Shot Digitizer is not often employed in “real time” systems. The use of a narrow RF bandwidth with the Snap Shot Digitizer illustrates the difficulty of processing accurate TOA data when multiple signals are present.

Ideally, a system is desired in which a wide band receiver can produce accurate TOA data with time resolution in the sub-nanosecond region and absolute (RMS) accuracies on the order of 1nS and 2nS. This would combine the high Probability Of Intercept (POI) capability of the wide band receiver with precise TOA data.

Achievement of this capability with a simple, real time, Extended TOA Digital Processor would be desirable for a number of critical applications. The present RWR application of employing TOA data to sort and identify the type of radar emitter could, by the improvement in TOA resolution and accuracy, be extended to real time identification of specific emitters, as the precision TOA data could be employed to extract fine grain differences in the specific radar timing.

Integration of a precision TOA processor with the GPS system and wide band receivers can provide a precision emitter location capability, using the GPS system for both receiver location and the time synchronism of multiple receivers which are physically separated.

For tactical aircraft, it should be possible to replace the existing amplitude comparison systems, now used to provide coarse directional threat data to the pilot, with precision TOA systems without modification of the existing aircraft antennas or cabling, clearly an advantageous and practical enhancement.

As a further extension of this concept, the ability to obtain improved accuracy angular data from the RWR might provide the additional capability to correlate the RWR angular data with the aircraft radar or IR (Infra-Red) sensor data, providing an improvement in the overall output obtained by fusing the inputs of multiple sensors.

The key to development of an extended TOA capability is in the development of the third generation IFM (Instantaneous Frequency Measurement) Receiver. The IFM Receiver is a miniature, low cost, wide band microwave receiver which provides digital parametric data on the received RF frequency, amplitude, TOA, and Pulse Width characteristics, on a pulse by pulse basis and in real time.

The instantaneous bandwidth of an IFM Receiver can be as high as 16GHz, for a single band 2-18GHz design. More commonly, instantaneous coverage of the 2-6GHz and 6-18GHz bands, with separate receivers, is the norm.

The early IFM Receivers (first generation) combined a Digital Frequency Discriminator (DFD) and a Diode Log Video Amplifier (DLVA) in a single unit. The DFD provided digital RF frequency data while the DLVA provided analog RF amplitude video. The IFM would trigger on the DLVA RF amplitude video, digitizing the RF amplitude data, and sampling the DFD digital RF frequency data. These receivers lacked pulse on pulse processing capability, exhibited relatively small (30-50dB) dynamic ranges, and provided TOA data which was RF amplitude dependent.

The second generation of IFM Receivers replaced the DLVA with a Digital Amplitude Quantizer, extending the RF dynamic range so that it was in excess of 70dB, and operated as a clocked unit, generating digital RF amplitude and digital RF frequency measurements every 50nS (20MHz clock). The receiver processed a running sequence of RF amplitude data to locate the leading and trailing edge of an RF pulse envelope, to the available 50nS resolution. The 20MHz clock limited the minimum RF pulse envelope, to the available 50nS resolution. The 20MHz clock limited the minimum RF pulse width for 100% POI to 100nS; the Digital Amplitude Quantizer had monotonicity problems and produced a digital sample which was time dependent on the RF amplitude.

The third, and current, generation of IFM Receivers increased the receiver clock frequency from 20MHz to 40MHz (25nS samples) and replaced the Digital Amplitude Quantizer with a Monotonic Digital Amplitude Quantizer, eliminating the monotonicity problems, providing digital RF amplitude samples which were not time dependent on the RF amplitude, and providing frequency dependent RF amplitude correction. The minimum RF pulse width for 100% POI moved down to 50nS.

As a consequence of the improved RF amplitude measurement accuracy and the 25nS time resolution capability of the 40MHz clocked IFM Receiver, it is now possible to obtain highly accurate measurements of the absolute TOA of a pulsed RF signal over a wide RF instantaneous bandwidth.

The Monotonic Digital Amplitude Quantizer circuit provides an extremely accurate digital logarithmic representation of the RF envelope over a wide (typically 70dB) dynamic range, providing 9-bit digital log amplitude data in 0.2dB steps, at a 40MHz sample rate. The data is amplitude corrected over RF amplitude and RF frequency.

The digital output of the Monotonic Digital Amplitude Quantizer is provided to a Standard Video Processor. The Standard Video Processor continuously examines a running sequence of RF amplitude data, locating the threshold reference point of the digitized RF envelope.

The IFM Receiver is provided with both a TOA Counter and a Pulse Width Counter. The TOA Counter is a crystal stabilized digital counter circuit with a "roll-over" time in excess of one second; the Pulse Width Counter is similar to the TOA Counter, but starts with the leading edge of Standard Video and stops on the trailing edge. The "roll-over" time of a TOA counter is the length of time that the counter can count without repeating; this time is set by the product of the clock period and the number of bits in the TOA counter. Both counter circuits are referenced to the stable 40MHz receiver clock oscillator. Normally, a precision 5MHz reference oscillator is multiplied to produce the 40MHz clock.

Coarse TOA data, to 25nS resolution, is obtained by latching the current state of the TOA counter with the leading edge of Standard Video. The RF pulse width data is similarly obtained by starting the Pulse Width Counter with the leading edge of Standard Video and stopping the counter with the trailing edge. The contents of the Pulse Width Counter are then latched out and the counter is reset, to await a new RF input.

While this process was proven to be very effective, it does have limitations. First, the Standard Video Processor must look at enough RF amplitude samples to simultaneously locate both the reference point (often chosen as the-3dBc point on the pulse) and the peak value of the pulse. This is a particular problem with slow rise time RF envelopes. Second, the technique was limited to a basic time resolution of 25nS, due to the 40MHz clock.

Improvement of the time resolution of the receiver by a substantial increase in the receiver clock rate presents problems with the sampled synchronous measurement of both RF frequency and RF amplitude, denies the use of TTL/CMOS digital processing, and would have a substantial adverse effect on both the power consumption and reliability of the receiver. This would also compound the problem of looking at enough RF amplitude samples to cover the time interval from the reference point to the peak RF amplitude of the pulse, for slow rise time pulses. Hence, such a brute force approach to TOA resolution improvement is undesirable.

Rather, a smart use of available data and resources is recommended. Since the Standard Video Processor locates the reference point on the RF envelope to the accuracy of the 40MHZ clock, we can examine multiple measured amplitude samples in the region of the reference point, in comparison to the sampled peak value of the RF envelope, to precisely locate the reference point of the RF envelope. This provides the required degree of precision without having to increase the clock rate.

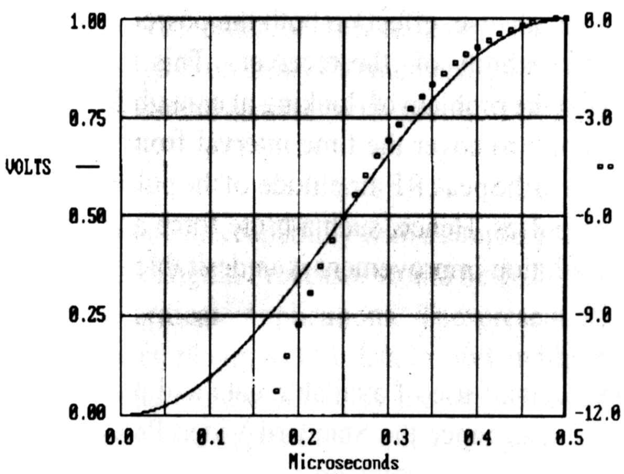
A typical RF envelope characteristic is shown in Figure 1 for a one microsecond cosine squared rise time RF envelope, plotting the voltage envelope and the logarithmic envelope in dBc, relative to the peak RF amplitude.

We note, from examination of Figure 1, that employing the -3dBc point on the cosine squared envelope as the RF envelope reference point requires fifteen samples between the peak value of the RF envelope and the -3dBc reference point to simultaneously cover both the region of the reference point and the peak value of the RF envelope.

The Standard Video Processor continuously examines a serial stream of 9-bit RF amplitude data to locate the leading edge of the RF envelope. The leading edge is defined as the -3dBc point of the RF envelope, to provide effective performance with slow rise time RF envelopes, as illustrated by Figure 1. The Standard Video Processor simultaneously examines a set of sixteen sequential leading edge

RF envelope amplitude data, shifting in a new data point every 25nS. The Standard Video Processor will, therefore, locate the -3dBc point on the RF envelope with an accuracy limited by the 25nS time resolution of the circuit and the amplitude resolution and linearity of the Amplitude Quantizer Circuits.

Figure 1. Rise time characteristics of a cosine squared 1 microsecond long pulse.



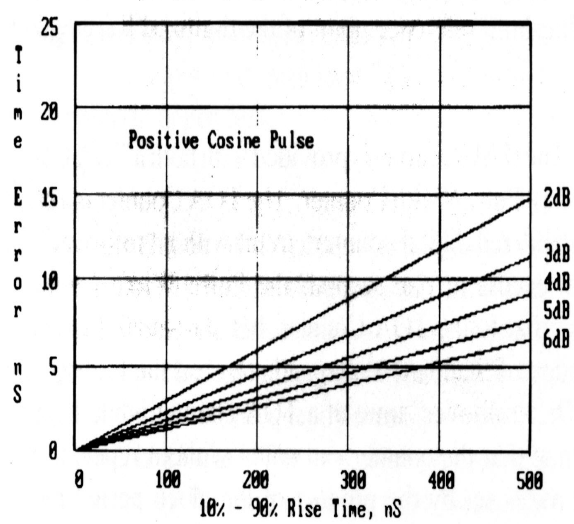
Extension of the TOA resolution and accuracy is achieved by analyzing a set of RF amplitude samples in the region of the -3dBc point of the digitized RF envelope. The Standard Video Processor, once the -3dBc point has been located, latches a set of 9-bit RF envelope data points, beginning with the data point which is one clock prior to the -3dBc point, and continuing to the peak value of the RF envelope. The data is compressed such that "N" 9-bit RF amplitude samples are represented by "N-1" 3-bit RF amplitude difference data.

As noted earlier, for slow rise time RF envelopes, as the peak value of the RF envelope is approached, multiple RF amplitude samples will eventually fall within a single 0.2dB RF amplitude quantum. Even if the circuit had the capability to analyze a large number of RF envelope samples, the digital quantization of the RF envelope, itself, will cause TOA errors for slow rise time RF envelopes.

The TOA error resulting from 0.2dB quantization of the RF amplitude is shown in Figure 2 for a series of reference points, in 1dB steps from -2dBC to -6dBc. As expected, the -6dBc reference point has the least sensitivity to RF amplitude quantization, because the slope of the RF envelope increases with the larger value reference points.

The extended TOA capability, therefore, cannot be effectively applied to extremely slow rise time RF envelopes because of the quantization of the RF amplitude data. Using a -3dBc reference point, Figure 2 indicates that, for rise times in excess of approximately 400nS, the RF amplitude quantization induced TOA error will be of the same magnitude as the basic time resolution of a 40MHz clocked receiver. There is no useful result obtained by trying to process all sixteen leading edge samples being processed in the Standard Video Processor.

Figure 2. Time of arrival (TOA) error as a function of pulse risetime, due to a 0.2 dB amplitude error for a positive cosine pulse.



RF pulse widths which are shorter than the sixteen sample duration are accommodated by artificially extending the pulse width in the Extended TOA Processor. In effect, the Extended TOA Processor observes that the end samples are of lesser magnitude than some intermediate sample and sets these end samples to the largest intermediate value.

The operation of the Extended TOA Processor places substantial requirements on the RF envelope amplitude digitization process, in terms of freedom from overshoot, accurate representation of the transient leading edge of the RF envelope, and freedom from time variation due to the magnitude of RF amplitude.

We noted, in the discussion of the Snap Shot Digitizer, that narrow RF bandwidths were employed to prevent attempting to resolve the TOA on multiple RF signals; the IFM Receiver neatly accomplishes this over a wide instantaneous bandwidth because each TOA measurement in the IFM Receiver is always associated with an RF frequency measurement.

This extended TOA processor has been implemented in a pair of IFM Receivers, to determine the utility of the technique. Test results with a six sample set, employing a fast rise time RF envelope, were consistent and repeatable. The actual circuit required less than ten IC's and provided 0.3nS resolution extended TOA data. This work is currently being extended to the sixteen sample set. One problem which has surfaced is the difficulty in accurately comparing a time measurement to a "standard". In the parallel measurement of RF Frequency and RF amplitude, the digital data is compared to a synthesizer; absolute time presents a more difficult instrumentation problem.

How to get more information

For additional information on Time of Arrival (TOA) measurements as they relate to Wide Band Systems' Instantaneous Frequency Measurement (IFM) receiver systems, performance data on specific models, or to discuss your application in detail, please get in touch with us today. We will respond to your inquiry promptly.

William B. Sullivan received the BS Degree in Electrical Engineering from San Jose State College in 1966.

He was with GTE Sylvania, West, from 1962-1969 engaged in the design of a variety of systems including the AN/PLQ-2, AN/MLQ-8, AN/MLQ-31, BATBOY, seismic intrusion systems, covert listening devices, very low power (3-6mW) VHF/UHF receivers and wide band radar using short (nanosecond) pulses.

He was a systems engineer for ESL, Inc. from 1971-1972. This was followed by the position of Director of Equipment Engineering for Probe Systems, Inc. from 1972-1976.

From 1976-1982 he was the Director of Engineering at Kuras-Alterman Corporation, Raytheon (New Jersey Operations).

From 1982-1984 he was the president of Northern Scientific Laboratory, Inc (NSL), responsible for the development of IFM/DFD technology for AN/ALR-77, IF Signal Analyzers, Waterfall Displays, and other applications. He founded this company and sold it two years later.

After the sale, he was the General Manager, from 1984-1991, of Northern Scientific Laboratory, Division of General Instrument Corporation and under his direction the company increased from a small group to a division with $8M annual sales.

In 1991 he founded Wide Band Systems, Inc. and is its president. Mr. Sullivan is a member of Tau Beta Pi, Eta Kappa Nu, and Phi Kappi Phi honorary fraternities.

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